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LATE CRETACEOUS THROUGH PALEOGENE EVOLUTION OF MAGURA BASIN

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Abstract: The evolution of the Magura Basin from the Middle Cretaceous to the Early Oligocene is outlined. The Magura Nappe is the largest tectonic unit of the Western Carpathians, linked with the Rheno-Danubian flysch of the Eastern Alps. During tectonic movements the Magura Nappe was completely uprooted from its substratum along ductile Upper Cretaceous rocks. Older deposits are known only from that part of the basin which was incorporated into the Pieniny Klippen Belt. In the sedimentary evolution of the Magura Basin three different periods can be distinguished: the Middle Jurassic - Albian long-lasting (96 MY), extensional period of the pelagic deposition, the Cenomanian - Campanian (23 MY) period of hemipelagic deposition, and the Maastrichtian - Early Oligocene (40 MY) mainly compressional period of turbiditic deposition. During the Eocene gradual shifting of coarse-clastic deposition from the south to the north took place. It was connected with development of two large submarine fans, partially superimposed one upon another. The progradation of these fans can be related to the shortening of the Magura Basin and to the development of accretionary prism.

Key words: Magura Basin, source area, turbidite sedimentation, submarine fans, accretionary prism.

Introduction

The Magura Nappe is the largest tectonic unit of the Outer Western Carpathians (Fig. 1), linked with Rheno-Danubian flysch of the Eastern Alps (Eliáš et al. 1990). The eastern termination of this unit is known from Poiana Botizii in the Romanian Eastern Carpathians (Bombita & Pop 1991). During the overthrust movements the Magura Nappe was completely uprooted from its substratum along ductile Upper Cretaceous rocks (Birkenmajer 1986). The Lower Cretaceous deposits are preserved only at a few locations (Hluk - Southern Moravia and the southern margin of the Mszana Dolna tectonic window). More or less complete sections of this unit are known only from that part of the basin which was incorporated into the Pieniny Klippen Belt (i.e the Grajcarek unit, Birkenmajer 1977, see also Birkenmajer & Oszczypko 1989). On the base of facial differentions of the Paleogene deposits the Magura Nappe has been subdivided into four facial-tectonic subunits: the Krynica, Bystrica (Nowy Sacz), Rača and Siary (see Koszarski et al. 1974).

In the sedimentary evolution of the Magura Basin, three different periods can be distinguished: the Middle Jurassic - Albian long- lasting (96 MY), extentional period of pelagic deposition, the Cenomanian - Campanian (23 MY) period of the hemipelagic deposition, and the Maastrichtian - Early Oligocene(40 MY) mainly compressional period of turbiditic sedimentation.

This work has been based on geological profiles of the Polish segment of the Magura Nappe, the largest and the best exposed one.

The pelagic/hemipelagic stage

According to Birkenmajer (1986) the Magura Basin was created as a part of the Outer Carpathian Basin in course of disintegration of the North European Plate. It was connected with rifting and formation of the oceanic crust both in the Magura Basin (Liassic - Dogger time) and in the Outer Dacides-Silesian Basin (Jurassic - Cretaceous boundary). The remnants of the oceanic crust are known only from the western and eastern terminations of the Magura Basin, close to the Vienna and Mures transform faults postulated by Birkenmajer (1985). In Sandulescu's (1988) opinion, during the Early Cretaceous (the end of spreading) the Magura Basin was part of the Transylvanian- Pieniny- Liguro-Piemont zone, located on the thinned continental or on the oceanic crust (Fig. 1). According to Soták (1990) the Magura Basin developed as a result of the Middle Triassic riftogenesis, proceeding the Early Anisian - Norian pelagic sedimentation.

