Volcanic activity in Late Variscan Krkonoše Piedmont Basin: petrological and geochemical constraints

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Abstract. Three groups of Late Palaeozoic volcanic rocks can be distinguished in the Krkonoše Piedmont Basin: (I) trachyandesites, andesites > trachytes, trachydacites, (II) basaltic trachyandesites, basaltic andesites > basalts, trachybasalts, and (III) rhyolites. Volcanic activity started in the Late Carboniferous, producing calc-alkaline (basic) to intermediate volcanics of group I in the southern part of the Krkonoše Piedmont Basin, and migrated north during the Permian, producing calc-alkaline transitional (mildly alkaline ?) intermediate and acid volcanics of groups II and III. Volcanic rocks of intermediate composition are of Carboniferous and Permian ages, whereas acid volcanics prevailed in the Permian. Basic to intermediate rock members (groups I and II) represent mantle-derived products affected by crustal contamination during the assimilation-fractional crystallization (AFC) process. Although the primary magma composition is obscured by pervasive crustal assimilation, DM or HIMU sources are more probable than the EM source. Heat input into the crust from the ascending basic to intermediate magmas and from the upper mantle led to the formation of anatectic crustal melts represented by rhyolites of the group III. Geochemical similarity of rhyolites of the group III with some late Variscan granites suggests their common source. Although the Late Palaeozoic volcanic rocks in individual basins in N Bohemia come from similar sources and are basically of the same origin, they probably evolved in separate crustal magmatic chambers.

Key words: Late Palaeozoic volcanism, Krkonoše Piedmont Basin, petrology, geochemistry, Sr-Nd isotopes

Introduction

The Bohemian Massif has a unique position within the central Europe as the largest exposed part of the Variscan Orogeny. In the last years, several attempts have been made to characterize the late- to post-collisional volcanic activity and its role in the late stages of the Variscan Orogeny (W. Franke, 1989; D. Franke, 1995). The Variscan Orogeny, a major continental collision episode culminating at about 360 Ma, was accompanied by the emplacement of a range of subduction- and extension-related magmas between 360 and 260 Ma (Lorenz & Nicholls, 1984; Downes & Duthou, 1988; Wilson & Downes, 1991). The mantle beneath the western and central Europe was metasomatized as a consequence of plate subduction during the Variscan Orogeny and especially during late phases of the Late Palaeozoic (LP) extension (Wilson & Downes, 1991). In the Late Carboniferous, the Bohemian Massif became dissected by a conjugate system of wrench faults associated with the accumulation of continental, often coal-bearing volcano-sedimentary sequences. Variscan continent-continent collision in the central Europe was followed by periods of magmatic activity both within the orogeny and in its foreland. Compositional differences between the volcanic rocks were controlled by different tectonic regimes and by the heterogeneity of the basement. Crustal thickening and southward-increasing depths of origin of basic magmas in the North German Basin may reflect the presence of a pre-existing subduction-influenced basaltic magma source (Benek et al., 1996).

Alkaline (rather transitional!) volcanic activity in marginal parts of the Variscan Orogeny is closely associated with pull-apart structures (Ziegler, 1990). Nevertheless, integrated studies on the Upper Palaeozoic (UP) volcanics of western and central Europe, considering both their structural position and geochemical signatures, have been published only rarely (Eigenfeld & Schwab, 1974; Seckendorf, 1989; Hoth et al., 1993; Korich, 1989, 1992; Benek et al., 1993, 1995, 1996; Kölbl-Ebert 1995). Volcanic series in the basins generally started with a minor basaltic phase and terminated with a voluminous rhyolitic one.

Late Variscan intramontane troughs of central Europe are aligned along old structural discontinuities and tectonic lineaments of the basement (e.g., E-W, NE-SW and/or NW-SE). The broad zone of the above-mentioned basins, together with intensive volcanism, implies a substantial tension and thinning of the crust (Benek et al., 1996). However, Jindřich (1971) related the UP volcanics associated with the graben and half-graben structures along Precambrian lineaments and/or strike-slip faults with the taphrogenic movements induced by updoming of the Bohemian Massif in the Late Palaeozoic and Cenozoic. The responsibility of the Variscan and Alpine orogenies for these phenomena is considered doubtful by

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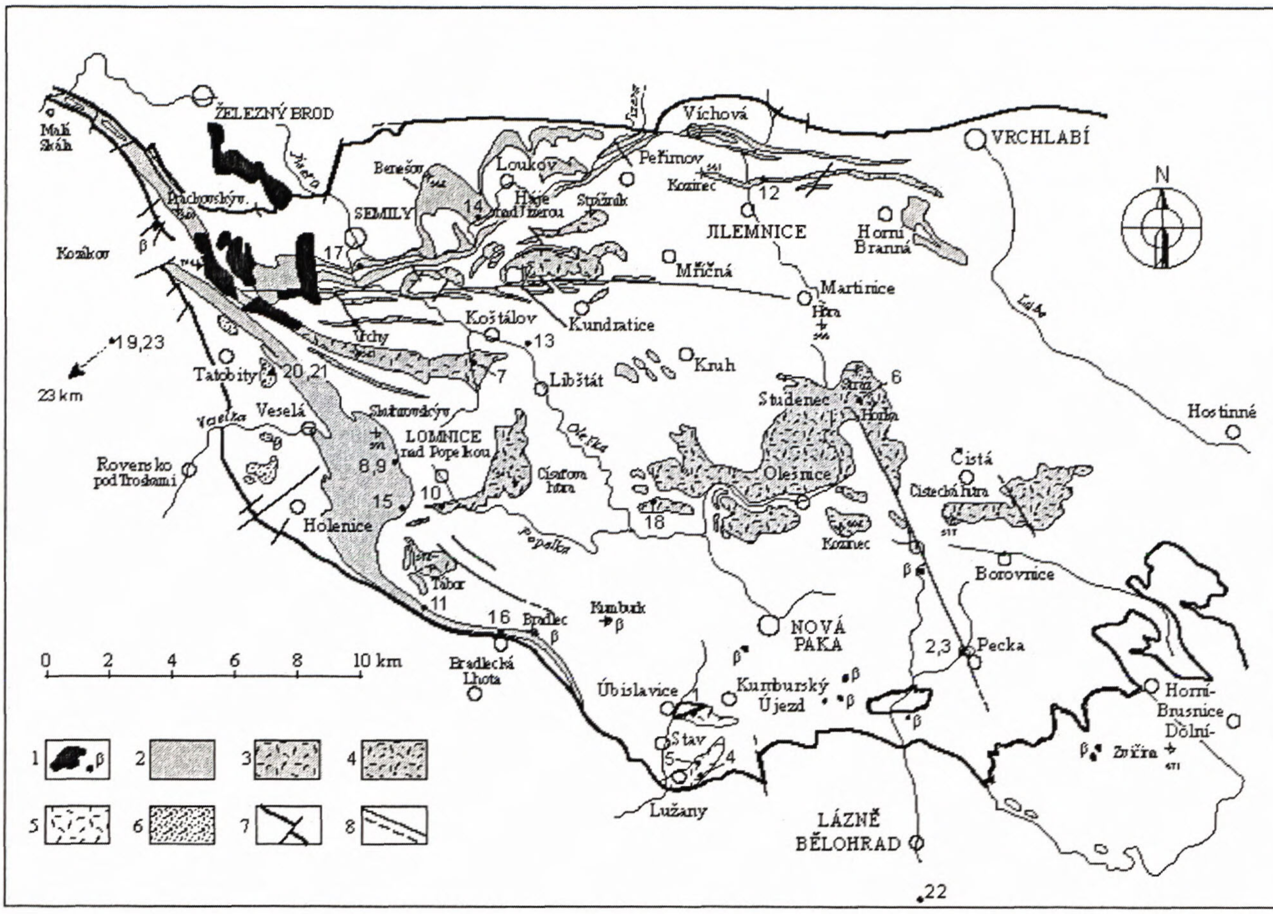

Fig. 1 A sketch of the Late Palaeozoic volcanic rocks within the Krkonoše Piedmont Basin with sample locations (Prouza & Tásler, 2001). Cenozoic: 1 – basaltic volcanics β; Permo-Carboniferous: 2 – basaltic andesites (effusions, locally with small bodies of subvolcanics), 3 – subvolcanics (sills and dykes, volcanic stocks), 4 – volcanic bodies formed by effusives, pyroclastics and subvolcanics, 5 – andesite, dacite, rhyodacite, 6 – rhyolitic ignimbrite, 7 – boundary of the Krkonoše Piedmont Basin with crystalline complexes and Upper Cretaceous sediments, 8 – reverse fault, normal fault, proved and assumed.

Jindřich (1971), as indicated by the taphrogenic character of tectonics and volcanic activity in the Bohemian Massif.

The aim of the study was to extend the knowledge of the geochemical character of the LP volcanism in space and time in the key regions of the Bohemian Massif (Ulrych et al., in prep.): in the Krkonoše Piedmont Basin (KPB) and the associated Mnichovo Hradiště (MHB), and the Česká Kamenice (CKB) basins. A special attention is paid to the study of the source of primary magmas and of the crustal control of the AFC process using trace element and Sr-Nd isotope constraints.

Geological setting of the Late Palaeozoic volcanism in the Bohemian Massif

Products of intensive volcanic activity associated with the late phases of Variscan Orogeny are abundant in the sedimentary fill of the LP basins. Accumulations of largely synchronous volcanic rocks are present in basins of North Bohemian (Lusatian) region (KPB, MHB, CKB and the Intra-Sudetic Basin) and Central Bohemian basins filled with Upper Carboniferous to Lower Permian continental ("limnic") sediments (Fig. 1). The LP volcanism in the Bohemian Massif (Pešek & Tásler, 1989) is characterized by predominance of acid volcanics including tuffs and tuffites over intermediate and basic rocks (except for the MHB).

Volcanic activity in the LP basins occurred in two phases: the first phase dates to the Carboniferous, mostly to Westphalian B and C, and the second phase to the Early Permian, especially Late Autunian (Pešek & Tásler, 1989; Pešek /Ed./, 2001). Products of coeval volcanism outside the LP basins occur in particular in the Altenberg-Teplice caldera (Benek et al., 1995; Breiter et al., 2001).

Although the diverse chemical composition of the UP volcanics (in particular the "melaphyre group") was recognized already by Fediuk (1965, 1967, 1973), no systematic study of this group has been conducted. The scarce unpublished geochemical data (Schovánková, 1985a, b; Bouška, 1985; Rutšek, 1995) indicate a wide range of chemical compositions, especially among the basic and intermediate members of the UP rocks.

Geochemical studies of the LP volcanism have been separated from the study of the relation between the magma composition and tectonomagmatic settings till the present (Pearce, 1982; Pearce et al., 1984). This approach led to the conservation of the classic petrographical interpretation of the volcanics as products of "subsequent" Variscan volcanism (Gotthard, 1933).

Only the latest studies of volcanic products in the Intra-Sudetic Basin by Dziedzic & Teissere (1990), Dziedzic (1996, 1998) and Awdankiewicz (1999a, b) represent modern trends in the study of the LP volcanism in the Bohemian Massif. Three volcanic suites have been recognized by Awdankiewicz (1999b): (i) the Early and the Late Carboniferous calc-alkaline suites, and (ii) the Late Carboniferous and Early Permian weakly alkaline volcanic suite.

Products of the Late Palaeozoic volcanism in the Krkonoše Piedmont Basin

The areal extent of volcanics represents about 10 % of the KPB, 30-50 % of the MHB and 25 % of the CKB. However, the areal extent of volcanic products in the narrow strip of UP rocks along the Lusatian (Lužice) Fault reaches 60-80 %.

Schovánková (1985a, b, 1989) presented the latest results of a comprehensive petrological study of the UP volcanics of the KPB, MHB and CKB. She proposed a collective term andesitoids for intermediate rocks, classified as "melaphyres" in older publications. Andesitoids prevail over other volcanic rocks in the basins, forming up to 90 % of the volume of the KPB. Rhyolitic rocks are abundant only in the upper part of the basin fill of the Upper Autunian age. Andesitoids are placed among potassic sub-route varieties (shoshonites) by their chemical composition.

The oldest products of the LP volcanism are known from the Kumburk Fm. (Westphalian D – Barruelian), and the youngest volcanic rocks are preserved in the Chotěvice Fm. of the Late Autunian age. Volcanic activity culminated in the Late Autunian by the Vrchlabí Fm. where volcanic rocks are the most widespread. The andesitic Kozákov Hill Complex (Fediuk, 1972) and bodies of the Levín Highland (Ponikelská, 1982), Čistecká hůra and Císařova hůra hills are present at this stratigraphic level. Andesitoid volcanics most frequently occur in the form of lava flows but rarely form subvolcanic bodies such as sills and dykes. Andesitic tuffs, tuffites and agglomerates occur only rarely.

