Palaeogeography, Palaeoclimatology, Palaeoecology 533 (2019) 109250

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

Depositional systems and paleogeography of Upper Cretaceous-Paleogene deep-sea flysch deposits of the Magura Basin (Western Carpathians)

František Teťák[a,*], Daniel Pivko[b], Martin Kováčik[a,1]

[a] State Geological Institute of Dionýz Štúr, Mlynská dolina 1, 817 04 Bratislava, Slovakia
[b] Faculty of Natural Sciences, Comenius University, Ilkovičova 6, 814 15 Bratislava, Slovakia

ARTICLE INFO

Keywords:
Paleooceanography
Paleocurrents
Gravity flow deposits
Lithofacies
Source areas

ABSTRACT

The Outer Western Carpathians are part of the Alpine-Himalayan orogenic belt, and they are formed mostly by the Upper Cretaceous and Paleogene deep-sea “flysch” sequences. Orava region (northern Slovakia), situated in the central part of the Magura Nappe, has an important position for the solution of the geological structure and development of the Magura Nappe. At the beginning of the research, determination of the sedimentary sequences of the Magura Nappe and the fundamental lithotypes and lithofacies was required. A total of 1164 paleocurrent measurements were measured and assigned to lithotypes and lithostratigraphic units obtained during the detailed sedimentological study. The main purpose of the research was the interpretation of the filling history and tectonic activity of the Magura Basin. The results of the detailed sedimentological study were integrated with published data from surrounding regions. Presented palinspastic maps propose a reconstruction of the filling history and tectonic activity in chronological order during the Upper Cretaceous to Oligocene. Maps focus in detail on the western part of the Magura Basin, but they display its surroundings as well. The sedimentary record reflects the activity and gradual shifting of the Western Carpathian accretionary wedge to the north, the uplift of source areas, and the changes in the sea level of the Magura Basin. The paleocurrent analyses joined with the sedimentological and petrographic research allowed to reconstruct the paleogeographic properties of the northern sources of detritic material (Hostýn, Fore-Magura and Silesian Ridges), of the southern source of the material (Western Carpathians accretionary wedge) and of intrabasinal sources as well (Szczawina and Southern-Magura Ridges). We propose a discussion about the character of filling history, defining and position of the source areas and about Hostýn Ridge defined here.

1. Introduction

In recent years, detailed sedimentological study has been carried out in the central part of the Magura Nappe in the Orava region (northern Slovakia) that was part of geological mapping (Fig. 1). This region has historically an important position in solving of the geological structure of the Western Carpathians because of suitable outcrops, wide age range and a large amount of lithofacies and lithotypes. The topic of the article focuses not only on this region, but it has combined new observations with older published data from the broader central and western part of the Magura Nappe.

The partial purpose of the article is to determine the fundamental lithofacies and lithotypes. A definition of the Magura Nappe stratigraphic sequence was based on this. Lithofacies processing is more suitable for paleogeographic reconstruction than lithostratigraphic processing. The reason is that the lithostratigraphic units are typically composed of several lithofacies from different sources. In contrast, the lithofacies or lithotypes are defined by typical petrography, lithology and sedimentation environment, and especially they were derived from a single source. The characteristic features of lithofacies and lithotypes are summarized in the Table 1. Facies analysis allows the reconstruction of the depositional environments and their evolution through time. Consequently, the palinspastic maps were proposed in chronological order and separately for each lithofacies and lithotype with the intention to construct paleogeographic evolution of the wider area of the Magura Basin.

The main purpose was the interpretation of the filling history of the Magura Basin. For this purpose, palinspastic maps connect the results of new detail sedimentological research with the results of previous works from the surrounding regions. Extensive earlier geological research was

* Corresponding author.
E-mail addresses: frantisek.tetak@geology.sk (F. Teťák), daniel.pivko@uniba.sk (D. Pivko).
[1] Deceased.

https://doi.org/10.1016/j.palaeo.2019.109250
Received 9 January 2019; Received in revised form 23 June 2019; Accepted 25 June 2019
Available online 28 June 2019

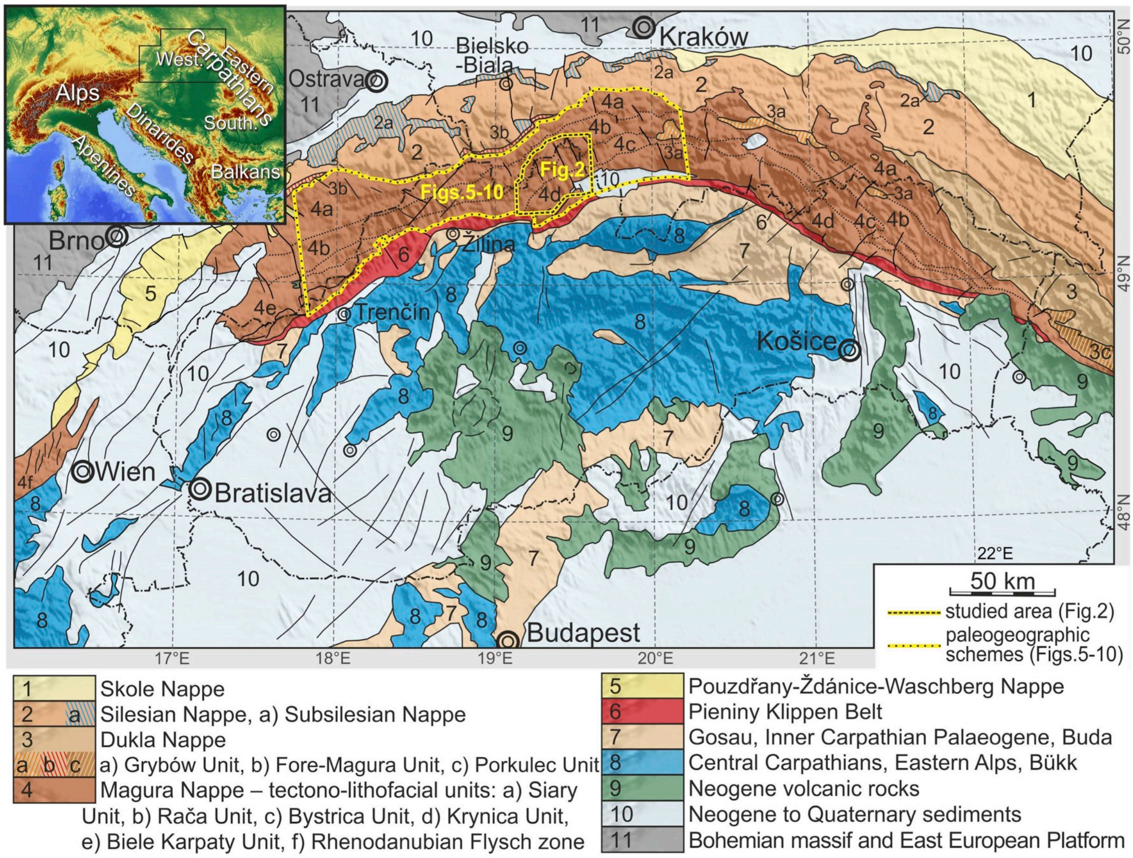

Fig. 1. Schematic geological map of the Western Carpathians and adjacent areas with location of Orava region and studied area (based on Lexa et al., 2000).

mostly focused on oil prospection and field geological mapping. The papers from Sikora and Żytko (1959); Książkiewicz (1962, 1966, 1977); Pesl (1968); Potfaj and Marschalko (1981); Marschalko and Potfaj (1982); Potfaj et al. (1991); Ryłko (1992); Bromowicz (1992); Oszczypko et al. (2005a, b); Teťák et al. (2016); Laurinc and Teťák (2017) and many other resources are significant to solve the development of deposition in the central and western part of the Magura Basin. Marschalko and Potfaj (1982), Pivko (2000, 2002) and Teťák (2008, 2010) dealt in detail with the paleogeography of the "flysch" deposits in the Orava region. From the junction of new and old information we expected the widening of knowledge especially with regard to the paleogeography of the central and western part of the Magura Basin.

