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Cambrian/Ordovician intracontinental rifting and Devonian closure of the rifting generated basins in the Bohemian Massif realms

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Abstract: The gravimetrically dense block of the Teplá-Barrandian terrane (TBT) forms the Bohemian Massif NW interior. The Late Proterozoic basement of the Bohemian terrane experienced low-grade Cadomian metamorphism and deformation. It is unconformably overlain by the simply folded unmetamorphosed Early Palaeozoic extension related sedimentary and volcanic sequences of the Barrandian basin. Along the Elbe fault (to the NE) another gravity high neighbours the Teplá-Barrandian terrane. This dense body in boundaries corresponds to the Krkonoše-Jizera Unit which is a suspect terrane in the West Sudetes mosaic, termed the Krkonoše-Jizera terrane (KJT).
The TBT and KJT share some essential features of the pre-Variscan history. On the other hand, they differ substantially in the Variscan orogenic development. In spite of many similarities they may represent separate basins fills, which were accumulated during Early Palaeozoic rifting of Cadomian peri-Gondwanan basement. According to the structural features and metamorphic inverse pattern, the KJT may be interpreted as the stack of para-autochthonous and allochthonous slices (derived probably from the Saxothuringian ocean and adjacent passive margin) thrust to the NW on the Saxothuringian foreland during Variscan collision of the Teplá-Barrandian and Saxothuringian terranes. Volcanic and sedimentary records of the KJT allochthonous slices commenced prior to the subduction related early Variscan blueschist facies metamorphism (terminated at ca. 360 Ma) which is rather ubiquitous in the KJT (with exception of the westernmost part – the Ještěd Unit). Taking into account modern active plate margin geometry and plate convergence rates, the onset of this metamorphism might be contemporaneous with the Early Givetian Variscan tectonism (375 to 380 Ma) which marks the end of the Early Palaeozoic sedimentation in the TBT. Provenance and palaeotectonic relations of the allochthonous slices thus are uncertain and hypothetic relations to the Teplá-Barrandian terrane may be considered.

INTRODUCTION

The Bohemian Massif has a unique position as the largest exposed part of the Variscan orogen in Central Europe. It consists of a mosaic of terranes differing in protolith and tectonometamorphic history. The terrane juxtaposition is interpreted as a result of the Variscan collisions of peri-Gondwanan microplates with Baltica (and terranes attached to it during previous cycles) followed by late Variscan large-scale shear movements. There were numerous attempts to identify individual terranes in the Bohemian Massif, to define them regionally and characterize their roles (e.g. Franke 1989; Matte *et al.* 1990; Oczlon 1992; Tait *et al.* 1997).

In considerations on the Bohemian Massif terrane development, a key role is attributed to the gravimetrically dense block of very-low grade metamorphosed to unmetamorphosed sequences forming the NW half of the Bohemian Massif interior. This uppermost tectonostratigraphic unit of Central European Variscan Internides is termed the Teplá-Barrandian terrane (Fig. 1). Along the NW and SE flanks it is squeezed between the higher grade units, Saxothuringian and Moldanubian Zones. Following the axis of the Teplá-Barrandian terrane towards the NE (i.e. beyond the Elbe fault), a less significant gravity high is encountered. It has been interpreted by Edel and Weber (1995) as a dense body whose boundaries approximately correspond to the Krkonoše-Jizera terrane (Fig. 1) of the West Sudetes.

A brief summary of the comparisons of volcanic activity and sedimentary records, as well as tectometamorphic developments of the Teplá-Barrandian terrane (TBT) and Krkonoše-Jizera terrane (KJT) is presented in this paper as a contribution to deciphering of pre-Variscan and Variscan history of the Bohemian Massif.

TEPLÁ-BARRANDIAN TERRANE

The Teplá-Barrandian terrane (Fig. 1), is considered to be one of the easternmost relics of the Late Proterozoic (Cadomian) terrane chain incorporated into the Variscan Belt of Europe from the northern Bohemian Massif to the eastern Paris Basin (Edel and Weber 1995). In the geological map it appears as a weakly deformed and very low-grade metamorphosed Cadomian basement of the NW half of the Bohemian Massif interior. However, along the NW, SW and SE margins with neighbouring Saxohuringian and Moldanubian units it is significantly overprinted by Variscan metamorphism and deformation. It is unconformably overlain by the weakly deformed Cambrian and Early Ordovician up to Middle Devonian sequences of the Barrandian.

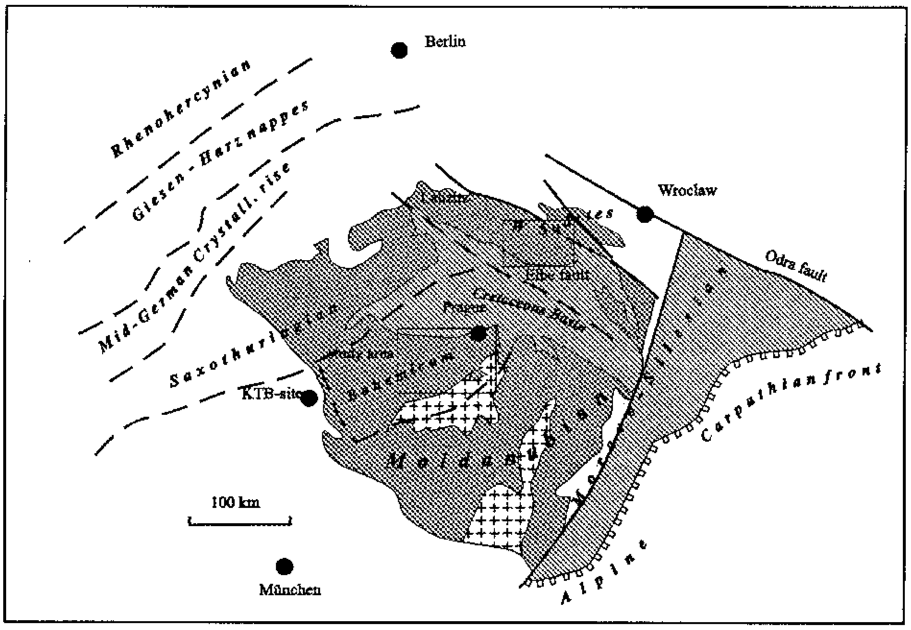

Fig. 1. Position of the studied areas (in rectangles) in framework of the major structural zones distinguished in the Central European Variscides.

(b) Ordovician to Devonian predominatly submarine WP-like basaltic volcanism (Fiala 1977, 1978; Patočka *et al.* 1993) represented by various types of pillow basalts, brecciated lavas, dolerite sills and rather subordinated pyroclastics (present in volcanic elevations) – Figs. 4, 5. The geochemistry of the Early Cambrian Barrandian basic to acid volcanics indicate tectonic setting of incipient lithospheric extension, and a thinned continental lithosphere is geochemically recorded also by the Late Cambrian WPG-like intermediate to acid volcanic rocks (Patočka *et al.* 1993). This corresponds with high subsidence rate along NE-SW trending synsedimentary normal faults during sedimentation of Early to Middle Cambrian continental siliciclastics, and development of transtensional structures and associated granitoids dated to 480-530 Ma (U-Pb zircon) which penetrate the Cadomian basement of the western part of TBT (Zulauf *et al.* 1997).

From the Ordovician until the Middle Devonian, the volcanic succession ranges from alkaline WPBs towards tholeiitic to alkaline basalts (Figs. 4, 5), indicating an extensional tectonic regime which resulted in considerable widening of the Barrandian (Patočka *et al.* 1993).

Cambrian and Early Ordovician to Middle Devonian volcanic rocks of the TBT

Early Palaeozoic volcanism in the Barrandian area (Figs. 2, 3) is divided into two groups:

(a) Cambrian subaerial explosive and mostly intermediate to acid WP-like volcanism (andesites and rhyolites and scarce basalts) (Waldhausrová 1971) – geochemically strongly influenced by crustal contamination and/or crustal origin of anatectic melts. This volcanism waned during the Early Ordovician.

