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32nd INTERNATIONAL GEOLOGICAL CONGRESS

CADOMIAN OROGENIC IMPRINTS IN THE BOHEMIAN MASSIF (AUSTRIA, THE CZECH REPUBLIC AND GERMANY)

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Pre-Congress

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Front Cover:
Field trip itinerary

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Introduction

The Bohemian Massif forms the largest surface ‘outcrop’ in central Europe where Cadomian (Pan-African) orogenic imprints are well documented (Figure 1). The main goal of the present field trip is to show individual parts of the Bohemian Massif (the Saxo-Thuringian, Teplá-Barrandian, and Brunovistuilian units) where Cadomian imprints are strikingly different. These units are peri-Gondwanan terranes (Armorican Terrane assemblage, ?Avalonia), which also include Florida and the Carolinas in the eastern United States, as well as the Ossa-Morena and Central-Iberian zones of the Iberian Massif. Further remnants of the Cadomian basement occur in the basement units of the Alpine chain, the Carpathians, Turkey, and in the Red Sea surroundings (Murphy et al., 2002, and references therein).

During the field trip Cadomian deformation, metamorphism and igneous activity will be studied at different structural levels, the metamorphic grade of which ranges from very-low to high grade. Major topics are (1) the depositional environment of synorogenic Neoproterozoic and postorogenic Lower Paleozoic rocks, (2) Cadomian igneous activity, (3) Cadomian deformation and related metamorphism, and (4) the geodynamic evolution of the Cadomian belt.

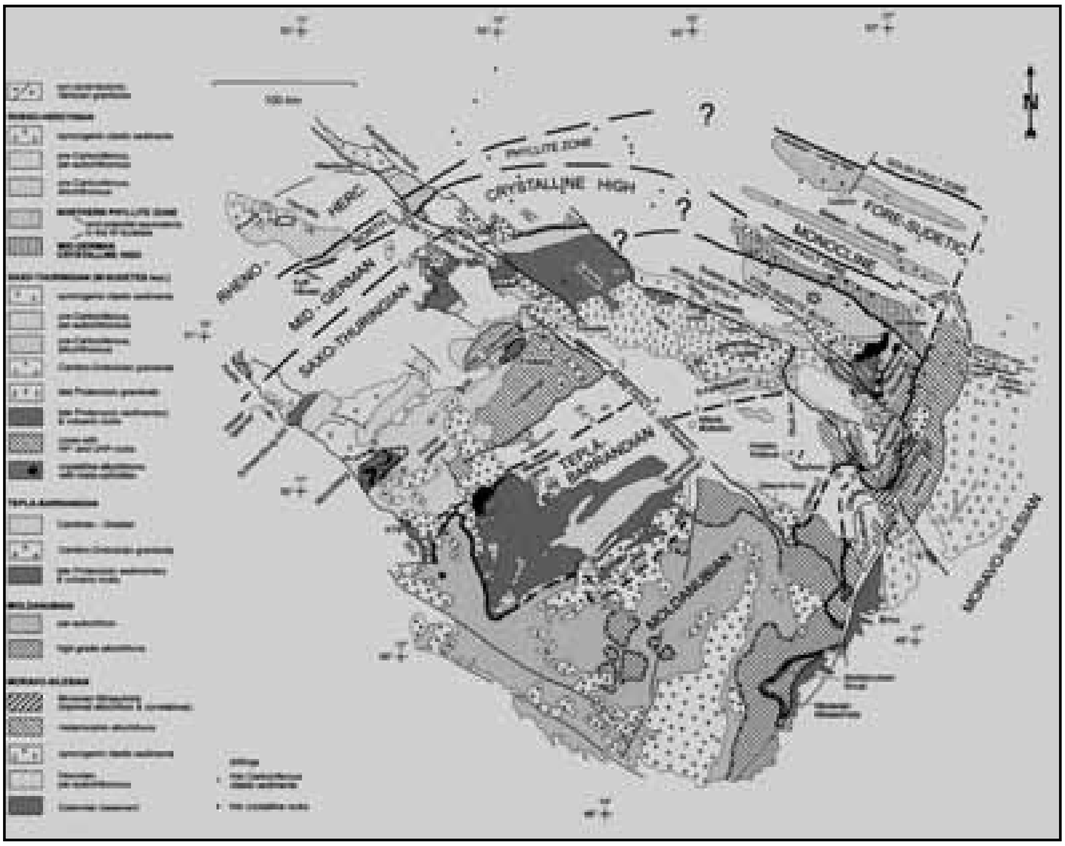

Figure 1 - Geological map of the Bohemian Massif (after Franke and Zelaznewicz, 2002)

The area studied is straddling three major units of the Bohemian massif (the Saxo-thuringian, Tepla-Barrandian and Brunovistulian units) and three different countries (Austria, the Czech Republic and Germany), the latter showing different cultures and history. There are several cities worth seeing, such as Dresden, Prague, Brno and Vienna, all of which will be viewed during the field trip.

Regional geological setting

The Saxo-Thuringian unit
(with contributions by R. Romer)

Saxo-Thuringia is a peri-Gondwanan crustal fragment that became incorporated into the Central European part of the Variscan orogenic belt (Figure 2). The oldest volcano-sedimentary rock complexes and plutonic massifs are not older than c. 570 Ma and were formed on the periphery of the West African craton (Linnemann et al., 2000; Linnemann and Romer, 2002). These Late Neoproterozoic to Early Cambrian rock units (ca. 570 – c. 540 Ma) were formed in an active-margin setting by processes that finally led to the build-up of the Avalonian-Cadomian orogenic belt.

In the Saxo-Thuringian part of the Avalonian-Cadomian Arc, subduction-related Cadomian orogenic processes led to the development of Neoproterozoic marginal basins younger than ca. 570 Ma. Tectonically separated remnants of these basins were intruded after the Cadomian orogeny by ca. 540 Ma old plutonic rocks. The Cadomian basement, which involves both sedimentary and magmatic units, was transgressed by Cambro-Ordovician overstep sequences, with depositional gaps during the earliest Cambrian (ca. 540 – 530 Ma) and the Late Cambrian (ca. 500 – 490 Ma), under a passive margin regime (Linnemann, 1995; Linnemann et al., 2000).

"Armorican affinities" (sensu Linnemann et al., 2000), such as the occurrence of a Cadomian unconformity, peri-Gondwanan Cambro-Ordovician faunas, glaciomarine diamictite of the Saharan glaciation during the Hirnantian, and the absence of a Caledonian unconformity, paleogeographically relate Iberia and Armorica, which includes Saxo-Thuringia. Matte (1986, 1991), Tait et al. (1995, 1997), Franke (2000), and Linnemann et al. (2000) demonstrated that the classical "Armorica" of Van der Voo (1979) does not represent a coherent microplate. Therefore, we use the term "Cadomia". Nance and Murphy (1994, 1996) presented a palinspastic reconstruction

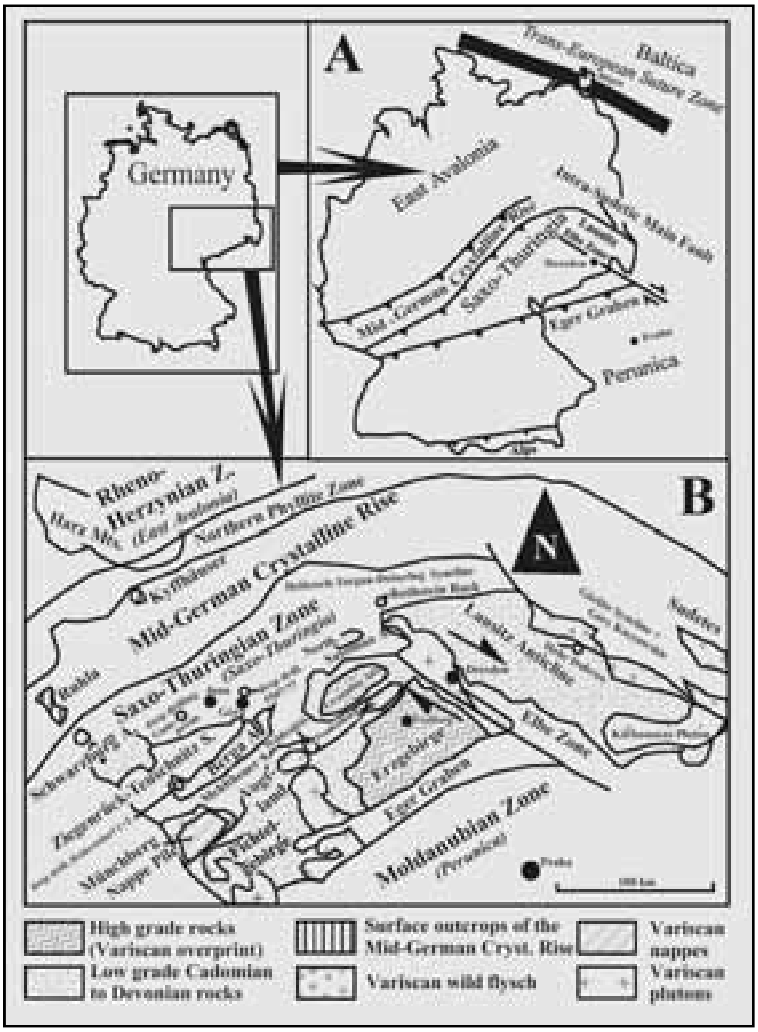

Figure 2 - Location of Saxo-Thuringia; A: present day distribution of Peri-Gondwanan units and their relation to important geological structures in Germany and bordering countries; B: Tectono-stratigraphic units of Saxo-Thuringia and adjoining areas, as well as the position of some deep drillings (circles) and locations mentioned in this paper. Note that the Mid-German Crystalline Rise does not belong to Saxo-Thuringia (from Linnemann et al, 2000).

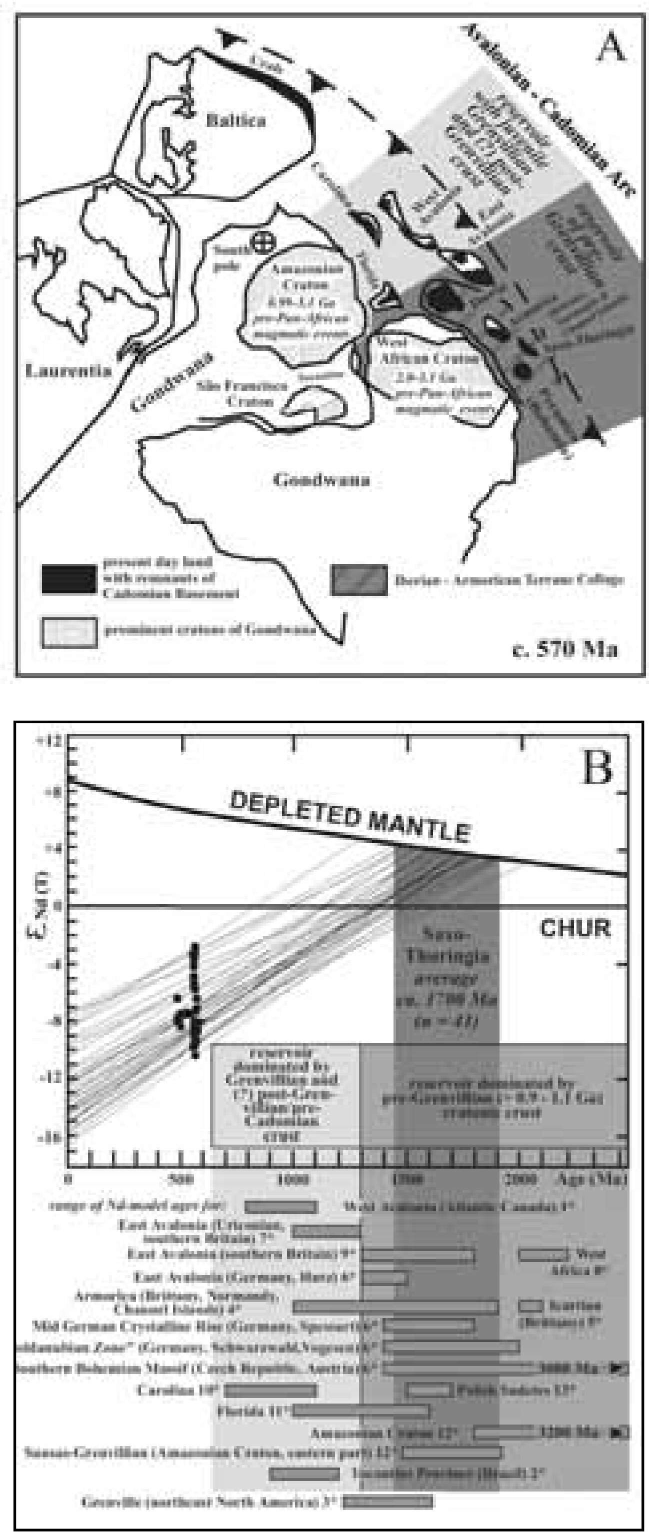

Figure 3 A - Palaeogeography of the Cadomian-Avalonian Arc and related prominent peri-Gondwanan terranes (modified after Nance and Murphy 1994, Linnemann et al., 2000). B. TDM Nd-model ages (DePaolo, 1981) of Saxo-Thuringia.l References of Nd-model ages from other regions, see in Linnemann and Romer, 2002. Depleted mantle curve from DePaolo (1981); CHUR = chondritic uniform reservoir (figure from Linnemann and Romer, 2002).

of the Avalonian-Cadomian Orogenic Belt on the basis of available age data from detrital zircon, initial Nd isotopic compositions, and palaeomagnetic data. This reconstruction was modified from the European point of view by Linnemann et al. (2000), especially due to the addition of basement slivers of the Urals, the change of the position of Iberia, the division of the "classical" Armorica, and the addition of Saxo-Thuringia.

The sedimentary record of Saxo-Thuringia encompasses a time span from the Cadomian arc setting to Early Palaeozoic shelf development, which is representative for large parts of Cadomia. This record not only reflects orogenic crustal growth and recycling within this tectonostratigraphic unit, but also dramatic changes in geotectonic setting and weathering behavior that come along with the uplift and rifting of the Gondwanan margin during the Early Paleozoic. Nd(T) values and resulting model ages of sedimentary rocks and granitoids indicate recycling of old crustal material from the Gondwana mainland. Nd(T) values, furthermore, support paleogeographic reconstructions showing Saxo-Thuringia as a part of the peri-Gondwana margin (Linnemann and Romer, 2002) (Figure 3).

The Neoproterozoic rock units of Saxo-Thuringia were first described in terms of the Cadomian Basement by Linnemann and Buschmann (1995a) after the discovery of the Cadomian unconformity in the core of deep drilling 5507/77 near Gera. The type locality of the Cadomian

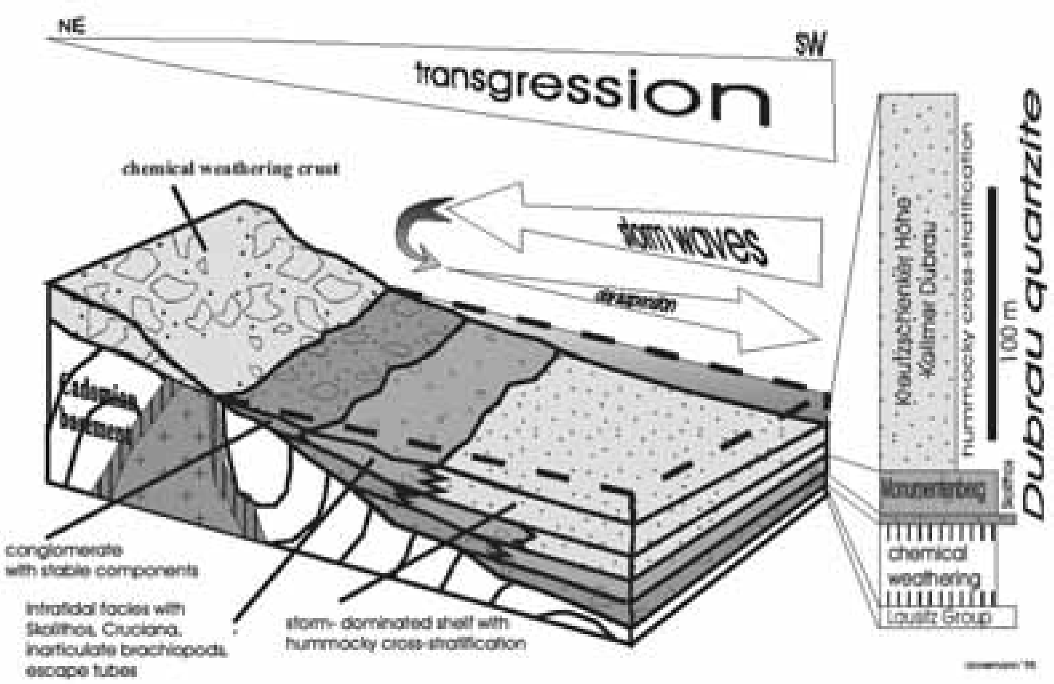

Figure 4 - Model of the Tremadocian transgession in the area of the Monumentenberg and the Hohe Dubrau (from Linnemann and Buschmann, 1995).

unconformity at the surface is located in the area of the Hohe Dubrau at the Monumentenberg, a hill near the village of Gross Radisch in the Lausitz Anticline (Linnemann and Buschmann, 1995b; Linnemann and Schauer, 2000).

The structural complexity of the Neoproterozoic to Lower Carboniferous rock units of Saxo-Thuringia is shown in a simplified geological map (Figure 2). The Cadomian basement of Saxo-Thuringia consists of several back-arc basin remnants that developed on the old Gondwanan basement in a continental arc setting (Linnemann et al., 2000) (Figure 4). The maximum age for sedimentary rocks of the back-arc basins is given by the age of detrital zircon and zircon in ca. 570 Ma granitoid pebbles. One ash layer is dated at ca. 565 Ma (Gehmlich, in Linnemann et al., 2000). The siliciclastic rocks are dominated by graywacke turbidites. In addition, hydrothermal cherts and related effusive volcanic rocks formed during back-arc spreading (Buschmann, 1995). Quartzites derived from the sedimentation of highly mature quartz sands during sea level low stand, and the occurrence of diamictites, show that the Cadomian marginal basins preserved in Saxo-Thuringia were influenced by sea level fluctuations (Linnemann, 1991) and possibly a post-570 Ma Neoproterozoic glaciation, which agrees with a suggested position of peri-Gondwanan crustal units at high latitudes in the southern hemisphere (Scotese et al., 1999).

For parts of the Cadomian basement preserved in Saxo-Thuringia, the continuation of sedimentation in Cadomian marginal basins from the Neoproterozoic up into the Early Cambrian cannot be excluded. Several dated, post-tectonic, granitoid plutons indicate that the Cadomian orogeny ended between 540 and 535 Ma (Gehmlich, in Linnemann et al., 2000).

Archaeocyathids, trilobites, and small shelly fossils (Elicki and Debrenne, 1993; Geyer and Elicki, 1995; Elicki, 1997) demonstrate that the Early Palaeozoic overstep sequence with passive margin signatures overlying the Cadomian unconformity starts post-530 Ma in the Atabanian or Ovetum, respectively. This palaeontological data restricts the time span available for the denundation of the Saxo-Thuringian part of the Avalonian-Cadomian Arc, to a small window between ca. 535 and ca. 530 Ma. Lower Cambrian siliciclastic and carbonate rocks and Middle Cambrian sandstones overly the Cadomian basement at several places (drill holes; Buschmann et al., 1995). Carbonate sediments, in several levels intercalated with red-bed deposits, and fauna assemblages, indicate a palaeogeographic position of Saxo-Thuringia as a part of the Iberian-Armorican Terrane Assemblage close to the equator (McKerrow et al., 1992; Elicki, 2000). Mafic sills and dykes emplaced in Lower Cambrian deposits formed under conditions of thinned continental crust (Jonas et al., 2000).

After a gap in sedimentation and formation of a chemical weathering crust during the Late Cambrian, which probably was related to block tilting and uplift, the Saxo-Thuringian part of the peri-Gondwana shelf was denuded again (Linnemann and Buschmann, 1995; Linnemann et al., 2000). Most of the Lower to Middle Cambrian deposits were reworked and eroded. Only in areas with originally thick sedimentary successions, such as local graben structures that developed as Cambrian pull–apart basins on the peri–Gondwana shelf (Nance and Murphy, 1991), were Lower to Middle Cambrian basin remnants locally preserved in Saxo-Thuringia.

After this second phase of denudation during the Late Cambrian (500 to 490 Ma), the Saxo-Thuringian shelf was transgressed during the Tremadoc (Linnemann et al., 2000). The disconformity between Lower to Middle Cambrian rocks and Tremadocian Quartzites with a basal conglomerate is only demonstrated in the drillcores Heinersdorf 1 & 2, first described by Wucher (1967). The maturity of Tremadocian quartzites and sandstones, which contain the reworked Upper Cambrian chemical weathering crust, is very high. Ordovician siliciclastic sedimentation on the shelf, and thus, also, shelf-subsidence, reached a maximum during the Tremadoc, when more than 3000 m of sediments were deposited. For comparison, Cambrian (< 1000 m) deposits and Arenig-through-Ashgill deposits combined only reach 500 m in thickness, whereas Silurian (ca. 50 m) deposits are subordinate. This unusually-high sedimentation rate during the Tremadoc is interpreted as reflecting the onset of rifting (Linnemann et al., 2000).

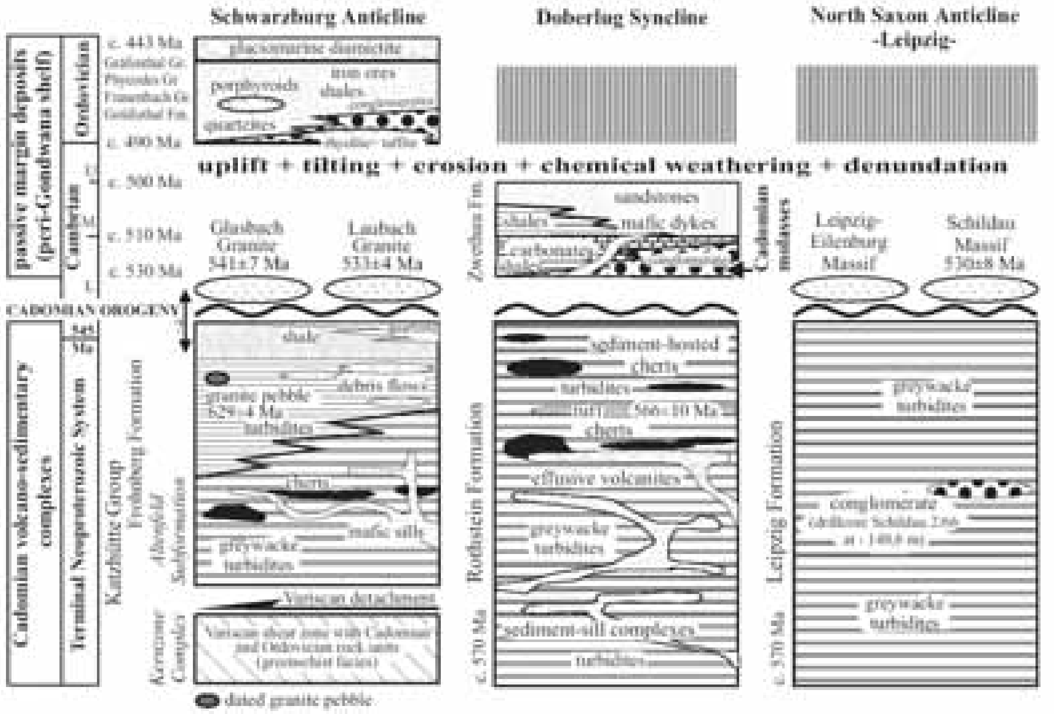

Figure 5 - Tectonostratigraphic columns for Neoproterozoic to Cambro-Ordovician rocks of the Schwarzburg Anticline, Doberlug Syncline, and the Leipzig Complex of the North Saxon Anticline (from Linnemann and Romer, 2002).

