

Paleogene depositional systems and paleogeography of the submarine fans in the western part of the Magura Basin (Javorníky Mountains, Slovakia)

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Abstract: This paper gives an overview of the depositional systems and paleogeography of the submarine fans in the western part of the Magura Basin. Four fundamental petrographic groups were distinguished within the sandstones of this area: Soláň, Riečky, glauconitic and Magura group. This classification responds to four source areas supplying sedimentary material into the western part of the Magura Basin. The sedimentation developed in a few separated depositional cycles. First the massive to the basin prograding wedge of the Soláň Formation was deposited along the northern margin of the Magura Basin during the Late Cretaceous to Early Paleocene. Later the central zone of the basin subsided probably more significantly. The coarse-clastic sedimentation shifted in the Rača Zone from the margin into the deeper part of the basin as a result of this subsidence since the Early Paleocene. The depositional fans of the Riečky sandstone type were formed there. Uplift of the Silesian Ridge advanced from the W to the E during the Middle Eocene. Its result was the shifting of the source of the sedimentary material. This new source supplied to the basin glauconite sandstones from the NE. This sedimentation represented an asymmetrical fan of the proximal coarse-grained Pasierbiec sandstone type and pelitic distal facies. Sedimentation of the Riečky sandstone type was renewed with a reduced volume once more during the Middle Eocene. The period of the subsided and uplifted basin floor blocks followed rather flattened subsidence of the basin floor since the late Middle Eocene (Lutetian). Two extensive depositional fans developed parallel to the basin elongation direction in that time. These were the glauconitic and Magura fans. Both fans existed side by side simultaneously and interfingered each other. These fans prograded from the South into the Rača sedimentation area. The depositional systems and paleogeography of the submarine fans in the western part of the Magura Basin were controlled mainly by basin floor subsidence, by the local sediment supply, synsedimentary tectonics, by the progress of the subduction of the southern Magura Basin margin and also by the depositional pressure of the adjacent fan.

Key words: Paleogene, Outer Western Carpathians, Magura Basin, paleogeography, submarine fan model, sedimentology, petrography.

Introduction

This paper is concerned with the deposits of the Magura Nappe, which form the Javorníky Mts and the adjacent area. The solution to the stratigraphic, lithofacies and petrographic problems of this region is decisive for the paleogeographical reconstruction of the Western Carpathians Flysch Belt. Particular attention was paid to the detailed restoration of the bed sequences, and the paleocurrent and petrographic analyses of this area during the last geological mapping (Mello et al. 2005). The present paper is intended to give in short a general picture of the depositional systems, paleogeography of the submarine fans and some reconstruction of the sea floor relief evolution in the western part of the Paleogene Magura Basin. The correlation of the relative lithostratigraphic units between Slovakia, Poland and the Czech Republic was not the intent of this paper.

Geological setting

The Javorníky Mts are formed by the Upper Cretaceous to Lower Oligocene flysch sediments deposited in the ancient

Magura Basin (Fig. 1). The sediments of this basin were folded into the north-vergent imbricated folds and slices of the rootless Magura Nappe. This nappe was detached from its substratum mainly along the ductile Upper Cretaceous rocks. In this manner the post Oligocene accretionary prism formed. Three tectonofacies units have been distinguished in the western part of the Magura Nappe on the basis of the deposit facies differentiation. These are from North to South: Rača, Bystrica and Krynica Units (Birkenmajer & Oszczyko 1989). The Krynica (=Oravská Magura) Unit is not present in this area.

The Rača Unit can be divided into the outer Rača Unit (=Siary Unit in Poland) and the inner Rača Unit. The sedimentation advanced in the Rača Unit in this area from the Soláň Formation (Campanian to Paleocene), through the Beloveža Formation (Early Paleocene to Middle Eocene) and the Luhačovice Formation (Middle Eocene) to the Zlín Formation (Middle to Late Eocene) (Fig. 2).

The Soláň Formation is formed by the Lukov Beds (=Mutne Sandstones in Poland) and the Ráztoka Beds (Pesl et al. 1984; Potfaj et al. 2003; Mello et al. 2005). The Ráztoka Beds are subdivided into the Claystone-sandstone Lithofacies (Soláň sandstone type) and the Sandstone-claystone