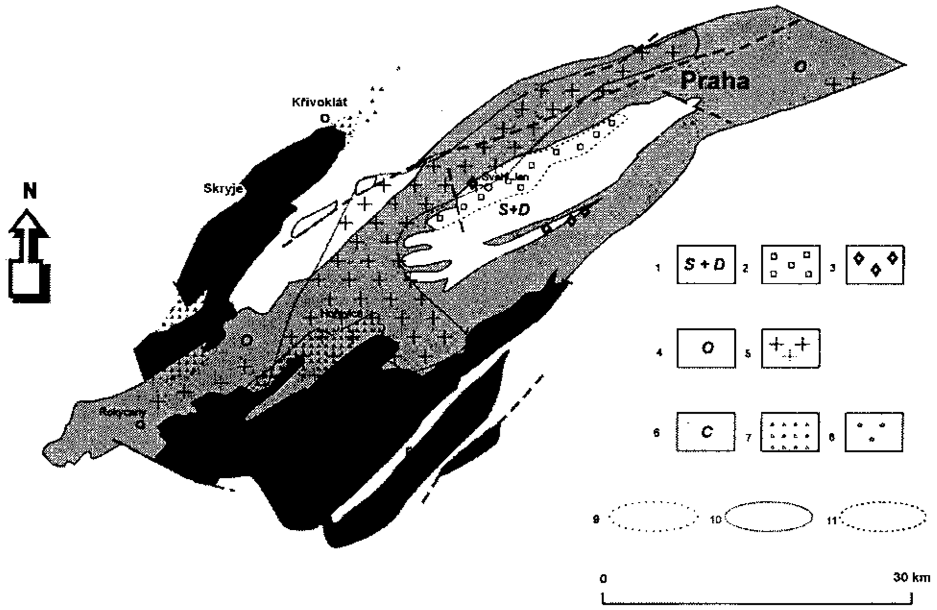

Fig. 2. Areal extent of the Early Palaeozoic volcanism in the Barrandian area s.s.: 1- Silurian and Devonian sediments; 2 – Silurian and Devonian basaltic volcanism; 3 – Silurian and Devonian picritic basalts (mostly dykes, sills); 4 – Ordovician sediments; 5 – extent of Ordovician basaltic volcanism; 6 – Cambrian sediments; 7 – extent of Late Cambrian to lowermost Ordovician intermediate to acid volcanism; 8 – acid volcanoclastics in the Early Cambrian continental deposits; 9 – supposed limit of Cambrian volcanic centres; 10 – supposed limit of Ordovician volcanic centres; 11 – supposed limit of Silurian and Devonian volcanic centres; (modified according to Štorch in Chlupáè *et al.* 1992).

Early Palaeozoic granitoids

Xenoliths of intensely metasoma-tized and deformed granitoid rocks were described in the Ordovician basalts of the Barrandian (Fiala 1978). The U-Pb method by Frýda *et al.* (1997) dated the age of the granitoid (metasomatic?) zircons to 474 ± 4 Ma (Late Arenig). On the basis of low ε_{Nd} values, measured on the zircons, these authors related the granitoid origin to the mantle source of the Prague Basin Ordovician basic volcanics. The presence of granitoid rocks in the Barrandian, possibly genetically associated with basalts related to continental lithosphere extension, seems to be of significant geotectonic implications accor-ding to the authors cited.

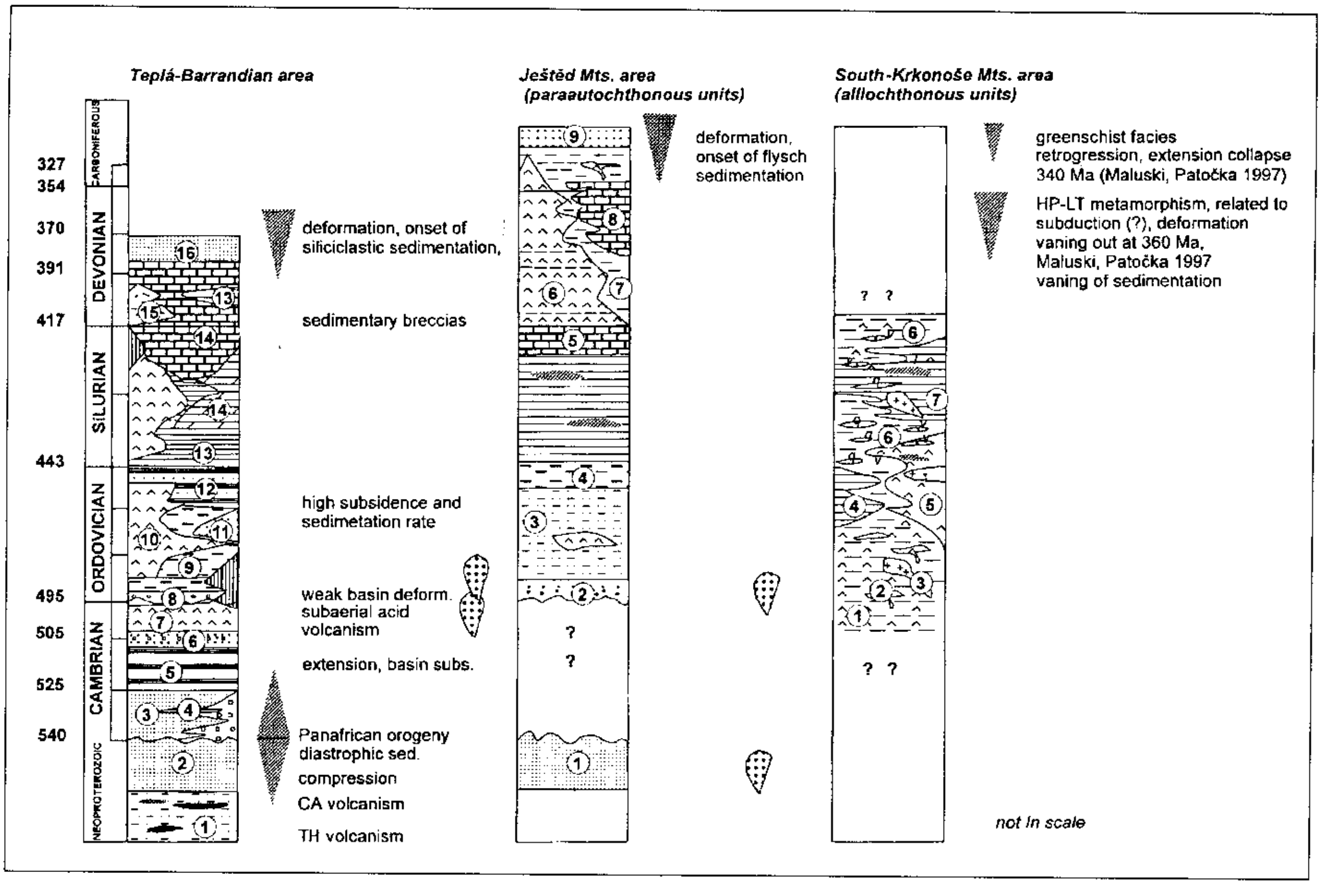

Fig. 3. Comparison of lithostratigraphic and tectonomagmatic development of the Teplá-Barrandian area, Ještěd Mts. area and Southern Krkonoše Mts. area. Teplá-Barrandian area: **(Barrandium are according to Chupáč *et al.* 1992);** Late Proterozoic: **1 – psammo-pelitic sediments associated with TH submarine volcanics, at the top passing to CA intermediate to acid ones; 2 – flysch deposits;** Cambrian: **3 – continental sandstones to conglomerates; 4 – laminated fresh-water to limited lagoonal shale; 5 – marine shale; 6 – continental siliciclastics; 7 – subaerial intermediate to acid volcanics;** Ordovician: **8 – basal sandstones and conglomerates; 9 – shales, aleuropelites; 10 – basaltic volcanics; 11 – sandstones with subordinate shales; 12 – sandstones – shales;** Silurian: **13 – graptolite shales, calcareus shales; 14 – limestones;** Devonian: **15 – reef limestones; 16 – siliciclastic flysch-like sediments.** Ještěd Mts. area: Late Proterozoic: **1 – flysch deposits (metagraywackes, slates);** (?) Ordovician: **2 – basal metapsamite to metaconglomerate; 3 – psammo-pelitic sediments with basaltic volcanic; 4 – metapelites; (?)** Silurian: **graphite shales with metacherts intercalations, 5 – marbles (Ockerkalk), 6 – metavolcanics (basaltic lavas, tuffs, tuffite), 7 – tuffitic shales, 8 – marbles;** Early Carboniferous: **9 – flysch deposits (metagraywackes, slates, metaconglomerates).** South Krkonoše Mts. area: **1 – volcanosedimentary sequence (metatuffites, tuffitic phyllites); 2 – diabase sills, dykes, feeding channels; 3 – phyllonitized granite; 4 – roofing phyllite, 5 – metavolcanics of the Železný Brod Volcanic Complex, in the upper part with intercalations of marbles (v) and volcanogenic quarzites; 6 – mepelites (sericite phyllite) with intercalations of quarzite, marbles; 7. – graphitic shales with intercalations of lydite, marbles and albitic phyllites.**

