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Abstract: Tectonic zones and palaeogeographic units (terranes) in the German segment of the Variscides correlate with equivalents in the Sudetes at the NE margin of the Bohemian Massif. This correlation defines an arcuate structure with an opening angle of about 90°. The structure is truncated to the SE by a crustal scale, NE-trending fault zone with dextral transpression, the Moldanubian Thrust (MT). The arc cannot have been formed by northeastward indentation of the Bohemian Massif, since there is no evidence of a fault zone on the NW flank of the notional indenter, and little evidence for northeastward tectonic transport. Kinematic and age constraints on the main fault zones instead suggest that the structural array was formed by a complex sequence of events. Northwestward displacement along the margin of the East European Platform (EEP) with clockwise rotation was followed by large southwestward movements along the Moldanubian Thrust, and renewed northwestward displacement along the SW margin of the East European Platform.

The Variscan Belt of Europe represents an orogenic collage composed of Avalonia, a complex Armorican Terrane Assemblage, and a suspect 'Moldanubia' Terrane, which possibly formed part of Gondwana mainland (see the latest summary in Franke 2000). Closure of narrow oceans or seaways between these terranes has produced separate orogenic belts, which largely correspond to the Rheno-Hercynian, the Saxothuringian and Moldanubian Zones defined by Kossmat (1927). Westwards, some of these tectonic belts can be traced through France into Iberia (e.g. Matte 1986, 1991; Franke 1989). Toward the east, the Variscan Belt abuts against the SW margin of the East European Platform (Fig. 1).

Recent studies have established firm correlations between the German segment of the Variscan Belt and the West Sudetes (eastern margin of the Bohemian Massif in the Czech Republic and Poland): it appears that the West Sudetes contains equivalents of the Saxothuringian Belt, and outliers of an intervening median massif, the Teplá-Barrandian Unit (Franke *et al.* 1993; Franke & Żelaźniewicz 2000; Floyd *et al.* 2000; Crowley *et al.* 2000; Aleksandrowski *et al.* 1997). The resulting structural pattern is a much disrupted arcuate structure, which forms the eastern termination of the Variscides.

In this paper, we summarize the tectonic and palaeogeographic subdivision of the Bohemian Massif, add some new structural observations, and attempt a synthesis of the tectonic evolution of the 'Bohemian Arc'. For the correlation of events at different crustal levels, we refer to the time tables of Menning *et al.* (2000) and McKerrow & van Staal (2000).

Geological framework

General setting

The structural complexity of the Bohemian Massif and adjacent areas has led some authors to propose a small-scale mosaic of microplates (e.g. Oliver *et al.* 1993; Cymerman 2000). However, detailed evaluation of new findings and comparisons with the Variscan basement in Germany are compatible with a simple model, in which the evolution of the north and east parts of the Bohemian Massif is attributed to one Variscan orogenic cycle. It commenced with Cambro-Ordovician rifting in Cadomian crust, which created a narrow ocean between the Saxothuringian and the Bohemian Terranes of the Armorican Terrane Assemblage (Franke *et al.* 1993). The alternative concept of an early Ordovician magmatic arc taken as evidence of a 'Caledonian' orogenic event (e.g. Oliver *et al.* 1993; Kröner & Hegner 1998) has been discussed and dismissed by numerous authors (e.g. Aleksandrowski 1994; Aleksandrowski *et al.* 2000; Franke & Żelaźniewicz 2000; Żelaźniewicz & Franke 1994; Crowley *et al.* 2000; Timmermann *et al.* 2000).

Variscan convergence was performed by Devonian subduction and early Carboniferous

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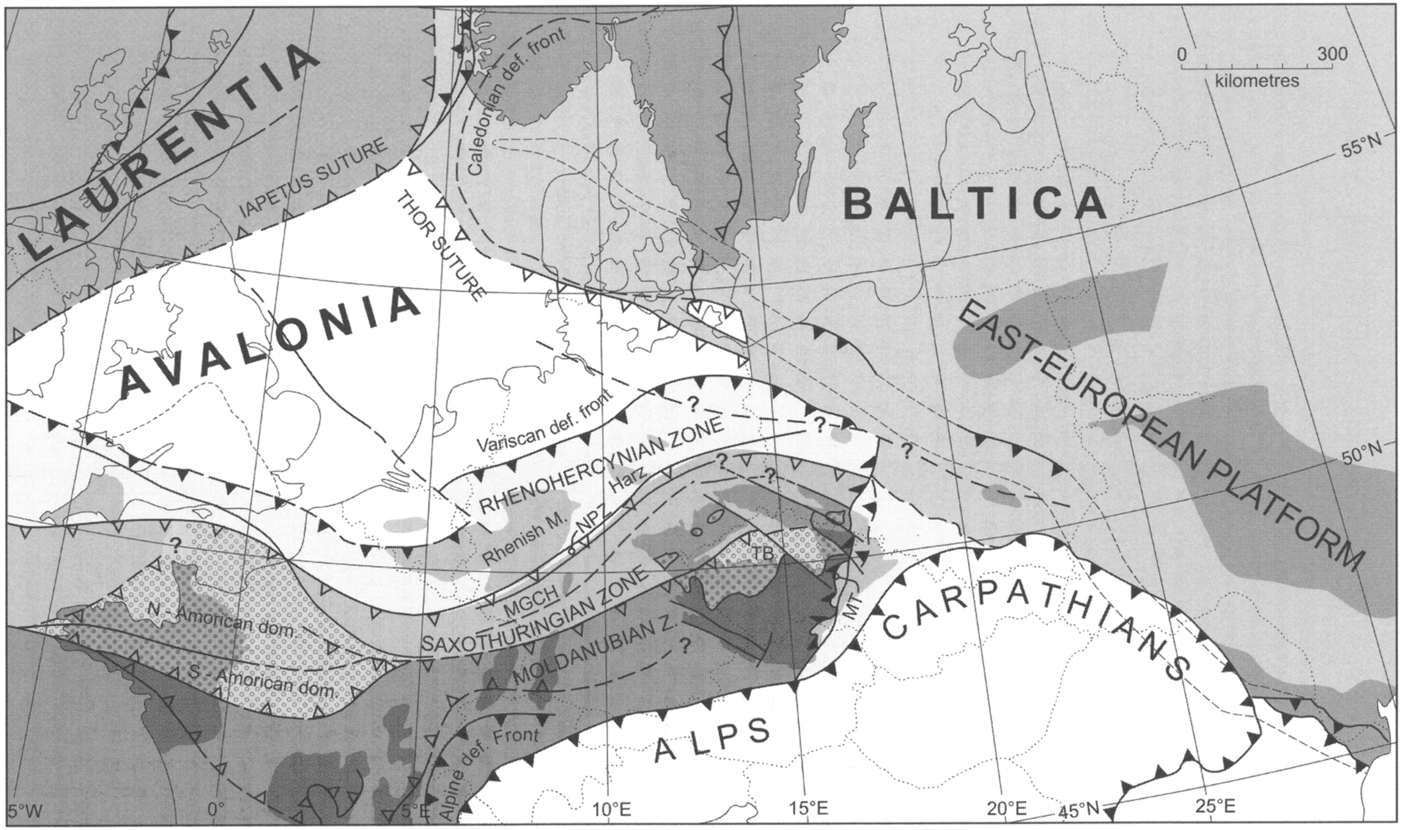