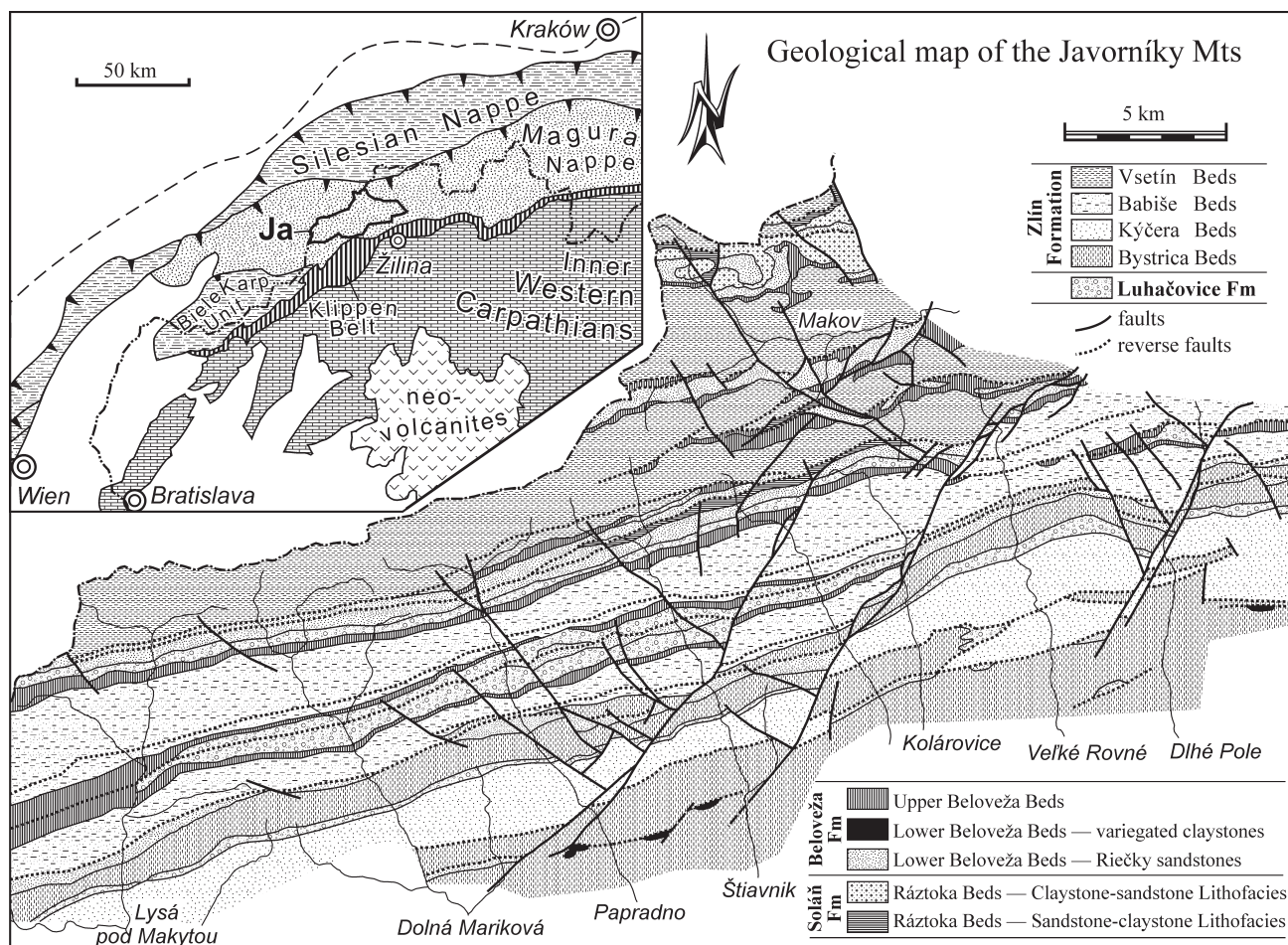


Fig. 1. Informative location map and geological map displaying the setting of the investigated Javorníky Mts (Ja) in the Western Carpathians (sensu Teták in Mello et al. 2005).

Lithofacies (thin-bedded flysch) (Pesl 1968). This is partly equivalent to the Inoceramus Beds (Sikora & Žytko 1959) or the Ropianka Beds in Poland.

The Beloveža Formation represents a lithofacies variegated complex divided into the Lower and Upper Beloveža Beds. The Lower Beloveža Beds are composed of the Riečky sandstone type (Potfaj et al. 2003; Teták in Mello et al. 2005, Skawce Sandstone Member — Cieszkowski & Waškowska-Oliwa 2001), variegated claystones and thin-bedded flysch (Łabowa Shale Formation or Ciężkowice Sandstones in Poland — Sikora & Žytko 1959). The Upper Beloveža Beds are represented by thin-bedded flysch (Hieroglyphic Beds in Poland).

The Luhačovice Formation is divided by a segment of thin-bedded flysch into the Lower Luhačovice Beds (Pesl 1968) and the Upper Luhačovice Beds (Teták in Mello et al. 2005). The Lower Luhačovice Beds are equivalent of the Pasierbiec Sandstones in Poland (Sikora & Žytko 1959). The Upper Luhačovice Beds are not developed in Poland.

The Zlín Formation is divided into the Vsetín, Babiše (Teták in Mello et al. 2005; Teták 2005b), Kýčera and Bystrica Beds. It is Middle-Late Eocene in age, maybe younger (Oszczypko-Clowes 2001). Two fundamental litho-

types of the sandstones are present in this formation — the glauconitic and Magura sandstone types (Stráník 1965).

The Bystrica Unit (= Sącz Unit in Poland) is formed by the Beloveža Formation (Paleocene to Early Eocene) and the typical Bystrica Beds of the Zlín Formation (Łacko Beds (Marls) or the Żeleźnikowa Formation in Poland — Oszczypko 1991) (Middle Eocene).

Previous studies

Many papers have been written about the paleogeographical evolution of the Magura Nappe in the Western Carpathians. From the wide list of the papers the lithofacies classifications of Książkiewicz (1956, 1966) and Pesl (1965, 1968) had the greatest weight for the writing of this article. They displayed in detail the distribution of the lithofacies in the western part of the Magura Basin. Also Golonka et al. (2000) and Oszczypko & Salata (2005) tried to reconstruct the evolution of the Magura Basin. Krystek (1963), Winkler & Ślaczka (1992, 1994) attempted to identify the character of the source terrains by heavy minerals analyses. Unrug (1968) interpreted the shifting of the Silesian Ridge from West to East. Poprawa et

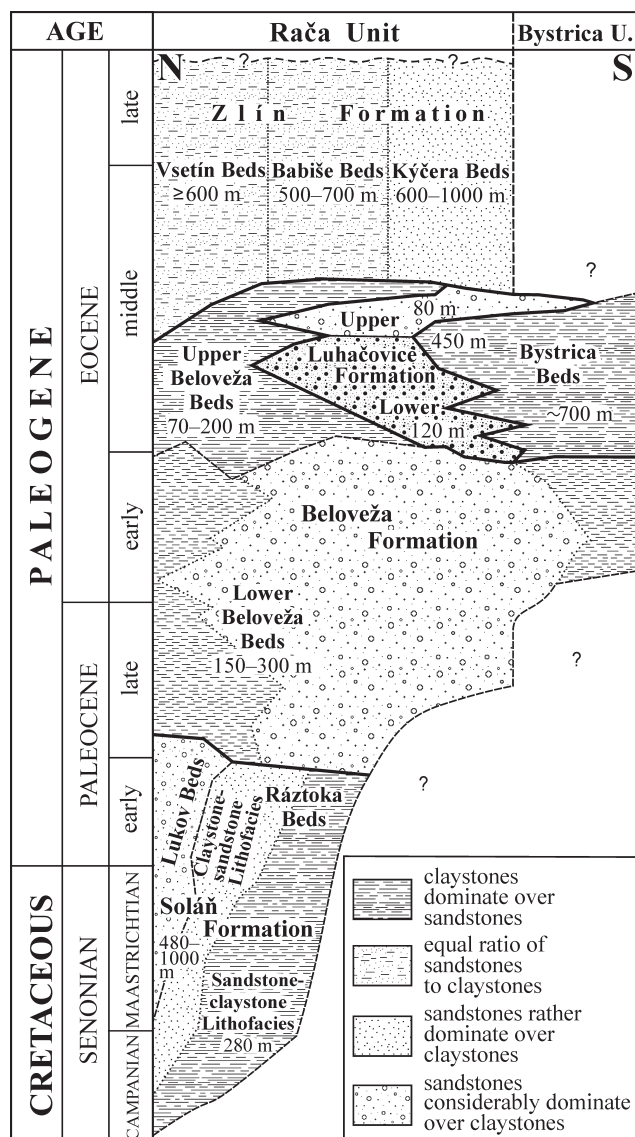


Fig. 2. Lithostratigraphic scheme of the Magura Nappe (Javorníky Mts).

al. (2002) interpreted the tectonic evolution of the flysch basins of the Outer Carpathians inferred from the basin subsidence analysis and sediment supply.