Saxo-Thuringia became a part of the Variscan orogenic belt during the Devonian to Early Carboniferous collision processes (e.g., Matte, 1986, 1991; Franke, 2000). During the Variscan extensional collapse and transpressional slivering, Saxo-Thuringia was divided into several tectono-stratigraphic units. Low-grade Cadomian to Early Palaeozoic units in Saxo-Thuringia occur in five main outcrop areas, which correspond to main structural units of this region: (1) the Schwarzburg Anticline (the Katzhütte and Frohnberg Groups), (2) the Northsaxon Anticline (the Clanzschwitz Group), (3) the Elbe Zone (the Weesenstein Group), (4) the Lausitz Anticline (the Lausitz Group), and (5) the Doberlug Syncline (the Rothstein Group).

The Lausitz Anticline and the Elbe Zone are objects of this field trip. For completeness, descriptions of the other units are included in this excursion guide.

The Schwarzburg Anticline: The Schwarzburg Anticline is the most complete succession of a volcano-sedimentary rock pile affected by the Variscan orogeny in Germany (Figure 5). The southeastern flank of the structure, originally mapped and described by von Gaertner (1944) and redescribed by many authors, represents the type section of Neoproterozoic to Lower Carboniferous sedimentary rocks in Saxo-Thuringia. The centre of the Schwarzburg Anticline was overprinted under greenschist-facies conditions. The traditional term of von Gaertner for this unit is “Kernzone”, which should be translated by “core zone”. Usually the “Kernzone” is described as the lowest part of the Neoproterozoic rock pile in a relatively undisturbed succession (e.g. Bankwitz and Bankwitz, 1995). Biostratigraphic data (Heuse, in Estrada et al., 1994), sequence stratigraphy (Linnemann and Buschmann, 1995), and geochronology (Gehmlich, in Linnemann et al., 2000), however, demonstrate gaps in the sedimentary record for the largest part of the Cambrian. Linnemann et al. (1999, 2000) re-interpreted the “Kernzone” as a part of a deeper crustal level that became detached from the low-grade Cadomian basement and the overlying Palaeozoic strata by Variscan transpression. The “Kernzone” consists of a tectonic mixture mostly of predominantly Cadomian (Neoproterozoic) meta-sedimentary rocks and a few Ordovician rock units (Linnemann et al., 1999, 2000).

The low grade part of the Cadomian basement in the Schwarzburg Anticline consists in its lowest part (Katzhütte Group) of graywacke turbidites accompanied by dark shales and hydrothermal cherts and associated mafic sills. The Frohnberg Group in the upper part is dominated by graywacke turbidites and dark shales. The youngest member is a quartzite related to a sea-level low-stand. The Cadomian sedimentary rocks were intruded after Cadomian deformation by several granites, dated at 541±7 Ma and 533±4 Ma (Gehmlich in Linnemann et al., 2000). The Ordovician overstep sequence starts with a 490-Ma-old rhyolite (Gehmlich in Linnemann et al., 2000), tuffites and conglomerates, which were described by von Gaernter (1944) as “Konglomeratische Arkose” (= “conglomeratic arkose”). The nearly 3500-m-thick Ordovician succession is continued by shales, quartzites, subvolcanic porphyroid intrusions, sedimentary iron ores, and the glaciomarine diamictite of the Saharan glaciation (Hirnantian). A mid–Ashgillian limestone layer of only 1 m thickness occurs 2 m below the base of the diamictite. A detailed stratigraphic column of the Ordovician has been published by Linnemann (1998) and Linnemann et al. (2000).

The Berga Anticline: The Cadomian Basement is not exposed in the Berga Anticline. Up to the 1960s only Ordovician to Devonian strata were known. The anticline is bound by Lower Carboniferoious flysch deposits of the Teuschnitz – Ziegenrück Syncline in the northwest and the Mehltheuer Syncline to the southeast. Cambrian sedimentary rocks were discovered unexpectedly in the cores of the drillings Heinersdorf 1 & 2 (Wucher, 1967). The succession is overprinted by greenschist facies metamorphism and consists of quartz phyllites and black to gray marbles. Palaeontological data confirm the Early to Middle Cambrian age of the pre-Ordovician part of the core (Blumenstengel, 1980). The Cadomian basement unfortunately was not reached by the drillings. The most important feature of the Heinersdorf 2 drilling is a disconformity between Lower to Middle Cambrian strata and Ordovician siliciclastics, which clearly documents the Upper Cambrian gap within the succession. The Lower to Middle Cambrian rocks obviously were transgressed during the Tremadoc with a sharp contact and a conglomerate at the base. The lithological spectrum consists only of stable components (quartzites, cherts, and silicified hornfelses) resistant to chemical weathering. The Cambrian rocks in the drill are overlain by the Upper Frauenbach Quartzite (Tremadoc). A number of additional Tremadocian strata present in the Schwarzburg Anticline (e.g. Goldisthal Group) are not found in the Berga Anticline or in the Heinersdorf 2 borehole (Linnemann et al., 2000). This observation demonstrates that the transgression during the Tremadoc was highly diachronous, possibly documenting a palaeorelief during the Late Cambrian that may be related to block tilting and the formation of grabens and horsts in Saxo-Thuringia, combined with an Late Cambrian tectonically forced regression. Consequently, Lower to Middle Cambrian sedimentary complexes were preserved only in grabens, whereas the rest was eroded. The Heinersdorf 1 and 2 drillings represent relict Cambrian deposit from such a graben filling. The local observations at the Heinersdorf 1 and 2 drillcores most probably reflect the Late Cambrian history which is characteristic of the Saxo-Thuringian peri–Gondwanan basement, since, with the exception of the Doberlug Syncline, all localities with Cadomian basement show Ordovician sediments, whereas Cambrian sediments are not present.

The Doberlug Syncline: This syncline consists of the Cadomian Basement, as represented by the Rothstein Formation and the Zwethau Formation, containing Lower to Middle Cambrian sedimentary rocks (Figure 5). With the exception of the Rothstein Fels, which consists mostly of Cadomian hydrothermalitic cherts, all units are known from drillings only. The Rothstein Formation was described by Buschmann (1995) and Buschmann et al. (1995, 2001). The succession predominantly consists of graywacke turbidites that commonly show soft-sediment deformation. The sedimentary rocks are accompanied by sills and effusive volcanites. The latter ones generally are associated with exhalative hydrothermal cherts. A tuff was dated at 566 ±10 Ma (Buschmann et al., 2001). Cadomian molasses-containing pebbles derived from the Rothstein Formation were described by Buschmann (1995) from drillhole 1706. Lower to Middle Cambrian shallow marine carbonates, shales, and sandstones overlie the Cadomian basement. There Lower Cambrian mafic sills occur (Jonas et al., 2000). Cadomian plutonic and Ordovician sedimentary rocks are not known.

The Northsaxon Anticline: The Northsaxon Anticline is structurally heterogeneous. At its northern border, it is bound by the Doberlug Syncline and parts of the Mid-German Crystalline Rise. The largest part of the anticline consists of Cadomian basement, which in the south is overlain unconformably by Ordovician shelf sediments. To the east, the Cadomian basement of the Northsaxon Anticline continues into the Lausitz Anticline. The Cadomian basement of the anticline consists of two main tectono-stratigraphic complexes, which are different in terms of sedimentary development and other geological observations in the field. Both the Leipzig Complex and the Clanzschwitz Complex are described separately.

The Leipzig Complex consists of graywacke turbidites and intercalated dark gray to black mudstones (Figure 5). The sedimentary rocks are summarized as the Leipzig Group. The only surface outcrop is located in Klein – Zschocher, which is a part of the city of Leipzig. All other parts of the whole area are only known from drillings. From the core of the Schildau 2/66 borehole, a conglomerate composed of predominatly granitoid pebbles is described at a depth of 148.6 m below surface. The well rounded pebbles are 1 to 5 cm in diameter approximately, and are dispersed in the graywacke matrix. The ca. 1-m-thick conglomerate is interpreted as being a debris-flow deposit associated with the turbidites, as there is no evidence for an unconformity within the Cadomian succession. After Cadomian deformation, the Leipzig Group was intruded by the granitoids of the Leipzig–Eilenburg massif and the Schildau Massif, which are only known from drill cores. The age of instrusion of the latter one has been determined at 530 ±8 Ma (Hammer et al., 1999). The Cambro-Ordovician overstep sequence does not exist here, and may have been eroded during post–Variscan denudation.

The second part of the Northsaxon Anticline is presented by the Clanzschwitz Complex. This unit is divided into the Cadomian part of the section, the so-called Clanzschwitz Group, including the Laas Granodiorite, and the Ordovician overstep-sequence (Figure 6). The lower part of the Clanzschwitz Group is composed of mudstones, with a few intercalations of graywacke beds. These rocks are overlain by quartz phyllites and quartzites, around 20 m in thickness, followed by diamictites with a matrix of graywacke and conglomerates. The pebbles within this unit predominately include graywackes, quartzites, and granitoids. One granite pebble was dated by Gehmlich (in Linnemann et al., 2000) at 577 ±3 Ma. There is no consensus concerning the interpretation of the diamictites as glaciomarine deposits or debris flows (see also the sub-chapter entitled "Elbe Zone – Weesenstein Complex"). After the Cadomian deformation, the Clanzschwitz Group was intruded by the ca. 537-Ma-old Laas Granodiorite (Gehmlich, in Linnemann et al., 2000). The Ordovician overstep-sequence is presented by the quartzites and conglomerates of the Collmberg and the Hainichen-Otterwisch Formations. Because of the weathering processes during the Late Cambrian, the conglomerates consist of stable components like pebbles of quartzites, hydrothermal quartz, cherts,

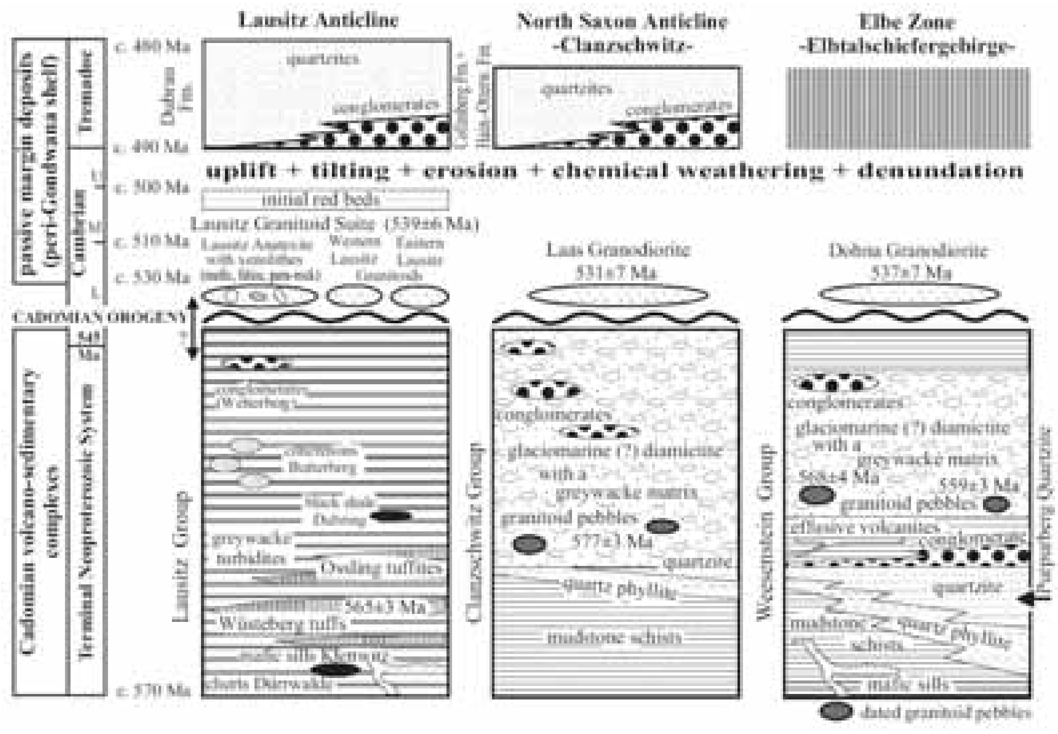

Figure 6 - Tectono-stratigraphic columns for Neoproterozoic to Cambro-Ordovician rocks of the Lausitz Anticline, the Clanzschwitz Complex of the North Saxon Anticline, and the Weesenstein Complex of the Elbe Zone (from Linnemann and Romer, 2002).

and hornfelses. Ichnofossils in the quartzites belong to the Cruziana facies (e.g. Cruziana semiplicata SALTER).

The Lausitz Anticline: The Lausitz area is traditionally described as an anticline, a custom that also is maintained here, although the basement of the Lausitz (from Latin: "Lusatia") represents a horst with a tilted peri-Gondwanan crustal profile (Figure 6). Its deepest units, exposed to the southeast, are dominated by a complex of different plutons. The Cadomian part of the magmatic rock suite is summarised here as the Lausitz Granitoid Suite, which is composed of granodiorites and granites from the western and the eastern Lausitz domains. The outer part of the western Lausitz shows abundant S-type two–mica granodiorite, with locally abundant xenoliths of meta-basalts, felsic remnants of altered volcanic (calc-silicate) rocks, meta-graywackes, and quartzites. The age of the Lausitz Granitoid Suite is disputed. The best estimate for a maximum age at 565 ±3 Ma (Pb/Pb age, Gehmlich, in Linnemann et al., 2000) and 574 ±8 Ma (SHRIMP, Nasdala, in Linnemann et al., 2000) is obtained from an ash layer within the Cadomian graywackes of the Lausitz Group which are intruded by the granitoids. Earlier-reported zircon ages are in part distinctly older. A series of datings yields ages in the range from 540 to 530 Ma (Hammer et al., 1999; Gehmlich in Linnemann et al., 2000), although there are a few younger intrusions, such as the Rumburk Granite (ca. 490 Ma) and Variscan plutons.

Sedimentary units mostly occur in the northwestern part of the tilted horst structure of the Lausitz. The low-grade sedimentary rocks of the Lausitz Group were deformed during the Cadomian orogeny in large open folds, and show a slight contact-metamorphic overprint close to the Lausitz Granitoid Suite. The sediments are dominated by monotonous graywacke turbidites with a few intercalations of dark-gray shale. A number of light gray to gray-green tuff layers, partially altered to calc-silicate rocks, are known from Wüsteberg, near Kamenz, and from a large quarry close to the village of Ossling. The graywacke turbidites locally show early diagenetic concretions,

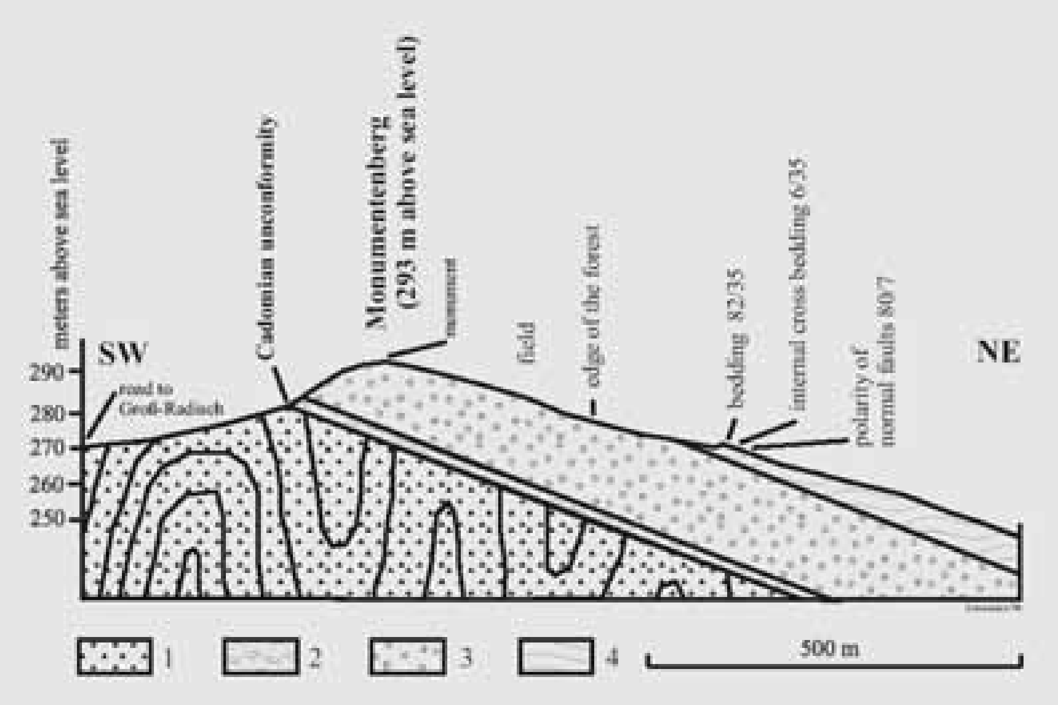

Figure 7 - Cross-section of the type locality of the Cadomian unconformity at the Monumentenberg: 1 - Cadomian graywacke, 2 - basal conglomerate, 3 - intratidal facies with Skolithos, Cruciana, Brachiopods, 4 - storm-dominated facies with HCS (from Linnemann and Schauer, 1999).

which are altered to calc-silicate rock, around rip-up clasts of shale (e.g. the Butterberg quarry, near Kamenz). Fine-grained conglomerates (pebbles < 5 mm) occur in the Wetterberg quarry, near Ebersbach. The clasts are dominated by graywacke, chert, and quartzite, although there are rare clasts of mafic and high-grade metamorphic rocks. There is no evidence of Cambrian sediments resting directly on the Cadomian basement of the Lausitz.

The post-Cadomian overstep-sequence of the Lausitz Anticline, including the type locality of the Cadomian unconformity for Saxo-Thuringia (Linnemann and Buschmann, 1995), is represented by the Dubrau Formation, which is only preserved in the area of the Hohe Dubrau, near Gross Radisch, approximately 40 km to the northwest of Görlitz (Figs. 4 and 7). Inarticulate brachiopod fossils place the c. 200-m-thick Dubrau Formation in the Tremadocian. The basal conglomerate resting unconformably on the Cadomian basement (Linnemann and Schauer, 1999) is composed of weathering-resistent pebbles of quartzite, quartz, and a schorl-cemented breccia. The conglomerate is overlain by variably-silicified sandstone quartzite, with well-preserved primary sedimentary structures. In the lower part, dominantly tidal deposits contain Scolithos sp. and brachiopod shells (Westonisca arachne BARRANDE), as well as poorly preserved specimens of Cruziana sp. In the upper part, the silicified sandstones are characterised by tempestite deposits, such as hummocky cross-stratification and gutter casts. This unit is interpreted as having been deposited in a storm-dominated open shelf (Linnemann and Buschmann, 1995). The top of the section is eroded.

Red beds (denoted as initial red beds in the column) overlying the Cadomian graywacke are preserved only at two locations near Oberprauske (Hohe Dubrau). Their age is only poorly constrained by field data. These red sandstones and shales are younger than the Cadomian basement and older than the conglomerates and quartzites of the Dubrau Formation, i.e., they cover a range from the Lower Cambrian and the lowermost Tremadocian. By analogy with Cambrian red sediments elsewhere in Saxo-Thuringia, we handle these problematic deposits as Lower Cambrian rocks.

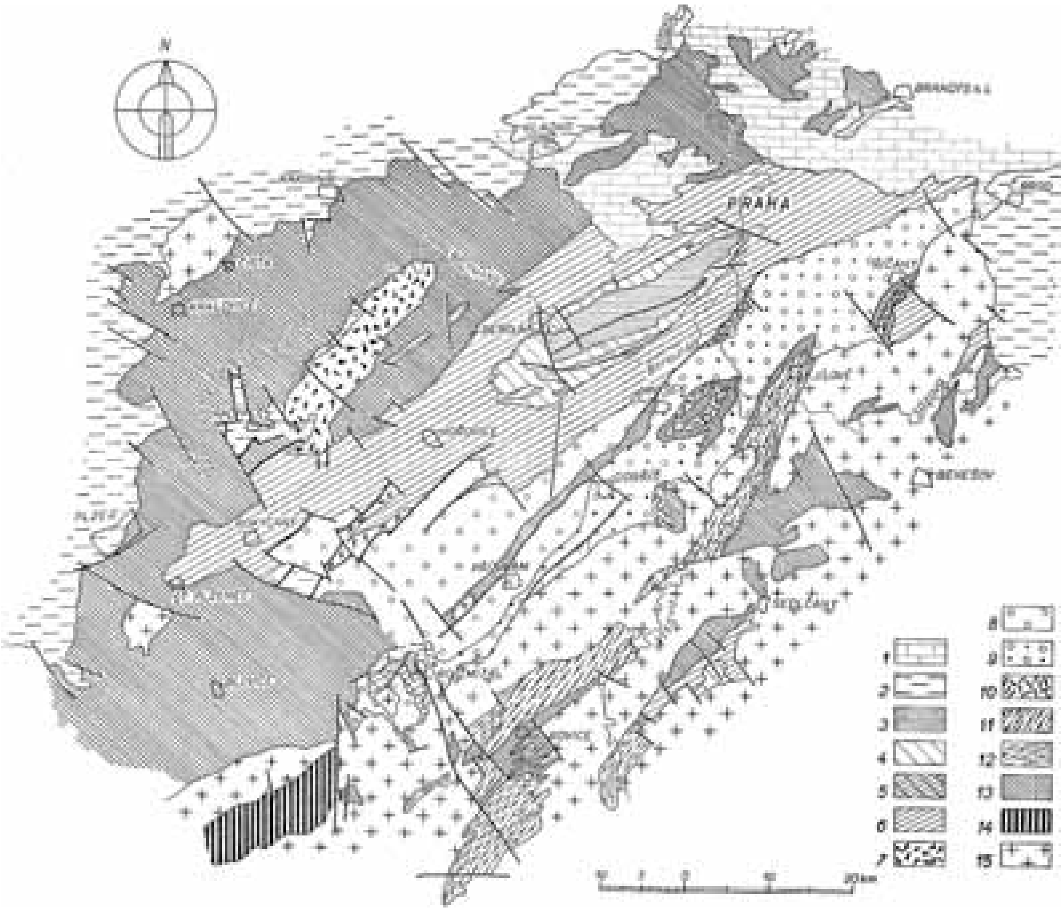

Figure 8 - Geological map of the Barrandian syncline (after Svoboda et al., 1966). 1 = Upper Cretaceous, 2 = Permo-Carboniferous, 3 = Devonian, 4 = Silurian, 5 = Silurian and Ordovician near Ro_mitál, 6 = Ordovician, 7 = K_ivoklát-Rokycany and Strašice volcanics, 8 = Cambrian, 9 = Proterozoic rocks (the Št_chovice group), 10 = Porphyry, 11 = the Jílové zone, 12 = Orthogneiss, 13 = Proterozoic rocks (the Kralupy-Zbraslav group), 14 = Moldanubian zone, 15 = Granitoids

The Elbe Zone: The Elbe Zone is a NW-SE striking major Variscan shear zone with more than 80 km of dextral displacement (e.g., Linnemann, 1995; Linnemann and Schauer, 1999) (Figure 2). The shear zone was active during Early Carboniferous times and separates the high-grade overprinted rocks of the Erzgebirge from the very-low-grade Lausitz Anticline. During Variscan strike-slip movements along the Elbe Zone, three major segments were separated from one originally united remnant of Cadomian basement, which had special features (Linnemann, 1995). These fragments are the Clanzschwitz, the Rödern, and the Weesenstein Complexes, though it should be noted that the Clanzschwitz Complex today is a part of the Northsaxon Anticline. The distinctive feature of the three complexes is the intercalation of diamictites, which may be due to a post-570 Ma Neoproterozoic glaciation or to debris flows. For an interpretation of the diamictites as debris flows, turbidites should be accompanied by turbidites. Turbidites, however, are not known from the Cadomian complexes of the Elbe Zone. Furthermore, the matrix of the diamictites is a diamictite itself, showing very angular clasts of quartz and feldspar.