Tectono-metamorphic development of the TBT

The several km thick Late Proterozoic (Late Riphean to Vendian age) sequence of the Teplá-Barrandian terrane comprises two parts (Fig. 3). The lower part consists of siliciclastic basinal sediments associated with predominantly basaltic tholeiitic volcanics; in the topmost level it involves IA-volcanics (Fiala 1978; Waldhausrová 1998). Associated volcanic rocks reflect change of extensional tectonic setting to convergent one during the basin evolution. The upper (flysch-like) unit is void of any significant volcanism.

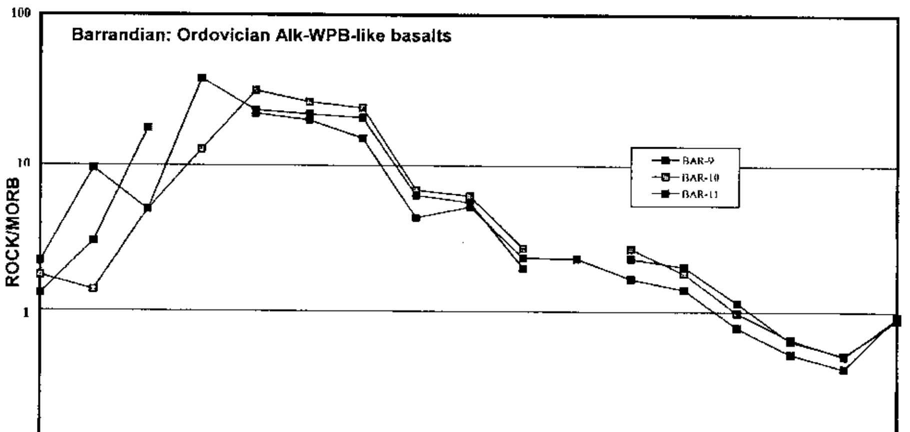

Fig. 4. MORB-normalized trace element distribution pattern of the Ordovician Alk-WPB-like basalts in the Barrandium area.

The Late Proterozoic basement rocks probably represent an accretionary wedge sequence scraped off the sea floor in front of an island arc system during the Late Cadomian orogeny (Jakeš *et al.* 1979). This deformation produced relatively simple upright folds with dense axial planar cleavage created in very-low grade regional metamorphic conditions (e.g. Cháb and Suk 1978).

The Early Palaeozoic volcano-sedimentary sequence of the

Barrandian (Fig. 3), reaching up to several km in thickness, was accumulated on top of the Late Proterozoic basement after erosion subsequent to the Cadomian deformation (Chlupáč *et al.* 1992).

The principal Cambrian sedimentation area in the Barrandian was the Příbram-Jince Basin. At the end of the Cambrian sedimentation was terminated in the Barrandian, with an inversion of relief evolving during the Czech phase (Havlíček 1963); the Příbram-Jince area became an elevation. At the same time a longitudinal depression began to subside in the axial parts of the Barrandian. Its axis is about 15° rotated from the axis of Cambrian troughs. The newly formed extensional Prague Basin was filled mainly by relatively shallow water siliciclastic sediments from Tremadocian to Early Silurian times. In the Late Silurian the siliciclastic sedimentation was substituted by deposition of carbonates which dominated in the Early Devonian. Sedimentation ceased in the Early Givetian in response to the early Bretonian phase of the Variscan orogeny (Havlíček 1963) which resulted in rapid input of flysch-like siliciclastic continental sediments into the Barrandian basin.

Based on the Ordovician to Silurian development of volcanic rock geochemical features (see above Figs. 4, 5) as well as the Silurian sedimentary record (indicating withdrawal of the clastic material source regions), the maximum extension can be dated possibly as occurring in mid-Silurian time; extension ceased in the Devonian (Patočka *et al.* 1993).

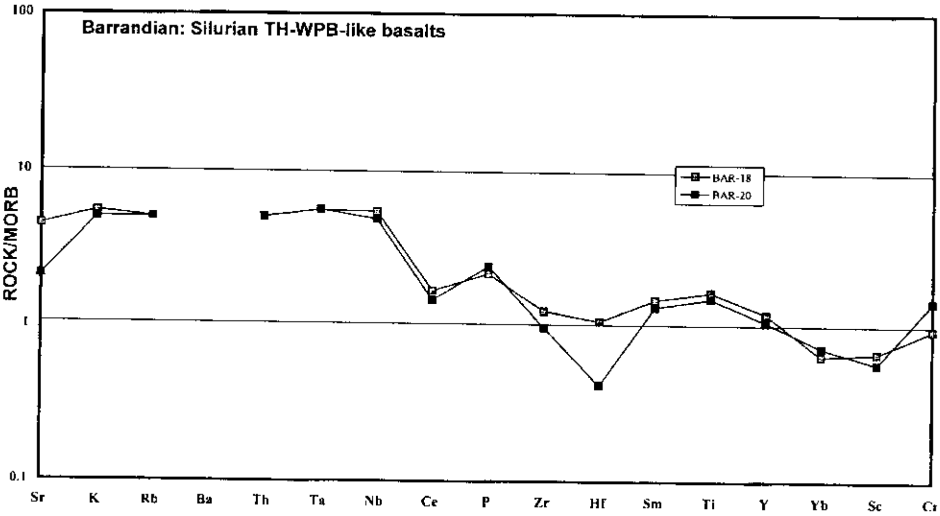

Fig. 5. MORB-normalized distribution trace element pattern of the Silurian TH-WPB-like basalts of the Barrandian area.

The Early Givetian (375-380 Ma – Fig. 3) onset of siliciclastic sedimentation marks the beginning of Early Variscan deformation in the Barrandian. This is in accordance with the Middle to Late Devonian peak of MP to HP metamorphism in the TBT borders (e.g. Beard *et al.* 1995; Dallmeyer and Urban 1998). The Early Palaeozoic Barrandian basin fill is unmetamorphosed and only gently folded by NE-SW directed upright folds. The shallow dipping small-scale thrusts, rooted in the centre of the Barrandian, are facing both flanks of the Barrandian synform.

KRKONOŠE-JIZERA TERRANE

The West Sudetes constitutes the northeastern margin of the Bohemian Massif – Fig. 1; in the scale of the European Variscan Belt this unit is often interpreted as the easternmost part of the Saxothuringian zone. The Krkonoše-Jizera terrane represents one of the several lithotectonic units (suspected terranes?) distinquished in the West Sudetes (Cymerman and Piasecki 1994; Narebski 1994). According to the recent state of knowledge following tectonostratigraphic units are distinguished in the KJT from bottom to top of the structural sequence – Figs 3, 6:

(1) Autochthonous unit which is composed of the Cadomian Lusatian granitoids dated at 540-587 Ma (Kröner *et al.* 1994a), and the associated country rocks (Machnín Group – Chaloupský *et al.* 1989). It is exposed along the NW margin of the Ještěd Unit (the westernmost part of the KJT at the boundary with the Lusatian terrane) as the foreland of the overlying lithotectonic units. The autochthonous unit experienced greenschist facies metamorphism of Cadomian age and a non-penetrative Variscan overprint.