Methods

The lithofacies structure and petrography of the Magura Nappe were reconstructed during the detailed geological mapping of the Javorníky Mts (Fig. 1 sensu Tefák in Mello et al. 2005). These allowed me to create the lithofacies scheme for each tectonic slice of the Magura Nappe separately (Fig. 3).

I have measured the paleotransport of the gravity flows on 737 bedding planes. The paleocurrent analyses (Fig. 5) and detailed reconstruction of the lithofacies and lithostratigraphic profiles (Fig. 3) of the investigated area enabled me to interpret the paleogeographical conditions and sedimentation evolution in the western part of the Magura Basin

(Fig. 6) (Tefák 2005a). The Magura Nappe is elongated in the WSW–ENE direction in its western part at present. This is not the original position of the Magura Basin. About 60° of counterclockwise rotation of the basin fill took place since the Oligocene (Krs et al. 1994; Panaiotu 1998). In this article I refer the azimuth orientations to the present geographical position without clockwise restoration.

107 samples of sandstones were sampled for the petrographic analyses during the detailed geological mapping of the Javorníky Mts (Gross 1997; Buček & Nagy 1997; Filo in Filo & Siránová 1998). These petrographic analyses (planimetry) were evaluated by Siránová (1997, 2001). Tefák (2005a) verified lithofacies classification of these samples and petrographically evaluated another 53 samples. All these samples were sampled in the Javorníky Mts region from the flysch formations of the Magura Nappe (Late Cretaceous to Late Eocene). The following petrographic analyses are based on Dickinson & Suczek (1979). They identified the character of the source areas of the submarine sandstones by the distribution of sandstones analyses in the QFL triangle petrographic diagram (Q — quartz and quartzite, F — feldspars, L — lithic detritus, see also Dickinson 1985). I plotted the obtained petrographic values onto the QFL diagram (Fig. 4). Palinspastic analyses are also based on the lithofacies analyses of Pesl (1968) and Książkiewicz (1966). (*The sandstone types are understood in this article not in the stratigraphic, but wholly in the lithofacies meaning*).

Results

Evolution of the sedimentation

The results of the petrographic analyses of the sandstones from the Javorníky Mts are displayed in the QFL diagram (Fig. 4). All the resultant points fall close the cusp of the Quartzite. The points are distributed into the characteristic petrographic groups. Four fundamental petrographic groups were distinguished within the sandstones of this area: Solán, Riečky, glauconitic and Magura group. These groups represent four main source areas supplying sedimentary material to the western part of the Magura Basin during the Paleogene. Consequently several evolutionary stages were distinguished in the deposition of the western part of the Magura Basin since the latest Cretaceous to Oligocene:

- marginal wedge
- longitudinal fans
- north-eastern source
- recycled orogen

Marginal wedge

The oldest sedimentation cycle in the studied area took place during the Late Cretaceous to Early Paleocene. The deposition with domination of sandstones and conglomerates represents this event. A massive to-the-basin prograding wedge of the Solán Formation was sedimented along the northern margin of the Magura Basin (Figs. 2 and 5). It creates the thick upward-coarsening cycle (Fig. 3). The thin-