Schovánková (1989) suggested that the basaltic andesites of the KPB originated from several independent magmatic chambers. The root zone of the basaltic trachyandesite volcanism may be associated with the E-W-striking first-order fault zone (Kundratice-Javorník Zone – Prouza & Tásler, 2001), accompanied by a series of dykes and subvolcanic bodies. Results of measurements of elliptical vesicles of amygdaloidal parts of andesitoids (Prouza et al., 2000) indicate that the lava flows were reaching out from several volcanic centres near Semily, Lomnice n. P., Nová Paka and the Kozákov Hill Complex, i.e., from centres associated with a fault zone lying near the present Lusatian Fault.

The largest effusive body is that of basalt andesite exposed in the upper part of the SW slope of the Kozákov Hill, and extending to Malá Skála and the N part of the MHB in the NW and to Tužín in the SE (Fediuk, 1972). Its minimum thickness is 160 m and its total length is about 46 km. Volcanic bodies of the Levín Highland and Čistecká hůra Hill near Nová Paka are interpreted as products of a stratovolcano (Schovánková, 1989) due to the relatively high abundance of andesitic tuffs, tuffites and agglomerates alternating with lava flows.

The largest subvolcanic body (max. 100 m in thickness, about 8 km in length) is the Košťálov sill, followed by the laccolith N of Kundratice (Schovánková, 1989), a.o.

Multiple superimposed bodies (up to several hundreds of metres thick) of basaltic andesite effusions, largely in the Vrchlabí, Prosečné and Chotěvice formations, were proved by boreholes drilled to the basement of the Late Cretaceous sediments in the MHB. The presence of pyroclastics of andesitic composition is sporadic. As an exception, two elongated effusive bodies of andesitoids accompanied by pyroclastics (Středa, 1971; Prouza, 1993) occur in the MHB in a strip of outcrops along the Lusatian Fault.

However, different types of volcanic rocks (dacite sensu Schovánková, 1985b) in the Upper Carboniferous Kumburk Fm. are present in the southern part of the KPB between Stav, Kumburský Újezd and Lužany. A small body of a similar rock is present near Pecka (andesite sensu Schovánková, 1985b).

Acid volcanism is represented by rhyolite ignimbrites (flows), rare rhyolites, rhyolite pyroclastics (tuffs) and mixed rock types such as tuffites and volcaniclastic sediments.

Ignimbrites are the most abundant volcanics, particularly in the MHB (Schovánková, 1985a) with the thickness exceeding 200 m. Ignimbrites form an elongated body (about 8 km long with a thickness of >250 m) between Proseč p. J. and the area S of Pelíkovice. Small bodies of ignimbrites (maximum thickness of ca. 50 m) at Tatobity, Žlábek and Rovensko p. T. and the elongated body S of Kozákov Hill and W of Prackovice Hill lie within the Chotěvice Fm. of the KPB.

Intrusions of rhyolites, partly porphyritic, forming lens-like bodies in phyllites on Mlázovice Chlum Hill SW of Šárovcova Lhota, are probably also products of the LP volcanism.

Methods of investigation

Bulk chemical analyses of rocks were performed using wet method in the Institute of Rock Structure and Mechanics, Academy of Sciences of the Czech Republic, Praha (analyst J. Švec). Trace element concentrations were determined using XRF (J. Štrublová, Gematest, Praha-Černošice) and INAA analytical methods (J. Frána, Nuclear Physics Institute, Academy of Sciences of the CR, Řež). The precision of XRF analyses varies about 5 % as checked by a series of duplicate analyses. The precision of INAA analyses is comparable with the data published by Řanda et al. (1970). The accuracy of individual element INAA determinations was tested against the rock standard B-1.

The analyses of Sr and Nd isotopes were performed in the Isotope Laboratory of the Department of Earth and

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Stage		Lithostratigraphic Unit		Character and thickness of volcanic products
KRKONOŠE PIEDMONT BASIN				
Autunian		Chotěvice Fm.		rhyolite tuffs and tuffites near Mladé Buky, Libeč and in boreholes at Ratibořice bodies of ignimbrites near Tatobity, Rovensko p.T., W of Kozákov Hill, NE of Smrčí
Autunian		Prosečné Fm.	U L	rhyolite tuffs and tuffites in the neighbourhood of the Arkose Horizon, effusive bodies of andesitoids at Kruh, Horní and Dolní Branná and Holenice; Horní Branná and Mladé Buky horizons
Autunian		Vrchlabí Fm.	U	effusives and pyroclastics of the Levín Highland and the Čistecká hůra Hill
			L	andesitoid effusives among Komárov, Loukov and Vrchlabí
Stephanian	C	Semily Fm.		rhyolite tuffs and tuffites in the Ploužnice and Štěpánice-Čikvásky Horizon small effusion of basaltic andesite near Ploužnice
Stephanian	B	Syřenov Fm.	U	intercalations of tuffs and tuffites (in cm) in a horizon of black claystones
			L	intercalations of tuffs and tuffites (tonsteins) (in cm) in the Syřenov Fm.
Stephanian	Barr.	Kumburk Fm.	U	
Cantabrian to Westphalian D		Kumburk Fm.	L	dacitic volcanics near Kumburský Újezd and Lužany
MNICHOVO HRADIŠTĚ BASIN				
Autuniam		Chotěvice Fm.		uniform, areally extensive body of andesitoids with max. thickness of 130 m at Všeň "loaf-like" bodies of ignimbrites – max. thickness of 200 m in the neighbourhood of Český Dub
Autuniam		Prosečné Fm.	U	extensive intercalatons of rhyolite tuffs and tuffites (ca. 0.1 m thick), andesite effusion between the N
			L	vicinity of Hodkovice n.M. and Bezděčín ("Upper Melaphyre Group")
Autuniam		Vrchlabí Fm.	U	multiple repeated flows of andesitoids of different thickness and extent (max. total thickness of about 500 m – Cetenov, Bezděčín) a local body of ignimbrite at Všeň (100 m thick)
			L	effusion of andesitoids near the Lusatian Fault ("Lower Melaphyre Group")
Stephanian	C	Semily Fm.		a small body of rhyolite at Cetenov (2 m thick) with intercalations of tuffs and tuffites a few cm thick (max. 10 cm), a local body of andesitoids up to 100 m thick at Všeň
Stephanian	B	Syřenov Fm.	U L	intercalations of rhyolite tuffs and tuffites (tonsteins) in the horizon of black claystones and in the Mělník Group of Seams
Stephanian	Barruelian	Kumburk Fm.	U	local thin bed of tuffites (volcaniclastic greywacke)
Cantabrian to Westphalian D		Kumburk Fm.	L	

U – Upper, L - Lower

Environmental Sciences at the Universität München using a technique described in Hegner et al. (1995) and Hegner & Kröner (2000).

Lithostratigraphy

Two volcanic suites were distinguished in the KPB based on the stratigraphic position and distribution of volcanic rocks (see Table 1):

- **the Late Carboniferous volcanic suite** comprises intermediate rocks from localities Pecka, Stav - quarry Rumchalpa, and from the Lužany area.
- **the Early Permian volcanic suite** comprises the andesitoid group (sensu Schovánková 1985b) with "melaphyre" (sensu Gotthard, 1933) composition, ranging from primitive basic and intermediate rocks to acid rocks including ignimbrites and tuffs.

Petrography

Older volcanic series

Andesites to trachyandesites (type locality of Pecka) are dark grey to pale purple in colour and almost aphyric in appearance. Glomeroporphyritic clots (~4.5 %) of original orthopyroxene (1-3 mm in diameter) together with sparse pseudomorphs after clinopyroxene? are seen in thin sections only. Occasionally, xenocrysts of undulatory quartz (1-2 mm in diameter, ~13 vol. %) are observed, probably resulting from magmatic resorption prior to, or during, the volcanic eruption. Quartz is lined with magnetite-vermiculite symplectites, 0.05-0.2 mm thick, originally composed of small pyroxene crystals. The trachytic-textured groundmass is formed by albitized plagioclase laths (0.2-0.4 mm in size, ~55 vol.%), interstitial chlorite, hematite and carbonate. Subhedral chlorite pseudomorphs after pyroxene phenocrysts were later affected by vermiculitization (producing pale brown pleochroism) and are surrounded by clinozoisite-epidote or opacite rims. Completely opacitized amphibole (?), altered olivine (?) and apatite are accessories.

Trachydacites (type locality of Lužany) are weakly porphyritic in hand specimens, purple in colour, with hematite coatings on cracks. K-feldspar with sieve-textured rims (up to 2.5 mm in diameter), chloritized biotite (~0.5 mm in size), and minute oligoclase laths are seen in thin sections as sparse microphenocrysts. The predominance of two feldspars over partly xenocrystic drop-like quartz and altered clinopyroxene suggests rather a trachytic than dacitic composition of magma. Pseudomorphs after pyroxene have subhedral outlines and are rimmed by hematite. The quench-textured groundmass is locally red in colour (rich in hematite staining) or contains colourless fields separated by devitrified glass bands. It consists of sodic plagioclase, alkali feldspar, hematite and vitreous patches (15-30 μm in size).

Hematitized trachytic dacites with moderately porphyritic texture and strongly altered groundmass (type locality of Rumchalpa) contain glomeroporphyritic clots of sericitized plagioclase (2-3 mm in diameter, 5 vol.%), totally kaolinitized alkali feldspar mantled by albite (1.8-2.3 mm in size, 5-7 vol.%), and sparse embayed quartz (1-1.5 mm in size, 21 vol.%) as phenocrysts. Quartz is resorbed by groundmass. Hematite pseudomorphs after plagioclase laths (0.2-0.4 mm), and chloritized biotite with hematite rims (0.3-0.4 mm in size) are a part of the fluidal-textured groundmass. K-feldspar and plagioclase in groundmass, varying in size between 0.05 and 0.15 mm, are strongly kaolinitized and sericitized. Goethite, hematite, magnetite and apatite are common accessories.

Younger volcanic series

Andesitoids (basaltic andesites to basaltic trachyandesites, rarely also basalts and trachybasalts) form a group of weakly to strongly altered rocks, corresponding to former "melaphyres":

Porphyritic and locally trachytic textured rocks (type locality of Všeň) forming lava flows are mostly massive, partly amygdaloidal, black grey or brownish red in colour. The phenocryst assemblage consists of tabular and lath-shaped andesine (An_{42-48}) and pseudomorphed clinopyroxene (as much as 2 vol.%). Low-temperature albite (Pivec, in press - type locality of Benešov), chlorite and hematite are important additional minerals, formed within spilitic-like reaction of andesine-labradorite. Locally observed traces of the original volcanic glass as well as clinopyroxene (pigeonitic augite) are affected by smectitization or chloritization. Subordinate groundmass containing also potassium feldspar is often totally altered (hematitized). Moreover, a few samples contain strongly corroded quartz xenocrysts lined with diopsidic clinopyroxene. Prismatic apatite, skeletal ilmenite and secondary iddingsite represent accessory minerals.

Rocks with intersertal to hyaloophitic textures are characterized by massive types (type localities of Studenec and Hrabačov). These rocks are generally aphanitic or amygdaloidal in hand specimens. The primary mineralogy reveals two plagioclase generations (An_{50-62} and An_{38-50}), pyroxenes (pigeonitic augite and/or orthopyroxene), and devitrified volcanic glass (commonly 20-35 vol.%). Lesser amount of alteration products such as chlorite, albite, clay minerals, calcite and hematite are also found. A high degree of devitrification is visible, passing from black-brown to yellow-brown colour and resulting from abundant magnetite, and hematite dust in the groundmass. Highly devitrified glass, especially that containing skeletal plagioclase, may be whitish grey in colour. Pseudomorphs after olivine and magnetite occur as accessory phases.

Rocks with ophitic or poikiloophitic textures are rare (type locality of Košťálov). When almost unaltered, this rock is dark grey to black in colour and massive in hand specimens. Due to oxidation, the rock colour passes into purple or red, mainly along fractures. A typical mineral assemblage comprises normally zoned plagioclase (An_{64-48}, 45-50 vol.%), both ortho- and clinopyroxenes, and pseudomorphs after olivine. Reddish-brown biotite and magnetite grains form overgrowths on pyroxenes. Subhedral pyroxenes, if only partly altered, can be recognized as very pale rose hypersthene or pale green-coloured pigeonitic augite. The size of plagioclase and pyroxene microphenocrysts ranges from 0.15 mm to 2.1 mm. Minor pseudomorphs after olivine (0-2 vol.%, up to 0.6 mm in size) are rimmed by magnetite and consist of serpentine or smectite minerals. Albitized plagioclase laths are also replaced by tiny colourless chlorite flakes. Acicular accessory apatite occurs in places.

A textural diversity is also typical for altered acid rocks, especially those including ignimbrites. Ignimbrites are often hematitized and kaolinitized, pink to pale purple in colour. They occur in two varieties:

Fine-grained rhyolite ignimbrite (type locality of Mlázovice) is usually characterized by predominance of silt-sized, moderately sorted ash with less abundant glass shards as well as broken feldspar clots or crystalloclasts, up to 2.5 mm in size. The ash particles have a spherical shape. Sieve-textured plagioclase fragments as well as areas or rims of unevenly altered glass show disequilibration. Clay minerals formed after vitreous particles and feldspars as well as hematite dust are ubiquitous. Small broken quartz crystals occur in substantial amounts.

