KROBICKI, M., GOLONKA, J. & AUBRECHT, R., 2003: Pieniny Klippen Belt: general geology and geodynamic evolution.
In: Golonka, J. & Lewandowski, M. (eds.): Geology, geophysics, geothermics and deep structure of the West Carpathians and their basement.
Publications of the Institute of Geophysics, Polish Academy of Sciences (Warszawa), monographic vol. M-28 (363), 25-33.

Chapter 3

PIENINY KLIPPEN BELT: GENERAL GEOLOGY AND GEODYNAMIC EVOLUTION

by M. KROBICKI, J. GOLONKA and R. AUBRECHT

Outline of geology

The Northern Carpathians are subdivided into an older range known as the Inner Carpathians and the younger ones, known as the Outer or Flysch Carpathians (Figs. 1, 9). At the boundary of these two ranges the Pieniny Klippen Belt (PKB) is situated.

The Pieniny Klippen Belt is composed of several successions of mainly deep and shallow-water limestones, covering a time span from the Early Jurassic to Late Cretaceous. This strongly tectonized structure is a terrain of about 600 km long and 1-20 km wide, which stretches from Vienna to the west, to Romania to the east (Figs 1, 9). The PKB is separated from the present-day Outer Carpathians by the Miocene sub-vertical strike-slip fault (Birkenmajer, 1986).

During the Jurassic and Cretaceous within the Pieniny Klippen Belt Basin the submarine Czorsztyn Ridge and surrounding zones (mainly Czorsztyn Succession) ("pelagic swell" – Mišík, 1994) were an elongated structure with domination of pelagic type of sedimentation. The orientation of the Pieniny Klippen Belt Basin was SW-NE (see discussion in Golonka and Krobicki, 2001, see also Aubrecht and Túnyi, 2001) (Fig. 10). The deepest part of the Pieniny Klippen Belt Basin is documented by extremely deep water Jurassic-Early Cretaceous deposits (pelagic limestones and radiolarites) of Złatna Unit (Sikora, 1971; Golonka and Sikora, 1981; Golonka and Krobicki, 2002) later described also as Ultra-Pieniny Succession (Birkenmajer, 1988; Birkenmajer *et al.*, 1990) or Vahicum (e.g. Plašienka, 1999). The close to central furrow somewhat shallower sedimentary zones are known as Pieniny, Branisko (Kysuca) successions and transitional slope sequences between deepest basinal units and ridge units are known as Niedzica and Czertezik successions (Podbiel and Pruské successions) near the northern (Czorsztyn) Ridge and Haligovce-Nižná successions near the southern Exotic Andrusov Ridge (Fig. 10). The strongly condensed Jurassic-Early Cretaceous pelagic cherty limestones (Maiolica type facies) and radiolarites were also deposited in northwestern (Magura) basin. This extremely deep-water basinal zone of the southern Magura Basin is known as Magura Succession (equivalent of tectonic Grajcarek Unit, sensu Birkenmajer, 1970; 1986) or Hulina Unit (Golonka and Sikora, 1981; Golonka *et al.*, 2000; Golonka and Krobicki, 2002; Golonka *et al.*, 2003). Ridge sequences as well as transitional slope sequences are also called Oravicum (e.g. Plašienka, 1999).

Generally, the Pieniny Klippen Belt Basin history is tripartite (i-iii) – from the (i) oxygen-reduced dark/black terrigenous deposits of the Early-early Middle Jurassic age (Fleckenkalk/Fleckenmergel facies) trough (ii) Middle Jurassic-earliest Cretaceous crionoidal, nodular (of the Ammonitico Rosso type) or cherty (of the Maiolica = Biancone type) limestones and radiolarites up to the (iii) Late Cretaceous pelagic marls (i.a. Scaglia Rossa = Couches Rouge = Capas Rojas; Bąk, 2000) facies and/or flysch/flyschoidal series (i.a. Birkenmajer, 1986; Mišík, 1994; Aubrecht *et al.*, 1997).