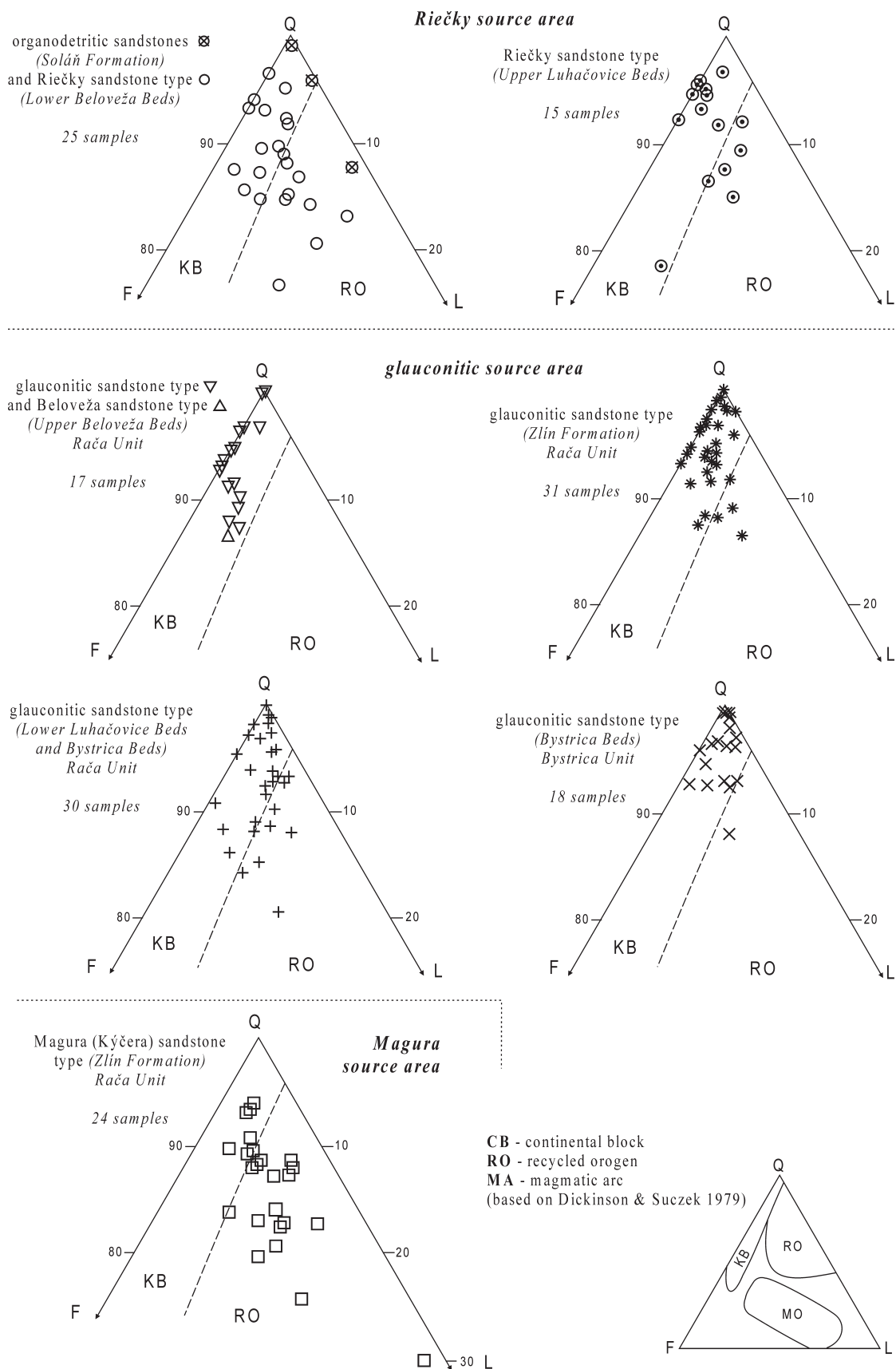


Fig. 4. The results of the petrographic analyses of the Magura Nappe sandstones are sorted according to their lithofacies affinity (Javorníkov Mts, 160 samples).

bedded flysch of the Sandstone-claystone Lithofacies lies on the base of this cycle and on the distal part of the wedge (150 up to 280 m thick). Sedimentation passed upward gradually into the Soláň sandstone type complex. "Wild-flysch" with intercalations of the slumps and olistolites of the Mesozoic carbonates sedimented near the basin margin on the proximal part of the wedge (Eliáš 1963; Chodyń 2002). The Soláň sandstone type complex reaches a thickness of almost 1000 m to the North from the Turzovka town (Lukov Beds sensu Pesl et al. 1984; Potfaj et al. 2003; Mutne Sandstones sensu Sikora & Žytka 1959; Chodyń 2002). The sandstone/claystone ratio and thickness of the sandstone wedge decline to the SE near the Makov village to 450 m (Claystone-sandstone Lithofacies). The sandstone wedge completely vanishes to the South towards the inner Rača Zone. There it is replaced by the distal thin-bedded flysch sediments of the Sandstone-claystone Lithofacies (Pesl 1968). The measured directions of the paleocurrents are variable, but their prevalent trend is mainly from the NW (Sikora & Žytka 1959; Eliáš 1963; Krystek 1963; Teták 2005a). Evidently the sedimentary material was supplied to the basin by several sources from the Silesian Ridge.

Longitudinal fans

The *Riečky sandstone type* forms two massive sandstone complexes of the Lower Beloveža and Upper Luhačovice Beds. They were deposited during the Paleocene to Middle Eocene (Fig. 2). The *Riečky sandstone type* forms 30–150 cm thick beds. The beds are often amalgamated in up to 40 m thick packages. Their granularity varies from fine-grained conglomerates to middle-grained sandstones with grains up to 5–15 mm (max. 20–60 mm). Lowe's S_3 and Bouma's $T_{ab(c)}$ divisions are typical. The sandstones consist of quartz, subordinately feldspar (about 5 %), epimetamorphic rock, igneous rocks, muscovite and quartzite (rarely carbonates and glauconite). The clasts are well rounded. The *Riečky sandstone type* represents the lobes of the suprafan. The sandstones are intercalated with the interchannel facies of the variegated (red and green) non-calcareous claystones and thin-bedded flysch. The thinner beds of sandy-clayey slumps occur in the Makov village area.

The distribution field of the *Riečky sandstone type* does not reach up to the cusp of Quartzite in the QFL petrographic diagram (Fig. 4). They are formed by less mature material with abundant feldspar and lithic clasts. The analyses demonstrate the slightly different petrographic character of the Lower Beloveža Beds the against Upper Luhačovice Beds, although these are formed by the same sandstone type. The points of the *Riečky sandstone type* of the Upper Luhačovice Beds are not so widely diffused in the QFL diagram. Their distribution field shifts from the field of the recycled orogen to the field of the continental block source area (sensu Dickinson & Suczek 1979). These petrographic changes could be caused by the advanced erosion and increased maturity of the source area. The sedimentary material was transported from the W (SW) to the E (NE).

The clastic sedimentation shifted in the Rača Zone from the margin into the deeper part of the basin after the sedi-

mentation of the Soláň sandstone type since the later Early Paleocene. The shifting of the maximum deposition zone suggest that the central zone of the basin subsided probably more significantly. The longitudinal depositional fans of the *Riečky sandstone type* (Lower Beloveža and Upper Luhačovice Beds) and the *Pasierbiec sandstone type* (Lower Luhačovice Beds) were formed in the centre of the basin (Pesl 1965, 1968; Potfaj et al. 2003; Teták 2005a). Orientation of the individual fans was parallel to the basin elongation (Fig. 6).

The fan of the *Lower Beloveža Beds* is thickest in the area to the South from the main crest of the Javorníky Mts, where their thickness reaches up to 250 m. The thickness of this mostly sandstone complex was reduced down to 30 m in the area to the North from the main crest of the Javorníky Mts near Makov village and only rare individual beds occur near Klokočov village (Fig. 3). About 30 m thick complex of the *Riečky sandstone type* wedge is found above 45 m and below 70 m of variegated claystones and thin-bedded flysch in the Makov village area. It follows that the *Riečky fan* reached its farthest northern extent at about half way through its existence. This fan extended to the S as far as the Bystrica Zone sedimentation area (Teták in Mello et al. 2005). The *Riečky sandstone type* of the Lower Beloveža Beds occur westward, near the Valašské Klobouky town in two tectonic slices of the Bystrica Unit. Their thickness is about 200 to 400 m (Roth in Buday et al. 1963 described these sediments as the Soláň Formation). The fan vanished quickly eastward in the Bystrica Zone realm. There it reached a thickness from 50 to 150 m near Mariková village. The most eastward occurrence of the *Riečky sandstone type* was observed in the Bystrica Unit, near Dlhé Pole village (Teták in Mello et al. 2005).

