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EVOLUTION OF THE WESTERN CARPATHIAN SUTURE ZONE - PRINCIPAL GEOTECTONIC EVENTS

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Abstract: A condensed review of the principal geotectonic events in the Western Carpathian suture zone is given. The geotectonic ideas resulted from sources manifestation in the **Mesoalpine accretionary prism** (*Pieniny Klippen Belt*) and **Neoalpine accretionary one** (*Carpathian Flysch Belt*). The evolution of the Western Carpathian suture zone is evaluated in the broader context of the plate-tectonic history of the Central European Alpides.

Key words: Western Carpathians, geotectonic evolution, suture zones, syn-collisional ridges, accretionary prisms.

Introduction

The Western Carpathians are the northernmost spur of the Central European Alpides. The formation of their structure was influenced by complex processes such as riftogenesis, crustal thinning, convergence, lateral displacement, rotational movements, collisional suturing, accretion, transpression-transtension. These processes were recorded e.g. in the facial development and paleogeographic changes of the Western Carpathian units (Rakús et al. 1990; Michalík & Mišík 1987; Kozur & Mock 1988; Kovács 1982), in the products recycled from subducted substrates (Mišík & Sýkora 1981; Mišík et al. 1977, 1980; Šímová 1985; Soták 1985, 1986, 1990), in regional linkage of the *Penninic* and *Transylvanian structures* through a *Periklippen Zone - Vahicum* (Maheľ 1981, 1988), in the *Penninic elements* identified in a not-deep underlier beneath the marginal parts of *Tatricum* (Maheľ 1981, 1983, 1988; Plašienka et al. 1991), in the accretion of the *Pieniny flysches* by a lateral plate movement - strike-slip plate junction (Marschalko 1978, 1986), in suture progradation into outer flysch trenches (Roth 1980; Tomek & Hall 1991), in tectonic styles of the zones strained by oblique shifting (Maheľ 1989; Birkenmajer 1985; Marko et al. 1990).

The geotectonic approaches presented in this paper resulted from the knowledge about the syn-collisional sources, which filled the flysch trenches accreted at the active margin of the **Western Carpathian plate** (*Pieniny flysches*) and at the passive margin of the **North-European plate** (*Outer Carpathian flysches*) and which were destroyed during plate-suturing. These ideas have also included geotectonic and palinspastic interpretations of the development of **rift systems, North-European plate shelfs, Apulian shelf fragments, intra-Alpine microcratons** and **large transform fault systems** within the Central-European Alpides (Burchfiel 1980; Roeder 1977; Dietrich 1976; Ratschbacher et al. 1991; Flügel et al. 1987; Kovács et al. 1989; Balla 1988; Sandulescu 1984; Ricou et al. 1986; Dercourt et al. 1986, etc.).

Evolution of the Pieniny suture zone

The results from the study of the detrital products of the Silesian cordillera proved that up to the Albian time the *Pieniny-Magura area had been developing as a unified paleogeographic zone. The Pieniny-Magura Zone* thus appears as a periplatform terrane of the Tethyan mobile realm bordered with oceanic troughs of the *Vahicum* (northern rift system) and the *Meliaticum* (southern rift system) - Fig. 1. Crustal thinning in the periplatform zone may have been a result of spreading mechanism along listric faults while in the *Vahicum-Meliaticum area* the preconditions for oceanization had already been created by weaker Hercynian stabilization (Fig. 3, I). Both rift troughs were formed as the couple diachronical system of the *Meliata branch* (initial Pelsonian - Illyrian rifting, Late Kimmerian reduction and closing) and the *Pieniny-Vahic branch* (Early Triassic deepening, Early Kimmerian rifting and Paleo-Mesoalpine closing). The *Vahic-Pieniny + Magura branch* of this oceanic realm seems to