(2) Paraautochthonous to allochthonous unit of very low-grade metamorphosed Early to Late Palaeozoic volcano-sedimentary suite showing close similarity with the Thuringian facies; these rocks are void of the Variscan HP-LT metamorphic features an show only weak late Variscan greenschist overprint. This unit forms several imbricated slices in the central and eastern part of the Ještěd Unit.

(3) Allochthonous composite unit. The major part of the unit is occcupied by large antiform of the Izera and Krkonoše gneisses. In the core of the antiform the Late Variscan Krkonoše-Jizera granite pluton was emplaced. The southern and eastern rims of KJT consist of the Early Palaeozoic volcanosedimentary sequences of the South and East Krkonoše Complexes (Chlupáč 1993; Winchester *et al.* 1995; Fajst *et al.* 1998). The complexes are showing considerable diversity both in the metamorphic grade and protolith composition, and are tectonically bounded for the most part. They experienced rather early Variscan blueschist metamorphism (terminated at ca. 360 Ma), followed by widespread greenschist facies overprint between 340-345 Ma (Maluski and Patočka 1997) which was connected with the Early Carboniferous tectonic uplift of the previously subducted crustal slices. The major late Variscan shearing and thrusting which produced NW-SE directed linear fabric of the KJT progressed in the time between 340 and 320 Ma (Marheine *et al.* in press a, in

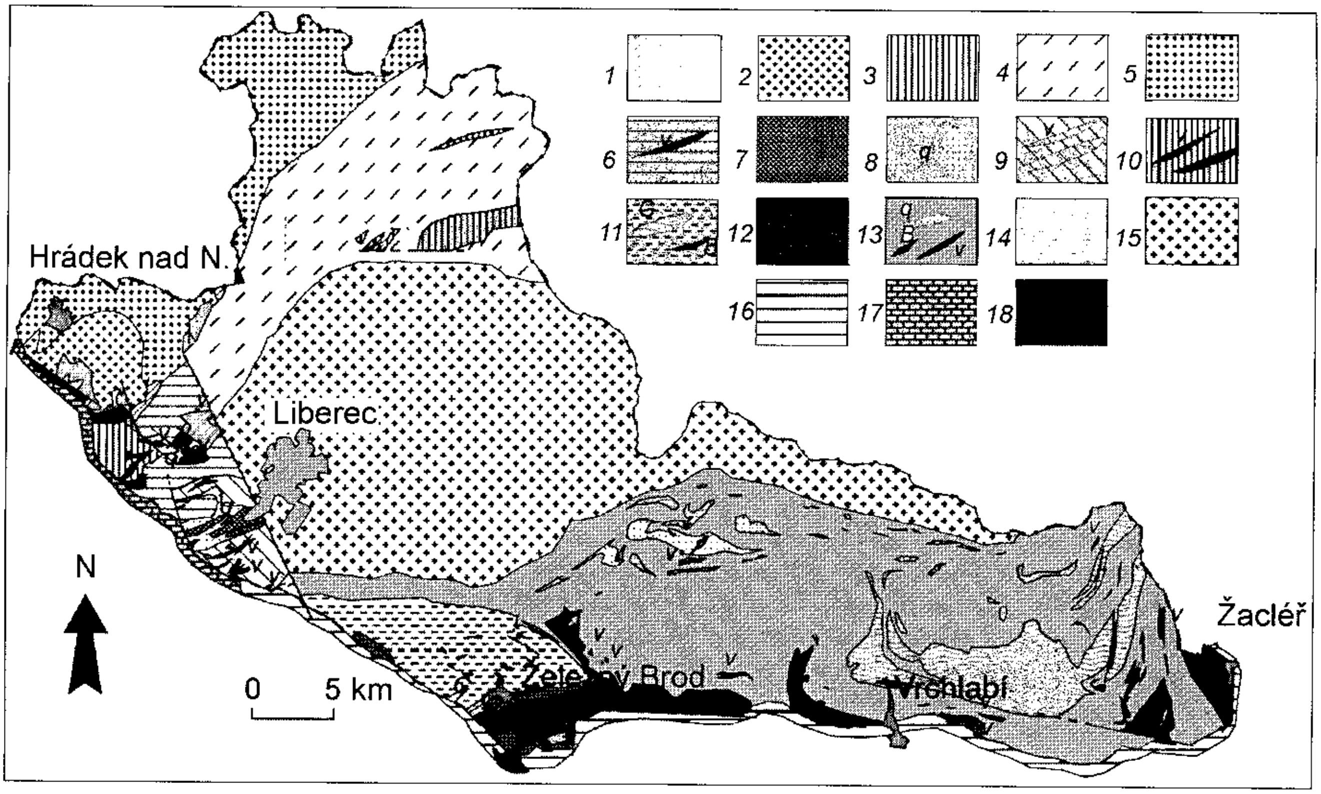

Fig. 6. Simplified geological map of the Krkonoše-Jizera Crystalline Unit: Basement unit: **1 – Late Proterozoic Machnín Group (metagraywackes, metapelites), 2 – Cadomian Zawidow Granodiorite; 3 – mica schists to gneisses in the Jizera Orthogneiss; 4 – Jizera Orthogneiss (510-480 Ma); 5 – Rumburk Granite (510 Ma);** Paraautochthnous slices: **6 – Early Palaeozoic phyllites, graphite phyllites (with metabasite, quartzite and marble intercalations – Silurian Ockerkalk), Devonian fossils (Chlupáč 1998); 7 – Early Paleozoic (?) Ordovician phyllites with quartzite intercalations overthrust over sequence with Late Devonian fauna (Chlupáč 1998); 8 – quartzites, 9 – phyllites with intercalations of Middle to Late Devonian marbles (Chlupáč and Hladil 1992; Chlupáč 1998); 10 – Late Devonian to Early Carboniferous flysch deposits with intercalations of metabasalts, acid volcanics and marbles with Famenian to Early Tournaisian Fauna (Chlupáč 1993);** Allochthonous units: **11 – (?) Cambrian – Ordovician volcanosedimentary unit (metatuffites, roofing phyllites, with metadiabase sills and dykes, rare metagabbros and picrites, phyllonitized granites; roofing phyllites with (?) Ordovician ichnofauna according to Chlupáč (1997); 12 – Železný Brod Volcanic Complex (metabasaltic pillow lavas, metatuffs and acid metavolcanics in the upper part with intercalations of marbles and mixed volcanogenic quartzites); 13 – sericite phyllites with intercalations of marbles and quartzites, product of basic volcanism wanig out towards top of the sequence); 14 – phyllonitized granites and orthogneisses;** Late Variscan granites: **15 – Krkonoše-Jizera granite;** Platform sediments: **16 – Permo-Carboniferous deposits of the Krkonoše Piedmont Basin; 17 – deposits of the Czech Cretaceous basin; Neovolcanics: basanites, olivine basalts (Pliocene).**

press b) and was followed by the Krkonoše-Jizera granite intrusion dated at 328 ± 12 (Pin *et al.* 1987), which is supposed to cool down at 313 ± 3 Ma (Marheine *et al.* in press a, in press b).

Early Palaeozoic metavolcanic rocks of the East and South Krkonoše Complexes

The system of volcano-sedimentary low- to medium-grade metamorphosed complexes occur along the eastern and southern margins of the KJT. The available geochronological results (both U-Pb zircon and Rb-Sr whole rock ages) date the outset of the volcanism around the Cambrian/Ordovician boundary (Oliver *et al.* 1993; Bendl and Patočka 1995). According to the fossil evidence yielded by intercalated metasediments, volcanic activity was rather protracted, lasting until Silurian (and possibly Devonian?) (in the South Krkonoše Complex), and/or Early Carboniferous (in the Ještěd Unit) (Chlupáč 1993, 1998) – Fig. 6.