The Rödern Complex lies within the Elbe Zone, between the Lausitz Anticline and the Meissen Massif (a large, Variscan, granitoid pluton). The Rödern Complex is poorly exposed. It consists of Cadomian graywackes with locally-intercalated pebble–bearing horizons (Schmidt, 1960) and is intruded by the 537

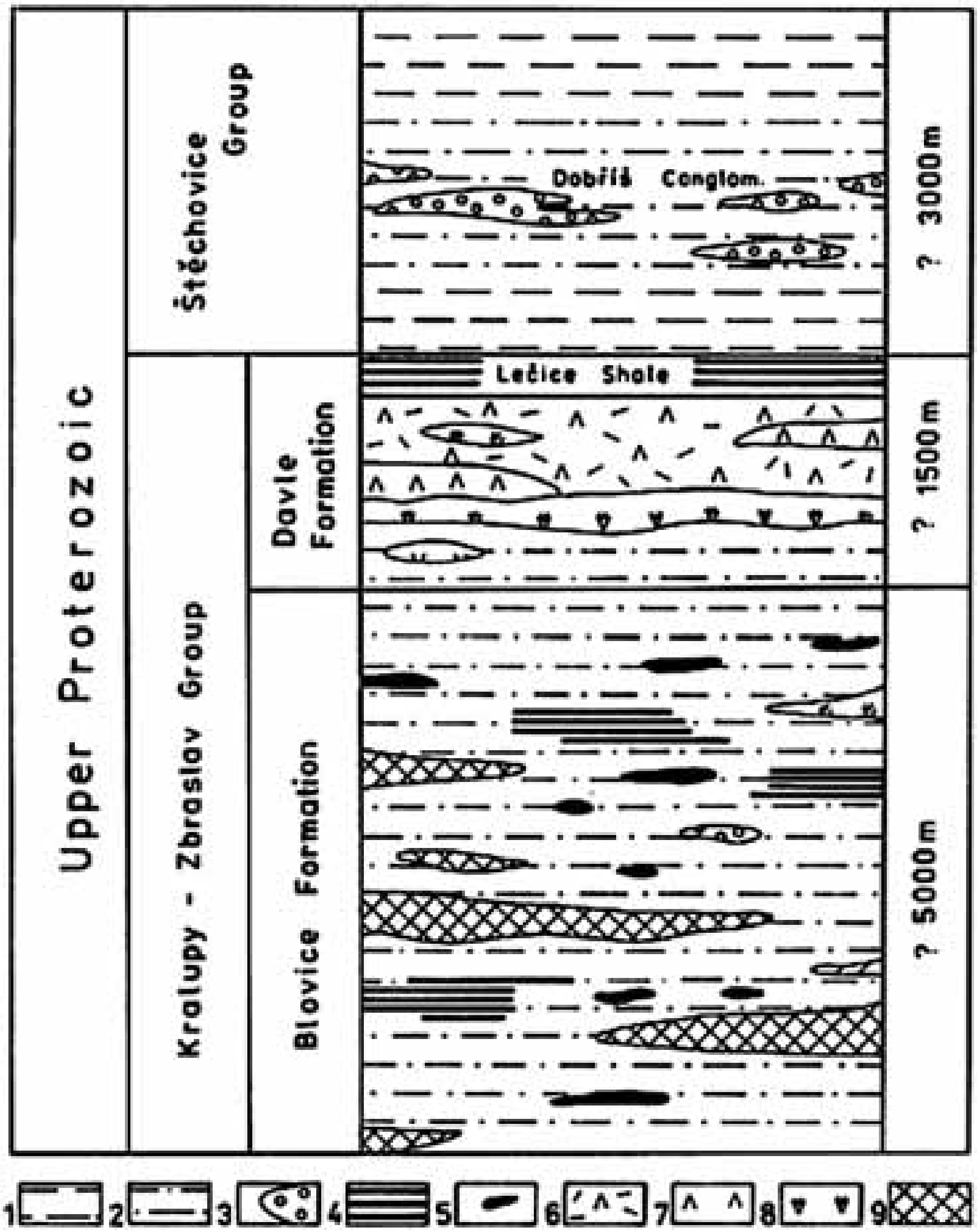

Figure 9 - Proterozoic stratigraphy in the Tepla-Barrandian unit (after Chlupá_, 1993). 1 = siltstone, shale, 2 = siltstone, greywacke, shale, 3 = conglomerate, 4 = black shale, 5 = chert, 6 = pyroclastics of acid and intermediate volcanics, 7 = acid volcanics, 8 = intermediate volcanics, 9 = basic volcanics (predominating).

±7 Ma old Grossenhain Orthogneiss (Gehmlich, in Linnemann, 2000).

The well-exposed Weesenstein Complex crops out about 20 km southeast of Dresden. It is traditionally referred to as “Elbtalschiefergebirge”. The excellent outcrop-situation allows an insight into the Elbe (“shear”) Zone. The metasedimentary part of

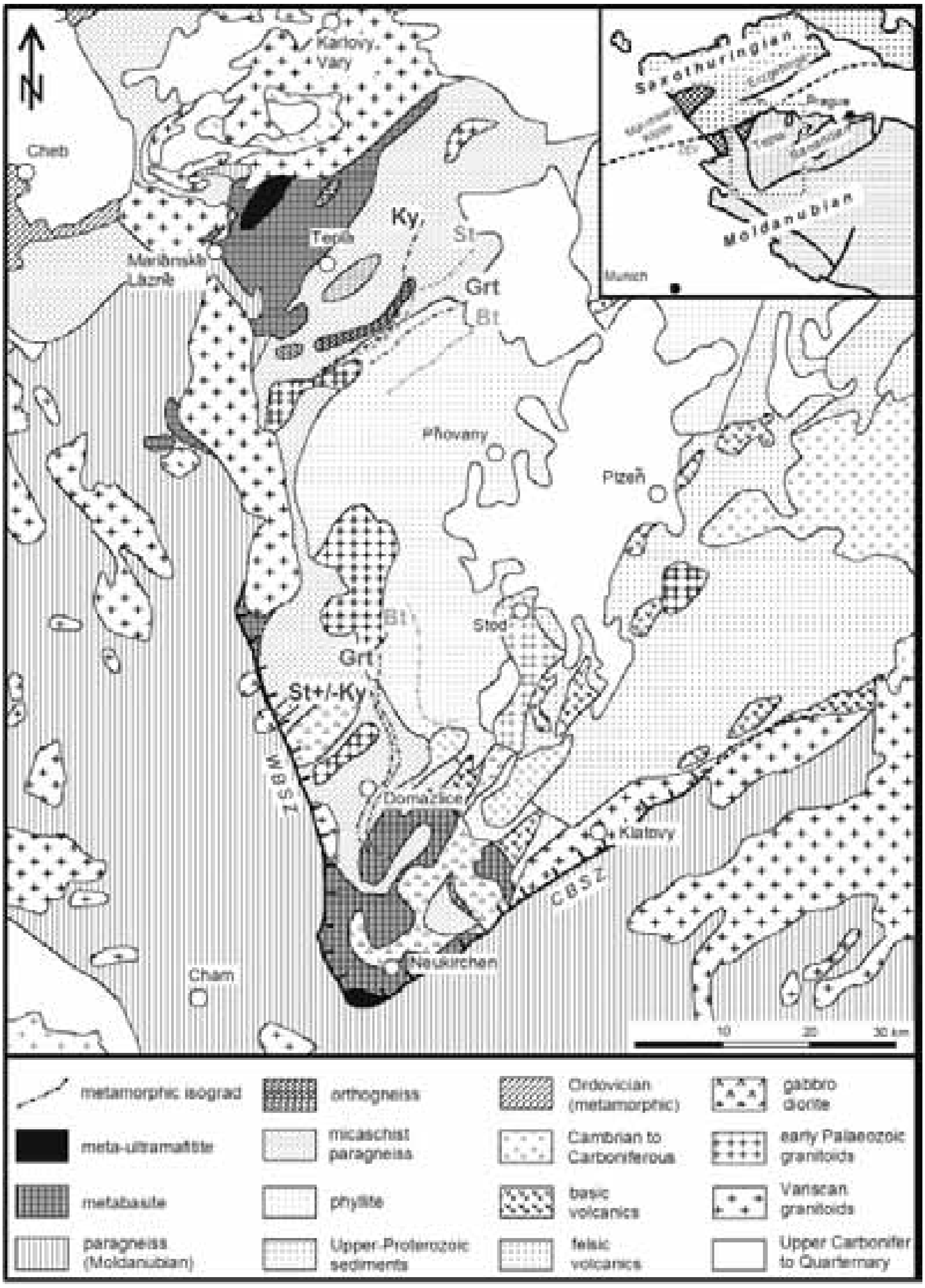

Figure 10 - Geological map of the western part of the Tepla-Barrandian unit (after Zulauf, 1997, and references therein).

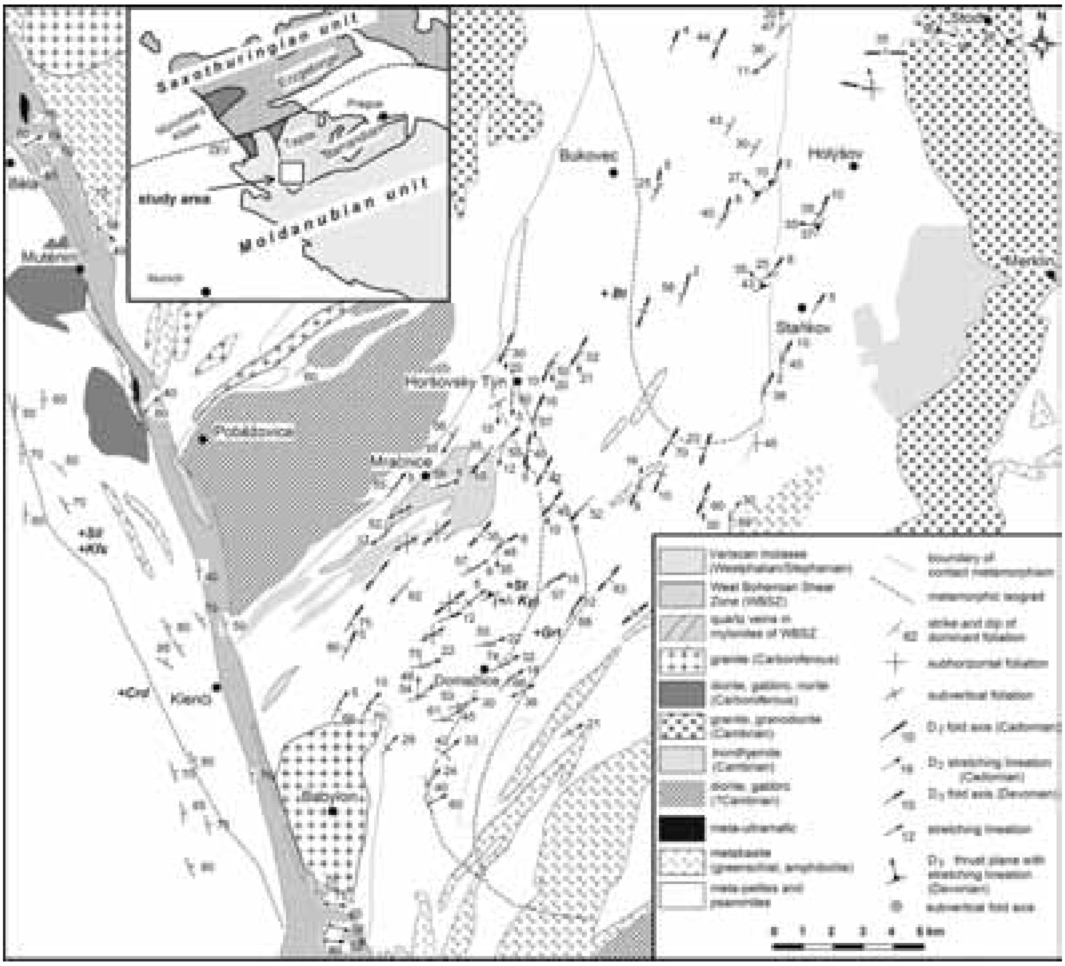

Figure 11 - Geological map of the Doma_lice crystalline complex (after Vejnar, 1982; Zulauf, 1997, and references therein).

the Weesenstein Complex is represented by the Weesenstein Group (Linnemann, 1991), which consists of mudstone schists in the lower part and, higher up, in the section of diamictites with a matrix, of graywackes. Both units are divided by the Purpurberg Quartzite, which shows quite well-preserved primary sedimentary structures. These features characterize the quartzite, accompanied by quartz phyllites at its base, and a conglomerate at the top as deposits that formed during sea level low stand (Linnemann, 1991). The conglomerate consists of weathering-resistant components, like quartz and hornfels pebbles. The quartzite within the Clanzschwitz Complex is interpreted as a more distal equivalent of the Purpurberg Quartzite. Two granite pebbles from the diamictite in the upper part of the Weesenstein Group were dated at 568 ±4 and 559 ±3 Ma (Gehmlich, in Linnemann et al., 2000). At a few locations, the pebbles from the diamictite were enriched as conglomerates, with pebbles derived from granitoids, pegmatites, graywackes, quartzites and felsic as well as mafic volcanites (Schmidt, 1960). In the lower part of the Weesenstein Group mafic sills occur, whereas from the upper part effusive mafic volcanics are known. The Weesenstein Group was intruded after the Cadomian deformation by the 537-±7 Ma old Dohna Granodiorite (Gehmlich in Linnemann et al., 2000).

The Teplá Barrandian unit
(with contributions by W. Dörr and Z. Vejnar)

The Teplá Barrandian unit (TBU) forms an

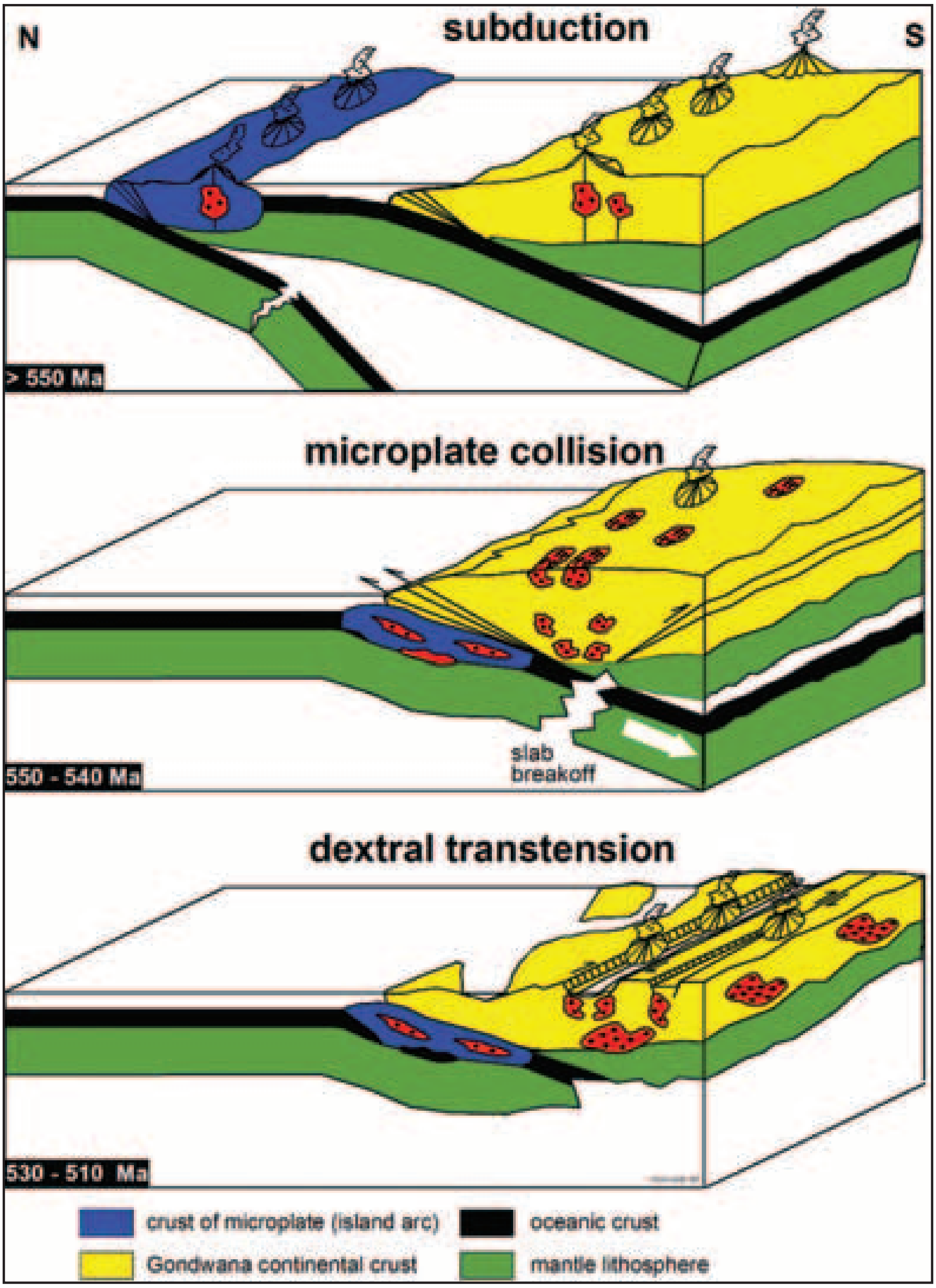

Figure 12 - Geodynamic model for the Cadomian orogeny in the Tepla-Barrandian unit (after Zulauf et al., 1999; Dörr et al., 2002).

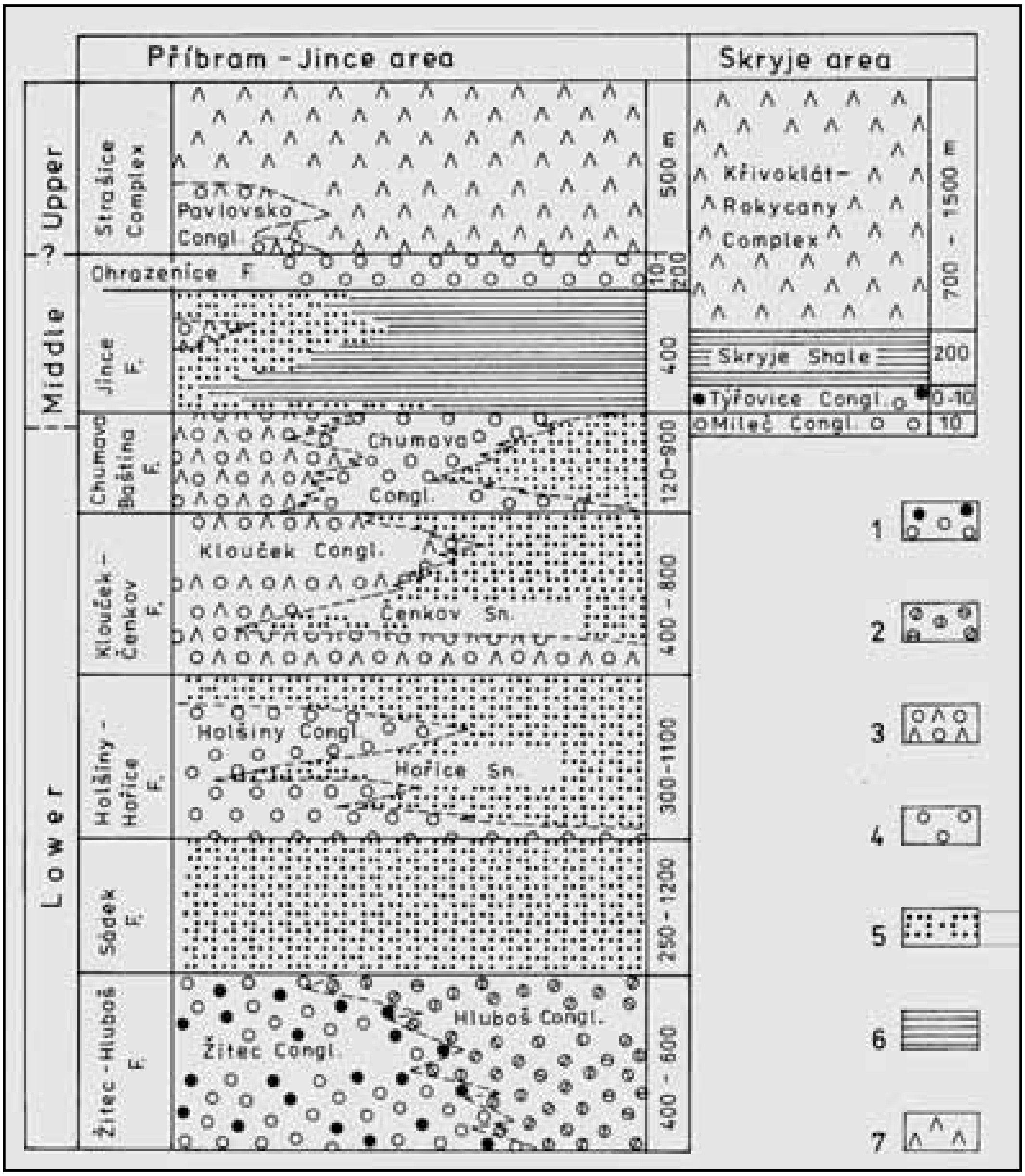

Figure 13 - Cambrian stratigraphy in the Tepla-Barrandian unit (after Chlupá_, 1993, and references therein); 1 = petromictic grey-green conglomerate, 2 = reddish petromictic and oligomictic conglomerate, 3 = conglomerate with volcanic material, 4 = white and grey quartzose conglomerate, 5 = sandstone and greywacke, 6 = siltstone and shale, 7 = effusive volcanics.

exceptional, largely supracrustal complex within Variscan Europe (Figure 1). In contrast to the surrounding units (the Moldanubian and Saxothuringian), the TBU was hardly affected by Variscan deformation and metamorphism. This is the reason why the records of Neoproterozoic to Cambrian (Cadomian) imprints are well preserved.

In the Barrandian syncline, located between Prague and Plzeò, unmetamorphic Cambrian to Middle Devonian sediments and volcanics rest unconformably

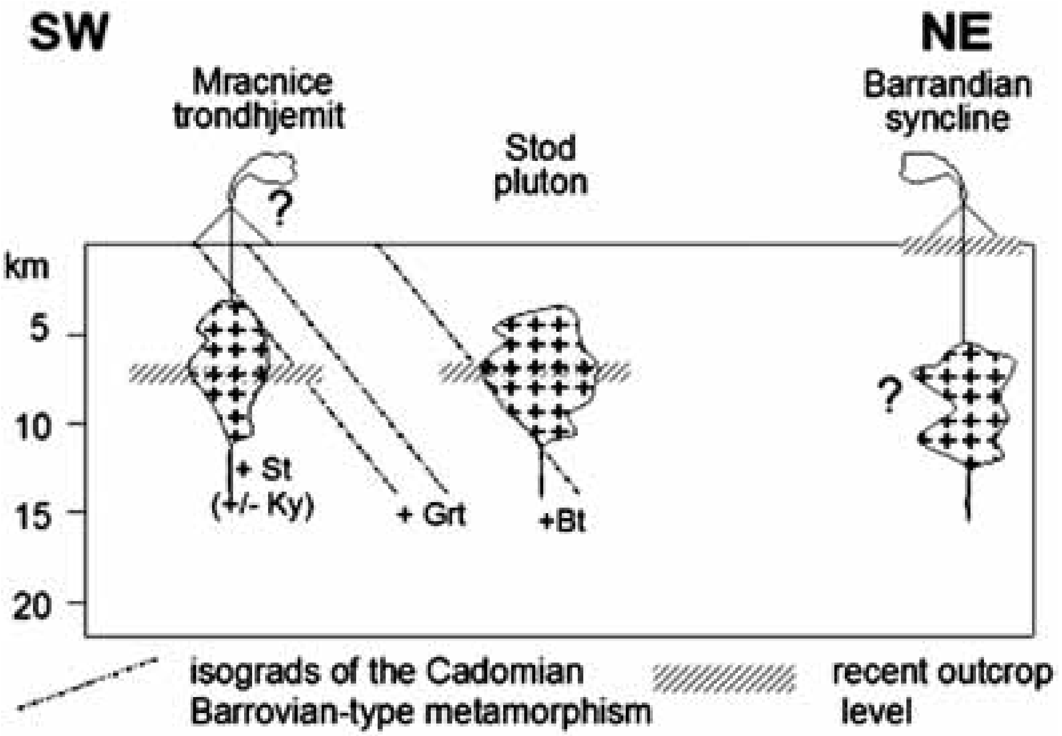

Figure 14 - Cambrian plutons intruded into a tilted crustal profile (between the West Bohemian shear zone and the Barrandian syncline) as is indicated by the tilted metamorphic isograd planes (after Zulauf, 1997).

on a Cadomian basement (Figure 8).