The equivalent of the *Riečky sandstone type* of the Lower Beloveža Beds is the Skawce Sandstone Member of the Łabowa Formation in Poland (Cieszkowski & Waškowska-Oliwa 2001, previous Ciężkowice Sandstones sensu Sikora & Žytka 1959; Książkiewicz 1966; Cieszkowski et al. 1999). This member occurs in Poland north-east of the Babia hora Mt. These sandstones are typical for the outer Rača Unit (Siary Zone) in Poland. Their stratigraphic position, lithology and petrography resemble the *Riečky sandstone type* of the Lower Beloveža Beds, but the Skawce Sandstone Member has a different paleocurrent configuration (transport from NNW to SSE). It formed a separated sedimentation fan situated along the northern margin of the basin. This fan did not reach the centre of the basin. This distinguishes it from the *Riečky sandstone type fan* (Książkiewicz 1966).

Sedimentation of the *Riečky sandstone type* was renewed once more with a reduced volume within the Middle Eocene as the *Upper Luhačovice Beds* (Pesl 1968). They form thick amalgamated sandstone beds. This fan spread over the inner Rača Zone (in recent the Medvedie, Luhačovice and Čertovy kameny Anticlinal Zones). The fan retained its extension parallel to the basin elongation. Its width was about 40 km and its length was over 80 km, which is the distance between Luhačovice and Kysucké Nové Mesto towns. The fan thickness decreased towards the fan margins from its maximal thickness of 120 m (near Papradno village, Fig. 3). Clastic

material was transported generally from the WSW to ENE (Fig. 5). Lack of the Riečsky sandstone type in the Upper Beloveža Beds in the outer Rača Zone suggests that the synsedimentary fault framed the northern fan margin on the same place as the Pasierbiec sandstone type of the Lower Luhačovice Beds. This fault completely inhibited the gravity currents to over-flow to the North over the elevated plain (Fig. 6), where thin-bedded flysch of the Upper Beloveža Beds was sedimented. The southern margin of this fan was not as distinct as the northern one. The fan was interfingered from the South by the quartz glauconitic sandstones of sugar-like appearance (Medvedie and Potoky Anticlinal Zones, Fig. 3).

A north-eastern source

The coarse-grained sedimentation of the Riečsky sandstone type was followed by the deposition of another longitudinal fan in the central part of the Magura Basin. This newly activated north-eastern source supplied the sandstones rich in

glauconite. These *glauconitic sandstones* form the Lower Luhačovice Beds (Pasierbiec Sandstones), Beloveža Formation, Bystrica and Vsetín Beds (Wątkowa Sandstones) of the Zlín Formation (Magura Formation in Poland) (Fig. 2). The glauconitic sandstones are green-white, fine- to medium-grained, siliceous, laminated or massive (T_b or T_{abc} Bouma's division) and well sorted. They form beds 5 to 250 cm thick. The coarse-grained massive type is called the *Pasierbiec sandstone type*. These sandstones are characterized by abundant glauconite (many times over 5 %). The clasts of feldspar, epimetamorphic rocks and carbonate detritus are also abundant. A special type of the glauconite sandstones is represented by the quartz glauconitic sandstones of sugar-like appearance.

Sandstones of the glauconitic source area are more siliceous than the other sandstones in this area. Their distribution field reaches in the QFL diagram up to the cusp of Quartzite (Fig. 4). Majority of the points fall into the field of the continental block source area (Dickinson & Suczek 1979).