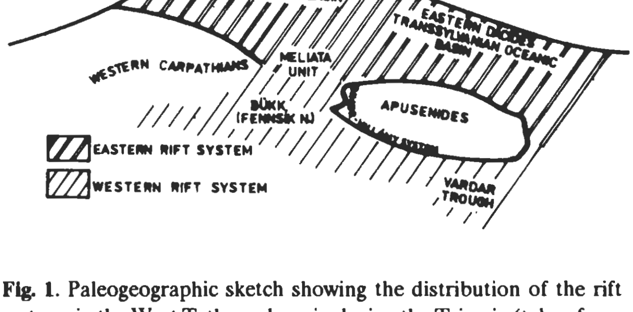
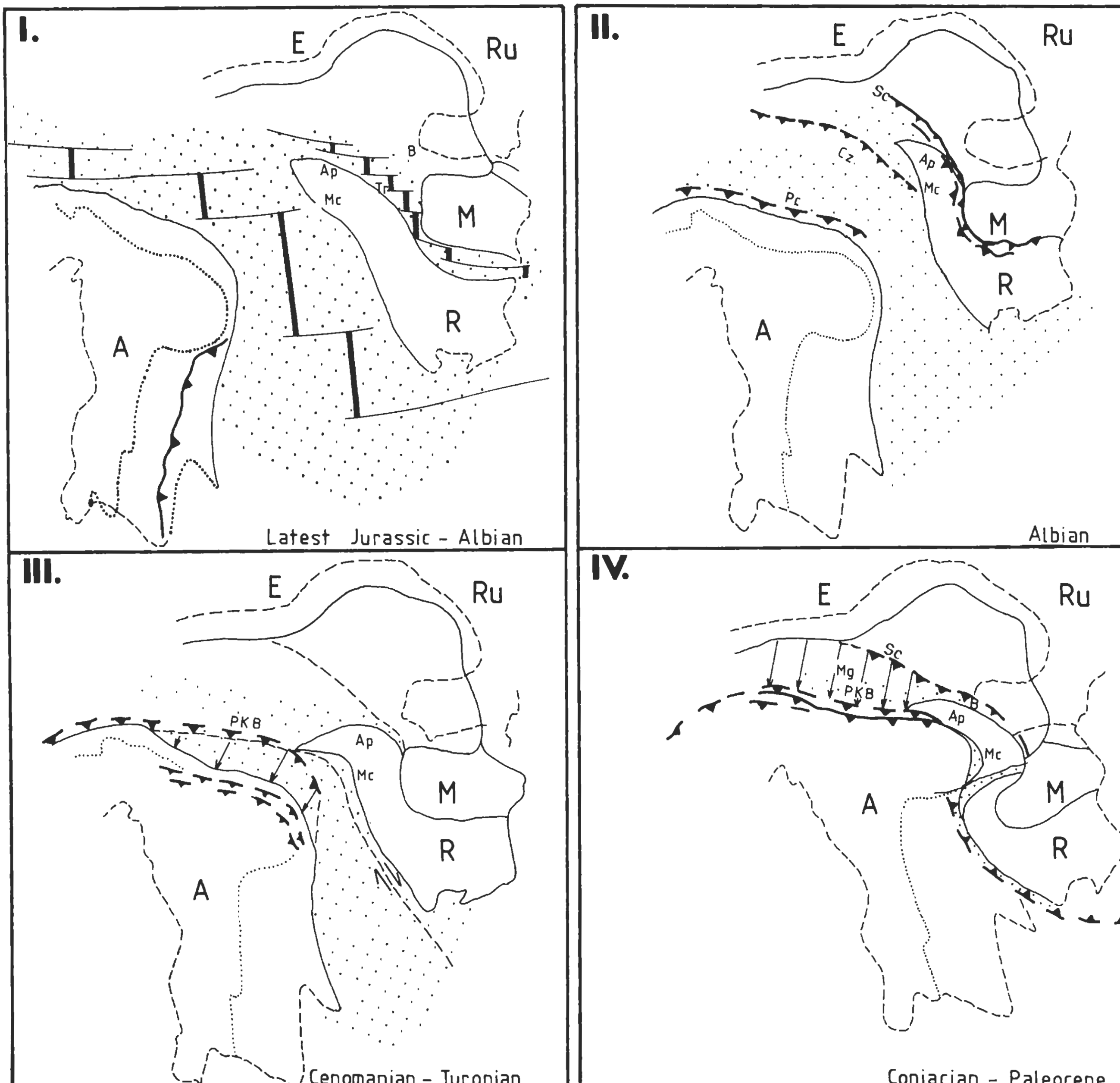