The Early Palaeozoic protolith history of the KJT metavolcanic complexes may be well compared to an evolution of intracontinental rift related bimodal magmatic suite according to the geochemical features and Sr and Nd isotopic signatures (Bendl and Patočka 1995; Kryza *et al.* 1995; Winchester *et al.* 1995; Maluski and Patočka 1997; Patočka *et al.* 1997; Fajst *et al.* 1998 etc.). The succession of the individual geochemical types of the KJT Early Palaeozoic volcanics (± shallow intrusives) may have been as follows: (i) transitional to alkaline WPBs + continental intraplate felsic rocks, (ii) N- to E-MORBs + attenuated continental lithosphere related felsic rocks, and (iii) picritic ultrabasites (Figs. 7, 8). The succession of rocks is suggested to indicate magmatic development of a laterally extending and linearly propagating (in present-day co-ordinates from E to W) intracontinental rift arm. As the MORB-like metabasites are far more abundant in the eastern complexes of the KJT (Furnes *et al.* 1994; Winchester *et al.* 1995; Patočka and Smulikowski 1997 etc.) it is suggested that in the history of the East Krkonoše sequences the intracontinental rift stage was rapidly substituted by generation of lithosphere of an incipient oceanic basin (e.g. of the Red Sea type).

However, this sequence does not include the Late Devonian/Early Carboniferous bimodal volcanics of the Ještěd Unit as they have not been studied from the viewpoint of tectonic setting of origin yet.

Early Palaeozoic deformed metagranitoids

A key problem facing the understanding of the KJT tectonomagmatic development is an interpretation of

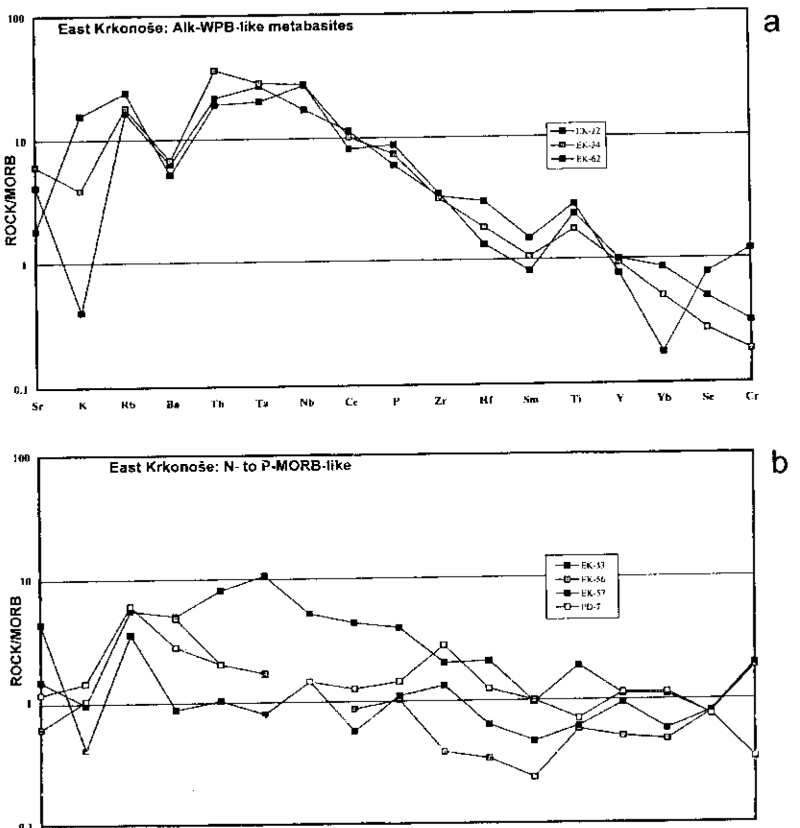

Fig. 7. a – MORB-normalized trace element distribution pattern of the Alk-WPB metabasites of the East Krkonoše area (? Cambrian-Ordovician); b – MORB-normalized trace element distribution pattern of the N- to P-MORB-like metabasites of the East Krkonoše area (? Cambrian-Ordovician).

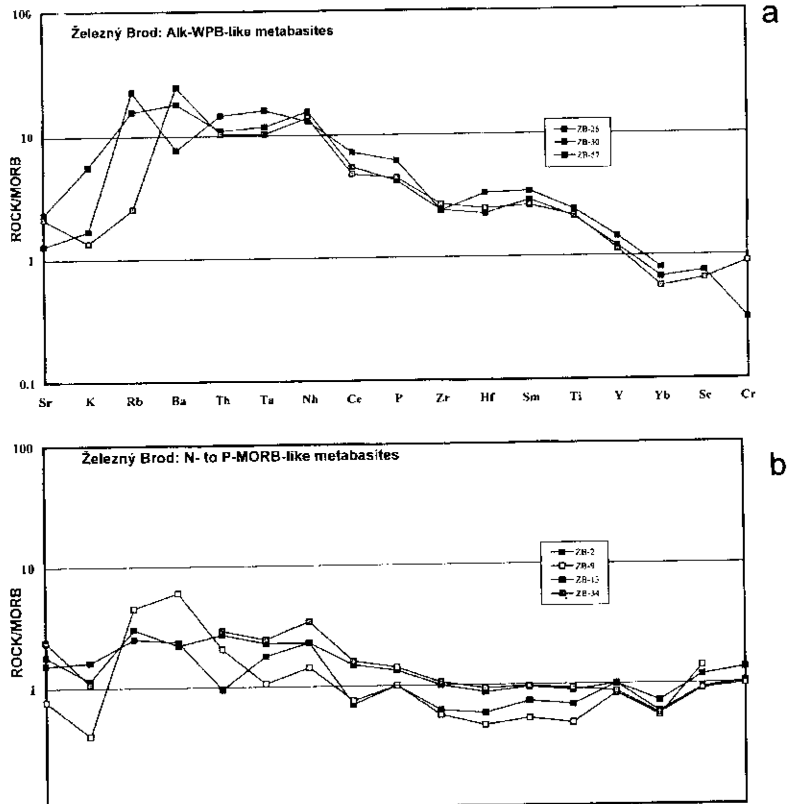

Fig. 8. a – MORB-normalized trace element distribution pattern of the Alk-WPB-like metabasites of Železný Brod area; b – MORB-normalized trace element distribution pattern of N- to P-MORB-like metabasites of the East Krkonoše area.

strongly sheared (mylonitized to phyllonitized) and subsequently folded porphyric metagranitoids exposed both as the large core antiform of the KJT and as rather small bodies scattered in the surrounding volcano-sedimentary complexes (Figs. 3, 6). However, precise ages of both metagranitoids and encompassing metasediments are missing till now. That is why several interpretations were developed (cf. Máška 1964; Grandmontagne *et al.* 1995; Kachlík 1997; Kachlík and Patočka 1998).

(a) At least some of the metagranitoids intruded as large bodies into the Neoproterozoic-Cambrian crust at ca. 515-480 Ma interval (Borkowska *et al.* 1980; Kröner *et al.* 1994a, 1994b); their origin and emplacement were related to the above described intracontinental rift development (Borkowska *et al.* 1980; Kryza and Pin 1997; Białek 1998). Subsequently they experienced intense deformation in greenschist to lower amphibolite facies PT conditions during Variscan nappe stacking.

(b) Smaller bodies of the metagranitoids are scattered in the higher levels of the Early Palaeozoic volcano-sedimentary sequence and may reflect rather protracted magmatic activity related to rifting (Ordovician-Silurian?). The primary intrusive contacts of these ingeous bodies with the country rocks were only slighly modified during Variscan shearing and folding with an absence of important lateral movements between metagranitoids and host metasediments.

(c) The deformed metagranitoids represent the Cambrian-Ordovician elements incorporated into the stratigraphically younger levels of the South Krkonoše Complex during emplacement of the Variscan nappes. The metagranitoids had not primary intrusive contact with the host rocks as both were juxtaposed during Variscan nappe stacking (cf. Kodym and Svoboda 1948). This interpretation is supported by several evidences: (i) the rate of shearing increases towards contacts of metagranitoids and surrounding metasediments, (ii) the metagranitoids are often mylonitized and phyllonized in zones several tens of metres thick, and (iii) the Cambrian-Ordovican Krkonoše gneiss (metagranite) forms the hanging wall (Kröner *et al.* 1994b) of the paleontologically dated Silurian metasediments (Perner 1919; Chlupáč and Horný 1955) in the Variscan architecture of the KJT.

