Late Proterozoic – Paleozoic Tectonostratigraphic Development and Paleogeography of Brunovistulian Terrane and Comparison with Other Terranes at the SE Margin of Baltica-Laurussia

Svrchnoproterozoický – paleozoický tektonostratigrafický vývoj a paleogeografie brunovistulického teránu a srovnání s dalšími terány na JV okraji Baltiky-Laurusie

(9 figs, 2 tabs)

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There are close similarities between the Brunovistulian Terrane and the Istanbul Zone both in the Neoproterozoic and Paleozoic. The geological structure, lithology and geochronology of the Cadomian Brunovistulicum show a broad fit with the crystalline basement of the Istanbul Zone. Their Gondwana or Baltica affinity is still poorly constrained and remains a matter of discussion. The Vendian and Cambrian sequences recognized in the central Malopolska, Brunovistulian and Moesian terranes correlate well with the Scythian Platform. In the Istanbul Zone the presence of pre-Ordovician sedimentary sequences has not been confirmed and may only be anticipated. In Paleozoic the best fit was attained in the Devonian–Carboniferous. The sedimentary record in the Zonguldak and Istanbul terranes correlates closely to the Moravian Karst and Ludmírov facies developments of the Brunovistulian Terrane. This correlation is reinforced by the good fit of the main Variscan deformation phases attributed in both the Brunovistulian Terrane and the Istanbul Zone to the late Visean–early Namurian and Westphalian-Stephanian intervals. This supports, together with the paleobiogeographical data, the interpretation that the Istanbul and Zonguldak terranes can be regarded as counterparts to the Rhenohercynian and Subvariscan Zone in Central Europe. The Istanbul Zone was juxtaposed against the Sakarya Zone viewed as a part of the Armorican Terrane Assemblage.

Key words: Brunovistulicum, Istanbul Zone, terranes, paleogeography, late Neoproterozoic, Paleozoic

A. Introduction

The affinity of the terranes at the SE margin of Laurussia to major continents is not clear and has been a matter of some discussion. A long term late Neoproterozoic (Cadomian, Panafrican) consolidation was regarded as a reliable criterion for distinguishing Perigondwana-derived terranes. Nevertheless, late Neoproterozoic deformations have been recently reported in the Timanides and the Urals or assumed in the Scythian Platform (Zoubek 1992, Puchkov 1998, Glasmacher et al. 1998, 1999, Pharaoh 1999, Gee 2001) and in southern Poland (Zelazniewicz et al. 1997). The supposed Panafrican provenance of some crustal elements thus requires careful scrutiny before an interpretation of their affinity.

The present paper builds on the work of the authors in Moravia where the best data on the Cadomian basement and Devonian–Carboniferous sediments and paleobiogeography are available and their study has a long tradition. An effort here is made to view these data within the broader pattern of the Neoproterozoic–Paleozoic tectonostatigrahic and paleogeographic development of the southern Baltica – Laurussia margin.

A collage of various crustal blocks was derived either from Baltica or Gondwana and accreted to the Precambrian East European Craton (EEC) along the Transeuropean Suture Zone (TESZ) to form the southeastern margin of Laurussia during the Variscan orogeny. These includes the Lysogory, Malopolska, Brunovistulian and Moesian terranes in Central and SE Europe and the Istanbul Zone in Asia Minor (Pharaoh 1999, Belka et al. 2000, Kalvoda 2001). Kalvoda (2001, 2002) termed these terranes as the Brunovistulian group based both on similar geotectonic position and paleobiogeographic similarities.

A comparison will be made also with the Scythian orogen (see Fig. 2) that fringes the southern margin of the East European Craton and is regarded as an eastern prolongation of the Variscan orogen in Central Europe.

B. Geological Setting

In the Brunovistulian Terrane, the Cadomian age of the basement cropping out primarily in the Brno Massif has been well established (van Breemen et al. 1982, Dallmeyer et al. 1994, Finger et al. 2000a). The term Brunovistulian is preferred here to other synonyms – Upper Silesian or Moravian-Silesian – because the Upper Silesian Massif forms only the northern part of the Brunovistulian unit and the Moravian and Silesian units are narrow zones formed mostly by metamorphosed Brunovistulicum at the contact with Moldanubian and Saxothuringian (Lugian) units of the Armorican Terrane Assemblage. The Brunovistulicum (BVT – see fig. 1) is separated from the Malopolska Terrane by a tectonic unit known as the Krakow-Lubliniec Fault Zone that is a part of the largely concealed Hamburg-Krakow Fault Zone (see fig. 1) parallel to the Transeuropean Suture Zone (TESZ). This fault zone continues southeast of Krakow, where Carpathian flysch is thrust over the Paleozoic basement (Bula – Jachowicz 1997). In the North the Holly Cross Fault sepa-

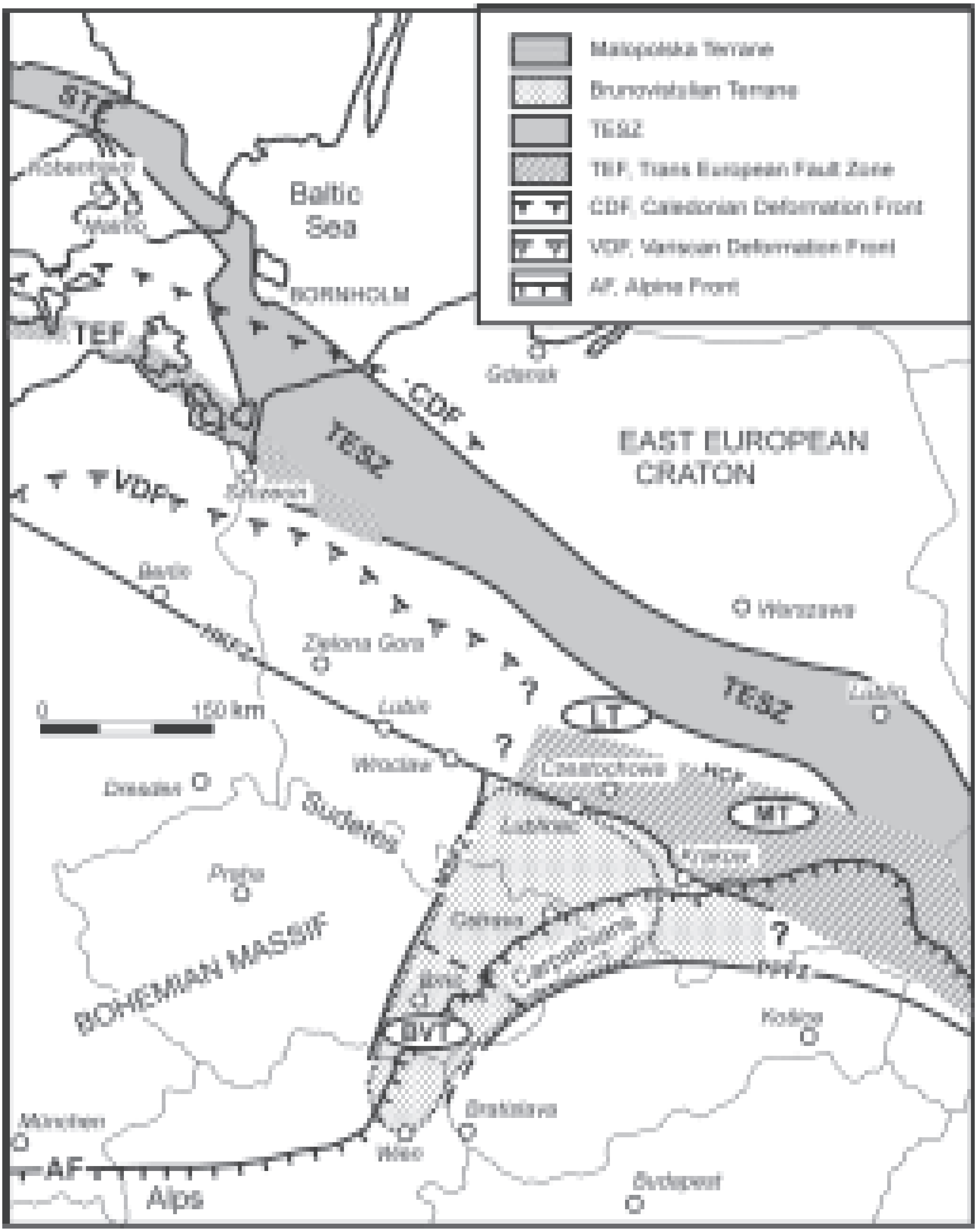

Fig. 1 Structural setting of the Brunovistulian, Malopolska and Lysogory terranes. Modified according to Bula et al. (1977). BVT – Brunovistulian Terrane, MT – Malopolska Terrane, LT – Lysogory Terrane, HKFZ – Hamburg-Krakow Fault Zone, HCF – Holy Cross Fault, TESZ – Transeuropean Suture Zone, MSFZ – Moravo-Silesian Fault Zone, PPFZ – Peri-Pieninian Fault Zone, VDF – Variscan Deformation Front, CDF – Caledonian Deformation Front, AF – Alpine Front.

rates the Malopolska Terrane from the Lysogory Terrane (see Fig. 1).

In the Malopolska Terrane the Cadomian basement has only been proposed based on the presence of late Neoproterozoic detrital micas (Belka et al 2000). In the Lysogory terrane (Fig. 1), detrital micas in Cambrian siliciclastic rocks show a wide age spectrum with well defined Archean, Early Archean, Mesoproterozoic and late Neoproterozoic ages (Valverde-Vaquero et al. 2000). Some interpretations favour a Gondwana origin for the Malopolska and Lysogory terranes (Belka et al. 2000). In other interpretations they are regarded as slivers of Baltica and it is inferred that the Neoproterozoic crust is of Assyntian affinity, derived either from the Scythian Platform or the Uralian margin of Baltica (Pharaoh 1999).

It is hypothesized that both the Brunovistulian Terrane and the Malopolska Terrane were detached from the ancestral Crimea-Dobrogea region (Scythian Platform) and dextrally transferred along the margin of the Laurussia during Variscan time (Lewandowski 1993, 1994, Grygar 1998, Belka et al. 2000). Unrug et al. (1999) and Nawrocki (2000), on the other hand, stressed the importance of late Silurian Caledonian movements.

The prolongation of the Malopolska Terrane to the SE may constitute the Dobrogean part of the Moesian Terrane (Unrug et al. 1999). A correlation between the Moesian and the Moravo-Silesian (Brunovistulian) Terrane, based on similar structural position with regard to the East European Craton, has been proposed by Burchfiel (1975) and Matte et al. (1990). According to Banks and Robinson (1997) the Moesian Terrane was sinistrally displaced from the Brunovistulian Terrane along the TESZ during the opening of the proto-Pannonian marginal basin in late Triassic–early Jurassic.

According to Pharaoh (1999), the basement of the Moesian Platform (see Fig. 2) resembles that of the Ukrainian Shield. However, the affinity of the terrane is poorly constrained at present. Geophysical evidence (Seghedi, 1998) suggests that the deep crustal boundary of the EEC (TESZ) corresponds to the surface position of the Peceneaga-Camena Fault, a NE-vergent Cimmerian-age thrust that juxtaposes Precambrian rocks of the Moesian Platform with Permian-late Jurassic strata of the North Dobrogea orogen (Seghedi 1998, Pharaoh 1999). The Paleozoic position of the Moesian Terrane is also a matter of discussion. Yanev (1997, 2000) inferred a Perigondwana affinity and middle Devonian accretion to Laurussia.