The Neoproterozoic rocks of the TBU can be subdivided into two members (Figure 9). The older *Kralupy-Zbraslav group* (Mašek and Zoubek, 1980) includes the rocks of the Blovice and Davle Formation. The Kralupy-Zbraslav group is present in the northern and western part of the TBU. There are meta-greywackes and –siltstone with intercalations of metavolcanics, as well as cherts and black shales. Mircrofossils suggest a late Riphean to Vendian age of sedimentation (Fatka and Gabriel, 1991). This age is compatible with a K-Ar whole-rock age of volcanics south of Plzeò which yield ca. 630 Ma (Pták and Wartha, 1966; recent decay constant is used). The composition of the volcanics suggests both MORB and subduction-related protoliths (Waldhausrová, 1993).

The *Štìchovice group* is present in the eastern part of the TBU, particularly in a NE-SW trending zone south and east of the Barrandian Paleozoic rocks. It consists of metagreywackes and metasiltstones with intercalated metaconglomerates. Subduction-related magmatism has been dated using magmatic pebbles of these metaconglomerates: 609 +17/-19 Ma, 585 ±7 Ma, and 568 ±3 Ma (U-Pb on Zirkon, Dörr et al., 2002).

Metamorphism in the basement increases from the Barrandian syncline (prehnite-pumpellyite facies, Cháb et al. 1995) towards the W and NW (amphibolite facies, Vejnar, 1982; Žáèek and Cháb, 1993).

Investigations of the crystallization-deformation relationships in the contact aureoles of several Cambrian plutons, described below, allowed separation of Cadomian from Variscan tectonometamorphic imprints. This holds for both the Domažlice crystalline complex (DCC, Figs. 10 and 11), located in the south (Zulauf, 1997; Zulauf et al., 1997), and the Teplá crystalline complex (TCC, Figure 10), located in the northwestern part of the TBU (Dörr et al., 1998; Zulauf, 2001).

There are at least two penetrative *Cadomian* deformation phases, D_1 and D_2, in the TBU. Garnet, staurolite and kyanite, which reflect Cadomian Barrovian-type metamorphism in the TCC and DCC, grew between D_1 and D_2. Quartz veins with pronounced crack-seal fabrics indicate elevated pore fluid pressures and unstable movements during

D$_1$. During D$_2$, E-W trending folds developed in the greenschist facies crustal level (west of Stod), whereas a penetrative mylonitic foliation developed in the amphibolite facies part. The D$_2$ mylonites mainly result from top-to-the-N movements, and late increments of these movements are portrayed by sillimanite that grew in pressure shadows of garnet.

Subsequent to the D$_2$ stage, a pronounced phase of low-pressure static annealing followed at deeper structural levels. This phase was stronger in the DCC than in the TCC. A similar distribution pattern shows the Cadomian low-pressure metamorphism that is related to D$_2$. This stage is also stronger in the DCC. Microprobe datings of monazites in amphibolite-facies greywackes of the DCC yield 540 ±16, 542 ±23, and 551 ±19 Ma (Zulauf et al., 1999). Although this age reveals a large uncertainty; it roughly reflects the time of late low-pressure/high-temperature metamorphism in the DCC at T = ca. 600 °C.

The D$_2$ kinematic data, the distribution of granitoid pebbles within the Upper Proterozoic flysch, and the N-S gradient with respect to the intensity of the D$_2$-related low-pressure metamorphism and post-D$_2$ static annealing, indicate a Cadomian magmatic arc located towards the S of the recent TBU (Figure 12).

The thickened Cadomian crust of the TBU collapsed close to the Proterozoic/Cambrian boundary. Normal faulting led to tectonic denudation and to the exhumation of the amphibolite facies rocks of the DCC. This exhumation was associated with a pronounced 'crustal tilting', that is particularly responsible for the present metamorphic isograds of the DCC (Vejnar, 1982; Figure 11). Apart from tectonic denudation, erosive removal of upper crustal levels has contributed to the exhumation of the deeper levels of the DCC. This is documented by the early Cambrian molasse-like sediments of the Barrandian basin (Figure 13). Thus, the Cadomian orogeny ceased no later than the Early Cambrian.

During the late Early Cambrian the Mra¹nice (523 +4/-5 Ma) and the Stod pluton (522 ±2 Ma), and probably also the Pob+žovice pluton, intruded into the tilted crust of the DCC at a depth of ca. 7 km (Zulauf et al., 1997; Figure 14). Similar ages have been derived for plutons of the Neukirchen-KdynÆ crystalline complex, located south of the DCC (Věepadly granodiorite, 524 ±3 Ma; Smézovice tonalite, 523 ±3 Ma; Smézovice gabbro, 523 ±1 Ma; Orlovice gabbro, 524 ±1 Ma; Dörr et al., 2002).

Marine sediments of Middle Cambrian age indicate that during this time the Cadomian relief was largely removed. However, the magmatic activity continued. The Lestkov metagranitoid and the Teplá orthogneiss yield upper-intercept U-Pb zircon ages of 513 +15/-1.3 Ma and of 513 +7/-6 Ma, respectively; the ^{207}Pb / ^{206}Pb age of 516 ±5 Ma of a nearly concordant zircon of the Hanov orthogneiss is a good estimation of its emplacement time (Dörr et al., 1998). Intrusion of associated magmatic dikes continued until early Ordovician times (Košler et al., 1994, Glodny et al. 1998). Despite their emplacement within thinned, extending Cadomian crust, both the plutons and the dikes are mainly of kalkalcalic affinity (Dörr et al., 1998). Most of them intruded into NE-SW- to ENE-WSWtrending, transtensive shear zones (Zulauf and Helferich, 1997). Along these shear zones the metamorphic isograds of the DCC, and probably also the Stod pluton, have been dextrally displaced by ca. 6 km (Figure 11).

The melt temperature of the Cambrian plutons varies, according to their composition, between 750 °C (trondhjemite) and 850 °C (diorite). Thermal modelling indicates that the cooling of the plutons was relatively slow. Thus, high-temperature low-viscosity deformation could occur in the synkinematically emplaced plutons for relatively long periods, from ca. 0.2 to ca. 1.5 m.y. (Zulauf, 1997). The synkinematic dikes were partly sheared under very high temperatures within periods of a few hours to a few days. In one particular case, a minimum strain rate of 2.8 * 10^{-6} s^{-1} has been calculated (Zulauf and Helferich, 1997). These phenomena indicate that the melts markedly softened the crust during Cambrian transtension.

The Cambrian transtension introduced the large-scale Ordovician rifting that led to the separation of the TBU from Gondwana, forming a part of the Armorican terrane assemblage (ATA, Tait et al., 2000). The northern drift of Armorica was associated with both production and destruction of oceanic lithosphere. From ?Silurian to Early Devonian times the lithosphere below the Saxo-thuringian ocean was subducted towards the SE beneath the Cadomian basement of the TBU. This *Variscan subduction* is well documented in the eclogite-bearing Mariánské-LáznÆ complex (MLC), situated at the boundary between the Saxo-Thuringian and the TBU (Figure 10). U-Pb zircon dating of gabbropegmatite yields an upper, nearly concordant intercept in the concordia diagram at 496 +/- 1 Ma interpreted as magmatic intrusion age (Bowes and Aftalion, 1991), which reflects initial rifting. Comparable eclogite-bearing

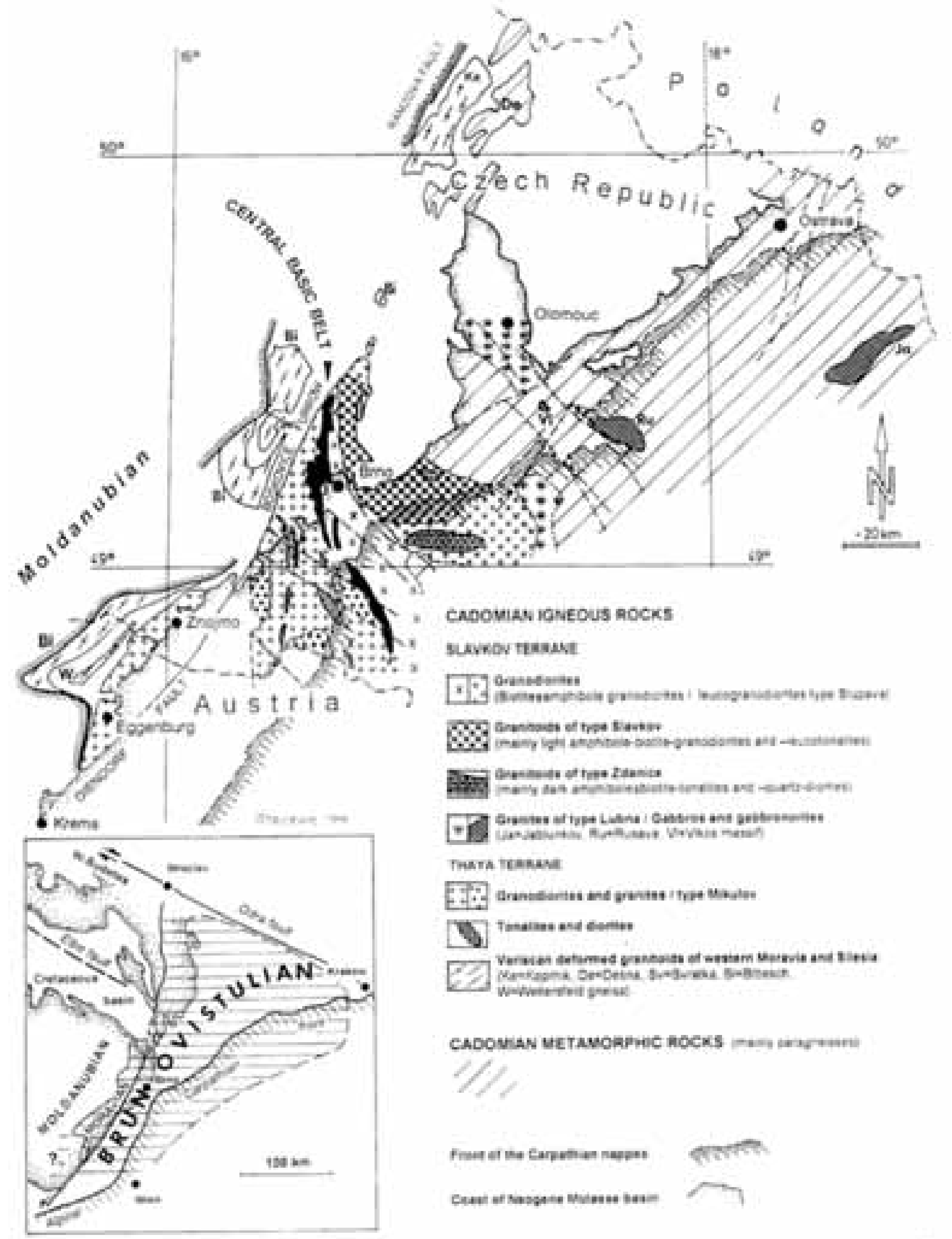

Figure 15 - Geology of the Brunovistulian block, as far as is known from drillings and the exposed basement massifs. Mainly after Dudek (1980) and official maps of the Czech Republic. Inset shows the presumed extent of the Brunovistulian (horizontally hatched), according to Dudek (1980), and its position in the tectonic framework of the Central European Variscides.

complexes, with protoliths, metamorphic records, and cooling ages similar to those of the MLC, have been found in the Münchberg klippe and in the Erbendorf Vohenstrauss zone (ZEV; Figure 1). The eclogites of all these crustal domains are interpreted as resulting from Silurian to Devonian southeastward subduction of 'Saxo-thuringian ocean' lithosphere beneath the Teplá Barrandian plate (Matte et al., 1990; Franke, 2000).

Variscan continent-continent collision of the Teplá Barrandian and Saxo-Thuringian units started during the early Late Devonian (Franke et al., 1995). During this time the intensity of the collapse of the overthickened wedge increased, promoting further extensional faulting and the exhumation of the deeply subducted rocks. Extensional movements led to strong crustal tilting, as is indicated by the metamorphic isograds in the TCC (Figure 10).

Along with the continent-continent collision, the convergent movements migrated towards southeast affecting also the Paleozoic cover of the Barrandian syncline. The F_3 folding in the Stod-Holýšov area started at ca. 370 Ma (Zulauf, 1997) which is close to the break in sedimentation of the Barrandian basin. Finally, the NW-SE compression, which persisted over several million years, led to an Upper Devonian mega-pop-up structure that includes NW vergent folds and thrusts in the northwestern part, including the TCC, and SE vergent folds and thrusts in the southeastern part of the TBU, including the DCC. There is a remarkable time gap of more than 10 M yrs. between the development of the structures in the N and those in the S.

Although Cadomian Barrovian-type mineral assemblages are present in the TCC, there is clear evidence that the major Barrovian imprint occurred during the Variscan cycle: (1) northwest of the staurolite isograd the Cambrian granitoids have been pervasively deformed and changed into mylonitic orthogneiss (Teplá and Hanov orthogneiss; Dörr et al., 1998; Zulauf, 1997), whereas the Lestkov granitoid, largely situated in the garnet zone, does not show a pervasive mylonitic fabric; (2) Variscan garnet developed in pressure shadows behind Cadomian garnet (Zulauf, 1997); (3) andalusite of early Ordovician pegmatites is replaced by Variscan kyanite (Žáèek, 1994); (4) cordierite in the northern contact aureole of the Lestkov pluton is replaced by staurolite (Cháb and Žáèek, 1994), indicating that the staurolite isograd reflects the Variscan cycle; (5) ^{39}Ar-^{40}Ar and K-Ar dating of hornblende and white mica from the TCC yield 383 Ma and 366-371 Ma, respectively (Dallmeyer and Urban, 1998; Wemmer and Ahrendt, unpublished data.; Kreuzer et al., unpublished data). The hornblende ages suggest a Devonian temperature of more than ca. 500° C for the northwestern part of the TCC, assuming a closure temperature of 500° C for the K-Ar isotopic system of hornblende.

Investigations of the crystallization-deformation relationships in the TCC indicate that the biotite and garnet isograd of Cháb and Žáèek (1994) (Figs. 1 and 3) reflect the Cadomian cycle, whereas the staurolite, and probably also the kyanite isograd reflect the Variscan cycle (Dörr et al., 1998; Zulauf, 2001). Variscan biotite and garnet appear just northwest of the Cadomian garnet isograd. Southeast of the garnet isograd, the Variscan deformation occurred under retrograde metamorphic conditions compared to the older Cadomian fabrics.

Enhanced Variscan collapse of the overthickened crust during the Early Carboniferous was related to the activity of the Bohemian shear zone (BSZ). Elevator-style movements along the BSZ led to the sinking of the TBU, as upper crustal level, into its hot substratum (Moldanubian, Saxothuringian). The bendings of the BSZ are used to subdivide it into the North Bohemian shear zone (NBSZ, Zulauf et al., 2002b), the West Bohemian shear zone (Zulauf et al., 2002a), the Hoher Bogen shear zone (HBSZ, Bues et al., 2002), and the Central Bohemian shear zone (CBSZ, Scheuvens and Zulauf, 2000). Elevator-style tectonics along the BSZ can be explained by overthickened crust that was weakened from below.

The Brunovistulian unit

Considerable amounts of well-preserved Cadomian crust are also present in the Moravo-Silesian Zone at the eastern termination of the central European Variscides (Brunovistulicum; Dudek, 1980). At the surface these Cadomian rocks can only be studied in relatively small massifs in the western parts of Moravia and Silesia (Thaya Dome, Svratka Dome, Brno Massif, Keprník and Desná Dome). Most of the Brunovistulian unit is hidden beneath younger sediments. However, thanks to dense oil and gas drilling in the Carpathian foredeep between Brno and Ostrava, and on the basis of additional geophysical data, Dudek (1980) was able to compile a geological sketch map for this subcrop part of the Brunovistulian (Figure15). Unfortunately, little information is available about the crystalline basement beneath the thick Devonian and Carboniferous Silesian sediments

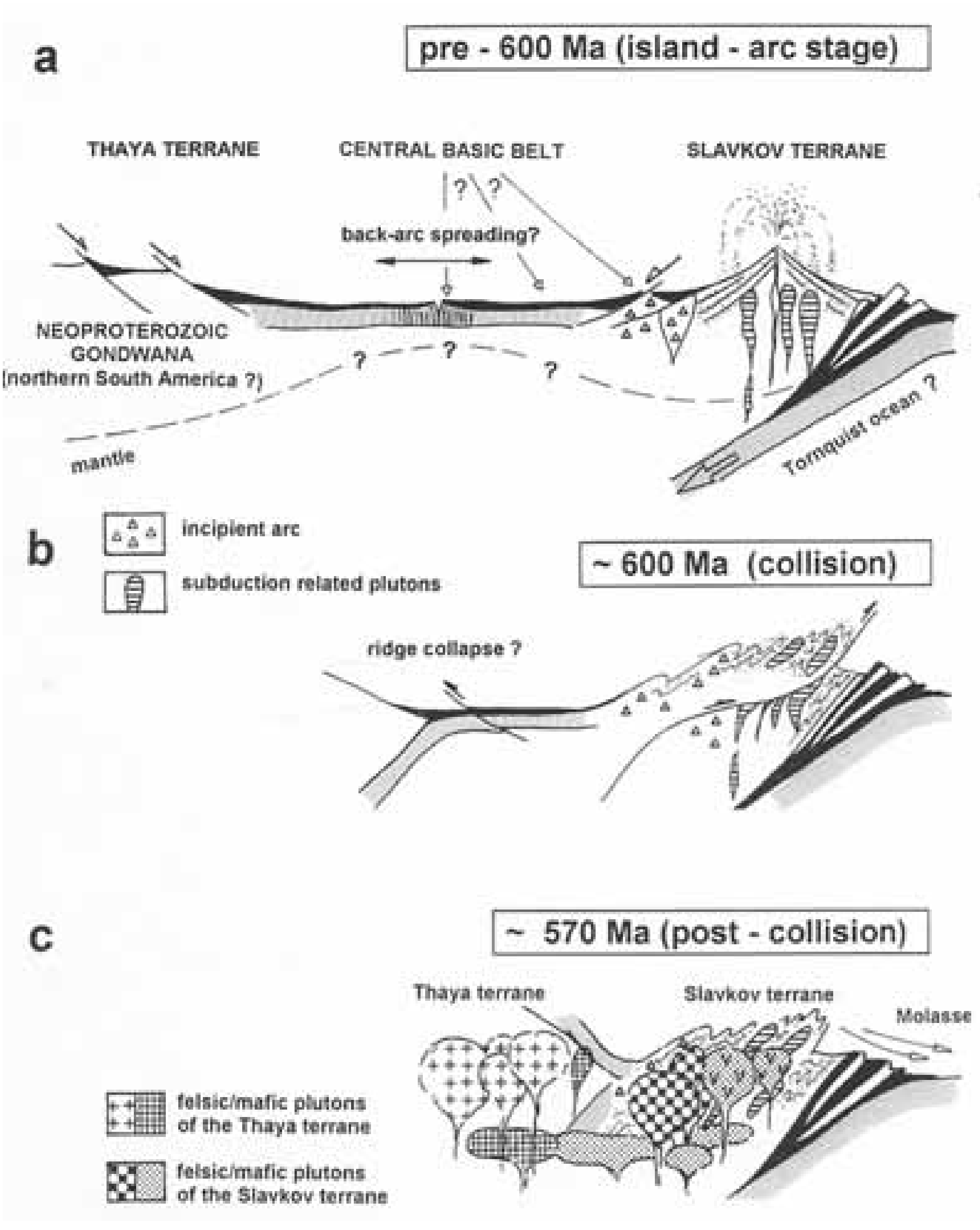

Figure 16 - Tentative geodynamic model for the evolution of the Brunovistulian (see text for explanation).

north of the Neogene Molasse basin. However, since Cadomian rocks outcrop again in the Hrubý Jeseník Mountains (Desná Dome), Dudek (1980) proposed that the whole Moravo-Silesian zone rests upon the same Cadomian-consolidated basement block.

In the Early Carboniferous, during the Variscan orogeny, the western parts of the Moravo-Silesian Zone (=Brunovistulian plus its Early Palaeozoic cover) were overthrust by the Moldanubian unit, the high-grade metamorphic core zone of the Variscan orogen. Due to the increasing Variscan deformation and metamorphism towards the Moldanubian boundary (Frasl 1970, 1991; Schulmann, 1990; Fritz et al., 1996), there is some uncertainty about the actual western limitation of the Brunovistulian Cadomian basement. Most geologists believe that the strongly-sheared granitoid pencil gneisses of western Moravia and Silesia (Bittesch Gneiss, Keprnik Gneiss) still represent parts of the Brunovistulian, although the bodies are probably more or less dislocated from the main basement block in the east. Some authors have argued that even some bodies of granitoid gneisses of the Moldanubian Unit in Lower Austria (Dobra Gneiss, Spitz Gneiss) might represent Variscan reworked and overthrust parts of the Brunovistulian plate (Matura, 1976; Finger and Steyrer, 1995). This concept is, however, still a matter of controversy (see e.g. Fuchs, 1998).

Figure15 illustrates how the Brunovistulian essentially consists of a large metamorphic complex, with mainly paragneisses in the (north)east, and a large granitoid complex in the (south)west (Brno Batholith, Thaya Batholith). The name Thaya Batholith is traditionally used for the granitoids in the Thaya Window, i.e. the area between Eggenburg and Znojmo, although the separation of the Thaya Batholith from the Brno Batholith is presumably a simple result of Permian sinistral strike slip along the Diendorf-Boskovice fault system. Near Brno, a striking narrow belt of metamorphosed basic and ultrabasic rocks passes through the Brno Batholith in a roughly north-south direction (Central Basic Belt).

The large abundance of *Cadomian granitoids* is one of the most outstanding features of the Brunovistulian block, and these rocks have been the subject of several detailed petrographical and geochemical studies (Dudek, 1980; Finger et al., 1989; Jelínek and Dudek, 1993; Leichmann, 1996; Hanžl and Melichar, 1997). All these studies conclude that the Brunovistulian granitoid terrane is essentially an I-type granitoid terrane. However, Finger et al. (1995) have additionally pointed out a pronounced east-west zoning of granite types, with the plutons east of the Central Basic Belt being relatively primitive in composition, resembling island arc magmas (Hbl-granodiorites, tonalites, quartzdiorites), whereas those in the west are mainly high-K granodiorites and granites. The magmatic zonality in the Brunovistulian granitoids is very clearly expressed in the Sr and Nd isotope values (Finger et al., 1995; Finger and Pin, 1997 and in prep.). These are generally primitive in the eastern province ($^{87}Sr/^{86}Sr_{580}$ mostly 0.704 – 0.705, εNd_{580} -1 to +3), and mostly in the typical crustal range in the western granitoids ($^{87}Sr/^{86}Sr_{580}$ 0.708 – 0.710, εNd_{580} –4 to –7). Intermediate initial ratios (0.705-0.707, -1 to -2) have been found in the rare diorite/tonalite bodies west of the Central Basic Belt, and in one distinct subalkaline granite pluton in the southern Thaya Batholith near Eggenburg (Finger and Riegler, 1999). Samples of Bittesch Gneiss yielded generally very mature isotope values (εNd_{580} –10 to –11; see also data in Liew and Hofmann, 1988), while the Keprnik Gneiss has εNd_{580} values of around –5 to –6 (Hegner and Kröner, 2000).

Regarding the magma sources, it is quite obvious from the isotope data that the western high-K granites and granodiorites, including the Bittesch and Keprnik Gneiss, are mainly crustal derived, with cratonic components involved in the melting process. Friedl et al. (2000) reported abundant Mesoproterozoic-inherited zircon cores from the Bittesch Gneiss. However, the additional occurrence of some isotopically more primitive tonalites and diorites in the western province indicates the presence of another magma source (mantle or juvenile crust).

The granitoid magmas east of the Central Basic Belt either formed through the melting of young calc-alkaline crust or contain a significant mantle component. Due to the dominance of felsic granitoids, a great importance is attributed to melting processes in the crust, although in some cases (e.g. basic massifs of Rusava and Jablunkov) the presence of mantle melts seems to be clear.

Geochronological data provide increasing evidence that most of the Brunovistulian granitoids formed during a relatively short plutonic episode at around 570 – 590 Ma. In addition to a number of zircon ages from granitoids of the western province, which all fall in this time span (Finger et al., 2000b), an Ar-Ar hornblende age of c. 590 Ma has been reported for one of the eastern granitoids (Fritz et al., 1996).