Tectono-metamorphic development of the KJT

Interpretations of the tectonometamorphic development of the KJT vary widely. In the focus of long-lasting discussions are the assumed roles of Cadomian, Caledonian (?) and Variscan orogenies – see review by Chlupáč (1993). Recent lithostratigraphic studies in the Ještěd Unit (e.g. Chlupáč 1993) and South Krkonoše Complex (Chaloupský 1963, 1966; Kachlík 1997; Chlupáč 1997, 1998) and Ar-Ar dating from the East Krkonoše Complex (Maluski and Patočka 1997) show that the structure of the KJT is a result of Variscan tectonometamorphic processes. However, a weak Cadomian (pre-Ordovician) deformation and metamorphism is evidenced by the relics of older fabric in the Late Proterozoic metasediments overprinted by the contact metamorphic aureole of Cadomian and Cambrian-Ordovician granitoids (Chaloupský 1966) in NW edge of the Ještěd Unit.

The KJT volcano-sedimentary successions were deposited during a protracted period of intracontinental rifting of the Cadomian basement, and (as suggested by the East Krkonoše metabasites) an incipient formation of oceanic basin of limited extent (Fajst *et al.* 1998).

The volcanic rocks, together with the surrounding metapelites, experienced a complicated metamorphic history. Primary magmatic mineral associations (documen-ted by relics of augitic to pigeonitic pyroxenes, kaersutitic amphiboles and ilmenites) were destroyed during ocean-floor burial metamorphism by secondary alterations.

Collision of the peri-Gondwanan microplates with Baltica/Avalonia in Middle to Late Devonian times closed the above mentioned basin, and produced progressive stacking of its fill. The older Variscan subduction related metamorphic event was characterized by substantial increase in pressure and less significant rise of temperature. The rocks of the subducted plate (lithosphere of the immature ocean) experienced HP-LT blueschist metamorphism of estimated peak conditions T = 400-450°C, and P = 10-12 kbar (Patočka *et al.* 1996). The waning of the blueschist metamorphism was dated at 360 Ma by the Ar-Ar method on phengitic micas by Maluski and Patočka (1997).

Sodic amphiboles in metabasites as well as chloritoid, paragonite, phengitic micas in metasediments define the oldest E-W to WNW-ESE trending flat laying L_1 mineral and stretching lineation, which orginated probably pene-contemporaneously with the subduction related deformation and recrystallization processes (D_1) (i.e. at ca. 360 Ma – Maluski and Patočka 1997; Marheine *et al.* in press a, in press b). Increasing buyoancy and resistive forces at the plate contact or break of subducted slab may caused steepening of active subduction zone. At this particular stage (D_2) started exhumation of deeply subducted parts of the allochthonous domains by thrusting (cf. Howell 1995). During this event originated the dominant metamorphic foliatiation S_2 which is associated with the development of southwestward facing closed to isoclinal transpressional folds with flat axial planar cleavage. Fold hinges are sub-parallel to composite stretching lineation L_1L_2 which is defined by deformed and recrystallized and L_1 minerals often partly or completely replaced by L_2 greenschist grade minerals (actinolite amphibole, chlorite, sericite).

The stratigraphically older rocks were thrust over and imbricated with the younger complexes in the map scale due to westward propagation of the deformation front. This event produced an inverse zonal pattern ranging from chlorite zone in the W to garnet one in the E. The older blueschist mineral assemblage was retrogressed in greenschist facies PT conditions. The peak of retrogression (dated at ca. 340 Ma – Maluski and Patočka 1997) corresponded to higher-grade greenschist facies (T = 450° to 500°C) as documented by very fine-grained (dynamically recrystallized) albite porphyroclasts in steeply dipping shear zones in some metagabbros (cf. Hammer 1982; Tullis 1983). It was followed by retrogression to low-grade greenschist facies PT conditions. Na-amphiboles and pyroxenes were substituted by actinolite and chlorite + calcite, respectively. The crystallization of the secondary minerals was associated with the dominant foliation origin.

Incorporation of the Late Devonian and Early Carboniferous rocks into the stacked pile as well as the late NW-SE directed linear fabric of the KJT dated at 325-320 (Marheine *et al.* in press b) is the evidence that the NW oriented thrusting ceased during the Early Carbonifeours.

The late phase of the compressional D_2 event was in the uppermost levels followed by NW-SE oriented extension contemporaneus with the Krkonoše-Jizera Pluton emplacement (Grygar *et al.* 1993; Mazur and Kryza 1996), The older D_1, D_2 overthusts were often reactivated as SE dipping normal faults. Non-penetrative D_3 post-Visean deformation produced NE-SW trending folds and shear zones of predominantly strike slip or extensional character with steep cleavage. The D_3 imprint is best preserved in the structurally lowermost domain (the western part of the Ještěd Unit) i.e. along the farthest edge of the Variscan deformation front in the West Sudetes.

DISCUSSION AND CONCLUSIONS

The Teplá-Barrandian terrane (TBT) and Krkonoše-Jizera Crystaline terrane (KJT) share some significant pre-Variscan (i.e. Early Palaeozoic) characteristics; nevertheless, they differ substantially in the Variscan orogenic development (Fig. 3):

The common pre-Variscan features are:

(1) Late Proterozoic basement subjected to Cadomian orogeny, and subsequently intruded by pervasive Cambrian-Ordovician calc-alkaline plutons (e.g. Svoboda *et al.* 1966; Chaloupský *et al.* 1989; Zulauf *et al.* 1997).

(2) Early Palaeozoic volcano-sedimentary sequences unconformably overlying the Cadomian basement (Chaloupský *et al.* 1989; Chlupáč *et al.* 1992 etc.).

(3) Long-lasting Early Palaeozoic lithospheric extension and intracontinental rift-related volcanic activity. In both units the peak of volcanism corresponded to the Cambrian-Ordovician period (Chlupáč *et al.* 1992; Fajst *et al.* 1998 etc.).

On the other hand, the TBT and KJT are different in some features related to the Variscan orogeny:

(1) The Early Palaeozoic sedimentation in the TBT stopped in the Early Givetian (Chlupáč *et al.* 1992); in the Ještěd Unit (i.e. in the westermost unit of the KJT) the sedimentary sequence is considered to be continuous throughout the Early Palaeozoic to the Early Carboniferous (Chlupáč 1993).

(2) Regarding the Ještěd Unit, the local Late Devonian to Early Carboniferous bimodal volcanism (coeval with the continuous sedimentation) does not have any counterpart in the TBT (e.g. Chlupáč *et al.* 1992; Chlupáč 1993).

(3) The Variscan tectonism started in the TBT in the Early Givetian, as already mentioned (Chlupáč *et al.* 1992 etc.), i.e. between 375 and 380 Ma according to geochronological scale after Gradstein and Ogg (1996). In the upper crust it is reflected in the TBT basin inversion and deformation as well as closure of the isotopic systems (Rb-Sr, Ar-Ar) in the TBT rocks before final late Variscan tectonothermal event evidenced in the Saxothuringian and Moldanubian units (Kreuzer *et al.* 1990; Dallmeyer and Urban 1994, 1998; Košler *et al.* 1994; Glodny *et al.* 1995).

The earliest Variscan tectonometamorphic phase in the KJT is the subduction related blueschist facies metamorphism waning at ca. 360 Ma (Maluski and Patočka 1997). Taking into account recent active plate margin geometries and convergence rates (e.g. Windley 1977), the onset of subduction in the KJT may be synchronous with the oldest Variscan tectonothermal processes (ca. 380 Ma!) from the KJT neighbouring Góry Sowie (van Breemen *et al.* 1988; Oliver *et al.* 1993 etc.). However, the principal tectonometamorphic event in the KJT is the Sudetian phase (Chlupáč 1993) corresponding to the greenschist facies retrogression, dated at 340 Ma by Maluski and Patočka (1997).

In conclusion, the Teplá-Barrandian terrane and Krkonoše-Jizera terrane – in spite of many similarities represent separate basins fills, both of which originated during rifting of the Cadomian peri-Gondwanan basement in the earliest Palaeozoic (Pin 1990 etc.). The KJT may be interpreted as a stack of para-autochthonous and allochthonous slices derived probably from the Saxothuringian passive margin (Thuringian facies) and Saxohuringian ocean (Bavarian facies), thrust to the NW on the Saxothuringian foreland after the closure of this ocean during the Variscan collision of the TBT with Saxothuringian microplate (Franke *et al.* 1993; Mazur and Kryza 1996 etc.).

