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LATE CARBONIFEROUS–NEOGENE GEODYNAMIC EVOLUTION AND PALEOGEOGRAPHY OF THE CIRCUM-CARPATHIAN REGION AND ADJACENT AREAS

Jan GOLONKA, Nestor OSZCZYPKO & Andrzej ŚLĄCZKA

Institute of Geological Sciences, Jagiellonian University, Oleandry Str. 2a, 30-063 Kraków, Poland

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Abstract: Twelve time interval maps were constructed which depict the plate tectonic configuration, paleogeography and general lithofacies. The aim of this paper is to provide the geodynamic evolution and position of the major tectonic elements of the area within the global framework.

The Hercynian orogeny was concluded with the collision of Gondwana and Laurussia, whereas the Tethys Ocean formed the embayment between the Eurasian and Gondwanian branches of Pangea. The Mesozoic rifting events resulted in the origin of the oceanic type basins like Meliata and Pieniny along the northern margin of the Tethys. Separation of Eurasia from Gondwana resulted in the formation of the Alboran-Ligurian-Pieniny Ocean as a part of the Pangean breakup tectonic system. During the Late Jurassic–Early Cretaceous time, the Outer Carpathian rift had developed.

Latest Cretaceous–earliest Paleocene was the time of the closure of the Pieniny Ocean. Adria-Alcapa terranes continued their northward movement during Eocene–Early Miocene time. Their oblique collision with the North European plate led to the development of the accretionary wedge of Outer Carpathians and foreland basin. The formation of the West Carpathian thrusts was completed by the Miocene time. The thrust front was still progressing eastwards in the Eastern Carpathians.

Abstrakt: Dla obszaru wokółkarpackiego skonstruowano 12 map przedstawiających konfigurację płyt litosferycznych, paleogeografię i uproszczony rozkład litofacji w okresie od późnego karbonu po neogen. Przedstawiono ewolucję geodynamiczną tego rejonu na tle ruchu płyt i pozycji głównych elementów tektonicznych w globalnym układzie odniesienia.

Orogeneza hercyńska zakończyła się kolizją Gondwany i Laurusji, a Ocean Tetydy utworzył zatokę pomiędzy dwoma ramionami Tetydy – Gondwaną i Laurazją. W wyniku mezozoicznych ryftów wzdłuż północnej krawędzi Oceanu Tetydy powstało szereg basenów typu oceanicznego takich jak Meliata i basen pieniński. Ocean albo-rańsko-liguryjsko-pieniński powstał w wyniku oddzielenia się Gondwany i Laurazji jako fragment tektonicznego sytemu rozpadu Pangei. W okresie od późnej jury do wczesnej kredy rozwinął się ryft Karpat Zewnętrznych.

Na przełomie kredy i paleocenu nastąpiło zamknięcie basenu pienińskiego pasa skałkowego. W okresie od eocenu do wczesnego miocenu terany Adri-Alkapy i Karpat Wewnętrznych kontynuowały ruch w kierunku północnym, a ich kolizja z płytą euroazjatycką doprowadziła do powstania pryzmy akrecyjnej Karpat Zewnętrznych i basenu przedgórskiego. Przy końcu miocenu środkowego uformowały się ostatecznie nasunięcia Karpat Zachodnich, podczas gdy w Karpatach Wschodnich ruchy te przetrwały do końca pliocenu.

Key words: plate tectonics, paleogeography, Tethys, Mediterranean, Carpathians, Carboniferous, Triassic, Jurassic, Cretaceous, Paleogene, Neogene.

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INTRODUCTION

Twelve time interval maps were constructed which depict the plate tectonic configuration, paleogeography and lithofacies for circum-Carpathian region (Fig. 1) and adjacent areas from the Late Carboniferous through Neogene. These maps were derived from the Jan Golonka's contribution to the Mobil project, which encompassed 32 global Phanerozoic paleoenvironment and lithofacies maps aimed to evaluate petroleum systems in time and space. The original maps were constructed in a 1:25,000,000 scale with a full variety of colors and patterns linked to computer databases. The

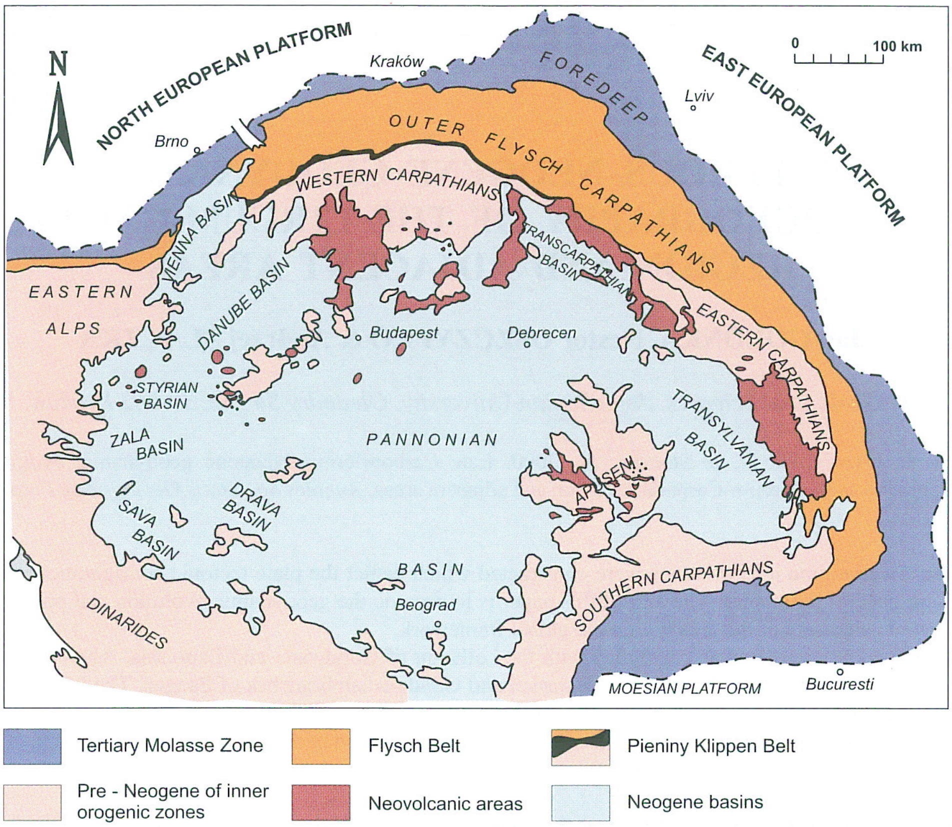


Fig. 1. Tectonic sketch map of the Alpine-Carpathian-Pannonian-Dinaride basin system (after Kováč *et al.*, 1998; simplified)

presented version of circum-Carpathian regional maps was constructed by the authors in 1999–2000 at the Institute of Geological Sciences, Jagiellonian University.

The aim of this paper is to provide the plate tectonic evolution and position of the major crustal elements of the area within the global framework (Fig. 2). Therefore, we restricted the number of plates and terranes modeled, trying to utilize the existing information and degree of certainty. We tried to apply geometric and kinematic principles, using computer technology, to model interrelations between tectonic components of the circum-Carpathian area. This general framework will provide a basis for the future integration of the local tectonics.

MAPPING METHODOLOGY

The maps were constructed using the following defined steps:

1. Construction of the base maps using the plate tectonic model. These maps depict plate boundaries (sutures), plate position at the specific time and outline of present day coastlines.

2. Review of existing global and regional paleogeographic maps.

3. Posting of generalized facies and paleoenvironment database information on base maps.

4. Interpretation and final assembly of computer map files.

The maps were constructed using a plate tectonic model, which describes the relative motions between approximately 300 plates and terranes. This model was constructed using PLATES and PALEOMAP software (see Golonka *et al.*, 1994; Golonka & Gahagan, 1997), which integrate computer graphics and data management technology with a highly structured and quantitative description of tectonic relationships. The heart of this program is the rotation file, which is constantly updated, as new paleomagnetic data become available. Hot-spot volcanics serve as reference points for the calculation of paleolongitudes (Morgan, 1971; Golonka & Bocharova, 1997). Magnetic data have been used to define paleolatitudinal position of continents and rotation of plates (see e.g., Van der Voo, 1993; Besse & Courtillot, 1991; Krs *et al*, 1996). Ophiolites and deep-water sediments mark paleo-oceans, which were subducted and included into foldbelts.

Information from several general and regional paleogeographic papers were filtered and utilized (e.g., Ronov *et al.*, 1984, 1989; Dercourt *et al.*, 1986, 1993; Robertson, 1998; Sengör & Natalin, 1996; Stampfli *et al.*, 1991; Ziegler, 1988; Zonenshain *et al.*, 1990; Kováč *et al.*, 1993, 1998; Plašienka, 1999). We have also utilized the unpublished maps and databases from the PALEOMAP group (University of Texas at Arlington), PLATES group (University of Texas at Austin), University of Chicago, Institute of Tectonics of Lithospheric Plates in Moscow, Robertson Research in Llandudno, Wales, and the Cambridge Arctic Shelf Programme. The plate and terrane separation was based on the PALEOMAP system (see Scotese & Langford, 1995), with modifications in the Tethys area (Golonka & Gahagan, 1997). The contents of the original maps were supplemented by detailed information concerning paleogeography of the Outer Carpathians basin (Książkiewicz, 1962; Ślączka, 1976; Golonka *et al.*, 1999; Ślączka *et al.*, 1999, Kovač *et al.*, 1998). The calculated paleolatitudes and paleolongitudes were used to generate computer maps in the Microstation design format using the equal area Molweide projection. The glossary with the definition of the plate tectonic is attached at the end of the paper.

MAP DISCUSSION

Late Carboniferous

The map on Fig. 2 depicts Europe and adjacent parts of North America, Africa, arctic and Siberia after the initial assembly of the Pangea supercontinent. The Paleotethys Ocean (Sengör & Natalin, 1996) was situated between northern, Laurussian (North America, Baltica and Siberia) and southern, Gondwanian (Africa, Arabia, Lut and other Iranian terranes) branch of Pangea. The collision between Gondwana and Laurussia (Ziegler, 1989) developed the central Pangean mountain range – Ouachita – Appalachian Mountains in North America (Hatcher *et al.*, 1989), Mauretanides in Africa and Hercynian mountains in Europe (Franke, 1989a, b; Ziegler, 1989).

The Hercynian orogeny in Europe was a result of collision of several separate blocks with the Laurussia margin (Franke, 1989b; Lewandowski, 1998), followed by the involvement of Gondwana continent. Widespread orogenic deformation occurred across western and central Europe in Iberia, Ligerian terrane, Massif Central, Sardinian–Corsican, Armorican, Harz Mts., Saxothuringian, Bohemian, and Silesia areas (Yilmaz *et al.*, 1996).

The Hercynian convergence in Europe led to large-scale dextral shortening, overthrusting and emplacement of parts of the accretionary complexes. The amount of convergence was modified by large, dextral and sinistral transfer faults. Late Carboniferous events were also marked in the Alps, Carpathians (Dallmeyer *et al.*, 1996; Gawęda *et al.*, 1998) and Rhodopes (Yanev, 1992). Mountains formed on the northern margin of Paleotethys, as results of these events, were connected with the Hercynian orogen in Europe. North-dipping subduction developed along the Paleotethys margin. This subduction was a major force driving Late Paleozoic and Early Mesozoic movement of plates in this area.

The basement of most of the plates, which play important role in the Mesozoic–Cenozoic evolution of the circum-Carpathian area, was formed during the Late Paleozoic collisional events. Moesia, Rhodopes and the Alcapa superterrane (Neubauer *et al.*, 1995), which includes Eastern Alps, Inner Carpathians, Tisa and adjacent terranes, were sutured to the Laurasian arm of Pangea, while Adria and adjacent terranes were situated near the Gondwanian (African) arm. The position of the Bohemian Massif, adjacent to the Carpathian plates, according to paleomagnetic study (Krs *et al.*, 1996) was located near Equator, agrees with the global Pangean model (Van der Voo, 1993; Golonka *et al.*, 1994).

Triassic

Many of the continental collisions, which began in the Carboniferous, reached maturity in the Early Permian. A major part of Pangea was assembled, and the new supercontinent, ringed by subduction zones, moved steadily northwards. The formation of Laurasia reached a main phase, with the suturing of Kazakhstan and Siberia with Laurussia (Nikishin *et al.*, 1996; Zonenshain *et al.*, 1990; Ziegler, 1989). Carboniferous–earliest Permian rifting of the Cimmerian plates (see Sengör & Natalin, 1996; Dercourt *et al.*, 1993; Golonka *et al.*, 1994) from Gondwana turned into drifting during the Permian, marking the inception of the Neotethys Ocean. Rifting and oceanic type of basin opening could also have occurred in the Mediterranean, recorded by the deep-water sediments of Sicily (Catalano *et al.*, 1991; Kozur, 1991), Lago Negro (Marsella *et al.*, 1993) and Crete (Kozur & Krahl, 1987).

The subduction zone along the Paleotethys margin (Fig. 3) caused back-arc rifting in the proto-Black Sea area and along the margins of Scythian-Turan platform (Zonenshain *et al.*, 1990; Kazmin, 1990, 1991). The Tauric basin was formed between the Pontides and the Dobrogea-Crimea segment of the Scythian platform. The opening of the Meliata-Halstatt Ocean, between the Eurasian margin and the Hungarian Tisa block (Kázmer & Kovács, 1989; Kozur, 1991; Plašienka & Kováč, 1999), was geodynamically related to this event (Fig. 3). In the proto-Mediterranean area, rifting and fragmentation of separated blocks continue to progress (Ricou, 1996; Golonka & Gahagan, 1997). In the Eastern Mediterranean area rifting occurred during the Permian and Triassic time (Stampfli *et al.*, 1991; Guiraud & Bellion, 1996), accompanied by Mid-Late Triassic, extensive, alkaline basalt flows evident between Levant and Morocco. The rifting was followed by sea-floor spreading recorded by Triassic Mamonia ophiolites from Cyprus (Robertson & Woodcock, 1979, Robertson, 1998).

Several blocks of the Cimmerian provenance (Sengör & Natalin, 1996) collided with the Eurasian margin in the Triassic–earliest Jurassic Early Cimmerian orogeny. Alborz and South Caspian microcontinent collided with the Scythian platform at an earlier time (Carnian), while the Serbo-Macedonian block collided with the Moesia-Rhodopes (Tari *et al.*, 1997), and the Lut block collided with the Turan platform, at a later (Norian) phase (Zonenshain *et al.*, 1990; Kazmin, 1990).