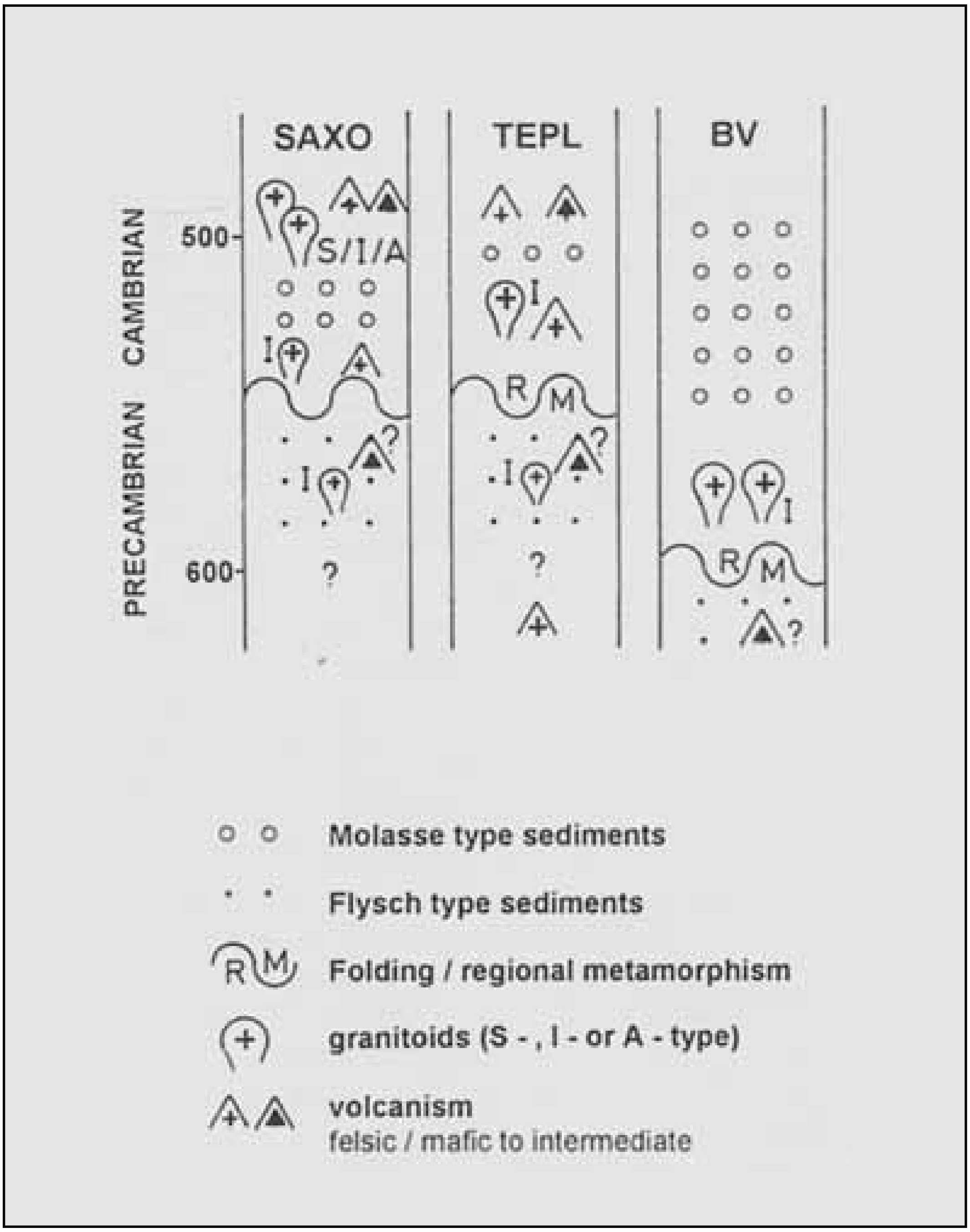

Figure 17 - Schematic comparison of the Cadomian/Cambrian stratigraphy in the Saxo-Thuringian, Teplá-Barrandian and Brunovistulian, using data from Dörr et al. (1998, 2000, and pers. comm.), Zulauf et al. (1999), Linnemann (1995), Linnemann et al. (1998), Tichomirowa et al. (1997).

Possible candidates for late Cadomian intrusions are the gabbroic massifs in the eastern Brunovistulian; in the contact aureole of the Jablunkov massif (Figure15), Th-U-total Pb monazite ages of c. 550 Ma have been obtained (Finger et al., 1999).

Because of their overall I-type nature, and on the basis of Pearce-type diagrams, the Brunovistulian granitoids were previously mostly interpreted as subduction-related (Finger et al., 1989; Jelínek and Dudek, 1993; Hanžl and Melichar, 1997). Based on the striking east-west zoning of plutonism, a westward dipping Cadomian subduction geometry has been inferred (Finger et al., 1995). However, the pulsed nature of plutonism, subsequent to a phase of regional metamorphism, may suggest a collision event. An arc-continent collision in a Pacific-type tectonic setting is considered as a potential model (see below).

A comprehensive description of the *metamorphic complex* in the eastern half of the Brunovistulian was given by Dudek (1980, 1995). Most of these rocks are derived from flyschoid clastic sediments, mainly greywackes, siltstones and psammites with subordinate pelitic layers. In the area south and southeast of Olomouc, the metasediments contain abundant layers of metavolcanic rocks, mainly metabasalts and meta-andesites.

Regional metamorphism mostly reached medium-pressure amphibolite facies grade. In some cases, partial melting occurred. Microfabrics sometimes provide evidence of two metamorphic phases, with a younger phase of contact metamorphism related to the intrusion of the granitoids (Dudek, 1980; Hanžl et al., 1999). During the Variscan orogeny, parts of the Cadomian metamorphic complex were subjected to penetrative retrograde shearing under greenschist facies conditions.

Dudek (1980) has already emphasized the relatively Al_2O_3-poor character of the metasediments in the eastern Brunovistulian, implying a calc-alkaline (volcanic arc) source area. New trace element and isotope data (Finger and Pin, in prep.) point in the same direction, indicating a young, chemically and isotopically little-evolved island arc-type source. $^{87}Sr/^{86}Sr_{580}$ and εNd_{580} values of the metasediments are generally very similar to those of the adjoining granitoids (0.704-0.706; -1 to +2). This shows that not only the granitoids, but the whole continental crust in the eastern part of the Brunovistulian, were primitive throughout.

In the western part of the Brunovistulian, Cadomian metamorphic rocks are much less abundant. However, paragneiss relics from the roof of the Thaya Batholith and the western Brno Batholith are chemically and isotopically more evolved (εNd_{580} –3 to –7) than the paragneisses in the east. The detritus of these western metasedimentary units obviously derives from much older, cratonic crust (Finger and Pin, in prep.).

Based on the evidence presented from the granitoids and paragneisses, it is unequivocal that the continental crust west of the Central Basic Belt is completely different from that in the east. The Central Basic Belt obviously marks an important terrane boundary. Finger and Pin (1997) have introduced the terms “Slavkov Terrane” for the eastern province and “Thaya Terrane” for the western province.

Kröner et al. (1999) and Hegner and Kröner (2000) have presented Nd isotope data from a number of metasedimentary and metagranitoid rocks from the Jeseníky mountains. This data suggests that the Desná Dome can be correlated with the Slavkov Terrane, while the Keprnik Dome has the isotopic characteristics of the Thaya Terrane.

No precise geochronological information is available for the timing of Cadomian regional metamorphism in the Brunovistulian. K-Ar hornblende and mica ages (Dudek and Melkova, 1975) and Th-U-total Pb monazite ages (Finger et al., 1999) broadly constrain its age between 610 and 580 Ma, suggesting that regional metamorphism and plutonism are related to one single Cadomian tectonothermal cycle. A zircon evaporation age of 599 ±2 Ma was obtained by Kröner et al. (1999) for migmatites from the Desná Dome.

Little is known regarding the age of the volcanic arc material present in the metasedimentary complex of the Slavkov Terrane. The generally-primitive isotope compositions suggest a Neoproterozoic age. For volcanic arc-type granitoid gneisses in the Desná Dome, Kröner et al. (1999) have determined formation ages of 612 ±2 and 684 ±1 Ma. Inherited magmatic zircons in a metagreywacke from the Desná Dome, probably representing volcanic arc detritus, gave evaporation ages of 629 ±2, 642 ±3 and 665 ±1 Ma (Kröner et al., 2000). Unlike in the Thaya Terrane, no evidence for Meso- or Palaeoproterozoic zircons has been found in the Precambrian basement of the Desná Dome.

The *Central Basic Belt* consists of metagabbros, metadiorites, some ultramafics, tholeiitic metabasalts and metarhyolites. In the exposed Brno Massif, a mainly plutonic subzone in the west can be distinguished from a mainly volcanic subzone in the east. Since contacts are generally tectonic, it is unclear if both formed during the same event or represent independent units. The metamorphic overprint of the Central Basic Belt was polyphase (Cadomian and

Variscan), but did not overstep low to moderate P-T conditions (greenschist to lower amphibolite facies; Leichmann, 1996).

Petrographic and geochemical data for rocks of the Central Basic Belt are given in Štelcl and Weiss (1986), Hanžl et al. (1995), Leichmann (1996), Hanžl and Melichar (1997), Finger et al. (2000). Evaluation of this data shows that in the volcanic zone the melts are mainly basaltic and derived from depleted to mildly-enriched mantle sources. According to Leichmann (1996), the degree of enrichment increases towards the north. The metagabbros and –diorites of the plutonic zone have mostly cumulate compositions. They show high LREE/HREE ratios and seem to be derived from a separate mantle source (Finger et al., 2000a).

It has been often suggested that the Central Basic Belt, or parts of it, might represent relics of an ophiolite (Mísaø, 1979; Leichmann, 1996). However, the relative abundance of rhyolites and diorites distinguishes the assemblage lithologically from normal mid-ocean-ridge crust. Alternatively, the belt could be interpreted as part of an ensimatic arc, or as related to back-arc basin extention.

Recently, the first geochronological data from the volcanic zone of the Central Basic Belt have been obtained. A zircon evaporation age of 725 ±15 Ma for a tholeiitic rhyolite suggests that this zone is much older than the granitoids (Finger et al., 2000a). Leichmann (1996) has reported field observations which show that the Central Basic Belt is intruded by granitoids of the Slavkov Terrane at its eastern margin, as well as by granitoids of the Thaya Terrane at its western margin. This means that at ca. 580 Ma the present-day assembly of the Central Basic Belt, the Slavkov and the Thaya Terrane may have been basically established. Nevertheless, during the Variscan orogeny the section was certainly shortened. Parts of the Central Basic Belt were thrust eastwards onto Devonian strata (Hanžl et al., 1999). Sinistral strike-slip tectonics led to a further disturbance of the original Cadomian relationships (Hanžl and Melichar, 1997). **A** *geodynamic evolution model* **for the Brunovistulian has to accommodate the following geological observations:**

- Presence of a distinctly zoned crust with an island arc-type chemical and isotopic signature in the east (Slavkov Terrane) and a continental signature in the west (Thaya Terrane).
- Remnants of an ensimatic basic belt between the Thaya and the Slavkov Terrane.
- Deposition of large masses of flyschoid, arc-derived sediments in the eastern Slavkov Terrane, probably mainly between 600-700 Ma.
- Cadomian deformation and regional metamorphism at ca. 600 Ma, followed by extensive post-kinematic granitoid plutonism.

Finger et al. (2000b) assumed that the starting situation was some kind of island arc–back arc basin setting (Figure16), which had formed in the Neoproterozoic in the subduction realm of the Tornquist ocean, outboard of the Gondwana continent. Similar “Pacific-type“ orogenic settings have been proposed for most other Peri-Gondwanan terranes of the Avalonian-Cadomian chain at that time (see Nance and Thompson, 1996). The existence of a pre-600 Ma volcanic arc is mainly inferred on an indirect basis: firstly, from the sedimentation of Neoproterozoic calc-alkaline material prior to 600 Ma in the eastern Brunovistulian, and, secondly, from the fact that large volumes of I-type granitoids of the Slavkov Terrane probably represent a remolten meta-igneous arc-type crust. Original volcanic-arc igneous rocks seem to be preserved under the Upper Moravian Basin (metabasalts and -andesites; see Dudek 1980) and in the Desná Dome (e.g. Ludvikov Gneiss: 684 ±1 Ma; Kröner et al., 2000).

The geological evidence for the proposed back-arc basin is still weak. As mentioned above, the rocks of the Central Basic Belt may equally well represent primitive parts of an ensimatic arc, and it cannot be excluded that this arc formed more or less adjacent to the Gondwana continent margin. However, since, during the Neoproterozoic, the northern Gondwana margin was a long-lived active margin (Nance and Thompson, 1996), the presence of island arcs and back-arc basins is quite likely. Furthermore, it remains open to discussion whether the inferred back-arc basin between the Slavkov and the Thaya Terrane consisted of remnant crust of the Tornquist ocean, or contained a new spreading centre. All this can only be a matter of speculation, until a much more detailed chemical and geochronological data set is available for the rocks of the Central Basic Belt.

Due to the deformation and regional metamorphism, which affected the Brunovistulian at ca. 600 Ma, it can be assumed that the arc system was in a state of compression at that time (Figure2b). It has been suggested that parts of the Central Basic Belt were obducted onto the Thaya Terrane, so that they could be later intruded by crustal granitoids.

Judging from its episodic nature following regional metamorphism, the ca. 580-590-Ma-old granitoid plutonism in the Brunovistulian can be viewed as post-collision plutonism, rather than as normal subduction-related plutonism. There is no need to claim that subduction of the Tornquist ocean still continued during this stage. For example, post-collisional slab break-off, or delamination of mantle lithosphere (see e.g. Henk et al., 2000), would also provide a suitable tectonothermal mechanism for triggering voluminous mantle and crustal melting. In fact, such a ”catastrophic“ scenario would better account for the pulsed nature of plutonism than continous subduction activity and water-induced melting in the mantle wedge. The chemical zoning of plutonism may reflect simply the pre-existing crustal heterogeneity and the different source rock composition of the Slavkov and the Thaya Terranes. In the model in Figure16 it is assumed that in the Slavkov Terrane much of the previous arc building was flooded by granitoid melts or remolten at that time.

Based on the SHRIMP age spectrum of inherited zircons found in the Bittesch gneiss, Friedl et al. (2000) have proposed that the Brunovistulian is derived from a Grenvillian cratonic province, and not from Africa, like the Teplá-Barrandian and Saxo-Thuringian terranes (i.e. the Armorican terrane assembly). It has been suggested that the Brunovistulian is a fully-independent peri-Gondwanan terrane, which was situated in the realm of the Amazonian cratonic province by the late Precambrian, comparable to the Avalonian terranes of North America and the United Kingdom (Finger et al., 2000b; Friedl et al., 2000; Winchester et al., 2002).

Figure17 illustrates that also the recorded Cadomian events in the Brunovistulian are significantly distinct from those in the Teplá-Barrandian and the Saxo-Thuringian.

A first important difference is that the Brunovistulian does not show evidence for Eocambrian regional metamorphism and tectonics, nor for Early to Mid-Cambrian granitoid plutonism or related volcanism, whilst Dörr et al. (1998, 2000) have pointed out that these two events are widely recorded throughout the Armorican terrane assembly, from central Europe over Brittany to Spain. In the case of the Teplá-Barrandian Unit, Zulauf et al. (1999) have interpreted these Eocambrian/Cambrian tectonothermal events as part of the process of microterrane accretion to the Armorican sector of the Gondwana margin (see above). At the same time, a non-orogenic, broadly Molasse-like overstep sequence is documented on the Polish side of the Brunovistulian (Bula et al., 1997) and also in a few boreholes in southern Moravia (Jachowicz and Pøichystal, 1997).

Secondly, the Brunovistulian apparently lacks evidence for the plutonic/volcanic event at ca. 500 Ma, which is widely documented in the Armorican parts of the Bohemian Massif (von Quadt, 1994; Tichomirowa et al., 1997; Kröner and Hegner, 1998; Glodny et al., 1998) and mostly interpreted as marking the time when Armorica started to rift from main Gondwana (Pin, 1990; Tait et al., 1997; Floyd et al., 2000). On the other hand, there is as yet no evidence for ~ 600 Ma high-grade regional metamorphism in the Armorican parts of the Bohemian Massif.

Field trip itinerary

DAY 1

(Arrival in Dresden, Introduction to the field trip, Dresden Sightseeing)

DAY 2

(Lausitz and Elbe area)

Stop 2.1:

Quarry Kindisch, 500 m W of the village of Kindisch, near Kamenz

Lower Cambrian granodiorite of the Lausitz Anticline (ca. 540 Ma).

Large areas of the Cadomian basement of the Lausitz Anticline are occupied by Cadomian granitoids that intruded into deformed Cadomian siliclastic rocks (mainly greywackes). Most of these granitoids are granodiorites. Traditionally, two petrographic types of Cadomian granitoids have been distinguished in the Lausitz Anticline: (1) Two-Mica-Granodiorite and (2) Biotite-Granodiorite. Furthermore, all transitional stages between anatexites and Cadomian meta-greywackes (the source rocks of the anatexites) can be recognized. In samples of the Two-Mica-Granodiorite, the large amount of recycled meta-sedimentary rocks is reflected by a high content of rounded zircon. The Cadomian magmatism in the Lausitz Anticline is interpreted as being subduction-related.

At the Kindisch quarry (Hartsteinwerke Kindisch GmbH), a Cadomian Biotite-Granodiorite is cropping out. The intrusion contact with the surrounding Cadomian greywackes (Lausitz Group) is exposed at the northern edge of the quarry. There occur some granodioritic dikes and apophyses within the greywackes. North-south striking basic dykes of unknown age penetrate the granodiorite. Greywacke xenoliths are distributed within the granodiorite, reflecting the position of the quarry close to the contact between the intrusion and the greywackes.

The intrusion age of the granodiorite was analysed by SHRIMP – U/Pb dating (Linnemann et al., in prep.) at ca. 540 Ma.

Stop 2.2:

Butterberg Quarry, 2.5 km N of Kamenz, near the village of Bernbruch

Neoproterozoic greywacke and shale from the Lausitz Group (Lausitz Anticline) with rare tuffogeneous intercalations.

The greywackes of the Lausitz Anticline represent Neoproterozoic turbidites of a back arc basin. The thickness of the entire sedimentary unit (Lausitz Group) is estimated at exceeding 3000 m. A subdivision is problematic due to the lack of key beds.

The facies scheme for the Lausitz Group corresponds to the Bouma turbidite intervals Ta - e. Its characteristics can be observed in the outcrop. Monotonous greywackes are dominated by the fine sand Ta-b interval, and siltstone and shale beds of Tc - e. The thickness of the sequences ranges from the decimetre to the decametre scale.

The age of sedimentation is determined at ca. 570 Ma by Pb/Pb and SHRIMP U/Pb dating (Linnemann et al. 2000, Buschmann et al. 2001). This age was obtained for an ash layer intercalated in the graywacke beds at Wüsteberg, near Kamenz.

The geochemical signatures of the sedimentary rocks of the Lausitz Group indicate deposition in an active-margin setting (Linnemann and Romer, 2002). The Nd-model ages range from ca. 1.5 Ga to ca.1.8 Ga (Linnemann and Romer, 2002). SHRIMP-U/Pb-data of detrital zircons give age intervals of ca. 570-800 Ma, ca. 1.9-2.2 Ga and 3.0-3.4 Ga (Linnemann et al., in prep.). These age groups and the Nd-model ages are typical features that suggest a highly probable West African provenance.

Stop 2.3:

Monumentenberg, 500 m E of the village of Groß-Radisch

Tremadocian conglomerates, quartzites (Dubrau quartzite) and silty shales of the Lausitz Anticline.

The area of the Hohe Dubau constitutes the type locality of the Cadomian unconformity of Saxo-Thuringia. Tremadoc conglomerates, quartzites, and silty shales are overlying tectonically deformed Cadomian greywackes. The succession is poorly exposed. Nevertheless, the Hohe Dubrau area represents the one and only surface outcrop of Saxo-Thuringia with a definite angular unconformity between the Cadomian basement and the superimposed Lower Palaeozoic sedimentary rocks. Therefore, the Monumentenberg hill in the area of the Hohe Dubrau, near Groß-Radisch, was suggested as type locality of the Cadomian unconformity in Saxo-Thuringia by Linnemann and Buschmann (1995).

The Tremadoc succession is divided into three units (from base to top):

- conglomerates, only consisting of stable components (quartz- and tourmalinised hornfelses);
- intratidal facies with Skolithos- and Cruziana-type trace fossil community and inarticulate brachiopods (Westonisca arachne), mud cracks and, very rarely, HCS;
- storm-dominated shelf facies with HCS;

Only one specimen of Cruziana ”dispar” has so far been described by Schwarzbach (1934). Unfortunately, this single slab has disappeared. Some new specimens of Cruziana sp. were discovered by R. Winkler, M. Röthel and U. Linnemann (Museum of Mineralogy and Geology of Dresden) in July 1997.

Stop 2.4:

Water-filled abandoned quarry of Kunnersdorf, ca. 10 km NW of Görlitz; north bordered by the Kunnersdorf rubbish dump

Early Cambrian (upper Marianian) carbonates and claystone/siltstone of the Charlottenhof Formation, Ludwigsdorf Member (Görlitz Syncline).

In the quarry of Kunnersdorf limestones and red shales of Early Cambrian age are exposed. A large part of the quarry is waterfilled. A short visit to the outcrop is included to give an impression of typical peri-Gondwanan Cambrian rocks that are involved in the Variscan structures of the Central European Variscides. The Cambrian of the Görlitz Syncline is interpreted as representing large olistoliths in a Lower Carboniferous wild flysch matrix. The Görlitz Syncline is the neighbouring structural unit at the northern flank of the Lausitz Anticline.

The sedimentary rocks of the outcrop belong to the Ludwigsdorf Member of the Charlottenhof Formation. A special feature is the so-called “Zebra”-limestone. The biostratigraphic age of the sedimentary succession is determined as Higher

Lower Cambrian. The environment is interpreted as a shallow marine calcimicrobial mudmound sequence (Elicki, 1997, 2000).

Stop 2.5:

Cliffs in the forest near the railway station of Weesenstein, ca. 1 km S of the village of Weesenstein (200 m E of the station)

Late Neoproterozoic pebbly mudstones and diamictites of the Weesenstein Group (Elbe Zone).

The Elbe zone is the neighbouring structural element at the southern flank of the Lausitz Anticline and is interpreted as a mega-shear zone established at ca. 330 Ma during Variscan orogenic processes. This structural element contains several slivers of rock units with distinctly different geological histories. One of them is the Weesenstein Group. The maximum age of the deposition, ca. 570 Ma, is given by SHRIMP-U/Pb data from detrital zircon (Linnemann et al., subm.). The northern part of the Weesenstein Group is intruded by the Dohna Granodiorite, which is dated at c. 540 Ma (Linnemann et al., 2000). This age represents the minimum age of sedimentation of the Weesenstein Group. The main lithologies of the sedimentary unit are diamictites, graywackes, and shales. The rock complex is overprinted under greenschist facies conditions and, in part, extremly sheared at around 330 Ma. Granitoid pebbles from the diamictites gave Pb/Pb and SHRIMP-U/Pb ages of ca. 570 Ma (Linnemann et al., 2000, Linnemann et al., in prep.). Because of the geochronological data, the Weesenstein Group is interpreted as being part of the Cadomian basement. The geochemical “fingerprint“ of the sedimentary rocks imply an active margin setting. The Nd-model age is around 1.8-2.0 Ga (Linnemann and Romer, 2002). The sedimentary environment of the diamictites and the related sedimentary rocks are interpreted as being glaciomarine (Linnemann and Romer, 2002).

DAY 3

(Travel from Dresden to Prague, View of Prague, View of outcrops in the Barrandian Syncline, Travel to Plzen)

Stop 3.1:

Quarries at Zábì hlice, near Praha-Zbraslav

Quarries on the left bank of the river Vltava, 2 km S of Praha–Zbraslav, expose a thick sequence of Neoproterozoic rocks of the uppermost part of the Kralupy–Zbraslav Group, the Davle Formation, interpreted now as a pre-Cadomian volcanic arc complex. The following description is according to Chlupáè (1993), although slightly modified.