Neverthelss, it should be stressed out that within the framework of the KJT only the Ještěd Unit contains the volcano-sedimentary succession of the Late Devonian to Early Carboniferous age; the succession of this age is considered to be the specific feature of the Saxothuringian Zone where it is related to the Late Devonian back-arc spreading connected with the closure of the Rhenohercynian ocean) (Falk *et al.* 1995; Franke *et al.* 1995). In the "rest" of the KJT the volcanic activity and sediment accumulation more probably commenced in relation to the Middle to Late Devonian subduction mentioned above. Following that, it is suggested that the Krkonoše Jizera terrane – except the Ještěd Unit – may represent a different crustal segment overthrust to the NW over the Saxothuringian paraautochthon (the Ještěd Unit itself); the provenance of the overthrust segments seem to be uncertain and hypothetic relations to the Teplá-Barrandian terrane may be considered consequently.

References

Beard B. L., Medaris L. G., Johnston C. M., Jelínek E., Tonika J., Riciputi L. R., 1995: Geochronology and geochemistry of eclogites from the Mariánské Lázně Complex, Czech Republic: Implications for Variscan orogenesis. *Geol. Rdsch* 84: 552–567.

Bendl J., Patočka F., 1995: The ^{87}Rb-^{86}Sr isotope geochemistry of the metamorphosed bimodal volcanic association of the Rýchory Mts. crystalline complex, West Sudetes, Bohemian Massif. *Geol. sudetica* 29: 3–18.

Bialek D., 1998: Aspect of geochemisty of the Zawidów granodiorite and the Izera granite – arc to rift transition. *Geolines* 6: 11.

Borkowska M., Hameurt J., Vidal P., 1980: Origin and age of Izera gneisses and Rumburk granites in the Western Sudetes. *Acta Geol. Pol.* 30: 121–145.

Breemen van O., Bowes D. R., Aftalion M., Żelaźniewicz A., 1988: Devonian tectonothermal activity in the Sowie Góry gneissic block, Sudetes, SW Poland: evidence from Rb-Sr and U-Pb isotopic studies. *Ann. Soc. geol. Pol.* 58: 2–19.

Cháb J., Suk M., 1978: The metamorphic development of the Bohemian Massif on the Czechoslovak territory. *Sbor. geol. Věd, Geol.* 31: 109–126.

Chaloupský J., 1963: Konglomeráty v krkonošském krystaliniku. *Sbor. Ústř. Úst. geol., Odd. geol.* 28: 143–190.

Chaloupský J., 1966: Kaledonská a variská orogeneze v ještědském krystaliniku. *Sbor. geol. Věd., Geol.* 12: 165–169.

Chaloupský J. (ed.), 1989: Geology of the Krkonoše and Jizerské hory Mts. Geological Survey, Praha, 288 pp. (In Czech, Engl. summary).

Chlupáč I., 1993: Stratigraphic evaluation of some metamorphic units in the N part of the Bohemian Massif. *Neu. Jb. Geol. Paläont., Abh.* 188: 363–388.

Chlupáč I., 1997: Palaeozoic ichnofossils in phyllites near Železný Brod, northern Bohemia. *J. Czech geol. Soc.* 42: 75–94.

Chlupáč I., 1998: New paleontological finds in the western part of the Krkonoše-Jizerské Hory Mts. metamorphics and their impact on stratigraphical and tectonical concepts. *Geolines* 6: 29–30.

Chlupáč I., Havlíček V., Kříž J., Kukal Z., Štorch P., 1992: Paleozoic of the Barrandian (Cambrian – Devonian). Geological Survey, Praha, 292 pp.

Chlupáč I., Hladil J., 1992: New Devonian occurences in the Ještěd Mts., North Bohemia. *Čas. Mineral. Geol.* 37(3): 185–191.

Chlupáč I., Horný R., 1955: Zpráva o paleontologickém výzkumu fylitové zóny v západosudetském krystaliniku. *Zpr. geol. Výzk. v Roce 1954*: 57–59.

Cymerman Z., Piasecki M. A. J., 1994: The terrane concept in the Sudetes, Bohemian Massif. *Geol. Quat.* 38: 191–210.

Dallmeyer R. D., Urban M., 1994: Variscan vs Cadomian tectonothermal evolution within the Teplá-Barrandian zone, Bohemian Massif, Czech Republic: evidence from 40 Ar/39 Ar mineral and whole rock slate/phyllite ages. *J. Czech geol. Soc.* 39: 21–22.

Dallmeyer R. D., Urban M., 1998: Variscan vs. Cadomian tectonothermal activity in northwestern sectors of the Teplá-Barrandian zone, Czech Republic: constraints from ^{40}Ar/^{39}Ar ages. *Geol. Rdsch.* 87: 94–106.

Edel J. B., Weber K., 1995: Cadomian terranes, wrench faulting and thrusting in the central Europe Variscides: geophysical and geological evidence.*geol. Rdsch.* 84: 412–432.

Fajst M., Kachlík V., Patočka F., 1998: Geochemistry and petrology of the Early Palaeozoic Železný Brod volcanic complex (W Sudetes, Bohemian Massif): geodymic interpretations. *Geolines* 6: 14–15.

Falk F., Franke W., Kurze M., 1995: V. B. 1. Stratigraphy, in: Dallmeyer R. D., Franke W., Weber K. (eds.), 1995: Pre-Permian Geology of Central and Eastern Europe. Springer Verlag, Berlin, pp. 221–233.

Fiala F., 1977: Proterozoic volcanism of the Barrandian and question of spilites. *Sbor. geol. Věd, Geol.* 30: 7–47. (In Czech).

Fiala F., 1978: Proterozoic and Early Paleozoic volcanism of the Barrandian – Železné hory zone. *Sbor. geol. Věd, Geol.* 30: 7–47.

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

Franke W., Kreuzer H., Okrusch M., Schussler U., Seidel E., 1995: Stratigraphy, Structure and Igneous activity, in: Dallmeyer R. D., Franke W., Weber K. (eds.), 1995: Pre-Permian Geology of Central and Eastern Europe. Springer Verlag, Berlin, pp. 277–293.

Franke W., Żelaźniewicz A., Porebski S. J., Wajsprych B., 1993: Saxothuringian zone in Germany and Poland: differences and common features. *Geol. Rdsch.* 82: 583–599.

Frýda J., Vokurka K., Kober B., 1997: Early Ordovician metasomatism of granitoids beneath the Prague Basin (Teplá-Barrandian Unit, Bohemian Massif (In Czech). *Zpr. geol. Výzk v Roce 1996*: 78–79.

Furnes H., Kryza R., Muszynski A., Pin C., Garmann L. B., 1994: Geochemical evidence for progressive, rift-related early Palaeozoic volcanism in the western Sudetes. *J. Geol. Soc. London* 151: 91–109.

Glodny J., Grauert B., Krohe A., Vejnar Z., Fiala J., 1995: Altersinformation aus Pegmatiten der westlichen Böhmischen Masse: ZEV, Teplá-Barrandium und Moldanubikum. Abstract., 8. DFG-Kolloquium Schwerpunktprogramm "Kontinentales Tiefbohrprogramm der Bundesrepublik Deutschland", 25–26 May 1995, Giessen, p. 27.

Gradstein J., Ogg F., 1996: A Phanerozoic time-scale. *Episodes* 19: 1/2.

Grandmontagne N., Heinisch H., Franke W., 1995: The South Krkonoše Mountains: Saxothuringian/Moldanubian Boundary in the Czech Sudetes? *Terra Nostra* 94(3): 54–56.

Grygar R., Vavro M., Kreml P., 1993: Kinematika krkonošské střižné zony ve vztahu k regionální deformaci krkonošského krystalinika. *Sbor. věd. Prací Vys. Šk. báň. (Ostrava)* 39: 85–95.