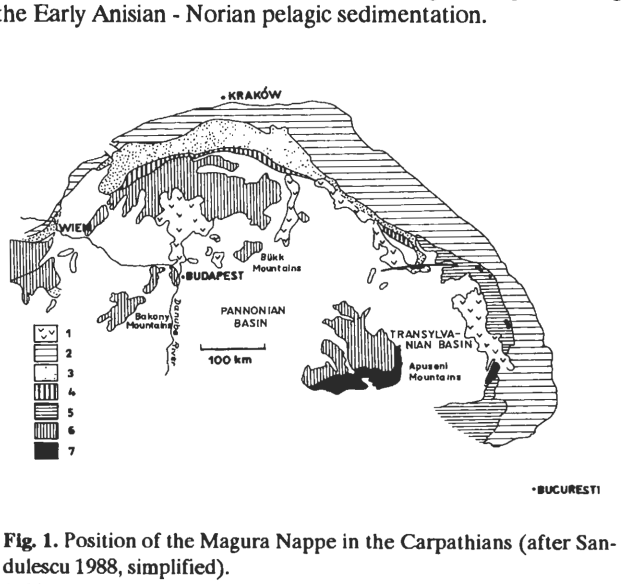

Fig. 1. Position of the Magura Nappe in the Carpathians (after Sandulescu 1988, simplified).
1 - Neogene volcanic rocks; 2 - Flysch nappes, nappes originating from oceanic regions; 3 - Magura group, 4 - Pieniny Klippen Belt; 5 - Middle Dacides; 6 - Inner Dacides (Tatrides, Austroalpides and correlative units); 7 - Transylvanides.

On the basis of lithostratigraphic sections of the Grajcarek unit (Birkenmajer 1977), Poiana Botizii Klippen (Bombita & Pop 1991) and exotic rocks from the Late Cretaceous - Paleogene deposits of the Magura Nappe (Krystek 1965; Eliáš & Eliášova 1984; Soták 1990; Mišík et al. 1991), the Jurassic - Early Cretaceous period of the Magura Basin sedimentation can be roughly characterized as mainly deep-water and pelagic. These deposits are represented by the following rocks: radiolarites, Aptychus limestones, cherty limestones (Biancone), Ammonitico Rosso, allodapic limestones, black shales and tuffites. In the Early Cretaceous, siliciclastic turbiditic sedimentation took place episodically (Black Flysch). It means that up to Albian the Magura and Pieniny sedimentary areas were a uniform paleogeogrphic zone, which was separated by the Silesian submerged ridge from the Outer Carpathian basins, dominated by flysch sedimentation. The appearing of the Silesian cordillera probably resulted from the lithospheric collision terminated in the Albian (see Soták, 1990).

During the Cenomanian - Turonian time there was unification of the sedimentary conditions in the whole basin of the Outer Carpathians (Ksiazkiewicz (ed) 1962). Radiolarites and radiolarian shales followed by variegated clays were deposited. In the Magura Nappe these deposits are represented by the Malinowa and Gbely Formations (Birkenmajer & Oszczypko 1989; Eliáš et al. 1990). Malinowa Shale Formation consisting of the hemipelagic mudstones with intercalations of thin-bedded turbidites deposited below CCD (Malata & Oszczypko 1990). In the Rača and Bystrica Subunits sedimentation of variegated clays finished at the Santonian/Campanian boundary, whereas in the Krynica and Biele Karpaty Mts. Subunits it still existed in the Maastrichtian (Birkenmajer & Oszczypko 1989; Eliáš et al. 1990).

The foraminiferal assemblages from the Upper Cretaceous red shales (Malinowa Shale Fm.) of the Magura Nappe consist exlusively of agglutined benthic taxa (Malata & Oszczypko 1990). Three assemblages are distinguished: 1 - *Uvigerinammina jankoi* assemblage, showing intermediate character between flysch-type and abyssal assemblages; 2 - *Hormosina gigantea* and 3 - *Plectorecurvoides* sp. representing flysch-type assemblages. The transition from the *U. jankoi* assemblage to the *H. gigantea* assemblage, noticed in the Krynica Subunit, reflected the global Early/Middle Campanian Event (Kuhnt & Kaminski 1989).

Turbidite stage

From the Maastrichtian through the Early Oligocene the Magura Basin was dominated by turbiditic sedimentation. At the beginning of that period the basin was probably still situated on the oceanic or thinned continental crust (see Sandulescu 1988). In course of the progressive shortening of the basin oceanic crust was subducted beneath the southern margin (Bb type of basin, conf. Mutti & Normark 1987). During that time the Magura Basin was supplied from the northern "passive" and southern "active" margins (Fig. 2).