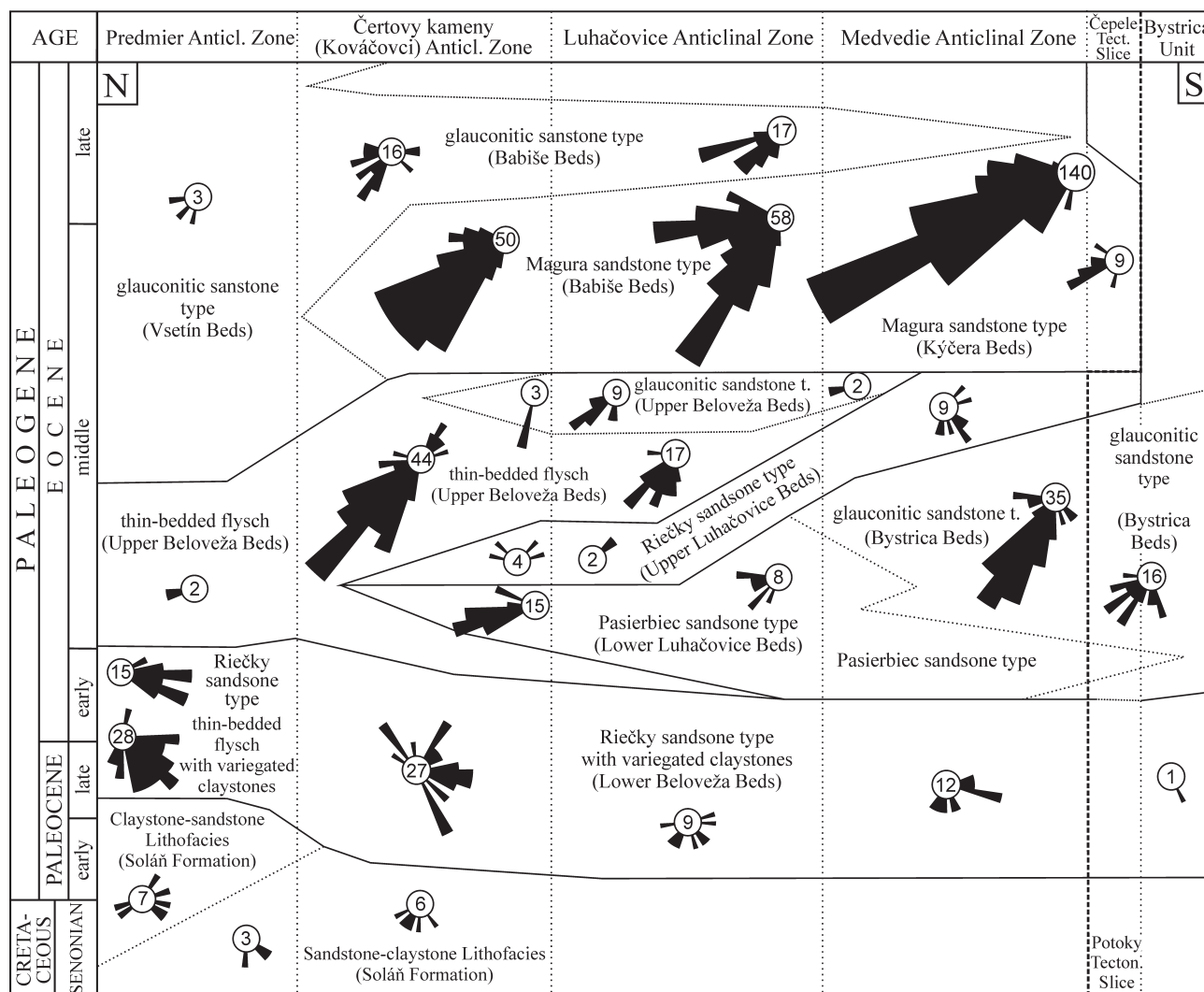


Fig. 5. Rose diagrams of the paleocurrent direction measurements in the Javorníky Mts sorted according to lithostratigraphy and tectonics (in the circle is the number of measurements).

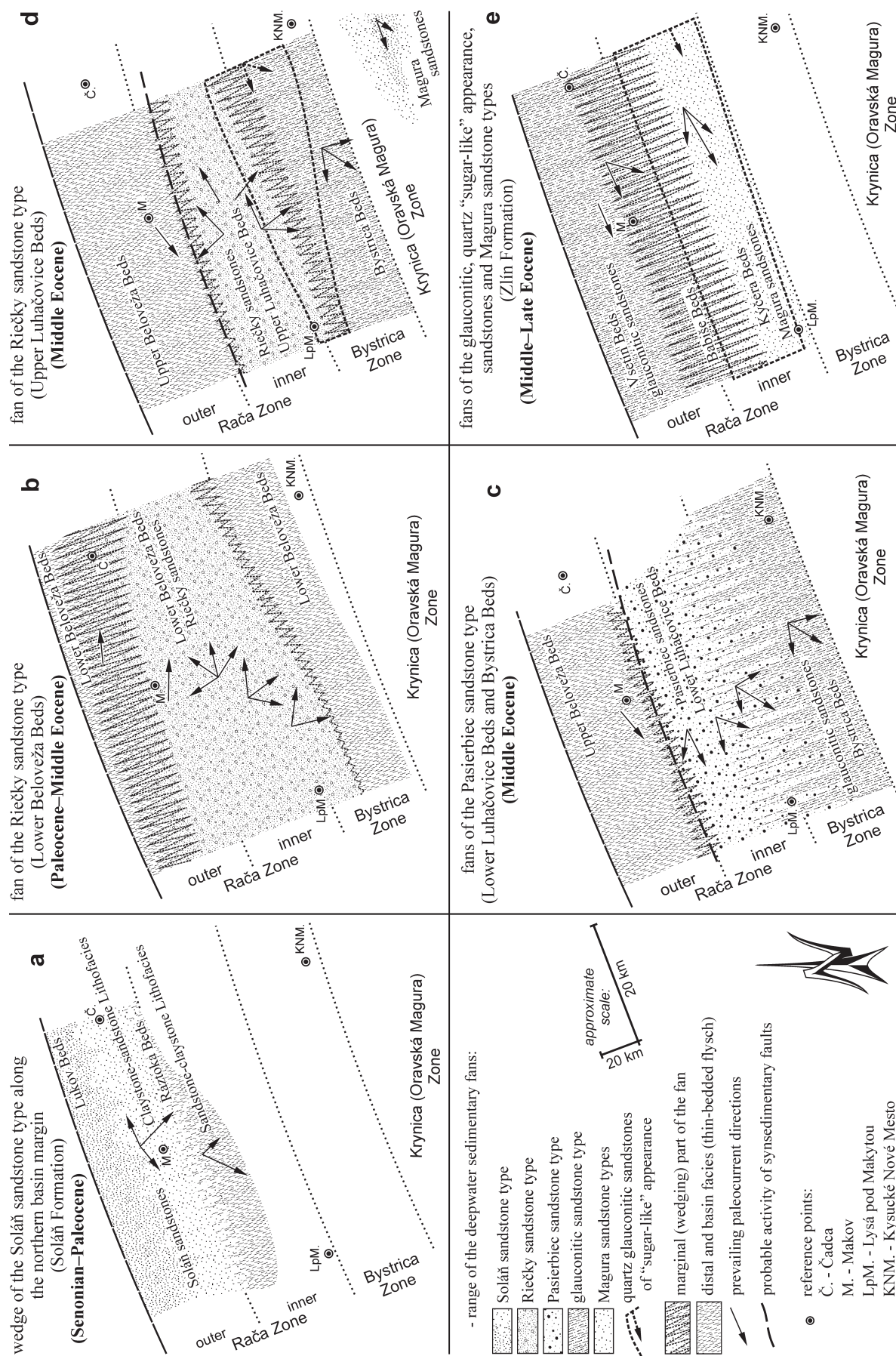


Fig. 6. Palinspastic scheme of the distribution and range of the depositional fans in the western part of the Magura Basin (Javorníky Mts area).

The eastern part of the Silesian Ridge was uplifted during the Middle Eocene (Unrug 1968). This source supplied to the basin an increased volume of metamorphic rocks and feldspar. The character of the sedimentary material was probably influenced by its resedimentation in the littoral area. The sediment was thus enriched by the glauconite and carbonate organic detritus from the uplifted littoral area. The clasts were well rounded. This could have been caused by long transportation or by reworking. The shelf along the Silesian Ridge with the carbonate platform sedimentation produced an enormous amount of the organic carbonate material and glauconite.