According to Nikishin et al. (1996, 1999) the Scythian orogen (see Fig. 2) that fringes the southern margin of the East European Craton includes the Scythian, Great Caucasus (Karpinsky Kryazh fold belt), Pontides and Moesian domains. It is viewed as being the eastern prolongation of the Variscan orogen of Western and Central Europe.

The Istanbul zone (Okay 1989, 2000, Okay et al. 1994) lies within the western Pontides in northern Turkey. It is assumed that it was located originally along the Odessa shelf between the Moesian Platform and Crimea and drifted southward along the major trasform faults following an oblique slip on the TESZ, to form the western Black Sea Basin during the development of the western Black

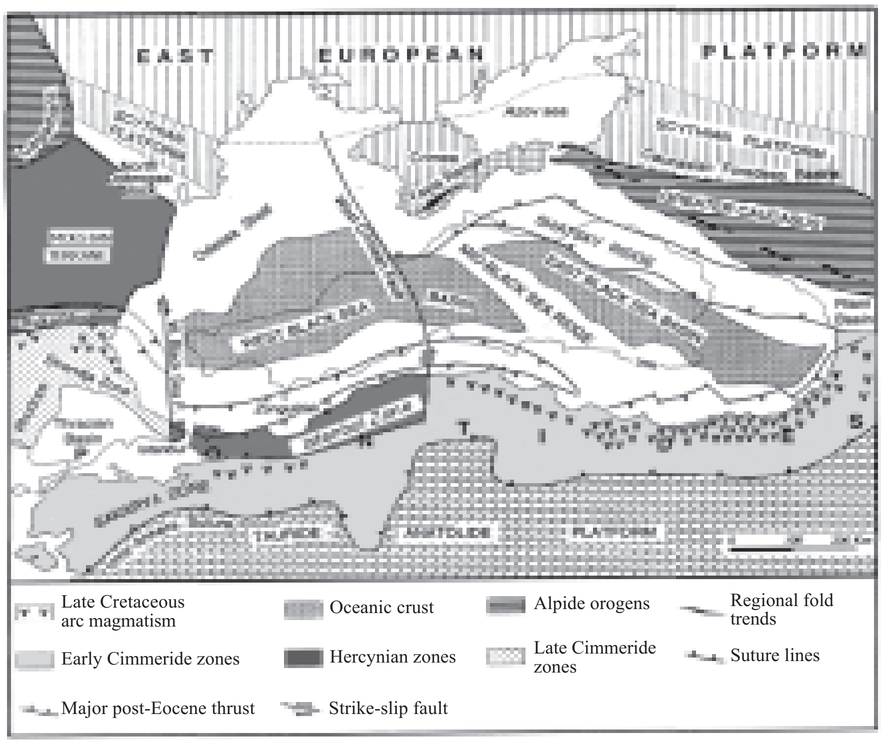

Fig. 2 Tectonic map of the Black Sea region showing the position of the Moesian and Zonguldak terranes. Modified after Okay et al. (1994).

Sea between the Albian and early Eocene (Okay et al. 1994, Pharaoh 1999). The close stratigraphic similarities of the Istanbul Zone to the Paleozoic rocks of the southern margin of Laurasia are presupposed (Görür et al. 1997) and a Cadomian age of the basement has been reported (Kozur – Göncüoglu 1998, Chen et al. 2002).

The Istanbul Zone (see Fig. 2) (Okay 1989) of the Pontides in northern Turkey is separated from the Sakarya Zone by the Intra-Pontide suture (Okay et al. 1994). Kozur and Göncüoglu (1998) divided the Istanbul zone into the Istanbul Terrane s.str. affected only by Variscan deformation and the Zonguldak Terrane which contains mainly Caledonian deformation. The former is bounded to the East by Strandja Massif, the latter to the west by Transcaucasia (Kozur – Göncüoglu 1998, Okay et al. 1994).

C. Proterozoic Basement, Vendian Flysch and Cambrian Molasse

C.1. Brunovistulicum

C.1.a. Proterozoic Basement

The easternmost margin of the Bohemian massif approximately between the Danube and the Odra Rivers, is built up by a complex of metamorphic and magmatic rocks called Brunovistulicum (BVT) (see Fig. 3) by Havlena (1976), Dudek (1980), Finger et al. (2000b) or the Brunovistulian Complex (Jelínek – Dudek 1993). The most important outcrops of Brunovistulicum are the Dyje Batholith (Finger et al. 1989, 1995), the Brno Batholith (Leichmann 1996, Hanžl – Melichar 1997) and the Desna Gneiss (Fišera – Patočka 1989). A buried part is known from deep drillings and was described by Jelinek – Dudek (1993) in the Czech Republic and by Moczydlowska (1995) in Poland. The western parts of BVT were involved in the Variscan nappe stacking while the easternmost parts are relatively autochthonous. The eastern, mostly buried part of the Brunovistulicum not reactivated during the Variscan orogeny, acted as a stable foreland massif for both, the Variscan and the Alpine fold belts.

The Brunovistulicum consists of three independent units. According to Leichmann et al. (1996) a Southwestern Unit or Thaya Terrane (Finger et al. 2000a), Ophiolite Unit and Eastern Unit or Slavkov Terrane (Finger et al. 2000a) can be distinguished from the west to the east. The southwestern complex including the Thaya Pluton, the western part of the Brno Pluton and burried sections could be interpreted as a large batholith with a complex internal fabric and evolution including S, I and A type granites. The geochronological data indicate that the plutonic activity occurs here in the period between 580–590 Ma (van Breemen et al. 1982, Finger et al. 2000a, Dallmeyer et al. 1994). Petrological observations (Leichmann – Höck 2002 in prep), as well as a high $^{87}Sr/^{86}Sr$ ratio (0.708–0.710) and a low δNd –4 to –7 (Finger et al. 2000a) indicate that the granites originated in tha volcanic arc environment with an important contribution of older crustal rocks. The widespread dark diorites and tonalites with lower $^{87}Sr/^{86}Sr$ (0.705–0.707) and higher δNd (–1 to –2) probably represent melts that result from heat required for extensive crustal melting. Metasediments were found in the roof of granites or only as enclaves. A strongly negative δNd –3 to –7 suggests that the detritus of these sediments derived from a cratonic crust (Finger et al. 2000a).

The ophiolite complex consists of two parts – plutonic and volcanic sequences. The plutonic sequence is metamorphosed up to the lower amphibolite facies, while the volcanics are metamorphosed in the greenschist facies (Leichmann 1996). The former sequence is comprised of prevailing diorites and gabbros with minor bodies of trondhjemites and ultramafics while the latter sequence comprises metabasalts with some intercalations and veins of felsic volcanics. The complex chemistry of the basalts indicates a supra-subduction zone origin for the ophiolites. The observed intrusion relationships between granites from both southwestern and eastern units indicate that the ophiolites are the oldest known part of the Brunovistulicum. The geochronological data obtained from a rhyolite vein cutting through the metabasalts – 725±15 (Finger et al. 2000b) – fully confirm earlier geological observations. The Slavkov Terrane comprises the eastern part of the Brno Pluton, Desná Gneiss and buried parts inclusive Vistulicum and the Upper Silesian Block. The southern half of this unit consists of primitive ($^{87}Sr/^{86}Sr$ 0.704–0.705, δNd –1 to +3, Finger et al. 2000a), I Type, island-arc granodiorites, tonalites and quartz diorites. The age determination is less well established in comparison with the southwestern complex. An Ar-Ar hornblende age of 596 Ma was reported by Dallmeyer et al. (1994) only. The granites intrude into the metamorphic complex that forms the northern half of the eastern complex.

The metamorphic rocks are known mainly from boreholes. Variscan overprinted members were reported from the Jeseniky Mts – Desna Gneiss (Finger et al. 2000a, Kröner et al. 2000). Most of these rocks are metamorphosed flyschoid Al_2O_3 poor greywackes, silstones and psamites with intercalations of metabasalts and metaandesites (Dudek 1980). $^{87}Sr/^{86}Sr$ and δNd values (0.704–0.706 δNd –1 to +2) are similar to those of the adjoining granites. Both petrological and isotopical data indicate a relatively primitive island-arc source area of the detritus. The metamorphic grade reaches primarily greenschist to lower amphibolite facies. The presence of sillimanite and manifestations of partial melting, indicating upper amphibolite conditions, were observed only locally, mainly in the easternmost part of the BVT.

C.1.b. Vendian Flysch and Cambrian Molasse

The crystalline basement of the Brunovistulicum is locally covered by a Vendian flysch (see Fig. 7) sequence of phyllites, metapelites, metapsammites and metaconglomerates in N and NE part of Brunovistulicum whose areal extent is still to be clarified. This anchimetamorphic rocks are regarded as deposits of a Cadomian foreland basin

(Bula – Jachowicz 1999). According to Zelazniewicz et al. (2001) the Upper Silesian Vendian flysch may have been sourced from terranes with older elements similar to the Osnitsk-Mikashevici Belt of the east European Craton and Fennoscandia.

In the Paleozoic two distinct lithological cycles can be ditinguished – a Lower Cambrian–Middle Cambrian and Devonian–Carboniferous.

The occurrences of Cambrian molasse (see Fig. 7) are located in two areas. One is in the N and NE part of Brunovistulicum in Upper Silesia and may be correlated with the Slavkov Terrane, and the one in the SE part corresponds to the Thaya Terrane. The two occurrences need not have been deposited in the same geotectonic position reflecting the not fully clear course of the Cadomian orogeny (Finger et al. 2000a).

The Cambrian rocks in Upper Silesia, well dated by acritarchs (Bula – Jachowicz 1996), discordantly overlie the crystalline and anchimetamorphic rocks (Bula – Jachowicz 1999). Their thickness increases markedly towards the east (Bula et al. 1997). Further occurrences were detected in the SE part of the Brunovistulian Terrane SE of Brno (Jachowicz – Přichystal 1997, Fatka – Vavrdová 1998).