Locations of source areas

The northern source area is commonly connected with the Silesian cordillera (Silesian ridge), being mostly active from the Late Senonian through Early Oligocene (Ksiazkiewicz 1962).

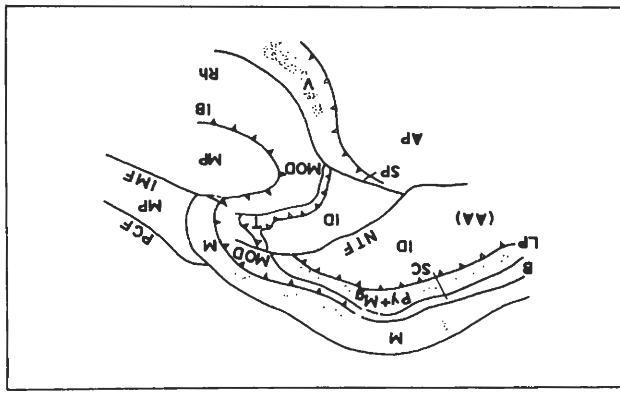

Fig. 2. Palinspastic sketch of the Carpathians during the Paleogene (after Cretaceous but before Miocene tectonism), after Sandulescu (1988).
AA - Austro-Alpine, AP - Apulia, B - Brianconais, ID - Inner Dacides, IB - Inner Balkanides, M - Moldavides, MOD - Middle and Outer Dacides (deformed), MP - Moesian platform, Py+Mg - Pieniny and Magura Nappes, Rh - Rhodopian units, Sc - Silesian cordillera, T - Transylvanides, V - Vardar zone, LP - Liguro-Piemont zone, SP - south Pannonian rift, PCF - Peceneaga-Camena fault, IMF - Intramoesian fault, NTF - North Transylvanian fault. Dotted area-the main Paleogene troughs.

According to Sandulescu (1988) the Silesian cordillera (Fig. 2) was a prolongation of the Median and Outer Dacides, tectonized during Middle Cretaceous deformation (see also Royden & Báldi 1988). The Silesian cordillera is interpreted as a "crystalline ribbon continent" 50 - 100 km wide (Soták 1990). Towards the south that ridge passed into narrow shelf and slope occupied by the Fore-Magura Basin with pelagic sedimentation.

According to Krystek (1965), Wieser (1970), Eliáš & Eliášová (1984) and Štelcl (1989), the Silesian cordillera was built up of the plutonic (granitoides), metamorphic (phyllites and quartzites) and sedimentary rocks, mainly limestones. The Jurassic - Lower Cretaceous limestones belong both to the shallow and deep-water deposits. During the Eocene - Oligocene time this cordillera supplied the Magura basin with matured, glauconitic sands (Tab. 1). The material from the north source area supplied several lithostratigraphic units (Ksiazkiewicz 1962; Bieda et al. 1963; Eliáš et al. 1990): biotite-glauconitic beds and Mutne Sandstones (Senonian - Palaeocene) and their equivalents (Soláň Fm.), the Lower - Middle Eocene Ciezkowice and Pasierbiec Sandstones (Luhačovice Ss), and finally the Magura glauconitic Sandstones (the Watkowa Ss, see Koszarski & Koszarski 1985).

The position of the southern source (or sources) is still debated. This source area existed in the Maastrichtian - Paleocene, being most active during the Eocene. The following formations have the southern source area affinity: the Maastrichtian - Paleocene Jarmuta Formation of the Grajcarek Unit (Birkenmajer 1977), the Maastrichtian - Paleocene? Szczawina Sandstones (Javorina Formation, cf. Eliáš et al. 1990) and all the lithostratigraphic units of the Krynica, Bystrica and Rača Subunits (Tab. 1). The exotic rocks from the Jarmuta Formation are rich in fragments and pebbles of the crystalline rocks of the basement (Birkenmajer 1988; Birkenmajer & Wieser 1990), the Triassic platform quartzites, red shales , limestones and dolomites, Lower Jurassic up to Aptian shallow-water and pelagic rocks mainly limestones, and plutonic, volcanic and pyroclastic rocks of the Late Jurassic (?) - Late Cretaceous subductional magmatism. In the Jarmuta Formation a relatively high content of