In the western Tethys area, Late Paleozoic and Triassic rifting and sea-floor spreading resulted in several separated carbonate platforms (Philip *et al.*, 1996; Kiessling *et al.*, 1999). The western part of the Neotethys is known as the Vardar Ocean (e.g., Sengör & Natalin, 1996, 1984; Kázmer & Kovács, 1989). The narrow branch of Neotethys separated the Apulia-Taurus platform from the African continent. The Apulia platform was connected with European marginal platforms. Its northernmost part was possibly separated from the Umbria-Marche region by a rift. The in-

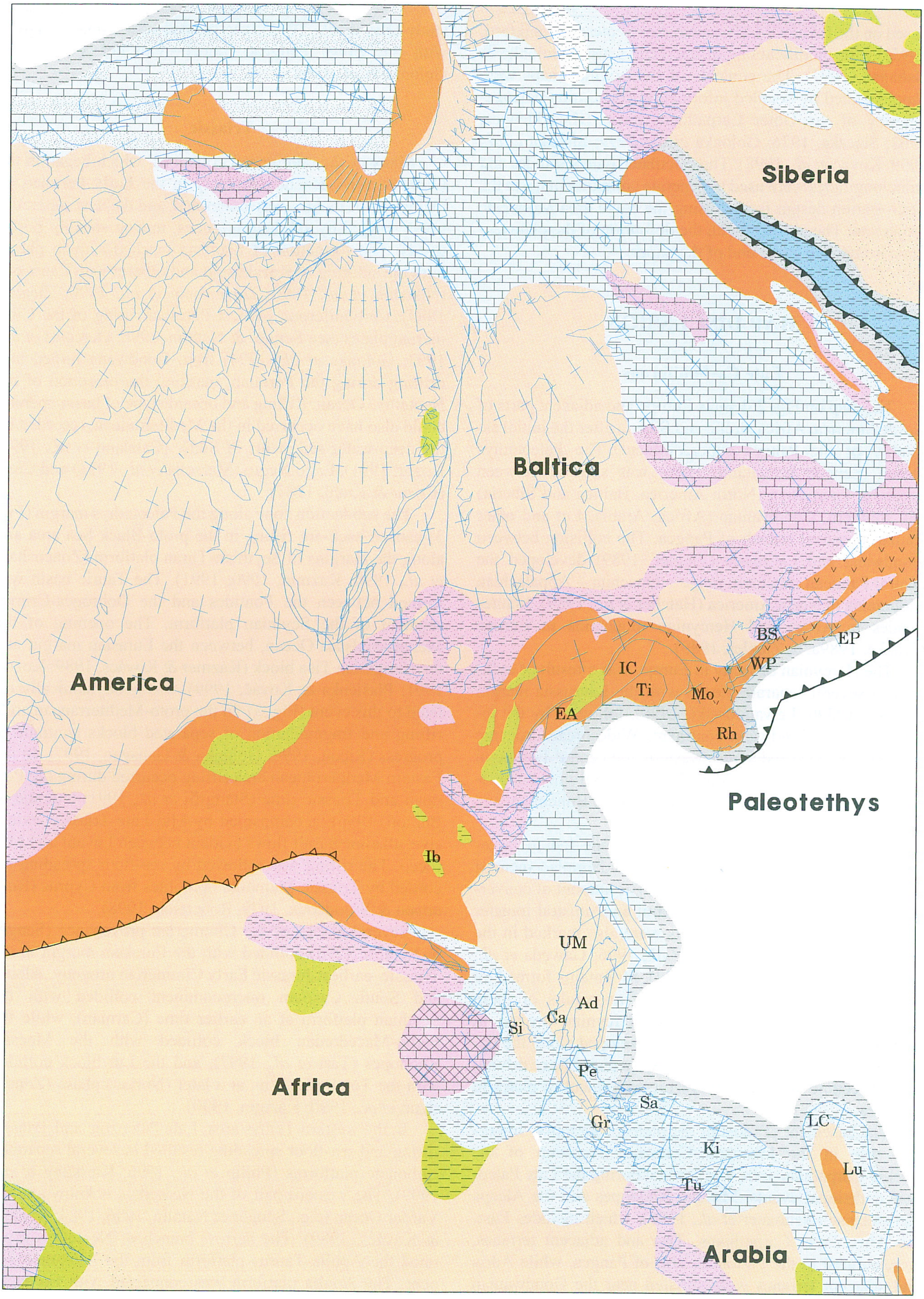


Fig. 2. Paleoenvironment and lithofacies of the circum-Carpathian area during Late Carboniferous; plates position at 302 Ma

Legend to Figs 2–10, 12, 13. Abbreviations of oceans and plates names: Ad – Adria (Apulia), An – Andrychov ridge, Ap – Apuseni Mts, Ba – Balearic terrane, Bl – Balkans, Br – Briançonnais terrane, BS – Black Sea, Ca – Calabria-Campania terranes, CF – Carpathian Foredeep, Cr – Czorsztyn ridge, Di – Dinarides, Du – Dukla basin, EA – Eastern Alps, EM – Eastern Mediterranean, EP – Eastern Pontides, GD – Getic depression, Gr – Greece, Gs – Gresten basin, Hv – Helvetic zone, Ib – Iberia plate, IC – Inner Carpathians, Ki – Kirsehir plate, Kr – Kruhel olistolith, LC – Lesser Caucasus terrane, Li – Ligurian (Piemont) Ocean, Me – Meliata/Halstatt Ocean, MB – Molasse basin, Mg – Magura basin, Mo – Moesia plate, Mr – Marmarosh massif & klippe, OC – Outer Carpathians, PH – Podhale Flysch basin, Pe – Pelagonian plate, Pi – Pindos Ocean, PKB – Pieniny Klippen Belt basin, Pm – Fore-Magura basin, Ps – Fore-Silesian basin, RD – Rheno-Danubian basin, Rh – Rhodopes, Sa – Sakariya plate, SC – Silesian ridge (cordillera), Si – Sicily plate, Sk – Skole basin, Sl – Silesian basin, Sn – Sinaia basin, St – Štramberk olistolith, Ta – Tarçau basin, Te – Teleajen basin, Tv – Transilvanian basin, Tu – Taurus terrane, Ti – Tisa plate, UM – Umbria-Marche, Vc – Vercors zone, Vl – Valais trough, Vo – Vocontian trough, WP – Western Pontides

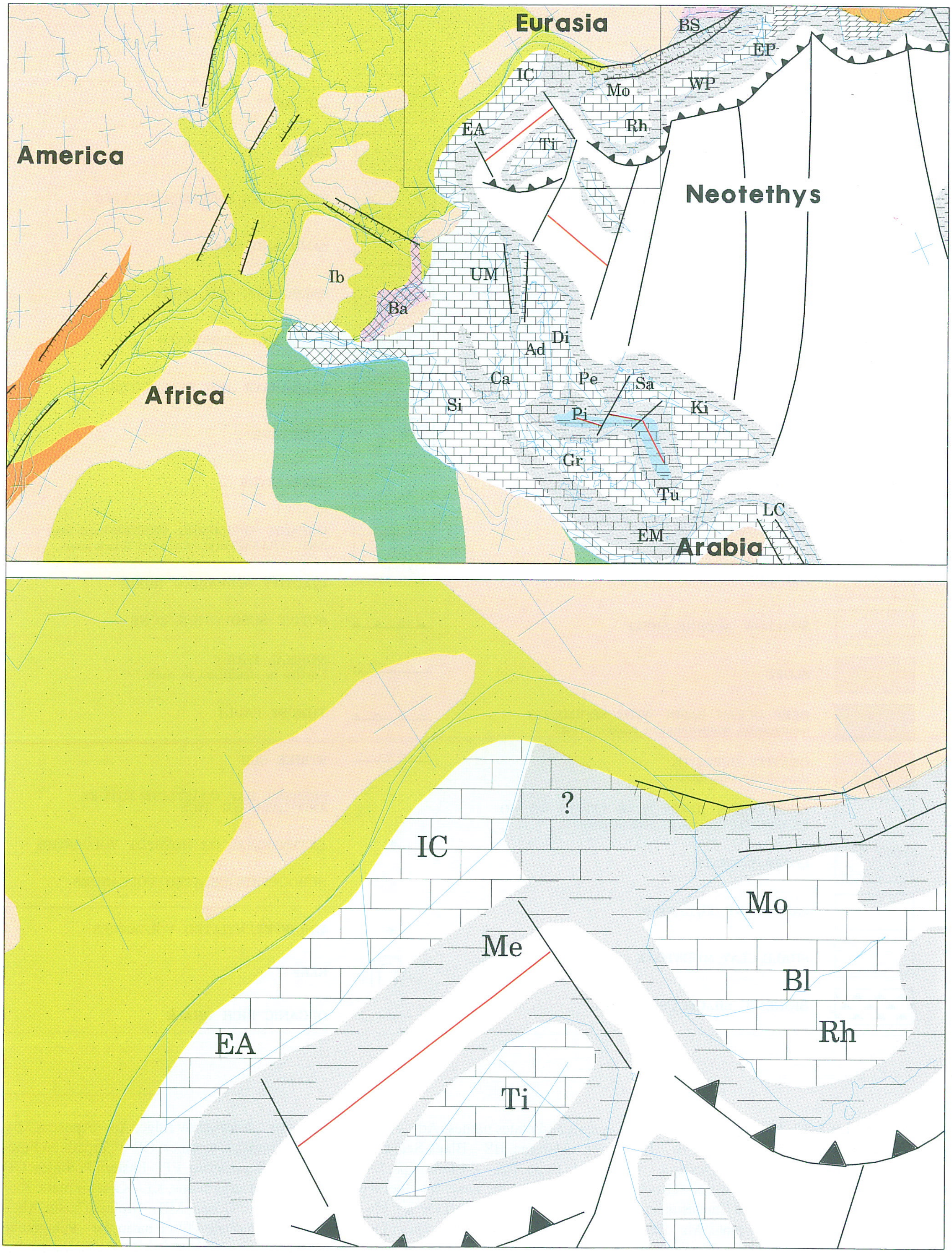


Fig. 3. Paleoenvironment and lithofacies of the circum-Carpathian area during Late Triassic; plates position at 225 Ma. For explanation – see Fig. 2

cipient Pindos Ocean separated the Pelagonian, Sakariya and Kirsehir block from the Ionian-Taurus platform (Robertson *et al.*, 1991, 1996; Stampfli *et al.*, 1991).

The Northern Calcareous Alps and Inner Carpathians formed the marginal platform of Europe (Plašienka & Kováč, 1999). In Late Triassic the Tisa block was fully separated from the European margin by the Meliata-Halstatt Ocean (Kozur, 1991; Channell & Kozur, 1997; Kázmer & Kovács, 1989; Stampfli, 1996; Golonka & Gahagan, 1997). There is a possibility of existence of the embayment of Meliata-Vardar zone between Inner Carpathian, Moesia and European Platform (Fig. 3). The pelagic Triassic pebbles in the exotic pebbles in the Pieniny Klippen Belt (Birkenmajer, 1988; Birkenmajer *et al.*, 1990) could have originated in this embayment. The Eurasian platform, east of the Meliata Ocean, was dissected by rift systems, which extended from the Dobrogea, through the Crimean lowland to the North Caucasus, Mangyshlak and southern Amu-Darya (Zonenshain *et al.*, 1990; Kazmin, 1991; Kazmin *et al.*, 1986). The Moesian block, the Western and Eastern Pontides, the Transcaucasus and the South Caspian blocks were located between this rifted zone and the remnants of Paleotethys.

Jurassic

Continued sea-floor spreading occurred during the Jurassic time within the Neotethys. The Pelagonian plate, Kirsehir and Sakariya (Robertson *et al.*, 1991), and perhaps the Lesser-Caucasus-Sanandaj-Sirjan plate (Adamia, 1991; Golonka & Gahagan, 1997; Golonka, 1999) were drifting of the Apulia-Taurus-Arabia margin. The Neotethys Ocean was divided into northern and southern branches. The Ligurian Ocean, as well as the central Atlantic and Penninic Ocean (Dercourt *et al.*, 1986, 1993; Channell, 1996) were opening during Early–Middle Jurassic. The oldest oceanic crust in the Ligurian-Piedmont ocean is dated as late Middle Jurassic in southern Apennines and in the Western Alps (Ricou, 1996). Marshalko (1986) quotes 179, 160 and 156 Ma radiometric data for pebbles from Pieniny Klippen Belt, possibly derived from obducted oceanic basement. According to Winkler & Ślączka (1994) this Pieniny data fit with the supposed opening of the Southern Penninic Ocean. Birkenmajer (1988; Birkenmajer *et al.*, 1990) postulated the earlier – Triassic opening of the Pieniny Klippen Belt Ocean. The oldest well documented deposits in the basinal part of Pieniny Klippen Belt Ocean are of Early Jurassic age (Birkenmajer, 1986). The Triassic pelagic limestones are known only from exotic pebbles transported from the enigmatic Andrusov ridge. These Triassic limestones could have been deposited in the mentioned above (Fig. 3) embayment of the Meliata Ocean. There is also a possibility of existence of the another basinal unit (Złatna) situated south of the main branch of Pieniny Klippen Belt Ocean, postulated by Sikora (1971). The documented from outcrops extremely deep-water deposits (pelagic limestones and radiolarites) from this basin are of Middle Jurassic–Early Cretaceous age (Golonka & Sikora, 1981).

Extension of Neotethys to the northwest into the proto-Mediterranean, established a connection with the Central Atlantic (Fig. 4). The Central Atlantic was in an advanced drifting stage during Middle–Late Jurassic (Withjack *et al.*, 1998). Rifting continued in the North Sea and in the northern Proto-Atlantic (Ziegler, 1988; Doré, 1991). The progressive breakup of Pangea resulted in a system of spreading axes, transform faults, and rifts, which connected the ocean floor spreading in the Central Atlantic and Ligurian Sea, to rifting which continued through the Polish-Danish graben to Mid-Norway and the Barents Sea (Golonka *et al.*, 1996). Tethys was connected with the Polish-Danish graben (Żytko, 1984, 1985) by transform fault and rift system which preceded opening of the Outer Carpathian basins. The Żegocina porfiritic andesite (Ślączka, 1998; Ślączka *et al.*, 1999) could be a volcanic expression of the Jurassic desintegration of the southern margin of the North European Plate which became later the site of the Outer Carpathian rifting. It could represent an early stage of the hot spot activity in this area.

The Inner Carpathian block and the Eastern Alps were moving away from Europe, and, at the same time, Apulia was moving together with Africa (Channell, 1996). Simultaneously, the Meliata-Halstatt Ocean began to narrow and subduct northwards under the Inner Carpathian and Eastern Alpine plates (Dallmeyer *et al.*, 1996). The Pieniny Klippen Belt Ocean was fully opened by the Middle–Late Jurassic time (Birkenmajer, 1986). The Czorsztyn ridge separated this basin from the Magura basin (Fig. 4). This Czorsztyn "pelagic swell" (Birkenmajer, 1986) was covered mainly with relatively shallow-water carbonate deposits an elongated structure limited from both the north and the south by basins with deep-water deposition of cherty limestones of the *Nannoconus* facies (Golonka & Sikora, 1981). The Czorsztyn ridge may be related to the Briançonnais zone in Alps (Stampfli, 1993), while Magura basin may be connected with the opening Valais trough. The paleogeographic extent of the Magura basin (Fig. 4) remains somewhat enigmatic and speculative. Plašienka (1999) represents somewhat different point of view on the Jurassic development of the Carpathian area. He divides the Pieniny Klippen Belt Ocean into Vahicum and Magura subbasins and separates them by Oravicum ridge. Oravicum is an equivalent of Czorsztyn ridge, while not very well defined Vahicum could be Pieniny Klippen Belt Ocean on our map (Fig. 4). According to Birkenmmajer (1986), the Czorsztyn ridge could be traced from the vicinity of Vienna trough Western Slovakia, Poland, Eastern Slovakia to Transcarpathian Ukraine. In the Eastern Carpathians, Bombiţă *et al.* (1992) suggest the Liassic–Early Dogger age sediments. The Dogger andesite tuffites, followed by radiolarites and pelagic deposits up to Barremian in the Poiana Botizi Klippe (NW Romania) represent the Magura basin. The andesite tuffites could be an expression of the early stage of the hot spot volcanism. According to Romanian geologists (Sandulescu *et al.*, 1981; Bombiţă *et al.*, 1992), the Marmarosh Massif is situated north of the Magura basin (see also Żytko, 1999b). The ophiolite blocks in Marmarosh area (Lashkevitch *et al.*, 1995) indicate existence of Mesozoic oceanic crust in this area. According to Ślączka (2000), one should look perhaps within the Magura basin for the continuation of the Marmarosh ridge. The existence of the cordillera separating the southernmost part of the Magura basin (Hulina unit =

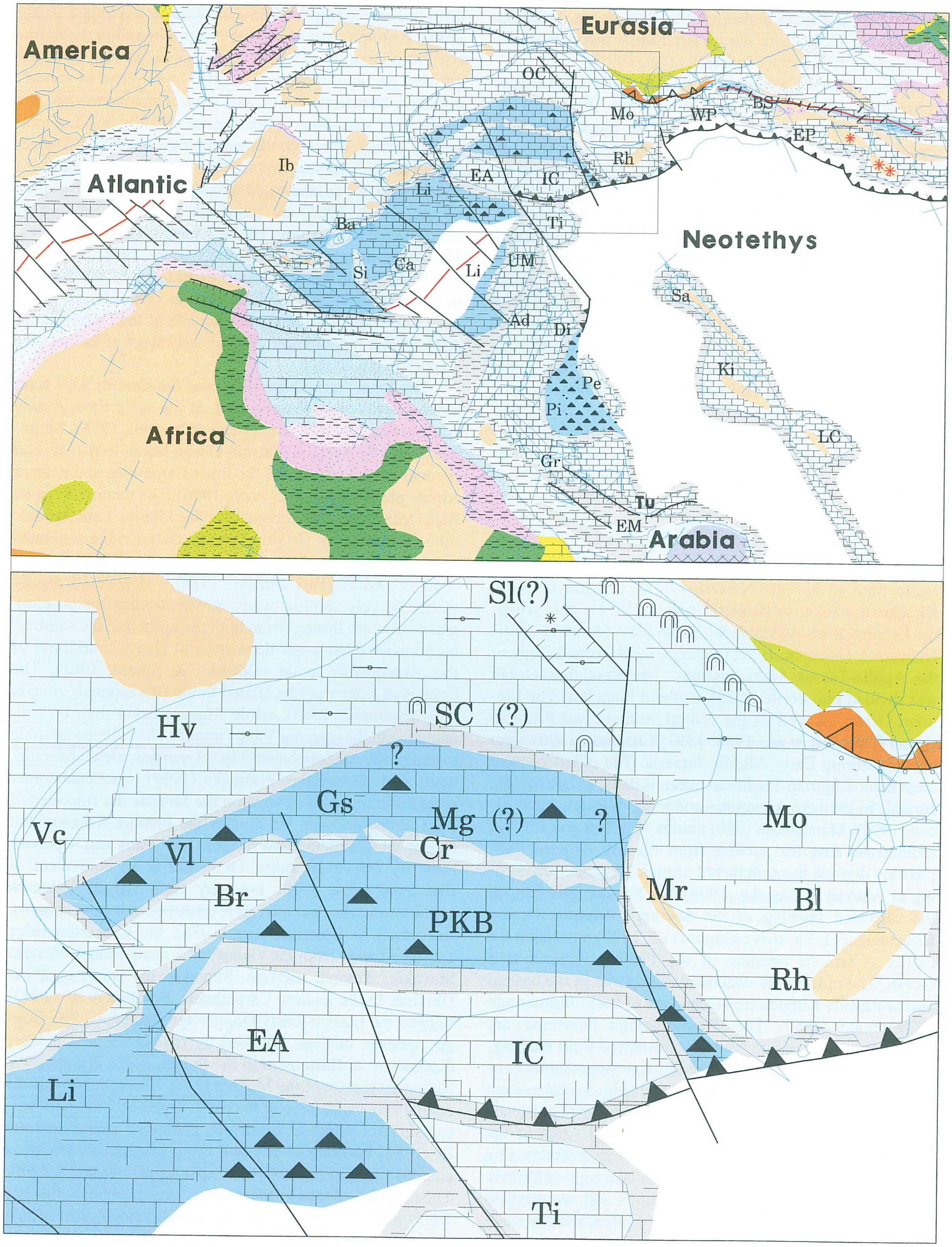


Fig. 4. Paleoenvironment and lithofacies of the circum-Carpathian area during Middle–Late Jurassic; plates position at 152 Ma. For explanation – see Fig. 2

Grajcarek unit *sensu* Birkenmajer, 1977, 1986) from the remaining part of this basin was postulated by Sikora (1971; Golonka & Sikora, 1981). These connections remain speculative and require future research.