Nevaditic rhyolite ignimbrite (type locality of Tatobity) predominantly contains subrounded and broken crystals of quartz (0.1-3 mm in size, 50-60 vol.%) and

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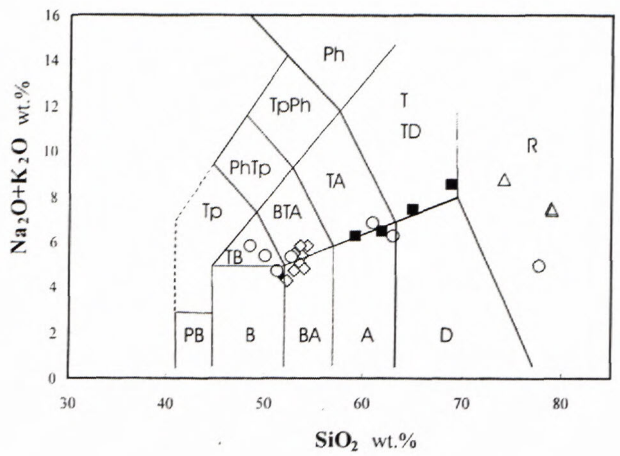

Fig. 2 Volcanics of the Krkonoše Piedmont Basin and the Mnichovo Hradiště Basin in the TAS diagram (Le Maitre ed., 2002). Altered samples (empty circles) plotted for comparison were not used for geochemical consideration.
Rock fields: B – basalt, BA – basaltic andesite, A-andesite, D – dacite, R – rhyolite, TB – trachybasalt, BTA – basaltic trachyandesite, TA – trachyandesite, T – trachyte, TD –trachydacite.
Explanations for symbol: full squares – group I (Carboniferous volcanics of the Krkonoše Piedmont Basin); diamonds – group II (empty diamonds – Permian volcanics of the Krkonoše Piedmont Basin, full diamond – Mnichovo Hradiště Basin); empty triangles – group III (Permian acid rocks of the Krkonoše Piedmont Basin and the Mnichovo Hradiště Basin); empty circles – altered samples.

alkali feldspar (0.1-2.8 mm in size, 10-20 vol.%) with subordinate but characteristic pseudofluidal banded groundmass. Otherwise fresh rock contains alternating thin bands of glass and fragments of quartz and alkali feldspar. Subordinate plagioclase grains show sieved texture or are totally sericitized. Quartz displays undulatory extinction. Secondary voids after leached plagioclase and glass occur in strongly weathered rocks. Flakes of dark brown biotite (0.1-0.7 mm in size), zircon and sphene occur as accessory minerals.

Geochemistry

Analytical data

The twenty-five samples from the KPB and 2 samples from the MHB were selected for geochemical study. The samples were selected with the purpose to cover a variety of regions and stratigraphical positions. Only a few outcrops of Carboniferous volcanics are present in the KPB, exposing highly altered rocks. For this reason, only four samples of Carboniferous volcanic rocks were included into the sample set. Samples with H_2O>3 wt.% were considered altered and excluded from the data set for geochemical study. Major and trace element analyses of all samples are summarized in Tables 2 a, b. Nine rock samples from the KPB and one sample from the Central Bohemian basins were chosen for Nd and Sr isotope study (Table 3).

Geochemical characteristics of volcanic rocks

The studied samples from the KPB and MHB show a wide range of SiO_2 contents (48-78 wt.% SiO_2). An uneven distribution of SiO_2 content was confirmed, with a compositional gap between SiO_2 contents of 54-59 wt.%. The rocks were subdivided into 3 groups according to their SiO_2 contents and stratigraphic positions (see Lithostratigraphy). In the TAS diagram (Fig. 2) of Le Maitre ed. (2002), the rocks can be classified as:

– ***group I,*** comprising four samples that plot along the trachyandesite-andesite boundary and in the trachyte-trachydacite field near the boundary with dacite. Schovánková (1985a, b, 1989) denoted all these rocks generally to dacites.

– ***group II,*** comprising samples that plot near the boundary of basaltic trachyandesite and basaltic andesite fields, with some scatter into the adjacent basalt and trachybasalt fields. According to Schovánková (1985a, b, 1989) these rocks are generally classified as andesitoids.

– ***group III,*** represented by four samples of rhyolites.

Group I volcanics of intermediate composition is of Carboniferous age, whereas groups II and III are of Permian age and reveal a basic-acid composition.

According to the Na_2O + K_2O vs. SiO_2 contents, prevailing part of Carboniferous and Permian rock samples shows transitional character between subalkaline and alkaline rock series of Miyashiro (1978). The high K_2O and relatively low TiO_2 contents reflect the pertinence of the studied rocks to those of continental character (Coleman, 1977; Pearce et al., 1975). In Harker's diagrams, FeO, MgO, TiO_2, MnO, CaO and P_2O_5 correlate negatively and K_2O correlates positively with SiO_2. The contents of Al_2O_3 and Na_2O are uniform in most samples and decrease at high SiO_2 contents (>65 %) only (cf. Table 2 a, b).

The rhyolites are alumina-rich and similar to peraluminous S-type granites. However, their $Al_2O_3/(CaO + Na_2O + K_2O)$ vs. $Al_2O_3/(Na_2O + K_2O)$ molar ratios display a trend analogous to post-orogenic granites (sensu Loiselle & Wones, 1979; Maniar & Piccoli, 1989), Fig. 3. When compared to experimental data (Altherr et al., 1999), the composition of the rhyolites is similar to that of partial melts of a metapelite source (Fig. 3).

In PM-normalized multi-element variation diagrams, groups I and II show very similar patterns with negative Rb, Nb, Ta, Eu and Ti anomalies (Fig. 4). However, the groups substantially differ in Sr anomaly, which is positive in the group I and negative in the group II. Rocks of group the III differ from other groups in better pronounced negative Sr, Ti and Eu anomalies, as well as in negative P and Ba anomalies.

The medium ΣREE is a characteristic feature of groups I and II of intermediate rocks (141-385 ppm) and acid group III rocks (125-171 ppm). Chondrite-normalized REE patterns of all groups show medium to low fractionation (Fig. 5) with La_N/Yb_N ratios between 8-21 (groups I and II) and 4-7 (III group). Negative Eu anomaly is present in all samples (Eu/Eu* = 0.5-0.9), however, the expressive negative anomaly is characteristic of acid derivatives (Eu/Eu* = 0.1-0.2), indicating strong plagioclase fractionation in parental magma.

Table 2: Chemical analyses of the Late Paleozoic volcanics A55from the Krkonoše Piedmont and the Mnichovo Hradiště basins.

	Krkonoše Piedmont Basin - group I					Krkonoše Piedmont Basin group II													MHB	Krkonoše Piedmont Basin - group III			MHB
Nos.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Sample No.	301	312	313	379	380*	303	304	305	306*	307	308	311	331*	376*	377	381*	382	383*	335	309	310	314	334*
	Rumchalpa	Pecka	Pecka	Lužany	Lužany	Studenec	Koštálov	Lomnice n. Popelkou			Doubravice	Hrabacov	Koštálov	Benešov u Semil	Lomnice n. Popelkou	Bradlecká Lhota	Semily, Varta	Stará Paka	Všen	Tatobity	Tatobity	Mlázovice	Všeň
SiO_2	67.33	58.39	56.63	62.72	59.41	53.12	52.70	52.10	46.52	50.72	52.23	51.64	58.46	43.75	51.65	51.06	52.07	50.06	50.51	77.99	78.01	72.79	71.71
TiO_2	0.51	0.88	0.78	0.72	0.75	1.54	1.45	1.35	1.51	1.55	1.62	1.61	1.11	1.35	1.61	1.54	1.59	1.46	1.62	0.11	0.10	0.10	0.11
Al_2O_3	15.03	16.67	16.16	15.68	16.88	15.84	16.21	16.41	15.57	16.27	15.95	15.85	17.74	17.36	17.31	16.26	16.51	16.10	16.33	11.33	11.42	14.66	12.23
Fe_2O_3	2.96	4.44	4.24	4.38	4.93	7.66	3.50	7.98	9.96	8.79	7.74	4.38	3.37	2.89	4.66	9.48	3.80	7.20	9.31	1.04	1.05	1.62	0.86
FeO	0.20	0.33	1.02	0.34	0.57	1.88	5.90	1.39	0.35	1.89	2.22	5.92	4.37	6.31	5.06	1.58	5.30	3.50	2.13	0.20	0.31	0.11	0.16
MnO	0.04	0.10	0.08	0.03	0.05	0.13	0.15	0.17	0.18	0.12	0.10	0.16	0.05	0.09	0.13	0.07	0.11	0.17	0.12	0.02	0.02	0.01	0.03
MgO	0.67	1.64	3.41	1.85	1.80	4.10	4.85	4.44	3.52	4.97	4.38	4.69	3.56	6.60	4.24	4.25	4.44	5.73	4.63	0.43	0.42	0.11	1.39
CaO	2.58	5.63	7.16	3.48	3.86	7.22	7.34	7.21	9.79	7.99	7.72	8.08	0.55	5.97	6.64	6.89	7.17	8.25	7.82	0.35	0.08	0.26	1.35
Na_2O	3.62	3.19	3.52	2.96	3.34	3.59	3.31	3.04	3.13	2.90	2.92	3.22	3.08	5.14	3.39	3.19	3.12	3.04	2.99	2.38	2.29	2.82	2.46
K_2O	4.73	2.92	2.49	4.25	2.57	2.11	1.94	2.63	1.87	1.24	1.96	1.37	3.48	0.09	1.94	2.00	1.50	1.58	1.28	5.03	5.04	5.82	2.09
P_2O_5	0.20	0.23	0.23	0.22	0.23	0.62	0.55	0.47	0.52	0.54	0.63	0.56	0.28	0.58	0.77	0.66	0.70	0.49	0.54	0.04	0.03	0.02	0.03
H_2O^+	0.71	1.54	1.15	1.21	1.71	0.90	0.93	1.08	2.96	1.11	0.79	1.24	3.32	4.95	1.01	1.03	1.78	1.00	1.08	0.64	0.79	1.16	2.15
H_2O^-	0.88	1.18	1.55	1.63	2.26	1.30	0.84	1.57	1.46	1.61	1.61	1.20	0.53	1.34	1.57	2.25	1.92	1.66	1.68	0.68	0.59	0.25	4.71
CO_2	0.77	2.73	1.76	0.55	1.53	0.00	0.00	0.00	2.50	0.03	0.00	0.00	0.00	3.08	0.00	0.06	0.09	0.00	0.01	0.09	0.00	0.09	0.15
S	100.23	99.87	100.18	100.02	99.89	100.01	99.67	99.84	99.84	99.73	99.87	99.92	99.90	99.50	99.98	100.32	100.10	100.24	100.05	100.33	100.15	99.82	99.43
As	3,3	4,8	2,3	2,4	1,7	4,6	n.d.	2,1	1,6	1,6	n.d.	2,5	9,5	8,4	0,7	0,9	63,3	1,9	4,1	15.9	26,4	15,0	11,7
Ba	841	1188	1156	837	1056	596	564	692	461	525	605	473	402	75	702	572	743	480	578	94	83	82	48
Ce	85,7	56,7	57,2	84,5	59,7	121,0	107,7	170,2	93,5	94,0	118,2	101,3	73,8	104,6	113,2	110,5	117,5	73,8	94,9	69,1	69,6	57,0	7,4
Co	5,6	n.d.	11,0	10,0	10,0	22	25	23	22	28	22	27	26	40	25	22	24	29	173	n.d.	n.d.	n.d.	10.0
Cr	11	82	83	90	96	82	103	49	111	99	80	100	117	241	48	79	156	111	19	2	2	2	25
Cs	5,89	4,50	2,04	7,19	2,68	0,40	0,46	0.76	0,34	0.53	0,39	0,46	10,61	0,48	0,68	0,39	5,58	0,48	3,13	15.47	10.09	3,81	7,36
Cu	32	35	49	n.a.	n.a.	79	94	49	80	49	97	99	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	18	18	292	n.a.
Eu	1,19	1,40	1,42	1,47	1,40	2,53	2,40	2,30	2,25	2,30	2,55	2,43	1,35	1,95	2,77	2,56	2,71	2,13	2,44	0,19	0,22	0,27	0.20
Gd	7,0	6,8	6,0	7,0	4,6	10,6	10,5	12,2	10,0	9,6	8,1	11,8	10,1	8,3	10,6	10,2	12,8	8,8	11,0	9,8	10,7	4,5	10,4
Hf	5,4	4,5	4,4	5,7	4,3	9,7	8,7	9,0	7,6	7,8	9,6	8,3	7,3	6,9	8,5	9,1	8,7	6,2	7,5	4,5	4,4	8,4	4,3
Ho	0,76	0,52	0,58	0,77	0,65	1,22	0,93	1,06	0,82	1,15	1,16	1,39	1,83	1,62	1,70	1,48	1,60	1,41	1,45	1,91	2,24	0,82	3,09
La	53,4	32,8	33,5	51,3	32,4	65,9	58,5	99,8	51,1	50,6	64,4	54,4	38,6	59,4	61,3	64,9	67,6	40,9	50,4	35,6	35,2	32,4	37,4
Lu	0,32	0,24	0,27	0,36	0,22	0,65	0,58	0,59	0,58	0,6	0,65	0,65	0,55	0,56	0,62	0,63	0,65	0,55	0,63	0,96	0,99	0,51	1,17
Nb	17	13	14	7	n.d.	36	29	27	31	27	31	26	20	21	22	20	22	11	19	33	31	40	25
Nd	42,7	35,7	37,0	40,2	27,0	68,8	59,9	80,8	50,2	54,4	66,9	54,9	35,0	52,5	61,4	59,0	64,1	41,3	51,4	34,5	34,9	22,5	36,9
Ni	13	35	57	32	54	53	56	48	63	59	55	53	73	88	38	53	52	59	93	n.d.	n.d.	21	2
Pr	n.d.	n.d.	n.d.	n.d.	n.d.	26,3	n.d.	29,4	n.d.	n.d.	n.d.	17,4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	13,4	n.d.	n.d.	n.d.
Rb	158	73	61	157	62	43	32	49	33	29	36	29	131	5	35	37	20	26	39	335	328	266	86
Sc	9,4	19,6	19,2	15,3	18,9	23,7	23,6	27,6	26,6	27,7	25,2	28,7	20,1	29,0	22,8	24,9	24,6	31,5	28,5	7,1	6,7	0,6	6,9
Sm	7,0	4,9	5,2	6,7	4,8	11,5	10,3	12,1	9,6	9,5	11,5	10,0	6,8	9,0	11,0	10,5	11,5	8,0	9,7	7,7	7.8	3,1	8,4
Sr	169	465	610	256	480	260	295	257	291	248	254	236	33	63	339	292	391	221	279	19	18	28	126
Ta	0,84	0,54	0,53	0,83	0,48	1,70	1,59	1,27	1,42	1,45	1,74	1,48	1,46	1,54	1,64	1,60	1,73	1,07	1,36	2,63	2,51	1,73	2,51
Tb	0,66	0,56	0,58	0,69	0,50	1,41	1,3	1,25	1,26	1,25	1,45	1,35	0,96	1,16	1,36	1,34	1,46	1,16	1,27	1,50	1,55	0,47	1,59
Th	23,96	9,68	9,67	21,44	9,18	8,14	7,17	11,61	6,09	6,08	7,86	6,35	14,61	6,85	6,52	7,39	7,36	4,61	6,95	20,29	19,45	56,78	21,37
Tm	0,27	0,31	0,37	0,39	0,34	0,66	0,60	0,70	0,67	0,68	0,74	0,68	0,49	0,95	0,84	0,70	0,76	0,62	0,70	0,90	0,97	0,35	1,08
U	4,19	2,12	3,13	3,63	2,46	1,43	1,16	1,39	1,94	0,8	1,93	1,17	3,01	1,67	1,09	2,67	1,29	1,10	1,55	4,40	3,59	3,45	12,46
V	23	79	83	38	74	100	102	108	135	113	93	124	112	168	96	85	106	119	125	n.d.	n.d.	n.d.	n.d.
Y	32	25	26	23	16	48	42	38	41	42	45	42	35	32	36	35	36	31	33	66	72	38	64
Yb	1,85	1,46	1,67	2,13	1,37	3,93	3,79	3,72	3,78	3,71	4,16	3,89	3,51	3,63	4,13	4,01	4,29	3,63	3,96	6,41	6,58	3,12	7,53
Zn	29	56	68	57	75	122	121	115	88	130	118	128	221	217	120	98	126	115	142	34	34	36	60
Zr	176	140	140	193	143	349	290	304	263	260	320	265	236	252	304	320	324	205	255	94	86	191	82
#Mg	32,91	44,29	59,66	47,53	42,98	49,49	52,92	52,07	44,22	51,54	50,00	49,93	50,21	60,83	49,00	46,85	51,64	54,63	48,03	44,25	41,24	12,82	75,73
K/Rb	248,47	332,00	338,80	224,68	344,05	407,28	503,19	445,49	470,33	354,90	451,89	392,10	220,49	149,40	460,06	448,65	622,50	504,38	272,41	124,62	127,54	181,60	201,71
Rb/Sr	0,93	0,16	0,10	0,61	0,13	0,17	0,11	0,19	0,11	0,12	0,14	0,12	3,97	0,00	0,10	0,13	0,05	0,12	0,14	17,63	18,22	9,50	0,68
Th/U	5,72	4,57	3,09	5,91	3,73	5,69	6,18	8,35	3,14	7,60	4,07	5,43	4,85	4,10	5,99	2,77	5,69	4,18	4,48	4,61	5,42	16,46	1,72
Zr/Hf	4,10	8,26	11,35	8,25	16,33	35,91	33,45	33,74	34,56	33,46	33,47	32,08	32,51	36,50	35,92	35,22	37,03	33,03	34,23	3,48	3,23	7,92	5,79
Nb/Ta	20,24	24,07	26,42	8,39	0,00	21,18	18,24	21,26	21,83	18,62	17,82	17,57	13,70	13,63	13,44	12,51	12,74	10,27	13,97	12,55	12,35	23,12	9,96
SREE	200,90	141,32	143,64	195,47	132,97	288,08	256,43	384,70	223,66	227,80	279,79	242,82	173,03	243,65	268,88	265,86	284,86	182,31	227,84	168,51	170,72	125,01	115,04
La_N/Yb_N	20,72	16,11	14,38	17,33	16,93	12,02	11,06	19,23	9,69	9,78	11,10	10,03	7,90	11,72	10,63	11,60	11,30	8,09	9,13	3,98	3,83	7,44	3,56
Eu/Eu*	0,51	0,74	0,78	0,65	0,90	0,69	0,70	0,57	0,70	0,73	0,77	0,68	0,50	0,67	0,78	0,75	0,68	0,77	0,72	0,07	0,07	0,22	0,07