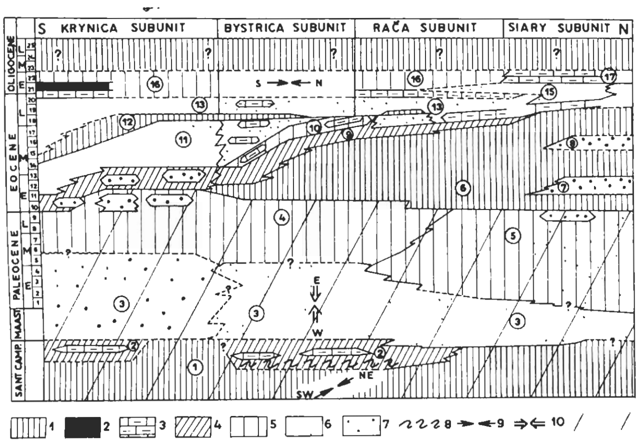

Table 1: Lithostratigraphic units of the Magura Nappe (Polish Carpathians); the Krynica Subunit after Birkenmajer & Oszczypko (1989), the Bystrica Unit after Oszczypko (in print), the Rača and Siary units after Bieda et al. (1963) and Koszarski and Koszarski (1985).
1 - variegated shales; 2 - black shales, 3 - limestones and marls; 4 - thin-bedded turbidites, 5 - medium-bedded turbidites; 6 - thick-bedded turbidites; 7 - conglomerates; 8 - chaotic deposits; 9 - axes of compression, 10 - axes of transpression; 11 - strongly deformed strata. *Lithostratigraphic units*: 1 - Malinowa Shale Formation; 2 - Haluszowa Formation; Poreba and Kanina Beds; 3 - Jarmuta Formation and Szczawina Sandstones; 4 - Szczawnica Formation and Inoceramian Beds; 5 - biotite-glauconitic beds; 6 - Labowa Shale Formation and variegated shales; 7 - Ciezkowice Sandstones, 8 - Pasierbiec Sandstones; 9 - Zarzecze Formation; Beloveza Formation and Hieroglyphic Beds; 10 - Zeleznikowa Formation (Lower Lacko Beds). Magura Formation: 11 - Piwniczna Sandstone Member and Maszkowice Member; 12 - Mniszek Shale Member; 13 - Poprad Sandstone Member; 14 - Sub-Magura Beds; 15 - Magura glauconitic sandstones (Watkowa Ss); 16 - Malcov Formation; 17 - Supra-Magura Beds.

chromian spinels was observed in heavy mineral assemblages (Winkler & Slaczka 1992). The rock fragments of this formation were derived from the erosion of both the Andrusov exotic ridge and the newly created nappes of the Pieniny Klipen Belt (Birkenmajer 1988).

The Szczawina Sandstones are dominated by monocrystaline quartz grains, feldspars, crystalline rock fragments and small amount of carbonates.

The Paleogene of the Krynica Subunit (the Magura Formation and its equivalent - Strihovce Formation) and Krynica Conglomerate Member of the Zarzecze Formation) are rich in exotic rock fragments (Eliáš 1961; Nemčok et al. 1968; Wieser 1970, Oszczypko 1975; Marschalko 1975; Mišík et al. 1991). The rock fragments are composed mainly of granitoides, gneisses, phyllites and quartzites, with relatively small amount of basic volcanic rocks and Mesozoic carbonates. The carbonates are represented mainly by Jurassic - Lower Cretaceous deep-water sediments. In the Strihovce Formation (conglomerates) fragments of shallow-water limestones of Triassic (Anisian), Kimmeridgian - Upper Tithonian, Early Cretaceous (Urgonian), Late Cretaceous, Early and Late Paleocene, and Early Lutetian (Mišík et al. 1990, see also Oszczypko 1975) have been also found. The Paleogene deposits of the Krynica Subunit (Szczawnica and Magura Formations) revealed increased chromite spinel contents (Winkler & Slaczka 1992).