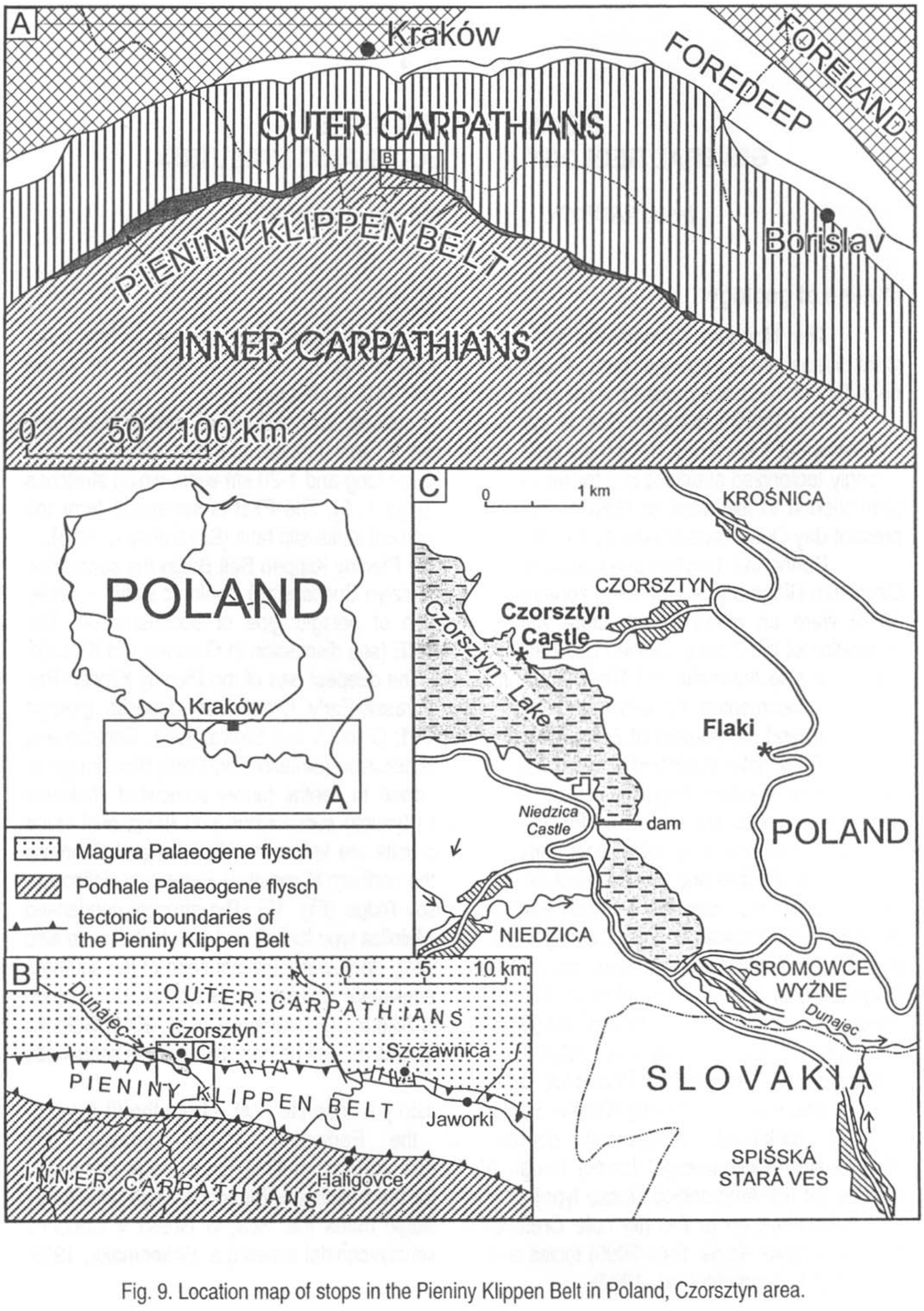


Fig. 9. Location map of stops in the Pieniny Klippen Belt in Poland, Czorsztyn area.