The oldest Cambrian sediments of the Sub-*Holmia* Zone have been originally found only in the marginal northeastern part of the Upper Silesia (Bula – Jachowicz 1996). The regressive Borzeta Formation was accumu-

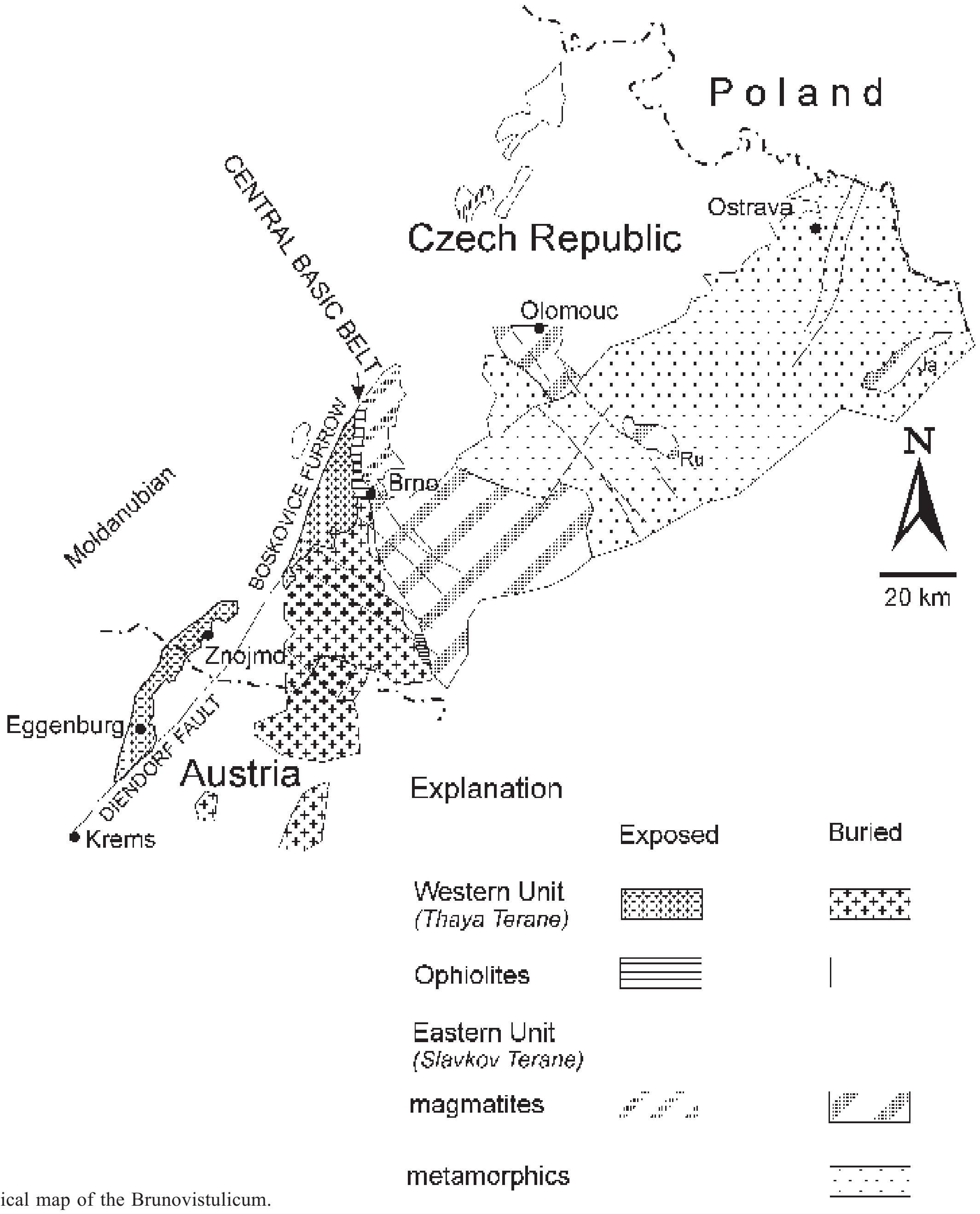

Fig. 3 Simplified geological map of the Brunovistulicum.

lated in a marine basin with shallowing upward sequence of claystones and siltstones, laminated sandy siltstones and quartz or arkosic sandstones. Recently, the sediments of the earliest Cambrian, most likely *Platysolenites antiquissimus* Zone, have been detetected in a borehole SE of Brno in SE part of the Brunovistulian Terrane (Vavrdová et al. 2002).

The sediments of *Holmia* Zone show also a wider distribution in the Upper Silesia (Bula – Jachowicz 1996) and their presence has also been reported in deep discontinuously cored boreholes in SE Moravia (Jachowicz – Přichystal 1997, Fatka – Vavrdová 1998). In Upper Silesia the transgressive cycle of the Goczalkowice Formation is formed by a deepening upward sequence of *Scolithos* sandstones, bioturbated sandstones and trilobite siltstones (Kotas 1982, Bula – Jachowicz 1996).

Fragments of the middle Cambrian represented by a sequence of alternating layers of quartz and quartzitic sandstones and laminated sandy siltstone were detected only in the northern part of the Upper Silesia (Bula – Jachowicz 1996).

C.2. Lysogory and Malopolska Terranes

In the Lysogory terrane the crystalline basement is unknown. The oldest rocks, middle Cambrian shales, are followed by fine grained mature sandstones, mudstones and shales of a shallow water origin (Stupnicka 1992, Valverde-Vaquero et al. 2000, Belka et al. 2000). This clastic 1800 m thick sequence extends into the Tremadoc and is lithologically similar to chronologically equivalent units of the East European Platform (Kowalczewski 1995). A provenance study of detrital zircon in Middle Cambrian sandstones reflects input from sources with late Neoproterozoic, Mesoproterozoic and Archean ages (Valverde-Vaquero et al. 2000). Detrital micas in the more shaly interbeds of the middle Cambrian have yielded a bimodal K-Ar age spectrum of ca. 600 Ma and ca. 1.7 Ga (Belka et al. 2000).

The data on the lithology of the Malopolska terrane are based on papers by Unrug et al. (1999), Bula et al. (1997), Belka et al. (2000). The crystalline basement of the Malopolska Massif is unknown. The oldest rocks comprise Vendian folded siltstones and greywackes with intercalations of volcanic rocks related to turbidites and debris flows and resemble those on the adjacent East European Platform (Moczydlowska, 1995). Acritarch studies have shown the Vendian age of the Malopolska flysch (Moryc – Jachowicz 2000). Compston et al. (1995) have dated a volcanic tuff at 549 ± 3 Ma (^{206}Pb/^{238}U SHRIMP age) from the top of the Vendian sequence. Lower Cambrian conglomerates, sandstones, and shales locally overlie discordantly Vendian rocks. Folding and greenschist metamorphism of Neoproterozoic–Cambrian rocks predated deposition of overlying Ordovician and Silurian sediments. Folding might be related to the docking of Malopolska against Baltica during Sandomierz Phase (Belka et al. 2000). Cambrian sequences has been interpreted as an accretionary wedge to the Brunovistulicum (Winchester et al. 2002).

According to Zelazniewicz et al. (1997) the Malopolska Flysch was apparently sourced by terranes that underwent tectonothermal events at >2.5 Ga and 1.9–2.1 Ga prior to recognized Neoproterozoic orogeny. Rocks of that age occur in the nearby Sarmatia and especially in the Osnitsk-Mikashevici Belt of the east European Craton (Zelazniewicz et al. 2001).

C.3. Moesian Terrane and Scythian Platform

The affinity of the basement underlying the Moesian Platform (see Fig 2) is poorly constrained at present (Pharaoh 1999). Archean gneisses and pegmatites overlain by Lower Proterozoic banded iron formation with Svecofennian metamorphism comparable to that of the Ukrainian Shield are encountered in south Dobrogea (Seghedi 1998, Seghedi et al. 2001). Metabasites and metapelites of the Altin Tepe Group in the northern margin of the platform show a late Neoproterozoic metamorphism (696 Ma, K-Ar on biotite) and arc/back-arc affinities (Seghedi et al. 2001, Crowley et al. 2000).

A low-grade Neoproterozoic volcano-sedimentary succession overlies the basement in South Dobrogea and was deformed at 547 Ma (K-Ar WR) (Kräutner et al. 1989, Seghedi et al. 2001). It is supposed that during the Neoproterozoic the cratonic basement was broken by transtensional rifting and filled with basalt (spilitic) flows and pyroclastics, topped by terrigenous sequence (Cocosu Formation) and later thrust in northward directed nappes. In front of the nappes deep water Neoproterozoic–lower Cambrian turbidites (Histria Formation) were deposited in a foreland basin (Kräutner et al. 1989, Seghedi 1998, Seghedi et al. 2001). The coexistence of volcanic clasts (basalts and rhyolites), as well as the presence of pyroxenes and amphiboles in the heavy mineral fraction indicate that a primary active volcanic arc source contributed together with a major terigeneous source that delivered metamorphic and granite debris (Seghedi et al. 1999, Zelazniewicz et al. 2001). The Histria Fm. was folded and metamorphosed during the Cadomian events (570 Ma, K-Ar WR) (Seghedi 1998).

In the basement of the Scythian Platform Neoproterozoic granitoid rocks (granites and diorites) atypical of the East European Craton were found (Seghedi 1998, Pharaoh 1999). The overlying Vendian sequence is composed of predominantly coarse marine deposits which grade upward to continental sequences. Their age was shown using K-Ar data yielded by pelitic rocks as well as by fossil remains of *Vendotaenia antiqua* and they show some similarities with the Avdarma Group from the top of the Vendian in the EEC (Seghedi 1998). Lower Cambrian red-beds have been described only in some boreholes.

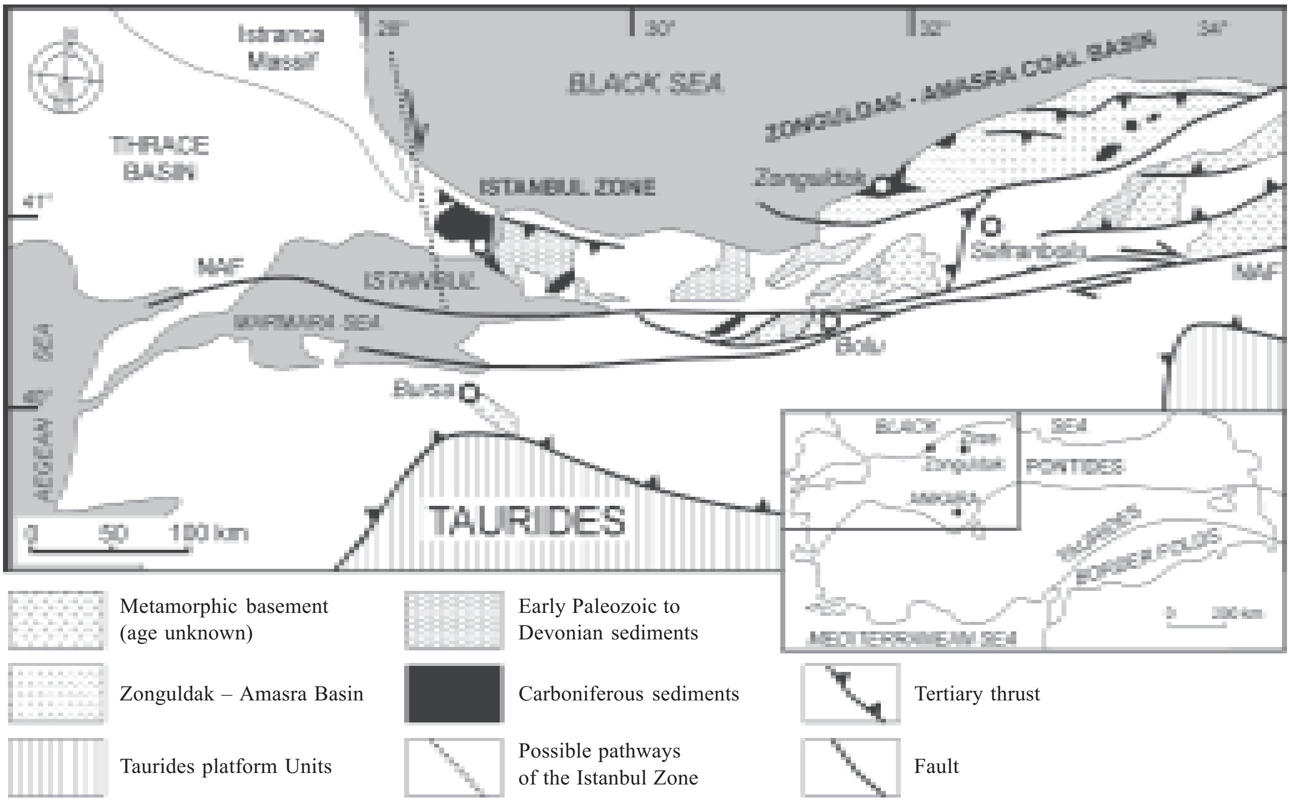

Fig. 4 Generalized geological map showing principal structural subdivisions of the Pontides in NW Turkey and localization of Paleozoic outcrops in the Istanbul Zone. Paleozoic rocks in black, Mesozoic rocks dotted. After Dean et al. 2000.