The location of the South-Magura cordillera (ridge) was discussed by many authors. According to Sikora (1971) that ridge was situated between the Magura nad Hulina Basins. A similar idea was presented by Marschalko (1975). In his opinion during the Late Paleocene - Early Eocene the South Magura cordillera separated the Magura Basin on the north and Kyjov-Inovce Basin on the south. Different opinion is presented by Birkenmajer (1977, 1986), who regards the "Hulina succesion" as the Magura succesion deposited north of the Czorsztyn ridge. During the Late Laramian movements the Magura succession was incorporated into Pieniny Klippen Belt as the Grajcarek Unit. According to the new palinspastic reconstructions (Birkenmajer 1986, 1988; Sandulescu 1988; Royden & Báldi 1988; Soták 1990) there was no crystalline massif exposed at the southern border of the Magura Basin after the Late Cretaceous - Early Paleocene compression.

However, Mišík et al. (1991) gave evidence for lack of the elements of the Czorsztyn unit in the material derived from the South Magura ridge. In their opinion there are also important differences between rock fragments derived from the Neo-Pieninian cordillera (Andrusov ridge) and South Magura ridge. They have suggested that the South Magura ridge could be a part of an uplifted subduction complex ("structural high"), comprising substratum of the Magura Basin.

According to the existing opinions there ise controversy on the relation between the Magura and Pieniny Basins. In both cases there is the problem of explaining the origin of the huge amount of crystalline clasts dominating in the Maastrichtian - Eocene deposits of the Magura Nappe. The volume of these deposits can be estimated at least n x $10^3 km^3$. It is easier to explain the occurrence of sedimentary clasts, which were probabbly derived from the basinal and shalow-water deposits incorporated into orogenic belt.

In my opinion the south Magura source area could be regarded as a heterogenic orogenic belt (accretionary wedge, see Dickinson 1988) which appeared as a result of the Late Laramian subduction in the front of the Klippen Foldbelt (Birkenmajer 1986). That belt comprised both crystalline and sedimentary rocks with different origin. This explains why clastic material which reached the Magura Basin from the south is so differentiated, many times recycled (Potfaj et al. 1991), and contains pebbles of the Paléogene flysch rocks (Oszczypko 1975).

Late Senonian - Early Oligocene deposition

During that time the Magura Basin was supplied both from the Silesian Cordillera and South Magura source area. The material derived from the Silesian Cordillera is restricted to the Siary Subunit and partly to the Rača Subunit west of the Rába River.

The Late Cretaceous - Paleogene flysch connected with South Magura source area (Tab. 1) may be subdivided into three turbiditic complexes (sensu Mutti & Normark 1987)): the Campanian/Maastrichtian - Paleocene, Early - Late Eocene and Late Eocene - Early Oligocene. Each of them begins with the pelitic basinal deposits (variegated shales) passing into thin- and medium-bedded turbidites bearing intercalations of allodapic limestones/marls, and into thick-bedded ones. Finally there are thin-bedded turbidites.

The Campanian/Maastrichtian - Paleocene complex, begins with chaotic deposits about 40 *m* thick (Poreba Beds). These deposits can be regarded as submarine slump body, composed of several scales. The initiation of slump movements were probably conected with seismic shocks located at the southern slope of the Magura Basin. The chaotic deposits are folloved by 50 *m* thick sequence of very thin bedded turbidites, strongly chevron folded and imbricated (Oszczypko et al. 1991). Higher up in the section, there appear thin-to medium-bedded turbidites, up to 50 *m* thick, with numerous 5 - 7 to 30 *cm* thick intercalations of turbiditic limestones (Kanina Beds and Haluszowa Formation, see Cieszkowski et al. 1989). These Campanian deposits can be regarded as an equivalent of the Helmintoides Flysch of the Swiss Alps and the Zementmergel Formation of the Rhenodanubian Flysch. These deposits pass upward into thick-bedded sandstones and conglomerates up to 400 *m* thick (Szczawina Sandstones). The Maastrichtian ammonite *Saghalinites wrighti* Birkelund has been found at the bottom of sandstones (Haczewski & Szymakowska 1984).