2. Geological background

The Western Carpathians are situated at the center of hundreds of kilometers long undulated mountain range including the Alps, Balkans, Dinarides and other mountain ranges as part of the Alpine-Himalayan orogenic belt (Fig. 1). Regionally the Western Carpathians can be divided into the Central Western Carpathians and the Outer Western Carpathians. Reconstruction of the geological evolution of the Outer Western Carpathians (synonym "Western Carpathian flysch belt") is difficult because the basins fill was intensively folded and thrusted. Moreover the area is significantly covered with vegetation. The outcrops are rare and just of smaller size. The Outer Western Carpathians are mostly formed by deep-sea "flysch" deposits. The term "flysch" was introduced in geologic literature in Switzerland by Studer (1827a, b) for the typically alternating sandstones and shales. The Outer Western Carpathians deposits are mostly of the Upper Cretaceous and Paleogene age. Their sedimentary sequences contain an extensive record of paleogeography of several basins and ridges (Fig. 2).

The Magura Nappe is the largest tectonic unit of the Outer Western Carpathians. Together with the Biele Karpaty Unit, which, however, occurs only in the west, outside the investigated area and has a special status, the Magura Nappe forms tectonically the highest part of the "flysch" belt. The stratigraphic extent of exposed deposits is from the uppermost Jurassic to early Miocene (Lexa et al., 2000; Oszczypko et al., 2015; Cieszkowski, 1992; Kaczmarek et al., 2016). The time, when the Magura Basin started to open, has not yet been reliably confirmed, because the nappe has completely detached from its substratum along the ductile Upper Cretaceous to Paleocene clayey formations. Rudimentary preserved Upper Jurassic lithostratigraphic units in Magura Nappe in Morava region (Hrouda et al., 2009; Picha et al., 2006) and Upper (Middle?) Jurassic lithostratigraphic units in Šariš (Grajcarek) Unit in Poland (Golonka et al., 2013; Oszczypko et al., 2015 and references therein) suggest at least the Upper Jurassic opening of the Magura Basin. The "flysch" sequences deposited mainly in the deep-sea character environment and partly on the slope and shelf by gravity flows and by pelagic sedimentation during the following periods (Fig. 3).

Five tectono-lithofacies units of the Magura Nappe are present in the studied area – Biele Karpaty, Krynica (former Oravská Magura), Bystrica, Rača Units and the northern part of the Rača Unit was designated in Poland by Koszarski et al. (1974) as a Siary Unit (Fig. 1). The first and last mentioned unit does not reach the Orava region, however. The units form a fold and thrust system of the Magura Nappe. The nappe was thrusted over the Silesian Nappe and together with other more external units of the Outer Western Carpathians they were thrusted over the inclined ramp of the Northern European Platform. Moreover, the Krynica Unit was as well backthrusted to the south over the Pieniny Klippen Belt (Pešková et al., 2012). Thus, the Outer Western Carpathians form a huge wedge-like body with large nappes folded-slices (present-day cross-sections were interpreted e.g. by Nemčok et al., 2000; Ślączka et al., 2006; Picha et al., 2006; Gągała et al., 2012).

Table 1
Characteristics of fundamental lithofacies and lithotypes found in the Orava region. See Fig. 4 for their chronological and spatial relationships.

Lithofacies lithotypes	Bed thichness	Grain size	Petrography	Lithostratigraphic equivalents
Malcov facies	Medium to thick-bedded	Fine (medium) grained sandstones	Calcareous and greywacke sandstones, mud slumps	Malcov Fm. (Świdziński, 1961)
Magura type sandstone	Thick to very thick-bedded	Medium to coarse-grained sandstones	Greywacke sandstones	Magura s s t (Potfaj et al., 1991), Kýčera s s t (Pesl, 1968), Babia hora s s t (Matějka and Roth, 1952)
Glauconitic sandstones and marls	Thick to very thick-bedded	Coarse grained sst, fine-grained conglomerates	Quartz glauconitic sandstones and conglomerates	Pasierbiec sst (Bieda, 1946)
	Medium to very thick-bedded	Fine (medium) grained sandstones	Quartz glauconitic sst, Bystrica type muds tones, Łącko type marls	Os ielec s s t (Książkiewicz, 1958)
	Medium to thick-bedded	Fine-grained sandstones, marls	Bys trica type muds tone, Łącko marls, quartz glauconitic sst	Bys trica type muds tones (Pesl, 1968), Łącko marls (Książkiewicz, 1958)
Thin-bedded (Beloveža and Ropianka) facies	Thin-bedded	Very fine-grained sandstones	Laminated sst with bioglyphs, non-calcareous mudstones	Beloveža Fm. (Leško and Samuel, 1968)
			(Green) laminated sst with bioglyphs, non-calcareous mudstones	Ropianka Fm. (Oszczypko, 1992)
Szczawina type sandstone	Mudstones/thin-bedded	Mudstones, (very fine-grained sandstones)	Red and green mudstones	Łabowa Fm. (Oszczypko, 1992), Ropianka Fm. (Oszczypko, 1992)
	Thick to very thick-bedded	Medium to coarse-grained sandstones greywacke muscovite sandstones	Mus covite s s t (Książkiewicz, 1966)	

The aforementioned tectono-sedimentary units of the Magura Nappe are composed of many lithostratigraphic units. The units are assembled from lithofacies and lithotypes clearly expressed in Tables 1 and 2. Their relationships in the central part of the Magura Nappe are graphically displayed in Fig. 4. The most recent knowledge about the geology of the Orava region was summarized by Tet'ák et al. (2016a, b)).

Original flysch basins were bordered by continental crust ridges which delivered a clastic material to the basins. Ridges in Carpathian Flysch Belt, formerly named "cordilleras", were firstly defined by Książkiewicz (1962, 1965). The existence of following ridges was important for development of the Magura Basin: the Hostýn Ridge (defined in this paper), Fore-Magura Ridge (Golonka et al., 2005), Grzybów Ridge (Cieszkowski, 2002), Bukowiec Ridge (Ślączka, 2005), Southern-Magura Ridge (Marschalko et al., 1976), and Neopieninic Exotic Ridge (Mišík et al., 1991b).

3. Methods

The Magura Nappe is formed mainly by sequences deposited in the deep-sea environment by gravity flows or pelagic sedimentation. The first step in the study of sedimentary basins is recognition of stratigraphy and definition of lithostratigraphic units and their spatial and chronological development. It is necessary to define basic building units for the characterization of the lithostratigraphic units. The basic building units of sedimentary sequences are lithotypes and lithofacies (Tables 1 and 2; Fig. 3). Under the term lithotype we understand rocks that originated during one event (usually single layer) and under the same conditions. The "same conditions" has been understood in this article in the deep-sea gravity flows environment, with the same source of the material (source area), transport (gravity flow, slump) and process of deposition (pelagic environment, a specific part of the depositional fan, slope, etc.). Lithofacies is composed of single lithotype or of a combination of several lithotypes which are mutually alternating. An important feature of deposits of one lithofacies is that it deposited in the same environment. Lithofacies in this article are understood differently than the lithofacies were characterized for the general description of the deep-water depositional environment, for example, by Pickering et al. (1986) and Mutti and Rocci-Lucchi (1972). The defined lithofacies are specific for the Magura Nappe.