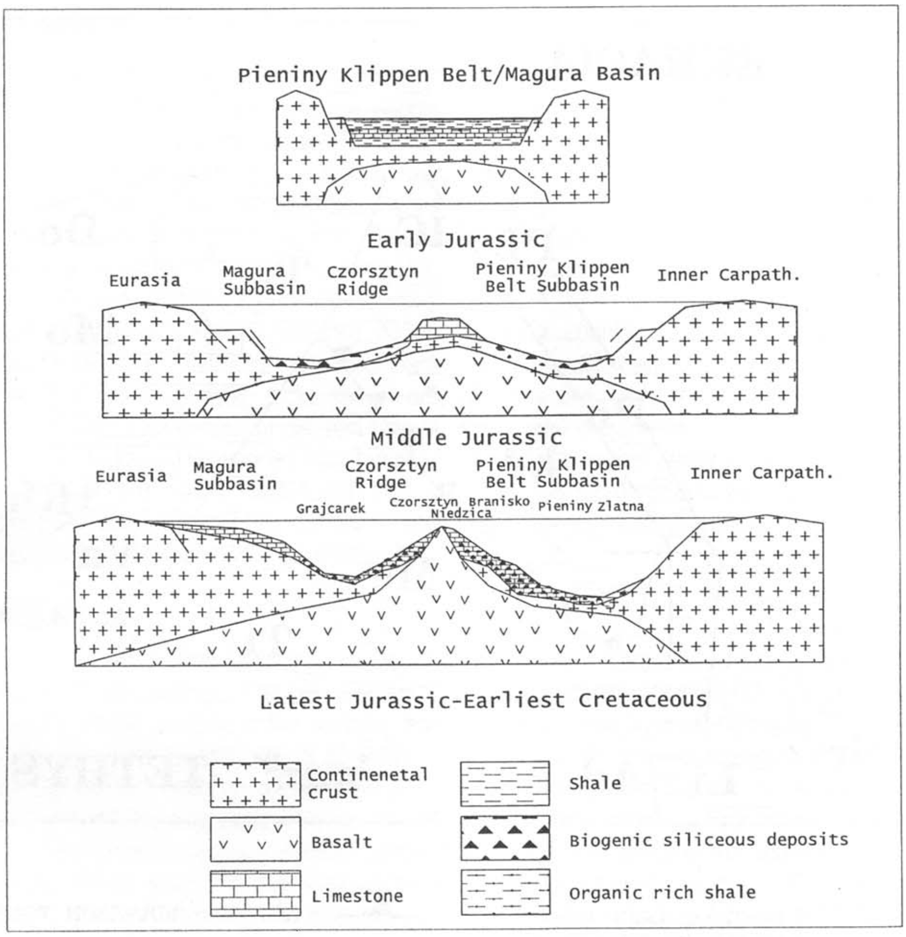


Fig. 10. Highly schematic (not to scale) profiles showing the evolution of the Pieniny Klippen Belt-Magura basin during the Jurassic-earliest Cretaceous time.

Geodynamic evolution

The Pieniny Klippen Belt realm (Figs. 1, 9) is the northernmost part of the Polish Inner Carpathians. Their palinspastic reconstructions attempt to restore the age and past location of basin, their age, their floor or basement, relations to the surrounding crustal elements as well as character of the paleostructural elements separating them. All these goals are still not easy to achieve, many problems have to be solved and many pitfalls have to be avoided.

Four time interval maps were constructed which depict the Jurassic–earliest Cretaceous plate tectonic configuration, paleogeography and lithofacies of the circum-Carpathian realm (Figs. 11-14). The aim of this paper is to provide an outline of the plate tectonic evolution paleogeography and position of the major crustal elements of the area within the global framework.