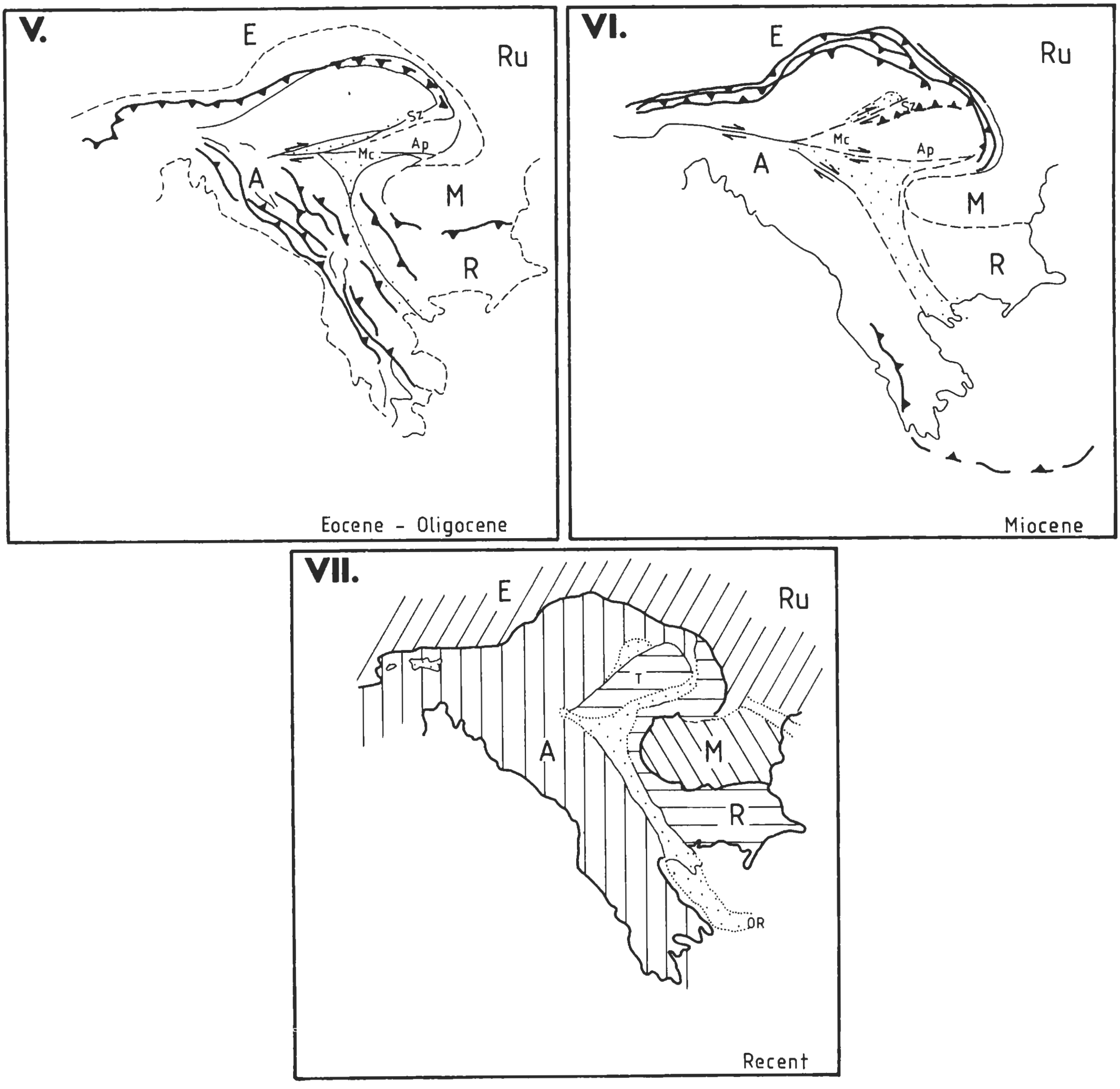