Fig.1. Structural map of north-central Europe for Late Carboniferous/Permian time (adapted from the map compiled by J. A.Winchester adapted from the TESZ working group map). Excluding Laurentia and Baltica, shades are: White, Avalonia; light grey, tectonic units derived from northern parts of the Armorican Terrane Assemblage; stipple, Bohemian and Armorican terranes (SE and western parts of the Armorican Terrane Assemblage); dark grey, ?north Gondwana. Basement outcrops in darker shades. Abbreviations: MGCH, Mid-German Crystalline High; MT, Moldanubian Thrust; NPZ, Northern Phyllite Zone; TB, Teplá-Barrandian.

collision. Tectonic structures reveal a bilateral symmetry: Subduction/underthrusting was grossly directed to the SE on the northern flank of the Variscides (Rheno-Hercynian and Saxothuringian Belts), and to the NW on the southern flank (Moldanubian Belt). The Teplá-Barrandian Unit in the heart of the Bohemian Massif acted as a median massif. Shear criteria in metamorphic rocks on both sides of the Teplá-Barrandian block are often sub-parallel with the main tectonic boundaries and reveal a regime of dextral transpression (Franke 2000).

On a larger scale, the eastern parts of the collisional belt (West Sudetes, east of the Elbe Fault Zone) define an arcuate structure with an opening angle of about 80° . Part of this effect is caused by stepwise dextral displacement along the NW-trending Elbe and Intra-Sudetic Fault Zones, and probably also on the Odra and Dolsk Fault zones (EFZ, ISFZ, OFZ, DFZ, Fig. 2). These faults parallel the SW margin of the East European Platform (EEP, Fig. 1) and controlled the formation of large pull-apart basins (Intra-Sudetic and Świebodzice Basins).

Correlation of stretching lineations and shear sense in the Saxothuringian and the Sudetes suggests some block rotation. In the Erzgebirge, the main ductile lineation indicates transport to the west (e.g. Konopasek *et al.* 2001). In the Izera region north of the Karkonosze granite and further east in the Kaczawa Mountains, main ductile transport is to the NW (Aleksandrowski *et al.* 1997; Seston *et al.* 2000). Northwestward ductile transport has also been reported from the Orlica Mountains (Cymerman 2000). This array would indicate rotation through about 65°, an angle similar to that defined by the boundaries of the tectonic units. However, it is uncertain whether all these lineations have the same tectonic significance, and if they are of the same age.

In areas to the NE of the Intra-Sudetic Fault Zone (IFZ), recent palaeomagnetic studies have been used to argue against rotation of these areas in time after the Silurian. However, a palaeopole from the Silurian/Early Devonian Góry Sowie ophiolite may also represent late Carboniferous remagnetization (Jeleńska *et al.* 1995). A supposedly Silurian mafic sill from the southwestern Holy Cross Mountains (Nawrocki 2000) lacks direct evidence of its age.

Unequivocal evidence for rotation is available for the Moravo-Silesian Belt to the SE of the Moldanubian Thrust (MT), which has been rotated clockwise through at least 90° (with respect to the Rheno-Hercynian Belt in Germany) since the Devonian. This is documented by palaeomagnetic studies (Krs *et al.* 1995; Tait *et al.* 1994). The palaeogeographic zonation within the Moravo-Silesian trends toward the NE (Hladil *et al.* 1999), thus including almost a hairpin bend with the palaeogeographic zonation of the Rheno-Hercynian Belt in Germany.

The Elbe and Intra-Sudetic Fault Zones are truncated by a crustal-scale fault zone, the 'Moldanubian Thrust' (MT) first recognized by F. E.Suess (1912), which evolved in a regime of dextral transpression (Schulmann *et al.* 1994; Schulmann & Gayer 2000; Misař & Urban 1995). This thrust cuts off equivalents of the Mid-German Crystalline High, the Saxothuringian Belt and the Moldanubian Belt against which it juxtaposes, at a right angle, the Moravo-Silesian Belt (Figs 1–3). Displacement along the Moldanubian Thrust must be larger than the width of the tectonic zones it truncates, i.e. must exceed 400 km.

The geological base map (Fig. 2)

The geological map of the Bohemian Massif of Franke & Żelaźniewicz (2000) needs modification in the western part of the Orlica-Śnieżnik Unit and the basement of the Intra-Bohemian Cretaceous basin. Mazur & Aleksandrowski (2001) have drawn attention to a fault zone separating the high-grade Orlica gneisses to the NE from the greenschist-grade Nové Město Unit to the SW (Olešnice-Uhřinov Fault). Along this fault zone, ductile dextral displacement has been overprinted by normal faulting. To the south of a minor east–west-displacement, this fault probably continues between the Zábřeh complex (of unknown palaeogeographic affinity) and the Śnieżnik gneisses. Further SE, it is probably continued in the Bušin fault, which shows southwestward normal faulting under greenschist conditions (Franke & Żelaźniewicz, unpubl. observations). We interpret the earlier, dextral movements along the fault as accommodating pull-apart at the southwestern margin of the Intra-Sudetic basin formed along the Intra-Sudetic Fault.