In the large, active quarry, and mainly in its southern vicinity, the Davle Formation is developed as layers and thick banks of grey-green volcano-sedimentary tuffaceous rocks, alternating with markedly coarse-grained volcaniclastics – agglomerates and breccias. Fragments of lighter intermediate to acidic volcanics of andesite, dacite and rhyolite composition (originally bombs and angular lapilli) are accumulated in grey-green tuffaceous groundmass. Layers with a larger amount of sedimentary material are obviously thinner-bedded and darker in colour.

These rocks are products of explosive, mostly submarine volcanic activity, which produced large amounts of pyroclastics, often dominating over the extrusives proper. The volcanics are intermediate to acidic, calc-alkaline types differing markedly from those of the Kralupy–Zbraslav Group in the NW flank of the Barrandian syncline.

All Proterozoic rocks are deformed. They are gently folded, the folds showing large wavelengths and amplitudes (up to km) and cut by many faults and fissures, mostly striking NW-SE. Anchimetamorphism under conditions of a prehnite-pumpellyte zone, and marked autometamorphism of volcanic rocks, are characteristic. Numerous secondary veins are mineralised with quartz, carbonates and uncommon axinite. The whole sequence is dipping towards the SE, and our further stops will be in younger parts of the sequence.

Behind the office building north of the active quarry, a thick sill of altered andesite is exposed. This rock, composed of albitic plagioclase, quartz, augite, chlorites, leucoxene, calcite and accessories, was taken to be an integrate part of the Davle Formation. The preliminary zircon U-Pb study of this rock, however, supplied a much younger Late Devonian intrusive age (W. Dörr, personal communication).

Stop 3.2:

Outcrops in the Vltava Valley, between Strnady and Vrané

Outcrops in the lower part of the Neoproterozoic Štìchovice Group (Cadomian flysch) on the roadside between Strnady and Vrané, especially near the bus station (description according to Chlupáè, 1993, slightly modified).

The dominant rock types are dark-grey shales (consolidated claystones and siltstones), with subordinate pale-grey to grey-green laminae, and interbeds of siltstones and greywackes. The sediments are interpreted as distal turbidites deposited in a rather deep sedimentary basin. Rocks are markedly affected by post-Cadomian deformation, exhibiting both brittle (fissures of different strike) and ductile (local schistosity overprinting the bedding) characteristics. This so-called "Jílové schistosity", most probably of Variscan origin, strikes usually NNE – SSW, steeply dipping to ESE.

Just above the bus station a distinct, about 2 – 3-m-thick interval of shales dipping SE exhibits typical slump structures: complex, small-scale, and discontinuous, asymmetrical, and even recumbent folds, lenses and small tongues, all well marked by colour contrast between dark shales and lighter coarser greywacke and siltstone laminae. Slump structures pass locally into convolute structures. Submarine slides could have been triggered by earthquake shocks within the mobile basin floor.

On the opposite, right bank of the river Vltava, magnificent outcrops expose the profile of the Štìchovice Group. The thick sequence of alternating siltstones, shales and greywackes shows a small- and even large-scale cyclicity, typical of the flysch deposits. The structure is monoclinal with a moderate dip towards the SE.

The underlying Davle Formation (see Stop 3.1) occurs some 400 m to the W of the present locality. Above the car-repair service there is exposed the terminating member of the Davle Formation - the Leèice Shale. The Leèice Shale here forms an about 60-m-thick layer of the typical black shale, with a higher content of organic carbon (but less than 1%) which causes its black colour. The monotonous development without coarser greywacke interbeds and without coarser effusive material is characteristic (volcanic material, however, is present as fine tuffaceous admixture). Rocks are commonly silicified and may laterally pass into dark silicites (cherts); disseminated or even clustered pyrite is common. The geochemistry can be characterised by increased contents of Zn, Cu, Ni, Mo, V and U, which are typical of anoxic environments (metallic components occur mostly as sulfides). The Leèice Shale is, therefore, interpreted as sediment of anoxic, low energy, and a rather deep marine environment. Organic carbon evidently derives from abundant phytoplankton (algae); recognizable globular microfossils belong mostly to Acritarcha (Bavlinella). Weathering of pyrite resulted in the production of sulphuric acid, which negatively influenced the vegetation.

Stop 3.3:

The Jezírko quarry at Dobøíš

The Jezírko quarry is situated at the southern periphery of the town of Dobøíš, 200 m W of highway 4, going from Praha to Pøíbram. It is the type locality of the Dobøíš conglomerate within the Neoproterozoic Štìchovice Group.

The dominant rock-type of the exposed upper part of the Štìchovice Group is flysch-like sediments, distinguished by the alternation of grey siltstones, greywackes and shales, with typical graded bedding and small-scale cyclicity (usually tens of cm). A 9- to 14-m-thick disorganised conglomerate is embedded in the above-mentioned sequence, well exposed, particularly on the western face of the quarry. They are typical petromictic conglomerates with unsorted boulders of various size (1 to 110 cm in diameter), mostly well rounded, irregularly distributed in greywacke groundmass. The boulders consist of about 60% fine- to coarse-grained greywackes (containing clasts of quartzite and cherts) and of about 25% acidic volcanics (rhyolites, trachytes) and volcaniclastic rocks (tuffs, tuffites). Less common are siltstones and shales (about 5%), intermediate and basic extrusive rocks, black cherts and rather rare granitoids. No boulders of the Moldanubian-type high-grade metamorphic rocks occur (according to Clupáè, 1993, slightly modified)

The Dobøíš conglomerate is a typical intraformational (not basal) conglomerate, constituting tongues and lens-like bodies within the middle and upper parts of the Štìchovice Group. According to Röhlich (1964) the conglomerate boulders were first rounded by river transport and then deposited in a near-shore marine environment; they were later redeposited by mudflows and fluxoturbidites, filling the channel of a submarine fan.

Rocks exposed in the quarry are monoclinally dipping westwards (40 – 60°); slump structures (irregular folds) are observable in beds closely under- and overlying the conglomerate. Sedimentary structures – flute casts preserved mostly on lower bedding planes of greywacke layers in the sequence underlying the conglomerates -- indicate NE–SW current direction. The source region of conglomerates, situated probably SE of the locality, largely consists of Neoproterozoic rocks of the Kralupy – Zbraslav Group, namely of its presumably younger member – the Davle Formation. Some of the pebbles show deformation which predates erosion and deposition (Zulauf, 1997)

Dörr et al. (2002) published radiometric U-Pb zircon ages of two boulders of acidic volcanics from this locality. The first one is a rhyolite containing small phenocrysts of quartz and feldspar in a fine-grained matrix. The major element composition is: SiO2 = 72.8%, Al2O3 = 14.6%, CaO = 0.62%, Na2O = 5.1% and K2O = 2.7%. Pyroxene and chlorite are rare.The second one is a crystal tuff of rhyolitic major element composition: SiO2 = 74.3%, Al2O3 = 12.9%, CaO = 0.49%, Na2O = 2.8% and K2O = 5.6%. Lapilli, phenocrysts of quartz, feldspar and hornblende are embedded in a fine-grained matrix. The rhyolite and crystal tuff supplies ages of 585 ±7 Ma and 568 ±3 Ma, respectively. These values are interpreted as extrusion ages of the Kralupy–Zbraslav Group volcanics.

According to the evolutionary model by Dörr et al. (2002), the Kralupy – Zbraslav Group may represent a back-arc volcano-sedimentary complex at the northern margin of the Late Proterozoic Gondwana. The Davle Formation then demonstrates the K-poor magmatism associated with the corresponding island arc. The following accretion, uplift and erosion of volcanic island arc (expressed in the proper Cadomian orogeny) are thus documented by the Dobøíš' conglomerate origin. The youngest sequence – the Štìchovice Group – is then interpreted as the Cadomian flysch.

Stop 3.4:

Outcrops of the Èertova skála rock

Rocky outcrops of Èertova skála on the left bank of the Berounka river, 8 km SW of Køivoklát, supply one of the most instructive occurrences of the Neoproterozoic Kralupy–Zbraslav Group's volcanic rocks. The description follows Chlupáè (1993) with slight modification.

The roadside outcrops and cuttings expose basaltic-type basic rocks known in the literature as "spilites". These are typical pillow-lavas showing globular and lenticular "pillows" of more than 1 m in diameter. Their characteristic structure originated due to rapid cooling of the flowing lava at contact with seawater during extrusion. In cross-section, the individual "pillows" show typical concentric zoning: a fine-grained hypocristalline and rather thin marginal zone, with occasional amygdaloid structures, and an internal part marked by coarser grain-size with intersertal and intergranular texture, enriched with Na2O (cooled more slowly; crystals well developed). The space among pillows was filled with volcanic glass, later palagonised and chloritised. The primary basaltic rocks were affected by autometamorphic (spilitisation), hydrothermal and metamorphic processes: basic plagioclases were replaced by the more acidic ones (oligoclase, albite), and augite, together with other dark minerals, were at least partially replaced by chlorite and/or other metamorphic minerals. The slight regional metamorphism linked with the Cadomian orogeny is documented by the prehnite-pumpellyite zone grading into the chlorite zone towards the NW. All Proterozoic rocks were twice deformed: first in the Cadomian, and later, with lesser intensity, in the Variscan cycle. The effects of tectonics and metamorphism are more intense than at the SE flank of the Barrandian syncline at Vrané.

The spilites of this locality belong to the main volcanic belt of the NW flank of the Barrandian syncline. This is distinguishable in metabasalts of the tholeiitic type, characteristic of oceanic magmatism. In the model by Dörr et al. (2002), these occurrences correspond to peri-Gondwanan back-arc basin geotectonic settings.

Stop 3.5:

Proterozoic–Middle Cambrian angular unconformity N of Týøovice

About 600 m upstream from Stop 3.4, a roadside exposure shows the angular unconformity between the Proterozoic shales of the Kralupy–Zbraslav Group and the transgressive Middle Cambrian strata.

On this outcrop, grey silty Proterozoic shales, strongly tectonised and phyllitised and dipping strongly northwards (on the right side of the outcrop), are sharply overlain by gently SE dipping, markedly less-tectonically-affected Middle Cambrian shales (with several beds of greywacke and polymictic conglomerate at the base). The Middle Cambrian age of overlying beds is constrained by findings of trilobite Hydrocephalus careens (Barr.). A marked difference between the strongly deformed and even metamorphosed Proterozoic, and the less tectonised and non-metamorphosed Middle Cambrian, documents the effects of the Cadomian orogeny, which acted here prior to the Middle Cambrian (Chlupáè, 1993).

Stop 3.6:

Exposures on the right bank of the river Berounka, N of Skryje

One of the most famous paleontological localities in the Middle Cambrian of Skryje is situated on the hillside facing the bridge, across the river Berounka, near the settlement of Luh. It is the place where many of the large paradoxidid trilobites housed in many of the world's collections were found.

The gently eastward-dipping Skryje Shale, cropping out in natural as well as artificial exposures dug by collectors, is developed as grey to grey-green richly fossiliferous silty shales. The principal trilobite species, whose fragments occur in all larger rocks fragments, is the large paradoxidid trilobite Hydrocephalus careens (Barr.), which may be found even as almost complete exoskeletons. The list of less abundant trilobites and other fossil species from this locality can be found in Chlupáè (1993).

On the left side of the road from Luh to Skryje, about 300 m NW of the paleontological locality, there are instructive outcrops in basal Middle Cambrian clastic deposits. In the lower part of the exposure (before the bend of the road) is the Mileè Conglomerate, which transgressively overlies the Proterozoic rocks of the Kralupy–Zbraslav Group below the road (contact not exposed). The quartzose conglomerates are pale-grey to yellow, monomictic, medium-grained with locally very thin claystone intercalations. The exposed thickness is about 5 m, the total thickness is 10 – 11 m.

Above thick banks of conglomerates, markedly thinner bedded sandstones with thin clayey interbeds occur, passing upwards into thicker beds of brownish coloured greywackes. These so called "Orthis Sandstones" exhibit larger amounts of unstable components (feldspars, etc.) and common brachiopods preserved as internal moulds. The orthid Pompeckium kuthani (Pomp.) is the predominant species.

The uppermost rock exposed in this outcrop belongs to the next lithostratigraphic unit – the Conglomerate. It is a typical petromictic and less sorted conglomerate with pebbles of very diverse rocks: Proterozoic shales, greywackes, dark silicites (cherts), spilitic metabasalts, Cambrian sediments (even large blocks of shales) and quartz. The rounding of the pebbles is fair in Proterozoic rocks, which may point to redeposited fluvial material mixed with products of submarine erosion and sedimented as mudflow deposit. The lower limit of the Týøovice Conglomerate is here expressively sharp, and connected with erosion of the underlying "Orthis Sandstone".

After Kukal (1971) the exposed sequence illustrates the transgressive Middle Cambrian deposits, indicating a successive and stepwise deepening of the basin. The Mileè Conglomerate represents marine beach sediments; the "Orthis Sandstone" points to a somewhat deeper environment (possibly below wave base). The Týøovice Conglomerate may be interpreted as flexoturbidites deposited in a rapidly subsiding basin at greater depth and under conditions of a rapid erosion than the source areas. The overlying Skryje Shale is a typical basinal deposit.

DAY 4

(Western part of the Tepla-Barrandian unit, Travel to Brno, Visit of Brno)

Stop 4.1:

Open quarry at Šibeni¹ní v., at the southeastern margin of Stod.

Brittle deformation and basic dikes in Cambrian Stod pluton.

The northeastern part of the quarry of Šibeni¹ní shows biotite granite of the Stod pluton that is locally strongly decomposed and weathered. Most parts of the weathered granite have been exploited as building material. The more or less intact biotite granite consists of quartz, plagioclase, K-feldspar, biotite (partly altered to chlorite), and accessories (apatite and zircon). There are also microscopic xenoliths consisting of strongly foliated country rock (metagreywacke). Overgrowth of magmatic biotite on the xenoliths postdates the stretching of quartz, the latter occurring as lenses within the metagreywacke material of the xenoliths.

There is a large number of deformation stages in the biotite granite, ranging from brittle-ductile to brittle. We are not able to resolve the complete deformation history by taking into account the observed cross-cutting relationships. The following sequence has been found: (1) early steep, normal and strike-slip faults, (2) low-angle thrust faults, and (3) late steep, normal faults. Similar to the normal faults, the strike-slip and reverse faults are themselves polyphase.

The strike-slip faults include: (1) N-S directed sinistral, (2) E-W directed dextral, and (3) NE-SW directed dextral types, the latter being related to the emplacement of lamprophyre dikes (spessartite) that show the same direction of strike as the dextral strike-slip faults (NE-SW). The quartz fabrics in the granite adjacent to the dike suggest shearing in the brittle ductile regime. There are fractures, subgrains (oriented parallel to the prism planes), and evidence for strain-induced grain boundary migration, including incipient bulging recrystallization. At the direct contact with the basic dike, plagioclase of the granite has been partly replaced by actinolite and sericite. Biotite has been transformed to chlorite.

As the brittle-ductile quartz fabrics are strongly restricted to the direct contacts of the lamprophyres, a synkinematic intrusion of the dike is suggested. The heat of the basic melt progressed into the adjacent granite, supporting thermally-activated deformation mechanisms, such as strain-induced grain boundary migration and bulging recrystallization. The lamprophyre itself shows a distinct magmatic foliation by shape-preferred orientation of hornblende phenocrysts and unhomogeneously-distributed opaque phases. Most of the hornblende phenocrysts occur as pseudomorphs that have been changed to chlorite. Microscopic extensional veins in the lamprophyre are mineralized with chlorite and laumontite and are cut by late shear planes. As the formation of laumontite is generally restricted to T < ca. 250 °C (Liou et al., 1987), the formation of the veins as well as the late strike-slip movements must have occurred at T< ca. 250 °C.

The data presented above suggests that the spessartite dike intruded into an existing brittle strike-slip fault, which was active until the dike had solidified and cooled down to ambient temperatures. An upper age limit for the origin of the spessartite dike is given by the age of the Stod pluton. A concordant U-Pb zircon age of 522 ±2 Ma has been determined for the T+šovice granite, located south of the present locality (Dörr et al., 1997). This age is compatible with an ^{39}Ar-^{40}Ar biotite age (518 ±5 Ma, Kreuzer et al., 1990), the latter suggesting granitic melt emplacement at supracrustal levels (ca. 7 km depth, Zulauf, 1997) and rapid cooling to the K-Ar blocking temperature of biotite still during the Cambrian. A lower, but more speculative, age limit for the spessartite emplacement is given by the following observation. Lamphrophyre dikes of the Barrandian syncline, which are similar to those of the Stod and Domažlice area, cut through the Mid-Cambrian sediments, but are themselves truncated by Ordovician strata (Pato¹ka et al., 1994).

The younger SE-directed thrusts of the outcrop probably reflect Variscan (Late Devonian) shortening. Similar thrust planes are described in the outcrop of the Radbuza valley, between Holýšov and Ohu¹ov.

Stop 4.2:

Railway cut north of Stéelice

The outcrop shows the contact between Stod granite and metagreywacke, the latter being changed to hornfels. The granitoid consists of quartz, plagioclase, K-feldspar, muscovite, and biotite. The metagreywacke (hornfels) is made of quartz, plagioclase, white mica, biotite, and prismatic sillimanite. There is evidence for at least two pre-plutonic deformation stages in the wall rock. Cadomian D_1 is indicated by a first generation of quartz veins that have been folded. Only at the direct contact to the pluton, the F_2 fold axes and S planes are subvertical, suggesting that the rising melt contributed to changing the attitude of the Cadomian structures. The contact metamorphic heating led to the striking static equilibration of almost all minerals (e.g. 120° triple junctions in quartz) and to the growth of ‘oblique’ biotite and muscovite. K-Ar dating of muscovite from the hornfels yields 483 ±10 Ma. The intrusion depth of the Stod pluton has been determined at ca. 7 km, using phengite barometry and petrogenetic considerations of the country rock (e.g. andalusite has been found in adjacent outcrops).

Stop 4.3:

Outcrop in the Radbuza valley, between Holýšov and Ohu¹ov.

Cadomian deformation and Devonian brittle-ductile top-to-the-ESE displacement along the Holýšov thrust (chlorite-sericite zone).

The map-scale structural inventory within the Upper Proterozoic rocks SW of Stod is characterized by ESE-vergent folds and related thrusts, that show top-to-the-ESE displacement. This type of folds and thrusts (Holýšov thrust) affect phyllites, metagreywackes and quartzites of the present outcrop. They result from a third (Devonian) deformation stage (D_3). Mineral phases observed in the above metasediments include quartz, sericite, chlorite, biotite, plagioclase, K-feldspar and opaque phases.

Relics of a first (Cadomian) deformation stage (D_1) are quartz veins and S_1 fabrics, the latter occurring between the S_2 planes of competent metagreywackes (only visible in thin sections). The S_1 planes are characterized by oriented sericite and a weak shape-preferred orientation of quartz and feldspar grains.

Cadomian D_2 deformation led to the dominant, tight foliation (S_2) that is characterized by the shape-preferred orientation of sericite and chlorite and by local, but strong, enrichment of opaque phases. At some places quartz veins have formed parallel to S_2. F_2 isoclinal folding, on the other hand, affects quartz veins that opened parallel to S_1. There is also evidence of non-coaxial deformation during D_2 (e.g. asymmetric pressure shadows of recrystallized quartz and mica behind plagioclase porphyroclasts). However, due to the Variscan D_3 deformation, which in most cases influenced the older fabrics and erased the D_2 stretching lineation, the sense of D_2 shearing determined is not very reliable.

Post-D_2 static growth of biotite and white mica, as well as the static recrystallization of quartz, is related to the contact heating of the Stod pluton that is only 4 km apart from the present outcrop (Figure 11).

Late Devonian F_3 folding of Cadomian S_2 foliation led to ESE-vergent, overturned to recumbent folds that show thickened hinges and thinned limbs. The associated axial-plane cleavage (S_3) is a widely spaced fracture or crenulation cleavage, depending on the mechanical properties of the rock.

The top-to-the-ENE mylonites are some cm wide and strongly foliated. The S_3 foliation of these mylonites results from shape-preferred orientation of synkinematic sericite, chlorite, stretched quartz grains and an unhomogeneous distribution of opaque phases. D_3-related deformation mechanisms of quartz include incipient bulging recrystallization, pressure solution and fracturing, all of which suggest a brittle-ductile regime, compared to the mechanical behavior of quartz. The distribution of quartz-c-axes suggests dominant <a> slip along the basal planes (Zulauf, 2001). The metamorphic conditions during D_3 were retrograde with respect to the Cadomian and Late Cadomian imprints. Biotite has been bent and chloritized. These metamorphic reactions, together with the quartz deformation fabrics, suggest lowermost greenschist facies conditions during D_3 deformation. D_3 top-to-the-ESE shear-sense indicators include mica fish, asymmetric pressure shadows of mica and quartz behind feldspar porphyroclasts (σ clasts), SC and shear-band fabrics (Zulauf, 1997).

The Si-content of the sericite of the D_3 mylonites ranges from 3.25 to 3.38. As the critical paragenesis for phengite barometry is present, these values suggest a metamorphic pressure between 4 and 5 kbar at T = 300 - 350 °C for the D_3 thrusting event.

K-Ar dating of synkinematic sericite, separated from the D_3 mylonites, yield 371 ±8 Ma (Wemmer and Ahrendt, unpublished data). As the sericite probably grew below the blocking temperature for the K-Ar isotopic system of white mica, this age is interpreted as the formation age of the syn-D_3 sericite, and thus as the age of the D_3 thrusting event. The Cadomian white micas of the wall rock of the D_3 mylonites yield a K-Ar age of 400 ±9 Ma (Wemmer and Ahrendt, unpublished data). This age is interpreted as a mixing age, meaning that the Cadomian age signature has been slightly influenced by the Variscan thermal imprints. Due to the low temperature and low D_3 strain, the age of the Cadomian sericite has not been completely reset to Devonian ages.

The Late Devonian radiometric age for the D_3 shortening event in the Stod-Holýšov area is compatible with the fact that the sedimentation in the Barrandian basin changed at the Eifelian/Givetian boundary from limy to siliciclastic, and finally ceased close to the Middle/Upper Devonian boundary (Chlupáè, 1993).

Stop 4.4:

Open quarry of NÆmèicky Les, SE of Mraènice.

The outcrop shows Mraènice trondhjemite that is cut by N-S trending pegmatite veins. U-Pb zircon dating of this trondhjemite yields an upper and lower intercept at 2017 +181/-168 and 523 +4/-5 Ma, respectively (Zulauf et al., 1997). The lower intercept is interpreted as the emplacement age. The upper intercept should result from inherited zircons of the pre-Cadomian basement, which is typical for the Armorican Terrane Assemblage (e.g. Icartian gneiss of northern Brittany). The intrusion depth of the Mra¹nice trondhjemite has been constrained at ca. 7 km using phengite barometry and petrogenetic considerations for the contact aureole (Zulauf et al., 1997).

Major minerals of the trondhjemite are plagioclase, quartz, muscovite and biotite. The strain geometry of quartz is of the constrictional type, with the long axis of the finite strain ellipsoid, *X*, trending ENE-WSW. Internal crystal plastic strain in quartz is indicated by shape-preferred orientation and boudinage of rutile needles (stretch = ca. 1.25). The quartz fabrics are further characterized by high-temperature (T > ca. 600 °C) chessboard patterns which result from subrain boundaries aligned parallel to the prism and basal planes. As these chessboard patterns do not occur in the gneiss and micaschist of the country rock, they are explained by being the result of subsolidus constrictional deformation during the initial cooling phase of the synkinematic pluton. The melt temperature of the trondhjemite has been determined at ca. 750° C. Thermal modeling suggests that the 500° C isotherm was reached after a cooling period of 350,000 years (Zulauf, 1997).

Stop 4.5:

Quarry of Hvízdalka at the northeastern margin of Domažlice.

Cooling history, strain and strain rate of a synkinematic trondhjemitic dike within a Cambrian strike-slip fault (staurolite/kyanite zone).