The fan of the glauconitic sandstones was asymmetrical during the Middle Eocene (Fig. 6). The central "proximal" part of the glauconitic fan was formed by the coarse-grained Pasierbiec sandstone type (Lower Luhačovice Beds). Their distal equivalent is the fine-grained glauconitic sandstones on the southern (left) fan side. The considerable volume of this sedimentation consists of thick pelitic deposits (Bystrica Beds or the Łącko Marls in Poland — Książkiewicz 1966, Żeleźnikowa Formation — Oszczytko 1992) (Fig. 2). The Bystrica Beds represent the distal part of the glauconitic fan. Equivalent glauconitic facies did not form on the northern fan margin. Therefore it is possible to suppose that the fan was blocked on its northern side by the synsedimentary fault. The elevation of the outer Rača Zone obstructed coarse-grained gravity currents flowing to the N over the thin-bedded flysch. Thus, the elevated plane with thin-bedded flysch deposition occasionally interrupted the turbidites of glauconitic sandstones (Fig. 3). This is proved by the lack of the glauconitic sandstones in the Upper Beloveža Beds (Submagura Member) in the outer Rača (Siary) Zone. The Pasierbiec sandstone type occurs in the Javorníky Mts in the similar stratigraphic position as well as eastward in Poland (Książkiewicz 1966). The sedimentation of the Pasierbiec sandstone type was replaced in Poland by the thin-bedded sedimentation of the Hieroglyphic Beds. The equivalent of the Upper Luhačovice Beds was not found in Poland (i.c.).

The Magura Basin underwent significant paleogeographical changes during the late Middle Eocene (Lutetian). The period of the subsided and uplifted basin floor blocks followed rather flattened subsidence of the basin floor. The separation of the zones with prevailing coarse-clastic and pelitic sedimentation terminated. Two extensive depositional fans spread parallel to the basin elongation (glauconitic and Magura fan, Fig. 6). They were supported by clastic material. The sediments deposited by these fans reached thicknesses of up to 1000 m. The clastic material of the quartz glauconitic sandstones originated from the northern margin of the Magura Basin (Silesian Ridge). The paleocurrent directions of the two fans were parallel to the Magura Basin elongation (from the ENE), but the paleocurrent directions of the glauconitic sandstones in the area N-NW of the Babia hora Mt were perpendicular to the Magura Basin margin (Cieszkowski et al. 1999). This could be one of the glauconitic sandstones source inflow areas. This paleogeographical situation lasted from the Late Lutetian to the Late Eocene (possible longer).

The quartz glauconitic sandstones of sugar-like appearance are another type of the sandstones (Tefák in Mello et al.

2005). These sandstones have only 0.1–0.2 % glauconite. The sandstones are off-white, well mineral- and grain-sorted quartzite sandstones. Their parting surface has a grainy sugar-like appearance. The beds are 1 to 3 m thick. The sandstones are massive or with water escape structures in the lower part of the bed (Lowe's S_3 division). They have weak parallel lamination in the upper part of the bed (T_b Bouma's division). Besides the quartzite and glauconite the sandstones contain also feldspar and the abundant flakes of muscovite. Its earliest occurrence is in the Upper Luhačovice Beds in the southernmost Rača Unit. Later they formed thinner separated intercalations in the Babiše and Kýčera Beds. These sandstones did not form a well developed fan, but they formed just occasional lobes between the glauconitic and Magura fans. The source of the sedimentary material was the Silesian Ridge. This source supplied mature clastic material to the Magura Basin from the NE (Fig. 6).

Recycled orogen

The *Magura sandstone type* is represented in this area by the Kýčera Beds. This sandstone type also forms the Magura Formation of the muscovite facies, Piwniczna, Mniszek, Kowaniec and Poprad Members in Poland (Birkenmajer & Oszczytko 1989). Its sedimentation took place during the Early Eocene to Oligocene (see Potfaj et al 1991; Oszczytko-Clowes 2001; Oszczytko et al. 2005). The Magura sandstone type is represented by the lithic wacke sandstones. They are mostly fine- to medium-grained thick-bedded massive sandstones with T_a Bouma's division (or Lowe's S_3 division). The sandstones contain commonly disseminated coarse grains. Their beds are 40–250 cm thick. Unweathered sandstones are blue-grey. Weathered sandstones are rusty grey-brown and display typical water escape structures. The reduced $T_{(b)cd}$ Bouma's division are usually accompanied by frequent shale intraclasts, abundant muscovite and coalified plant detritus in the uppermost part of the layers. The petrological composition of the sandstones is found further from the cusp of Quartzite in the QFL diagram. Majority of points in petrographic analyses fall into the field of the recycled orogene source area or on its border (Fig. 4) (Dickinson & Suczek 1979). The immaturity of the sedimentary material and high amount of lithic clasts are the signs of the recycled orogen source. The orogen supplying clastic material of the Magura sandstone type situated probably to the South of the Magura Basin. The source entered into the basin approximately in the East Slovak part of the Magura Nappe. The erosion eroded the orogen prograding to the North into the basin. It is possible that the source was just the accretionary prism in front of the orogen (Inner Western Carpathians). The sediment supply entered the basin from the South and then turned westward. This fan was situated parallel to the basin elongation (Marschalko & Potfaj 1982; Potfaj et al. 1991). It was the largest fan in the Magura Basin with more than 250 km in length and 100 km in width. This could be interpreted following lithofacies and paleocurrent measurements (Stráňík 1965; Bromowicz 1992).

The paleocurrent systems of both glauconitic and Magura sandstone types in the Javorníky Mts are directed from the

NE to SW (Fig. 5). This system of two fans lasted after the sedimentation of the Beloveža and Luhačovice Formations during the Middle Eocene. The subduction along the southern margin of the Magura Basin progressed from the Middle Eocene. In its consequence the fan of the Magura sandstone type was pushed to the North in front of the orogen by the advancing fans. Along the southern margin of the basin the Racibor and Malcov Formations were deposited (Potfaj et al. 1991). These formations represent marginal facies with slumps, slides and other unusual facies. The progradation of the Magura sandstone type fan could effect migration of the glauconitic sandstone type fan to the North from the Bystrica and Lower Luhačovice Beds to the Vsetín Beds (Fig. 3). The Magura and glauconitic sandstone type deposition systems coexisted simultaneously side by side during the Middle to Late Eocene (Zlín Formation, compare Stráník 1965 from East Slovakia, Teták 2005b). Both fan systems interfingered each other. This can be demonstrated by the alternation of both types of sandstone in the middle of the Rača Zone (Čertovy kameny and Luhačovice Anticlinal Zones — Babiše Beds — Teták in Mello et al. 2005; Teták 2005b; Stráník 1965).

The relation of the Magura sandstone type to the glauconitic sandstone type is evident in the Babiše Beds of the Medvedie Anticlinal Zone (Rača Unit, Fig. 3), but the superposition of those interfingering fans is less known in the older formations. The Bystrica Beds are another formation where this relation was observed. The intercalations of the Magura sandstone type occur among the glauconitic sandstone type beds. This relation was observed on the contact of the Bystrica and Krynica (Oravská Magura) Unit south-eastward from the Nová Bystrica village in the Kysuce and Orava regions (Potfaj et al. 2003).