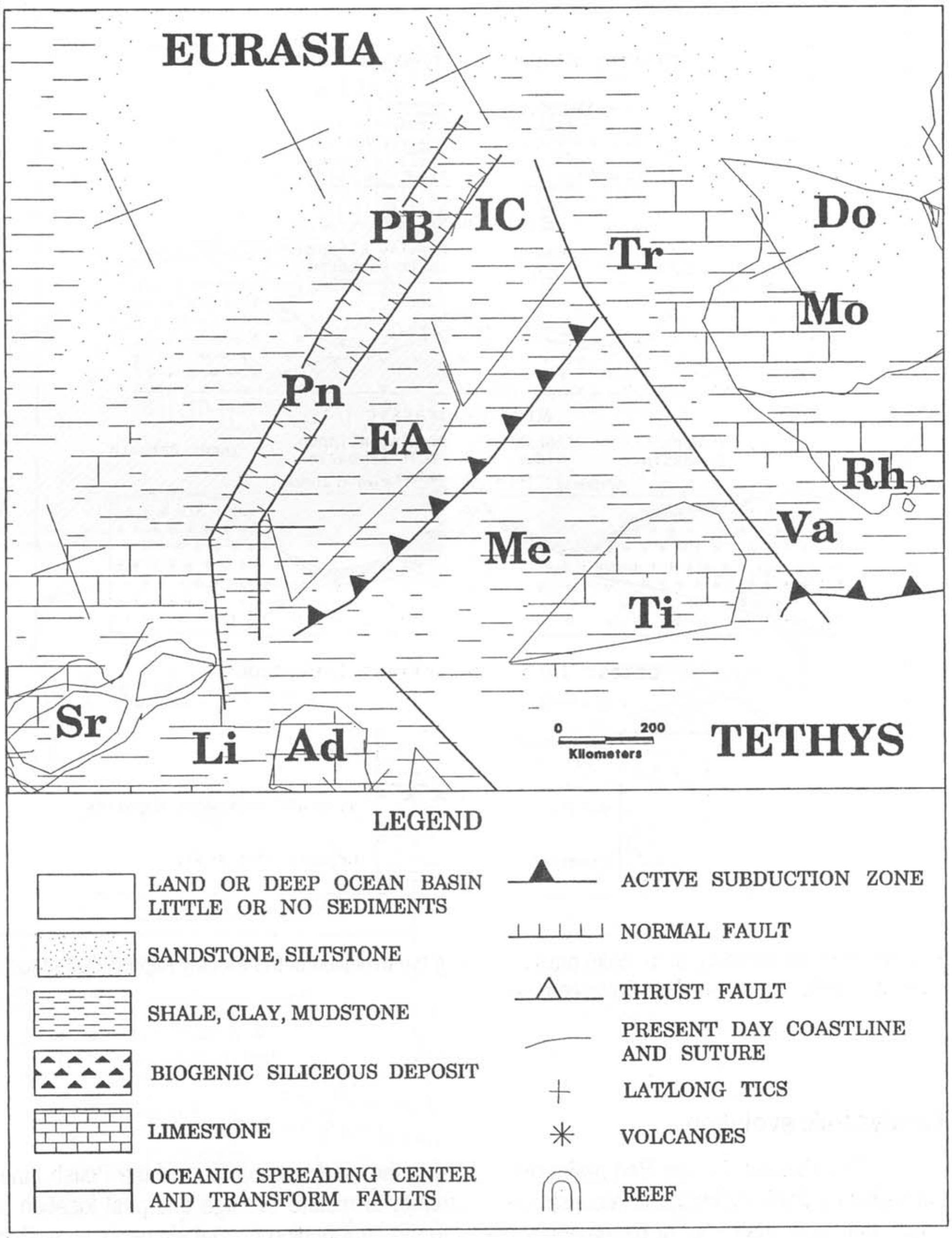


Fig. 11. Palaeogeography of the circum-Carpathian area during Early Jurassic; plates position at 195 Ma. Abbreviations of oceans and plates names: Ad – Adria (Apulia), Do – Dobrogea, EA – Eastern Alps, IC – Inner Carpathians, Li – Ligurian rift (site of future Ligurian Ocean), Me – Meliata/Halstatt Ocean, Mo – Moesia plate, PB – Pieniny Klippen Belt rift (site of future Pieniny Klippen Belt /Magura Basin), Pn – Penninic rift (site of future Penninic Ocean), Rh – Rhodopes, Sr – Sardinia, Ti – Tisa plate, Va – Vardar Ocean.

Early Jurassic

The earliest stage of the basin history is enigmatic and documented only by pebbles in the Cretaceous-Tertiary flysch. These pebbles indicate the possibility of an existence of an enigmatic embayment of the Vardar-Transilvanian Ocean (see Fig. 11 – Va-Tr) which separated the Tisa (Bihor-Apuseni) (Ti) block from the Moesian (Mo)-Eastern European Platform (Săndulescu, 1988). The pelagic Triassic limestones in the exotic pebbles in the Pieniny Klippen Belt (Birkenmajer *et al.*, 1990) and the Outer Carpathian Flysch (Magura Unit, see Soták, 1986) could have originated in this embayment. The Alpine Tethys, that is Ligurian (Figs. 11, 12 – Li), Penninic Oceans (Pn) and Pieniny/Magura Basin (Figs. 11, 12 – PB, Mg) constitute the extension of the Central Atlantic system (Golonka, 2000). The basins' opening is related to the closure of the Meliata Ocean (Me). The restricted environment prevailed in this newly formed basin.

The oldest Jurassic rocks known only from the Ukrainian and Slovakian part of the Pieniny Klippen Belt consist of different type of Gresten-like clastic sediments with intercalations of black fossiliferous limestones with brachiopods and grypheoids (?Hettangian–?Sinemurian). Still younger are spotty limestones and marls of oxygen-depleted, widespread Tethyan Fleckenkalk/Fleckenmergel-type facies (Pliensbachian–Lower Bajocian in age) and *Bositra* ("*Posidonia*") black shales with spherosiderites.