n.a. - not analysed, n.d. - not determined, below detection limit, * - altered samples excluded from the A136geochemical study, MHB - Mnichovo Hradiště Basin.

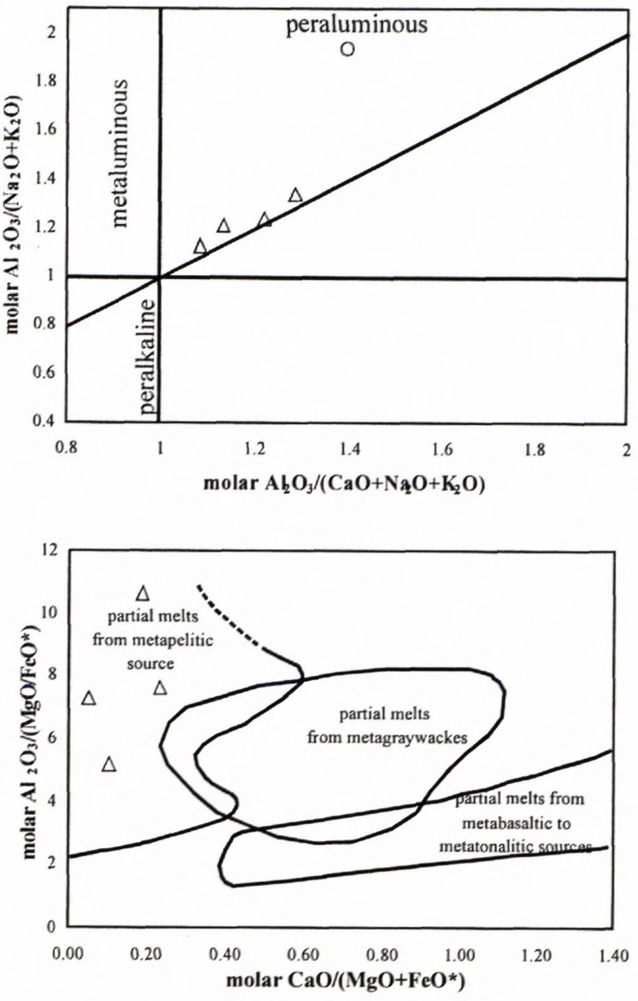

Fig. 3 Acid volcanic rocks of the Krkonoše Piedmont Basin plotted in the diagrams of Maniar & Piccoli (1989) and Altherr et al. (1999). For explanation of symbols see Fig. 2. These diagrams show the rock series affinity to peraluminous S-type granites and to partial melts from a metasedimentary source.

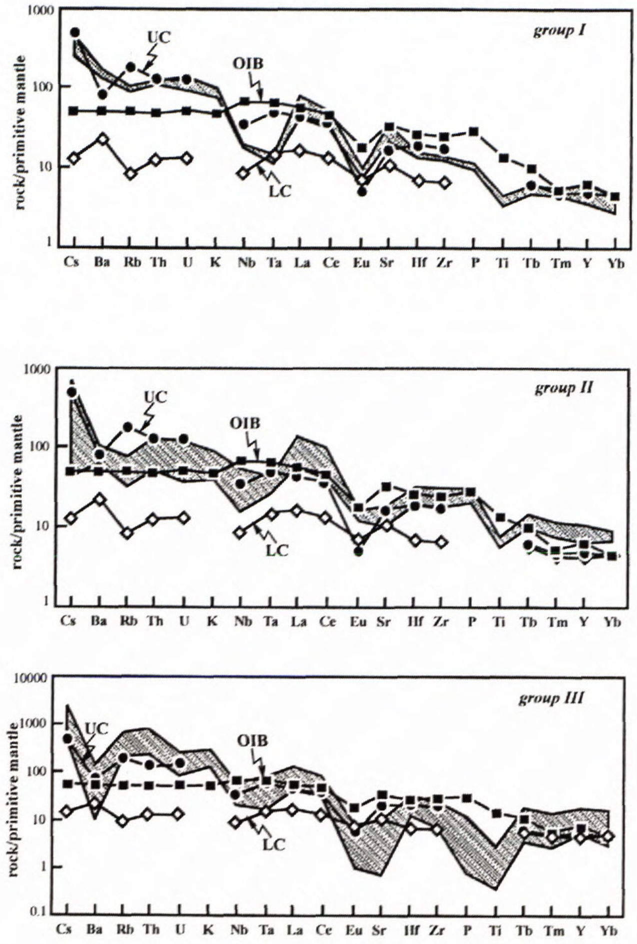

Fig. 4 Volcanics of the Krkonoše Piedmont Basin and Mnichovo Hradiště Basin in the PM-normalized multi-element variation diagram. For explanation of symbols see Fig. 2, cross-hatched areas correspond to rocks of individual groups I to III. Normalization values after Sun & McDonough (1989).

The following differences were recognized between the geochemical signature of comparable volcanics of groups I and II (see Table 3 for data):

– ***Group I*** of more evolved intermediate to acid volcanics is relatively impoverished in compatible elements as Ni, Sc, V and incompatible elements as Sr, REE, Zr, Ti, P, Nb and enriched in incompatible elements as K, Rb, Ba, Th and characterized with high La_N/Yb_N ratio associated with low ΣREE and low K/Rb ratio.

– ***Group II*** of more primitive intermediate to basic volcanics is relatively enriched in incompatible elements as Sr, REE, Zr, Nb, P and compatible elements as Ni, Sc, Ti, V, impoverished in incompatible elements as K, Rb, Ba, Th and characterized with low La_N/Yb_N ratio associated with high ΣREE and high K/Rb ratio.

Within groups I and II kindred differentiation trends in Harker's diagrams point to a fractionation of magma of similar composition. Geochemical data indicate that the rocks of the group I represent more advanced differentiates compared to the group II. The main differences are in higher K, Rb (Ba, Th), and lower Sr (REE, Zr, Ti, P, Nb, Ta) and V (Ni, Sc) contents in the volcanics of the group I compared to volcanics of the group II. Negative Nb-Ta anomaly, depletion in P, Ti are typical features of subduction-related magmas (Bailey 1981).

Prevailing intermediate rocks of both groups were compared with geochemically similar rocks from the doubtless active continental margin and subduction regime of (i) the Andes and (ii) island arcs of the southwest Pacific (e.g. Ewart, 1982). Geochemistry of rocks of groups I and II can be paralleled to Andean andesites and basaltic andesites, respectively (Ewart, 1982). Considering the systematic increase in K, Rb, Ba, La, Ce, Th, Zr, Hf and decrease in Y along a profile from island arc to thick continental margin (Bailey 1981), the Krkonoše Piedmont Basin is herein proposed to represents a region with very thick crust. Volcanics of both groups show very similar geochemical features with the Andean volcanic rocks, primarily of the Central Active Volcanic Zone - East (Thorpe et al., 1984). In the K_2O vs. SiO_2 diagram (Peccerillo & Taylor 1976) volcanics of both groups plot into the high-K field, less commonly also to the field of shoshonitic series.

Table 3: Sr and Nd isotope ratios of the Late paleozoic volcanics from the Krkonoše Piedmont Basin.