C.4. Istanbul Zone

The basement of the Palaeozoic sequences within the Istanbul Zone is exposed on the Armutlu peninsula, in the Safranbolu area and the largest outcrops are occurring in the Bolu Massif (see Fig. 4, Tab. 1), located in the centre of the west Pontides (Chen et al. 2002). According to Ustaömer (1999), three rock units form this basement. A high-grade metamorphic unit, the Sünnice Group, consists of alternations of pale and dark green amphibolite, and quartzo-feldspatic layers of various thicknesses and thick gneisses with occasional thin (~10 cm thick) amphibolite interlayers representing a metamorphosed supra-subduction ophiolite complex (Ustaömer 1999, Yigitbas et al. 2001). The Casurtepe Formation is interpreted as arc-type volcanic and volcanoclastic sequence that has been metamorphosed in greenschist facies grade (Ustaömer 1999, Ustaömer – Kipman 1998). Geochemical data show that the Casurtepe Formation lavas are tholeiitic to calc-alkaline, fractionated basaltic andesite, andesitic and rhyolitic lavas. Tectonic discrimination diagrams and the patterns observed on spidergrams are compatible with those of supra-subduction zone tholeiitic-calc-alkaline volcanic rocks, with LIL-elements enrichment and Nb depletion relative to LREE (Ustaömer 1999).

The Bolu Granitoid Complex intrudes into the Casurtepe Formation, their contact to the Sünnice Group is tectonic (Ustaömer 1999). The granitoids from the Bolu Granitoid Complex are calc-alcaline, per- to metaaluminous tonalites, granodiorites with a minor occurrence of gabbros and granites. The presence of amphibole and allanite indicates their I-typ affinity. The locally observed granophyric texture indicates rather shallow intrusion level. A low ^{87}Sr/^{86}Sr ratio and high dNd values (0.7045–0.7085, –4.9 to +2.6, Satir et al. 2000), supported by an interpretation of geochemistry with low HFS and LIL elements, suggest that the granites were derived in a volcanic arc environment. The granite intrusions in the Istanbul Zone were dated to 570–590 Ma (Satir et al. 2000).

There are no data on the Vendian flysch and Cambrian molasse sequences even though some lithologies resemble Cambrian sediments of the Brunovistulian or Malopolska terranes.

D. Ordovician–Permian Sedimentary Record

D.1. Brunovistulian Terrane

A locally restricted occurrence of Ordovician clayey siliceous rocks, light green interbedded with fine-grained quartz sandstones with variable degree of silicification was encountered only in the northern part of Upper Silesia (Gladysz et al. 1990, Bula – Jachowicz 1996).

The Silurian basaltic dyke was described in the central part of the Brno Massif (Přichystal 1999). The record of Silurian sedimentation is preserved in a single location near Stínava in the SW part of the Brunovistulian Terrane, which is a tectonic slice cropping out at the base of one of Carboniferous flysch overthrusts (Kettner – Remeš 1938, Chadima – Melichar 1998). The Silurian succession is composed of black shales with subordinate impure limestone lenses containing graptolites and nautiloid cephalopods, which indicate Telychian, Sheinwoodian, Gorstian and Ludfordian ages (Kettner – Remeš 1936, Kraft – Marek 1999). The rare occurrence of Ordovician and absence of Silurian rocks in the Brunovistulian Terrane is presumably a result of erosion (Moczydlowska 1997). There is no distinct angular unconformity at the Cambrian–Devonian contact (Bula et al. 1997). Zaba (1999) reports late Caledonian deformation in northern marginal parts of the unit.

During the Devonian–Permian interval the Brunovistulian, Malopolska and Lysogory blocks formed floor of a larger basin located at the southern margin of Laurussia, generating similar Devonian and Carboniferous lithological sequences (Dvořák et al. 1995, Belka et al. 2000), whose key sections are best exposed and studied in the Brunovistulian Terrane. Devonian to Lower Carboniferous rocks of the Brunovistulian Terrane (see Fig. 5) provide a complex record of: (i) early Devonian (Pragian) to late Tournaisian rifting and plate extension; (ii) Tournaisian to earliest Namurian plate convergence and flysch sedimentation; and (iii) Namurian to Westphalian final plate collision and molasse sedimentation (see fig. 6).

In the Pragian to late Tournaisian interval, the Brunovistulian Terrane underwent a complex evolution associated with the extension of the Rheno-Hercynian system of basins (Leeder 1984, Ziegler 1988, Franke 1989, Hladil 1996, Dittmar 1996, Hladil et al. 1999). The extensional regime resulted in a pronounced facies differentiation (Chlupáč 1988). Five major facies domains (see Fig. 5) running parallel with the present-day NNE-SSW to NE-SW tectonic strike have been distinguished in the pre-flysch successions of the Brunovistulian Terrane: (i) Moravian Karst Facies; (ii) Ludmírov Facies; (iii) Drahany Facies; (iv) Vrbno Facies; and (v) Tišnov Facies (Chlupáč 1965, Hladil 1992).

Sedimentary successions of the Moravian Karst Facies Domain were deposited upon the Brunovistulian basement of a Neoproterozoic (Cadomian) age (Dudek 1980, Dallmeyer et al. 1992) that formed a part of the southern continental margin of Laurussia during the Devonian to early Carboniferous times (Kalvoda 2001). Following a phase of continental and shallow-marine siliciclastic sedimentation (Emsian to Frasnian), depositing an up to 1000 m thick pile of sandstones, siltstones and conglomerates, large areas of the Brunovistulian basement were covered by a vast, shallow-water carbonate platform. The carbonate sedimentation flourished in the period from late Emsian to late Frasnian, depositing an up to 1600 m thick succession of coral-stromatoporoid peri-reefal deposits, *Amphipora* bank interplatform deposits and peritidal algal laminites and *Amphipora* wackestones (Hladil 1986, 1994). In the interval from the early Frasnian to the late Viséan the shallow-water carbonate shelf was gradually destroyed as a result of an incipient crustal extension and enhanced subsidence rate, creating a series of half-graben basins filled with up to 300 m thick successions of carbonate turbidites, debris-flow deposits, red nodular pelagic carbonates and finally pelagic shales with trilobites (Kalvoda et al. 1996a, 1999).

Sedimentary successions of the Ludmírov Facies were deposited upon the less stable Brunovistulian Terrane basement. At the base of the succession there is a thin blanket of terrestrial and marine siliciclastics of Emsian to early Eifelian age, which are overlain by an up to 20 m thick succession of deep-water, tentaculite- and trilobite-bearing shales of early Eifelian age. The siliciclastics pass upward into an about 100 m thick succession of upper Eifelian to lower Givetian carbonates indicating deposition in platform margin to platform foreslope setting. In early Givetian the carbonate platform margin was de-

Table 1 Schematic comparison of the geological structure of the Brno and Bolu massifs.

Brunovistulicum	Istanbul Zone
1) Lithology	**1) Lithology**
Metaophiolites Metasediments+volcanics Granites	Metagranitoids, Metaophiolites Metasedimentary-volcanic succesion
2) Geochronology	**2) Geochronology**
Ophiolites- < 725±Ma **Granites- 580–590 Ma**	Metasediments- ~900–700 Ma **Metagranites- 560–590 Ma**
3) Tectonic setting of granitoids	**3) Tectonic setting of granitoids**
Diorites+tonalites = Volcanic arc (^{87}Sr/^{86}Sr – 0.705–0.707; εNd –1 to –2)	Metatonalites = Volcanic arc ^{87}Sr/^{86}Sr ~ 0.705; εNd 2.1–2.2
Granites = Volcanic arc with crustal contamination (^{87}Sr/^{86}Sr – 0.708–0.710; εNd –4 to –7)	Granites = Volcanic arc with crustal contamination ^{87}Sr/^{86}Sr ~0.708; εNd –5
4) Metamorphism	**4) Metamorphism**
Variable – very low grade to amphibolite facies. Western part affected by Variscan tectonics.	Mostly amfibolite facies, strong deformation, imbrication.

stroyed, giving way to an approximately 170 m thick calciturbidite succession indicating an overall extensional tectonic regime (Bábek 1996). The deposition of carbonates was finally replaced by pelagic shales, radiolarites and distal carbonates of early Famennian to Tournaisian age that were presumably related to terminal cessation of carbonate platform growth in the Ludmírov Facies source area.

The Drahany Facies Domain comprises a series of tectonic relics of submarine volcanic seamounts covered with thin caps of reef limestones, calciturbidites, tentaculite-bearing pelagic carbonates and pelagic radiolarian shales. These successions of Pragian to late Tournaisian age reflect evolution in a tectonic setting located relatively further offshore than the Moravian Karst Facies and Ludmírov Facies that are parts of the Laurussian continental margin (Galle et al. 1995, Kalvoda et al. 1996b). The geochemistry of Devonian and Tournaisian alkali basalts and tholeiites of the Drahany Facies volcanic complex revealed WPB and MORB magma sources indicating evolution on extremely thin continental crust and/or oceanic crust (Přichystal 1990, Souček 1981). The pre-Devonian basement of the Drahany Facies is not known.

The Vrbno Facies Domain was deposited on top of the Brunovistulicum, which was sheared, ductile deformed and metamorphosed during the final phases of the Variscan orogeny to become a part of the Silesicum as assumed by Cháb et al. (1990) and Schulmann and Gayer (2000). The Vrbno Facies is composed of Pragian to Famennian successions of submarine acid, intermediate and basic volcanics evolving as a result of within-plate continental rifting (Patočka – Valenta 1990) and interfingering with marine siliciclastics and sparse, small carbonate patches (Hladil 1992).

As is the case with the Vrbno Facies Domain, the Tišnov Facies evolved upon a Brunovistulian Terrane-derived basement, that was metamorphosed in its marginal parts during the Variscan orogeny and which is commonly referred to as the Moravicum (Mísař – Urban in Dallmeyer et al. 1995). The Tišnov Facies comprises a shallow water succession of lower Devonian to Givetian marine quartzose sandstones and conglomerates and Givetian to Frasnian algal laminites and *Stachyodes* patch reefs (Hladil 1992).

In the Tournaisian to late Viséan interval the pre-flysch depositional regime in the Brunovistullian Terrane was gradually replaced by an eastward prograding flysch (Culm facies). The flysch facies recorded a multiphase deposition in early Viséan to early Namurian remnant and foreland basins developing as a result of the closure of the Moravo-Silesian part of the Rheno-Hercynian basin system (Kumpera – Martinec 1995, Hartley – Otava 2001).