Middle Jurassic

The central Atlantic (Withjack *et al.*, 1998) and Alpine Tethys went into a drifting stage during the Middle Jurassic. The oldest oceanic crust in the Ligurian-Piemont Ocean was dated as late as the Middle Jurassic in the southern Apennines and in the Western Alps (see Ricou, 1996 and literature cited therein). Bill *et al.* (2001) date the onset of oceanic spreading of the Alpine Tethys by isotopic methods as Bajocian. According to Winkler and Ślączka (1994) the Pieniny data fit well with the supposed opening of the Ligurian-Penninic Ocean (Li-Pn).

The initial movements during Toarcian-Aalenian had to precede the appearance of the Czorsztyn Ridge which did not exist as the main paleogeographic unit before Bajocian (e.g., Aubrecht *et al.*, 1997). One of the most rapidly change of sedimentation/paleoenvironments within this basin took place from late Early Bajocian (Krobicki and Wierzbowski, in press) when well-oxygenated multicoloured crinoidal limestones replaced dark and black sedimentation of Early-early Middle Jurassic period. These crinoidal limestones were developed in more elevated parts of the Pieniny Klippen Basin (Czorsztyn, Niedzica and Czertezik successions), and were redistributed to deeper-water Branisko Succession as the grey crinoidal cherty limestones.

The Bajocian emergence of the Czorsztyn Ridge (CR) within the Pieniny/Magura Basin (PB/Mg) was connected with the postrift phase of the basin evolution (Golonka *et al.*, 2003). However, sedimentation of still younger (since latest Bajocian) red nodular Ammonitico Rosso-type limestones was effect of Meso-Cimmerian vertical movements which subsided Czorsztyn Ridge (Figs. 12-14 – CR) and produced tectonically differentiated blocks as well as accompanied by the formation of neptunian dykes and scarp-breccias (e.g. Birkenmajer, 1986; Aubrecht *et al.*, 1997; Wierzbowski *et al.*, 1999; Aubrecht, 2001; Aubrecht and Túnyi, 2001).

Late Jurassic

The Late Jurassic (Oxfordian-Kimmeridgian) history of the PKB reflects strongest facial differentiation within sedimentary basin (Fig. 4) where mixed siliceous-carbonate sedimentation took place. The formation of limestones of the ammonitico-rosso type was mostly related with existence of elevated part of sea bottom (Czorsztyn Ridge and its slopes), whereas deposition of

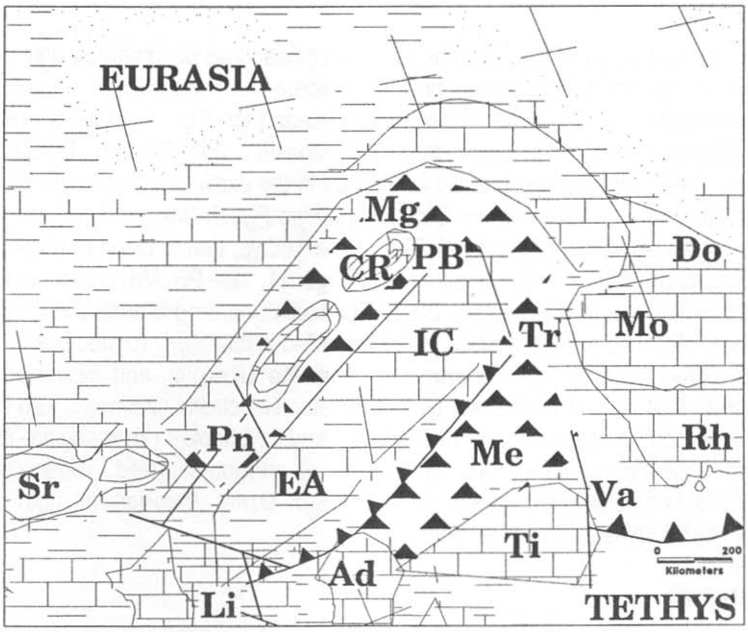
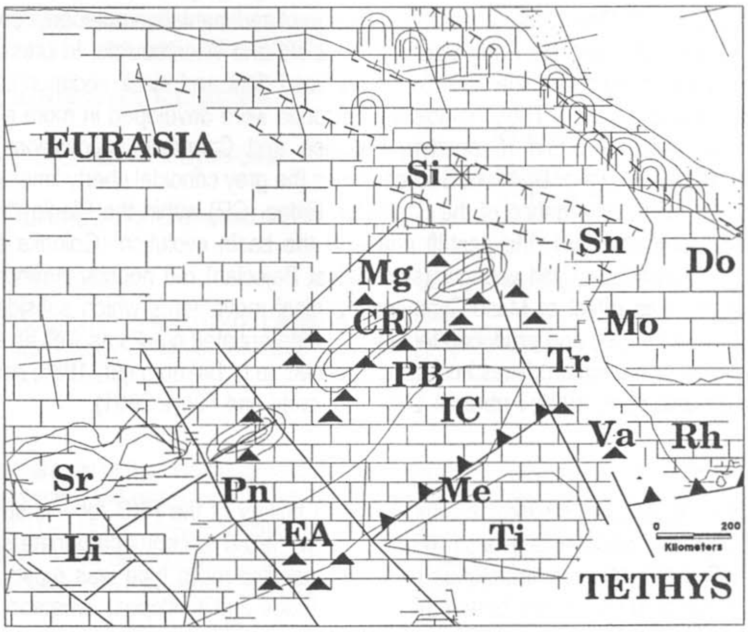