Fig. 1. Paleogeographic sketch showing the distribution of the rift systems in the West Tethyan domain during the Triassic (taken from Kozur & Mock 1987, adapted).



be the Carpathian analogue of **the Siret Ocean** (Transylvanian oceanic basin - cf. Kozur & Mock 1987), the *Meliata branch* had probably lain in the prolongation of the **Vardar protoocean** (*Central Dinaric ocean* sensu Kozur 1991). In the Jurassic - Lower Cretaceous period the **Vardar Ocean** was extended to a wider corridor (Fig. 2, I). Besides the *Vardar Zone* s. str., which apparently originated from a sea-floor spreading in the Jurassic, the **Vardar Ocean** s. l. also involved pre-Jurassic rift structures (*Transylvanian oceanic basin, Meliata Ocean, Pieniny oceanic branch*) newly affected by the spreading reactivation (*Mures Ophiolite Belt, Bátor back-arc rift, Vahic Ocean*). The **Vardar Ocean** tended westward to the obliquely rifted *Pennine-Ligurian Ocean*. This oceanic corridor separated the Alpine-Carpathian segment (**Kreios Block**), which up to the Middle Cretaceous time had been taking the **peri-Apulian position**, from the North-European shelfs (Fig. 2, I-II).

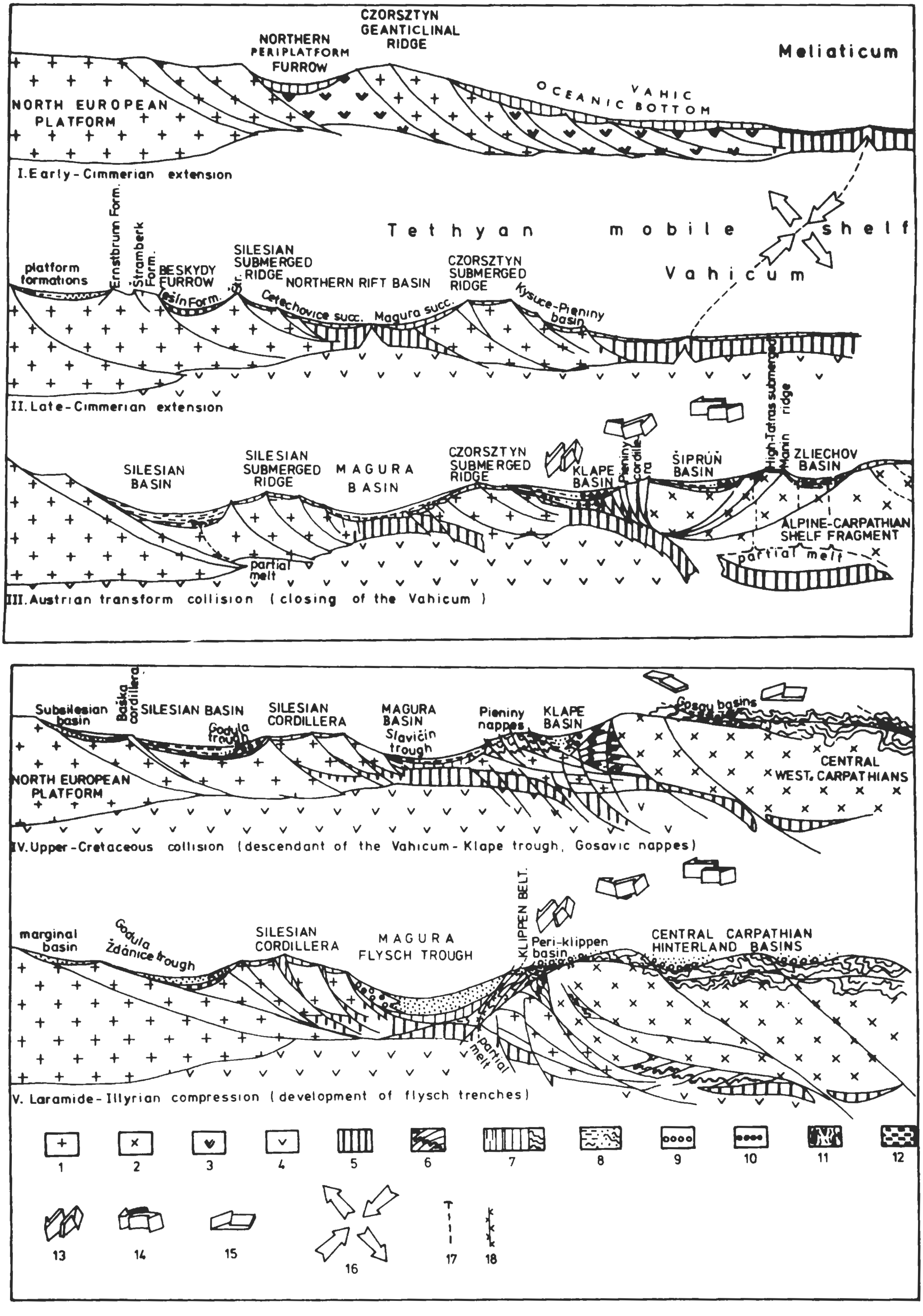
The attribution of the *Western Carpathian block* and *Pieniny Klippen Belt* to the **Apulian promontory** has already been suggested by some authors. Burchfield (1980, p.48) recovering the geotectonic synthesis of the European Alpine system came to the opinion that: Along the northern border of the **Apulian fragmet** a synthetic imbrication and narrowing took place within the *Pieniny Klippen Belt*. Parts of the Klippen Belt may represent exotic fragments underlain by continental crust, but its more southerly parts are clearly part of the Apulian continental crust. Kázmér & Kovács (1989) also regarded the *Pieniny cordillera* as a displaced suture zone of the **Vardar Ocean**. The idea of the Apulian provenience of the Western Carpathian block has been accepted by Kozur &Mock (1987 a,b, 1988). The attribution of the Alpine-Carpathian block to the **Apulian promontory** also resulted from the provincionality of the various fossil groups (brachiopods - Vörös 1988 etc., ammonites - Rakús 1988, 1989 etc., dasyclad algae and large foraminifers - Soták & Mišík in press; Mišík 1990). Independently, similar conclusions were brought by paleomagnetic investigations not only from the Inner, but also from the Outer Western Carpathians. According



Figs. 2 Palinspastic organization of the plates and fragments in the Eastern European Alpine system during the Latest Jurassic to Miocene time period (modified Burchfield's reconstructions 1980).
Explanations: **E** - *European plate*, **Ru** - *Russian plate*, **A** - *Apulian fragment*, **R** - *Rhodopean fragment*, **M** - *Moesian fragment*, **Ap** - *Apusenides*, **Mc** - *Mecsek Mts*., **Tr** - *Transylvanides*, **B** - *Bucovinicum*, **Cz** - *Czorsztyn ridge*, **Pc** - *Pieniny cordillera*, **PKB** - *Pieniny Klippen Belt*, **Sc** - *Silesian cordillera*, **Sz** - *Szolnok trough*, **T** - *Tisia block*, **OR** - oceanic remnants between the *Apulian* and *North-Tethyan fragments*.