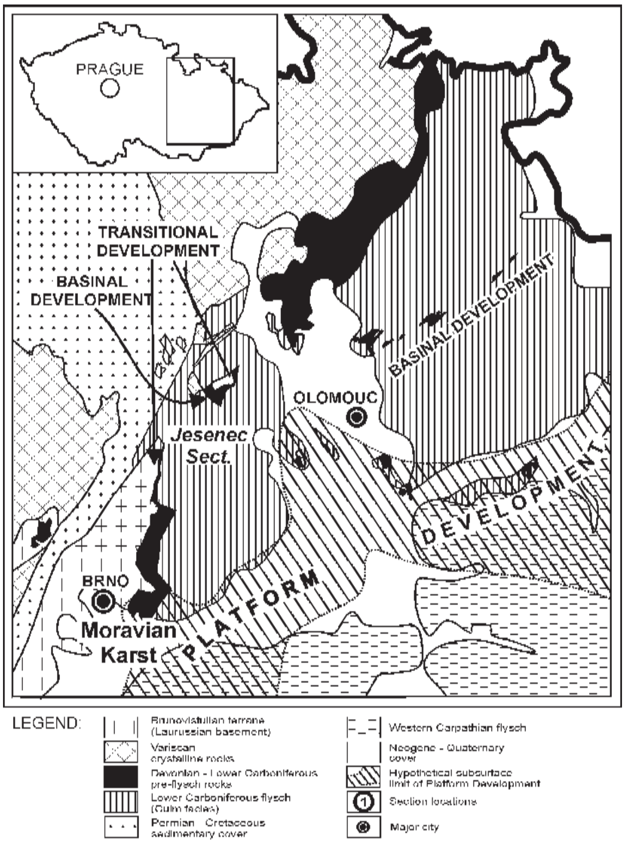

Fig. 5 Simplified geological map of Moravia with the location of three major pre-flysch developments. According to Kalvoda et al. (1999).

Basic lithostratigraphy, biostratigraphy, rough paleogeographic constraints and the deformational history of the Drahany and Nízký Jeseník basins have been proposed by several authors during the last 30 years (Čížek and Tomek 1991, Dvořák 1994, Grygar and Vavro 1994, Kumpera 1971, 1983, Kumpera and Martinec 1995). The basins were filled with an up to 12 km thick successions of deep-marine siliciclastic turbidites, fine-grained turbidites, debris-flow deposits and olistoliths and they were most probably connected, as suggested by their similar paleocurrent and clastic provenance patterns (Kumpera 1983, Hartley and Otava 2001). The flysch successions of the Moravian-Silesian region show a distinct W–E to NW–SE polarity in age and grain composition from an older, immature greywacke composition to younger, more mature quartzose sandstone composition. Hartley and Otava (2001) assumed that these observations represent typical features of a peripheral foreland basin, with the orogenic wave migrating towards the foreland. The Moravian Culm foreland basin was initiated at the time of emplacement of the Moldanubian nappe pile at the eastern margin of the Bohemian massif between 341 and 337 Ma (Hartley and Otava 2001, Schulmann and Gayer 2000). According to Kumpera and Martinec (1995), however, the basins underwent polyphase depositional evolution, which they subdivided into a lower to middle Viséan remnant basin phase and upper Viséan to lowermost Namurian peripheral foreland basin phase. This alternative view is supported by the geochemistry of pre-flysch MOR-type basalts of Devonian to Tournaisian age, which were incorporated into the flysch accretionary wedge (Souček 1981).

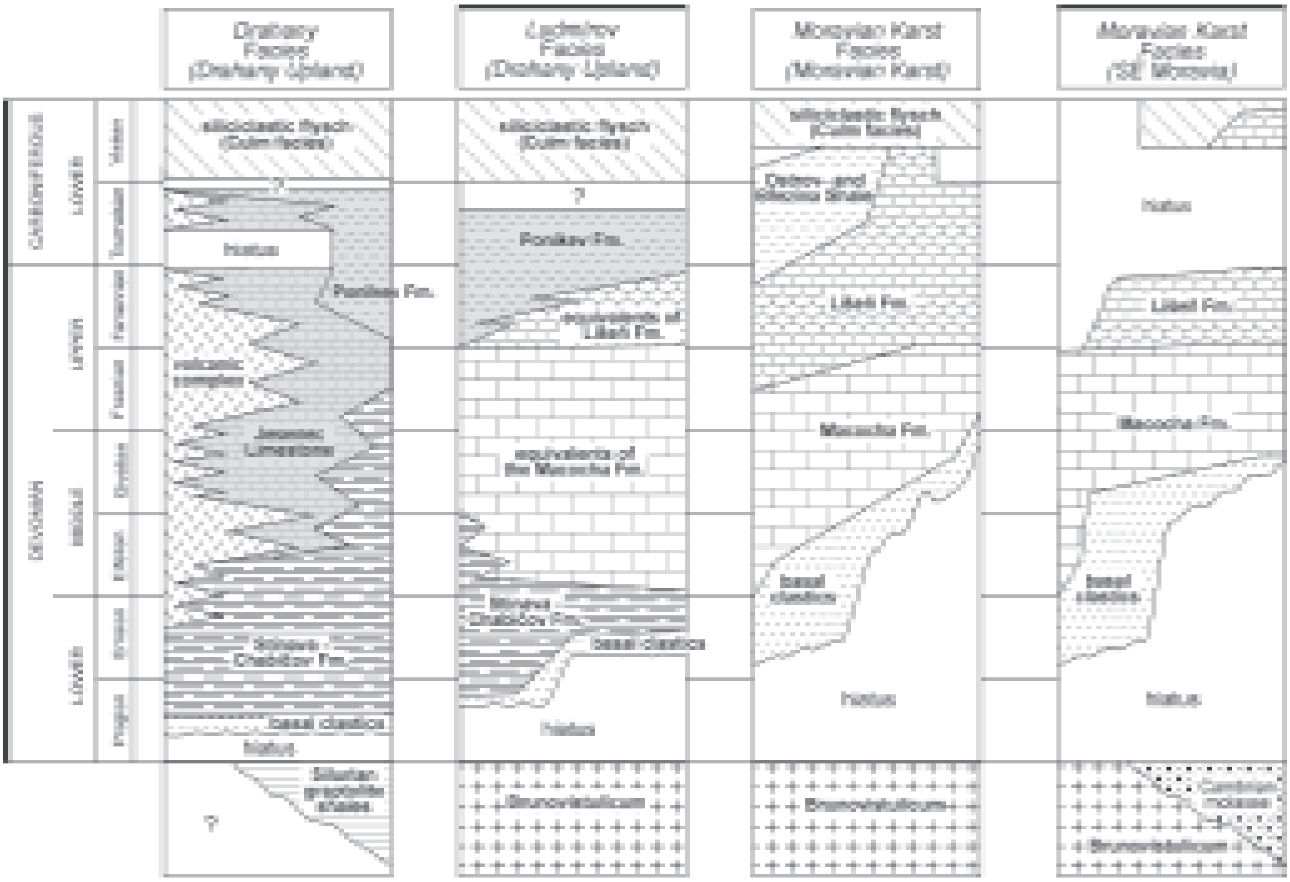

Fig. 6 Schematic correlation of the Paleozoic sedimentation in central and E Moravia.

Deep-marine foreland siliciclastics of the Culm facies pass gradually upward into the Namurian–Westphalian Carboniferous coal-bearing paralic and lacustrine molasse reaching about 3800 m of thickness. The molasse sedimentation reflects the final evolutionary stages of the peripheral basin inherited from deposition of the underlying flysch. In the eastern part of the Brunovistulian Terrane, molasse deposits directly overlie the pre-flysch basement.

In the western part of the Brunovistulian Terrane, the red siliciclastics of aluvial fans and limnic deposits of the Boskovice Furrow document the extension in late phases of the Variscan orogeny.

D.3. Malopolska and Lysogory Terranes

In the Malopolska Terrane lower Ordovician basal clastics (predominately conglomerates) are followed by Ordovician to lower Silurian limestones, Silurian graptolite shales and upper Silurian greywackes with volcanic source rocks (see Fig. 7) (Stupnicka 1992, Unrug et al. 1999). A slightly different development can be recognized in an eastern covered part of the Malopolska Massif which Belka et al. (2000) call the San Block. Here the Ordovician and Silurian sequence lie conformably on the Cambrian succession.

Ordovician–Silurian sediments were strongly affected by Scandian-Acadian deformation (Unrug et al. 1999) and after a period of erosion lower Devonian continental quartzitic sandstones and red shales were deposited (Belka et al. 2000). The overlying deepening upward sequence is composed of Eifelian to Frasnian carbonates, Famennian shales with limestone intercalations and lower Carboniferous cherty shales with radiolarites with abundant felsic volcanic detritus. The deposition of synorogenic distal flysch started by the end of early Carboniferous (Dvořák et al. 1995, Kumpera et al. 1995). The sequence was folded in the late Visean and after a period of erosion overlain by upper Permian clastics (Stupnicka 1992).

In the Lysogory Terrane the data on lithological development are based on papers by Stupnicka (1992), Valverde-Vaquero et al. (2000) and Belka et al. (2000).

The Middle Cambrian–Tremadocian clastic sequence is overlain by limestones and basinal graptolite shales of the late Ordovician to early Silurian age. A hiatus, comprising Arenig, Llanvirn and Llandeilo time and disconformably overlying Silurian sediments are reported over a major part of the terrane by Unrug et al. (1999). Late Silurian consists of fine grained greywackes and mudstones interbeddded with volcaniclastic rocks. The Devonian sequence starts with polymict sandstones and claystones with tuffs of continental and marine origin followed by carbonates in the middle and late Devonian and shales in latest Devonian and Tournaisian. The absence of angular unconformities in the pre-Carboniferous stratigraphy represent a significant and distinctive feature.

D.4. Moesian Terrane and Scythian Platform

In the Moesian Terrane the data on the Paleozoic lithological development come from papers by Yanev (1997), Haydoutov and Yanev (1997) and Seghedi (1998). The Paleozoic sequence starts with 510 m of Ordovician quartzites and argillites; nevertheless a Cambrian age in some parts cannot be excluded. This is followed by Silurian black and greyish–black argillites, marls and clayey limestones and lower Devonian pelites. At the top, coarse clastics of a Middle Devonian age are overlain by shallow water platform limestones and evaporites. In much of the early Carboniferous biodetrital limestones dominate. At the end of the Visean, the marine environments retreated to the east and a very thick siliciclastic succession, initially paralic and, from the Namurian to the Westphalian, limnic, fluvial and coal-bearing was deposited in Dobrogea. The Permian sediments are typical inmature red clastic rocks, in the upper Permian deposits of anhydrite and halite also occur.

In the Scythian Platform the presence of Ordovician and Silurian is strongly suggested by palynological data (Vaida – Seghedi 1997). The thick Lower Devonian terrigenous sequence often unconformably overlies Vendian deposits. It is continental at the base and marine at the top. The middle–upper Devonian carbonate sequence with evaporites and thin terrigenous interbeds is overlain by the dark coloured carbonate succession of the early Carboniferous age. In the top, paralic and limnic formations of the Visean–middle Namurian age and Permian red clastics (sandstones, aleurites, argilites), evaporites and volcanoclastics were deposited.

The Scythian Paleozoic structures show two important tectogenic episodes: the late Devonian one, that deformed the Vendian–Devonian formations and generated schistosity, and a mid-Carboniferous one of lesser tectonic intensity.

D.5. Istanbul Zone

As mentioned above, the Istanbul Zone is composed of the Istanbul Terrane and the Zonguldak Terrane.

The data on lithological development of the Zonguldak Terrane are based on papers by Dean et al. (1997, 2000), Görür et al. (1997), Göncüoglu (1997) and Kozur and Göncüoglu (1998). The localization of Paleozoic outcrops can be seen in Fig. 4.

Cambrian rocks represented by arkosic sandstones and reddish coarse clastics are only predicted and a Cambrian age for them has yet to be confirmed (Dean et al. 1997). Sandstones and siltstones which start the Ordovician–Silurian sequence are overlain by nonfosiliferous quartzites. At the top, mudstones with few quartzitic beds of Arenig–early Llanvirn age occur followed by Caradoc black limestones and dark-grey siltstones and mudstones. The estimated thickness of the Ordovician is about 1300 m. Black and grey graptolitic shales and mudstones with subordinate pelagic limestone intercalations correspond to the early Silurian.