		Sample No.	Locality	Rb*	Sr*	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	$^{87}Sr/^{86}Sr(t)$	Sm*	Nd*	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	$\varepsilon_{Nd}(t)$
Krkonoše-Piedmont Basin	Group I	303	Studenec	43	260	0,48	0.708681(11)	0,70670	10,80	56,42	0,11580	0.512331(11)	-3,0
		304	Košťálov	32	295	0,31	0.708433(11)	0,70715	9,73	50,43	0,11670	0.512303 (9)	-3,6
		305	Lomnice n. P.	49	257	0,55	0.708246(11)	0,70598	11,30	69,87	0,09743	0.512316(10)	-2,6
		308	Doubravice	36	254	0,41	0.708482(11)	0,70679	10,60	54,97	0,11640	0.512334(11)	-3,0
		311	Hrabačov	29	236	0,36	0.707933(11)	0,70645	9,40	47,59	0,11940	0.512348(10)	-2,8
	Group II	301	Rumchalpa	158	169	2,71	0.718442(12)	0,70726	6,11	36,29	0,10180	0.512153(11)	-6,0
		313	Pecka	61	610	0,29	0.707580(12)	0,70638	4,68	24,60	0,11500	0.512345(10)	-2,7
	Group III	309	Tatobity	335	19	52	0.976319(12)	0,76174	6,71	28,10	0,14430	0.512280(10)	-5,1
		314	Mlázovice	266	28	28	0.853164(12)	0,73762	2,53	14,20	0,10780	0.512364 (9)	-0,9
Central Bohemian Basins		323	Záhoří	49	272	0,52	0.709497(12)	0,70735	14,7	75,51	0,11780	0.512311(11)	-3,5

$\varepsilon_{Nd}(t)$ and $^{87}Sr/^{86}Sr(t)$ are recalculated for 290 Ma; * in ppm; data in paranthesis - standard deviation.

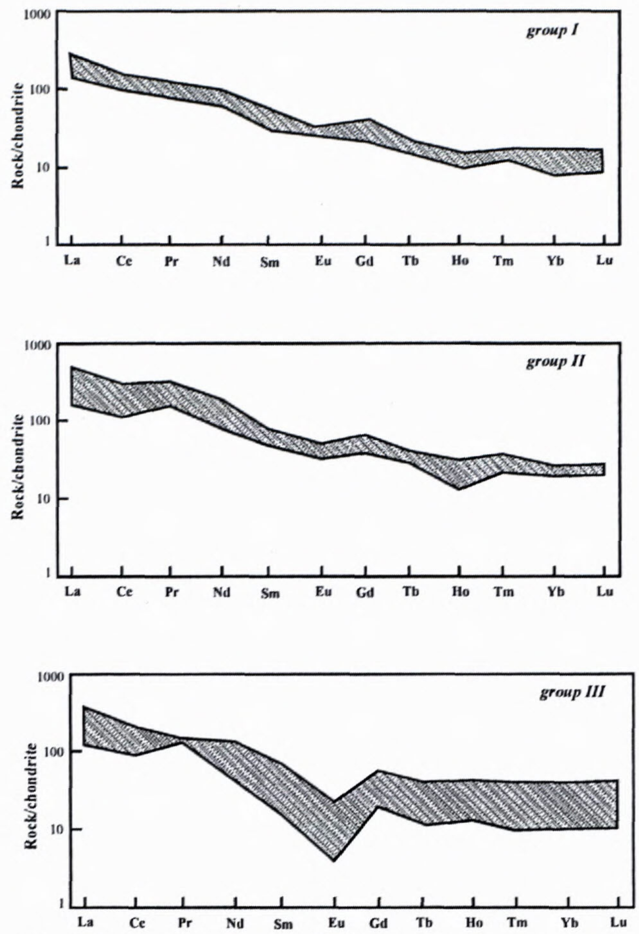

Fig. 5 Chondrite-normalized REE patterns of volcanics of the Krkonoše Piedmont Basin and Mnichovo Hradiště Basin. Normalization values after Sun & McDonough (1989).

All samples have low initial ε_{Nd} values between –1 and –6 and corresponding $(^{87}Sr/^{86}Sr)_i$ ratio of ca. 0.706 to 0.707 (Table 4). Two samples with very high Rb/Sr ratios (samples 309 and 314) yielded much higher calculated $(^{87}Sr/^{86}Sr)_i$ ratios, which is probably due to the modification of Rb and Sr concentrations during sample alteration, as suggested by a similar Sm-Nd isotopic systematics as in other samples. In the $(^{87}Sr/^{86}Sr)_i$ vs. ε_{Nd} diagram (Fig. 6), the data for samples of groups I and II produce a vertical trend whereas rhyolitic rocks of group III show higher calculated $(^{87}Sr/^{86}Sr)_i$ ratio; this is probably due to the disturbance of the Rb-Sr system in these samples. Rocks of group II show negative correlation of ε_{Nd} values with some trace element contents (Sr, Cr, Ni).

Origin and differentiation of magmas

Similar patterns in PM-normalized multi-element variation diagrams and isotopic data point to the same source material of parental magma for rocks of groups I and II. Negative Ta, Nb and Ti anomalies, high K_2O content and the position of the studied samples in the Th/Yb vs. Ta/Yb diagram (Fig. 7) are characteristic for lower crustal contamination (Pearce, 1983). Low ε_{Nd} and $(^{87}Sr/^{86}Sr)_i$ values, trending to the lower crust in the ε_{Nd}-$(^{87}Sr/^{86}Sr)_i$ diagram, and negative Rb anomaly in

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Table 4 Contrasting geochemical features of the Carboniferous (I) and Permian (II) groups of volcanics in the Krkonoše Piedmont Basin

	Group I		Group II	
	intermediate to acid volcanics		intermediate to basic volcanics	
	average	range	average	range
Mg#	47	33-60	51	49-53
Ni (ppm)	34	13-57	52	38-59
Sc	15	9-19	26	23-29
V	48	23-83	105	96-124
K_2O (Wt %)	3.82	2.49-4.73	1.83	1.24-2.63
Rb	125	61-158	34	20-49
K/Rb	271	248-338	440	220-622
Sr	162	169-610	280	236-391
Ba	947	841-1156	613	473-743
REE	180	144-201	279	228-385
La_N/Yb_N	18	14-21	12	10-19
Zr	170	140-193	302	260-349
Th	18	10-24	8	6-12
TiO_2	0.67	0.51-0.78	1.54	1.35-1.62
P_2O_5	0.22	0.20-0.23	0.61	0.54-0.77
Nb	13	42917	28	22-36

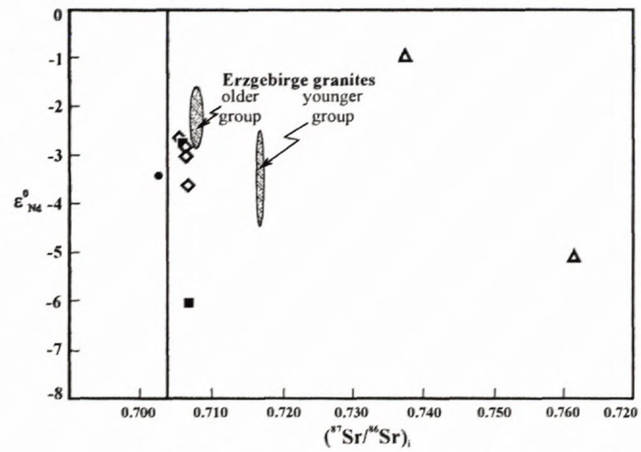

Fig. 6 Volcanics of the Krkonoše Piedmont Basin in the $(^{87}Sr/^{86}Sr)_i$ vsε_{Nd} diagram. For explanation of symbols see Fig. 2. Samples from Central Bohemian basins (full circle) and from Erzgebirge granites (Förster et al., 1999) are plotted for comparison.

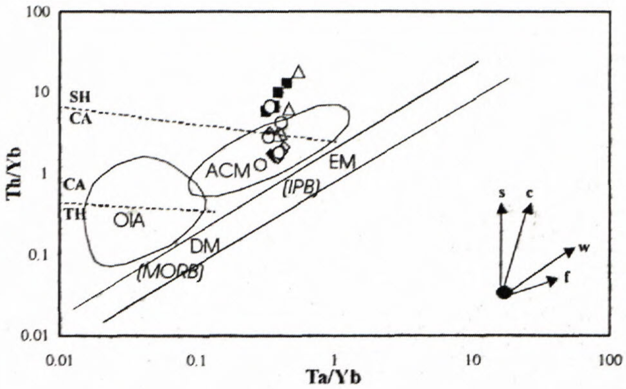

Fig. 7 Volcanics of the Krkonoše Piedmont Basin and Mnichovo Hradiště Basin in the Th/Yb-Ta/Yb diagram (Pearce, 1983). Symbols as in Fig. 2.
SH – shoshonites, CA – calc-alkaline series, TH – tholeiites, ACM – active continental margins, OIA – oceanic island arcs, EM – enriched mantle, DM – depleted mantle, IPB – intra-plate basalts, MORB – mid-ocean ridge basalts, s – subduction enrichment, c – crustal contamination, w – within-plate enrichment, f – fractional crystallization.

PM-normalized multi-element variation diagrams point also to the contamination by lower crustal material. The samples of groups I and II, however, are enriched in most incompatible elements compared to the lower crust (Fig. 4). Such enrichment can be achieved either by a fractional crystallization or by mixing with acid partial melts or by source enrichment. Both fractional crystallization and mixing with acid partial melts should produce an increase in SiO_2 content. However, some samples of the group II are basic (of basaltic composition), and the source enrichment is therefore more probable. Affinity to the OIB (see Fig. 4) points to EM as a possible source of initial magma for groups I and II. Similar patterns in the PM-normalized multi-element variation diagram and characteristic trends in Harker's diagrams point to the fractionation of one initial magma within the individual groups. Nevertheless, variation in the Sr anomaly in the PM-normalized multi-element variation diagram cannot be explained by fractional crystallization or crustal assimilation. It is therefore probable that parental magmas of the individual groups evolved in different ways. The presumption that the rocks of groups I and II cannot represent members of a single differentiation path is also clear from the SiO_2 contents, which are lower in younger rocks (group II) than in the older ones (group I). On the other hand, similar patterns in PM-normalized multi-element variation diagrams for rocks of groups I and II point to very similar initial magma for both groups. The evolution from more acid to basic members can be explained by replenishment of one magmatic chamber by a new basic magma, although an evolution in different magmatic chambers can be neither excluded. Although the rhyolitic magma of group III has some characteristics close to the rocks of groups I and II (negative Ti, Nb, Ta and Sr anomalies, low ε_{Nd} values), the compositional gap between coexisting intermediate and acid rocks of the same age (groups II and III), the affinity of rhyolites to the S-type granites and different $(^{87}Sr/^{86}Sr)_i$ and ε_{Nd} values point to different sources of basic and acid magmas. According to $(^{87}Sr/^{86}Sr)_i$ and ε_{Nd} values and the pattern in the PM-normalized multi-element variation diagram (Fig. 4) the parental magma of acid rocks (group III) formed by partial melting of the upper crustal material.

Compositional trends of the group II in the $(^{87}Sr/^{86}Sr)_i$ vs.ε_{Nd}, ε_{Nd} vs. Sr, ε_{Nd} vs. Cr and ε_{Nd} vs. Ni diagrams point to a typical lower crustal contamination (cf. Fig 8). Especially the increase in incompatible element contents together with decreasing ε_{Nd} values show that the magma composition was affected by assimilation as well as by fractional crystallization. However, simple mixing models of crustal assimilation cannot explain the observed trends (Fig. 8), and a combined AFC is a more probable process of magma evolution. To test this hypothesis, the evolution of ε_{Nd}, $(^{87}Sr/^{86}Sr)_i$, Sr, Ni and Cr contents in the magma during the AFC process was modelled (for methods used in modelling see the Appendix). As demonstrated by this modelling, the parental magma of the rock