to Krs et al. (1991, p. 149), the paleomagnetic pole positions derived for the Outer Western Carpathians (*Magura Zone*) suggest a palaeogeographic affinity of the flysch belt to the **African lithospheric plate** and not to the blocks of the North-European platform. Moreover, the pre-Gosauian paleomagnetic data prove the **Adriatic origin** of the *Northern Calcareous Alps*, too (Mauritsch & Frisch 1979).

Along the northern border of the **Apulian fragment**, *B-type* subduction of the *Meliata-Vahic oceanic terrane* took place (Fig. 2 , I-III). In the Late Kimmerian stage of initial plate convergence the *Meliata Ocean* was becoming detached and subducted beneath the *Apulian Fennsik shelfs* (cf. Kozur 1991). The *Vahic Ocean* was being closed by the laterally displacing Central Carpathian segment, at the collision edge of which an accretion pyramid was created in the Albian - the *Pieniny cordillera* (Andrusov ridge) - Fig.3, III. The consumed members of the *Vahic-Penninic domain* occur in the lowermost unit of the Malé Karpaty Tatricum (Mahel' 1981, 1983, 1988; Plašienka et al. 1991), in fragmentary sequences incorporated into the crystalline basement of the northern part of the Považský Inovec Mts. (Mahel' 1988; Plašienka et al. in prep.), etc. Penninic-like sequences also form.the pre-Neogene basement of the *Transcarpathian Depression*. Here the sub-Tatric units disappear in a coulisse-like way and lower units analogous to the *Penninicum*


NORTHERN PERIPLATFORM FURROW
CZORSZTYN GEANTICLINAL RIDGE
Meliaticum
NORTH EUROPEAN PLATFORM
OCEANIC VAHIC BOTTOM
I. Early-Cimmerian extension
Tethyan mobile shelf
Vahicum
platform formations
Ernstbrunn Form.
Stramberk Form.
BESKYDY FURROW
Těšín Form.
SILESIAN SUBMERGED RIDGE
NORTHERN RIFT BASIN
Čertechovice succ.
Magura succ.
CZORSZTYN SUBMERGED RIDGE
Kysuce-Pieniny basin
II. Late-Cimmerian extension
High-Tatras submerged ridge
Manin
SILESIAN BASIN
SILESIAN SUBMERGED RIDGE
MAGURA BASIN
CZORSZTYN SUBMERGED RIDGE
KLAPE BASIN
Pieniny cordillera
ŠIPRÚŇ BASIN
ZLIECHOV BASIN
ALPINE-CARPATHIAN SHELF FRAGMENT
partial melt
III. Austrian transform collision (closing of the Vahicum)
Subsilesian basin
Baška cordillera
SILESIAN BASIN
Godula trough
SILESIAN CORDILLERA
MAGURA BASIN
Slavičín trough
Pieniny nappes
KLAPE BASIN
Gosau basins
CENTRAL WEST. CARPATHIANS
NORTH EUROPEAN PLATFORM
IV. Upper-Cretaceous collision (descendant of the Vahicum-Klape trough, Gosavic nappes)
marginal basin
Godula
Ždánice trough
SILESIAN CORDILLERA
MAGURA FLYSCH TROUGH
KLIPPEN BELT
Peri-klippen basin
CENTRAL CARPATHIAN HINTERLAND BASINS
partial melt
V. Laramide-Illyrian compression (development of flysch trenches)
1 2 3 4 5 6 7 8 9 10 11 12
13 14 15 16 17 18