Disconformably overlying Devonian basal clastics are represented by conglomerates, quartzitic sandstones and shales. The Caledonian discordance is post-Silurian/pre-Emsian and is connected with thermal alteration (Kozur – Göncüoglu 1998). At the top, they are followed by shallow water platform limestones ranging from Emsian to Visean and by a middle to upper Carboniferous coal-bearing molasse. This sequence starts with paralic sedimentation of shales, sandstones and coal seams of a Namurian age followed by Westphalian continental clastics with the most important coal seams. The contact of green-coloured shales and sandstones with the red sandstone intercalations that are probably Stephanian in age with underlying rocks is not clear.

The data on lithological development in the Istanbul Terrane are based on papers by Haas (1968), Görür et al. (1997), Göncüoglu (1997) and Kozur and Göncüoglu (1998).

The Paleozoic rocks are here tectonically superposed on neighbouring units (Okay et al. 1994) and start with the sequence of 1000 m of conglomerates, arkosic sandstones and violet to pinkish mudstones (see Fig. 7), interpreted as of alluvial fan origin. While the precise age is not known, an Ordovician age is considered likely based on the position below overlying lower Silurian sediments. Nevertheless, similar lithologies in the above discussed terranes are consistent also with a Cambrian age.

The Llandovery shallow marine sequence starts with laminated quartz arenites with *Cruziana* with interbeds of greenish grey shale. Overlying graptolite shales are followed by lower Silurian shales and siltstones with some limestone beds. In Wenlock–Přídolí shallow water limestones were deposited, followed by shallow water limestones and clastics in the Devonian up to the Emsian. In deeper environments nodular limestones pass into the overlying fossiliferous shale of Early Devonian age (Görür et al. 1997). In the middle Devonian a deepening upward sequence starts with alternating calciturbidites and shales. Above, with an increasing frequency of limestone beds, the calciturbidites pass into a typical cherty and nodular deep-water micritic limestone of late Devonian age and radiolarian cherts of late Tournaisian–early Visean age intercalated with shales containing phosphatic nodules. The presence of siliciclastic turbidites suggests that the transition to the flysch sequence had already begun.

The Culm facies of Thracian flysch comprise alternating greywackes, siltstones and shales. In a few localities the youngest turbidites are associated with shallow marine bioclastic limestones (late Visean) that probably are olistholiths (Cebeciköy Limestone). The Thracian flysch is unconformably overlain by Triassic sandstones.

The pre-flysch sedimentation represents a south facing Atlantic-type continental margin. The main Variscan event took place during the early Carboniferous (late Visean to early Namurian) (Okay et al. 1994).

E. Paleobiogeography

E.1. Cambrian–Silurian

Controversial results come from the Upper Silesian part of the Brunovistulian Terrane. The Early Cambrian trilobite associations reported by Orlowski (1975) are regarded by Belka et al. (2000) as characteristic of the Baltic zoogeographic province. In the view of Nawrocki et al. (2001) the fauna is, however, endemic or inconclusive for paleogeography. According to Fatka and Vavrdová (1998), there exists a pronounced similarity between the Early Cambrian acritarch assemblages of the Brunovistulian Terrane and the EEC. In Ordovician, a Baltic affinity is inferred based on conodont fauna (Belka et al. 2000).

Belka et al. (2000) regard Early Cambrian olenellid trilobites in the Malopolska Terrane (Orlowski 1985) as diagnostic of the Baltica. In contrast, Jendryka-Fuglewicz (1998) reports here Early Cambrian brachiopods with Avalonian affinities that differ from the EEC. The Malopolska Terrane and EEC associations, however, represent quite different facies-environmental conditions. A progressive migration of Baltic elements is reported for Middle Cambrian brachiopod associations and Ordovician faunas belong essentially to the Baltic Province (Dzik et al. 1994, Belka et al. 2000).

In the Lysogory Terrane middle and late Cambrian brachiopods and trilobite trace fossils show Gondwana and Perigondwana affinity while the clastic material was derived both from Baltic and Gondwana sources (Belka et al. 2000).

Obviously the Cambrian paleobiogeographic data show contradictory results that are often not compatible with the data on the provenance of clastic micas (Valverde-Vaquero et al. 2000, Belka et al. 2000). This raises the necessity of a critical reexamination of paleobiogeographical data in all the aforementioned terranes. They are of little value without closer facies interpretations – faunas of different facies from the same terrane may often differ more significantly than do faunas of the same facies in different terranes.

In the Moesian Terrane the Silurian bivalvian assemblages are closely related to those known from the EEC sediments of Eastern Poland (Iordan 1999) and elements of both Rhenish and Bohemian faunas are present in the Devonian. The gastropod assemblages are characteristic of the tropical-subtropical marine conditions of the Old World Realm such as in Poland, Moravia and north-western Turkey (Iordan 1999).

Arenig and early Llanvirn graptolites include taxa of both Anglo-Welsh and cosmopolitan affinities and late Arenig trilobites are Anglo-Welsh in the Zonguldak Terrane. On the other hand early Caradoc conodonts are of North Atlantic Province including Scandinavia and parts of North America (Dean et al. 1997, 2000, Kozur – Göncüoglu 1998). Tremadoc and Arenig acritarch associations yielded no Perigondwana cold-water forms and contain cosmopolitan acritarchs and early Caradoc conodont *Amorphognathus tvaerensis* typical in the warm-water faunas of Scandinavia, Estonia and North America (Dean et al. 1997, Kozur – Göncüoglu 1998). The shift of paleobiogeographic affinities from Perigondwana to Baltica in the Zonguldak Terrane may be thus compatible with the AvalonianTerrane Assemblage.

In the Istanbul Terrane, late Caradoc ostracods and brachiopods include a typical Baltoscandian genus *Piretella*, *Klimophores* very common in Baltica and also present in Perigondwana and *Eochilina* known only in Siberia and Laurentia (Kozur – Göncüoglu 1998).

The Ordovician of the Istanbul Zone contains apparently a fauna with close connection to Avalonia (Perigondwana) in the early Ordovician and to Baltica and Siberia/Laurentia in the late Ordovician. Consequently, it may have been already located close to Baltica in the late Ordovician.

E.2. Devonian–Carboniferous

Calcareous foraminifers are the only group that can be well applied in all the terranes in the Devonian–Carboniferous interval. Kalvoda (2001, 2002) has distinguished, based on the study of late Frasnian, late Famennian and late Tournaisian–early Visean associations, the Fennosarmatian and Armorican provinces of the North Paleotethyan Realm. The Fennosarmatian Province also comprised terranes of the Brunovistulian group which included the Lysogory, Malopolska, Brunovistulian, Moesian and Istanbul Zone while the Armorican Province included Armorican Terrane Assemblage and Intra-Alpine terranes (see Fig. 9).

The diagnostic features of the Fennosarmatian Province can be summarized in the following way: the late Frasnian diversified *Multiseptida-Eonodosaria-Eogeinitzina* association, late Famennian diversified *Quasiendothyra* association, late Tournaisian–early Visean Kizel-Kosvin association and the presence of some middle and late Visean taxa reported only at the southern margin of Laurussia (Kalvoda 2001, 2002).

In the Zonguldak Terrane, a typical Fennosarmatian association has been recognized (Kalvoda 2001) while the Istanbul Terrane *s. s.* is included with some reservation (Kalvoda 2002). Foraminiferal fauna is poor here and richer associations are reported only in the middle–upper Visean Cebeciköy Limestone (Kaya – Mamet 1971, Kaya in Catal et al. 1978) which may represent olistholiths in the Thracian flysch. The faunal list contains the typical middle–late Visean North Paleotethyan

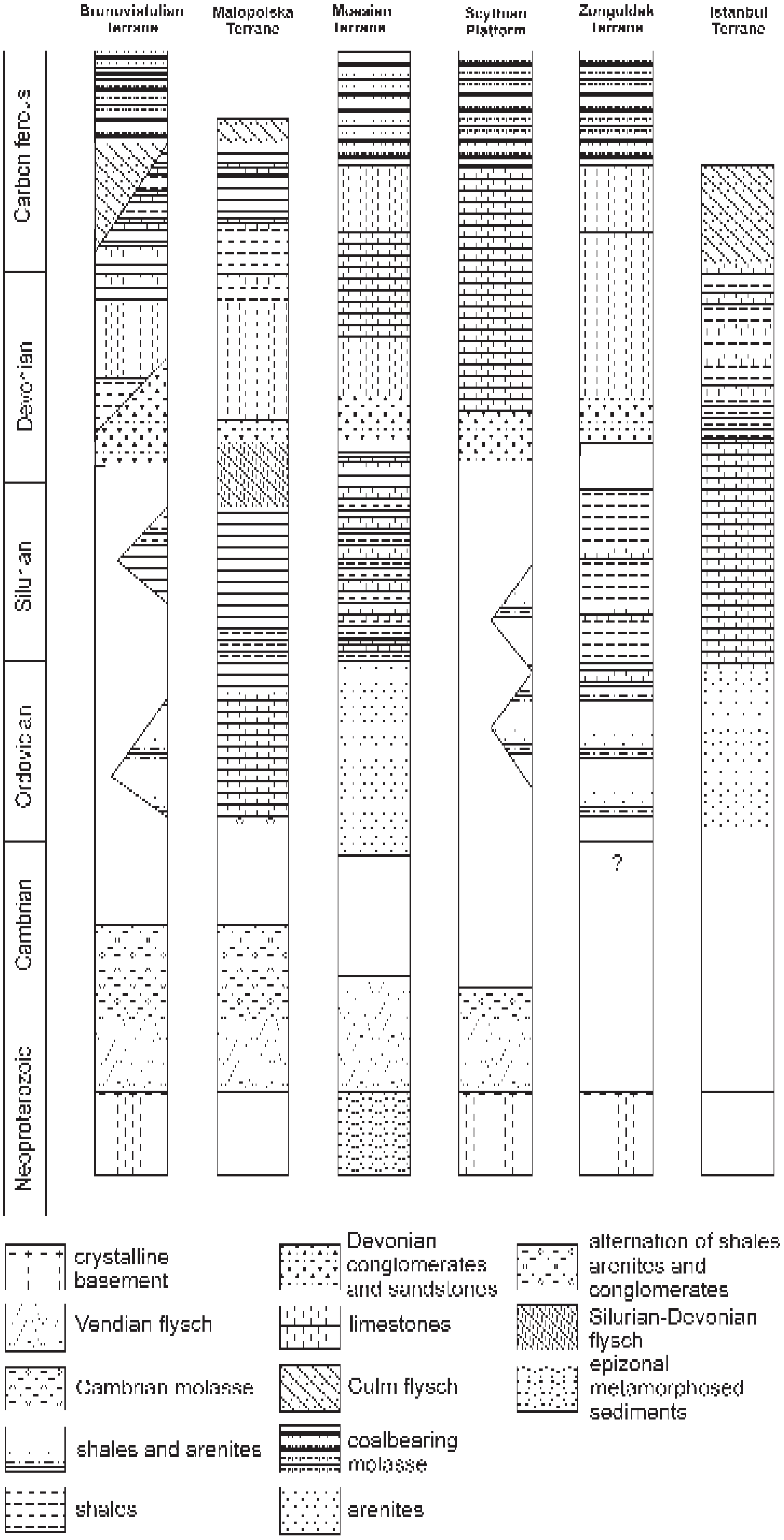

Fig. 7 Correlation scheme of lithological developments in the Brunovistulian, Malopolska, Moesian, Zonguldak and Istanbul terranes and western part of the Scythian Platform.

association of *Eostaffella*, *Forschiella*, *Lituotubella magna*, *Archaediscus karreri*, *Vissarionovella tujmasensis*, *Globoendothyra globulus*, *Omphalotis omphalota* and bilayered paleotextulariids. Nevertheless, as there is no notion of the Carboniferous separation of the Zonguldak and Istanbul terranes, they are both regarded as a part of Laurussia in geotectonic position similar to the Rhenohercynian and Subvariscan zones in Central Europe.