Paleocurrent measurements and field sedimentological analysis are necessary before interpretation of the paleogeographic development of any basin. The paleocurrent directions are usually measured from the sole marks such as flute casts, load casts, groove casts and prod casts found on the basal erosive surface of sandstone layers. These sole marks are the casts of seabed affected by gravity currents erosion. Rarely, the paleocurrent direction was determined from the orientation of the oblique lamination in a layer. The bed planes are mostly tilted or even overturned in the Magura Nappe outcrops. Standard stereonet techniques based on projection of the lineation into the projection hemisphere were used to retilt the oriented lineations in to the horizontal position (e.g. Fossen, 2010). Due to a large number of measurements, new numerical methodology proposed by Tet'ák (2018) was mostly used to measure and retilt lineations. Each lithostratigraphic unit has different areal and age extent. At the same time, some units are more or less suitable for the development and preservation of outcrops and sole marks. Therefore, the number of measurements in the individual units varied considerably. Aforementioned research has been carried out within two separate surveys in the Orava region. D. Pivko measured 336 paleocurrent measurements during the geological mapping in the Pilsko Mt. surroundings in the years 1989 to 1992 (Pivko et al., 1991). Later, F. Tet'ák measured 611 measurements and M. Kováčik measured 217 measurements within the geological mapping and research of Orava region in the years 2011 to 2015 (Tet'ák et al., 2016a, b). Generally were processed 1164 paleocurrent measurements (see the Table in Supplementary data). Measured paleocurrent directions are

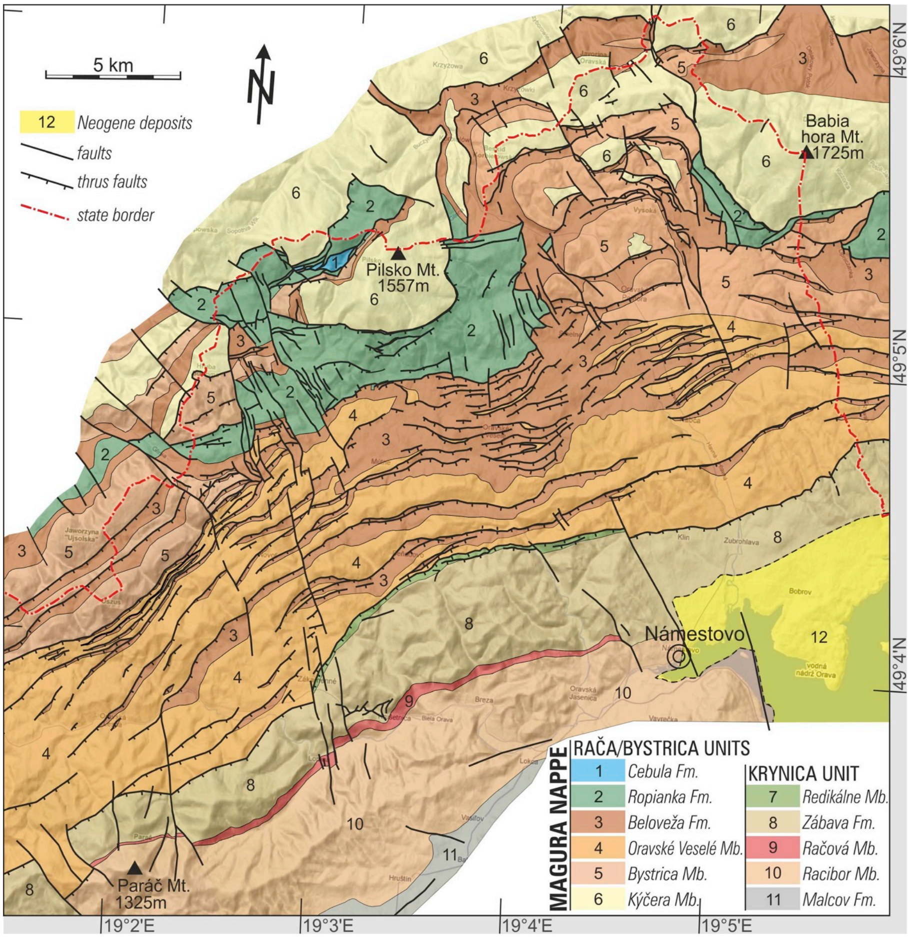

Fig. 2. Simplified geological map of the studied area – Orava region, with an overlap into Poland (based on Teťák et al. 2016; Ryłko, 1992; Sikora and Żytko, 1959; Książkiewicz, 1966).

displayed according to the lithostratigraphic and lithotype attributes in the lithostratigraphic table as paleocurrent rose diagrams with a resolution of 5° (Fig. 4).

Acquired paleocurrent results were combined with older paleocurrent research from Orava region (Potfaj and Marschalko, 1981) and from neighboring Kysuce region and Javorníky Mts. (Teťák, 2008), Morava region (Eliáš, 1963) and Polish part of Magura Nappe (Sikora and Żytko, 1959; Książkiewicz, 1958, 1962, 1966; Bromowicz, 1992; Ryłko, 1992; Cieszkowski and Waśkowska-Oliwa, 2001; Oszczypko, 2006; Oszczypko and Salata, 2005; Cieszkowski et al., 1999, 2007) and with present research (Wójcik et al., 2018; Bónová et al., 2016, 2017, 2018, 2019; Figs. 5–10).

Paleogeographic schemes (Figs. 5–10) display the aforementioned paleocurrent measurements from the middle and western part of Magura Nappe. Paleocurrent measurements are presented in paleogeographic schemes in present orientation without taking into account of Miocene CCW rotation. The thrust sheets of the Magura Nappe were palinspastically undeformed within the construction of paleogeographic schemes only in part. The schemes are not displayed in scale; therefore they are not palinspastic maps.

The changes in the depth of the basin and the speed and amount of the supplied detritic material must be taken into account during the reconstruction of the paleogeographic evolution of ancient areas. The paleobathymetry of the Magura Basin, as well as surrounding basins was estimated by Poprawa et al. (2002) on basis of many studies on ichnofauna, microfauna and CCD estimate (e.g. Książkiewicz, 1975). Poprawa et al. (2006) determined the rate of sedimentation based on the thickness and age of the lithostratigraphic units. Authors also took into account the compaction of deposits due to the pressure of the overburden complexes.

In the case of the Carpathians, it is very important to rotate the entire Western Carpathians, including the Magura realm, to the original position. Paleomagnetic measurements demonstrate general 50° to 60° CCW rotation of the Outer Western Carpathians along with the Central Western Carpathians within the Miocene (Krs et al., 1991; Panaiotu, 1998; Márton et al., 2015). Mentioned rotations in palinspastic maps were took into account (Figs. 12–19).

The palinspastic reconstruction of depositional systems is displayed on Figs. 12–19. Paleogeographic results from Orava region (Fig. 5) are shown in the wider context in order to obtain a better image of the deposition systems. The proposed palinspastic reconstruction accepted the existing framework and basins arrangement in the Upper Cretaceous to Oligocene elaborated by Kováč et al. (2016). Palinspastic schemes designed by Kázmér et al. (2003) were used to modify the area of the Eastern Alps and Western Carpathians. But the Magura Basin and its surroundings were much more complex. Therefore it was necessary to add four additional schemes for a period of the Santonian – Campanian, Maastrichtian – early Paleocene, early – middle Eocene and Bartonian. Proposed model differs significantly from previously presented paleogeographic models (e.g. Oszczypko and Salata, 2005; Golonka, 2011). Especially heavy minerals and petrographic analysis, in addition to facial and paleocurrent analyses, should be the key to solve the paleogeographic development of the Magura Basin (e.g. Laurinc and Teťák (2017); Bónová, 2018; Bónová et al., 2018).