To the south of the Nové Město Unit, a one kilometre-wide, subvertical, ductile shear zone thrown down to the north (Rychnov Fault Zone) has been identified. This fault splays off from the Orlica Mountains. towards the WNW and changes its orientation to a southwestward trend east of Rychnov. From there it can be correlated, across the Cretaceous cover, with the Hlinsko normal fault, that is with the southern boundary fault of the Teplá-Barrandian block against the Moldanubian. These relationships support the assignments of rocks to the north of the

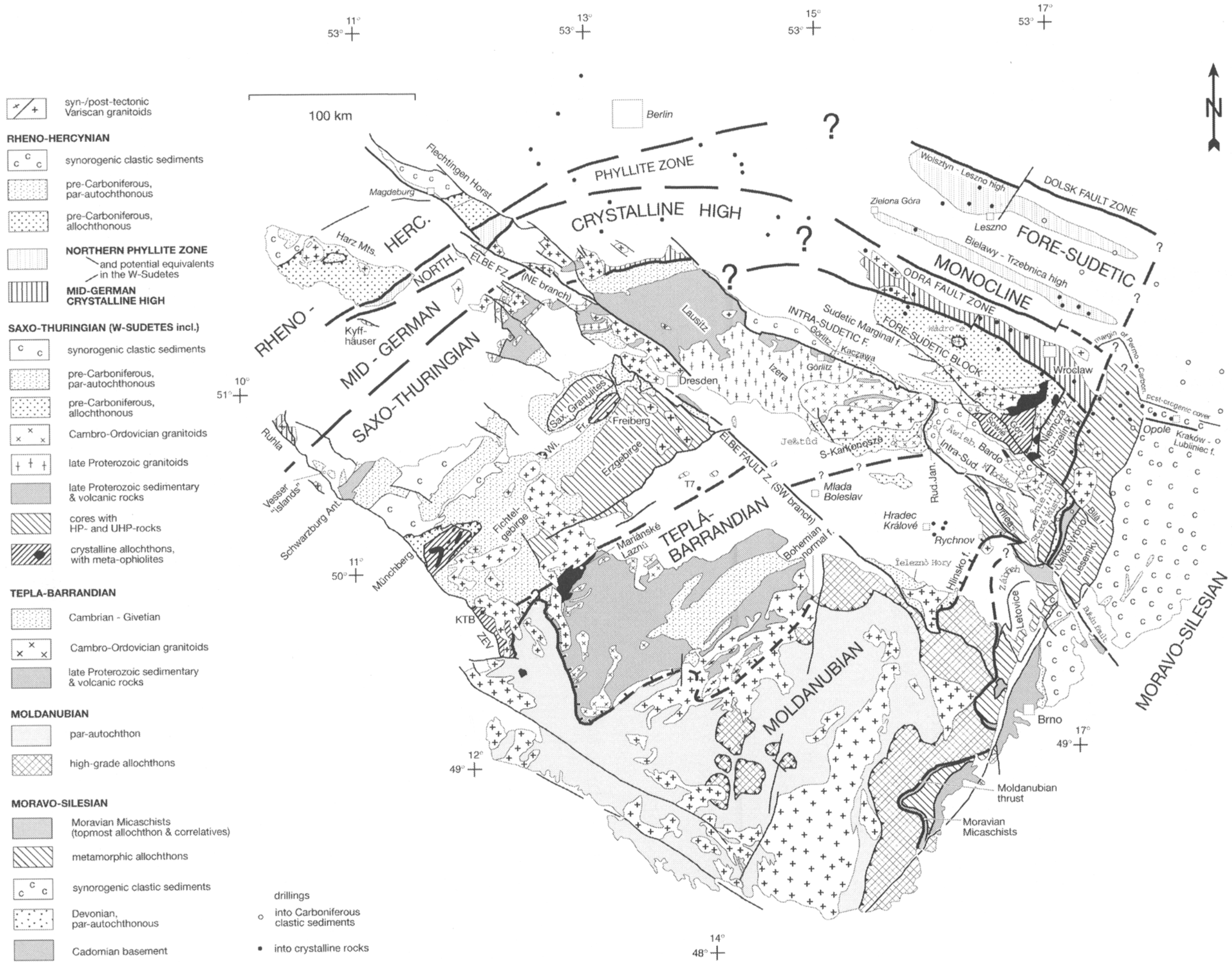

Fig. 2. Simplified geological map of the Bohemian Massif (after Franke & Żelaźniewicz 2000).