F. Discussion

F.1. Cadomian Basement

A Cadomian basement was found only in the Brunovistulian Terrane and the Istanbul Zone. Although a perfect fit between both units could not be established, because of their different size, degree of exploration, and post-Cadomian evolution, the broad similarity in the geological structure, lithology and geochronology between both units may point to a cognate origin (see Tab. 1, Tab. 2).

The broad fit of the geological structure (older ophiolites and metamorphic rocks surrounded by younger granites) and of the geochronology between the Brunovistulicum (BVT) and parts of the Eastern Desert in Egypt (El Gaby et al. 1988) may indicate the close relation of the BVT to the northern Gondwana margin during the Cadomian orogeny (Belka et al. 2000, Finger et al. 1989, Finger et al. 2000a). On the other hand, there also seems to exist a good correlation with the geochronological data from the Urals. Scarrow et al. (2001) reported the Cadomian Enganepe 670 Ma ophiolite and 560 Ma calc-alkaline granites (Gee 2001) in Polar Urals. In southern Ural an amphibole age of 718±5 Ma and muscovite ages of 550±5 Ma were obtained in the Beloretsk Metamorphic Complex (Glassmacher et al. 1999). The accretion of an exotic Beloretsk Terrane to the eastern margin of the East European Platform (Glassmacher et al. 1999) may have resulted in the Vendian flysch and molasse sedimentation in the adjoining Bashkirian Megaanticlinorium (Maslov et al. 1997, Giese et al. 1999). Summarizing, it seems probable that the Cadomian Avalonian arc extended along the entire length of the eastern margin of Baltica. In the SW part of Baltica Zoubek (1992) hypothesized that the Brunovistulicum, together with the central Dobrogea, represents a part of the European pericratonic Cadomides (Baikalides) rimming the SW margin of the Fennosarmatian craton. More data on the extent and geochemistry of the Uralian Cadomides are, however, needed to establish a more precise correlation with Brunovistulian and Istanbul Cadomides.

The limited isotopic data presently available for the Proterozoic basement of the Moesian Terrane do not provide strong constraints on its affinity. A correlation with the Moravo-Silesian (Brunovistulian) Terrane, which is in a similar structural position with regard to the EEC, has been proposed by Burchfiel (1975) and Matte et al. (1990).

F.2. Vendian–?Early Cambrian Flysch and Cambrian Molasse

A crucial role in the interpretations of the terrane provenance is played by the Vendian and Cambrian sequences. In central Malopolska, Brunovistulian and Moesian terranes late Neoproterozoic–early Cambrian flysch and molasse correlate well with the Scythian and Moldavian platforms. In the Istanbul Zone Vendian anchimetamorphic flysch and Cambrian sediments have not been detected so far, however, some lithologies may suggest the presence of Cambrian sediments.

The evidence on the provenance of the terranes and interpretation of the Vendian–Cambrian sequences are often contradictory, which makes it difficult to formulate a viable tectonic model. Some authors interpret the Brunovistulian Malopolska and Lysogory terranes as fragments of Gondwana (Belka et al. 2000, Crowley et al. 2000a, Winchester et al. 2002) while others prefer an origin in E Baltica (Pharaoh 1999) or in SW Baltica (Zelazniewicz et al. 1997, Zelazniewicz et al. 2001).

The model of Zelazniewicz et al. (1997, 2001) assumes the existence of the Vendian foreland basin between the BVT and EEC. In their view Malopolska, Brunovistulian and Central Dobrogea (Moesia) are crustal fragments that obliquely collided with the EEC along its present-day SW margin and remained next to it during the Phanerozoic.

Even though the close lithological similarities of the Vendian–Cambrian sequences of the Brunovistulian, Malopolska and Moesian terranes and the Scythian Platform make it tempting to adopt the idea, there are some inconsistencies in the model. First of all there is still no proof of a Cadomian-age orogeny at the southern margin of Baltica. Moreover, the flysch foreland sequence in central Dobrogea is regarded as Neoproterozoic–early Cambrian, while the folding and metamorphosis is Vendian, similar to flysch sequences in the Malopolska and Brunovistulian Terrane. If we do not accept the idea of significant dextral translations, the model is also in contradiction with sedimentological data from the Peri-Tornquist and Baltic basins (Poprawa et al. 1999, Nawrocki et al. 2001, Poprawa – Paczesna 2001, Sliaupa – Ershov 2001).

Belka et al. (2000), based on the study of the provenance of clastic micas and interpretations of previous paleobiogeographic studies, invoked the quick transit of exotic Cadomian terranes (Brunovistulian, Malopolska) across the Iapetus Ocean from Gondwana to Baltica. In their view, the Malopolska Terrane was the first Gondwana-derived microplate that accreted to the margin of Baltica during the “Sandomierz Phase” after Mid-Cambrian and before late Tremadocian time.

Even this model has, however, some inconsistencies. The first point is that some detrital micas reported by Belka et al. (2000) may be early Cambrian and thus nearly coeval in age with the the trilobite fauna of the inferred Baltic affinity. Consequently, the time interval may have

Table 2 Correlation scheme showing the main characteristics of the terranes based on references to the individual terranes discussed in the text. Some terranes such as e.g. the Lysogory and Malopolska terranes may have experienced two accretions, first the Vendian (or Cambrian) docking, then early Paleozoic rifting away from Baltica and the subsequent Silurian docking. The Cadomian basement is known only in the Brunovistulian Terrane and in the Istanbul Zone while Cadomian events represented mostly by Vendian flysch and Cambrian molasse sedimentation are more widespread, recorded in all terranes except the Istanbul Zone. The Caledonian events are well demonstrated only in the Malopolska Terrane (Caledonian flysch and deformation) and the Lysogory Terrane (Caledonian flysch); in the Moesian and Zonguldak terranes, Devonian unconformities related to the Caledonian events are reported. All the terranes were more or less strongly affected by Variscan orogeny – either directly by Variscan thrusting (the Istanbul Terrane, and in part the Brunovistulian Terrane and Scythian Platform) or indirectly by the deposition of Variscan flysch and molasse sequences.

Terrane	**Crystalline basement**	**Accretion to Baltica (Laurussia)**	**Orogenic events**	**Carboniferous foraminiferal affinity**
Scythian	Neoproterozoic	?Vendian	?Cadomian ?Caledonian Variscan	Fennosarmatian Province
Lysogory	unknown	?Vendian or Cambrian Silurian	Cadomian Caledonian Variscan	Fennosarmatian Province
Malopolska	unknown Silurian	?Vendian or Cambrian Cadomian	Caledonian Variscan	Fennosarmatian Province
Brunovistulian	Cadomian	?Vendian early Paleozoic	Cadomian Variscan	Fennosarmatian Province
Moesian	Archean ?Cadomian ?Devonian	?Vendian Cadomian	?Caledonian Variscan	Fennosarmatian Province
Zonguldak	Cadomian	Devonian	Cadomian Caledonian Variscan	Fennosarmatian Province
Istanbul	?Cadomian	Devonian	?Cadomian Variscan	Fennosarmatian Province
Armorican group	Cadomian	Carboniferous	Cadomian Caledonian Variscan	Armorican Province

been too short to expose the Cadomian source rocks, deposit the sequence, separate the Malopolska Terrane from Gonwana and move it the long distance to the Baltica margin. The second point is that if we accept a significant dextral translation (Lewandowski 1993, 1994, Pharaoh 1999, Winchester et al. 2000) we can not compare the detrital micas with Fennoscandian source rocks of the EEC in Poland and have to look rather in the Sarmatian part of the EEC.

The third model argues for the origin of Cadomian terranes along the eastern Uralian margin of Baltica and their large-scale dextral dispersal along the Tornquist margin of Baltica (Pharaoh 1999). More data on the extent and geochemistry of the Uralian Cadomides are, however, needed to establish a more precise correlation with Central European terranes and with the Istanbul Zone.

The antagonism of the mentioned models is minimized in the interpretation of Hartz and Torsvik (2002). They proposed that Baltica from 580 to 550 Ma was inverted and drifted south toward Gondwana and that Baltica's northern margin (present-day coordinates) then remained close to the Gondwana margin until the Early Ordovician (see Fig. 8). This rift-trench-right-lateral fault model directly links contraction between Baltica and Gondwana to Timanian-Avalonian-Cadomian events (Roberts 2001) and relates them to the opening of the Iapetus Ocean. The dextral translation of Cadomian terranes along Baltica could have been then related to the counterclockwise rotation of Baltica to its post-Cambrian right-side-up position (see Fig. 8).

The paleobiogeographic data in the Cambrian may be crucial in this respect; unfortunately, they are still not conclusive enough to give an unequivocal constraint to the paleogeography of the Brunovistulian and other terranes of the group in central Europe. Paleomagnetic data suggest a nearly equatorial position in the Early Cambrian and its paleolatitude differs by about 25° from the coeval palelatitude of the closest margin of Baltica (Nawrocki et al 2001).

In summary, it can be stated that the Vendian–Cambrian data are often contradictory and that without a careful reexamination of biostratigraphic, paleobiogeographic, geochemical, sedimentological, paleomagnetic and geochronological data along the TESZ, no further advancement is possible.

F.2. Ordovician–Carboniferous Sequences

There seems to exist a broad fit in the lithological development in all the discussed units (see Fig. 7). In the Ordovician, arenites with variable amount of shales and argilites occur in most terranes. Only in the Malopolska

Terrane are the basal Ordovician clastics overlain by a carbonate sequence. In the Istanbul Terrane the oldest thick sequence of conglomerates, arkosic sandstones and violet to pinkish mudstones (Görür et al. 1997) may resemble the Cambrian sequences in other terranes. There is a poor sedimentary record in the Brunovistulian Terrane and Scythian Platform, where the Ordovician sediments are quite rare.

In the Silurian, shale facies with a variable amount of basinal carbonates and rare arenites predominate. Again, the Silurian is only rarely represented in the Brunovistulian Terrane and the Scythian Platform. The Caledonian orogeny is manifested best in the Malopolska and Lysogory terranes where a late Silurian flysch sequences are documented (see Fig. 7). In the Istanbul Terrane, shallow water limestones predominate in contrast to the Zonguldak Terrane, where graptolitic shales and mudstones with subordinate pelagic limestone intercalations became established. This pattern, as well as the absence of the Devonian unconformity in the Istanbul Terrane, is consistent with the assumed distal and proximal position of the Istanbul and Zonguldak terranes respectively, during the Caledonian orogenic event.

The available evidence shows close similarities between all terranes in the Devonian–Carboniferous interval. In a generalized scheme, the basal clastic formation is followed by a predominatingly carbonate preflysch sequence topped either with Culm flysch (proximal foreland) and/or a coal bearing molasse. In terranes with a more mobile basement (Istanbul Terrane, partly Brunovistulian and Malopolska Terrane), deeper sequences occur represented by calciturbidites, basinal shales and radiolarites, while in the remaining units shallow water carbonates predominate.