Fig. 12. Palaeogeography of the circum-Carpathian area during Middle Jurassic; plates position at 166 Ma. Abbreviations of oceans and plates names: Ad – Adria (Apulia), CR – Czorsztyn RidgeDo – Dobrogea, EA – Eastern Alps, IC – Inner Carpathians, Li – Ligurian Ocean, Me – Meliata/Halstatt Ocean, Mg – Magura Subbasin, Mo – Moesia plate, PB – Pieniny Klippen Belt Subbasin, Pn – Penninic Ocean, Rh – Rhodopes, Sr – Sardinia, Ti – Tisa plate, Tr – Transilvanian Ocean, Va – Vardar Ocean. For explanation of lithological symbols – see Fig. 11.



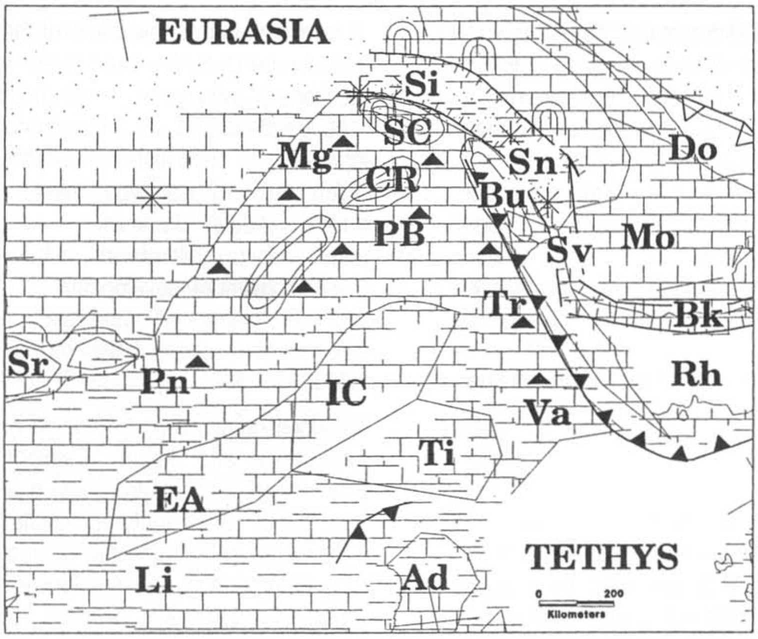


Fig. 14. Palaeogeography of the circum-Carpathian area during latest Late Jurassic–earliest Early Cretaceous; plates position at 140 Ma. Abbreviations of oceans and plates names: Ad – Adria (Apulia), Bk – Balkan rift, Br – Branisko succession zone, Bu – Bucovinian-Getic terrane, CR – Czorsztyn Ridge, Cz – Czertezik succession zone, Do – Dobrogea, EA – Eastern Alps, Gr – Grajcarek succession zone, IC – Inner Carpathians, Ku – Kurovice succession zone, Li – Ligurian Ocean, Me – Meliata/Halstatt Ocean, Mg – Magura subbasin, Mo – Moesia plate, Nd – Niedzica succession zone PB – Pieniny Klippen Belt Subbasin, Pi – Pieniny succession zone, Pn – Penninic Ocean, Rh – Rhodopes, SC – Silesian Ridge (Cordillera), Si – Silesian Basin, Sn – Sinaia Basin, Sr – Sardinia, Sv – Severin, Ti – Tisa plate, Tr – Transilvanian Ocean, Va – Vardar Ocean, Zn – Zlatna succession zone, Zw – Zawiasy succession zone. For explanation of lithological symbols – see Fig. 11.