4. Results

The Szczawina type sandstone, thin-bedded (Ropianka and Beloveža) facies, glauconitic and Magura type sandstones are the fundamental lithofacies and lithotypes distinguished in the Orava region in

(caption on next page)

Fig. 3. Examples of some basic lithofacies from the Orava region: A – Ropianka Fm. – thin-bedded facies, “flysch” sediments with red and green mudstones (Bystrý potok creek SW from Pilsko Mt.), B – Upper Beloveža Mb. – thin-bedded facies – up to 20 layers per meter (Oravské Veselé village), C – Zábava Fm. – load casts on the bottom of Magura type sandstone layer and horizon of the claystone intraclasts (quarry north of Breza village), D – Zábava Fm. – Magura type sandstone and thin-bedded facies (quarry north of Breza village), E – Bystrica Mb. – glauconitic sandstones and Bystrica type mudstones, thick light layers on the top right are Łącko type marls (quarry NW of Novoť village), F – Újezd Mb. – from the left are glauconitic sandstones, thin-bedded facies and Bystrica type mudstones (Jalovec creek), G – Racibor Fm. –layers of Magura type sandstone and mud slumps (Veselianka creek in Oravská Jasenica village), H – Malcov Fm. – grey mudstones calcareous sandstones and mud slumps (Hruštínka creek SE from Hruštín village). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the central and western part of the Magura Basin (Tables 1 and 2). It is preferable to describe lithofacies and lithotypes instead of lithostratigraphic units for the paleogeographic characteristic. The paleocurrent measurements were sorted according to the classification of sandstones to lithotypes and lithofacies (Fig. 5).

Cebula Fm. provided 18 paleocurrent measurements. These measurements have a significant spread to the west, southwest, and southeast. Despite the fact that measured sandstone layers differ petrographically from other selected lithotypes, but a new lithotype was not yet defined for their heterogeneity, small area of occurrence and the low number of outcrops and measurements. Aforementioned variety of lithotypes and sources may result in the dispersion of the measurements in the Cebula Fm. The oldest larger deposition fan was made of Szczawina type sandstone, which is a specific lithotype separated from the Ropianka Fm. Dispersion of 90 paleocurrent measurements of the Szczawina type sandstone is significant (Fig. 5).

Thin-bedded “flysch” facies is the most widespread deposit in the Magura Basin. Thin-bedded deposits can be divided according to the character of sandstones and claystones into two facies. Both facies have constantly stable paleocurrent nature. Green laminated sandstones of the Ropianka facies were deposited during the Upper Cretaceous and Paleocene (41 paleocurrent measurements). The paleocurrent directions of the Ropianka facies are significantly dispersed like in the Szczawina type sandstone (Fig. 5). Brownish and grey laminated sandstones of the Beloveža facies were deposited during the Eocene. This lithofacies occurs not only in the Beloveža Fm., but it is common as well in the Redikálne, Zábava, Racibor, Újezd Mbs. and Vychylovka Fms. (together 342 measurements; Fig. 5). The directions to SW significantly prevail in the Beloveža facies (Figs. 6 and 7). The paleocurrent directions to SE and S are common as well.

The glauconitic sandstones occurred in a smaller amount already in the “Senonian” and lower Paleocene sequences, but the glauconite in sandstones was abundant in the Magura Basin especially in the middle Eocene. Glauconitic sandstones formed then an extensive depositional fan in the central northern part of the basin. The glauconitic sandstones are conventionally divided according to their grain size into three partial lithofacies (Table 2). Glauconitic sandstones are the part of several lithostratigraphic units. Together 96 measured paleocurrent directions are significantly dispersed to NW, SW, and SE with general direction to the SW in Orava region (Fig. 4). Depositional fan of glauconitic sandstones gradually shifted to the northern margin of the basin at the end of middle Eocene (Figs. 8–10).

The Magura type sandstone deposited in several lithostratigraphic units. The deposition of the Magura type sandstone in a single large fan resulted in a clear orientation of the paleocurrents to the SW (555 measurements; Fig. 4). Sandstones formed large volumes in the Krynica Unit throughout the Eocene. The Magura type sandstone occurred in the Bystrica Unit only during the middle Eocene (Oravské Veselé Mb.), but in the larger amount it occurred externally in the Rača Unit (Kýčera Mb.) during the late Eocene (Figs. 7–10).

Paleocurrent directions of the Malcov facies (sandstones and slumps) reflected the dynamics of the environment in which they originated (22 measurements). The paleocurrent measurements are significantly dispersed. There is a slight predominance of the direction to SW, but there are also directions to the NW and N. The fusion of measurements from different lithotypes may affect the dispersion of the paleocurrent directions as well.

5. Discussion

5.1. Source areas

Sedimentary fill of Magura Basin was preserved only as the root-less nappes. The original basement of the basin as well as the source areas do not protrude on the current surface. The geological structure of the source areas can be interpreted only from the detritic material, pebbles and rare olistolithes. Paleocurrent directions and the increasing proximity of clastic facies focus the localization of the source areas.

Three types of the source areas can be distinguished in the Magura Basin – the northern sources (passive margin), the intrabasinal sources (thrust belts) and the southern source (active accretionary wedge). The northern sources are the Hostýn, Fore-Magura and Silesian Ridges as the sources of the Soláň, Mutne, Skawce, Riečky, Pasierbiec, Bystrica, Vsetín, in part Ropianka, and other lithostratigraphic units. The southern source is represented by the prograding Western Carpathian accretionary wedge (Western Carpathian thrust belt or Neopieninic Exotic Ridge). The wedge gradually consumed the Magura Basin from the south. This source supplied the basin with particularly quartz-carbonate sand for e.g. the Jarmuta, Proč, Javorina, Svodnica and Chabová Fms. Intrabasinal sources (Szczawina and Southern-Magura Ridges) supplied the detritic material to the Szczawina, Piwniczna, Zábava, Kýčera, Poprad, in part Ropianka and other lithostratigraphic units.

5.1.1. Northern sources

The northern source has been traditionally called as Silesian Ridge (Książkiewicz, 1962; Eliáš, 1963). The existence of other sources, e.g. Fore-Magura Ridge (Golonka et al., 2005; Cieszkowski et al., 2012), Grzybów Ridge (Cieszkowski, 2002) and Bukowiec Ridge (Ślączka, 2005), was considered later. A new ridge – Hostýn Ridge is proposed as a separate western continuation of the Fore-Magura Ridge.

The *Silesian Ridge* was composed of mostly Variscan metamorphic and igneous rocks according to pebbles and heavy minerals. The ridge was built of phyllites, schists, gneisses, granulites and quartzites, felsic igneous rocks and sedimentary rocks, mainly limestones (Oszczypko and Salata, 2005 and references therein). The Silesian Ridge supplied clasts with the late Carboniferous (Pennsylvanian) to Permian metamorphism (Poprawa et al., 2004, 2006). The Silesian Ridge was a fragment of the Bohemian Massif (Moravian Variscides/Moldanubicum/Brunovistulia), with similar geological structure (Oszczypko et al., 2015; Gavęda et al., 2019 and references therein).

The clastic material of the Soláň Fm. (Eliáš, 1963; Teťák, 2008), Altlengbach Fm. (Faupl, 1996) and Riečky type sandstone (Teťák, 2008) was supplied from the northwestern margin of the Magura Basin. The character of the source area was similar to the Silesian Ridge (Faupl, 1996; Hanžl et al., 2000; Poprawa et al., 2004). It was necessary to define a new separate ridge – *Hostýn Ridge*. This name was chosen upon the marginal Hostýn lithofacial zone and Hostýn Mts., for which the Soláň type sandstone, derived from this ridge, are typical. Soláň type sandstone forms more than 1000 m thick complex (Pesl, 1968). The Hostýn ridge can be compared rather with Fore-Magura Ridge and regarded as its continuation to the west. Ridge was active mostly at the end of the “Senonian” to Paleocene, and in short events also during the

Table 2
Characteristics of the lithostratigraphic units distinguished in the Orava region.