Latest Late Jurassic–earliest Lower Cretaceous

In the Alpine-Carpathian area in Europe the subduction of the Meliata-Halstatt Ocean and the collision of the Tisa block with the Inner Carpathian terranes was concluded at the end of Jurassic (Froitzheim *et al.*, 1996; Dallmeyer *et al.*, 1996; Plašienka, 1999) (Fig. 5). Subduction jumped at this time to the northern margin of the Inner Carpathian terranes and began to consume the Pieniny Klippen Belt Ocean (Birkenmajer, 1986, 1988). In the area south of the Rhodopes in southeastern Europe, subduction was characterized by northward polarity (Shanov *et al.*, 1992). A northward-dipping subduction existed also along the southern margin of Eurasia, between Rhodopes (Bulgaria) and Tibet-Lhasa (Ricou, 1996; Kazmin *et al.*, 1986; Sengör & Natalin, 1996).

Major plate reorganization happened during the Tithonian time. The Central Atlantic began to propagate to the area between Iberia and the New Foundland shelf (Ziegler, 1988). According to Driscoll *et al.* (1995), sea-floor spreading did not propagate beyond the Figueiro Fracture until the Aptian time. The Ligurian-Pieniny Ocean reached its maximum width and stopped spreading (Golonka *et al.*, 1996; Golonka & Bocharova, in print). The Tethyan plate reorganization resulted in extensive gravitational faults movement. Several tectonic horsts and grabens were formed, rejuvenating some older, Eo- and Meso-Cimmerian faults. Initial stages of subduction of the oceanic crust of the Pieniny Klippen Belt Ocean, under the northern, active margin of the Inner Carpathian plate, may have been related to these movements (Birkenmajer, 1986, 1988). The Outer Carpathian rift (Silesian basin) had developed with the beginning of calcareous flysch sedimentation and may be the earliest phase of the teschenites extensional volcanism (Książkiewicz, 1977a, b; Narębski, 1990). The Magura and perhaps Silesian basins were connected with Rheno-Danubian and Vocontian rift zones in Alps (Fig. 5). The Silesian basin probably extended in the Eastern Carpathian into Ceahleau (Sinaia) and may be "black flysch" zone. Rifting also developed in the Balkan area (Bulgaria), between Moesia and Rhodopes (Tchoumatchenko & Sapunov, 1994). The Marmarosh Massif was located at the junction of Pieniny Klippen Belt Ocean, Balkan rift, Czorsztyn ridge, and Magura basin. The rifting in the Balkan area had impact on the future movement of the Marmarosh terrane.

The Polish-Danish rift turned into aulacogen (Żytko, 1984, 1985) with marginal marine, sometimes evaporitic sediments. The remnants of carbonate platforms with reefs (Štramberk) along the margin of Silesian basin were results of the fragmentation of the European Platform in this area. The Silesian ridge (Książkiewicz, 1977a, b) separated the Silesian and Magura basins. The subsidence in the Silesian basin was accompanied by the extrusion of basic lavas (teschenites) in the Western Carpathian and diabase-melaphyre within the "black flysch" of the Eastern Carpathians (Ślączka *et al.*, 1999). The subsidence reached as much as 69 m/Ma during the earliest Cretaceous, while the foraminiferal assemblages implies gradual deepening of the basin (Ślączka *et al.*, 1999).

Early Cretaceous

During Hauterivian–Aptian the Ligurian Ocean entered into its compressional phase (Marchant & Stampfli, 1997). Subduction was active on the southern margin of the Pieniny Klippen Belt Ocean (Birkenmajer, 1986, 1988).

In the Black Sea area in southeastern Europe a rift developed between the Western Pontides and adjacent parts of Ukraine (Fig. 6). Spreading continued in the Greater Caucasus–proto-Caspian Ocean (Kazmin, 1990; Banks & Robinson, 1997). The drift of the Taurus plate opened again the Eastern Mediterranean basin and formed its oceanic crust (Bogdanov *et al.* 1994; Robertson, 1998).

In the Alpine-Carpathian area, the Rheno-Danubian and Outer Carpathian troughs, on the partially oceanic crust and partially on the attenuated continental crust, were open during this time (Golonka & Gahagan, 1997; Winkler & Ślączka, 1994; Ślączka, 1996a). To the west, this troughs extended into the Valais Ocean, which entered into a sea-floor spreading phase (Marchant & Stampfli, 1997; Froitzheim *et al.*, 1996), and further into the area between Spain and France and to the Biscay Bay (Stampfli, 1993, 1996). To the east, the through system was connected with the subsiding Balkan area. Main phase of intrusion of teschenites occurred in the Western Carpathians during Hauterivian–Barremian time (Ślączka *et al.*, 2000). These intrusions display the features of oceanic islands and were perhaps generated by a hot spot activity. It looks like there were two hot spots in the Carpathian region. The first one, in the Western Carpathians was connected with the Jurassic Żegocina andesites and Early Cretaceous teschenites. Today, the Western Turkey and Northern Aegean volcanics are located at the same latitude and longitude. The second hot spot, in the Eastern Carpathians was connected with the Jurassic andesitic tuffites and Early Cretaceous diabase-melaphyre. Today, the Levantine (e.g., Dead Sea) hot spot volcanics are located at the same latitude and longitude (see Golonka & Bocharova, in print).

During Aptian–Albian (Fig. 6) complex tectonics began to take place in the future Alpine belt zone, between southern Europe and North Africa/Arabia. Continued closure of the western part of Neotethys was related to the subduction along the Neotethys margin. This closure was marked by collisional deformation in the early stage of Trupchun phase in Alps (Froitzheim *et al.*, 1996) and by the formation of eclogites in Austroalpine units. The thrusting and shortening was also noted in the Inner Carpathians (Plašienka, 1999). Convergent margin and north-dipping subduction along the Western Pontides block caused the southward movement of this terrane and the opening of the western Black Sea as a back-arc basin (Kazmin, 1990; Banks & Robinson, 1997). The north-dipping subduction was consuming the main branch of Neotethys, between the Pontides, Sakarya and Kirsehir plates (Yilmaz *et al.*, 1996).

Spreading continued in the Eastern Mediterranean (Ri-

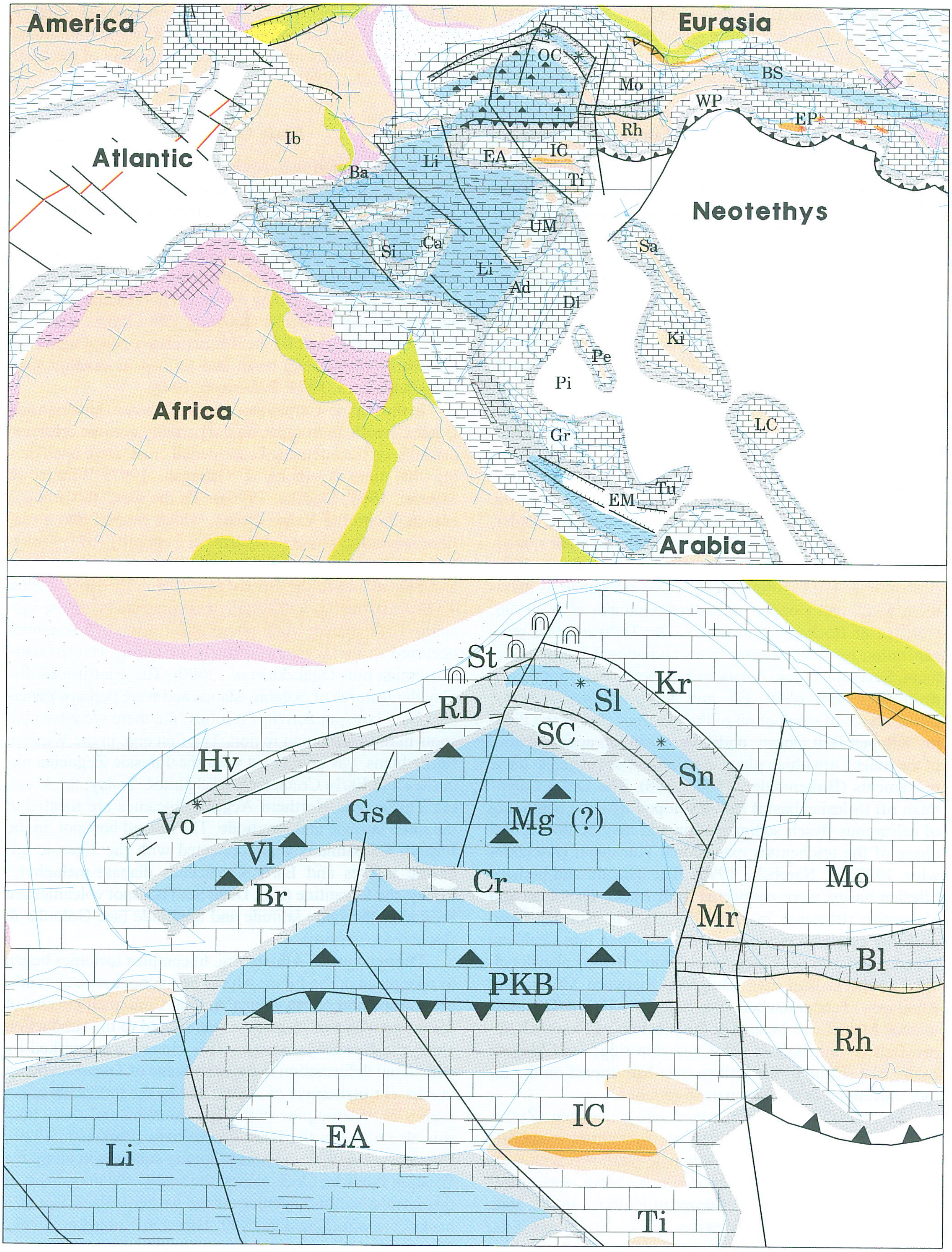
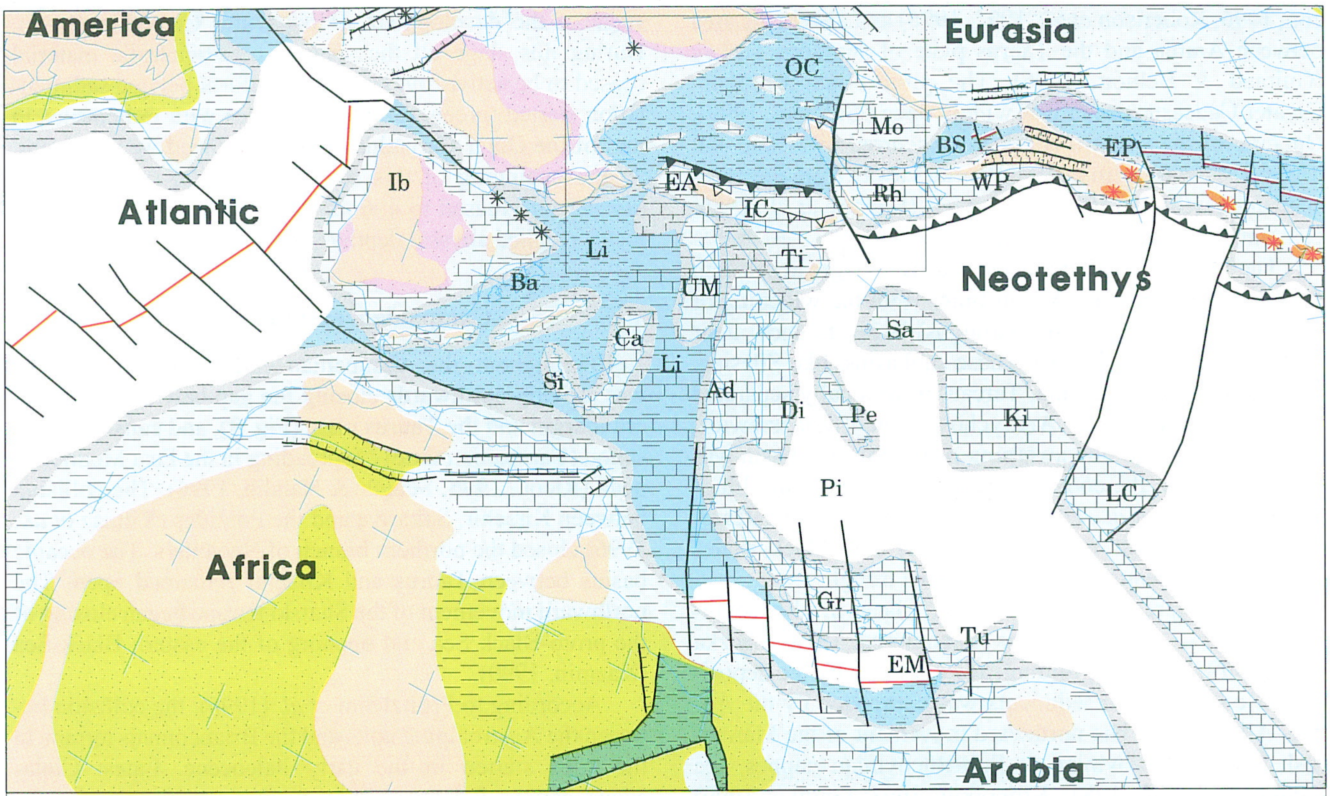


Fig. 5. Paleoenvironment and lithofacies of the circum-Carpathian area during latest Late Jurassic–earliest Lower Cretaceous; plates position at 140 Ma. For explanation – see Fig. 2