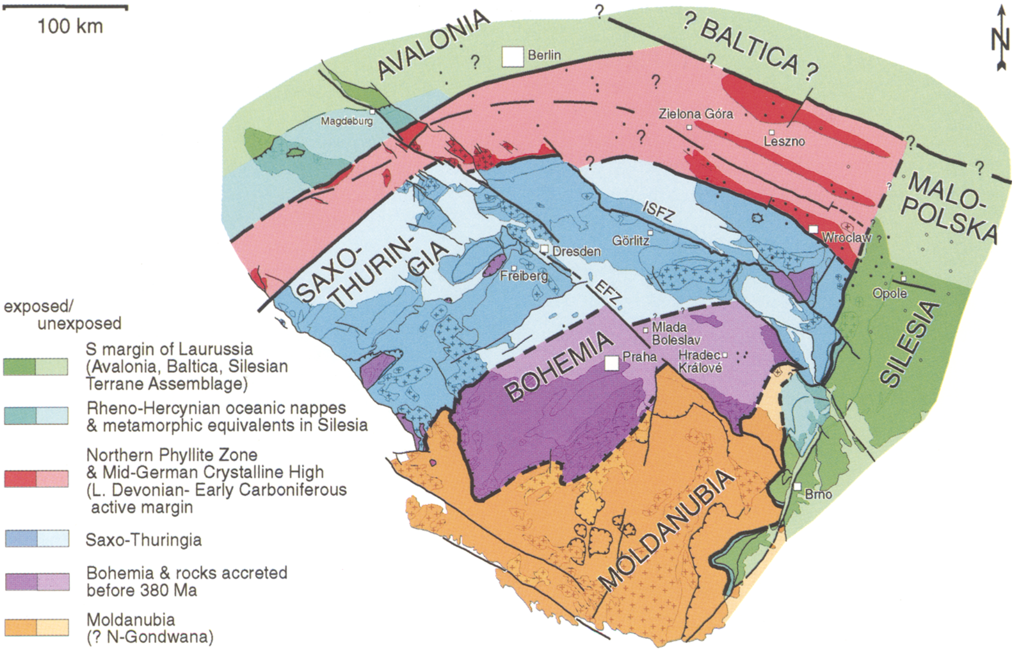

Fig. 3. Terrane map of the Bohemian Massif and adjacent areas (after Franke & Żelaźniewicz 2000). Geological boundaries as in Figure 2.

Rychnov Fault to the Teplá-Barrandian Unit. The curvature in the fault east of Rychnov parallels curved magnetic anomalies on the magnetic map of the Czech Republic. This pattern, together with bends in the exposed Hlinsko Fault, point to late refolding during SW/NE-directed compression.

Palaeogeographic assignment of tectonic units

The palaeogeographic interpretation of the Bohemian Massif is shown in Figure 3, and discussed below, in order from north to south. Unless cited otherwise, details are discussed in Franke (2000) and Franke & Żelaźniewicz (2000).

Avalonia

The periphery of the Bohemian arcuate structure is occupied by palaeogeographic units which were situated, at least from the late Lower Devonian onwards, at the southern margin of Laurussia. Such a position is well documented for the Devonian sediments of the Rheno-Hercynian Belt, which were deposited on the southern margin of the Avalonian segment of Laurussia. Correlatives on the SE margin of the Bohemian Massif are discussed in the end of this section.

Northern Phyllite Zone (NPZ) and Mid-German Crystalline High (MGCH)

The Northern Phyllite Zone and the Mid-German Crystalline High (Fig. 2) are tectonic assemblages of metamorphic rocks, which evolved from the southern margin of Avalonia, a Silurian/Devonian magmatic arc and from a northern member of the Armorican Terrane Assemblage (Franke 2000). The pre-Carboniferous palaeogeography of these units is poorly constrained, because protolith ages are much too scarce. However, the Northern Phyllite Zone and the Mid-German Crystalline High formed a northwestward growing active margin, formed in a regime of grossly southeastward subduction (e.g. Oncken 1997). It is characterized by Early Carboniferous pressure-dominated metamorphism in the Northern Phyllite Zone and part of the Mid-German Crystalline High (Massonne 1995; Okrusch 1995) and Devonian to early Carboniferous subduction-related magmatism

(Altherr *et al.* 1999). Although it lacks resolution for the Early Palaeozoic, this snapshot at a late stage of evolution of the Northern Phyllite Zone and Mid-German Crystalline High serves the purpose of our paper, which focuses upon tectonic displacements in Carboniferous time. The Mid-German Crystalline High probably correlates with the concealed basement high of the Odra Fault Zone. The greenschist grade rocks of the Bielawy-Trzebnica and Wolsztyn-Leszno Highs invite comparison with the Northern Phyllite Zone, but might also represent a suspect terrane of the Armorican Terrane Assemblage.

Saxothuringia

Units within the western part of the Bohemian Massif may easily be traced into the West Sudetes (east of the Elbe Fault Zone). Saxothuringia is represented by the par-autochthon of the Saxothuringian Belt W of the Elbe Fault Zone, by the Lausitz-Izera Unit, the South Krkonoše Unit (see also Mazur & Aleksandrowski 2001) and the Wądroże Window in the Fore-Sudetic Block. These foreland units have been accreted during the Late Viséan (e.g. Marheine *et al.* 2002) to the overriding Bohemia Terrane.

Eclogites and granulites formed around 340 Ma occur in the Erzgebirge and Granulitgebirge (Saxonian Granulites) of the Saxothuringian foreland and in the Orlica-Śnieżnik dome (see compilations in DEKORP & Orogenic Processes Working Groups 1999; Franke & Stein 2000 and Marheine *et al.* 2002). These rocks probably record subduction of Saxothuringian continental crust and subsequent hydraulic expulsion into the foreland (Franke & Stein 2000; Henk 2000; Krawczyk *et al.* 2000).

The southeasternmost part of Saxothuringia is probably represented by the narrow Staré Město Belt to the SE of the Orlica-Śnieżnik Unit. It records early Palaeozoic rifting (Kröner *et al.* 2000), which characterizes the Saxothuringian tectonic belt (and especially the foreland, i.e. the Saxothuringian Terrane).

Bohemia and rocks accreted to its northwestern margin

Bohemia (mainly exposed in the Teplá-Barrandian block) is characterized by Late Proterozoic sedimentary and volcanic rocks, deformed and metamorphosed during the Cadomian orogeny, and unconformably overlain by Cambrian and Ordovician sediments (Chlupáč 1993; Pouba & Skoček 2000; Zulauf 1997).

East of the Elbe Fault Zone, the concealed basement rocks known from drillings NE of Hradec Králové (Čech *et al.* 1989) and the isolated exposures of the Zvičin hills west of Králův Dvůr are also assigned to Bohemia. We propose the the same interpretation for the greenschist grade rocks to the north of the Rychnov fault, on the SW flank of the Orlické hory (see above).

Along the northwestern margin of Bohemia and in equivalent parts of the Sudetes, there are subduction-related, high pressure metamorphic rocks which evolved from oceanic or thinned continental crust of the Saxothuringian narrow ocean. Such rocks are known from the Saxothuringian Münchberg Klippe (395 Ma; review in Franke *et al.* 1995) and the Góry Sowie (402 Ma; O'Brien *et al.* 1997; Brueckner *et al.* 1996).