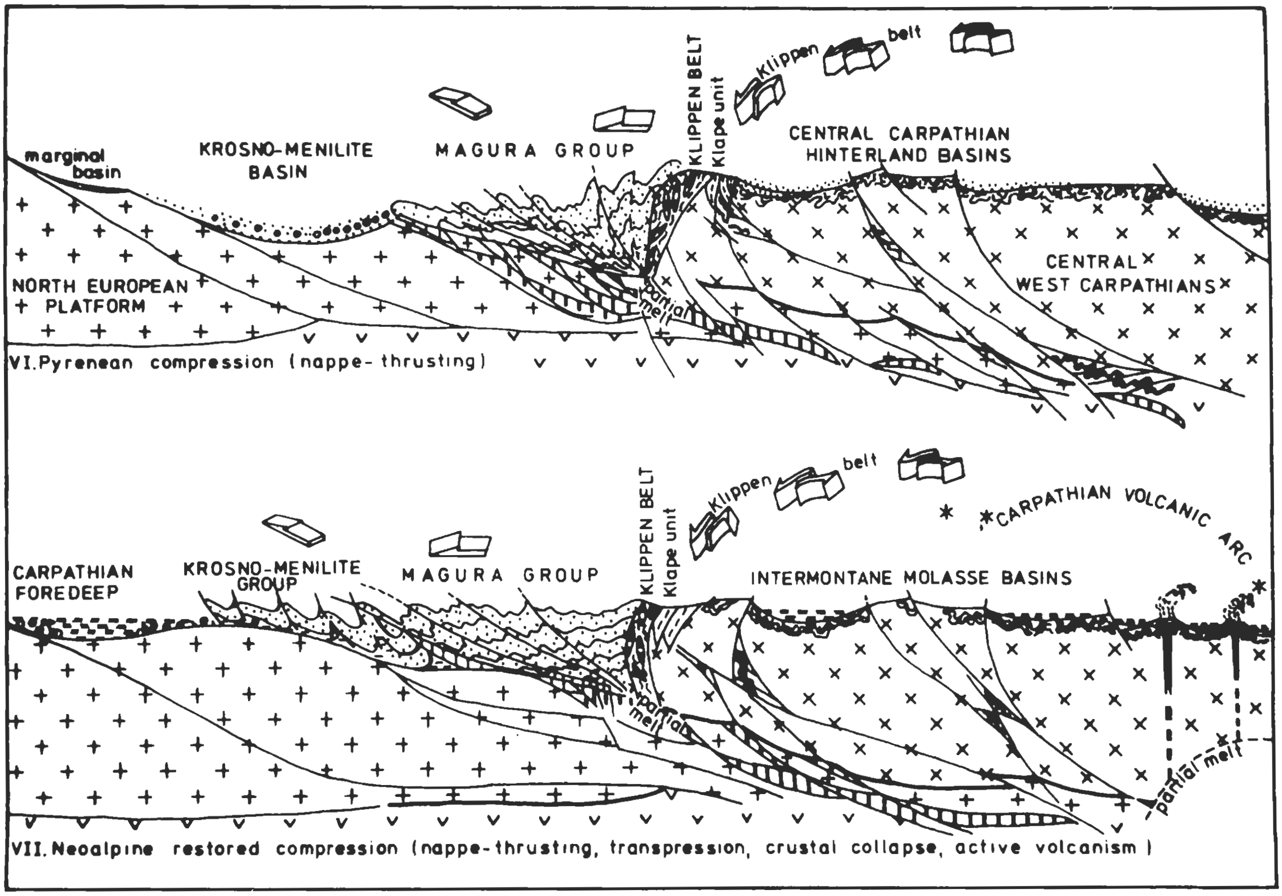


Fig. 3. The evolution of the subduction, collision and suture zone between the North-European Platform and Western Carpathian plates. The model sections show the structural and kinematic manifestation of the *Kimmerian extension, Eoalpine collision, Mesoalpine compression* and *Neoalpine transpression-transtension.*

Explanations: 1 - crystalline foreland of the North European platform; 2 - crystalline basement of the Tatricum and Veporicum; 3 - mobile (paraoceanic) crust; 4 - upper mantle; 5 - oceanic crust; 6 - subduction mélange of the Vahicum; 7 - Triassic, Jurassic and Lower Cretaceous sedimentary formations; 9 - coarse clastic sediments of the foot or transgressive facies; 10 - exotic rocks in pebbles (Triassic pelagic limestones, peculiar shallow-water facies of the Malm, spinel detritus, high-pressure metamorphic rocks, younger granite rocks, volcanic rocks a.o.); 11 - klippen style of the Pieniny belt; 12 - Miocene molasse of the Carpathian foredeep and intramountain basins; 13 - transform boundaries; 14 - transpressional strike-slip faults; 15 - overthrusting; 16 - diachronically opened and closed structures in the oceanic realm; 17 - sills and dykes penetrations of the Lower Cretaceous volcanics; 18 - sills and dykes of the Neogene volcanics in the Pieniny Andesite Line - PAL.

emerge (*Iňačovce-Krichevo unit*). The bored complexes are very close to "Bündnerschiefer-Schistes lustrés"formation (Soták et al. 1993) in age (Triassic to Paleogene - "Série Compréhensive"), sequence development (shaly-turbiditic sequences - "flysch schisteux"), lithological and metamorphic deformation character (anchizonally metamorphosed shales, marble and arenaceous rocks with schistose textures, stretching lineation, crenulation, etc.) and the presence of intrusive phase ophiolites (metaperidotites, serpentinites, prasinites, etc.). There is a possibility to connect the Vahicum with Transylvanian units of the Eastern Carpathians through the *Iňačovce-Krichevo unit.*