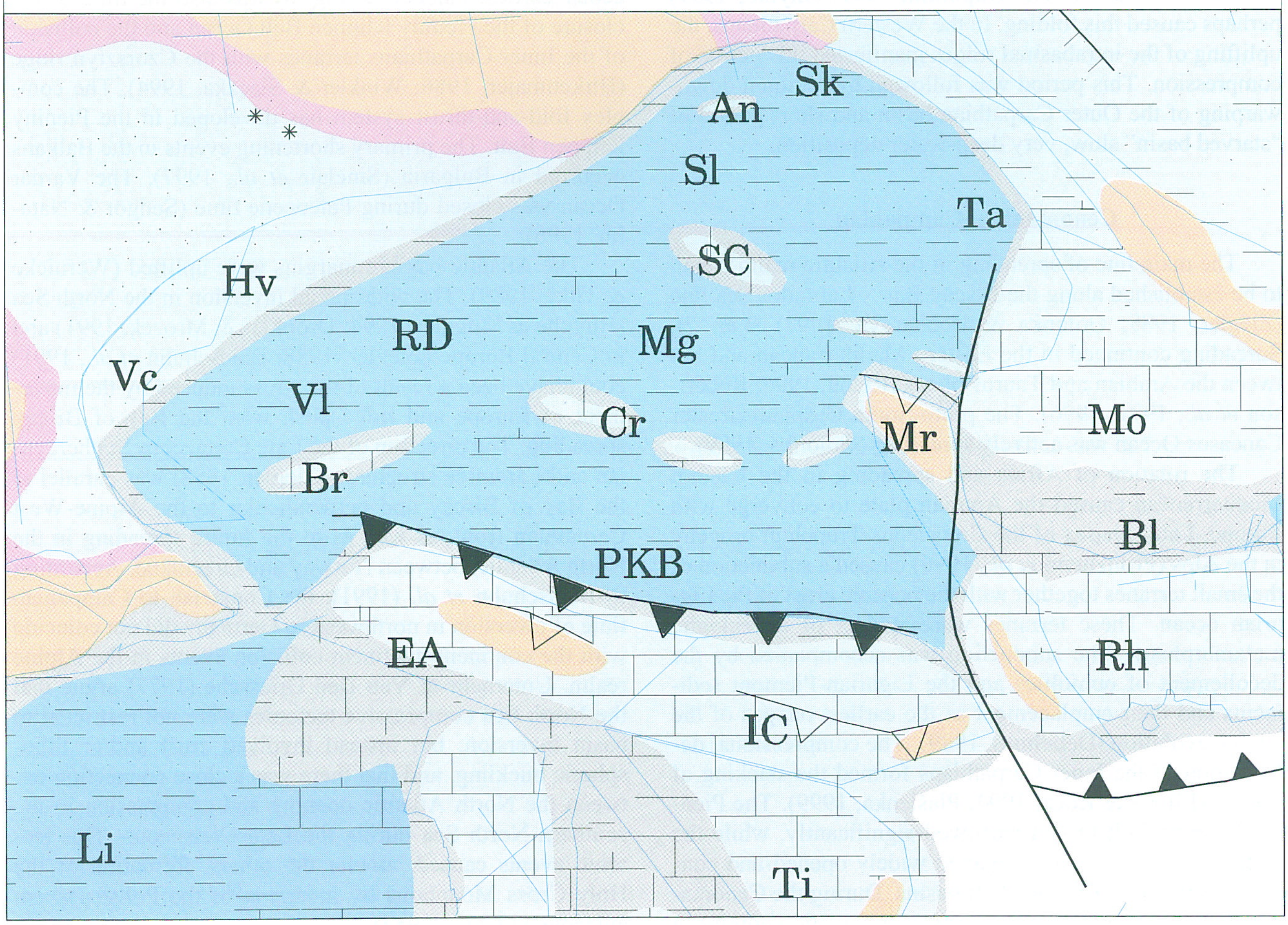


Fig. 6. Paleoenvironment and lithofacies of the circum-Carpathian area during latest upper Aptian–middle Cenomanian; plates position at 112 Ma. For explanation – see Fig. 2

cou, 1996; Robertson *et al.*, 1991, 1996) and also in the area between Arabia and the Taurus plate of southern Turkey (Guiraud & Bellion, 1996). The proto-South Caspian–Greater Caucasus ocean was widely open (Golonka, 1999). Opening of the western Black Sea occurred by rifting and drifting of the western-central Pontides away from the Moesian and Scythian platform of Eurasia (Kazmin *et al.*, 1986; Kazmin, 1990; Banks & Robinson, 1997).

The Outer Carpathian basin reached its greatest width during the Hauterivian–Aptian time. With the widening of the basin, several subbasins (troughs) began to show their distinctive features (Fig. 6). These subbasins, like Silesian, Sub-Silesian, Skole, Dukla, Tarcau, were locally separated by uplifted areas, e.g. Andrychów zone (Książkiewicz, 1960). The general downwarping of the Silesian basin was probably due to the cooling effect of the underlying lithosphere (Ślączka *et al.*, 1999). The sedimentation of calcareous sediments pass upwards gradually into black shales with turbiditic sequences in the Silesian trough.

The compressional event took place in the south-eastern part of the Carpathians (Sandulescu, 1988; Ślączka *et al.*, 1999). Intensive folding, accompanied by the deposition of coarse clastic sediments was completed by the Aptian–Albian time. The northward movement of the Marmarosh terrane (Bucovinian or Sub-Bucovinian nappes, see Sandulescu *et al.*, 1981; Kropotkin, 1991; Gnylko, 1999) perhaps caused this folding. In the Western Carpathians, the uplifting of the intrabasinal ridges manifested this period of compression. This period was followed by regional downwarping of the Outer Carpathian basin and short period of "starved basin" slow, very deep-water deposition.

Cenomanian–Campanian

The main line of spreading in the Atlantic realm began to be established along the Biscay Bay – Labrador Sea line (Ziegler, 1988; Golonka & Bocharova, 1997) (Fig. 7). Spreading continued in the Eastern Mediterranean and between the Arabian and Taurus plates (Ricou, 1996; Robertson *et al.*, 1991, 1996). The proto-South Caspian–Greater Caucasus Ocean was actively spreading (Golonka, 1999).

The rotation of Africa and spreading in the Eastern Mediterranean caused the Apulian plate to converge with Europe. Later phases of the Cretaceous Trupchun orogeny in the Alps (Froitzheim *et al.*, 1996) caused a subduction of the small terranes together with the oceanic crust of the Ligurian ocean. These terranes were subject of an eclogite metamorphism. The subduction was accompanied by the decollement of ophiolites and the Ligurian-Piemont sediments and their emplacement as the earliest nappes of the Alpine evolution (Debelmas, 1989). The compressional deformation of the Inner Carpathians formed the stacking of nappes (Ellouz & Roca, 1994; Plašienka, 1999). The Pieniny Klippen Belt Ocean narrowed significantly, while the Outer Carpathian basin remained widely opened and connected with the European shelf basins. During the Cenomanian, a period of slow and uniform sedimentation embraced all Carpathian basins, and well-oxygenated conditions began to develop (Bieda *et al.*, 1963). Ślączka *et al.* (1999) have distinguished the uppermost Albian–earliest Turonian stage of the development of the Outer Carpathian basin. During this stage all the sources of siliciclastic material ceased to be active and generally uniform pelagic sedimentation started: green, radiolarian shales with radiolarites in part of the Outer Carpathian basin, followed by red shales. At the beginning of this stage, the rate of sedimentation radically decreased to 4–6 m/Ma, whereas the paleobathymetry reached abyssal depth (Ślączka *et al.*, 1999).

Campanian–early Paleocene

Throughout the Campanian–early Paleocene Africa was moving northwards closing the gap between its northern margin and the Taurus plate (Fig. 8), and causing a cessation (Campanian time) of spreading in the East Mediterranean (Ricou, 1996; Sengör & Natalin, 1996). The collision between Kirsehir, Sakariya and the Pontides (Yilmaz *et al.*, 1996) closed the northern branch of Neotethys. The oceanic basins between Taurus and Kirsehir remained open. The northward movement of the Shatski terrane began closing of the proto-Black Sea and opening of the eastern Black Sea (Kazmin, 1990).

According to Froitzheim *et al.* (1996), the collision between the Austroalpine units and the Briançonnais terrane in the Alps started in the early Paleocene. Latest Cretaceous–earliest Paleocene (Fig. 8) was also the time of the closure of the Pieniny Klippen Belt Ocean and the collision of the Inner Carpathians terranes with the Czorsztyn ridge (Birkenmajer, 1986; Winkler & Ślączka, 1994). The complex fold-and-thrust system has developed in the Pieniny Klippen Belt. The primary shortening events in the Balkans occurred in Bulgaria (Sinclair *et al.*, 1997). The Vardar Ocean was closed during Paleocene time (Sengör & Natalin, 1996).

The Atlantic passive margins were uplifted (Wernicke & Tilke, 1989). The widespread inversion in the North Sea (Huyghe & Mugnier, 1994; Dronkers & Mrozek, 1991) and in Central Europe (Ziegler, 1988; Baldschuhn *et al.*, 1991) could have been a result of the stress induced by the movement of Europe and ridge push from the Bay of Biscay spreading. The direction of the Late Cretaceous Subhercynian and Laramide structures (Ziegler, 1988) was parallel to the Bay of Biscay and perpendicular to the Alpine-West Carpathian front, as well as to the future spreading in the North Atlantic, between Norway and Greenland. According to Baldschuhn *et al.* (1991), the Coniacian to Campanian time of inversion in northwestern Germany did not coincide with the continent-continent collision events in the Alpine realm. Unternehr & Van Den Driessche (1977) argue that the North Sea compressive tectonics were not restricted to basin inversion, but instead involved crust and/or lithospheric buckling, and that there was a close connection between the North Atlantic opening and compression in the southern North Sea during the Late Cretaceous. This tectonic events caused, among the others, formation of the Holy Cross Mountains by inversion of the Polish-Danish aulacogen (Żytko, 1984).

The subduction zone jumped from the southern margin of the Pieniny Klippen Belt Ocean to the northern margin of the Czorsztyn ridge (Fig. 8) and began consume the Magura

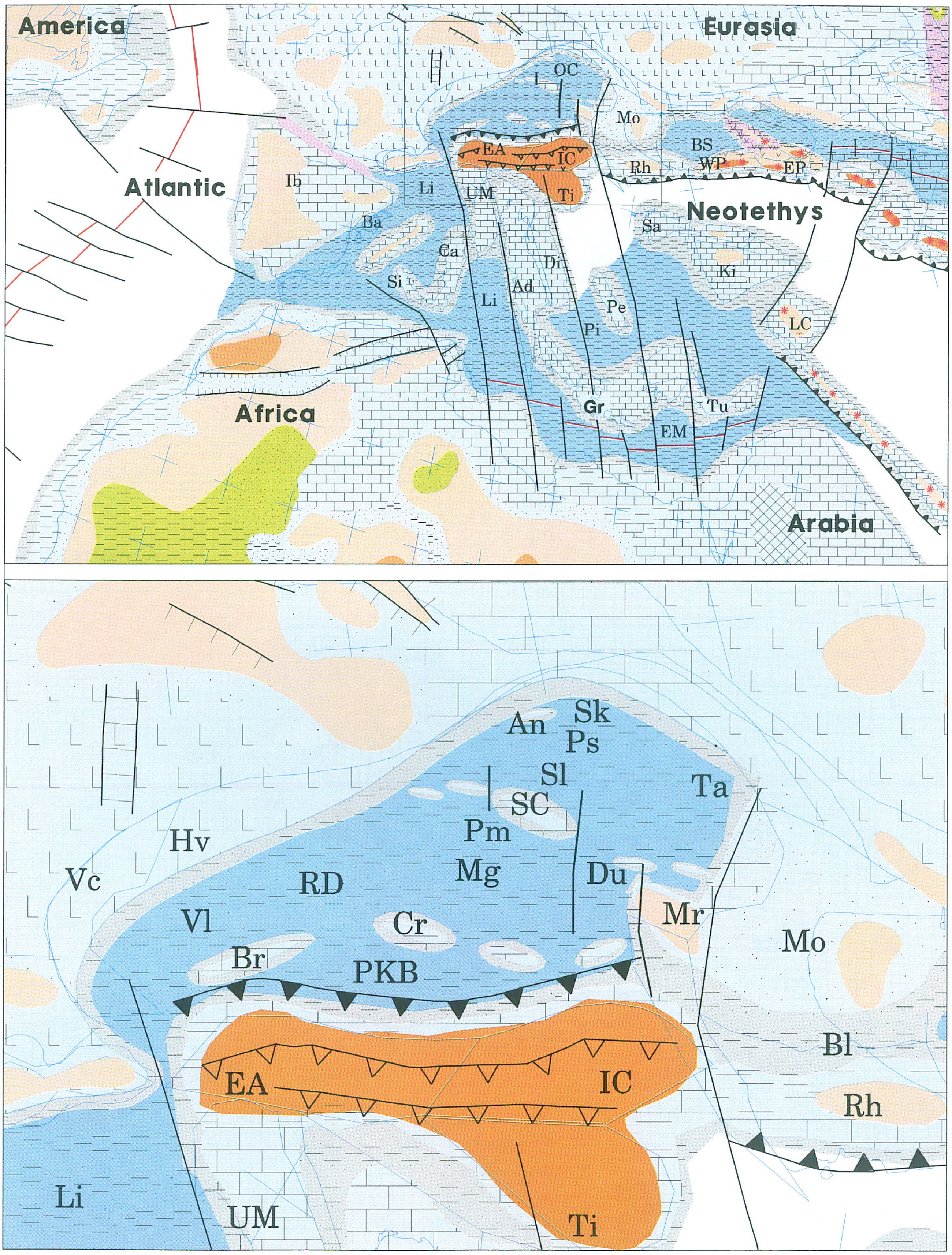


Fig. 7. Paleoenvironment and lithofacies of the circum-Carpathian area during late Cenomanian–middle Campanian; plates position at 90 Ma. For explanation – see Fig. 2

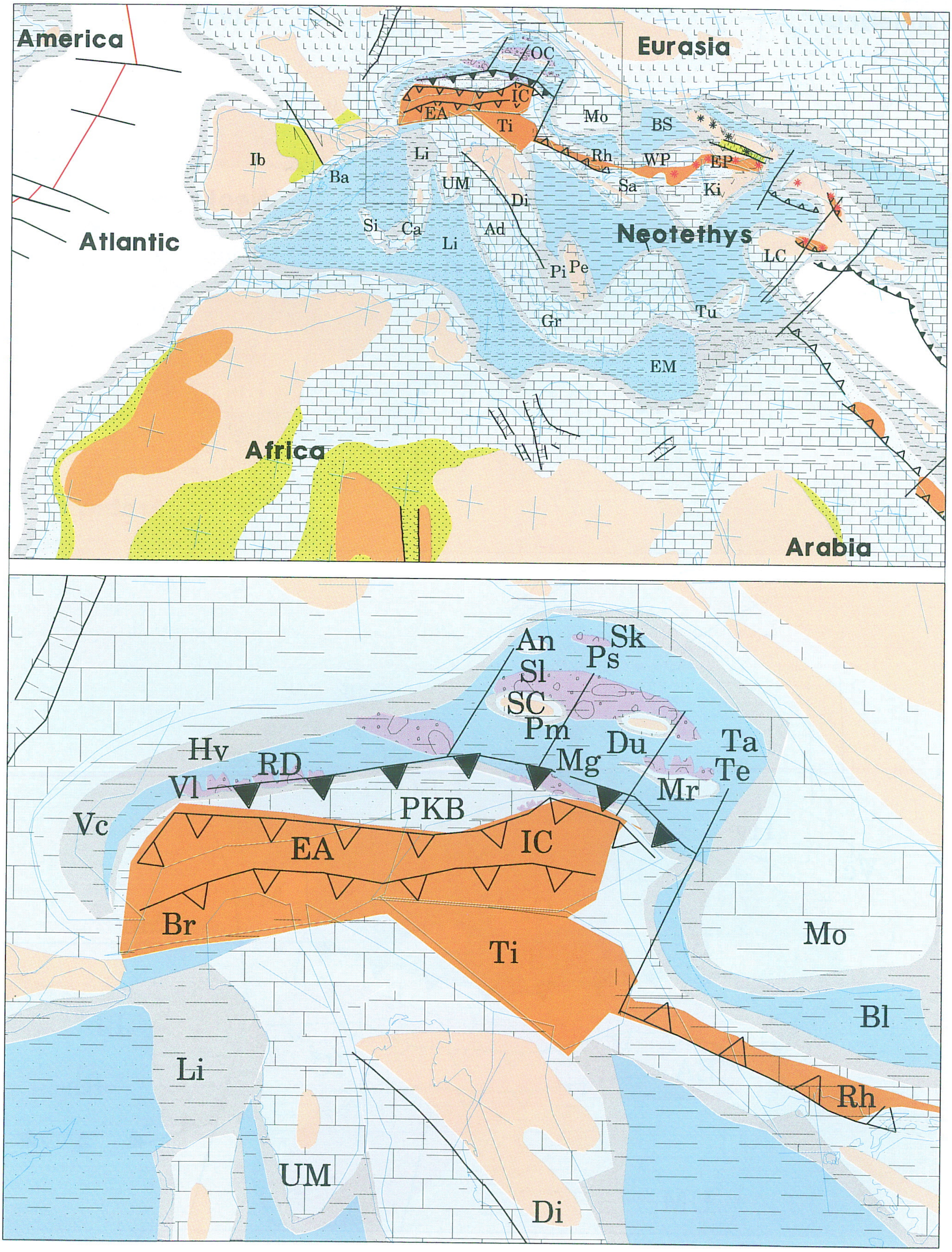
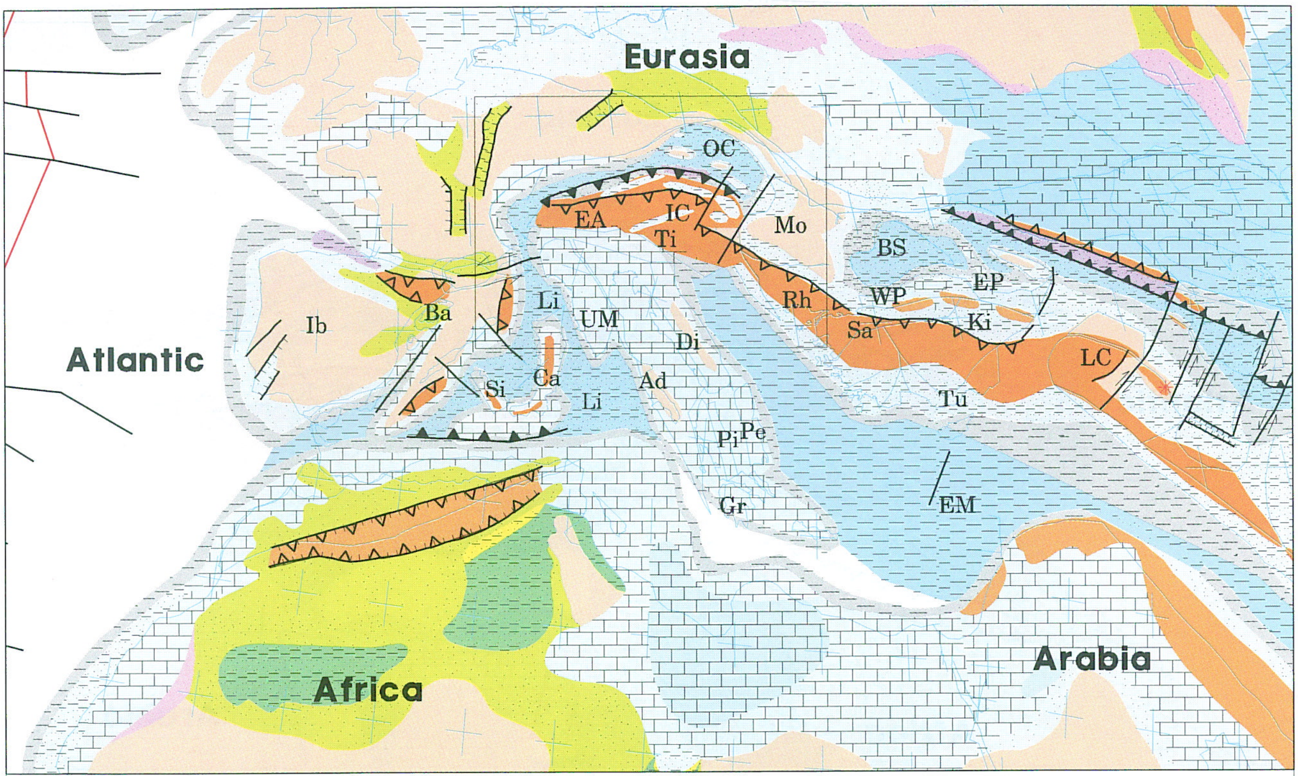