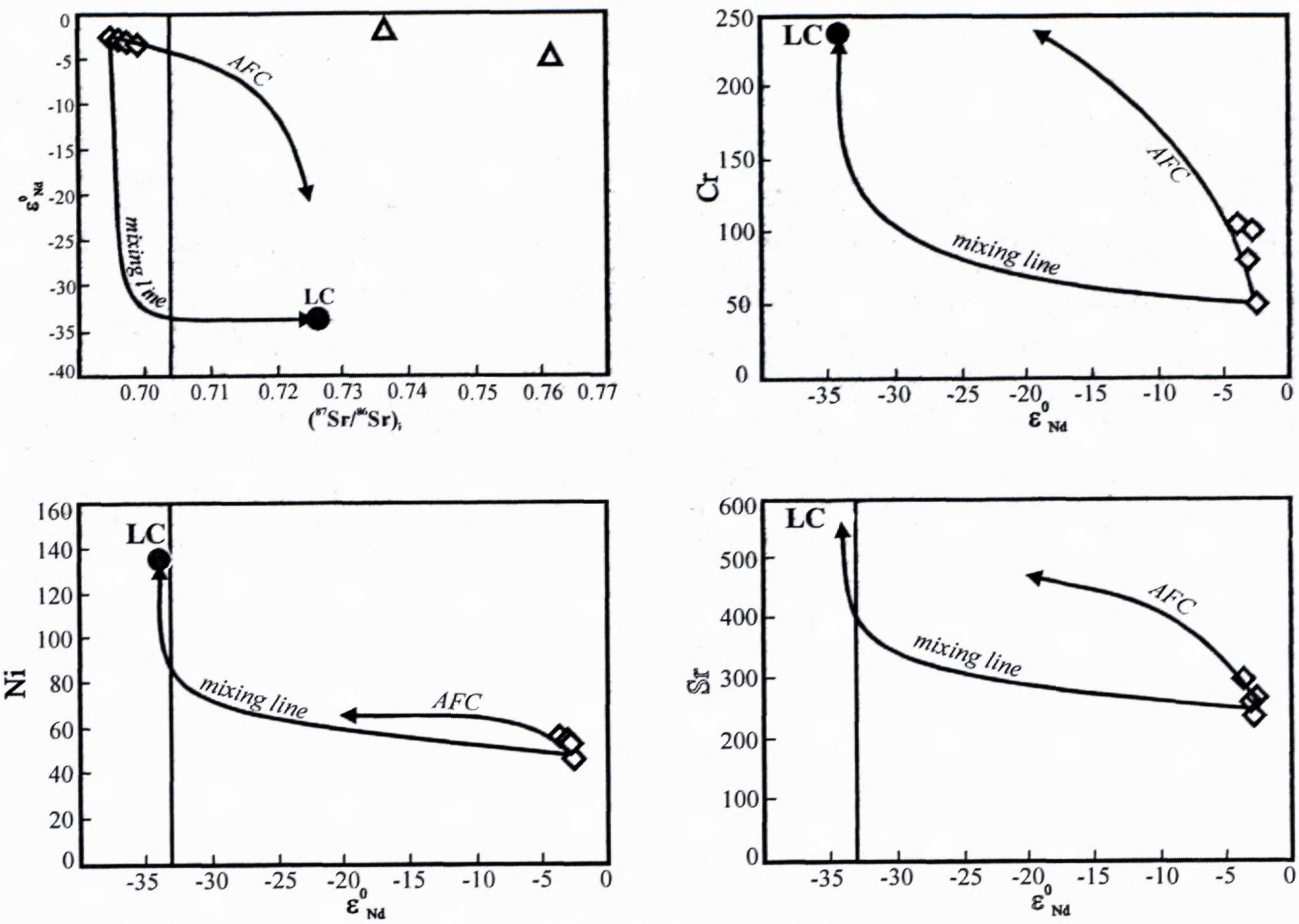

Fig. 8 Results of modelling of magma evolution. Composition of sample No. 305 was used as a starting magma composition, trace element contents in the lower crust are from Taylor & McLennan (1985), ε_{Nd} and $(^{87}Sr/^{86}Sr)_i$ were calculated for the age 290 Ma from the values of DePaolo et al. (1982). The line AFC was modelled using the following parameters: fractionated phase consists of 20 % plagioclase, 35 % olivine, 10 % clinopyroxene, 25 % orthopyroxene, 5 % Fe-oxide and 5 % apatite and r = 1 (mass assimilated/mass fractionated). Mixing line is shown for comparison; it models simple assimilation without fractionation. For the method of modelling see Appendix.

group II could have evolved by the AFC process. The contaminant was represented by the lower crust, and the fractionated phase consisted of 20 % plagioclase, 35 % olivine, 10 % clinopyroxene, 25 % orthopyroxene, 5 % Fe-oxide and 5 % apatite, while r = 1 (mass assimilated/mass fractionated) – see Fig. 8.

Comparison to other Upper Paleozoic volcanics of the Bohemian Massif

Basic to intermediate rocks of the KPB (groups I and II) were compared to volcanic rocks of other LP basins in the Bohemian Massif (Central Bohemian basins, the Česká Kamenice Basin and the Intra-Sudetic Basin). In PM-normalized multi-element variation diagrams the rocks from the Česká Kamenice Basin and the Intra-Sudetic Basin show very similar characteristics - negative Nb, Ta, Eu and Ti anomalies (Fig. 9), enrichment in most of incompatible elements, pointing to similar sources of their parental magmas. Nevertheless, differences were found in the magnitude of Sr, Rb and Eu anomalies. Such differences can be explained by fractionation of plagioclase and by a different degree of crustal contamination. Rather unclear trends in the Harker's diagrams show that rocks from different basins could not have formed by a continuous evolution of the same initial magma.

More differences exist between the studied rocks of groups I and II and basic to intermediate rocks of the Central Bohemian basins. In PM-normalized multi-element variation diagram, the elements from Nb to Yb show patterns similar to those of the group II with the exception of Ce anomaly in one sample from the Central Bohemian basins, whereas the elements from Cs to K show rather different patterns (Fig. 10). The similarity of the patterns for Nb to Yb may indicate a similar source of magma, however, the low number of unaltered samples of volcanics from the Central Bohemian basins makes a comparative study difficult (Pešek et al., in press).

When rocks of similar ages from different basins are compared, it is also difficult to find and explain the relationship between magma composition and the age of extrusion/intrusion. Thus the discussed rocks can hardly be linked to an evolution in one large, uniform magmatic chamber, and it is much more likely that several smaller magmatic chambers existed beneath the Bohemian Massif. Some of them could have been replenished several times by new primitive (basic) magma batches. On the other hand, the initial magma in individual chambers was

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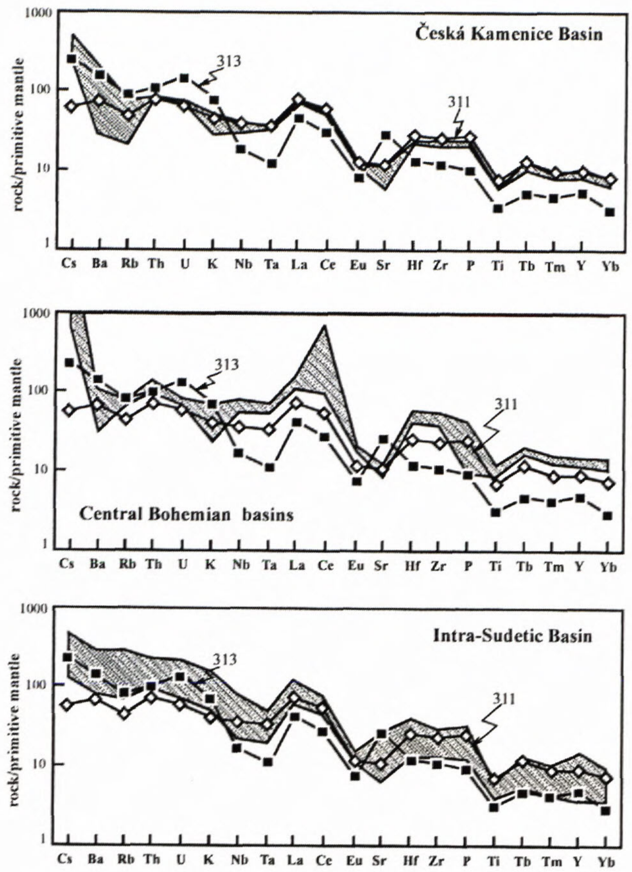

Fig. 9 Basic to intermediate volcanic products of the Česká Kamenice Basin, Central Bohemian basins and the Intra-Sudetic Basin in the PM-normalized multi-element variation diagrams. Representative samples of the group I (No. 313) and the group II (No. 311) of the Krkonoše Piedmont Basin are plotted for comparison.

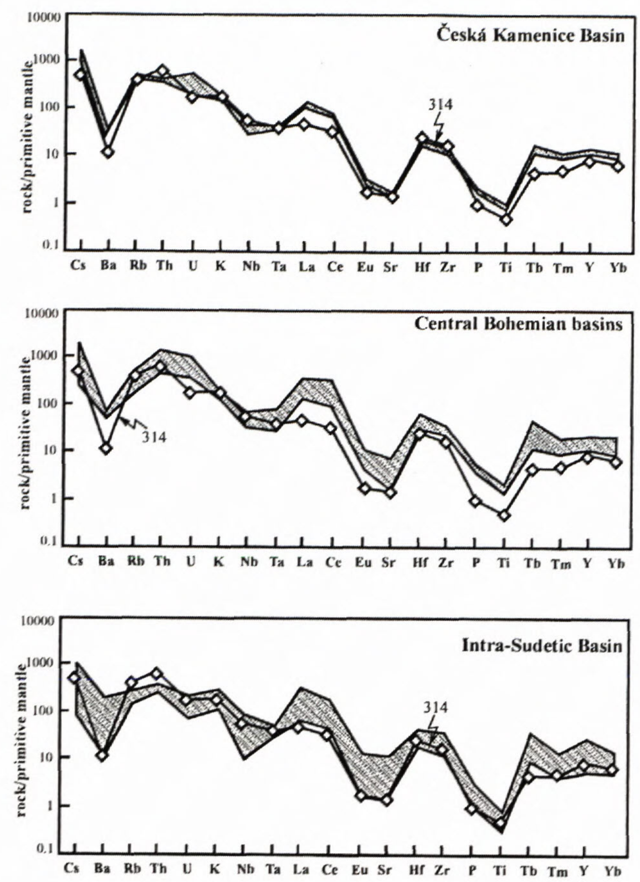

Fig 10 Acid volcanics of the Česká Kamenice Basin, Central Bohemian basins and the Intra-Sudetic Basin in the PM-normalized multi-element variation diagrams. Representative samples of the group III (No. 314) of the Krkonoše Piedmont Basin are plotted for comparison.

very similar and came from the same source. However, a separate study would be necessary to do to establish the number of the chambers and details of their evolution, but this is out of the scope of the present paper.

Basic and intermediate rocks were correlated with the published data on UP volcanic rocks from regions outside the Czech Republic – the Polish part of the Intra-Sudetic Basin (Dziedzic, 1998; Awdankiewicz 1999 b) and the Northeast German Basin (Benek et al., 1996). Rocks of the Intra-Sudetic volcanic field show similar patterns in the PM-normalized multi-element variation diagrams as those of the group II, thus possibly indicating a similar magma source. On the other hand, most of the rocks from the Northeast German Basin are rather different. Only the andesitic rocks from the Mecklenburg-Vorpommern area have similar geochemical features.

A comparison of the acid rocks of the KPB with their analogues from other basins in the Bohemian Massif shows a striking similarity in PM-normalized multi-element variation diagrams (Fig. 10), suggesting similar magma sources. Acid rocks have their equivalents in rhyolites of the Intra-Sudetic Basin (Dziedzic, 1998; Awdankiewicz, 1999a, b) and in rhyolites and microgranitoids of the Mecklenburg-Vorpommern area of the Northeast German Basin (Benek et al. 1996).

The acid rocks of the KPB (group III) were also correlated with the late Variscan granitic rocks of the Bohemian Massif. Most of the late Variscan granitoids (Breiter & Sokol, 1997) were found to differ in their geochemical signatures from the studied acid volcanics of the KPB. A similarity was found to some granitic rocks from the Eastern Erzgebirge – the Preisselberg type only (Breiter & Sokol, 1997; Förster et al., 1999).

Discussion

The geochemical study shows that the parental magma of absolute majority of rocks of the group II evolved in a lower crustal chamber by the AFC process. This is in accordance with the conclusions of Dziedzic (1998) for volcanic rocks of the Intra-Sudetic Basin.

It is probable that the initial basic magma was derived from an enriched mantle source (see previous chapter). The similarity of the studied rocks with those of the Mecklenburg-Vorpommern region suggests analogues in their origin. Their generation was explained by the underplating of basic melts at the mantle-crust boundary (Benek et al., 1996).

Opinions on the origin of acid volcanic rocks having similar geochemical characteristics as the rhyolites of the

KPB are rather different. Benek et al. (1996) supposed that the rhyolites and microgranitoids from the Mecklenburg-Vorpommern area represent dry anatectic melts of the lower crust. However, Dziedzic (1998) assumed that the parental magma of rhyolitic rocks formed by the anatexis of the upper crust. Nd and Sr isotope signatures of the studied rhyolitic rocks and their trace element data imply the upper crustal origin. In general, the origin of UP volcanics can be explained by underplating of basic, mantle-derived melts at the mantle-crust boundary, where they were substantially affected by lower crustal material. Heat from the magma together with extension movements led to the melting of the upper crust and formation of shallow magmatic chambers of rhyolitic magma.

The LP volcanic activity in general is usually associated with the collapse of the Variscan Orogeny. Despite of the limited amount of Carboniferous volcanics (group I), a successive change in the geochemical character of volcanic rocks is evident. Volcanic activity in the KPB started with the Carboniferous intermediate volcanism (andesite to dacite), which was replaced by more basic volcanic products (basalts to basaltic andesites) in the Permian. Volcanics of both series represent products of late to post-collisional volcanism associated with the eastern part of the Variscan orogeny. The rocks of the Carboniferous group I show primarily calc-alkaline characteristics of volcanics of convergent plate margin-like setting, plotting near the discrimination boundary to alkaline series. However, the rocks of the Permian group II with similar geochemical characteristics reveal some closer affinity to transitional to mildly alkaline volcanics typical of a within-plate, post-collisional extensional setting. A similar transitional development of geochemical characteristics of the LP volcanic activity was reported by Awdankiewicz (1999b) from the Intra-Sudetic Basin. Calc-alkaline volcanic rocks with geochemical characteristics of convergent plate margins need not be always associated with the subduction at convergent plate boundaries. They can also originate in a post-collisional extensional setting, adjacent to former active continental margin, with a transition towards volcanism with alkaline affinity. An example of such a development is the Basin and Range Province, SW USA (Desonie 1992; Davies & Hawkesworth 1995).