The *Pieniny cordillera*, as a northern accretion boundary of the **Apulian fragment**, was built by para-collision sediments of the Urgonian carbonate platform (limestones with residual ophiolitic detritus), by accreted associations of the consumin oceanic realm and by products of volcanic, igneous and high-pressure metamorphic activity. The **Siret Ocean**, which was created as an intracratonic rift, was being closed by the **Rhodopean microcraton** (with pendant of the Tisia Block) in the Albian period, when the **Apulian fragment** apparently started to move (Fig. 2 , II). The subduction of the **Vardar Ocean** was taking place diachronously following the counterclockwise rotation of the **Apulian fragment**. The subduction of the *Vahic branch* of this domain accelerated in the Upper Cretaceous period, when the *Pieniny flysch trenches* were being founded. Dismembered products of the oceanic crust, volcanic chain and high-pressure metamorphism were recycled into the clasts of the *Klape accretionary complex*. The supplementary manifestation of collision tectonics was also intracratonic crustal shortening of the **northern Apulian zones**, which generated the Gosau nappes thrusting and suturing their crystalline basements (*Gemericum - Veporicum - Tatricum*) - Fig. 2, III, Fig. 3, IV. Along the North-Transylvanian fault, the **Tisia Block** was detached from the Rhodopean microcraton and was being rotated clockwise (Fig. 2 , IV). After the closing of the Vahic oceanic realm, the *Pieniny accretion boundary* was changed to a large transform boundary in the Uppermost Cretaceous - Early Tertiary period (Fig. 2 , IV, Fig. 3, IV-V). Along this boundary, the **Kreios Block**, which at the Gailtal-Balaton-Darnó fault system was detached from the **Apulia**, was shifted to the northeast.

During transform displacing the *Klippen Belt* was modified to a subduction cryptic suture with imbricate structural style. In the Eocene - Oligocene the collision reached the stage continent-continent (*A-type*). It activised intracrustal subduction processes and the escape of the Western Carpathian segment eastward (Fig. 2 ,V, Fig. 3, VI). Along the sinistral transform boundary situated in front of the destructive margin of the overriding **Western Carpathian plate** the sedimentary comlexes of the **North European passive margin** (*Pieniny Klippen Belt successions*) were annexed. The Oligocene - Lower Miocene collision caused the folding-overthrusting deformations on the *active plate borders* (e.g. in the Dobrá Voda Depression - Marko et al. 1990, in the Periklippen area of the Eastern Slovakia with the double-level structure of the Central Carpathian Paleogene - Rudinec 1989, in the Pre-Neogene basement of the Eastern Slovakian basin), while inside the *rigid Central Carpathian block* the collisional effects can be recognized only through brittle deformations related to strike-slip faults (Marko et al. 1991, etc.). The prograding neoid compression resulted in the transpression regime in the *Klippen Belt*, which is manifested by its arcuate shape, desintegration and a coulisse-extention of structural elements and by hypoabyssal volcanism in the *Pieniny Andesite Line* (Mahel' 1989; Birkenmajer 1985) - Fig. 3,VI-VII. The Miocene collision also controlled the development of molasse basins related to the mobile Periklippen zone strained by an oblique shifting (*Vienna* and *Eastern Slovakian Basins*).

Evolution of suture zone in the Flysch Carpathians

The substratum, on which the external sedimentary areas had been developing, did not emerge above the flysch cover anywhere (with exception of the *Marmarosh Massif* - Vialov 1980). We suppose that the original substratum of the *Magura belt* was formed by a crustal basement, the tectonometamorphic evolution of which resembles a basement of **Dobrogea type**. This assumption was inferred by Stille (1953) when he cosidered that the so-called "greenschist zone" continued from the Northern Dobrogea to the Vistulicum in the substratum of the Carpathian Flysch Belt. This crustal type is designated as a basement of Dobrogea type in the Eastern Carpathian substratum , too. The crust was evidently favourable for an early riftogenesis. The evidence about it is given by the fact, that the Triassic intracratonic rift troughs were founded on this sort of substratum in the Northern Dobrogea and Transylvanides.

The *externides* - as a periplatform zone of the **Vahic-Transylvanian domain** - also underwent a very vivid Kimmerian tectogenesis. Its effects can be seen for example in the separation of the Triassic sediments from the Jurassic - Lower Cretaceous sequences in the *Pieniny Klippen Belt* which could indicate the Paleo-Kimmerian space reduction and the opening of the Neo-Kimmerian structures (cf. Michalík & Kováč 1982), in paleotectonic differentiation of the *externides* in the Kimmerian period accompanied with significant facial polarity, in emersions, local exposures and draining of exotic sources, in extinction of carbonate platforms, in the coarsening of clastic material in the Berriasian - Valanginian carbonates, in the opening of fissures, hiatuses, local karstification, denivelisation of the basin floor, allodapic outwash, etc.