Fig. 8. Paleoenvironment and lithofacies of the circum-Carpathian area during late Campanian–early Paleocene; plates position at 65 Ma. For explanation – see Fig. 2



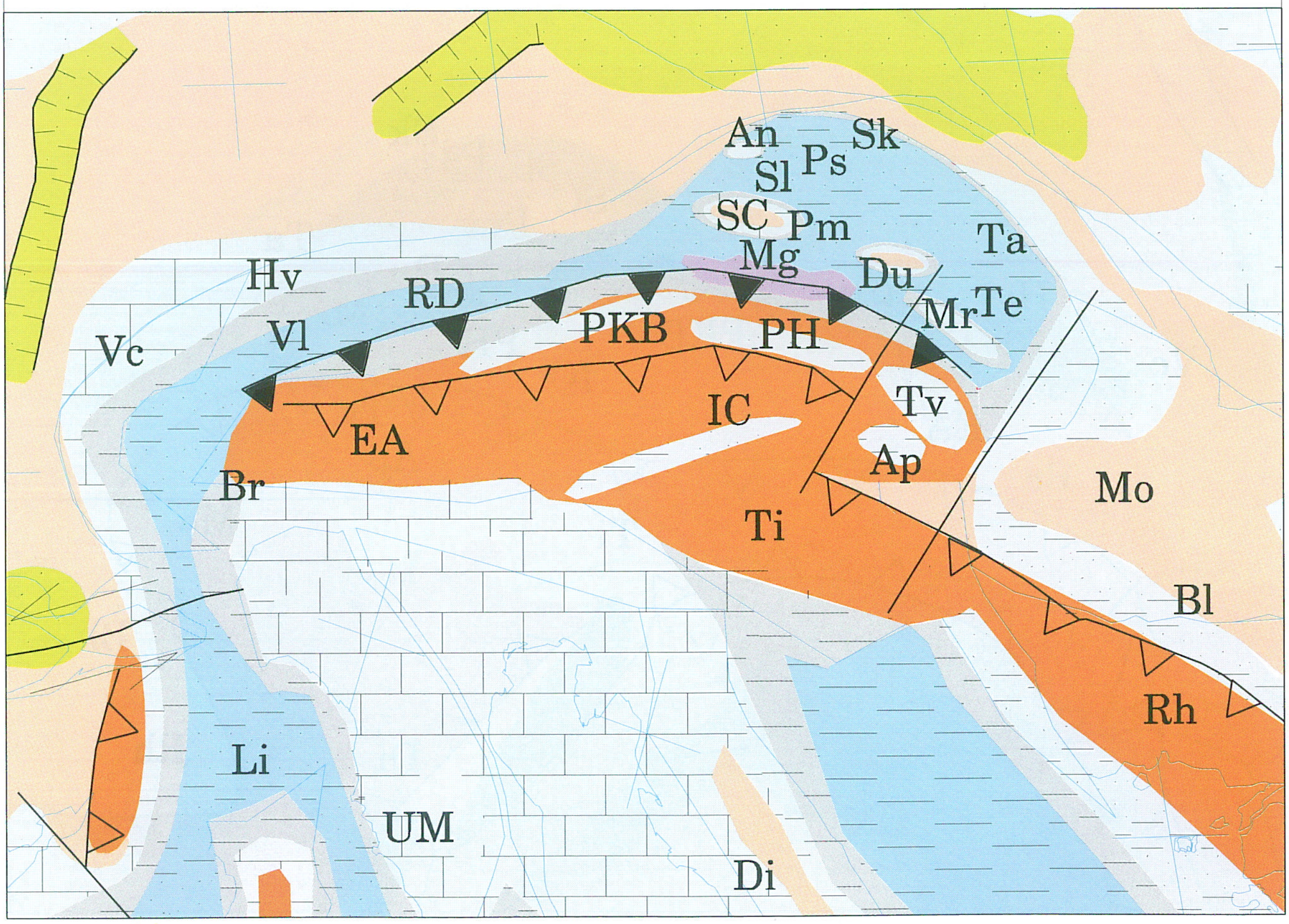


Fig. 9. Paleoenvironment and lithofacies of the circum-Carpathian area during Lutetian–Bartonian; plates position at 45 Ma. For explanation – see Fig. 2

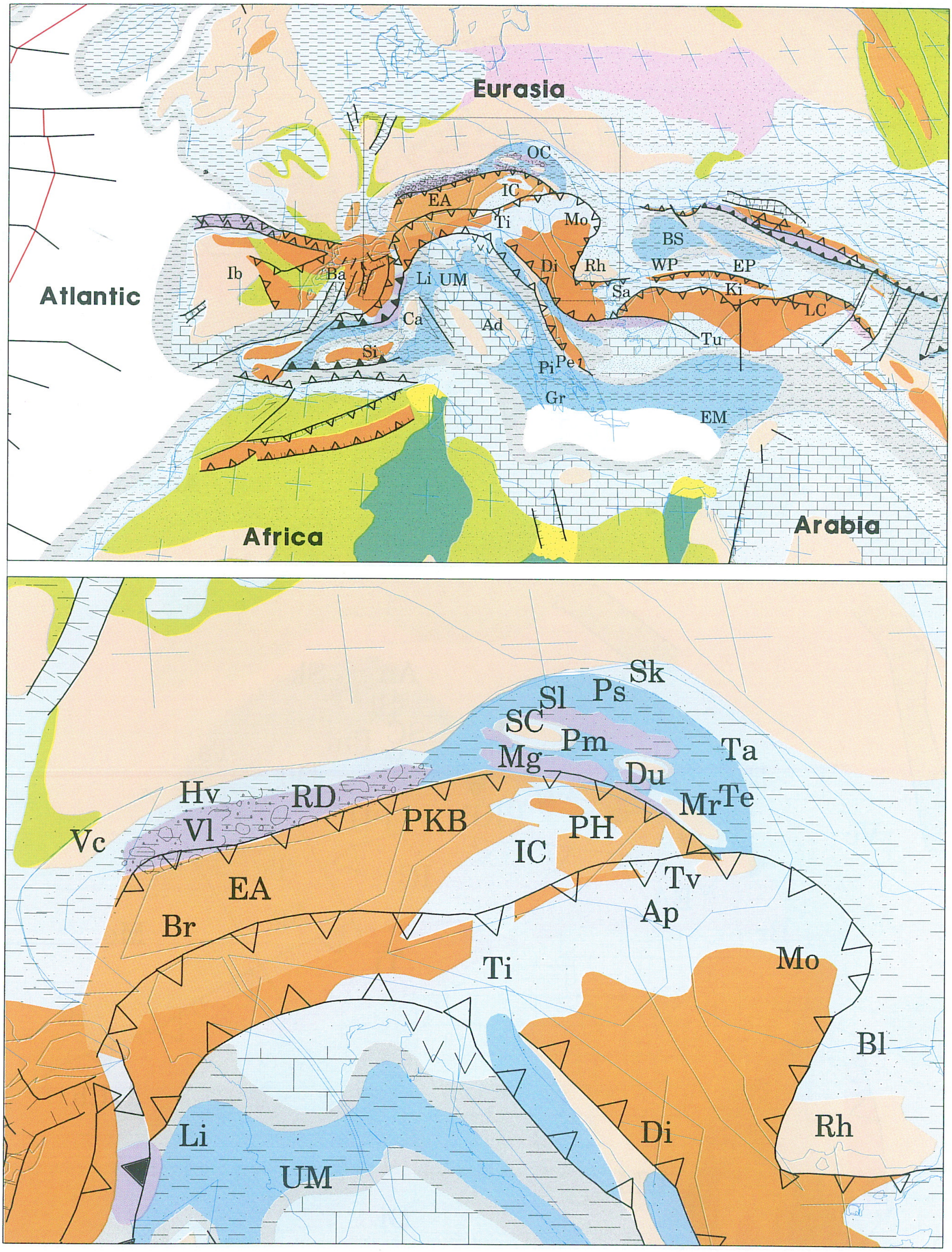


Fig. 10. Paleoenvironment and lithofacies of the circum-Carpathian area during Priabonian; plates position at 36 Ma. For explanation – see Fig. 2

basin (Birkenmajer, 1986). The Paleocene subsidence in the Magura basin was related to the development of the trench connected with this subduction zone (Oszczypko, 1998). The sedimentation and subsidence rate accelerated distinctly in the Silesian basin more than in the Magura basin, and were accompanied by a continuos uplifting of the Silesian cordillera, as well as of southern margin of the European Platform, Marmarosh Massif and also of the southern margin of the Magura basin. This uplift produced an enormous amount of the clastic material. The development of the accretionary prism may be started at this time.

Late Paleocene–Eocene

The process of the closing of Neotethys by the Alpine and Himalayan orogenies continued. The Adria (Apulia) plate was continuously moving northwards together with the Eastern Alpine (Austroalpine) and Inner Carpathian blocks (Fig. 9). Their collision with the European plate began in the Alps about 47 Ma (Decker & Peresson, 1996). The Valais Ocean in the Alps finally closed (Froitzheim *et al.*, 1996; Stampfli, 1996). According to Plašienka & Kovač (1999), the Alcapa block was formed at that time by welding together Eastern Alps, Inner Carpathian, Tisa as well as smaller terranes, like Bükk, Transdanubian or Getic. The main phase of compression and formation of the thrust belt of the Balkanides in Bulgaria occurred during the Eocene time (Tari *et al.*, 1997; Sinclair *et al.*, 1997). The closing of the Pieniny Klippen Belt Ocean in the Carpathians was also concluded, and Pieniny domain accreted to the Magura basin (Birkenmajer, 1986; Winkler & Ślączka, 1994). The folding of the Rheno-Danubian zone occurred in the late Eocene.

The Magura basin narrowed significantly due to the northward Alcapa movement (Oszczypko, 1992, 1999). The Maastrichtian–Paleocene inversion was followed by a new episode of subsidence which began at the end of Paleocene and accelerated during Lutetian and Priabonian (Oszczypko, 1999). The load of the accretionary prism caused the migration of depocenters northward. Thin-bedded flysch deposits passed into a thick complex of turbidites and fluxoturbidites. The Dukla, Silesian, Fore-Silesian, and Skole-Tarçau basins remained open with the flysch mainly in the southern part (Dukla and Silesian basins) and pelagic facies sedimentation farther towards the north (Fig. 9) (Bieda *et al.*, 1963).

Foreland basin development proceeded in southern Europe, coinciding with a general uplift of European continent. The closure of the Pindos Ocean began (Robertson *et al.*, 1991). Compression continued in the Balkan area in Bulgaria (Tari *et al.*, 1997).

Collision between Kirsehir, Sakariya and Pontides was concluded (Yilmaz *et al.*, 1996). The Lesser Caucasus, Sanandaj-Sirjan and Makran plates were sutured to the Iranian-Afghanistan plates in the Caucasus-Caspian Sea area (Adamia, 1991; Golonka, 1999). A north dipping subduction zone jumped to the Scythian-Turan Platform.

Early Oligocene

Collisions continued in the area between Africa and Eurasia. The conclusion of the compression of the Balkanides, in Bulgaria, occurred during the Oligocene time (Sinclair *et al.*, 1997). The Pindos Ocean was finally closed (Robertson *et al.*, 1991) (Fig. 10). The collision of Apulia as well as the Alpine-Carpathian terranes with the European Plate continued (Decker & Peresson, 1996). The metamorphism of the undercrusted Penninic nappes in the Alps reached peak thermal conditions at about 30 Ma (Kurz *et al.*, 1996). The Calabrian terranes in the Western Mediterranean began to progress eastward (Van Dijk & Okkes, 1991). In the Carpathians, the subduction consumed part of the Magura basin (Oszczypko, 1992, 1998). After the late Oligocene folding, the Magura Nappe thrust northward and covered the remnant of the Silesian ridge, and in the more outer part of the Carpathian basin (Dukla, Silesian-Subsilesian, Skole-Tarçau), flysch sedimentation continued during the Oligocene (Fig.10, 11). Initial folding occurred in a part of Silesian basin (Żytko, 1999a). Restricted basin with organic-rich Menilitic shales sedimentation was formed. Sedimentation of the Podhale Flysch covering parts of Inner Carpathian terrane was fully developed during the Oligocene time (Książkiewicz, 1977b).

The Paratethys sea developed in Europe and central Asia, ahead of the progressing northwards orogenic belts (Dercourt *et al.*, 1986, 1993). Geodynamic evolution of the basins in the Alpine belt led to a transition from flysch to molasse type of sedimentation.

Rifting events were initialized during the Oligocene time in the several countries in Europe between France and Ukraine (Ziegler, 1988; Bois, 1993; Wilson & Downes, 1991; Żytko *et al.*, 1989) and were associated with the alkaline volcanism. According to Bois (1993), extension occurred in part of the European plate, with the rifting of the Rhine, Limagne and Bresse Trough, contemporaneous of the climax of Alpine compression. Part of this rift system included the Gulf of Lions, associated with the mantle plume, expressed by volcanics in the Massif Central and Provence, and on Corsica and Sardinia (Wilson & Downes, 1991). Rifting in this area was followed by oceanic sea-floor spreading and drifting of the Corsican and Sardinian plates (Bois, 1993; Ricou, 1996). North Sea subsidence, renewed during the Tertiary (Joy, 1992) could have been related to Central European rifting.