Hammer S. K., 1982: Microstructure and geochemistry of plagioclase and microcline in naturally deformed granite. *J. struct. Geol.* 4: 197–213.

Havlíček V., 1963: Tektogenetické porušeni barrandienského paleozoika. *Sbor. geol. Věd, Geol.* 1: 77–102.

Howell D. G., 1995: Principles of terrane analysis – new applications for global tectonics. Chapman & Hall, London, 244 pp.

Jakeš P., Zoubek J., Zoubková J., Franke W., 1979: Graywackes and metagraywackes of the Teplá-Barrandian Proterozoic area. *Sbor. geol. Věd., Geol.* 33: 83–122.

Kachlík V., 1997: Litostratigrafie a stavba železnobrodského krystalinika: výsledek variských tektodeformačních procesů. *Zpr. geol. Výzk. v Roce 1996*: 30–31.

Kachlík V., Patočka F., 1998: Lithostratigraphy and tectonomagmatic evolution of the Železný Brod crystalline unit: some constraints for the paleaeotectonic development of the W Sudetes (NE Bohemian Massif). *Geolines* 6: 34–35.

Kodym O., Svoboda J., 1948: Kaledonská příkrovová stavba Krkonoš a Jizerských hor. *Sbor. St. geol. Úst. Čs. Republ.* 15: 109–180.

Košler J., Rogers G., Bowes D. R., Hopgood A. M., 1994: Rb-Sr isotopic evidence for polymetamorphism in the Domažlice crystalline complex from a study of mica-feldspar pairs in a segregation pegmatite near Stráž, western Bohemia. *Mitt. Österr. mineral. Gesell.* 139: 75–76.

Kreuzer H., Müller P., Okrush M., Patzak M., Schüssler U., Seidel E., Šmejkal V., Vejnar Z., 1990: Ar-Ar confirmation for Cambrian, early Devonian and mid-Carboniferous tectonic units at the western margin of the Bohemian Massif. *Zbl. Geol. Paläont., Tl. I* 1991(5): 1332–1335.

Kröner A., Hegner E., Hammer J., Haase G., Bielicki K.-H., Krauss M., Eidam J., 1994a: Geochronology and Nd-Sr systematic of Lusatian granitoids: significance for the evolution of the Variscan orogen in east-central Europe.*geol. Rdsch.* 83: 357–376.

Kröner A., Jaeckel P., Opletal M., 1994b: Pb-Pb and U-Pb zircon ages for orthogneisses from eastern Bohemia: further evidence for a major Cambro-Ordovician magmatic event. *J. Czech geol. Soc.* 39(1): 61.

Kryza R., Mazur S., Pin C., 1995: The Leszcyniec metaigneous complex in the eastern part of the Karkonozse-Izera Block, Western Sudetes: trace element and Nd isotope study. *Neu. Jb. Mineral., Abh.* 170: 59–74.

Kryza R., Pin C., 1997: Cambrian/Ordovician magmatism in the Polish Sudetes: no evidence for subduction-related setting. *Terra Nova* 7: 144.

Maluski H., Patočka F., 1997: Geochemistry and ^{40}Ar-^{39}Ar geochronology of the mafic metavolcanics from the Rýchory Mts. complex (W Sudetes, Bohemian Massif): paleotectonic significance.*geol. Mag.* 133: 703–716.

Marheine D., Kachlík V., Patočka F., Maluski H., in press a: The Variscan polyphase tectonothermal development in the South Krkonoše Complex (W Sudetes, Czech Republic). Abstracts EUG 10, *Terra Nova*.

Marheine D., Kachlík V., Patočka F., Maluski H., in press b: The Palaeozoic polyphase tectonothermal record in the Krkonoše-Jizera Crystalline Unit (West Sudetes, Czech Republic). *Geolines* 9.

Máška M., 1964: K tektonické analýze krystalinika. MS, Library of the Czech Geological Survey, Praha, 27 pp.

Matte P., Maluski H., Rajlich P., Franke W., 1990: Terrane boundaries in the Bohemian Massif: Result of large-scale Variscan shearing. *Tectonophysics* 177: 151–170.

Mazur S., Kryza R., 1996: Superimposed compressional and extensional tectonic in the Karkonosze-Izera block, NE Bohemian Massif, in: Oncken O., Janssen C. (eds.), Basement Tectonics. Kluwer Acad. Publishers, Dordrecht, pp. 51–66.

Narebski W., 1994. Lower to Upper Paleozoic tectonomagmatic evolution of NE part of the Bohemian Massif. *Zbl. Geol. Paläont., Tl. I* 1994(9/10): 961–972.

Oczlon M. S., 1992: Gondwana and Laurussia before and during the Variscan orogeny in Europe and related areas. *Heidelberg. Geowiss. Abh.* 53: 1–56.

Oliver G. J. H., Corfu F., Krogh T. E., 1993: U-Pb ages from SW Poland: evidence for a Caledonian suture zone between Baltica and Gondwana. *J. Geol. Soc. London.* 150: 355–369.

Patočka F., Dostal J., Pin C., 1997: Early Paleozoic intracontinental rifting in the central West Sudetes, Bohemian Massif: geochemical and Sr-Nd isotopic study on felsic-mafic metavolcanics of the Rýchory Mts. complex. Abstracts EUG 9, Abstract Supplement 1, *Terra Nova* 9: 144–145.

Patočka F., Pivec E., Oliveriová D., 1996: Mineralogy and petrology of mafic blueschists from the Rýchory Mts. crystalline complex (Western Sudetes, Bohemian Massif). *Neu. Jb. Mineral., Abh.* 170: 313–330.

Patočka F., Smulikowski W., 1997: Petrology and geochemistry of metabasites of the Rýchory Mts. – Rudawy Janowickie Mts. crystalline complex (West Sudetes, Bohemian Massif). *Pol. Tow. mineral., Prace spec.* 9: 146–150.

Patočka F., Vlašímský P., Blechová K., 1993: Geochemistry of Early Paleozoic volcanics of the Barrandian Basin (Bohemian Massif, Czech Republic): implications for paleotectonic reconstructions. *Jb. Geol., Bundesanst.* 136: 871–894.

Perner J., 1919: Silur v Krkonoších. *Čas. Mus. Král. čes.* 43: 33–34.

Pin C., 1990: Variscan oceans: ages, origins and geodynamic implications inferred from geochemical and radiometric data. *Tectonophysics* 177: 215–227.

Pin C., Mierzejewski M. P., Duthou J. L., 1987: Age of the Karkonosze Mts. granite dated by the izochrone Rb/Sr and its initial Sr/Sr value. *Przegl. geol.* 10: 512–517.

Svoboda J. (ed.), 1966: Regional geology of Czechoslovakia, I. Geol. Survey, Praha, 882 pp.

Tait J. A., Bachtadse V., Franke W., Soffel H. C., 1997: Geodynamic evolution of the European Variscan fold belt: paleomagnetic and geological constraints. *Geol. Rdsch.* 86: 585–598.

Tullis T. E., 1983: Deformation of feldspars, in: Ribbe P. H. (ed.), Feldspar mineralogy. (Rev. Mineral., vol. 2). Mineral. Soc. Am., pp. 297–323.

Waldhausrová J., 1971: The chemistry of the Cambrian volcanics in the Barrandian area. *Krystalinikum* 8: 45–75.

Waldhausrová J., 1998: Geochemistry of volcanites (metavolcanites) in the western part of the TBU Precambrian and their original geotectonic setting. *Sbor. geol. Věd, Geol.* 47: 85–90.

Winchester J. A., Floyd P. A., Chocyk M., Horbowy K., Kozdroj W., 1995: Geochemistry and tectonic environment of Ordovician meta-igneous rocks in the Rudawy Janowickie Complex, SW Poland. *J. Geol. Soc. London* 152: 105–115.

Windley B. F., 1977: The Evolving Continents. J. Wiley & Sons, Chichester, 385 pp.

Zulauf G., Dörr W., Fiala J., Vejnar Z., 1997: Late Cadomian crustal tilting and Cambrian transtension in the Teplá-Barrandian unit (Bohemian Massif, Central European Variscides). *Geol. Rdsch.* 86: 571–584.