Another group of tectonic units spread out along the Saxothuringian/Bohemian suture zone underwent metamorphism and deformation during the Late Devonian and earliest Carboniferous (*c.* 380–350 Ma). Such rocks occur in the lower parts of the Saxothuringian Klippen in Germany, in the NW part of the Teplá-Barrandian block, in the East Krkonoše Unit and in the Góry Sowie (see compilations in Franke *et al.* 1995; Franke 2000; Franke & Żelaźniewicz 2000; Marheine *et al.* 2002). A similar age of deformation and metamorphism is likely for blueschists in the South Krkonoše Unit and the higher grade, upper parts of the Kaczawa tectonic pile to the NE of the Intra-Sudetic Fault, but remains to be proven. The Devonian metamorphic ages occur in units both structurally below as well as above the metamorphosed mafic and ultramafic rocks, which are taken to trace the Saxothuringian Suture (eclogites and serpentinites within the Münchberg thrust stack and in the Marianské Lazne meta-ophiolite at the NW margin of the Teplá-Barrandian block). Where the meta-ophiolites are missing, it is difficult to attribute the metamorphic rocks either to the Saxothuringian or the Bohemian Terrane, so that Franke & Żelaźniewicz (2000, fig. 6) have referred to all rocks with Devonian metamorphism as 'suture zone Saxothuringia/Bohemia'.

In the revised terrane map of the Bohemian Massif (Fig. 3), a more differentiated approach is proposed. The best-preserved example of Saxothuringian subduction/collision, the Münchberg Klippe, shows downward younging and decreasing grade of metamorphism within the thrust stack, which reflects northwestward accretion of foreland units (review in Franke *et al.* 1995). Rocks of amphibolite and higher metamorphic grades with mineral ages (zircon, hornblende, white mica) of more than 380 Ma occur in rocks close to the meta-ophiolites. In Fig. 3, only these higher grade and older metamorphic rocks have been assigned to the category "Bohemian Terrane and rocks accreted to it before 380 Ma". This applies to the Góry Sowie and to higher grade thrust sheets in the Saxothuringian Klippen (the lower grade, lower thrust sheets are too small to figure separately on the map).

These lower grade thrust sheets with younger metamorphic ages are taken to indicate derivation from the foreland of the Saxothuringian tectonic belt (Saxothuringia Terrane). This applies to the lower parts of the Saxothuringian Klippen in Germany, to the East Karkonosze Unit and its equivalents in the Kaczawa Mountains and probably also to the Kłodzko Unit. The lower parts of the Rudawy Janowickie and Kaczawa Units, which underlie meta-ophiolites (Seston *et al.* 2000) are likewise assigned to the foreland (Saxothuringia).

Silesian Terrane Assemblage

The Moravo-Silesian Belt contains Devonian and Carboniferous sequences that were deposited on a complex array of older rocks, in which it is possible to distinguish three terranes separated by NW- to WNW-trending faults (Silesian, Małopolska and Łysogóry Terranes). These terranes are summarized, in this paper, as the Silesian Terrane Assemblage (STA). The palaeogeographic affinities of the Silesian Terrane Assemblage and neighbouring parts of Baltica have been assessed by studies of zircons (Compston *et al.* 1995; Finger *et al.* 2000; Oberc-Dziedzic *et al.* 2001;Valverde-Vaquero *et al.* 2000; Żelaźniewicz *et al.* 2001), of detrital white micas (Belka *et al.* 2000, 2002) and by biogeographic data (Belka *et al.* 2002). It appears that the members of the Silesian Terrane Assemblage were derived from northwestern parts of Gondwana, became detached during the Cambrian and arrived at the Baltic margin at different times between the Cambrian and Silurian. In Devonian time, the Silesian Terrane Assemblage was firmly anchored to the southern margin of Laurussia.

The record of the Moravo-Silesian Belt has much in common with that of the Rheno-Hercynian Belt: Devonian rifting and mafic volcanism, Middle and Late Devonian reef carbonates, Early Carboniferous synorogenic clastic sediments, an Early Carboniferous external carbonate platform, and Late Carboniferous coal-bearing molasse Germany (e.g. Engel & Franke 1983; Havlena 1966; Schulmann & Gayer 2000). The NW part of the Jeseníký segment contains Devonian and early Carboniferous deeper water sediments, whereas the SE part represents a shelf (Dvořák 1995; Hladil *et al.* 1999). Deepening toward the internal (now northwestern) part of the Bohemian Arc conforms with the palaeogeographic pattern of the Rhenohercynian Belt in Germany.

The northwesternmost and structurally highest unit of the Jeseniky segment, the Velke Vrbno thrust sheet, contains eclogite relicts (Schulmann & Gayer 2000). This unit is probably continued, to the SW of the Bušin Fault, in the Zábřeh and Letovice complexes, and by the thin band of the 'Moldanubian Micaschists', which form the top of the Moravo-Silesian tectonic pile in the Svratka and Thaya Windows, immediately below the Moldanubian Thrust (e.g. Misař & Urban 1995; Schulmann *et al.* 1995). The high pressure rocks contained in these units probably represent deeper parts of the Rheno-Hercynian/Moravo-Silesian basin, which were subducted, then exhumed and overthrust on the Moravo-Silesian foreland. The southwestward narrowing of these rocks is due to tectonic excision by the Moldanubian Thrust.

Large scale structure

Taken altogether, the palaeogeographic zonation of the Bohemian Massif delineates an arc structure, which is slightly disrupted by the Elbe and Intra-Sudetic Fault Zones (see Fig. 2). Although the German and the Sudetic parts of the Saxothuringian Belt define an opening angle of about 90°, correlation of the Moravo-Silesian rocks with the Rheno-Hercynian rift in Germany implies almost a hairpin bend (Fig. 3). It appears, that about half of this curvature is primary.

Finger & Steyrer (1995) have proposed that a tight bend also exists within the Moldanubian Unit, where orthogneisses within the Variegated Unit are taken as equivalents of the Moravian Biteš Gneisses. However, these orthogneisses show different ages. We therefore prefer the view of Tollmann (1982), in which the Moldanubian and Moravo-Silesian are interpreted as different palaeogeographic units, and the Moldanubian Thrust is interpreted to truncate an older, intra-Moldanubian thrust stack.