Chattian–Aquitanian

Collisions continued in the area between Africa and Eurasia. Thrusting occurred in the Riff area in Africa and the Betic area in the southern Spain, due to the collision of the Alboran Sea arc (Morley, 1993; Vissers *et al.*, 1995) (Fig. 12). Transpressive thrusting in the Balearic margin was related to the displacement of the Alboran block (Vegas, 1992). The movement of Corsica and Sardinia caused the plates to push eastwards in the future, resulting in deformation of the Alpine-Carpathian system. This deformation reached as far as to Romanian Carpathians (Ellouz & Roca, 1994; Royden, 1988) and continued throughout the Neo-

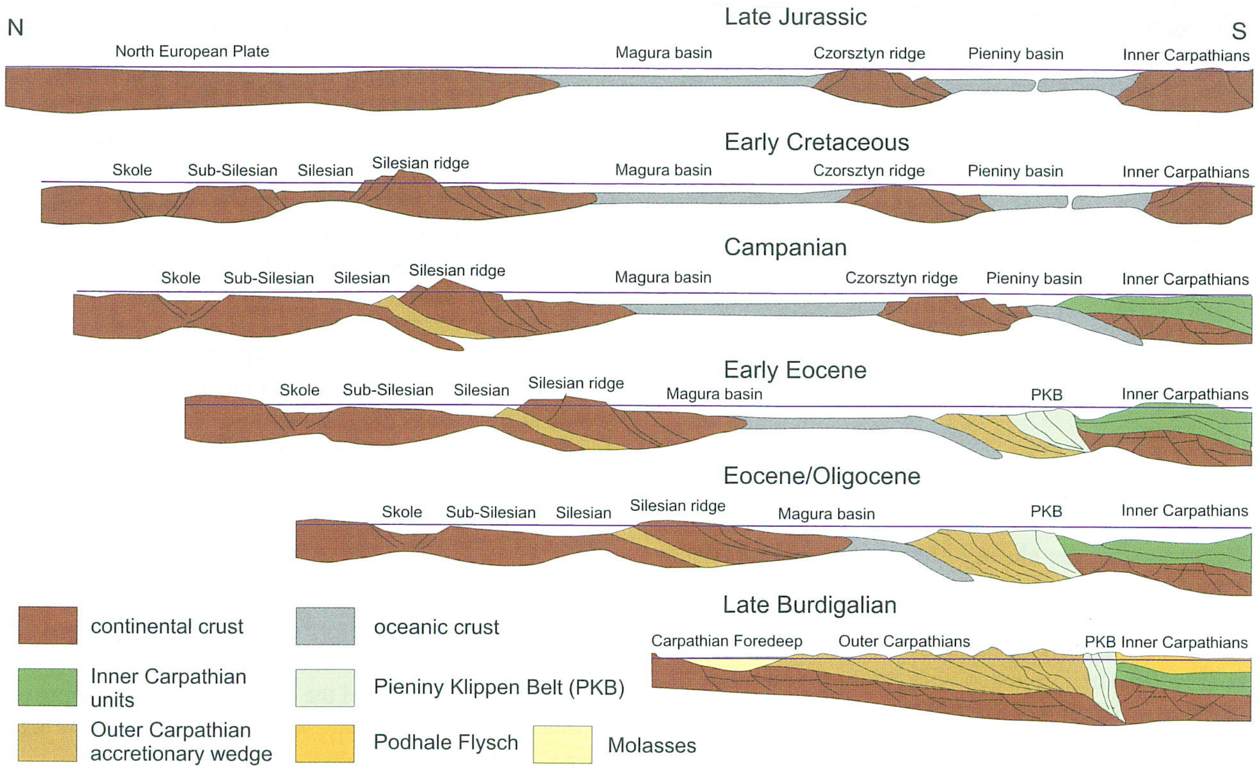


Fig. 11. The Late Jurassic–Late Burdigalian palinspastic evolution model of the West Outer Carpathians (after Oszczypko, 1999)

gene. The Calabrian terranes in the Western Mediterranean continued to progress eastwards (Dewey *et al.*, 1989; Van Dijk & Okkes, 1991). Corsica and Sardinia pushed the Umbria-Marche terrane towards collision with the Apulian block. The thrust-and-fold-belt of the Apennines began to develop (Pialli & Alvarez, 1997).

The Apulia and the Alpine-Carpathian terranes were moving northwards, colliding with the European plate, until 17 Ma (Decker & Peresson, 1996). This collision caused the foreland to propagate north. The north to NNW-vergent thrust system of the Eastern Alps was formed. Oblique collision between the North European plate and the overriding Western Carpathian terranes led to the development of the outer accretionary wedge, the built up many flysch nappes and the formation of a foredeep (Kováč *et al.*, 1993, 1998; Ślączka, 1996a, b). These nappes were detached from their original basement and thrust over the Paleozoic–Mesozoic deposits of the North European Platform covered partly by Tertiary deposits. This process was completed in the Vienna basin area and then progressed northeastwards (Oszczypko, 1997). After the Late Oligocene folding, the Magura nappe was thrust northward in the direction of the terminal Krosno flysch basin (Oszczypko, 1999). Synorogenic basin with the flysch sedimentation Krosno beds formed during Oligocene as a continuation of the older Fore-Magura (with the outer part of Magura), Dukla, Silesian-Subsilesian, Skole-Tarçau, and other units of the Outer Carpathian. The initial folding in this zone also occurred.

The Alboran Sea extensional basin developed in the western Mediterranean behind the arc located between Iberia and Northern Africa (Watts *et al.*, 1993; Morley, 1993; Vissers *et al.*, 1995). The first stage of rifting in Valencia Trough (Vegas, 1992) was initiated. Crustal extension of the internal zone of the Alps started in the Early Miocene, during the continued thrusting (Decker & Peresson, 1996). Early to Middle Miocene extension and back-arc type rifting resulted in the formation of a intramountain Pannonian basin in Central Europe (Royden, 1988; Decker & Peresson, 1996). A new period of extension began in the Pontides-Sakariya continent in Turkey (Yilmaz *et al.*, 1996).

Burdigalian–Serravallian–Recent

This was the time of the major Alpine orogenic phase, the formation of mountains in the Alpine-Carpathian area, the Mediterranean, Central Asia and the Himalayans (Fig. 13). The continued of thrusting occurred in the Riff area in Africa and in the Betic area in southern Spain as a result of the collision of the Alboran Sea arc with the Africa and Iberian plates (Morley, 1993; Vissers *et al.*, 1995). The Calabrian arc and subduction zone collided with Africa and the Southern Sicilian-Maltese platform (Dewey *et al.*, 1989; Van Dijk & Okkes, 1991; Ricou, 1996). The wing of this collision formed the southern Apennines. Thrusting also continued in the northern Apennines.

During the Early Burdigalian the front of the Magura nappe in Outer Carpathians reached the S part of the Silesian basin (Oszczypko, 1998). This was followed by a progressive migration of axis of subsidence northward. During the course of the Burdigalian transgression, part of the Magura basin was flooded and the seaway connection with the Vienna basin via Orava was probably established (Osz-

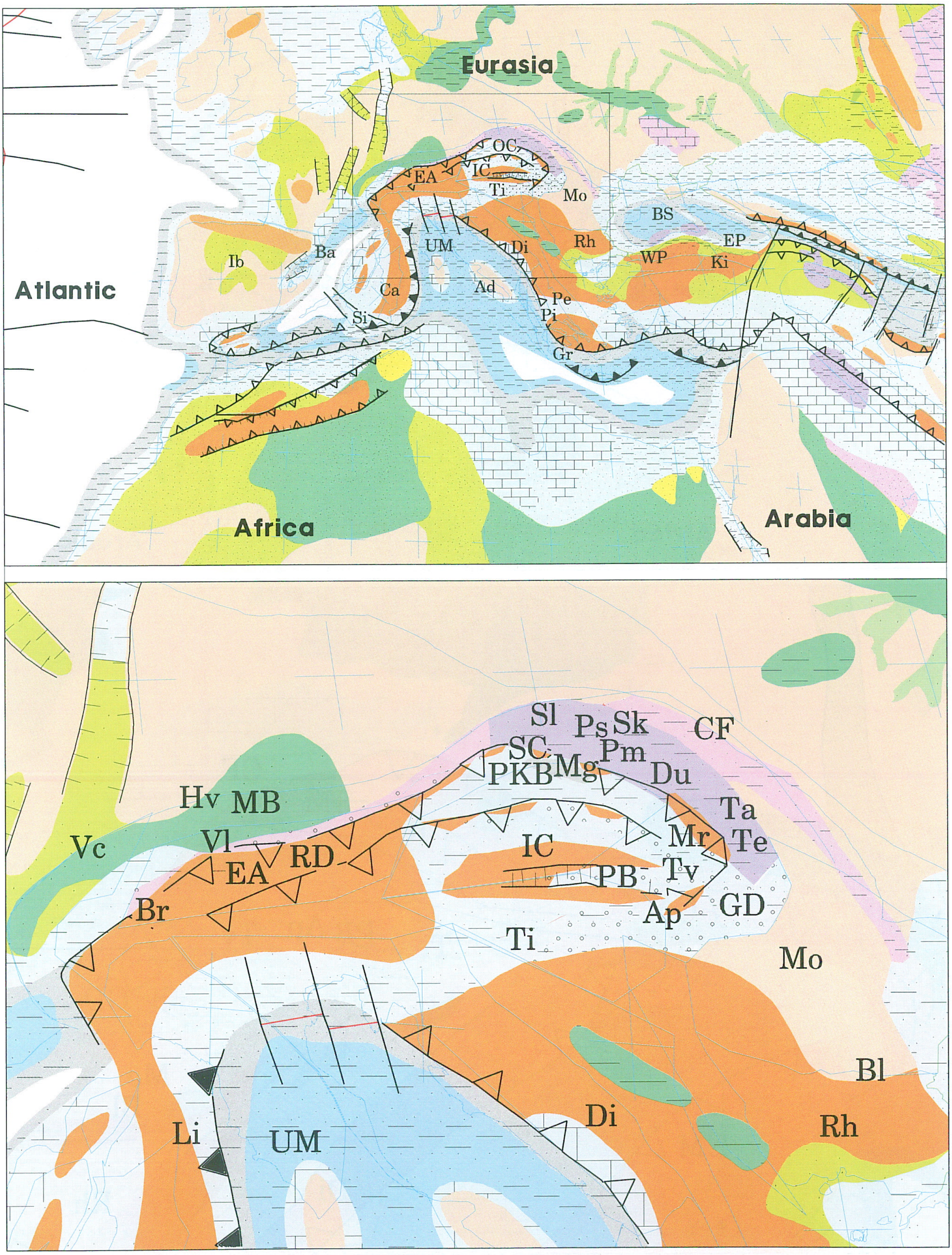


Fig. 12. Paleoenvironment and lithofacies of the circum-Carpathian area during Chattian–Aquitanian; plates position at 22 Ma. For explanation – see Fig. 2

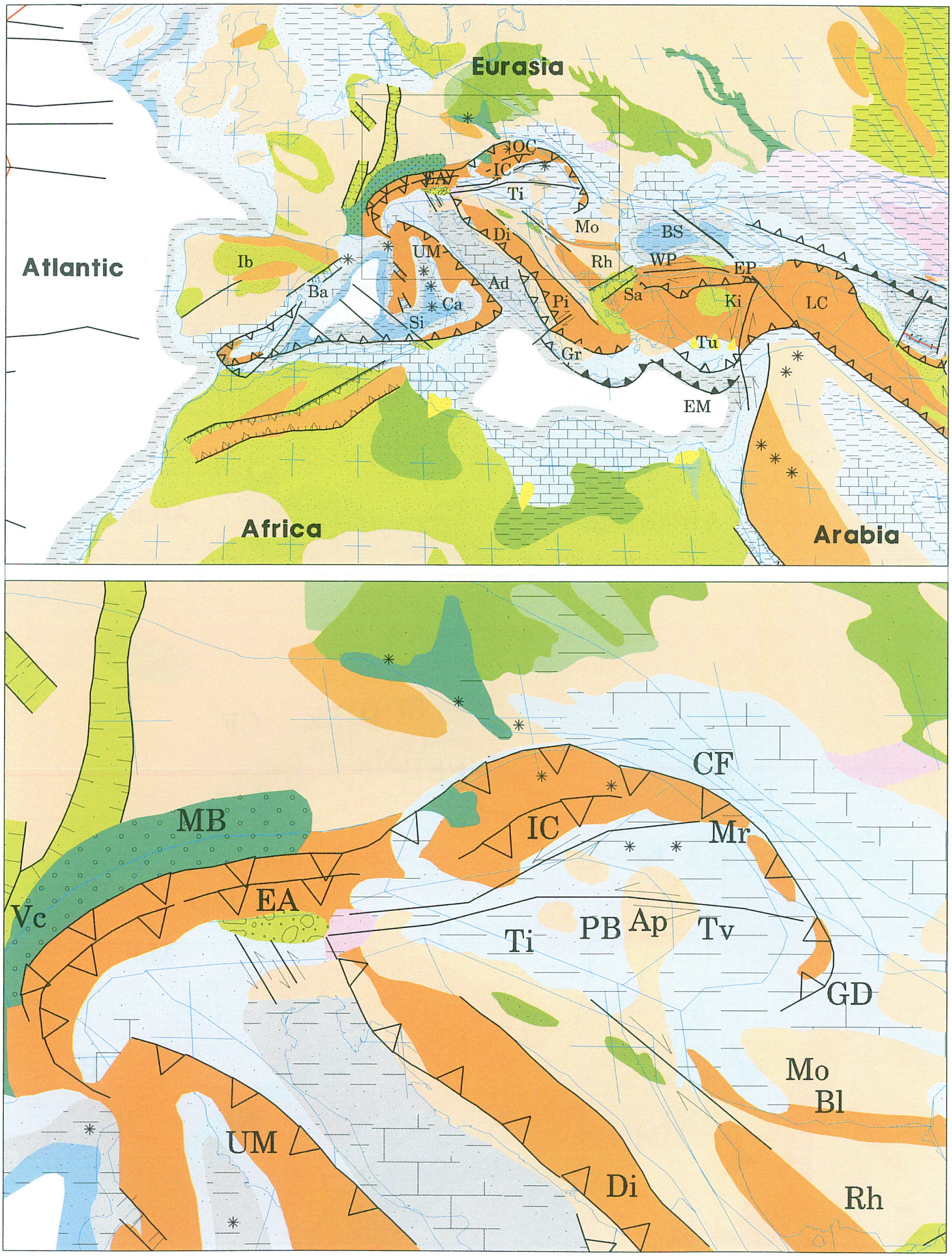


Fig. 13. Paleoenvironment and lithofacies of the circum-Carpathian area Burdigalian– Serravallian; plates position at 14 Ma. For explanation – see Fig. 2