Tectono-lithofacial unit	Lithostratigraphic unit		Age	Unit thickness	Lithofacies and their arrangement	Correlation (equivalents)
Siary/Rača Unit	Zlín Fm.	Vsetín Mb. (Pesl, 1968)	Middle to late Eocene (Oligocene)	Over 600 m	Glauconitic sandstones, Bystrica type mudstones	Magura Fm. - glauconite facies (Książkiewicz, 1953), Zembrzyce Mb. (Książkiewicz, 1974)
Rača Unit		Babiše Mb. (Teťák, 2005)	(Middle?) to late Eocene (Oligocene)	700 m	Magura type sandstone and glauconitic sandstones, (Bystrica type mudstones)	Kýčera Mb., partially Maszkowice Mb. (Oszczypko, 1991)
Rača/Bystrica Unit		Kýčera Mb. (Pesl, 1968)	(Middle?) to late Eocene (Oligocene)	1600 m/up to 400 m	Magura type sandstone	Kýčera development of Zlín Fm. (Pesl, 1964), Magura sst (Roth et al., 1963), Babia hora sst (Matějka and Roth, 1952), Wątkowa sst (Cieszkowski et al., 2006), arkose and muscovite facies of Magura sst (Książkiewicz, 1953), Makovica Mb. (Leško and Samuel, 1968)
		Újezd Mb. (Pesl, 1968)	Middle to late Eocene	30 to 150 m	Thin-bedded facies, glauconitic sandstone, Bystrica type mudstones	Sub-Magura Mb. (Paul, 1980), Hieroglyphic Mb. (Cieszkowski et al., 2006), Lower Zlín Mb. (Matějka and Roth, 1956), Oščadnica Mb. (Potfaj, 2003)
		Bystrica Mb. (Sikora and Żytko, 1959)	middle to late Eocene	200 to 500 m/up to 1000 m	Glauconitic sandstone, Łącko type marls	Osielec sst (Książkiewicz, 1958), Pasierbiec sst (Bieda, 1946), Łącko Mb. (Książkiewicz, 1958), Żeleznikowa Fm. (Oszczypko, 1991), Vsetín Mb. (Pesl, 1968)
Bystrica Unit		Oravské Veselé Mb. (Teťák et al. 2016)	Middle to late Eocene	300 to 500 m	Magura type sandstone and glauconitic sandstones	Bystrica Mb. (Pesl, 1968), Poprad Mb. (Birkenmajer and Oszczypko, 1989)
	Vychylovka Fm. (Potfaj, 1989)		Middle Eocene	Few 10 m	Glauconitic sandstones, thin-bedded facies and Bystrica type mudstones	Hieroglyphic Mb. (Cieszkowski et al., 2006), Beloveža Fm. (Leško and Samuel, 1968), Bystrica Mb. (Pesl, 1968), Łącko Mb. (Książkiewicz, 1958)
Rača/Bystrica Unit	Beloveža Fm.	Upper Beloveža Mb. (Stráník, 1965)	Early to middle Eocene	70 to 200 m	Thin-bedded facies	Hieroglyphic Mb. (Cieszkowski et al., 2006), Beloveža Fm. (Leško and Samuel, 1968)
		Lower Beloveža Mb. (Stráník, 1965)	Paleocene to early Eocene	Up to 150 m	Thin-bedded facies and variegated mudstones	Łabowa shale Fm. (Oszczypko, 1992)
	Ropianka Fm.	Ropianka Fm. (Teťák et al., 2017)	Maastrichtian to Paleocene	Up to 400 m	Thin-bedded facies, variegated mudstones	Inoceramian Mb. (Książkiewicz, 1966), Soláň Fm. (Pesl, 1968), biotite-feldspar Mb. (Sikora and Żytko, 1959), Mutne sst (Cieszkowski et al., 2007), Ráztoka Mb. (Pesl, 1981), Ondrášovec Mb. (Potfaj, 1993), Altlengbach Fm. (Schnabel, 1992), Szczawnica Fm. (Birkenmajer and Oszczypko, 1989)
		Szczawina Mb. (Sikora and Żytko, 1959)	Maastrichtian to Paleocene	150 to 800 m	Szczawina type sandstone	Muscovitic sst of Inoceramian Mb. (Książkiewicz, 1966), Altlengbach Fm. (Schnabel, 1992)
Rača Unit	Cebula Fm. (Sikora and Żytko, 1959)		Cenomanian to Campanian	cca 200 m	Calcareous and non-calcareous red claystones and marls, thin-bedded facies, bedded green grey marls with patina	Variegated sh. (Sikora and Żytko, 1959), Cebula variegated marls (Golonka and Malata, 1977), Haluszowa Fm. (Birkenmajer and Oszczypko, 1989), Malinowa Fm. (Birkenmajer and Oszczypko, 1989), Kaumberg Fm. (Schnabel, 1992)
Krynica Unit	Malcov Fm. (Świdziński, 1961)		Late Eocene to late Oligocene (early Miocene?)	Up to 660 m	Malcov facies (sandstones, slump bodies, variegated mudstones)	Menilite-Krosno series (Jucha and Kotlarczyk, 1958)
	Racibor Fm.	Racibor Fm. (Potfaj et al., 1991)	Middle Eocene to early Oligocene	1500 m	Magura type sst, thin-bedded facies, Bystrica type mudstones, (slump bodies, glauconitic sst)	Magura Fm. (Potfaj et al., 1991), Poprad Mb. (Birkenmajer and Oszczypko, 1989)
		Račová Mb. (Potfaj et al., 1991)	Middle Eocene	100 to 200 m	Bystrica type mudstones (Magura type sandstone, Łącko type marls and variegated mudstones)	Kowaniec Mb. (Cieszkowski, 1979), Mniszek Shale Mb. (Birkenmajer and Oszczypko, 1989), Hanuszów sh. (Wójcik et al., 1995, Piotrowski and Piotrowska, 2004)
	Zábava Fm.	Zábava Fm. (Potfaj et al., 1991)	Late Paleocene to middle Eocene	Up to 3000 m	Thin-bedded facies and Magura type sandstone	Magura Fm. (Potfaj et al., 1991), Piwniczna Mb. (Birkenmajer and Oszczypko, 1989), Turbacz beds (Watycha, 1976; Cieszkowski and Olszewska, 1986), Zarzecze Fm. (Birkenmajer and Oszczypko, 1989), Jaszcze beds (Alexandrowicz et al., 1984, Cieszkowski and Olszewska, 1986), Krynica congl. (Alexandrowicz et al., 1984)
		Redikálne Mb. (Teťák et al. 2016)	Paleocene(?)	Up to 150 m	Thin-bedded facies and variegated mudstones	Variegated sh. (Jankowski and Kopciowski, 1999)