The youngest unit of the complex, 150 - 200 *m* thick, is composed of medium to thick-bedded turbidites of Paleocene age (Szczawnica Formation and Inoceramian Beds). According to nannoplankton study the top of that unit belongs to Early Eocene. These deposits are overlain by 20 - 150 (250?) *m* thick formation of variegated shales, which starts the next Eocene turbidite complex (Tab. 1).

This complex begins with variegated shales (Labowa Shale Formation) and passes upward into thin-bedded turbidites of the Zarzecze, Beloveža and Hieroglyphic Formations few hundred metres thick. In the Bystrica Subunit the Beloveža Formation is overlain by thin to medium-bedded turbidites with intercalations of the Lacko type marls. These intercalations sometimes have a megaturbidite character. In the Rača Subunit (Tab. 1) the sub- Magura Beds are probably an equivalent of the Lacko marls. In the Krynica, Bystrica and Rača Subunits the youngest deposits of the Eocene complex belong to the Magura Formations. This formation reached in the Krynica Subunit 2000 - 2500 *m* thickness and at least 1000 *m* and 1000 - 2000 *m* in the Bystrica and Rača Subunit respectively. The Magura Formation is represented by the thick-bedded turbidites and fluxoturbidites, deposited in distributary channels and lobes of the middle submarine fans (Birkenmajer & Oszczypko 1989; Marschalko & Potfaj 1982; Potfaj et al. 1991). The Magura Formation locally pass upward into red Globigerina marls, Menilite shales and the Malčov Formation. The Globigerina marls probably began the youngest (Late Eocene - Early Oligocene) turbidite complex in the Magura Basin.

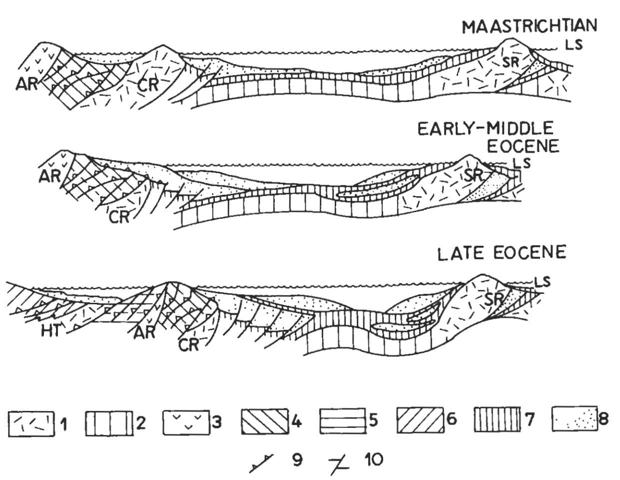

Fig. 3. Evolutionary model of the Magura Basin (Senonian - Late Eocene).
1 - continental crust; 2 - oceanic crust; 3 - Andrusov ridge (AR); 4 - Late Cretaceous nappes of the Pieniny Klippen Belt; 5 - the Klapa, Manín and Kostelec units; 6 - High Tatra, Krížna and Choč units; 7 - pelagic and hemipelagic deposists; 8 - turbidite deposits; 9 - overthrusts; 10 - faults; HT - High Tatra ridge, Cr - Czorsztyn ridge, Sr - Silesian ridge, HS - high sea level, LS - low sea level. Model of the Pieniny Klippen Belt and the Inner Carpathian after Birkenmajer (1986, 1988).

In the Early - Late Eocene complex all boundaries of the formations, except the upper limit of complex, are diachronous. Diachronous boundaries of formations are related to the northward progradation of lithofacies. Depositional sequences of the Campanian/Maastrichtian - Paleocene and Early - Late Eocene complexes reflect stages of groving and progradation of the submarine fans. The variegated shales had been deposited in the deep-water enviroments with restricted influx of clastic material. It explains its low depositional rates and occurrences of manganeous nodules. In the terms of sequence stratigraphy (Van Wagoner et al. 1991) these stages of the Magura Basin could be connected with highstand systems tract. In the contrary thick-bedded turbidites (Szczawina Sandstones and Magura Formation) were deposited in relatively shalow-water enviroments, with intensive clastic influx and high depositional rates which are connected with lowstand fan systems tract. Origin of the carbonate turbidites may reflect early stages of sea level lowering and development of submarine slumps on the slope of basin.