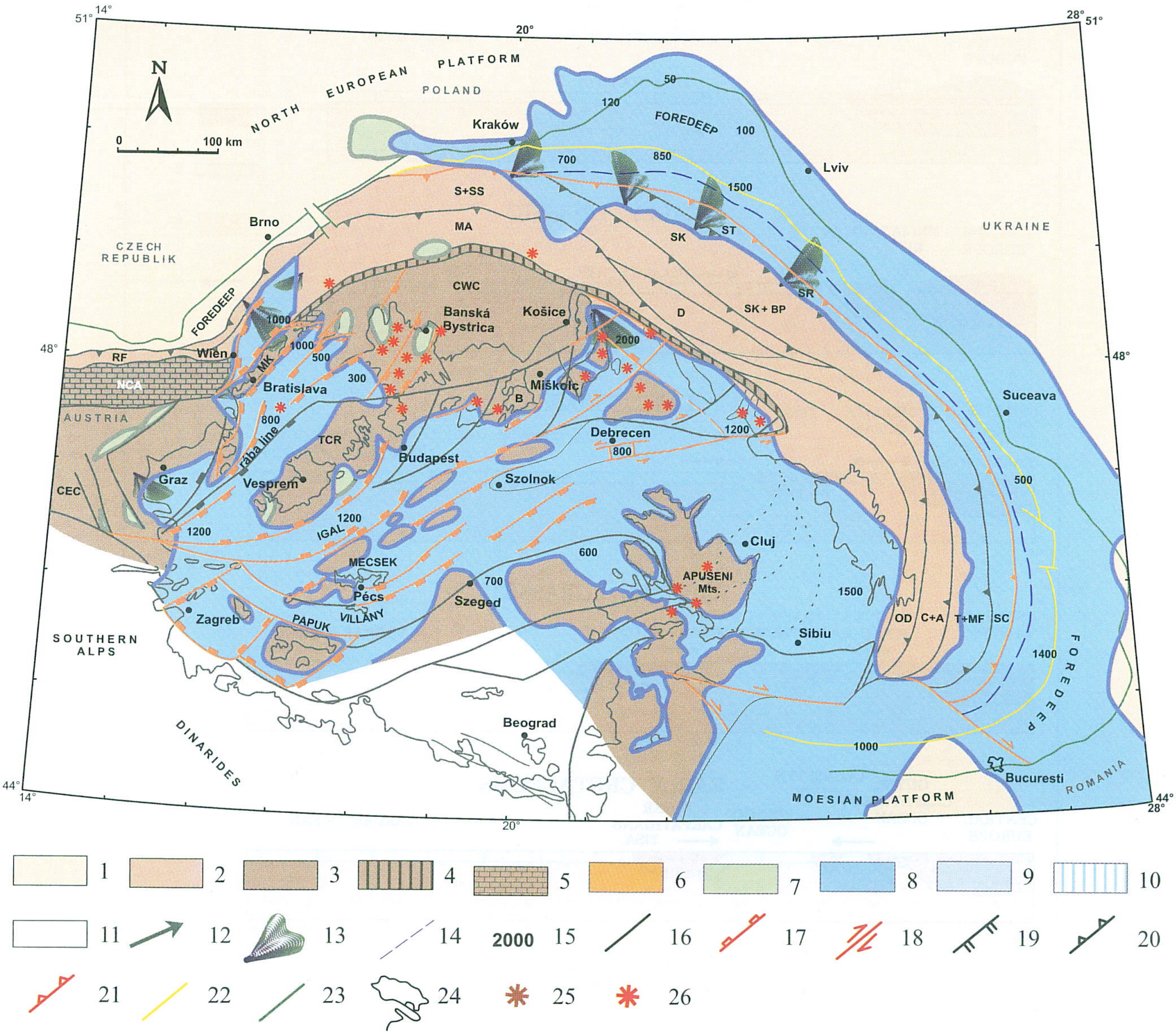


Fig. 14. Alpine–Carpathian–Pannonian–Dinaride region palinspastic map during Late Badenian (Kováč *et al.*, 1998; simplified). *1* – uplifted area of the platform; *2* – uplifted area of the Rhenodanubium Flysch zone and Outer Carpathians; *3* – uplifted area of the Alcapa and Tisza – Dacia microplates; *4* – Pieniny Klippen Belt; *5* – Northern Calcareous Alps; *6* – terrestrial-fluvial paleoenvironment; *7* – brackish-lacustrine paleoenvironment; *8* – marine paleoenvironment; *9* – expected marine paleoenvironment; *10* – lagoonal paleoenvironment; *11* – areas without information; *12* – direction of sediment transport; *13* – delta; *14* – axis of subsidence; *15* – thickness of sediments; *16* – passive fault; *17* – active normal fault; *18* – active strike-slip; *19* – future thrust; *20* – passive thrust; *21* – active thrust; *22* – present front of the Carpathians; *23* – present margin of the Carpathian foredeep; *24* – present contours of mountains; active volcanic centers: *25* – basic; *26* – acid and calc-alkaline

czypko *et al.*, 1999). The thinned continental crust of the residual flysch basin was under thrust beneath the overriding Carpathian orogen. This underthrusting was connected with the Intra-Burdigalian folding and uplifting of the Outer Carpathians. The formation of the West Carpathian thrusts was completed (Kováč *et al.*, 1993, 1998; Ślączka, 1996a, b; Oszczypko, 1997) (Fig. 13, 14). The Carpathians continued overriding the Eurasian Platform and caused flexural depression – a peripheral foreland basin related to the moving Carpathian front (Oszczypko, 1998). The thrust front was still migrating eastwards in the Eastern Carpathians. The Carpathian foreland basin continued its development partly on the top of the thrust front with mainly terrestrial deposits forming the clastic wedge. This clastic wedge along the Carpathians could be comparable with the lower-freshwater Molasse of the Alpine Foreland basin. During Serravallian, the marine transgression flooded the foreland basin and adjacent platform. After Serravallian the sea retreated from the Carpathian peripheral foreland basin. This was followed by the last overthrust of the Carpathians toward their present-day position (Oszczypko, 1998). During Tortonian–Gelasian time, Carpathian thrusting progressed east and south-eastwards, with a strong element of translation (Ellouz & Roca, 1994; Royden, 1988; Linzer, 1996). The thrusting

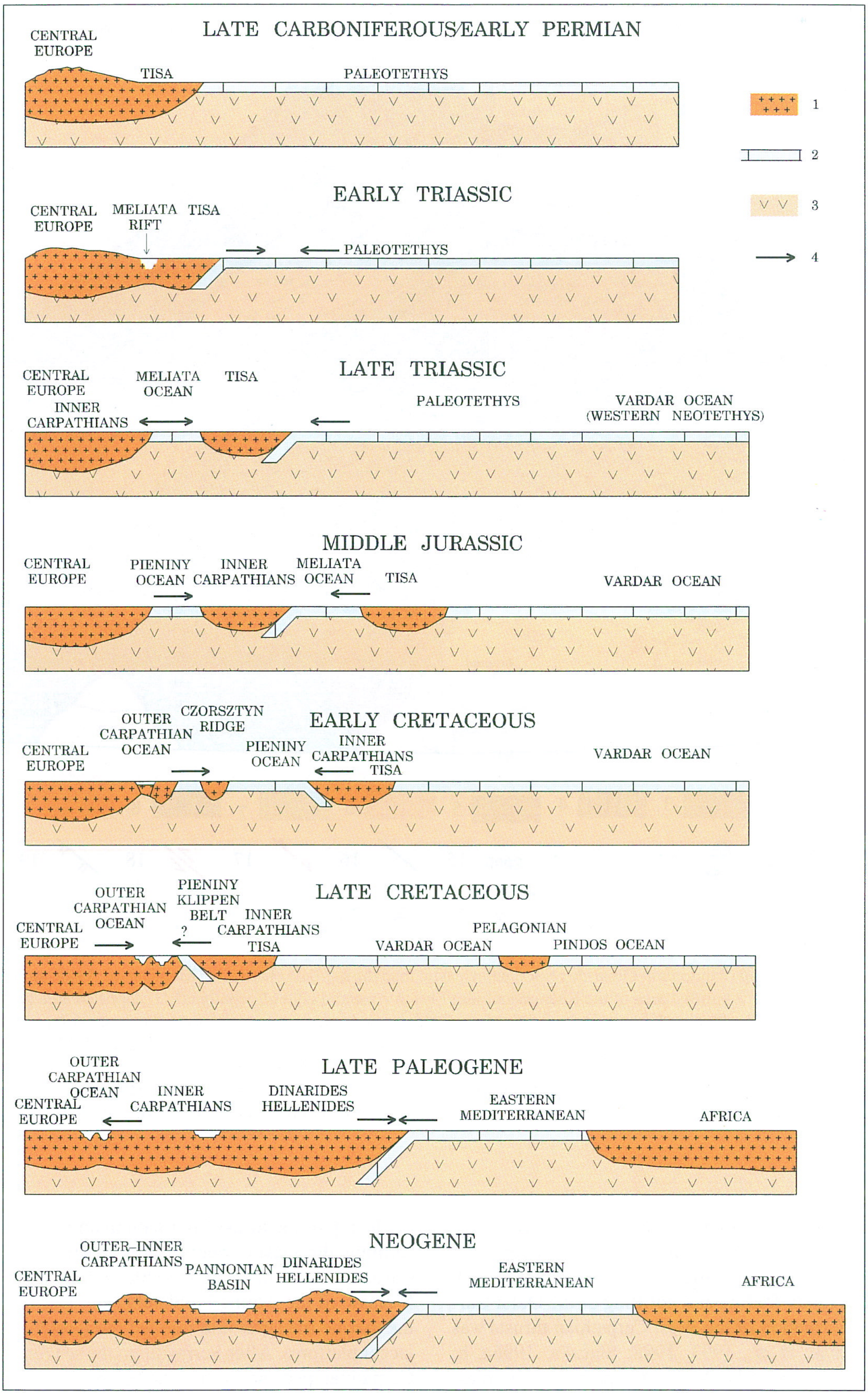


Fig. 15. Plate tectonic profiles. Central Europe–Carpathians–Greece. *1* – continental crust (including obducted; allochtonous rocks and sedimentary cover); *2* – oceanic crust (including deposits); *3* – upper mantle; *4* – direction of plate movement

was completed during the Pliocene–Quaternary in the Vrancea Mountains in Romania. The eastward movement of the orogen was related to the movement of Corsica and Sardinia. The extrusion caused by collision of Apulia plate with Europe could have played a role in the eastward movement of the orogen (Decker & Peresson, 1996).

The opening of the Tyrrhenian Sea (Spadini *et al.*, 1995) as well as Valencia Trough (Vegas, 1992) was initiated. Extension in the Alpine-Carpathian system continued. Extension also occurred in the Apennines (Carmignani *et al.*, 1994). Strike-slip, in the Pannonian basin (Decker & Peresson, 1996), contributed to the formation of pull-apart elements of the Pannonian system. In Central Europe, the NW–SE trending rift system was perpendicular or diagonal to the thrust front of the Carpathians (Żytko *et al.*, 1989). Tertiary magmatism was crossing the Carpathians between Moravia and Upper Silesia, on one side, and the Pannonian basin, on the other. Mantle doming contributed to crustal stretching (Golonka & Bocharova, in print).

The Tyrrhenian Sea (Channell & Mareschal, 1989; Spadini *et al.*, 1995) as well as the Valencia Trough (Vegas, 1992; Torres *et al.*, 1993) went through the main phase of opening. The rifting in the Pantelleria Trough, between Africa and Sicily occurred in the Pliocene and Quaternary. The rift depicted by Casero & Roure (1994) cut the Sicilian-North African thrust front perpendicularly. A back-arc basin formed in Aegean area behind the subduction zone (Bogdanov *et al.*, 1994.

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APPENDIX
Glossary of plate tectonic and paleogeographic terms

Adria – see Apulia plate.

Alcapa – superterrane, which includes Eastern Alps, Inner Carpathian, Tisa and adjacent terranes, welded together during Late Cretaceous–Paleocene.

Alpine Orogeny – series of the Cretaceous through Cenozoic collisional orogenic events between Africa, Europe, Arabia and Central Asia. The orogeny was most intense during the Miocene. It involved continental plates like Iberia, Apulia/Adria, Sardinia, Kabylia, Calabria, Alpine, Carpathian (Inner Carpathians and Tisa), Greek (Ionian, Greece, Pelagonian, Serbo-Macedonian, Turkish Taurus, Kirsehir, Sakariya, Pontides), Iranian (Lesser Caucasus, Alborz, Sanandaj-Sirjan, Lut), Afghan (Helmand, Farah) plates. The Alpine Orogeny formed numerous orogenic belts in Europe, North Africa, and the Middle East.

Andrusov ridge – see Black Sea.

Andrychov ridge – uplifted area between Silesian and Fore-Silesian basin in Outer Carpathians.

Apulia plate – continental plate that was rifted from Gondwana and collided with central Europe during the Alpine Orogeny. It includes Adriatic Sea and adjacent part of Italy, Southern Alps and Dinarides. It existed as a separate plate during Cretaceous-Tertiary time. On a generalized, small-scale global maps Apulia includes Italy, Greece, the Balkan area, the Pannonian basin, and central (Inner) Carpathian.

Apuseni Mts. – mountains in Rumania between Pannonian and Transilvanian basin formed of fragments of Tisa plate and Neogene volcanics.

Austroalpine – see Ligurian.

Balearic Islands – terrane rifted off the Iberia plate in Neogene. See also Valencia trough.

Balkans – mountains in Bulgaria, Balkan rift developed in latest Jurassic, closed during Eocene–Oligocene time.

Baltica – separate continental plate in the Early Paleozoic, consisting of the major part of northern Europe. It was bounded on the west by the Iapetus suture, on the east by the Ural suture, on the south by the Variscan/Hercynian suture, and on the southwest by a suture located near the Tornquist-Teisseyre line. Baltica collided with Laurentia forming Laurussia in the Silurian (Scandian Orogeny).

Black Sea – deep-water sea between Europe and Asia. Divided into eastern and western Black Sea by Andrusov ridge. Western Black Sea opened as back-arc basin in Early Cretaceous. Eastern Black Sea opened during Late Cretaceous–Paleogene time.

Bresse Trough – see Rhine.

Briançonnais terrane – terrane in Alps between Ligurian Ocean and Valais trough.

Calabrian terranes – separate terranes in the western Mediterranean during Mesozoic–Paleogene; associated with the Neogene opening of the Tyrrhenian Sea; collided with Apulia.

Carpathian Foredeep – foreland basin formed in front of the overthrust Carpathian Mountains.

Cimmerian Orogeny – series of collisional events between Laurasia, Cimmerian, and the South-East Asian plates during the Late Triassic–Jurassic.

Cimmerian terranes (continent) – series of continental plates rifted away from Gondwana during the opening of the Neotethys Ocean in the Early Permian. They include Turkish, Iranian, Afghan plates, Tibet (Qiantang and Lhasa), and the Malaya plates; connected with Indochina, and Sibumasu. Some of these plates collided with Laurasia during the Cimmerian orogeny in Late Triassic to Late Jurassic, some were amalgamated into the Alpine orogenic system in Cretaceous and Cenozoic.

Czorsztyn ridge – intraoceanic ridge between the Pieniny Klippen Belt Ocean and Outer Carpathian trough.

Dinarides – mountains between Pannonian basin and Adriatic Sea, formed as the trust-and-foldbelt in Tertiary. The Dinaride terrane was perhaps situated at the margin of Apulia plate.

Dukla basin – northern part of the Magura basin, perhaps between the Silesian ridge and enigmatic extension of the Marmarosh massif. See also Outer Carpathian basin.

Eastern Alps Plate – see Ligurian.

Eastern Pontides – mountains in northeastern Turkey; see Pontides.

Eastern Mediterranean basin – eastern part of the Mediterranean Sea between Turkey, Greece and Africa, with partly oceanic crust; opened in Permian–Triassic time, reopened in Late Jurassic–Cretaceous; reduced in size (partly subducted) in Tertiary.

Ellesmerian Orogeny – see Innuitian Orogeny.

Fore-Magura (Dukla) basin – northern part of the Magura basin.

See also Outer Carpathian basin.

Fore-Silesian basin – northern part of the Silesian basin. See also Outer Carpathian basin.

Getic Depression – foreland basin formed in front of the overthrust Southern Carpathian Mountains in Rumania.

Getic terranes – small terranes in the Rumanian Carpathians; in the Mesozoic located somewhere between Inner Carpathians, Tisa and Moesia.

Gondwana – supercontinent from Cambrian to Jurassic time. The core of Gondwana includes South America, Africa, Madagascar, India, Antarctica, and Australia. Plates that have been part of Gondwana at some time during the Paleozoic include Yucatan, Florida, Avalonia, central and southern Europe, China (three separate blocks), Tarim, Karakum, Turkey, Iran, Afghanistan, Tibet, and Southeast Asia. Gondwana collided with Laurussia forming Pangea in the Carboniferous, and separated again in the Middle Jurassic. It was fragmented in a series of Middle Jurassic–Cretaceous rifting and sea-floor spreading events.

Grajcarek unit – see Hulina unit.

Greater Caucasus – mountains between SE Europe and Asia formed after closing Greater Caucasus–proto-South Caspian Ocean in the Neogene as a result of the collision of the Lesser Caucasus and Transcaucasus blocks with Eurasia. Greater Caucasus plate collided with Baltica in the late Paleozoic.

Greece – complex mosaic of terranes, fold-and-thrust belts and basins. Large part of Greece in Mesozoic–Paleogene time belonged to the large carbonate platform, which also included Apulia and Taurus plates.

Gresten basin – Mesozoic basin, perhaps connected with Magura basin and Valais trough; its deposits are known from Eastern Alps.

Halstatt Ocean – see Meliata Ocean.

Helvetic zone – part of the European platform involved in the Alpine thrusts in Switzerland. Vercors Mountains are French equivalent of the Helvetic Zone.

Hercynian Orogeny – Devonian–Carboniferous collisional events between the European part of Laurussia and terranes from Spain to Poland. The Hercynian Orogeny and related North American events (Alleghenian and Ouachita) formed the central Pangean Mountain belt during the Permo-Carboniferous.

Himalayan Orogeny – series of Cretaceous through Tertiary orogenic events, which culminated with the Tertiary collision of India and Eurasia, forming Himalayan and adjacent mountain belts and strike-slip fault systems in Asia. Himalayan Orogeny has had major impact on Southeast Asian plate tectonic development during the Tertiary.