Discussion — fan models

Representative models of the deep-sea fans have been offered by Reading & Richards (1994). The western part of the Magura Basin is characterized by deep-sea fans with single point sandy and muddy-sandy sources sensu l.c. Reading & Richards (1994) characterized the *sandy source* fan type as follows — size of the fan: moderate; length: 10–100 km; shape: radial/lobate; the slope gradient: 2.5–36 m/km; source area (size and distance): moderate/small, close; feeding: by shelf failure or canyon; sand percentage: >70 %;

principal architectural elements: proximal area — channels; distal area: channelized lobes; channel system: braided to low sinuosity impersistent channels and chutes, rapid lateral migration.

They also characterized the *muddy-sandy source* fan type as follows — size of the fan: large-moderate; length: 10–450 km; shape: lobate; the slope gradient: 2.5–18 m/km; source area (size and distance): moderate; feeding: large delta and/or canyon; sand percentage: 30–70 %; principal architectural elements: channel levees; distal area: lobes; channel system: moderate scale, meandering to braided systems laterally migrating with levees.

The deep-sea fans of the Magura Basin can also be evaluated according to these criterions (Table 1). The Soláň sandstone type formed the depositional wedge along the Silesian Ridge margin. This wedge was probably formed by several overlapping small-sized fans.

The Riečky and Pasierbiec sandstone types deposited in the single-point sandy source deep-sea fan depositional system (sensu Reading & Richards 1994). The sources of these sandstone types were of sandy character. The supply of the mature material from the platform source and admixture of the shelf character material was typical for the Bystrica and Lower Luhačovice Beds.

The glauconitic and Magura depositional systems were different. In this case it is possible to admit one (or maybe several) point sources. The Magura sandstone type was deposited in a wide deep-sea fan from a sandy source. The sedimentary material supplied by these sources originated in the recycled orogen on the basis of the petrographic analyses. The material of the glauconitic sandstones was supplied by a muddy-sandy or sandy source with a platform character.

Conclusions

The results of the petrographic analyses of the sandstones from the Javorníky Mts area confirm the division of sandstones into four fundamental petrographic groups: the Soláň, Riečky, glauconitic and Magura groups. These groups represent four main source areas of the sedimentary material supplied into the western part of the Magura Basin during the Paleogene. The deposition lasted in the western part of the Magura Basin from the Late Cretaceous to Oligocene. It passed through several evolutionary stages: marginal wedge, longitudinal fans, north-eastern source and recycled orogen.

A massive, to-the-basin prograding wedge of the Soláň Formation was sedimented along the northern margin of the Magura Basin during the Late Cretaceous to Early Paleocene. Several sources supplied sedimentary material to the basin mainly perpendicularly from the Silesian Ridge to the South. This source formed several overlapping small-sized fans. The sedimentation of this sandstone wedge passes gradually from the proximal “wild-flysch” along the ba-

Table 1: Characteristics of the fans deposited in the western part of the Magura Basin.

fans	No. of sources	fan size	source character	source area
Soláň sandstones (Soláň Fm)	several	small	sandy	tecton. platform
“sugar-like” s. (Luhač./Zlín Fm)	1?	small	sandy	platform
Riečky s.– Upper Luhačovice B.	1	moderate	sandy	platform
Magura sandstones (Magura Fm)	1(>1?)	mod.-large	sandy	recycled orogen
Magura sandstones (Zlín Fm)	1(>1?)	mod.-large	sandy	recycled orogen
Pasierbiec sandst. + Bystrica B.	1(>1?)	large	muddy-sandy	platform + shelf
glauconitic sandst. (Zlín Fm)	1(>1?)	large	muddy-sandy	platform (shelf)

sin margin, through the massive sandstone wedge to the thin-bedded distal flysch sedimentation.

The central zone of the basin probably subsided more significantly from the later Early Paleocene. Therefore the clastic sedimentation shifted from the margin into the deeper part of the basin in the Rača Zone after the sedimentation of the Soláň sandstone type. The depositional fans of the Riečky and Pasierbiec sandstone type were formed there. The clastic material of the Riečky sandstone type was transported in the longitudinal direction from the West from the Middle Paleocene. The eastern part of the Silesian Ridge was uplifted during the Middle Eocene. This source supplied glauconitic sandstones to the basin from the NE and it initiated deposition of the proximal coarse-grained Pasierbiec sandstone type and pelitic distal facies. Sedimentation of the Riečky sandstone type was renewed once more during the Middle Eocene. This reappearance of the Riečky sandstone type sedimentation was only in a reduced volume.

The Magura Basin underwent significant paleogeographical changes during the late Middle Eocene (Lutetian). The period of the subsided and uplifted basin floor blocks was followed by rather flattened subsidence of the basin floor. The separation of the coarse-clastic fans against distal pelitic sedimentation terminated. Two extensive depositional fans developed parallel to the basin elongation — glauconitic and Magura sandstone type fans. These fans prograded from the South into the Rača sedimentation area. Their current systems were directed from the NE to SW in the Javorníky Mts. Both fan systems interfingered each other. The clastic material of the glauconitic sandstones originated from the platform-type Silesian Ridge. The material of the Magura sandstone type probably originated from the South. It was the recycled material from the front of the prograding orogen.

Uplift of the Silesian source area advanced from the W to the E. Its result was the shifting of the source of the sedimentary material in the same direction. The maturity of the sediments gradually increased in the same way. Accumulation of the clastic sediments was controlled mainly by subsidence of the basin floor, by the local sediment supply and by the progress of the subduction of the southern Magura Basin margin. The distribution and shape of the deep-sea depositional systems was significantly influenced by basin topography. For example, the northern, rather sharp boundary of the Luhačovice Formation represents the synsedimentary (tectonic) subsidence boundary. This boundary inhibited the Pasierbiec and Riečky sandstone types to over-flow to the North over the uplifted Upper Beloveža Beds. The Magura Basin floor was segmented probably by abundant longitudinal synsedimentary depressions and lifted plains. This held sedimentation of the fans in a longitudinal direction. The shapes of the fans were also influenced by the depositional pressure of the adjacent fan as in the case of the contact of the Magura and glauconitic fans.

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