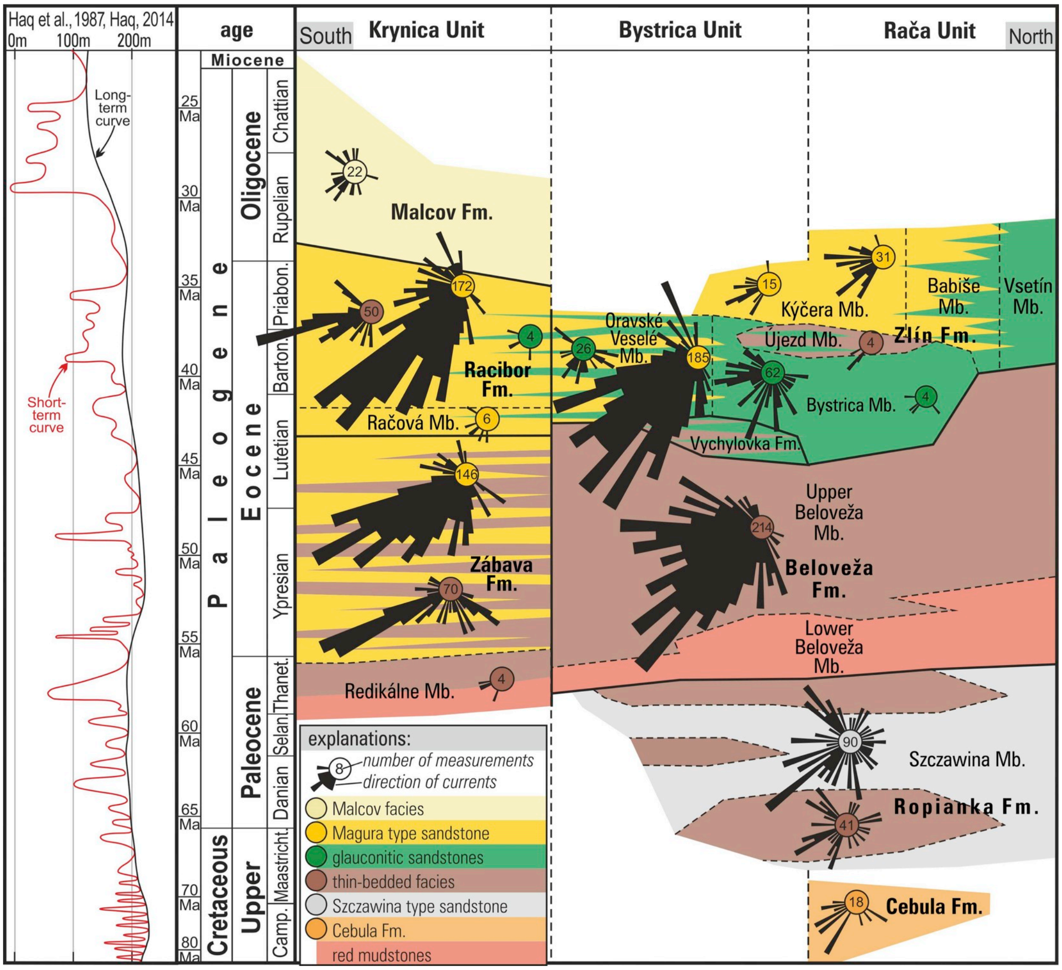

Fig. 4. Paleocurrent measurements of gravity currents directions of the Magura Nappe from the Orava region sorted according to lithofacies affiliation (lithostratigraphic scheme modified after Teťák et al. 2016) along with long- and short-terms global sea-level curve of Haq et al. (1987) and Haq (2014).

middle and late Eocene (Faupl, 1996; Eliáš, 1963). The Hostýn Ridge, as a Moravian equivalent of Silesian Ridge, is "crystalline ribbon continent" (Soták, 1990). According to granite clasts character it is Variscan age (Hanžl et al., 2000).

The *Fore-Magura Ridge* was not separately studied with respect to its rock composition and age, as it was usually confused with the Silesian Ridge. The Fore-Magura Ridge was located south of the Silesian Ridge. Their similar basement could be supposed (Cieszkowski, 2002; Cieszkowski et al., 2007). This postulate is indirectly affirmed by the studies which deal with the northern source of the Magura Basin. Oszczypko et al. (2015) mentioned a Variscan age of the plutonic and metamorphic rocks derived from the Silesian Ridge to the Magura Basin, ignoring the existence of the Fore-Magura Ridge. Based on the U-Pb zircon age of mafic exotics, Gawęda et al. (2019) presume, that unlike Brunovistulia character of the Silesian Ridge, the source of Magura Basin was the Fore-Magura Ridge, whose basement potentially represents an ancient accretionary prism on the margin of Eastern European Craton.

The Fore-Magura Ridge was the source area for the glauconitic sandstones of Bystrica Mb. The ratio of monocrystalline to polycrystalline quartz in glauconitic sandstones is high (56.7%/8.8%). Lithic fragments form only 2.9%; sedimentary lithic fragments form 2.2%. Microsparitic and micritic carbonates prevail. Mica schist and phyllites are common, but the gneisses are rare. Felzic volcanic fragments are common, but basic volcanites are rare. The glauconite content is on average 7.5%. In many samples, the content of large foraminifera is increased (Laurinc in Teťák et al., 2016c; Laurinc and Teťák, 2017). The composition of the glauconitic sandstones indicates passive character of the ridge with features of the inner craton and only in part also of the recycled orogen (Fig. 11).

Hostýn, Silesian and Fore-Magura Ridges contain, except Variscan crust similar to the Bohemian Massif, incorporated element of Cadomian (Pan-African) crust similar to Brunovistulian, Malopolska and Dobrogea terranes and Moesia platform (Soták, 1992; Winchester et al., 2002; Budzyń et al., 2011). Based on heavy minerals analysis Bónová (2018) assumes a different structure of source area for sandstones of Mrázovce and Makovica Mbs. in contrast to the sandstones from the western part of Rača Unit.

5.1.2. Intrabasinal sources

The *Szczawina Ridge*, as a source of the Szczawina type sandstone, was built predominantly from magmatic and metamorphic rocks during the Maastrichtian and Paleocene (Oszczypko and Salata, 2005; Teťák et al. 2016). The absence of oceanic crust rocks and a small amount of chromian spinels points to continental crust. Laurinc and Teťák (2017) defined source area like quartz, less transitional quartz-lithic up to the lithic recycled orogen (Fig. 11, in sense Dickinson, 1985). Several smaller depositional fans were deposited north of the Szczawina Ridge. The composition of the western and eastern part of the Szczawina Ridge was similar (Oszczypko and Salata, 2005). The Szczawina type sandstone has analogous lithological composition to the Magura and Kýčera type sandstones with indistinctive differences. The ratio of monocrystalline to polycrystalline quartz in Szczawina type sandstone is low (44%/13.5%). Lithic fragments form 5.9%; sedimentary lithic