There is a strong evidence of close similarities both in the Devonian and Carboniferous lihological development, facies differentiation and in the main Variscan events (late Visean to early Namurian and Westphalian–Stephanian – Okay et al 1994, Grygar 1997) between the Brunovistulian Terrane and the Istanbul Zone.

The shallow water sedimentation of the Zonguldak Terrane compares well with the platform Moravian Karst Facies development of the Brunovistulian Terrane. Here the same sequences as in the Zonguldak Terrane were encountered (basal clastics, shallow platform carbonates of the middle–upper Devonian and lower Carboniferous topped by coal-bearing Namurian paralic and Namurian–Westphalian limnic molasse) in the eastern and especially northeastern part of the terrane, which represented a distal foreland during the Variscan orogeny (see Fig. 7). The same shallow water sequences are also recognized in the Moesian Terrane and in the Scythian Platform. This similarity may favour the views that assume the Carboniferous dextral translation of the Brunovistulian Terrane and locate it in the proximity of the Scythian Platform (Grygar 1998). Nevertheless, the close similarities of the lithological development at the SE margin of Laurussia make also a more distal position of terranes viable.

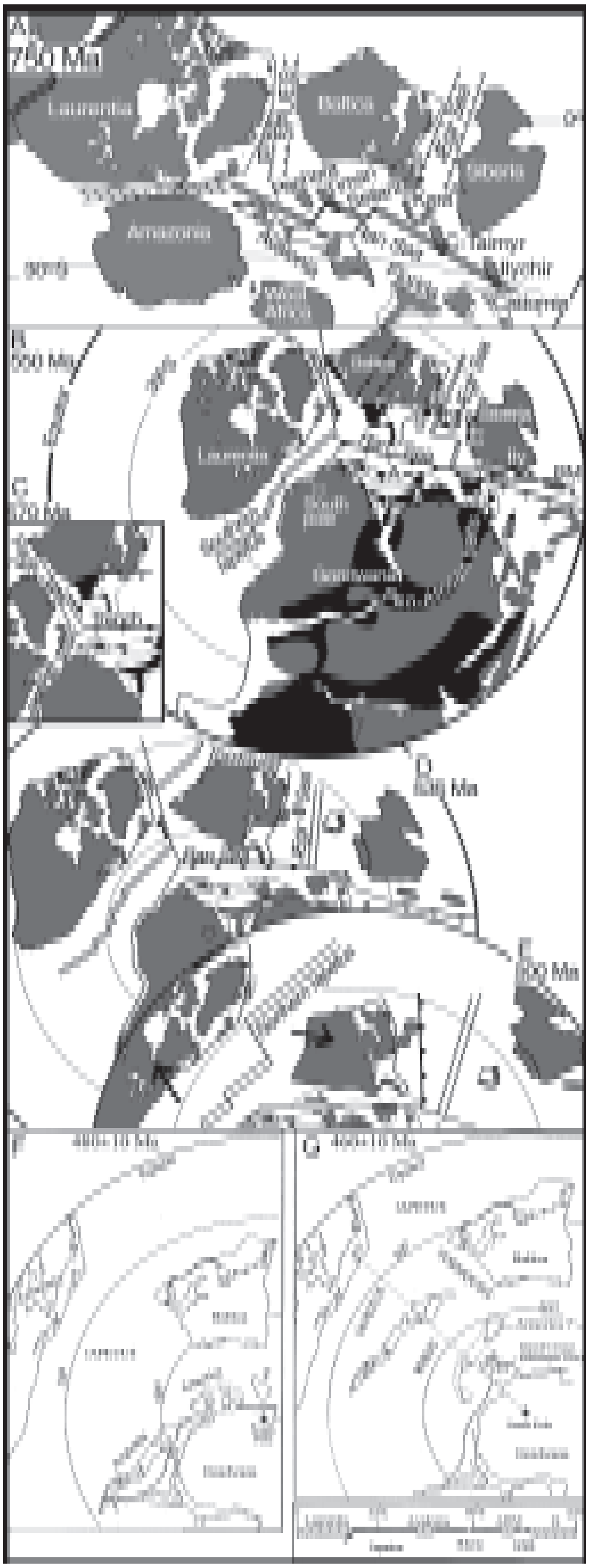

Fig. 8 Paleogeographic scheme showing the relative position of Baltica and Gondwana in Neoproterozoic–Ordovician interval. In black the late Neoproterozic orogenic belt – Panafrican. Cadomian-Avalonian and Timano-South Ural. Modified after Hartz & Torsvik (2002) and Nysaether et al. (2002). Abbreviations: C – Cadomia; F – Florida; P – Perunica; K – Kara; I – Iberia; M – Massif Central; S – Säve Nappe; Sl – Seiland igneous province; CT – Central Taimyr; B – Barentia; Y – Yenisei Ridge; GSB – Galicia-Southern Brittany Ocean; SPUEG – southern peri-Urals–East Greenland.

Fig. 9 Early Carboniferous paleogeographic scheme showing the location of paleobiogeographic units and terranes discussed in the text with alternative positions of the Sakarya and North Anatlolide-Tauride Terranes. According to Kalvoda (2002). Abreviations: KAZ – Kazakh microcontinent, AP – Arabian Plate, WC – Western Cimmeria, NAT – North Anatolide -Tauride Terrane, Sa – Sakarya Terrane, SEU – group of South European terranes, I – Istanbul Zone, M – Moesian Terrane, B – Brunovistulian Terrane, Ma – Malopolska Terrane, L – Lysogory Terrane, Mold – Moldanubian Terrane, ARM– Armorica, EAV – Eastern Avalonia, WAV – Western Avalonia, IBR – Iberia, MEG – Meguma, T – Turan Terrane, Ta – Tarim Terrane, NAT –North Anatolid-Tauride Terrane.

In contrast, the deeper sequences of the Istanbul Terrane correlate well with the Ludmírov Facies development of the Brunovistulian Terrane. The facies of calciturbidites, nodular limestones and shales topped by shales with radiolarites and Culm flysch are in a tectonic contact with the basement in both mentioned areas. In our view, the lithological differencies between the Zonguldak and Istanbul Terranes can be attributed to their distal and proximal position respectively during Variscan orogenic events in similar way as the differences between the Moravian Karst and Ludmírov facies (see Fig. 6, 7).

The close Devonian–Carboniferous similarities of all the terranes of the Brunovistulian group to Laurussia are in good accord with the outlined paleobiogeographic ties. Consequently, the comparison of the Paleozoic sequences of the Istanbul Zone with the southern side of the Variscan chain (Görür et al. 1997) or with the Intra-Alpine Terrane (Stampfli 1996, Neubauer – von Raumer 1993, Neubauer 2002) are only general and based mostly on the similarities of the Cadomian basement. In our view, a more plausible alternative is that during the Variscan events the Istanbul Zone represented a lower plate at the southern margin of Laurussia and thus the Istanbul Terrane and the Zonguldak Terrane correlate very well with the Rhenohercynian and Subvariscan Zones respectively.

G. Conclusions

There seem to exist close similarities in the tectonostratigraphic and paleogeographic development of terranes at the southern Baltica – Laurussia margin during Paleozoic and in part during Neoproterozoic.

A broad similarity in the geological structure, lithology and geochronology between the Cadomian crystalline units of the Brunovistulian Terrane and the Istanbul Zone may point to a cognate origin. Such an interpreration may be, however, in contradiction with a Baltica provenance of the Brunovistulian Terrane as the Ordovician Anglo-Welsh, i.e. Perigondwana faunistic affinities in Istanbul Zone are being reported. This fact raises the possibility of a different provenance (both Baltica and Gondwana) for the Cadomian terranes. To clarify whether the Gondwana or Baltica provenance is more plausible requires, however, more precise data on the paleobiogeography, geochronology, geochemistry and location of the Cadomian events at the margins of Baltica.

In the central Malopolska, Brunovistulian and Moesian terranes, an important role in the interpretation of the provenance is played by Vendian and Cambrian flysch and molasse sequences, which correlate well with the Scythian Platform, and may have been deposited in a single foreland basin.

There seem to exist a broad fit in the Ordovician and Silurian sequences in all units. Closer interpretations are, however, hampered by a poor record in some terranes. A close similarity in lithological development is apparent in the Devonian–Carboniferous interval and corresponds well with the Fennosarmatian faunistic affinities of the studied terranes.

The Zonguldak and Istanbul terranes were in proximal and distal position during the Caledonian events and in distal and proximal position during the Variscan events and their facies and tectonic development compares well with the Moravian Karst and the Ludmirov Facies, respectively, of the Brunovistulian Terrane. In our interpretation, the Istanbul Zone was in a similar geotectonic position as the Brunovistulian Terrane, representing a lower plate at the southern margin of Laurussia during Variscan time. This zone thus can not be viewed as an equivalent to the Intra-Alpine or other Variscan terranes of the southern branch. The interpretation that best fits the available evidence is that the Istanbul Terrane and the Zonguldak Terrane may thus be correlated with the Rhenohercynian and Subvariscan zones of Central Europe, respectively. Both the Brunovistulian Terrane and the Istanbul Zone may have been located along the Scythian Platform (Odessa shelf) (Okay et al.1994, Lewandowski 1993, Grygar 1997) in Paleozoic time.

The aforementioned correlation is reinforced by the fact that similar to the way the lower plate of the Brunovistulian Terrane is juxtaposed to the Armorican Terrane Assemblage (Moldanubian and Saxothuringian terranes) (Kalvoda 2001, 2002), the lower plate of the Istanbul Zone is juxtaposed to the upper plate of the Sakarya Zone. Even though the age of this juxtaposition and the Paleozoic location is still a matter of debate, the Sakarya Zone can be regarded as a part of the Armorican Terrane Assemblage similarly as the North Dobrogea Terrane (Pharaoh 1999).

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Svrchnoproterozoický - paleozoický tektonostratigrafický vývoj a paleogeografie brunovistulického teránu a srovnání s dalšími terány na JV okraji Baltiky-Laurusie

V neoproterozoiku a paleozoiku existují značné podobnosti mezi brunovistulickým teránem a istanbulskou zónou. Geologická stavba, litologie a geochronologie kadomského brunovistulika vykazuje širokou shodu s krystalinikem istanbulské zóny. Jejich gondwanská nebo baltická afinita je zatím nedostatečně vymezena a zůstává předmětem diskusí. Vendské a kambrické sekvence v centrálně malopolském, brunovistulickém a moesijském teránu se dají velmi dobře srovnat se skytskou platformou. V istanbulské zóně přítomnost předordovických nemetamorfovaných sledů zatím nebyla potvrzena a pouze se předpokládá. V paleozoiku pozorujeme největší shodu v intervalu devon – karbon. Sedimentární záznam v zonguldakském a istanbulském teránu istanbulské zóny velmi dobře koreluje s vývojem Moravského krasu a ludmírovským vývojem. Tato korelace je posílena rovněž dobrou shodou hlavních variských deformačních fází připisovaných jak v brunovistulickém teránu tak istanbulské zóně intervalům svrchní visé-spodní namur a westphal-stephan. To spolu s paleobiogeografickými údaji podporuje interpretaci, že istanbulský a zonguldakský terán mohou být považovány za ekvivalenty rhenohercynské a subvariské zóny ve střední Evropě. Istanbulská zóna kolidovala se zónou Sakarya považovanou za součást armorického společenstva teránů.