Timing of post-collisional fault zones

The activity of the Intra-Sudetic Fault (ISF) is constrained by the infill of the Intra-Sudetic Basin (ISB), which represents a pull-apart structure controlled by the Intra-Sudetic Fault

(Aleksandrowski *et al.* 1997; Franke & Żelaźniewicz 2000). Miospores from the deepest part of the sequence are not older than the TS spore zone (Turnau *et al.* in prep.: approximately Viséan 2b to 3a). U–Pb zircon SHRIMP dating of a tuff in Australia, which ranges within this interval, has yielded an age of 332.3 ±2.2 Ma (see the correlation chart in Menning *et al.* 2000). A marine ingression higher up in the Intra-Sudetic Basin occurred during the *Goniatites crenistria* zone of the goniatite zonation, which corresponds to an isotopic age of about 326 Ma (Trapp, cited in Menning *et al.* 2000). The overlying intramontane clastic sequence with coal seams in the Upper Carboniferous extends into the Permian, although the main subsidence occurred in Late Viséan time (Dziedzic & Teisseyre 1990).

Direct isotopic evidence from the Intra-Sudetic Fault is available in Marheine *et al.* (2002). Mylonites from the fault zone yielded Ar/Ar white mica ages of 333 ± 3 and 324 ± 3 Ma. In addition, several white mica ages between 336 and 332 Ma have been obtained from the eastern part of the South Krkonoše and from the East Krkonoše Complex (Marheine *et al.* 2002). These areas show late-tectonic extension with movement down to the SE. These extensional faults and the cooling ages in their footwall most probably represent shoulder uplift to the NW of the subsiding Intra-Sudetic Basin. The isotopic ages fit well with the biostratigraphic record and confirm tectonic activity along the Intra-Sudetic Fault between about 333 and 325 Ma (Late Viséan).

The Elbe Fault Zone (EFZ) displaces the Teplá-Barrandian block (Bohemia) towards the SE. A marker is provided by correlation of the important normal fault at the southeastern boundary of the Teplá-Barrandian (Zulauf 1997) with the Hlinsko normal fault (Fig. 2), which implies an offset of about 70 km. Further to the NW, in the Mid-German Crystalline High (MGCH), displacement is much smaller. This apparent discrepancy is probably explained by the fact that the present-day tectonic structures of the Mid-German Crystalline High and areas to the NW largely post-date the main activity of the Elbe Fault Zone. A similar consideration might apply to the Intra-Sudetic Fault, but the area NE of the Lausitz-Izera block is not exposed. To the SE, both the Elbe and the Intra-Sudetic Fault are clearly truncated by the Moldanubian Thrust.

The age of the Moldanubian Thrust is best constrained by the infill of the Moravo-Silesian foreland basin, which received detritus from the Moldanubian rocks in the hanging wall. High grade metamorphism and rapid uplift in the Moldanubian nappes occurred between about 340 and 335 Ma (see the compilation in Franke 2000). Heavy minerals and pebbles derived from the Moldanubian granulite nappes do not occur before the latest Viséan (Myšlejovice Fm.; Hartley & Otava 2001). These youngest flysch sediments of the Moravo-Silesian foreland basin have yielded single grain Ar/Ar detrital mica ages of 340–331 Ma (Schneider *et al.* 1999). The isotopic age of the Viséan/Namurian boundary is approximately 325 Ma, fittingly younger than the age of the detrital minerals in the latest Viséan sediments. These relationships indicate that the present-day juxtaposition of blocks along the Moldanubian Thrust was largely accomplished at about 325 Ma. In the Desná and Keprník domes of the Moravo-Silesian Belt, which underlie the Moldanubian Thrust, Maluski *et al.* (1995) obtained Ar/Ar ages on white mica and biotite ranging between 310 and 280 Ma. Such late events might well have been accomodated within the present-day tectonic assemblage.

Taking into account the error bars on the isotopic data, it is not possible to differentiate between the ages of activity of the Intra-Sudetic Fault and the Moldanubian Thrust. However, the map pattern clearly reveals that the main displacement along the Moldanubian Thrust postdates that of the Intra-Sudetic and Elbe Faults.

Discussion

Statement of problem

The structural observations discussed above reveal three chapters of tectonic evolution:

- late Devonian to early Carboniferous ductile dextral transpression along the Variscan sutures
- block rotation and transverse dextral shearing in the Sudetes, leading to an arc-like structure with an opening angle of about 90° . Formation of intra-montane pull-apart basins along the NW-trending fault zones
- truncation of the arc by dextral transpression along the NE-trending Moldanubian Thrust.

The resulting arc-like-structure is contained, today, in an embayment defined by the Avalonian crust of the Rheno-Hercynian Belt to the NW, the East European Platform to the NE, and the Silesian Terrane Assemblage to the SE. Any plate-tectonic model must explain the arc-like arrangement of terranes and its truncation by the Moldanubian Thrust.

Model A: Northeastward displacement of parts of the Bohemian Massif

Although dextral displacement along the Moldanubian Thrust amounts to at least 400 km, there is no indication of a continuation of the Moldanubian Thrust into the East European Platform. Thus the present position of rocks contained in the core of the arc may have been brought about by northeastward, dextral transpression of central parts of the Bohemian Massif against a stable Silesian Terrane Assemblage to the SE, which itself was firmly anchored against the East European Platform. In this model, the core of the arc would either have been accomodated into a pre-existing embayment on the SW margin of Laurussia, or else represent an indenter moving northeastwards over the margin of the East European Platform. In both these cases, the Bohemian block would have been bounded by a dextral transpressive fault to the SE (the Moldanubian Thrust) and some sinistral equivalent on its NW flank.