←

Fig. 13. Palaeogeography of the circum-Carpathian area during Late Jurassic; plates position at 152 Ma. Abbreviations of oceans and plates names: Ad – Adria (Apulia), CR – Czorsztyn RidgeDo – Dobrogea, EA – Eastern Alps, IC – Inner Carpathians, Li – Ligurian Ocean, Me – Meliata/Halstatt Ocean, Mg – Magura Subbasin, Mo – Moesia plate, PB – Pieniny Klippen Belt Subbasin, Pn – Penninic Ocean, Rh – Rhodopes, Si – Silesian Basin, Sn – Sinaia Basin, Sr – Sardinia, Ti – Tisa plate, Tr – Transilvanian Ocean, Va – Vardar Ocean. For explanation of lithological symbols – see Fig. 11.

radiolarites (Birkenmajer, 1977; 1986; Mišík, 1999) took place in deeper parts of the bordering basins. Greatest deepening effect is indicated by widespread Oxfordian radiolarites which occur in the all basinal successions, whereas the shallowest zone (Czorsztyn Succession) is completely devoid of siliceous intercalations at that time. The change of oceanic circulation in northernmost Tethyan Realm during the Oxfordian is probably responsible for such distribution of facies. It very well corresponds with microfacial sequence within Ammonitico Rosso-type limestones as well, with domination of: filament (*Bositra* filaments) (Middle Jurassic) – *Globuligerina* ("*Protoglobigerina*") (Oxfordian) – *Saccocoma* (Kimmeridgian) microfacies, where boom of planktic *Globuligerina* forams was simultaneously with maximum development of radiolarites (Wierzbowski *et al.*, 1999).

Latest Jurassic – Early Cretaceous

The Czorsztyn Succession (see Fig. 17) includes hemipelagic to pelagic organogenic carbonate deposits of medium depth, for example white and creamy *Calpionella*-bearing limestones. Several tectonic horsts and grabens were formed, rejuvenating some older, Eo- and Meso-Cimmerian faults (Birkenmajer, 1986; Krobicki, 1996). Such features resulted from the intensive Neo-Cimmerian tectonic movements which affected the intrabasinal Czorsztyn pelagic swell and are documented by facies diversification, hardgrounds and condensed beds with ferromanganese-rich crusts and/or nodules, sedimentary-stratigraphic hiatuses, sedimentary breccias, neptunian dykes and/or fauna redeposition (for example famous ammonite coquinas of the so-called "Rogoźnik beds" – sensu Arkell, 1956; see also Kutek and Wierzbowski, 1986). These processes were caused by formation and destruction of submarine tectonic horsts attributed mainly to the Neo-Cimmerian period of tectonic activity in the Carpathians (Birkenmajer, 1958; 1975; 1986; Michalík and Reháková, 1995; Krobicki, 1996; Aubrecht *et al.*, 1997; Krobicki and Słomka, 1999; Golonka and Krobicki, 2002; Plašienka, 2002; Golonka *et al.*, 2003). Additionally, the paleogeographical and paleoclimatological evidences, particularly in the Upper Jurassic-Lower Cretaceous limestones (abundance of benthic fossils and phosphate deposits) suggests that major upwelling zone in northern Tethys which divided the Inner and Outer Carpathian oceanic realms (Birkenmajer, 1986; 1988; Krobicki, 1996; Golonka and Krobicki, 2001).

In the same time within deeper successions, as to Branisko and Pieniny ones (see Fig. 18) cherty limestone of Maiolica-type (= Biancone) facies deposited. It is one of the most famous, widespread Tethyan facies, well known both from Alpine and Apennine regions. In whole western Tethys this facies originated mainly in deep basins (above CCD but above ACD levels) but also on submarine elevations or drowned platforms and around the Jurassic/Cretaceous boundary reflects the greatest facies unification in this ocean (e.g., Winterer and Bosellini, 1981; Wieczorek, 1988). These white-grey, micrite well bedded calpionellid-bearing limestones built now highest part of the Pieniny Mts (e.g., Trzy Korony Mt, Sokolica Mt etc).