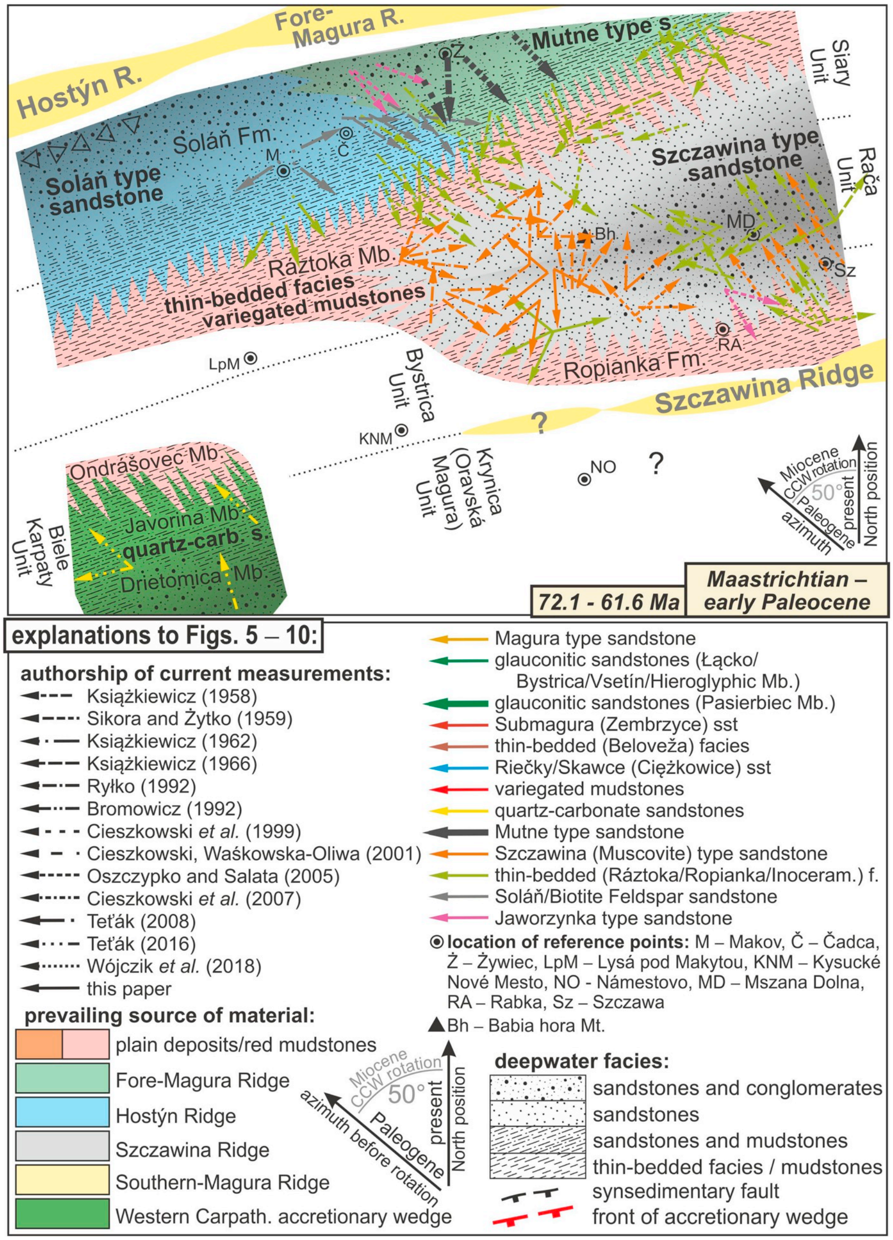

Fig. 5. Paleogeographic scheme of the western and central part of the Magura Basin during the Maastrichtian to early Paleocene (50° CCW Miocene rotation into present position was applied; modified after Pivko, 2000 and Teťák, 2008, 2016).

fragments form 2.9%. Microsparitic, sparitic, (less micritic) carbonates prevail. Typical is the high content of muscovite (6.7%) and biotite (4.5%). The mica schist and phyllites are common, but the gneisses are rare. Besides felsic volcanic fragments, basic volcanites are common. Fossils and glauconite are present in lesser extent (Laurinc in Teťák et al., 2016c; Laurinc and Teťák, 2017).

The *Southern-Magura Ridge* (cordillera) was defined by Marschalko (1975) and lately more precisely described as a SE source within Magura Basin with uplifted tectonized continental crust (Marschalko et al., 1976; Mišík et al., 1991a). The Southern-Magura Ridge was ambiguously described by some authors as a south part of Magura Basin and simultaneously thrust belt at the front of the Western Carpathians accretionary wedge, or north part of Pieniny Klippen Belt (e.g. Poprawa and Malata, 2006). The Southern-Magura Ridge, as a source of the Magura type sandstone, derived from the ridge during the early to the late Eocene (Oszczypko and Salata, 2005; Teťák et al. 2016), was predominantly built of magmatic and metamorphic crystalline rocks. The ridge supplied clasts with the late Carboniferous to Permian metamorphism (Poprawa et al., 2004, 2006). The absence of oceanic crust rocks and chromian spinels points to continental crust, also confirmed by Oszczypko et al. (2015). The ridge did not contain sedimentary rock typical for the Bohemian Massif (Silurian shales, Devonian and Carboniferous limestones, etc.; Mišík et al., 1991a, b). The ridge did not supplied the material from the south zones like Pieniny Klippen Belt and Central Carpathian units until late Eocene to Oligocene when Southern-Magura Ridge was incorporated to Western Carpathian accretionary wedge (Mišík et al., 1991a, b; Olszewska and Oszczypko, 2010; Salata and Oszczypko, 2010).

The Southern-Magura Ridge was quartz, less transitional quartz-lithic up to lithic recycled orogen according to the character of the material (Fig. 11). The material derived from this source was similar to the Szczawina Ridge. The Kýčera type sandstone is the subtype of Magura type sandstone. The composition of both is similar. The ratio of monocrystalline to polycrystalline quartz is low (43.6%/14.4%, in

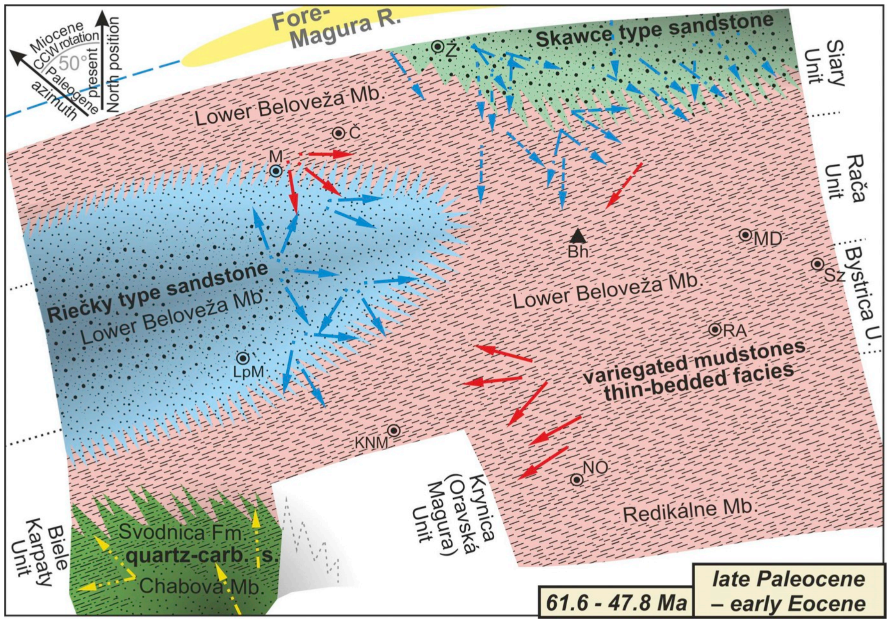

Fig. 6. Paleogeographic scheme of the western and central part of the Magura Basin during the late Paleocene to early Eocene (50° CCW Miocene rotation into present position was applied; modified after Pivko, 2000 and Teťák, 2008, 2016) (explanations are in Fig. 5).

Kýčera type sandstone 43%/18%). Lithic fragments form 10.5%; sedimentary lithic fragments form 7.8%. Microsparitic, sparitic, (less micritic) carbonates prevail (5.6%, in Kýčera type sandstone only 1.1%). The mica schist and phyllites are common, but the gneisses are rare. Felzic volcanic fragments are commonly accompanied by basic volcanites. Fossils and glauconite are negligible (Laurinc in Teťák et al., 2016c; Laurinc and Teťák, 2017).

Bromowicz (1992) confirms a similar composition of clastic sediments containing quartz, feldspars, granitoids, intermediate and felsic volcanites, limestones and metamorphics rocks. The Southern-Magura Ridge had character of thrust belt with mountain topography (Poprawa and Malata, 2006) which supplied clastic material for a deep-water submarine fan in to the Krynica and later as well to the Bystrica and Rača part of the Magura Basin since the early Eocene (e.g. Bromowicz, 1992; Teťák et al. 2016). The Eocene deposits of the Krynica Unit of the Magura Basin contain fragments of the crystalline basement rocks derived from the continental crust and the clasts of the Mesozoic deep and shallow-water limestones (Olszewska and Oszczypko, 2010). The clastic material was not derived by erosion of the Czorsztyn Ridge or the Pieniny Klippen Belt, but according to Mišík et al. (1991a) from "the basement of the Magura Basin" (Oszczypko et al., 2015).