The following points may be raised against this view:

- There is no evidence of any sinistral counterpart to the Moldanubian Thrust in the NW part or to the NW of the Bohemian Massif. Some sinistral movements in the Northern Phyllite Zone have been dated by K–Ar on white mica at 323 ± 4 and 308 ± 4 Ma (Klügel 1997). They therefore post-date the main activity of the Moldanubian Thrust.
- Northeastward movement of the Bohemian Massif towards a relatively stable East European Platform could only be explained by tectonic escape of the Massif as an orogenic wedge, which is not backed up by the configuration of main fault zones in central Europe (Fig.1).
- Within the exposed Bohemian Massif, there are no indications of NE-directed ductile tectonic transport. Stretching lineations in the Sudetes are generally oriented NW–SE, with a frequent sense of shear top to the NW.
- Geophysical and borehole evidence indicate that the SW margin of the East European Platform does not extend beyond the Elbe Line (Fig. 1, see also Krawczyk *et al.* 1999). Therefore, the overlap of Variscan deformation on Baltic basement does not exceed about 100 km, whereas dextral movements along the Moldanubian Thrust are in excess of 400 km.

One kinematic alternative – dextral, southwestward displacement of the Silesian Terrane Assemblage along the Moldanubian Thrust relative to a stable Bohemian Massif – is ruled out by the right angle at which the thrust abuts against the East European Platform: in this configuration, any southwestward movement of the Silesian Terrane Assemblage would have produced an extensional corridor between it and the East European Platform, for which there is no evidence.

Model B: Alternating displacements along NW- and NE-trending fault zones

Problems inherent with the above concepts may be overcome if large-scale tectonic shearing along NE-trending fault zones occurred in a position to the south or at the southern margin of the East European Platform. The important dextral displacements along the Variscan sutures between about 380 and 340 Ma definitely required such a position. This also applies to the dextral displacement of at least 400 km along the Moldanubian Thrust after 325 Ma. Both these episodes of dextral, orogen-parallel shearing cannot have been performed within the present-day tectonic configuration.

Matte (2001) has even suggested that the Moldanubian Thrust continues toward the SW through the Variscan basement of the Alps into southern France. In his paper, segments of a Variscan suture zone contained in the Massif de Maures (west of Nice) and in Sardinia are interpreted as continuations of the suture zone between Bohemia and Moldanubia. Such a large offset of about 1000 km would definitely imply that the Moldanubian Thrust was formed to the south of the Baltic part of Laurussia, where dextral shearing along NE-trending faults was unimpeded.

We therefore evaluate a model, in which the terranes now contained in the Variscides of central Europe were originally situated to the SE of Baltica (in present-day co-ordinates; Fig. 4a). The large-scale fault zones are attributed to the westward displacement of Gondwana with respect to Laurussia (Arthaud & Matte 1977; Tapponier 1977). This displacement occurred during the late stage of the Variscan collision in an environment of dextral transpression. Transpression was partitioned into two sets of dextral shear zones: one orogen-parallel (grossly

SW/NE) and another one in NW/SE, which transsects the orogenic trend. This latter fault system was mechanically guided by the NW-trending margin of the East European Platform, but may additionally have functioned as Riedel shears associated with the main, orogen-parallel faults. Furthermore, we propose that the kinematic evolution implied an alternation of orogen-parallel and transverse shearing.

When Gondwana impinged upon the Variscan terrane assemblage, Variscan terranes were displaced towards the NW along the Elbe and the Intra-Sudetic Fault Zones and possibly also along concealed faults within the Trans-European Suture Zone (TESZ; Fig. 4b). An early stage of the Bohemian Arc was formed by a combination of stepwise dextral displacements and clockwise rotation of blocks set between these faults.

During continued westward displacement of Gondwana, the NW-trending shear zones were truncated by a new, NE-trending zone of dextral transpression, the Moldanubian Thrust (Fig. 4c). The Silesian Terrane Assemblage was displaced towards the SW, and, thereby, rotated clockwise.

Later still, the Moldanubian Thrust was displaced by renewed dextral translation along the southwestern, Baltic margin of Laurussia (Fig. 4d). Shearing may have occurred either along the Tornquist-Teisseyre Fault Zone, along the Holy Cross Dislocation and possible northwestern continuation (Dolsk Fault Zone, Fig. 1). It was during this late stage, that the Variscan deformation fronts on the NW and the SE of the Bohemian Massif acquired their present-day positions. They were therefore not affected by the northwestward displacement. Some later change in the direction of compression then 'drove' the Bohemian block to the NE, with limited overthrusting on the Polish Caledonides and the margin of Baltica.

Testing the late stage of model B

The SE margin of Baltica trends from the Danube Delta across the Crimean Peninsula to the north of the Greater Caucasus (e.g. Görür *et al.* 1997), about 1000 km to the SE of the present-day position of the Moldanubian Thrust. Hence, model B requires northwestward displacements of the Moldanubian Thrust after its main period of activity (after about 325 Ma). Basic support for such large-scale northwestward displacements of the Silesian Terrane Assemblage along the Baltica Margin comes from palaeomagnetic findings Lewandowski 1993, 1995; Mizerski 1995). The following observations also permit a quantitative estimate of the notional displacement:

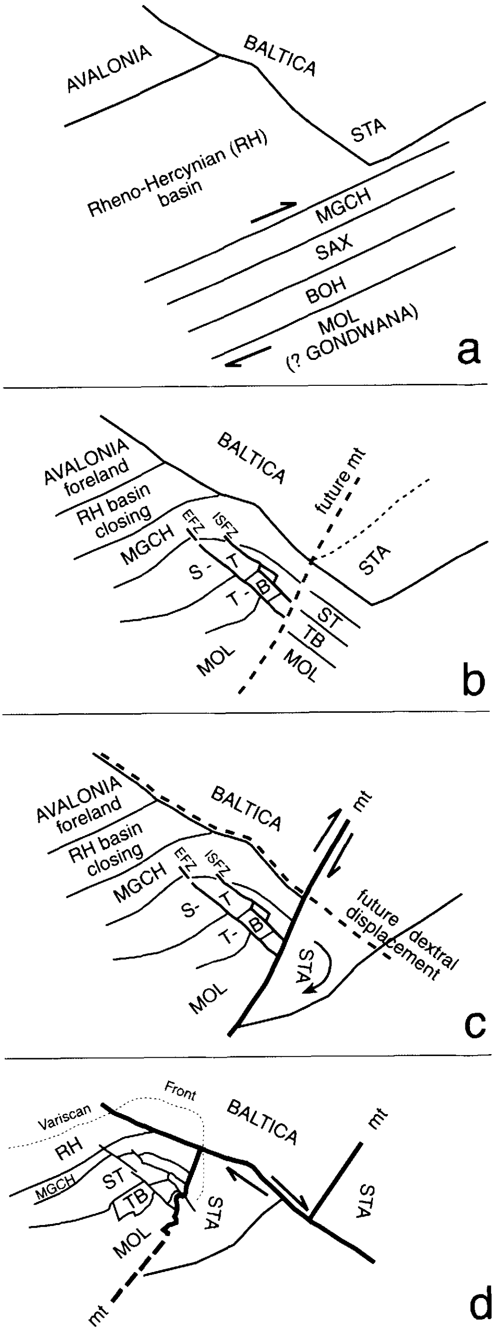

Fig. 4. Plate-kinematic sketch sequence illustrating the formation of the Bohemian Arc. (a) 380–340 Ma; (b) *c.* 335 Ma; (c) ≥ 325 Ma; (d) *c.* 305 Ma. Mt, Moldanubian thrust; MGCH, Mid-German Crystalline High; MOL, Moldanubia Terrane resp. Moldanubian Zone (in d); RH, Rheno-Hercynian Belt; ST, Saxothuringian Terrane resp. Saxothuringian Belt (in d); STA, Silesian Terrane Assemblage; TB, Teplá-Barrandian Block.

- An important part of shortening within the Rheno-Hercynian belt occurred after about 325 Ma, and amounted to a minimum of 175 km (Oncken *et al.* 2000).
- Southeastward backthrusting of the Mid-German Crystalline High over the Saxothuringian Belt contributes a conservative estimate of about 100 km for the Late Carboniferous tectonic activity (Schäfer *et al.* 2000).
- Within the Bohemian Massif, NW and NE-trending faults active during the late Carboniferous and Permian form a conjugate set which has accommodated north–south directed shortening of some some tens of kilometres (Handler *et al.* 1991; Urban & Synek 1995).

Together, these increments amount to a minimum of about 300 km.

Further displacements have been proven, but are difficult to quantify:

- Some southeastward ductile thrusting has been documented for the SE part of the Moldanubian Belt in Austria, and dated by Ar/Ar on biotite at 323 ± 7 Ma (Matte *et al.* 1985).
- Recent palaeogeographic and tectonic studies in the Rheno-Hercynian Belt have revealed continental allochthonous units between the oceanic Giessen/Harz Nappe and the par-autochthon, which Oncken *et al.* (2000) did not consider in their conservative estimate of shortening (Franke 2000). This may add another 100 km to the amount of thrusting.
- Late Carboniferous/Permian dextral movements also occurred along various fault zones within the Trans-European Suture Zone (e.g. Thybo 1997).
- Late Cretaceous inversion tectonics in the northern foreland of the Alps (e.g. Ziegler 1987) likewise required dextral displacements along the TESZ.
- Late Carboniferous basin inversion by NW/SE-directed shortening has also been documented for northern parts of the British Isles (Chadwick *et al.* 1993).

Lastly, the Moldanubian Thrust might have been displaced to the NW by reactivation of the British segment of the Iapetus suture, which might be responsible for the preservation of higher structural levels in Scandinavia as compared with Scotland.

Taken altogether, the southern segment of the Moldanubian Thrust has been displaced to the NW, more recently than about 325 Ma, for several hundreds of kilometres. Since the quantitative constraints yield only conservative estimates, the observed displacements are at least in the same order of magnitude as the 1000 km required by model B.

Conclusions

Terrane correlation and evaluation of fault activities of Variscan Units to the SW of the East European Platform permit discrimination of two basic models:

(A) Large-scale, northeastward movement of the Bohemian Massif as an indenter, limited to the SE by the Moldanubian Thrust. Although this model cannot be entirely ruled out, it has fundamental deficiencies: any large sinistral shear zone on the NW flank of the indenter remains to be identified, and there is no evidence of large-scale northeastward tectonic transport.

(B) Tectonic units now contained in the central European segment of the Variscides were originally situated to the south of Baltica, where they underwent orogen-parallel dextral shearing in Devonian and earliest Carboniferous time. Later, these units were dextrally displaced and rotated clockwise by northwestward movement along the SW margin of the East-European Platform (TESZ and parallel faults). This incipient arc structure was then truncated in the south by long-distance southwestward transport of units south of the Moldanubian Thrust. Renewed displacement toward the NW across a distance of about 1000 km brought the thrust into its present position. This model conforms to the sequence of events, and the demonstrable displacement of the Moldanubian toward the NW amounts at least to some hundreds of kilometres.

Other palaeogeographic tests of our model would require discussion of a still wider geological framework. If the Variscan terrane assemblage, in Late Devonian/Early Carboniferous time, was situated in a position south of the Baltic segment of Laurussia, 'along-strike' continuations of these terranes should exist along the southern margin of Laurussia, e.g. in Turkey and areas further east. Variscan basement outcrops in Turkey have been compared with possible counterparts in central Europe (Görür *et al.* 1997). Similarly, the tectonic concept for the Moldanubian Thrust proposed by Matte (2001) needs further confirmation: in this model equivalents of the Bohemian and Saxothuringian Terranes should be present to the NE of the Variscan suture linking the Massif de Maures (south France) with Sardinia, i.e. within the basement of the Alps. It also remains uncertain, whether the late Viséan and younger transpressional movements at the eastern and southern margins of the Bohemian Massif were caused by the impingement of a continental block to the south (Gondwana), or else by oblique northwestward subduction of oceanic crust. All these issues would require extensive discussion of the Balkan Peninsula and Turkey, as well as of the Variscan basement in the Alps, and therefore go beyond the frame of this paper.

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