Paleogeographical implications

The Magura Campanian-Paleogene flysch trench-basin was situated along a convergent southern margin. The beginning of the flysch deposition was related to subduction at the northern margin of the Pieniny Klippen Belt. The subduction of oceanic or thinned crust of the Magura Basin beneath continental crust of the Czorsztyn ridge begun at the Campanian - Maastrichtian boundary. The development of the Maastrichtian - Paleocene fans was tectonically controlled by uplift of the source area, caused by rate of subduction and underplating.

During the Maastrichtian - Early Oligocene a huge amount of coarse clastic material was derived from this area and deposited at the southern edge of the Magura Basin (Fig. 3, Tab. 1). According to paleocurrent measurements the southern part of the Magura Basin was supplied from the S, SE and E (Ksiazkiewicz 1962). Only in the Orava region is there evidence of the paleotransport from the NE (Marschalko & Potfaj 1982; Potfaj et al. 1991). Probably it was connected with anti-clockwise rotation of this segment of the Magura Nappe.

In the Eocene period, gradual shifting of the coarse-clastic material from the south to the north took place. It was connected with development of two large submarine fans, partially superimposed one upon another. Their formation was connected with tectonically induced sea level (see Shanmugam et al. 1985; Van Wagoner et al. 1990). Progradation of these fans can be related to the shortening of the Magura Basin and the development of accretionary prism. There is evidence of variable compression (Oszczypko et al. 1991) in the Magura Basin: NE - SW before the Maastrichtian, W - E transpression before the Eocene, and N - S compression after the Paleogene (Tab. 1). In the Lower Eocene deposits of the Krynica Subunit there is evidence that folding of these strata was, in some places, significantly advanced before their complete lithification (Tokarski et al. 1991). Manifestations of the Middle Eocene and Eocene/Oligocene boundary tectonic movements were also reported by Ksiazkiewicz & Leško (1959) and Oszczypko & Zytko (1987).

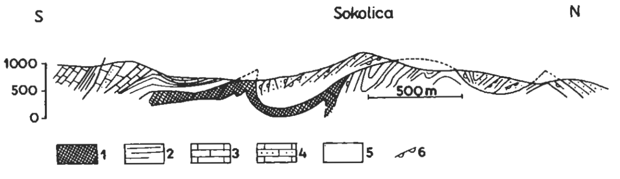

Fig. 4. Geological cross-section of the Babia Gora Range, after Ksiazkiewicz (1966).
1 - variegated shales; 2 - Beloveza Beds; 3 - Lacko marls (Bystrica Formation); 4-Lacko marls with intercalations of thick-bedded sandstones (Maszkowice Member of the Magura Formation); 5 - Magura Beds (Poprad Member of the Magura Formation); 6- position of sole markings.

At the southern boundary of the Magura Basin the material of the prism was scraped from down-going slab and internally deformed (Fig. 3). At some places the Magura Formation probably overlaid the older deposits with angular discordance (Fig. 4). This process was probably completed before the Late Oligocene. When the front of the Magura Nappe was formed, the Silesian ridge colapsed as a result of lithosphere flexure caused by surface load at the front of overriding nappes. After that event the Outer Carpathian flysch basin attained features of a relatively deep-water foreland basin (0szczypko & Slaczka 1991). It was manifested during sedimentation of the Krosno Formation and later as the marine molasses in the Carpathian Fore-deep.

Conclusions

1 - During the Middle Jurassic - Early Cretaceous the Magura Basin, in contrary to the other Outer Carpathian basins, was dominated by pelagic, deep-water sedimentation.

2 - The initiation of the turbidite sedimentation in the Magura Basin (Campanian) was connected with the beginning of compression at the southern border of the basin.

3 - Three turbidite complexes: Campanian/Maastrichtian - Paleocene, Early to Late Eocene and Late Eocene - Early Oligocene could be distinguished in the Magura Nappe.

4 - The South-Magura source area was the heterogenic orogenic belt uplifted after the Campanian.

5 - The Senonian - Paleogene deposits of the Magura Basin were incorporated into an accretionary prism and probably partly deformed in submarine conditions.

6 - The Magura overthrust developed step by step from the south to the north in course of accretionary prism growing.

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