The outcrop shows highly-sheared, retrograded paragneiss (phyllonite) that has been intruded by Cambrian synkinematic trondhjemitic dikes. Results of detailed investigations about the kinematics, crystallization/deformation relationship, wall rock and melt temperature, and cooling history have been described by Zulauf and Helferich (1997). The age of the dike should be close to that of the nearby Mra¹nice trondhjemite (523 +4/-5 Ma, see Stop 4.4). This is supported by the following facts: i) the similarity in mineralogy and geochemistry between the Mra¹nice pluton and the trondhjemitic dikes (Vejnar, 1984), ii) the trondhjemites are cut by late Cambrian to early Ordovician pegmatites, iii) in the quarry U baldovske Kaple (N of Domažlice), the trondhjemitic dikes are affected by Devonian thrusts and folds (Zulauf, 1997). Rb-Sr whole rock and K-Ar dating of white mica of the dike yield ages between 362 and 371 Ma (Zulauf et al., 2002a). These ages are comparable with those of the adjacent metasediments of the Domažlice area and thus are interpreted as cooling ages. They suggest that the K-Ar and Rb-Sr isotopic systems were still open during the Variscan cycle. This is compatible with greenschist facies conditions obtained for the Devonian imprints.

Far from the dike the country rocks are not affected by contact metamorphism. The phyllonites result from pervasive shearing along east-northeast trending transcurrent shear zones that cut the entire quarry under retrograde metamorphic conditions. They display a pronounced stretching lineation (pressure shadows behind garnet, elongated grains of quartz and feldspar, fishes of mica and chlorite) that plunges 20 to 30° east-northeast, mostly on steeply north-northwest dipping planes. Macroscopic shear sense indicators like S-C and shear band fabrics indicate a dextral displacement that was also confirmed under the microscope using drag structures in micas as well as asymmetric pressure shadows of chlorite behind rigid porphyroclasts of garnet, sillimanite, muscovite and biotite.

Within the sheared phyllonite the primary minerals of the paragneiss are strongly altered. Garnet is replaced by biotite, and sometimes both minerals are altered into green chlorite. Plagioclase, sillimanite and staurolite are sericitized. In high-strain domains, garnet and staurolite display pervasive fracturing. Micas are also broken but usually rather show bending and kinking. Deformation features in quartz include subgrain boundaries, aligned parallel to the prism planes, and grain boundary migration, marked by local dynamic recrystallization. Plagioclase is deformed by fracturing and cataclasis.

The trondhjemitic melt emplaced at T = 750 °C into the active low-temperature (ca. 350 °C) east-northeast trending dextral transcurrent shear zone. Thermal modeling indicates that the rheologically critical melt fraction and the solidus of the dike were achieved after 1 and 3 days of cooling, respectively. The major part of the shearing occurred within 8 days after the melt emplaced (Zulauf and Helferich, 1997).

The zonation of the dike, in strain magnitude, mineralogy and geochemistry, can be explained by the laterally varying rheology (from margin to centre) during cooling and shearing. The deformation was volume-constant, and the strain data plot in the apparent constrictional field, suggesting a transtensional tectonic setting during the Cambrian. The unusually high value of the calculated longitudinal strain rate (> 2.8 * 10^{-6} s^{-1}; equivalent to a displacement rate of > 2 cm h^{-1}) is probably related to the intruding melt that 'lubricated' the shear zone and thus enhanced its displacement velocity.

Stop 4.6:

Cliffs at the top of Hrdek, SW of jezd.

The Cadomian basement of the Domažlice crystalline complex (DCC) is exposed at the Hr?dek hill in the form of paragneiss and sheared Late Cambrian/Early Ordovician pegmatite, both of which are situated in the staurolite + kyanite zone. The outcrop is further located within the contact aureole of the Lower Carboniferous Babylon granite. The main foliation of the paragneiss dips steeply (60-80°) ESE. Parts of the pegmatites intruded subparallel to this foliation and are sheared along the foliation planes. The stretching/mineral lineation is almost horizontal, trending NE-SW.

Paragneisses consist of quartz, plagioclase, muscovite, biotite, garnet, staurolite, kyanite, and sillimanite. Quartz is characterized by static fabrics (120° triple point patterns) which might result from contact metamorphic heating of the Babylon pluton. Cadomian Barrovian-type minerals (garnet, staurolite, kyanite) are deformed by fracturing and bending. Kyanite shows margins consisting of sericite. Silliminate, on the other hand, is hardly deformed. It appears along the foliation planes and is included in quartz and muscovite.

Quartz of the pegmatite shows relics of chessboard patterns that result from two sets of subgrains, one with boundaries parallel to the prism planes, the other with boundaries parallel to the basal planes. The latter suggest c-slip in quartz at T > ca. 600° C (Mainprice et al., 1986), which could be explained by synkinematic emplacement of the pegmatite. T > 600° C is further consistent with the fact that the plagioclase of the pegmatite is partly recrystallized. There are some asymmetric structures, such as asymmetric pressure shadows of biotite behind garnet, which, however, do not indicate an unequivocal sense of shear.

U-Pb dating of monazite, separated from paragneiss, yields ages at ca. 490 Ma (Timmermann, pers. commun.) which is close to the age of the DCC pegmatites (Glodny et al., 1998). K-Ar dating of muscovite and biotite yield 350 ±7 and 306 ±6 Ma (Zulauf et al., 2002). The K-Ar ages might have been influenced by the intrusion of the nearby Babylon pluton. The distance from Hr«dek hill to its northern margin is only ca. 1 km. White mica of gneisses from the DCC, situated remote from the Babylon pluton, yield Ar-Ar and K-Ar ages at ca. 362 Ma (Dallmeyer and Urban, 1998, Zulauf et al., 2002).

DAY 5

Field trip to the Brunovistulian unit (with contributions by P. Hanžl)

Stop 5.1:

Cadomian island-arc-type crust of the Slavkov terrane: The Blansko granodiorite pluton

Cliffs and large fresh blocks of a mafic facies of the Blansko granodiorite pluton can be studied in a small valley at the eastern margin of Blansko, along the Blansko–Tìchov road (19 km NNE of the centre of Brno). Most of the exposed rocks represent medium-grained biotite-hornblende tonalites. Microdiorite enclaves can often be seen.

The rocks experienced slight alteration at greenschist facies conditions. Epidote is a common secondary mineral. Primary accessory minerals are zircon, apatite, sphene, allanite and magnetite. As most granitoids of the Slavkov terrane, the Blansko granodiorite has a particularly high magnetic susceptibility (Hrouda, 1980).

Geochemistry: The Blansko granodiorite is a normal-K, I-type granitoid with A/CNK ratios slightly below 1. Typical are low Nb (< 10 ppm) and low Th values (< 5 ppm). Chondrite-normalized REE patterns are steep with La/Lun ~10 (La ≈20 ppm) and show no significant Eu anomalies. $^{87}Sr/^{86}Sr$ initial ratios are very low (~0.704) and, together with εNd_i values of around 0, indicate an immature source (Finger et al., 2000b).

Geochronology: Fritz et al. (1996) reported Ar-Ar hornblende ages of ca. 590 Ma for one sample of the Blansko granodiorite. This age is considered to approximately date the formation of the pluton.

Further reading: Hanžl and Melichar (1997).

Stop 5.2:

Early Cadomian metavolcanic rocks of the Central Basic Belt: quarry at Opálenka

The abandoned quarry at the northern slope of the Opálenka Hill, 2 km E of the railway station in Kuøim (13 km NNW of the centre of Brno) exposes three types of metavolcanic rocks. Dominant are metabasalts, which probably represent former lava flows. Metarhyolites form layers and up to 10-m-thick dikes within the metabasalts. Additionally, lense-shaped bodies of metadolerites occur.

The metabasalts are aphanitic to fine-grained with an ophitic to intersertal or microglomerophyric texture. The metadolerites are similarly mafic, but with a coarser texture, containing mm-sized plagioclase and light-green amphiboles. The metarhyolite dikes are aphanitic to fine-grained rocks, sometimes with a porphyritic texture.

Greenschist facies metamorphism caused a significant alteration of the entire igneous rock assemblage of the quarry. This alteration includes the growth of actinolite, chlorite, epidote, sericite, and albite, and was most severe in the mafic rocks.

Geochemistry: Both metabasite types are olivine-normative and have trace-element compositions similar to MORB. The metadolerite may contain a certain cumulate component (low REE contents!). The metarhyolite displays a fractionated REE pattern with La/Lun of c. 3 (La ≈25 ppm) and a pronounced, negative Eu anomaly. The MORB-normalized trace-element patterns show negative Sr, P, and Ti anomalies, very probably as a result of plagioclase, apatite, and magnetite fractionation. Chemical and isotopic data (εNd_i: around +7) indicate that the metarhyolite represents a mantle-derived magma, which is cosanguinous with the surrounding MORB-type metabasites.

Geochronology: The metarhyolite was dated by means of the zircon evaporation method at 725 ± 15 Ma (Finger et al., 2000a). The metabasalts and metadolerites are considered to be of the same age and represent the oldest MORB-type metabasites currently known in Central Europe. The rocks are interpreted as having formed in an incipient arc or a back arc basin setting at the active northern Gondwana margin (see introduction).

Further reading: Leichmann (1996), Hanzl et al. (1999), Finger et al. (2000a)

Stop 5.3:

The Plutonic zone of the Central Basic Belt: the quarry at Želešice

The quarry at Želešice (9 km SSW of the centre of Brno) contains several different rock-types: Hornblendites and medium-grained gabbrodioritic rocks, variably sheared and retrogressed, belong to the plutonic subzone of the Central Basic Belt. The mafic rocks were intruded by medium-grained granitoids of the Thaya terrane and stocks and dykes of brown-red granite porphyries, which are probably genetically related to the granitoids. Fine-grained olivine-basalt dykes represent the youngest magmatic event.

Geochemistry: The older mafic rocks (hornblendites and metagabbros) have MORB-like compositions with low REE contents and flat- to slightly-LREE-depleted REE patterns. As opposed to this, other gabbros of the plutonic subzone of the Central Basic Belt show high LREE/HREE ratios, indicating that at least two different magmatic series are involved (Finger et al., 2000a). For the gabbros of Želešice a depleted mantle source is indicated by positive εNd_{600} Ma values in the range of + 5. The granite porphyries and granitoids have crustal isotopic signatures (εNd_i ~ -2 to -5). The youngest olivine-basalt dikes have mildly-enriched trace-element and REE patterns.

Geochronology: Nd model ages for the amphibolites and metagabbros would be compatible with an early Cadomian (~ 700 Ma) formation, coeval with the volcanic rocks of the Central Basic Belt. Granitoids and granite porphyries are presumably of the same age as the Thaya terrane granitoids (~ 580 Ma). For the olivine basalt dikes a Silurian age has been suggested, based on Ar-Ar data (Hanžl et al., 1999).

Further reading: Hanžl et al. (1999)

Stop 5.4:

A Cadomian high-K diorite from the Thaya terrane: the quarry at Dolní Kounice

In the active quarry between the villages of Moravské Bránice and Dolní Kounice, on the left bank of the Jihlava river (18 km SW of the centre of Brno), diorites (quartzdiorites, quartzmonzodiorites) of the Thaya terrane are exposed. Compared to the mafic plutons in the Slavkov terrane, these mafic rocks are isotopically and chemically more evolved. In the quarry, mixing phenomena between different magmas can be studied. The main type of diorite is medium-grained. It carries amphibole, plus variable amounts of biotite, as mafic constituents, and is typically ilmenite-bearing (resulting in a lower magnetic susceptibility compared to the Blansko granodiorite). Further accessory minerals are zircon, apatite, titanite and allanite.

Geochemistry: The diorites from Dolni Kounice are high-K I-type granitoids. They have enriched REE patterns (La/Lun ~ 8) and relatively high Sr, Ba, Rb, Zr, Nb and Th contents. ^{87}Sr/^{86}Sri isotope ratios are intermediate (~ 0.705-0.707), εNd_i values are negative (-2), indicating an enriched mantle source or a crustal contamination.

Geochronology: The main diorite was dated by Van Breemen et al. (1982) at 584 ±5 Ma (upper intersect zircon age). Fritz et al. (1996) published a hornblende Ar-Ar age of 599 ±1 Ma for the same diorite from another locality (Anenský Mlýn).

Further reading: Leichmann (1999).

Stop 5.5:

Cadomian, high-K, I-type granodiorite of the Thaya batholith: a quarry near Retz

In an abandoned quarry near Retz (ca. 10 km SW of Znojmo), on the southern slope of the Gollitsch hill, a Cadomian, medium-grained biotite-granodiorite can be studied. The rock shows a slight Variscan deformation of greenschist-facies grades involving the recrystallisation of quartz and the growth of secondary green biotite. Slightly metamorphosed granodiorites of this type are very abundant in the Thaya batholith and are termed "Hauptgranit" ("main granite") in the literature.

Geochemistry: The chemical composition of the rock is high-K, calc-alkaline. The A/CNK ratio is pivoting around 1.1, but it is probably partly increased due to metamorphic alteration. Little-deformed variants have A/CNK values between 1 and 1.1. Therefore, the granodiorite represents rather an I-type than an S-type magma. This interpretion is also supported by generally-high Sr contents. ^{87}Sr/^{86}Sri ratios of around 0.709 (Scharbert and Batik 1980) and negative εNd_i values of -4 to -7 (Finger et al., 2000b) suggest that old (meta)igneous crust served as magma source.

Geochronology: No precise ages are presently available for this rock. An Rb-Sr errorchron gave an age of 610 ± 54 Ma (Finger and Riegler, 1999). Other, subalkaline variants of the Hauptgranite with distinctly high Zr contents have been recently dated at 567 ± 5 Ma (SHRIMP zircon age, Friedl et al. 2004).

Further reading: Finger et al. (1989), Finger (1999)

Stop 5.6:

Overprinted Cadomian Basement close to the Moldanubian thrust: The Weitersfeld pencil-gneiss

The small abandoned quarry near the church of Weitersfeld (ca. 20 km WSW of Znojmo) provides an example of how strongly the western part of the Brunovistulian unit was overprinted during the Variscan orogeny. The grey, mylonitized granite displays a horizontal foliation with a striking NE-trending lineation. K-feldspar augen sometimes show primary Karlsbad twinning; the matrix consists of biotite, muscovite, quartz and plagioclase.

Geochemistry: The exposed pencil gneiss has the composition of a felsic high-K granite. $^{87}Sr/^{86}Sr_{600}$ Ma ratios are high (~ 0.713), εNd_{600} Ma values are strongly negative (-11). Generally, it can be stated that the deformed granitoids at the western margin of the Brunovistulian plate have the most evolved isotope composition of all Brunovistulian granitoids, and are apparently derived from very old cratonic crust (maturation of crust from east to west!).

Geochronology: An Ar-Ar muscovite age of 326 ±1 Ma (Dallmeyer et al., 1990) dates the cooling stage of the Variscan regional metamorphosis. Electron-microprobe-based monazite dating (Finger, unpubl.) revealed a relict population of ca. 600 Ma old monazites.

Further reading: Finger et al. (1989)

Stop 5.7:

Roof rocks of the Cadomian granitoids: The Fugnitz calcsilicate schists (quarry at Raisdorf, ca. 17 km NW of Eggenburg)

In some places the older roof of the Cadomian granitoids of the Thaya terrane is preserved. This comprises various micaschists (Libowitzky, 1989) as well as distinct, banded fine-grained calcsilicate schists, the sedimentary protoliths of which are considered Late-Proterozoic in age (Frasl, 1991). In the quarry of Raisdorf these rocks display a Variscan, amphibolite-facies metamorphic mineral paragenesis with diopside, hornblende, clinozoisite, quartz and plagioclase (strong inverse zoning with oligoclase cores and labradorite rims), additionally some K-feldspar, biotite, calcite and titanite. Aplitic and pegmatitic layers in the rocks are interpreted as being related to the Cadomian granitic plutonism. Frasl (1991) considered the calc-silicate rocks as having initially experienced Cadomian contact metamorphism.

Further reading: Frasl (1968), Bernroider (1989), Libowitzky (1989)

Stop 5.8:

The Bittesch gneiss: A deformed Cadomian granite with abundant Mesoproterozoic zircon relics (active quarry 1 km NW Harmansdorf, 6 km SW of Eggenburg)

The Bittesch gneiss is a felsic, biotite-muscovite augen-gneiss with granitic to granodioritic composition. It forms an elongated orthogneiss body immediately below the Moldanubian thrust, which accompanies the western margin of the Moravo-Silesian unit over more than 100 kilometres. Microscopic structures and textures display top-to-the-N thrusting.

Geochemistry: A characteristic geochemical feature of the Bittesch gneiss is its relatively high Sr content (~ 300 ppm) and low Rb/Sr ratio (~ 0.5), at a generally high SiO_2 content of 70-75 wt %. The rock is believed to represent a low-T, crustally-derived I-type granite magma (Finger and Sturm 1994). $^{87}Sr/^{86}Sr$ initial ratios are in the range of 0.712 - 0.714, the εNd_i values are strongly negative (-11 to -12).

Geochronology: Ar-Ar muscovite ages of ca. 329 Ma date the cooling of the rock after Variscan regional metamorphism (thrusting of the Moldanubian unit over the Brunovistulian plate). SHRIMP zircon dating has provided magmatic formation ages of 584 ±6 Ma and 578 ±7 Ma for two samples of Bittesch gneiss (Friedl et al., 2004). Furthermore, many inherited zircons with Mesoproterozoic and Early Palaeoproterozoic ages of c. 1.2 Ga, 1.5 Ga, 1.65-1.8 Ga have been found. This has been taken as evidence that the Brunovistulian terrane is derived from a Grenvillian cratonic province, and not from north Africa. A Late Precambrian position close to the Amazonian craton has been inferred (Friedl et al. 2000), comparable to the Avalonian terranes of North America and the United Kingdom.

Further reading: Finger et al. (1989), Friedl et al.

(2000, 2004)

DAY 6

(Departure in the morning for Vienna, visit of Vienna, and travel on to Florence)

References cited

Bankwitz, P. and Bankwitz, E., 1995. Proterozoikum/ Schwarzburger Antiklinorium. In: G. Seidel (Editor), Geologie von Thüringen. E. Schweitzerbart´sche Verlagsbuchhandlung, Stuttgart, pp. 46-77.

Bowes, D.R. and Aftalion, M., 1991. U-Pb isotopic evidence for early Ordovician and late Proterozoic units in the Mariánské Lázné Complex, Central European Hercynides. N. Jb. Miner. Mh., 1991: 315-326.

Bues, C., Dörr, W., Fiala, J., Vejnar, Z. and Zulauf, G., 2002. Emplacement depth and radiometric ages of Paleozoic plutons of the Neukirchen-KdynÆ massif: Differential uplift and exhumation of Cadomian basement due to Carboniferous orogenic collapse (Bohemian Massif). Tectonophysics, 352: 225-243.

Bula, Z., Jachowicz, M. and Pøichystal, A. 1997. Lower Palaeozoic deposits of the Brunovistulicum. Terra Nostra 97/11: 32-38.

Buschmann, B., 1995. Geotectonic facies analysis of the Rothstein Formation (Neoproterozoic, Saxothuringian Zone, Germany). Unpublished Ph.D. Thesis, Bergakademie Freiberg, 122 pp.

Buschmann, B., Linnemann, U., Schneider, J. and Süss, T., 1995. Die cadomische Entwicklung im Untergrund der Torgau-Doberluger Synklinale. Z. geol. Wiss., 23: 729-749.

Buschmann, B., Nasdala, L., Jonas, P., Linnemann, U. and Gehmlich, M., 2001. SHRIMP U-Pb dating of tuff-derived and detrital zircons from Cadomian marginal basin fragments (Neoproterozoic) in the northeastern Saxothuringian Zone (Germany). N. Jb. Geol. Paläont. Mh., 6: 321-342

Cháb, J., Suchý and Vejnar, Z., 1995. Metamorphic evolution. In: Dallmeyer, R.D., Franke, W. and Weber, K. (eds.). Pre-Permian Geology of Central and Eastern Europe, pp. 404-410; Springer-Verlag, Berlin, Heidelberg.

Cháb, J. and Žáèek, V., 1994. Metamorphism of the Teplá Crystalline Complex. KTB Report, 94-3. 33-37.

Chlupáè, I., 1993. Geology of the Barrandian. A Field Trip Guide, 163 pp.; Waldemar-Kramer, Frankfurt a.M.

Dallmeyer, R.D. and Urban, M., 1998. Variscan vs Cadomian tectonothermal activity in northwestern sectors of the Tepl -Barrandian zone, Czech Republic: constraints from 40Ar/39Ar ages. Geol. Rundsch., 87: 94-106.

DePaolo, D.J., 1981. Neodymium isotopes in the Colorado Front Range and crust-mantle evolution in the Proterozoic. Nature, 291: 193-197.

Dörr, W., Fiala, J., Vejnar, Z. and Zulauf, G., 1998. U-Pb zircon ages and structural development of metagranitoids of the Teplá crystalline complex - evidence for pervasive Cambrian plutonism within the Bohemian massif (Czech Republic). Geol. Rundsch., 87: 135-149.

Dörr, W., Zulauf, G., Fiala, J., Franke, W. and Vejnar, Z. 2002. Neoproterozoic to Early Cambrian history of an active plate margin in the Tepl« Barrandian unit – a correlation of U-Pb Isotopic-Dilution-TIMS ages (Bohemia, Czech Republic). Tectonophysics, 352: 65-85.

Dudek, A. 1980. The crystalline basement block of the Outer Carpathians in Moravia: Bruno-Vistulicum. Rozpravy Ceskoslovenské Akademie Vìd Øada matematických a pøirodních Vìd, 90/8: 3-85.

Dudek, A. 1995. Metamorphic evolution of the Moravo-Silesian basement. In Dallmeyer et al. (eds) Pre-Permian Geology of Central and Eastern Europe. Springer, Berlin, pp. 508-511.

Dudek, A. and Melkova, J. 1975. Radiometric age determination in the crystalline basement of the Carpathian Foredeep and of the Moravian Flysch. Vìstnik Ústøedního ústavu geologického, 50: 257-264.

Dvoøák, J. 1995. Stratigraphy of the Moravo-Silesian zone. In: Dallmeyer et al. (eds), Pre-Permian Geology of Central and Eastern Europe. Springer, Berlin, 477-489.

Elicki, O., 1997. Biostratigraphic data of the German Cambrian - present state of knowledge. Freib. For. Hft., C 466: 155-165.

Elicki, O., 2000. Die kambrische “Görlitz-Fauna”: Charakteristik und Bedeutung für die stratigraphische und paläogeographische Rekonstruktion Mitteleuropas. Z. geol. Wiss., 28: 11-32.

Elicki, O. and Debrenne, F., 1993. The Archaeocyatha of Germany. Freib. For. Hft., C 450: 3-40.

Fatka, O. and Gabriel, Z., 1991. Microbiota from siliceous stromatolitic rocks of the Barrandian Proterozoic (Bohemian Massif). Cas. Mineral. Geol., 36: 143-148..

Finger, F., Frasl, G., Dudek, A., Jelínek, E. and Thöni, M., 1995. Cadomian plutonism in the Moravo-Silesian basement. In: Dallmeyer et al. (eds.) Pre-Permian Geology of Central and Eastern Europe. Springer, Berlin, pp. 495-507.

Finger, F., Frasl, G., Höck, V. and Steyrer, H.P., 1989. The granitoids of the Moravian Zone of north-east Austria - Products of a Cadomian active continental margin? Precambrian Research 45: 235-245.

Finger, F., Hanžl, P., Pin, C., Von Quadt, A. and Steyrer, H.P., 2000. The Brunovistulian: Avalonian Precambrian sequence at the eastern end of the Central European Variscides? Geological Society of London, Special Publication, 179: 103-112.

Finger, F. and Pin, C., 1997. Arc-type crustal zoning in the Bruno-Vistulicum, Eastern Czech Republic: A trace of the late-Proterozoic Euro-Gondwana margin. Journal of the Czech Geological Society, 42: 53.

Finger, F. and Riegler, G., 1999. Der Thayabatholith und der kristalline Untergrund des Weinviertels. Arbeitstagung Geologische Bundesanstalt, 1999: 23-31.

Finger, F. and Steyrer, H.P., 1995. A tectonic model for the eastern Variscides: indications from a chemical study of amphibolites in the south-eastern Bohemian Massif. Geologica Carpathica, 46: 137-150.

Finger, F., Schitter, F., Riegler, G. and Krenn, E., 1999. The history of the Brunovistulian: Total-Pb monazite ages from the Metamorphic Complex. Geolines, 8: 21-23.

Finger, F., Tichomirowa, M., Pin, C. and Hanžl, P., 2000. Relics of an early-Panafrican metabasite-metarhyolite formation in the Brno Massif, Moravia, Czech Republic. International Journal of Earth Sciences, 89: 328-335.