The substratum of the Flysch Carpathians from the Middle Cretaceous was being uncovered in the structures of the *Silesian cordillera*, which represented a basic source of the clastic material in the Magura and Krosno-Menilite flysch troughs. The existence of the *Silesian cordillera* in the Middle - Upper Cretaceous and Paleogene period is proved by brackish to hypergene products (Albian charophyte limestones, pisolitic ironstones and pisooncoids in the pebbles, grains of recalcified Triassic dolomites a. o.), by products of its shallow marine litoral (rhodophyte and nummulite limestones), by sedimentary records in the flysch troughs (proximality of the marginal zone of the Magura belt - the Rača unit, counterdirectional paleocurrents in the adjacent troughs, garnet facies bordering the zone of the coarse and wild flysch of the Rača unit a. o.). The uplift of the *Silesian cordillera* resulted from the lithospheric collision. It is interpreted as a 50 to 100 *km* wide crystalline ribbon continent, which was driven out by the mechanism of listric thrust in the significant geotectonic boundary (probably at platform margin) - Fig. 3, IV-V. The pre-Albian formations of the *Magura substrate* (sometimes including the products of oceanization) and tectonically annexed parts of the *Brunia* were incorporated in the *Silesian cordillera*.

The evidence for the oceanic substratum of the *Magura zone* and its equivalents (*Rhenodanubian flysch*) is given by the blocks of ophiolite rocks in the klippes near Poiana Botizii and Ybbsitz (the klippes near Poiana Botizii belong to the Mesozoic substratum of the Magura nappe according to Bombita & Pop 1991). In the *Magura unit* itself the indications of oceanization and volcanism were also recorded (carbonatized spilites - ophicalcites with dykes of Upper Triassic? - Liassic red limestones - see Soták 1986, 1990; pebbles of quartz porphyries, basaltoid andesites, diabasic rocks, mafic rocks with prasinite textures - see Wieser 1951; pebbles of radiolarites with albite veinlets and volcanic admixture in the Strihovce conglomerates - Mišík et al. 1991), etc. From the *Marmarosh Zone*, the complexes of which are regarded as a substratum of the *Magura unit* (Vialov 1980; Bombita & Pop 1991), several Jurassic volcanogenic-sedimentary formations (*Chivchin formation, Trostenec volcanic complex*, etc. - Lomize 1968; Spitkovskaya 1985) have been known.

The Albian compression event, which generated a folding of the *Transylvanian nappes* and sheet thrusting in the *Marmarosh Massif*, had been reflected in the Outer Western Carpathians too. As a result of it the *Silesian cordillera* was driven out in the same position as the *Middle* and *Outer Dacides* (Sandulescu 1984) - Fig. 2, II. An Eastern Alpine equivalent of the *Silesian cordillera* was the so-called *Cetic ridge*, representing a continental marginal high of the European plate, which saturated the *North-Penninic basins* (Frasl & Flügel 1987).

The subduction of the *Magura basement* generated the foundation of marginal trenches, which were piled up to accretionary prisms - for example *Biele Karpaty - Krynica Nappe* - by neoid folding events (Pyrenean, Laramic and Savian - Styrian phases) - Fig. 3, V, Fig. 3, VII-VIII. The course of the Neogene Carpathian subduction reflected the oblique plate collision. That is why, the flysch nappe thrusting showed an obvious discrepancy (Jiříček 1979) documented by the overlaping of still younger foredeep sediments from SW to NE. By and large the autochthonous Oligocene and Lower Miocene molasse was covered as can be seen from the course of gravimetric low deep under the thrusted Western Carpathian units (Tomek et al. 1979). In the last stage of the Miocene Carpathian subduction the suture was gradually moved up to the Krosno area. It is manifestated by an echelon left strike-slip faults rooting in the plate boundary e.g. in the Ždánice Forest area (Tomek & Hall 1991; Tomek et al. 1989). The subduction processes were taking place in a non-accretionary way in the terminal stage. The uplift of folding flysch zones was accompanied by a migration of the molasse depocenters, first into the residual troughs of the Krosno-Menilite units (*Pyrenean molasse*), then into the nappe fronts (*piggy-back basins*) and onto the activated slopes of the platform (*foredeep basin*). Along with the Flysch Carpathian foldding the separation of the Paratethys from the Mediterranean was still graduate. The closing of this connection is supported by the Lower-Oligocene menilite event and culminated in the brackishing of the Sarmatian and Pannonian basins. Space reduction in the outer units was taking place along with the opening of the basins inside the Carpathians, where a partial melting of the subducted North-European plate, and mantle diapir activity generated the development of inner-arc calc-alkaline volcanism (Balla 1981; Vass et al. 1988, etc.)

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