Hulina basin – southernmost part of the Magura basin in Jurassic and Cretaceous, equivalent of Grajcarek basin.

Iberia – plate formed during the Hercynian Orogeny as a part of Pangea; rifted away from North America during the latest Jurassic–Cretaceous time; rifted away from Eurasia in Cretaceous time, during the opening of the Biscay Bay; sutured to France along Pyrenean Mts.

Inner Carpathians – mountains in Central Europe; separate plate during Jurassic–Cretaceous, accreted to Europe in Late Cretaceous–Paleogene. See also Ligurian Ocean.

Ionian Platform – western Greece and the adjacent Ionian Sea, in the Mesozoic connected Apulia and Taurus plate. See also Pindos Ocean.

Kirsehir plate – central Turkey, separate plate in the Mesozoic. See also Pindos Ocean.

Kruhel olistolith – fragment of the Mesozoic sedimentary (carbonate) cover of the Eurasian margin found in the Outer Carpathian Flysch.

Laramide Orogeny – orogenic movements in western North America during the Eocene through Oligocene. Term is often incorrectly used for the Late Cretaceous–Paleocene phase of the Alpine Orogeny in Europe. See also Subhercynian structures.

Laurasia – supercontinent from Late Paleozoic to Early Cretaceous time, consisting of Laurentia, central and northern Europe, and Asia (excluding India and Arabia). The assembled Laurasia was the northern part of Pangea from Late Permian to Early Jurassic. It separated from Gondwana in the Middle Jurassic, and continued to fragment into the Tertiary, when North America was separated from Eurasia by the opening of the North Atlantic.

Laurentia – separate plate in the Early Paleozoic, consisting of the major part of North America, northwest Ireland, Scotland, Greenland, Barentsia (Svalbard), and the Chukotka Peninsula. The Early Paleozoic margin of Laurentia can be recognized in the Appalachians.

Laurussia – separate, large continental plate in Silurian through Devonian time; originated by collision of Baltica and Laurentia during the Scandian Orogeny. It was the part of Pangea during the Late Paleozoic.

Lesser Caucasus – mountains in Asia. Lesser Caucasus terrane was part of Gondwana during the Late Paleozoic. It rifted away from Gondwana in Jurassic; collided with Eurasia in Neogene. See also Greater Caucasus.

Lhasa Plate – present day southern Tibet, existed as separate plate in the Mesozoic. The relationship between the Lhasa plate and the Cimmerian continent during periods of rifting and collision is speculative. It finally collided with Eurasia during Cretaceous time.

Ligerian terrane – Paleozoic terrane in Western Europe; do not confuse with Ligurian Ocean or Ligurian Sea.

Ligurian, Penninic, Pieniny Klippen Belt Oceans – oceans opened in the Jurassic time between Apulia Eastern Alps (Austroalpine units), Inner Carpathian plates and Europe; closed during the Alpine orogeny in Tertiary.

Limagne trough – see Rhine trough.

Lut plate – eastern Iran, separate plate, a part of the Cimmerian terranes; collided with Eurasia in the Late Triassic; rifted away in Early Cretaceous; amalgamated with the Asian blocks in the Alpine Orogeny in the Neogene.

Magura basin – basin in the Outer Carpathians, North of Czorsztyn ridge. During Jurassic, it was a speculative basin with oceanic crust and dramatically reduced sedimentation. Somehow related to the Pieniny Klippen Belt basin. After closing of the Pieniny Klippen Belt basin, the Magura basin was part of the Outer Carpathian basin. The northernmost part forms Fore-Magura – Dukla subbasin.

Małopolska High – structural unit in southern Poland; a terrane in Paleozoic; perhaps a part of Avalonia; collided with Baltica in the Silurian–Devonian.

Mamonia ophiolites – Triassic ophiolites on Cyprus.

Marmarosh – massif in the Eastern Carpathian with crystalline rock of Precambrian–Paleozoic age; initially part of the Moesian plate, moved during Jurassic–Cenozoic to its present position. Marmarosh zone includes this massif as well as Marmarosh Klippen with Mesozoic ophiolites and flysch nappes.

Mauretanides, Bassarides, Rokelides – mountain systems in western Africa; remnants of the central Pangean Mountain Belt, which originated as a result of collision between Gondwana and North America in the Late Paleozoic.

Meliata–Halstatt Ocean – narrow basin with the oceanic crust, opened in the Triassic between Eurasian margin and Hungarian Tisa block.

Moesia plate – parts of Rumania and Bulgaria; plate sutured to Baltica during Paleozoic (Silurian–Devonian?).

Molasse basin – foreland basin formed in front of the overthrust Alps; filled with molasse deposits.

Neotethys – large Mesozoic ocean between Gondwana (Australia, India, Arabia, Africa) and Eurasia. It was formed by rifting of the Cimmerian plates away from Gondwana in the Early Permian, enlarged in the Triassic, and connected with central Atlantic during the Jurassic. Several branches: Ligurian-Penninic-Pieniny Klippen Belt, Meliata, Vardar, Pindos, Tauric, Greater Caucasus, Sebzevar, and Sistan oceans existed during the Mesozoic time. Most of Neotethys was closed in the Himalayan-Alpine Orogeny; fragments are included in the present day Indian Ocean and Mediterranean Sea.

Outer Carpathian basin – complex basin with the partially oceanic or transitional crust; existed in Jurassic–Tertiary between Inner Carpathians and European margin; divided into subbasins: Magura, Fore-Magura, Dukla, Silesian, Subsilesian, Skole and Tarçau. The Magura part opened earlier; see Magura basin. The other subbasins opened in the latest Jurassic–Cretaceous as a result of rifting, which effected the European margin. The Outer Carpathian basin was closed in the Tertiary.

Outer Carpathians – fold-and-thrust belt mountains in the central and eastern Europe, formed in the Tertiary.

Paleotethys – large Paleozoic ocean between eastern Gondwana and the East Siberia, Kazakhstan, and Baltica plates, originated in the Early Devonian as a remnant of the eastern part of the Rheic Ocean. Paleotethys closed in the Early to Middle Jurassic during the collision of Cimmeria with Laurasia. The limits of the eastern Paleotethys and the relationship with Panthalassa and the Chinese plates are speculative.

Pamir – mountains in central Asia; several Pamir terranes, like North Pamir, Kurgovat, South Pamir, collided with Asia during Paleozoic and Mesozoic time.

Pangea – single continent comprising all the world's landmasses. The term Pangea describes the continental configuration from the Carboniferous through Middle Jurassic time. By the Late Paleozoic, Laurussia, East Siberia, Kazakhstan, and Gondwana had collided to form the western, major part of Pangea. The Asian plate was still separate until the Early to Middle Jurassic. Almost all continental plates were assembled for a relatively short time (about 20 million years) in the Early Jurassic following the Early Cimmerian Orogeny.

Pangean Mountain Belt – see Hercynian Orogeny.

Pannonian basin – intermountain basin in Central Europe, behind the Carpathian foldbelt, formed in the Tertiary.

Paratethys – large sea in south-central Europe and central Asia formed during the Alpine Orogeny. The Black, Caspian, Azov and Aral Seas are Paratethys remnants.

Pelagonian plate – central Greece, separate plate in the Mesozoic. See also Pindos Ocean.

Penninic Ocean – see Ligurian Ocean.

Pieniny Klippen Belt – fold-and-thrust belt in Carpathians. See also Ligurian Ocean, Czorsztyn ridge.

Pindos Ocean – branch of Tethys with the oceanic crust, between Pelagonian, Kirsehir and Sakariya blocks and Taurus-Ionian platform.

Podhale Flysch basin – intermountain basin in the Inner Carpathians in Eocene–Oligocene; inverted in the Neogene.

Polish-Danish Graben – rift in Central Europe, originated during the Jurassic, turned into aulacogen in the early Cretaceous, inverted in the late Cretaceous–Paleogene.

Pontides – northern Turkey; separate Pontides plates were involved in the opening of the Black Sea. In the Paleogene, Pontides were sutured with the other Turkish plates.

Proto-Black Sea – see Tauric basin.

Proto South-Caspian – see Greater Caucasus.

Rheno-Danubian trough – rift with the partially oceanic crust opened in the Early Cretaceous in Alps; closed in the Tertiary.

Rhine, Limagne and Bresse troughs – Tertiary rift system in Europe, associated with the hot spot activity.

Rhodopes – mountains between Bulgaria, Greece and Turkey. Rhodopes plate was accreted to Europe in the Late Paleozoic.

Sakariya – central Turkey, separate plate in the Mesozoic. See also Pindos Ocean.

Scythian Platform – parts of Ukraine and SW Russia, accreted to Europe in the Paleozoic.

Shatski terrane (Rise) – fragment of the Black Sea with the continental crust basement, related to the Paleogene opening of the eastern Black Sea.

Sicily terrane – separate terrane in Mesozoic–Paleogene; collided with the African plate in Neogene forming the Sicily island.

Silesian basin – basin in the Outer Carpathians; opened as a rift in Late Jurassic–Early Cretaceous between Silesian ridge and Eurasian margin. See also Outer Carpathian basin.

Silesian ridge (cordillera) – uplifted area between Magura–Fore-Magura and Silesian basins in Outer Carpathians.

Sinaia basin – basin in the Outer Carpathians, perhaps equivalent of the Silesian basin in Rumania.

Skole basin – basin in the Outer Carpathians; opened as a rift in Cretaceous between Andrychov ridge, Subsilesian basin and Eurasian margin; in Rumania known as Tarçau basin. See also Outer Carpathian basin.

South Caspian microcontinent – separate plate during the Mesozoic, included in the Cimmerian terranes; today block with the continental crust in the Caspian Sea.

Subhercynian and Laramide Structures – intracontinental Late Cretaceous–Early Paleogene intracontinental deformations in Europe, effecting, among the others, the Harz and Holy Cross Mountains. Subhercynian and Laramide names are sometimes referred to the phases of the Alpine Orogeny.

Štramberk olistolith – fragment of the Mesozoic sedimentary (carbonate) cover of the Eurasian margin found in the Outer Carpathian Flysch.

Tarçau basin – Rumanian equivalent of the Skole basin. See also Outer Carpathian basin.

Tauric basin – proto-Black Sea; a back-arc basin opened in the Triassic.

Taurus – mountains in the southern Turkey; separate plate during the Mesozoic time.

Teisseyre-Tornquist Line – major NW–SE striking suture between the east European Platform (ancient Baltica plate) and the remaining part of Europe; well defined in Sweden, the Baltic Sea, and Poland; probably beneath the Carpathian Nappes in the Ukraine; terminates in the Black Sea area.

Teleajen basin – equivalent of the Dukla basin in Rumania.

Tisa plate – Mesozoic plate in Hungary and Rumania; separated in Triassic from Eurasia, sutured to Inner Carpathians in the latest Jurassic–earliest Cretaceous; a part of Alcapa superterrane since Paleocene. See also Alcapa superterrane and Meliata Ocean.

Transdanubian terrane – terrane in Hungary between Tisa, Eastern Alps and Apulia; may be a part of Tisa plate.

Transilvanian basin – intramontane basin in Rumania between Apuseni Mts and Carpatians; opened in Neogene.

Trupchun phase – Alpine orogeny deformations in the Cretaceous.

Umbria-Marche – western central Italy, amalgamated with the Apulia platform in Tertiary.

Valais trough – basin with the oceanic crust between the Briançonnais terrane and European platform, opened in the Early Cretaceous, closed in the Tertiary.

Valencia trough – back-arc basin in the western Mediterranean, between Spain and Balearic Islands, opened in the Neogene.

Vardar Ocean – western part of Neotethys.

Vercors – mountains in France; French equivalent of the Helvetic zone.

Vocontian trough – rift opened in the early Cretaceous; perhaps a western extension of the Rheno–Danubian trough.

Western Pontides – mountains in northwestern Turkey. See Pontides.

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Streszczenie

PÓŹNOKARBOŃSKO-NEOGEŃSKA GEODYNAMICZNA EWOLUCJA I PALEOGEOGRAFIA REJONU WOKÓŁKARPACKIEGO I OBSZARÓW PRZYLEGŁYCH

Jan Golonka, Nestor Oszczypko & Andrzej Ślączka

Celem publikacji było przedstawienie ewolucji rejonu wokółkarpackiego z punktu widzenia tektoniki płyt i pozycji głównych elementów skorupy badanego obszaru w globalnym układzie odniesienia. Skonstruowano 12 map, przedstawiających paleogeografię od późnego karbonu po neogen. Mapy opracowano przy użyciu modelowania tektoniki płyt za pomocą programów PALEOMAP i PLATES służących do rekonstrukcji położenia płyt tektonicznych. Jako punkty reperowe wykorzystano współczesne plamy gorąca.

W karbonie w następstwie orogenezy hercyńskiej został uformowany superkontynent Pangea. Ocean Tetydy tworzył zatokę pomiędzy dwoma ramionami Pangei, Gondwaną i Laurazją. W tym czasie uformowało się podłoże większości płyt, które odgrywały znaczącą rolę w mezozoiczno-kenozoicznej ewolucji obszaru wokółkarpackiego.

W następstwie utworzenia ryftu mezozoicznego wzdłuż północnej krawędzi Oceanu Tetydy powstało szereg basenów typu oceanicznego. W zachodniej części rejonu były to Ocean Meliaty i pienińskiego pasa skałkowego, a na wschód od platformy mezyjskiej Ocean Tauryjski i Wielkiego Kaukazu. W wyniku oddzielenia się Gondwany i Laurazji utworzył się ocean alborańsko-liguryjsko-pieniński, sięgający na wschodzie aż po Karpaty ukraińskie. Ocean ten był połączony z Atlantykiem centralnym systemem uskoków przesuwczych, będących rezultatem tektonicznego rozpadu Pangei. Ku północy ocean ten łączył się z aulakogenem polsko-duńskim poprzez system ryftów i uskoków, rozciągając się dalej w kierunku Morza Północnego, Norweskiego i Barentsa. W okresie od późnej jury do wczesnej kredy rozwinął się ryft Karpat Zewnętrznych z przejawami wulkanizmu ekstensyjnego. Powstał wówczas basen śląski, oddzielony grzbietem śląskim (kordylierą) od basenu magurskiego. Z kolei grzbiet czorsztyński oddzielał basen magurski od pienińskiego.

W tytonie nastąpiła generalna reorganizacja płyt. Ocean Atlantycki zaczął się rozszerzać w kierunku Iberi i Nowej Funlandi. Liguryjsko-pienińskie odgałęzienie przestało się rozszerzać, czemu towarzyszyło powstanie strefy subdukcji wzdłuż południowej krawędzi basenu pienińskiego pasa skałkowego. W albie powstały pierwsze deformacje kompresyjne w obszarze alpejskim i karpackim.

Basen Karpat Zewnętrznych osiągnął maksymalną szerokość w apcie. Powstało w tym czasie szereg basenów cząstkowych takich jak podśląski, dukielski, skolski, Tarçau, oddzielonych lokalnymi strefami wyniesień.

W okresie od późnej kredy do paleocenu nastąpiło zamknięcie basenu pienińskiego pasa skałkowego i kolizja teranów Karpat Wewnętrznych z grzbietem czorsztyńskim. Terany Adri, Alp Wschodnich i Karpat Wewnętrznych kontynuowały ruch w kierunku północnym. W Europie centralnej nastąpiły ruchy górotwórcze larmijskie, inwersja basenów, oraz deformacje tektoniczne osadów Morza Północnego i strefy polskiej-duńskiej. W paleocenie uformował się superteran Alkapa, poprzez połączenie bloków Alp Wschodnich, Cisy, Karpat Wewnętrznych i innych małych teranów. W eocenie na skutek subdukcji została skonsumawana większa część basenu magurskiego. W wyniku fałdowań poźnooligoceńskich uformowała się płaszczowina magurska, która przykryła większą część grzbietu śląskiego. W pozostałej części Karpat Zewnętrznych rozwinęła się w tym czasie synorogeniczna sedymentacja warstw krośnieńskich.

Ruch płyt Adri i Alkapy w kierunku północnym kontynuował się w miocenie. Na przedpolu sfałdowanych Alp i Karpat utworzył się basen przedgórski Paratetydy. Płaszczowiny Karpat Zewnętrznych, odkłute i nasunięte na utwory platformy północnoeuropejskiej, ostatecznie uformowały się w miocenie środkowym. Ruchy nasuwawcze kontynowały się aż po czwartorzęd. Kierunek wschodni stał się kierunkiem dominującym od późnego miocenu.