The heat input into the crust from the primary basic magmas and from the upper mantle thermal layer led to the formation of anatectic crustal melts as represented by the group III rhyolites.

Variable evolutionary trends in volcanic activity in different basins point to the existence of several independent lower crustal magmatic chambers. The rise of basaltic magmas and their emplacement at the mantle-crust boundary (Benek et al., 1996) can well explain the variations observed in the rock suites. Formation of a number of small-scale plumes is characteristic of the passive rifting (Buck, 1986), which was probably the principal mechanism of extension in the region of LP basins in the Bohemian Massif. Rifting can be well explained by a post-orogenic collapse of the Variscan Orogeny.

Conclusions

The Late Palaeozoic volcanic activity of the KPB shows the following characteristics:

- three separate groups of volcanic products were recognized: group I consisting of trachyandesites, (andesites) and trachydacites, group II including basaltic andesites and basaltic trachyandesites (alkali basalts, trachybasalts), and group III including rhyolites only;
- volcanic activity in the KPB started in the late Carboniferous with calc-alkaline andesitic to trachyandesitic activity (group I) in the southern part of the basin, and migrated northwards during the Permian time. In the Permian, basaltic to andesitic (group II) and rhyolitic (group III) types of volcanism coexisted;
- the parental magma for basic to intermediate rocks was probably derived from an enriched mantle source and retained in lower crustal chamber(s) for a long time, where it evolved by the AFC process;
- the heat input from primary magmas (together with that from the mantle thermal layer) led to the formation of anatectic melts;
- volcanic products of different LP basins of the Bohemian Massif are principally similar in their sources and origin; however, they probably evolved in separate, lower-crustal magmatic chambers. This can be explained by the existence of a number of small-scale mantle plumes, characteristic of passive rifting;
- the origin of the LP volcanic activity in the N Bohemia can be linked with the collapse phase of the Variscan Orogeny and the tensional regime.

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Appendix

Changes in the trace element contents in the magma during assimilation of lower crustal material and during combined AFC process have been modelled. The composition of a sample with relatively high ε_{Nd} (recalculated to 290 Ma) – e.g., sample No. 305 was taken as a starting magma composition. The trace element contents in the lower crustal material were taken from Taylor & McLennan (1985) and ε_{Nd} and $(^{87}Sr/^{86}Sr)_i$ were calculated from values of DePaolo et al. (1982). The used lower crustal composition is summarized in the following tables:

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Ni	135
Sr	569
Nd	18.5
Cr	235

($^{87}Sr/^{86}Sr$)	0.717	**($^{143}Nd/^{144}Nd$)**	0.51071
($^{87}Rb/^{86}Sr$)	0.056	**($^{147}Sm/^{144}Nd$)**	0.0943
($^{87}Sr/^{86}Sr)_i$	0.7168	ε_{Nd}	-33.84

Initial $(^{87}Sr/^{86}Sr)_i$ and ε_{Nd} are recalculated for 290 Ma.

Modelling of magma mixing (simple assimilation)

For the calculation of trace element evolution during simple assimilation of lower crustal material, the following mixing equation was used:

$$c^i_{mix} = X_m c^i_m + (1 - X_m) c^i_a$$

where $\mathbf{c^i}$ is the concentration of element **i**, indexes $_{m,\ a,\ mix}$ stand for the initial magma, the assimilant and the resulting magma affected by assimilation, $\mathbf{X_a}$ is the weight fraction of the resting magma expressed by the ratio of masses **M**:
$$X_m = \frac{M_m}{M_m + M_a}.$$

For the evolution of $^{87}Sr/^{86}Sr$ isotope ratio during simple assimilation, the equations of Langmuir et al. (1978) were used:

$$\left(\frac{^{87}Sr}{^{86}Sr}\right)_{mix} = \varphi_m \left(\frac{^{87}Sr}{^{86}Sr}\right)_m + \varphi_a \left(\frac{^{87}Sr}{^{86}Sr}\right)_a ,$$

where

$$\varphi_m = \frac{c^{Sr}_m X_m}{c^{Sr}_m X_m + c^{Sr}_a (1 - X_m)},$$

$$\varphi_a = \frac{c^{Sr}_a (1 - X_m)}{c^{Sr}_m X_m + c^{Sr}_a (1 - X_m)}.$$

Explanation of symbols: c^{Sr} – concentration of Sr; subscripts $_{a,\ m,\ mix}$ stand for the assimilant, the initial magma and the resting magma affected by assimilation, respectively; X_m stands for magma fraction (see the mixing equation).

The same type of equation was used for the evolution of $^{143}Nd/^{144}Nd$ in the magma upon mixing.

Modelling of assimilation-fractional crystallization process (AFC)

The equation used for the calculation of the trace element concentrations, $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$ ratios in the magma during the combined AFC process was taken from Allègre & Minster (1978) and DePaolo (1981).

a) trace element concentration during AFC:

$$\frac{c^i_m}{c^{i_0}_m} = F^{-z} + \left(\frac{r}{r-1}\right)\frac{c^i_a}{z c^{i_0}_m}(1 - F^{-z})$$

where

$$z = \frac{r + D - 1}{r - 1}$$

c^i is the concentration of trace element i, subscripts $_{m,\ a}$ stand for the magma and the assimilant, respectively, superscript ^{0} stands for the initial magma, r is the ratio of assimilated mass/fractionated mass, F means the magma fraction (mass of initial magma/mass of evolved magma) and D is the bulk partition coefficient of fractionated solid phase. For the calculation of the bulk partition coefficient, the following mineral-liquid partition coefficients were used:

	Plg	Ol	cpx	opx	Fe-Ti oxide	apatite
Ni	0.06[2)]	4.3[6)]	1.2[9)]	0.79[2)]	3.8[2)]	
Sr	5.28[1)]	0.02[4)]	0.5[3)]	0.01[3)]	0.11[7)]	1.1[12)]
Nd	0.09[3)]	0.02[3)]	0.12[13)]	0.05[2)]	0.0079[13)]	14[11)]
Cr	0.02[2)]	0.63[5)]	3.5[8)]	0.95[10)]	6[8)]	

Data source: [1)]Ewart & Griffin (1994), [2)]Luhr & Carmichael (1980), [3)]Bacon & Druitt (1988), [4)]Villemant (1988), [5)]Beattie (1994), [6)]Drake & Holloway (1981), [7)] Burke et al. (1982), [8)] Ringwood (1970), [9)]Duke (1976), [10)]Dunn & Sen (1994), [11)] Paster et al. (1974), [12)]Watson & Green (1981), [13)]Fujimaki & Tatsumoto (1984)

The following equation was used for the calculation of the isotope ratio during the AFC process:

$$\frac{\alpha^i_m - \alpha^{i_0}_m}{\alpha^i_a - \alpha^{i_0}_m} = 1 - \left(\frac{c^{i_0}_m}{c^i_m}\right) F^{-z},$$

where α^i is the isotope ratio ($^{87}Sr/^{86}Sr$ or $^{143}Nd/^{144}Nd$), other symbols are the same as in the previous equation.

References

Allègre C.J. & Minster J.F., 1978: Quantitative models of trace element behavior in magmatic processes. Earth Planet. Sci. Lett., 38, 1-25.

Altherr R., Henes-Klaiber U., Hegner E., Satir M. & Langer C., 1999: Plutonism in the Variscan Odenwald (Germany): from subduction to collision. Int. J. Earth Sci., 88, 422-443.

Awdankiewicz M., 1999a: Volcanism in a late Variscan intramontane through: the Carboniferous and Permian volcanic rocks of the Intra-Sudetic Basin, SW Poland. Geologica Sudetica, 32, 13-47.

Awdankiewicz M., 1999b: Volcanism in a late Variscan intramontane through: the petrology and geochemistry of the Carboniferous and Permian volcanic rocks of the Intra-Sudetic Basin, SW Poland. Geologica Sudetica, 32, 83-111.

Bacon C.R. & Druitt T.H., 1988: Compositional evolution of the zoned calc-alkaline magma chamber of Mt. Mazama, Crater Lake, Oregon. Contr. Mineral. Petrol., 98, 224-256.

Bailey J.C., 1981: Geochemical criteria for redefined tectonic discrimination of orogenic andesites. Chemical Geology, 32, 139-154.

Beattie P., 1994: Systematics and energetics of trace-element partitioning between olivine and silicate melts: Implications for the nature of mineral/melt partitioning. Chem. Geol., 117, 57-71.

Benek R., 1991: Aspects of volume calculation of palaeovolcanic eruptive products – the example of the Teplice rhyolite (East Germany). Z. Geol. Wiss., 19, 379-389.

Benek R., 1995: Late Variscan calderas/volcano-tectonic depressions in Eastern Germany. Terra Nostra, 7, 16-19.

Benek R., Katzung G. & Röllig G., 1976: Variszischer subsequenter Vulkanismus und tektogene Entwicklung im Gebiet der DDR. Jb. Geol., 8, 17-31.

Benek R., Kramer W., McCann T., Schenck M. Negendank J.F.W., Korich D., Huebscher H.-D. & Bayer U., 1996: Permo-Carboniferous magmatism of the Northeast German Basin. Tectonophysics, 266, 379-404.

Bouška V., 1985: Petrological and geochemical investigation of the Upper Palaeozoic volcanics. Unpublished Report, Faculty of Sci., Charles University, Praha, 81 pp (in Czech).

Breiter K., 1997: The Teplice rhyolite (Krušné hory Mts., Czech Republic) - chemical evidence of a multiply exhausted stratified magma chamber. Věst. Čes. geol. Úst., 72, 205-213.

Breiter K. & Sokol A., 1997: Chemistry of the Bohemian granitoids: Geotectonic and metallogenic implications. Sbor. geol. Věd, Ř. LG, M, 31, 75-96.

Breiter K., Novák J.K. & Chlupáčová M., 2001: Chemical evolution of volcanic rocks in the Altenberg-Teplice caldera (Eastern Krušné hory Mts., Czech Republic, Germany). Geolines, 13, 17-22.

Buck W.R., 1986: Small-scale convection induced by passive rifting: the cause of uplift of rift shoulders. Earth Planet Sci. Lett., 77, 362-372

Burger K., 1985: Die Kohlentonsteine in Niederrheinisch-Westphälischen Steinkohlrevier. Erkenntnissstand 1983. C.R. 10ème Int. Congres Stratigr. Géol. Carbon. (Madrid) 4, 211-234.

Burke W.H., Denison R.E., Hetherington E.A., Keopnick R.B., Nelson H.F. & Otto J.B., 1982: Variation of seawater $^{87}Sr/^{86}Sr$ throughout Phanerozoic time. Geology, 10, 516-53.

Cerai E. & Testa C., 1968: Separation of rare earths by means of small columns of Kel-F supporting di(2-ethyl)orthophosphoric acid. J. Inorg. Nucl. Chem., 25, 1045-1050.

Coleman R.G., 1977: Ophiolites. Springer-Verlag, Berlin.

Davies J.M. & Hawkesworth C.J., 1995: Geochemical and tectonic transitions in the evolution of the Mogollon-Datail Volcanic Field, New Mexico, U.S.A. Chem. Geol., 119, 31-53.

DePaolo D.J. 1981: Trace element and isotopic effects of combined wallrock assimilation and fractional crystallisation. Earth Planet. Sci. Lett., 53, 189-202.

DePaolo D.J., Manton W.I., Grew E.S. & Halpern M., 1982: Sm-Nd, Rb-Sr, U-Th-Pb systematics of granulite facies rocks from Fyfe Hills, Enderny Land, Antarctica. Nature, 298, 614-618.

Desonie D.L., 1992: Geologic and geochemical reconnaissance of Isla San Esteban: post-subduction orogenic volcanism in the Gulf of California. J. Volcanol. Geoth. Res., 52, 123-140.

Downes H. & Duthou J.L., 1988: Isotopic and trace element arguments for the lower-crustal origin of Hercynian granitoids and pre-Hercynian orthogneisses, Massif Central (France). Chem. Geol., 68, 291-308.

Drake M.J. & Holloway J.R., 1981: Partitioning of Ni between olivine and silicate melt: the 'Henry's Law problem' re-examined. Geochim. Cosmoch. Acta, 45, 431-437.

Duke J.M., 1976: The distribution of the period for transition elements among olivine, calcic clinopyroxene and basic silicate liquid. J. Petrology, 17, 499-521

Dunn T. & Sen C., 1994: Mineral/matrix partition coefficients for orthopyroxene, plagioclase, and olivine in basaltic to andesitic systems: A combined analytical and experimental study. Geochim. Cosmoch. Acta, 58, 717-733.

Dziedzic K., 1996: Two-stage origin of the Hercynian volcanics in the Sudetes, SW Poland. Neu. Jb. Mineral. Geol. Paläont., Abh., 199, 65-87.