Floyd, P.A., Winchester, J.A., Seston, R., Kryza, R. and Crowley, Q.G., 2000. Review of geochemical variation in Lower Palaeozoic metabasites from the NE Bohemian Massif: intracratonic rifting and plume-ridge interaction. Geological Society of London, Special Publication, 179: 155-174.

Franke, W. and Engel, W. 1982. Variscan Sedimentary Basins on the Continent and relations with south-west England. Proceedings of the Ussher Society, 5: 259-269.

Franke, W., 2000. The mid-European segment of the Variscides: tectonostratigraphic units, terrane boundaries and plate tectonic evolution. In: Franke, W., Haak, V., Oncken, O., Tanner, D. (eds.), Orogenic Processes: Quantification and Modelling in the Variscan Belt. Geol. Soc. London, Spec. Publ., 179: 35-61.

Franke, W., Dallmeyer, R.D. and Weber, K., 1995. Geodynamic Evolution.- In: Dallmeyer, R.D., Franke, W. and Weber, K. (eds.), Pre-Permian Geology of Central and Eastern Europe, pp. 579-593; Springer, Berlin, Heidelberg.

Franke, W. and elaÿniewicz, A., 2002. Structure and evolution of the Bohemian Arc. In: Winchester, J.A., Pharaoh, T.C. and Verniers, J. (eds.), Palaeozhoic Amalgamation of Central Europe. Geological Society Special Publication, 201: 279-293.

Frasl, G., 1970. Zur Metamorphose und Abgrenzung der Moravischen Zone im niederösterreichischen Waldviertel. Nachrichten der Deutschen Geologischen Gesellschaft, 2: 55-61.

Frasl, G., 1991. Das Moravikum der Thaya-Kuppel als Teil der variszisch deformierten Randzone des Bruno-Vistulikums – eine Einführung. Arbeitstagung Geologische Bundesanstalt, 1991: 49-62.

Friedl, G., 1997. U/Pb-Datierungen an Zirkonen und Monaziten aus Gesteinen vom österreichischen Anteil der Böhmischen Masse. unpublished PhD Thesis, Salzburg University, 242 p.

Friedl, G., Finger, f., Mcnoughton, N. and Fletcher, I.R., 2000. Deducing the ancestry of terranes: SHRIMP evidence for South American-derived Gondwana fragments in central Europe. Geology, 28: 1035-1038.

Fritz, H., Dallmeyer, R.D. and Neubauer, F., 1996. Thick-skinned versus thin-skinned thrusting: Rheology controlled thrust propagation in the Variscan collisional belt (The southeastern Bohemian Massif, Czech Republic – Austria). Tectonics, 15: 1389-1413.

Fuchs, G., 1998. Kritische Gedanken zur neueren geodynamischen Forschung in der östlichen Böhmischen Masse. Jahrbuch der Geologischen Bundesanstalt, 141/1: 39-43.

Gaertner, H.R., 1944. Die Schichtgliederung der Phyllitgebiete in Thüringen und Nordbayern und ihre Einordnung in das stratigraphische Schema. Jb. Reichsanst. Bodenforsch., 62: 54-80.

Geyer, G. and Elicki, O., 1995. The Lower Cambrian triliobites from the Görlitz Synclinorium (Germany) - review and new results. Paläont. Z., 69: 87-119.

Glodny, J., Grauert, B., Fiala, J., Vejnar, Z., Krohe, A., 1998. Metapegmatites in the western Bohemian massif: ages of crystallization and metamorphic overprint, as constrained by U-Pb zircon, monazite, garnet, columbite and Rb-Sr muscovite data. Geol Rundsch 87: 124-134

Hammer, J., Eidam, J., Röber, B. and Ehling, B.-C., 1999. Prävariscischer and variscischer granitoider Magmatismus am NE-Rand des Böhmischen Maasivs - Geochemie und Petrogenese. Z. geol. Wiss., 27: 401-

415.

Hanžl, P. and Melichar, R., 1997. The Brno massif: a section through the active continental margin or a composed terrane? Krystallinikum, 23: 33-58.

Hanžl, P., Melichar, R. and Leichmann, J., 1999. Field excursion on Brno Massif. Geolines, 8: 80-95.

Hanžl, P., Pøichystal, A. and Melichar, R., 1995. The Brno Massif: volcanites of the northern part of the metabasite zone. Acta Universitatis Palackiane Olomucensis, Geologica, 34: 73-79.

Hegner, E. and Kröner, A., 2000. A rewiev of Nd isotopic data and xenocrystic and detrital zircon ages from the pre-Variscan basement in the eastern Bohemian Massif: speculations on palinspastic reconstruction. Geological Society of London, Special Publication, 179: 113-130.

Henk, A., von Blanckenburg, F., Finger, F., Schaltegger U. and Zulauf, G., 2000. Syn-convergent high-temperature metamorphis and magmatism in the Variscides – a discussion of potential heat sources. Geological Society of London, Special Publication, 179: 387-400.

Jachowicz, M. and Pøichystal, A., 1997. Lower Cambrian sediments in deep boreholes in south Moravia. Vìstník Èeského geologického ústavu, 72/4: 329-332.

Jelínek, E. and Dudek, A., 1993. Geochemistry of subsurface Precambrian plutonic rocks from the Brunovistulian complex in the Bohemian massif, Czechoslovakia. Precambrian Research, 62: 103-125.

Jonas, P., Buschmann, B. and Gaitzsch, B., 2000. Unterkambrischer und unterkarbonischer Vulkanismus der Torgau-Doberlug Synklinale (NE Saxothuringische Zone). Z. geol. Wiss., 28: 157-175.

Kerr, A., Jenner, G.A. and Fryer B.J., 1995. Sm-Nd isotopic geochemistry of Precambrian to Palaeozoic granitoid suites and the deep-crustal structures of the southeast margin of the Newfoundland Appalachians. Canadian Journal of Earth Sciences, 32: 224-245.

Košler, J., Rogers, G., Bowes, D.R. and 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. Öster. Miner. Ges., 139: 75-76.

Kreuzer, H., Müller, P., Okrusch, M., Patzak, M., Schüßler, U., Seidel, E., Šmejkal, V. and Vejnar, Z., 1990. Ar-Ar conformation for Cambrian, Early Devonian, and Mid-Carboniferous Tectonic Units at the Western Margin of the Bohemian Massif. 6. Rundgespräch Geodynamik des europ. Variszikums, 15. - 18.11.1990; Clausthal-Zellerfeld (abstr.).

Kröner, A. and Hegner, E., 1998. Geochemistry, single zircon ages and Sm-Nd systematics of granitoid rocks from the Gory Sowie (Owl Mts), Polish West Sudetes: evidence for early Palaeozoic arc-related plutonism. Journal of the Geological Society, London, 155: 711-724.

Kröner, A., Štípská, P., Schulmann, K. and Jaeckel, P., 2000. Chronological constraints on the pre-Variscan evolution of the northeastern margin of the Bohemian Massif, Czech Republic. Geological Society of London, Special Publication, 179: 175-198.

Leichmann, J., 1996. Geologie und Petrologie des Brünner Massivs. Unpbulished PhD Thesis, University Salzburg, 118 p.

Liew, T.C. and Hofmann, A.W., 1988. Precambrian crustal components, plutonic associations, plate environment of the Hercynian Fold Belt of central Europe: Indications from a Nd and Sr isotopic study. Contributions to Mineralogy and Petrology, 98: 129-138.

Linnemann, U., 1991. Glazioeustatisch kontrollierte Sedimentationsprozesse im Oberen Proterozoikum der Elbezone (Weesensteiner Gruppe/Sachsen). Zbl. Geol. Paläont. Teil I, 12: 2907-2934.

Linnemann, U., 1995. The Neoproterozoic terranes of Saxony (Germany). Precambr. Res., 73: 235-250.

Linnemann, U. and Buschmann, B., 1995a. Der Nachweis der cadomischen Diskordanz in einer Tiefenbohrung bei Gera und deren Bedeutung für das proterozoisch-paläozoische Standardprofil im Schwarzburger Antiklinorium. Geowiss. Mitt. Thüringen, 3: 1-11.

Linnemann, U. and Buschmann, B., 1995b. Die cadomische Diskordanz im Saxothuringikum (oberkambrisch-tremadocische overlap-Sequenzen). Z. geol. Wiss., 23: 707-727.

Linnemann, U., Gehmlich, M., Heuse, T. and Schauer, M., 1999. Die Cadomiden und Varisziden im Thüringisch-Vogtländischen Schiefergebirge (Saxothuringisches Terrane). Beitr. Geol. v. Thür. N.F., 6: 7-39.

Linnemann, U., Gehmlich, M., Tichomirowa, M., Buschmann, B., Nasdala, L., Jonas, P., Lützner, H. and Bombach, K., 2000. From Cadomian Subduction to Early Palaeozoic Rifting: The Evolution of Saxo-Thuringia at the margin of Gondwana in the light of single zircon geochronology and basin development (Central European Variscides, Germany). In: W. Franke, V. Haak, O. Oncken, and D. Tanner (eds.), Orogenic processes - Quantification and modelling in the Variscan Belt of Central Europe. Spec. Publ. Geol. Soc. London, 179: 131-153.

Linnemann, U., Gehmlich, M., Tichomirowa, M. and Buschmann, B., 1998. Introduction to the Pre-Symposium Excursion (part I): The Peri-Gondwanan Basement of the Saxo-Thuringian Composite Terrane. In: U. Linnemann, T, Heuse, O. Fatka, P. Kraft, R. Brocke, B.-D. Erdtmann (Editors), “Pre-Variscan Terrane Analysis of Gondwanan Europe - Excursion Guides and Abstracts”-Schr. Staatl. Mus. Min. Geol. Dresden Nr. 9. Staatliches Museum für Mineralogie und Geologie zu Dresden, Dresden, pp. 7-13.

Linnemann, U. and Heuse, Th., 2000. The Ordovician of the Schwarzburg Anticline: Geotectonic setting, biostratigraphy and sequence stratigraphy (Saxo-Thuringian Terrane, Germany). Z. dt. Geol. Ges., 151/4: 471-491.

Linnemann, U., McNaughton, N.J., Romer, R.L., Gehmlich, M., Drost, K., and Tonk, C. (subm.). West African Provenance for Saxo-Thuirngia (Bohmeian Assif): Did Armorica ever leave pre-Pangean Gondwana? – U/Pb SHRIMP zircon evidence and the Nd-isotopic record. Int. J. Earth Sci. (submitted)

Linnemann, U. and Romer, R.L., 2002. The Cadomian Orogeny in Saxo-Thuringia, Germany: geochemical and Nd-Sr-Pb isotopic characterisation of marginal basins with constraints to geotectonic setting and provenance. Tectonophysics, 352: 33-64.

Linnemann, U. and Schauer, M., 1999. Die Entstehung der Elbezone vor dem Hintergrund der cadomischen und variszischen Geschichte des Saxothuringischen Terranes - Konsequenzen aus einer abgedeckten geologischen Karte. Z. geol. Wiss., 27: 529-561.

Linnemann, U., Tichomirowa, M., Gehmlich, M., Buschmann, B. and Brombach, K. 1998. Das cadomisch-frühpalaeozoische Basement des Saxothuringischen Terranes (geotektonisches Setting, Geochronologie, Sequenzstratigraphie). Terra Nostra 98/2, 99-101.

Liou, J.G., Maruyama, S. and Cho, M., 1987. Very low-grade metamorphism of volcanic and volcaniclastic rocks - mineral assemblages and mineral facies.- In: Frey, M. (eds.), Low temperature metamorphism, pp. 59-112; Chapman and Hall, New York.

Mainprice, D., Bouchez, J.-L., Blumenfeld, P. and Tubia, J., 1986. Dominant c-slip in naturally deformed quartz: implications for dramatic plastic softening at high temperatures. Geology, 14: 819-822.

Mašek, J. and Zoubek, J., 1980. Návrh vymezení a ozna¹ováni hlavních stratigrafických jednotek barrandienského proterozoika. VÆst. Ústé. Úst. geol., 55,2: 121-123.

Matte, P., 1986. Tectonics and plate tectonics Model for the Variscan belt of Europe. Tectonophysics, 126: 329-374.

Matte, P., 1991. Accretionary history and crustal evolution of the Variscan belt in Western Europe. Tectonophysics, 196: 309-337.

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

Matura, A. 1976. Hypothesen zum Bau und zur geologischen Geschichte des Grundgebirges von Südwestmähren und dem niederösterreichischen Waldviertel. Jahrbuch der Geologischen Bundesanstalt, 119: 63-74.

McKerrow, W.S., Scotese, C.R. and Brasier, M.D., 1992. Early Cambrian continental reconstructions. J. Geol. Soc. London, 149: 599-606.

Mísaø, Z. 1979. Ultrabazika jako indikátory hlubinné, blokové a vrásové stavby na pøíkladì východního okraje Èeského masívu. Zbornik predn konference Smolenice, 1979: 191-210.

Murphy, J.B., Strachan, R.A., Nance, R.D., Parker, K.D.; and Fowler, M.B., 2000. Proto-

Nance, R.D. and Thompson, D., 1996. Avalonian and Related Peri-Gondwanan Terranes of the Circum-North Atlantic. Journal of the Geological Society of America, Special Paper, 304: 1-390.

Nance, R.D. and Murphy, J.B., 1994. Contrasting basement isotopic signatures and the palinspastic restoration of peripheral orogens: Example from the Neoproterozoic Avalonian-Cadomian belt. Geology, 22: 617-620.

Nance, R. D. and Murphy, J. B., 1996. Basement isotopic signatures and Neoproterozoic paleogeography of Avalonian - Cadomian and related terranes in the circum - North Atlantic, In: R.D. Nance and M.D. Thompson (Editors), Avalonian and Related Peri - Gondwanan Terranes of the Circum - North Atlantic. Geol. Soc. Am. Spec. Pap., 304: 333-346.

Nance, R.D., Murphy, J.B., Strachan, R.A., D´Lemos, R.S. and Taylor, G.K., 1991. Late Proterozoic tectonostratigraphic evolution of the Avalonian and Cadomian terranes. Precambr. Res., 53: 41-78.

O´Brien, S.J., O´Brien, B.H., Dunning, G.R. and Tucker, R.D., 1996. Late Neoproterozoic Avalonian and Related Peri-Gondwanan Rocks of the Newfoundland Appalachians. In Nance, R.D. and Thompson, D. (eds.) Avalonian and Related Peri-Gondwanan Terranes of the Circum-North Atlantic. Journal of the Geological

Society of America, Special Paper, 304: 9-28.

Pato¹ka, F., Galle, A., Vavdrová, M. and Vlašímský, P., 1994. Early Paleozoic evolution of the Barrandian Terrane, Bohemian Massif, Czech Republic: Paleotectonic implications of sedimentary, fossil and volcanic record.- J. Czech Geol. Soc., 39, 82-83.

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

Pták. J. and Wartha, K., 1966. Fabric analysis and the major fold structure of the Upper Proterozoic in the Plzeò area. Sbor. geol. vìd, Geologie, 11: 33-48.

Scharbert, S. and Batik, P., 1980. The age of the Thaya (Dyje) Pluton. Verhandlungen der Geologischen Bundesanstalt, 1980: 325-331.

Scheuvens, D. and Zulauf, G., 2000. Exhumation, strain localization, and emplacement of granitoids along the western part of the Central Bohemian shear zone (central European Variscides, Czech Republic). Int. J. Earth Sci., 89: 617-630.

Schmidt, K., 1960. Geologie: Die Geröllführung algonkisch-kambrischer Grauwacken des Westlausitzer Zuges. Freib. For. Hft., C 91: 1-98.

Schulmann, K., 1990. Fabric and kinematic study of the Bites orthogneiss (southwestern Moravia): Result of large-scale northeastward shearing parallel to the Moldanubium/Moravian boundary. Tectonophysics, 177: 229-244.

Scotese, C.R., Boucot, A.J. and McKerrow, W.S., 1999. Gondwanan palaeogeography and palaeoclimatology. J. African Earth Sci., 28: 99-114.

Štelcl, J. and Weiss, J., 1986. Brnìnský masív. Universita J.E. Purkyne, Brno. pp. 1-255.

Tait, J., Bachtadse, V. and Soffel, H., 1995. Upper Ordovician palaeogeography of the Bohemian Massif: implications for Armorica. Geophys. J. Int., 122: 211-218.

Tait, J.A., Bachtadse, V. and Soffel, H.C., 1996. Eastern Variscan fold belt: Palaeomagnetic evidence for oroclinal bending. Geology, 24: 871-874.

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

Tait, J.A., Schätz, M., Bachtadse, V. and Soffel, H., 2000. Palaeomagnetism and Palaeozoic palaeogeography of Gondwana and European terranes. In: Franke, W., Haak, V., Oncken, O., Tanner, D. (eds.), Orogenic Processes: Quantification and Modelling in the Variscan Belt .Geol. Soc. London, Spec. Publ., 179: 21-34.

Tichomirowa, M., Linnemann, U. and Gehmlich, M., 1997. Zircon ages as magmatic time marks – Comparison of the crustal evolution in different units of the Saxo-Thuringian zone. Terra Nostra, 97/11: 137-141.

Van Breemen, O., Aftalion, M., Bowes, D.R., Dudek, A., Misaø, Z., Povondra, P. and Vrana, S., 1982. Geochronological studies of the Bohemian massif, Czechoslovakia, and their significance in the evolution of Central Europe. Transactions of the Royal Society of Edinburgh Earth Sciences, 73: 89-108.

Vejnar, Z., 1982. Regionální metamõrfoza psamiticko-pelitických hornin domažlické oblasti.- Sborník geologických vÆd, Geologie, 37: 9-70 (in Czech with English abstract), Prague.

Vejnar, Z. (1984): Magmatismus. In: Vejnar, et al. (eds.), Geologie domažlicke oblasti, pp. 48-83; Ustøedni Ustav Geologický, Prague.

Von Quadt, A. 1994. U-Pb zircon data and Pb-Sr-Nd isotope chemistry from metagabbros from the KTB-borehole. Journal of the Czech Geological Society, 39/1: 87-88.

Winchester, J.A., Pharaoh, T.C.and Verniers, J. 2002. Palaeozoic amalgamation of Central Europe: an introduction and synthesis of new results from recent geological and geophysical investigations. Geological Society of London, Special Publication, 201: 1-18.

Wucher, K., 1967. Ergebnisse der Kartierungsbohrungen Heinersdorf 1/60 und 2/62 (Thüringisches Schiefergebirge). Jb. Geol., 1: 297-323.

Žáèek, V. and Cháb, J., 1993. Metamorphism in the Tepla upland, Bohemian Massif, Czech Republic (preliminary report). VÆstnik ‡eskeho geologickeho Ustavu, 68/3: 33-37, Prague.

Zulauf, G., 1997. Von der Anchizone bis zur Eklogitfazies: Angekippte Krustenprofile als Folge der cadomischen und variscischen Orogenese im Teplá-Barrandium (Böhmische Masse). Geotekt. Forsch., 89: 1-302.

Zulauf, G., 2001. Structural style, deformation mechanisms and paleostress along an exposed crustal section: Constraints on the rheology of quartzofeldspathic rocks at supra- and infrastructural levels (Tepla-Barrandian unit, Bohemian Massif). Tectonophysics, 332: 211-237.

Zulauf, G., Bues, C., Dörr, W. and Vejnar, Z., 2002a. 10 km minimum throw along the West Bohemian shear zone: Evidence for dramatic crustal thickening and high topography in the Bohemian Massif (European Variscides). Int. J. Earth Sci, 91: 850-864.

Zulauf G, Dörr W, Fiala J, Kotková J, Maluski H, Valverde-Vaquero P, 2002b. Evidence for high-temperature diffusional creep preserved by rapid cooling of lower crust (North Bohemian shear zone, Czech Republic). Terra Nova, 14: 343-354.

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. Rundsch., 86: 571-584.

Zulauf, G. and Helferich, S. 1997. Strain and strain rate in a synkinematic trondhjemitic dike: evidence for melt-induced strain softening during shearing (Bohemian Massif, Czech Republic). J. Struct. Geol., 19: 639-652.

Zulauf, G., Schitter, F., Riegler, G., Finger, F., Fiala, J. and Vejnar, Z., 1999. Age constraints on the Cadomian evolution of the Teplá Barrandian Unit (Bohemian Massif) through electron microprobe dating of metamorphic monazite. Zeitschrift der Deutschen Geologischen Gesellschaft, 150: 627-639.

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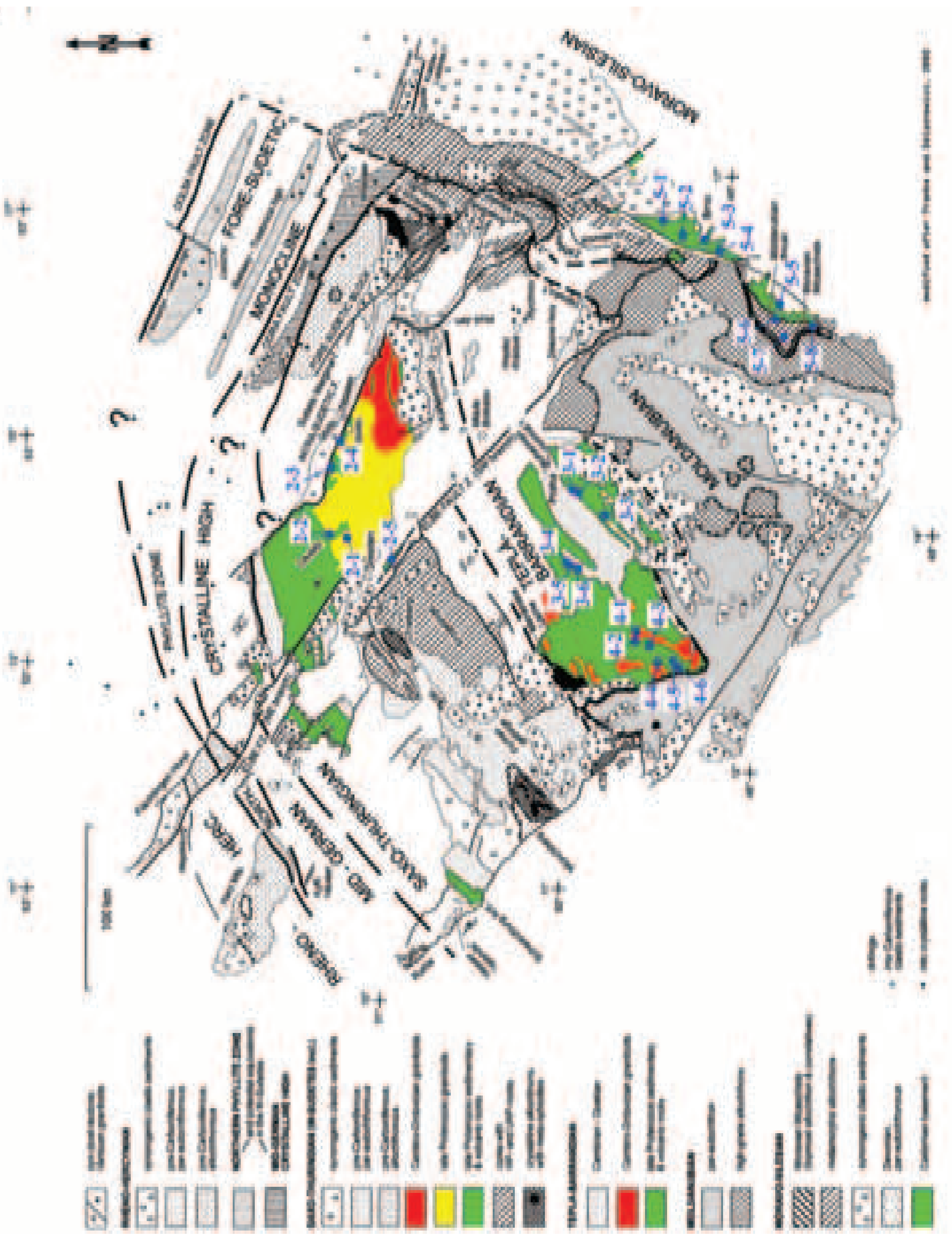
field trip itinerary

32nd INTERNATIONAL GEOLOGICAL CONGRESS

FIELD TRIP MAP



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