Late Cretaceous

Late Cretaceous pelagic deposits with the youngest part developed as Scaglia Rossa type marls (= Couches Rouge = Capas Rojas) deposited during the latest, third episode of evolution of the Pieniny Klippen Belt Basin (Birkenmajer, 1986; 1988; Bąk, 2000), when unification of sedimentary facies took place within all successions. Still younger are flysch and/or flyschoidal facies (i.a. Birkenmajer, 1986; Mišík, 1994; Aubrecht *et al.*, 1997).

Pelagic foraminiferal-marl deposition (dominated by hedbergellids) started during Albian time (Birkenmajer, 1986; Aubrecht *et al.*, in press). These deposits continued until Early Maastrichtian in the more shallow part of the Czorsztyn Succession. Within its southern part and deeper successions, foraminiferal globigerinid/globotruncanid marls (Albian-Coniacian) occurred with characteristic multicoloured green/variegated/red sequence of marls. Further these marls were replaced by flysch deposits (Santonian-Campanian) (Birkenmajer and Jednorowska, 1983; 1984; 1987a,b; Gasiński, 1991; Birkenmajer and Gasiński, 1992; Bąk K., 1998; Bąk M., 1999). During this syn-orogenic stage of the development of the Pieniny Klippen Belt Basin these flyschoidal deposits with several episodes of debris flows with numerous exotic pebbles took place (Late Albian-Early Campanian). The main "exotic source area" in the Pieniny Klippen Basin was emerged so-called Exotic Andrusov Ridge as effect of Czorsztyn Ridge/Andrusov Exotic Ridge collision (Birkenmajer, 1986; 1988). This emerging region was source of abundant exotic pebbles predominantly of Triassic to Lower Cretaceous rock fragments (e.g., Upper Jurassic pebbles represented by microbolithic-sponge boundstones and grainstone-packstone with ooids and oncoids (?Kimmeridgian/?Tithonian) – Krobicki *et al.*, 2002; Urgonian facies represented by *Orbitolina*-bearing and reefoidal limestones – Birkenmajer and Lefeld, 1969; etc.). These exotic-bearing flysch/flyschoidal clastics were deposited as submarine turbidites wedges, fans and canyon fills (Radwański, 1978; Birkenmajer, 1988).

The Pieniny Klippen Belt Basin was closed at the Cretaceous/Tertiary transition as effect of strong Late Cretaceous (Subhercynian and Laramian) thrust-folding (Birkenmajer, 1986; 1988). From south to north folding of the successive nappes, built by Jurassic-Cretaceous deposits of early mentioned sedimentary successions, took place. Simultaneously with this Laramian nappe folding the uppermost Cretaceous (Maastrichtian) fresh-water and marine molasse with exotic material was deposited and Paleocene flysch was continuation of this sedimentary event. They covered with unconformity several klippen nappes folded earlier and this so-called Klippen Mantle was refolded together with them somewhat later.

The second tectonic episode was connected with strong Savian and Styrian (Early and Middle Miocene, respectively) compression, when the Cretaceous nappes, the Klippen Mantle and the new Paleogene deposits were refolded together (Birkenmajer, 1986) and originated system of transverse strike-slip faults. This author suggests strike-slip translation and related transpression along northern and southern boundaries of the Pieniny Klippen Belt.

Good visible effect of several tectonic phases of folding and deformations within Pieniny Klippen Belt is geomorphologic view of tectonically isolated klippes of Jurassic and Cretaceous hard rocks surrounding by softer shales, marls and flysch deposits. Process of megabrecciation and megaboudinage is clear from regional point of view where Pieniny Klippen Belt is very narrow tectonic structure between two huge part of Carpathians: Inner on the south and Outer (Flysch) on the north.

The last important event in the Pieniny Klippen Belt was Middle Miocene (Sarmatian) volcanism represented by calc-alkaline andesite dykes and sills which cut mainly Paleogene flysch rocks of the Outer Carpathians (Magura nappe) (Małkowski, 1958; Birkenmajer, 1979; 1986; 1988) recently precise dating radiometrically (Birkenmajer and Pécskay, 1999; 2000) (see Wżar Mt stop). They formed the so-called Pieniny Andesitic Line (PAL).