Dziedzic K., 1998: Genesis and evolution of the Sudetic late Hercynian volcanic rocks inferred from the trace element modelling. Geologica Sudetica, 31, 79-91.

Eckhard F.J., 1979: Der permische Vulkanismus Mitteleuropas. Geol. Jb. Reihe D, Heft 35, 84 pp.

Eigenfeld F. & Schwab M., 1974: Zur geotektonischen Stellung des permosilischen subsequenten Vulkanismus in Mitteleuropa. Z. geol. Wiss., 2, 115-137 .

Ewart A., 1982: The mineralogy and petrology of Tertiary-Recent orogenic volcanic rocks: with special reference to the andesitic-basaltic compositional range, 26-87. In Thorpe R.S. (ed.): Andesites: Orogenic Andesites and Related Rocks. Wiley & Sons, Chichester,

Ewart A. & Griffin W.L., 1994: Application of proton-microprobe data to trace-element partitioning in volcanic rocks. Chem. Geol., 117, 251-284

Fediuk F., 1965: Melaphyres in structural boreholes of the profile line Mělnik-Ještěd. Sbor. Geol. Věd, Ř. G, 9, 103-108 (in Czech).

Fediuk F., 1967: Permokarbonische Vulkanite unter der Böhmischen Kreidetafel. Ber. Deutsch. Gesell. geol. Wiss., B- Mineral. Lagerstättenforsch., 12 173-179.

Fediuk F., 1972: Lower Paleozoic, Upper Paleozoic and Neoidic volcanics from the Železný Brod area. Unpublished Report, Faculty of Sci., Charles University, Praha (in Czech).

Fediuk F., 1973: Melaphyre rocks of northern margin of the Mnichovo Hradiště Depression. Sbor. Severočes. Mus., přír. Vědy, 5, 85-96 (in Czech).

Förster H.J., Tischendorf G., Trumbull R.B. & Gottesmann B., 1999: Late-collisional granites in the Variscan Erzgebirge, Germany. J. Petrology, 40, 1613-1645.

Franke D., 1995: The North Variscan Foreland. In: Pre-Permian Geology of Central and Eastern Europe, Dallmayer, R.D., Franke, W. & Weber, K. (Eds.). Springer Verlag, Berlin, 554-566.

Franke W., 1989: Variscan plate tectonics in Central Europe – current ideas and open questions. Tectonophysics, 169, 221-228.

Fuijimaki H. & Tatsumoto M., 1984: Partition coefficients of Hf, Zr and REE between phenocrysts and groundmass. Proceedings of the 14th Lunar Planetary Science Conference. J. geophys. Res., 22, 662-672

Gotthard J., 1933: Petrographic characteristic of melaphyres in the Podkrkonoší (Krkonoše Piedmont) area. Arch. přírod. Prozk. Čech, 18, 2, Praha (in Czech).

Hegner E. & Kröner A., 2000. Review of Nd isotopic data and xenocrystic and detrital zircon ages from the pre-Variscan basement in the eastern Bohemian Massif: speculations on palinspastic reconstructions. Spec. Pub. Geol. Soc. London, 179, 113-129.

Hegner E., Walter H.J. & Satir M., 1995. Pb-Sr-Nd isotopic compositions and trace element geochemistry of megacrysts and melilitites from the Tertiary Urach volcanic field: source composition of small volume melts under SW Germany. Contrib. Mineral Petrol., 122, 322-335.

Hoth, K. Huebscher H.-D., Korich D., Gabriel W. & Enderlein F., 1993: Die Lithostratigraphie der permokarbonischen Effusiva im Zentralabschnitt der Mitteleuropäischen Senke. Geol. Jb., A 131, 179-196.

Jindřich V., 1971: New views in tectonic significance of platform sediments in the Bohemian Massif, Czechoslovakia. Geol. Soc. Amer. Bull., 82, 763-768.

Kölbl-Ebert M., 1995: Paläozoische Ganggesteine (Rhyodazite/Dazite und Lamprophyre) des Südschwarzwaldes. Tübinger Geowiss. Arbeiten, Reihe A, Band 23, 206 pp.

Korich D., 1989: Zum Stoffbestand jungpaläozoischer basicher Magmatite aus dem DDR - Teil der Mitteleuropäischen Senke. Z. angew. Geol., 35, 72-78.

Korich D., 1992: Zu Stoffbestand und Genese der saueren und intermediären Vulkanite des Darss-Uckermark-Eruptivkomplexes in Mecklenburg-Vorpommern. Z. geol. Wiss., 20, 337-350.

Langmuir C.H., Vocke R.D., Hanson G.N. & Hart S.R., 1978: A general mixing equation with applications of Icelandic basalts. Earth Planet Sci. Lett., 37, 380-392.

Le Maitre, R.W. ed., 2002: Igneous Rocks A Classification Glossary of Terms. Cambridge University Press, Cambridge.

Loiselle N.C. & Wones D.R., 1979: Characteristic and origin of anorogenic granites. Geol. Soc. Amer., Abstr. 11, 468.

Lorenz V. & Nicholls I.A., 1984: Plate and intraplate processes of Hercynian Europe during the Late Palaeozoic. Tectonophysics, 107, 25-56.

Luhr J.F. & Carmichael I.S.E., 1980: The Colima Volcanic Complex, Mexico I. Post-caldera andesites from Volcan Colima. Contrib. Mineral. Petrol., 71, 343-372

Maniar P.D. & Piccoli P.M., 1989: Tectonic discrimination of granitoids. Geol. Soc. Am. Bull., 101, 635-643.

Miyashiro A., 1978: Nature of alkalic volcanic rocks series. Contrib. Mineral. Petrol., 66, 91-104.

Paster T.P, Schauwecher D.S. & Haskin L.A., 1974: The behavior of some trace elements during solidification of the Skaergaard layered intrusion. Geochim. Cosmochim. Acta, 38, 1549-1577.

Pearce J.A., 1982: Trace element characteristics of lavas from destructive plate boundaries. In: Andesites, Orogenic Andesites, and Related Rocks, Thorpe, R.S. (Ed.). J. Wiley & Sons, London, 525-548.

Pearce J.A., 1983: The role of sub-continental lithosphere in magma genesis at destructive plate margins. In: Continental Basalts and Mantle Xenoliths, Hawkesworth, C.J. & Norry, M.J. (Eds.). Shiva, Nantwich, 230-249.

Pearce J.A. & Cann J.R., 1973: Tectonic setting of basic volcanic rocks determined using trace element analysis. Earth. Planet. Sci. Lett., 19, 290-300.

Pearce T.H., Gorman B.E. & Birkett T.C., 1975: The TiO_2-K_2O-P_2O_5 diagram: a method of discriminating between oceanic and non-oceanic basalts. Earth Planet. Sci. Lett., 24, 419-426.

Pearce J.A, Harris N.B.W. & Tindle A.G., 1984: Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. J. Petrology, 25, 956-983.

Peccerillo A. & Taylor S.R. 1976: Geochemistry of Eocene calc-alkaline volcanic rocks from the Kastamonu area, northern Turkey. Contrib. Mineral. Petrol., 58, 63-81.

Pešek J. & Tásler R.. 1989: Volcanism and volcanogenic rocks in the Upper Palaeozoic limnic basins of the Bohemian Massif. Folia Mus. Rer. Natur. Bohemia Occid. (Plzeň), 30, 3-55.

Pešek J. (Ed.), 2001: Geology and deposits of the Upper Palaeozoic limnic basins of the Czech Republic. Czech Geological Survey, Praha (in Czech).

Pešek J., Jelínek E., Bouška V. & Kühn J., in press: Geochemistry of the Late Palaeozoic volcanic rocks of the Central and Western Bohemian basins. Proccedings 9th Coal-Geology-Conference (Praha 2001). Acta Univer. Carol., Geol., 18 pp.

Pivec E., in press: Rock-forming minerals in albitization (spilitization) process in melaphyres of the Krkonoše Piedmont PermoCarboniferous Basin. Bull. mineral.-petrolog. Odd. Nár. Muz. (Praha), 10 pp (in Czech).

Ponikelská B., 1982: Melaphyres of the Levín Platform. Unpublished MSc. Thesis, Charles University, Praha (in Czech).

Prouza V., 1993: Results of new geological mapping of Permo-Carboniferous between Kozákov and Hodkovice nad Mohelkou. Proccedings 7th Coal Conference, January 26-28, 1993, Faculty of Sci., Charles University, Praha, 167-169, (in Czech).

Prouza V. & Tásler R., 2001: The Krkonoše Piedmont Basin. In: Geology and Deposits of the Upper Palaeozoic Limnic Basins of the Czech Republic, Pešek, J. (Ed.). Czech Geological Survey, Praha, 128-167 (in Czech).

Prouza V., Coubal M. & Málek J., 2000: Flow directions of lava flows of the Krkonoše Piedmont Upper Palaeozoic andesitoids and localisation of their volcanic centres. Zpr. geol. Výzk. v roce 1999, 73 (in Czech).

Řanda Z., Benada, J., Kuncíř J., Vobecký, M. & Frána J., 1970: Radioanalytical methods for nondestructive analysis of lunar samples. J. Radioanal. Chem., 11, 305-337.

Ringwood A.E., 1970: Petrogenesis of Apollo 11 basalts and implications for lunar origin. J. geophys. Res., 75, 6453-6479.

Rutšek J., 1995: Permo-Carboniferous volcanics in the basement of the Bohemian Cretaceous Basin in northern Bohemia. In: Final Report on the Activities of the Uranium Survey in the Bohemian Cretaceous Basin in 1959-1990. Part III, Basement of the Cretaceous, Team of authors, 42-67. Unpublished Report, Archive DIAMO s.p., Stráž p. Ralskem.

Schneder J. Rösler R. & Gaitzsch B., 1994: Time lines of Late Variscan volcanism, Geodynamik des Europäisches Variszikums. Bayerisches Geoinstitut, 3-4, Bayreuth.

Schovánková D., 1973: Petrography of paleorhyolites in borehole Vš-1 (a preliminary report). In: Structural borehole Vš-1 Všeň (near Turnov), Tásler, R. Unpublished Report, Geofond, Praha (in Czech).

Schovánková D., 1984: Upper Palaeozoic volcanism. In: Česká Kamenice Basin - Evaluation of Geological and Economic-Geological Conditions. Vejlupek, M. et al. (Eds.). Unpublished Report, Geofond, Praha (in Czech).

Schovánková D., 1985a: The Upper Palaeozoic volcanism of the Mnichovo Hradiště and the Krkonoše Piedmont basins. In: The Krkonoše Piedmont Basin. Evaluation of Geological and Coal Economic-Geological Conditions, Tásler, R. et al. (Eds.). Unpublished Report, Archive Czech Geological Survey, Praha (in Czech).

Schovánková D., 1985b: Petrological types and chemical trends in the Upper Palaeozoic volcanism in the Bohemian Massif. Unpublished Report, Archive Czech Geological Survey, Praha (in Czech).

Schovánková D., 1989: Petrology of the Upper Palaeozoic volcanics of the Krkonoše Piedmont Basin. Part I. Permian basaltic andesites. Unpublished Report, Archive Czech Geological Survey, Praha (in Czech).

Seckendorf v. V., 1989: Geologische, petrographische und geochemische Untersuchungen an permischen Magmatiten im Saarland (Blatt 6507 Lebach). Berichte Geol.-Paläont. Inst. Univ. Kiel, Nr. 39, Kiel.

Středa J., 1971: Geological-petrographical characteristics of the Mnichovo Hradiště Basin near Hodkovice. Sbor. geol. Věd, Ř. G, 21, 109-155 (in Czech).

Sun S.S. & McDonough W.F., 1989: Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. In: Magmatism in the Ocean Basins, Geol. Soc. Spec. Publ., 42, Washington, 313-345.

Taylor S.R. & McLennan S.M., 1985: The continental crust: its composition and evolution. Blackwell Scientific, Oxford.

Thorpe R.S., Francis P.W. & O'Callaghan L. 1984: Relative roles of source composition, fractional crystallisation and crustal contamination in the petrogenesis of Andean volcanic rocks. Phil. Trans. R. Soc. London, A310, 675-692.

Ulrych J., Pešek P., Martinec, Lloyd F.E. & Bosák P., in prep.: Magmatism in Late Variscan basins of the Bohemian Massif: structural setting and geochemical constraints. Chem. Erde, 35 pp.

Villemant B., 1988: Trace element evolution in the Plegrean Fields, Central Italy: fractional crystallization and selective enrichment. Contrib. Mineral. Petrol., 98, 169-183.

Watson E.B. & Green T.H., 1981: Apatite/liquid partition coefficients for the rare earth elements and strontium. Earth planet. Sci. Lett., 56, 405-421.

Wilson M., 1993: Magmatism and the geodynamics of basin formation. Sed. Geol., 86, 5-29.

Wilson M. & Downes H., 1991: Tertiary-Quaternary extension-related alkaline magmatism in western and central Europe. J. Petrology, 32, 811-849.

Ziegler P.A., 1990: Geological Atlas of Western and Central Europe. Shell Intern. Petrol. Maatschappij BV, The Hague.