Bónová (2018) and Bónová et al. (2018), based on a comparison of clastic material and heavy minerals from Krynica Unit with possible sources, despite the considerable differences, report that Tisza Megaunit cannot be excluded as a partial source of material supplied in to the Krynica zone of Magura Basin. The more likely source of siliciclastic material is Marmarosh Massif, which emerged on the eastern edge of the Magura Basin at the time of sedimentation. It is possible, that the

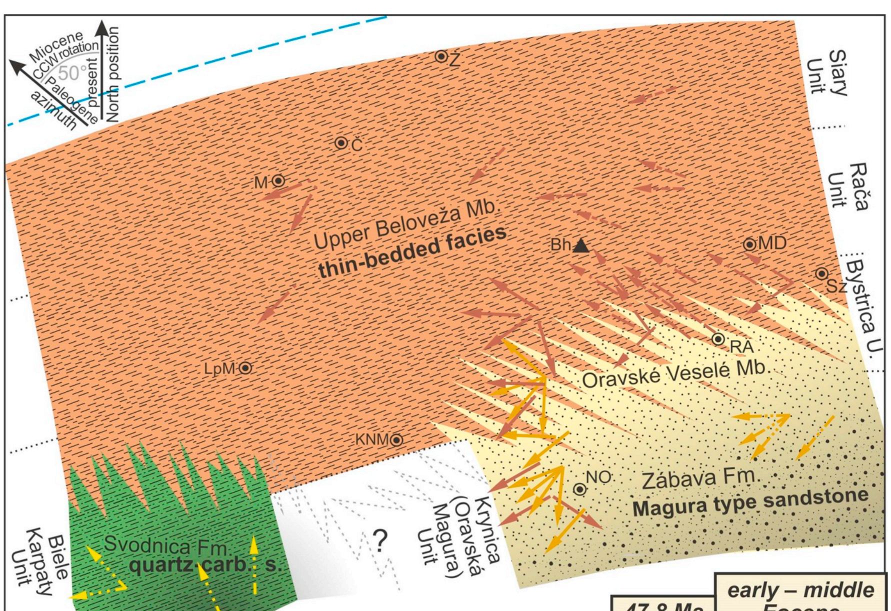

Fig. 7. Paleogeographic scheme of the western and central part of the Magura Basin during the early to middle Eocene (50° CCW Miocene rotation into present position was applied; modified after Pivko, 2000 and Teťák, 2008, 2016) (explanations are in Fig. 5).

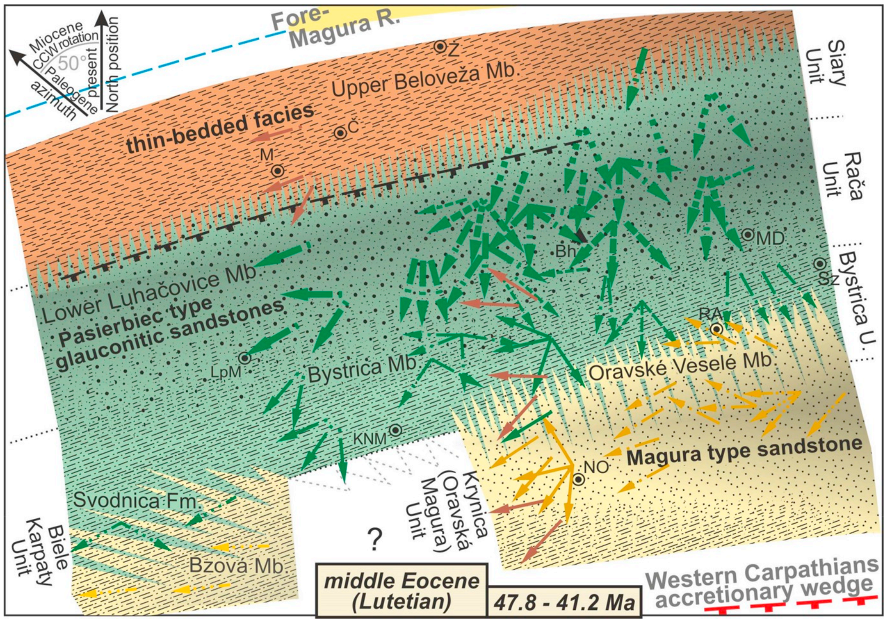

Fig. 8. Paleogeographic scheme of the western and central part of the Magura Basin during the middle Eocene (Lutetian) (50° CCW Miocene rotation into present position was applied; modified after Pivko, 2000 and Teťák, 2008, 2016) (explanations are in Fig. 5).

erosion of the Dacia Mega-unit (Marmarosh Massif crystalline basement, sub-ophiolitic Fore-Marmarosh Suture Zone) and Tisza Mega-unit supported detrital material including Cr-spinels in to the Magura Basin (Oszczypko et al., 2006; Olszewska and Oszczypko, 2010; Oszczypko et al., 2016; Bónová et al., 2017, 2018, 2019).

The Hostýn, Silesian, Fore-Magura, Szczawina and Southern-Magura Ridges were exposed by the compression, which uplifted the ribbons of thinned continental crust with Variscan crystalline rocks similar to the Bohemian massif and the fragments of Cadomian crust (Soták, 1992; Poprawa and Malata, 2006; Golonka et al., 2003; Golonka, 2011). Deposition of the red mudstones from the Campanian to early Eocene (in some region up to Bartonian) in the studied region point to the connection of the Magura Basin with the Atlantic Ocean through the Ligurian Ocean and with the Neotethys through the Ceahlau-Severin Ocean (compare Oszczypko et al., 2015).

5.1.3. Southern source

The Western Carpathian accretionary wedge was extended along the southern margin of the Magura Basin. At the end of the Cretaceous, Czorstyn Ridge, a continental ribbon, was incorporated to the wedge (Plašienka, 2012). The accretionary wedge was defined in Eastern Slovakia as Neopieninic Exotic Ridge, uplifted during the Paleocene to early Eocene (Marschalko et al., 1976; Mišík et al., 1991b). The wedge was characterized by its prograding, which culminated during the late Eocene and Oligocene (e.g. Kováč et al., 2016). The wedge supplied high amount of the quartzite and carbonate clastic material (up to pebbles and olistoliths) into the basin, accompanied with low- to medium grade metamorphic rocks with only low content of feldspar,

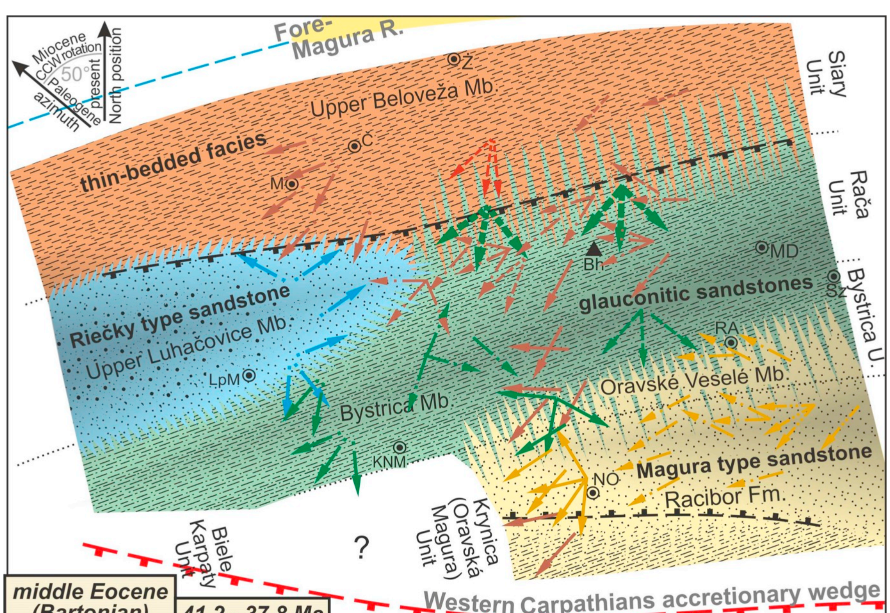

Fig. 9. Paleogeographic scheme of the western and central part of the Magura Basin during the middle to late Eocene (50° CCW Miocene rotation into present position was applied; modified after Pivko, 2000 and Teťák, 2008, 2016) (explanations are in Fig. 5).

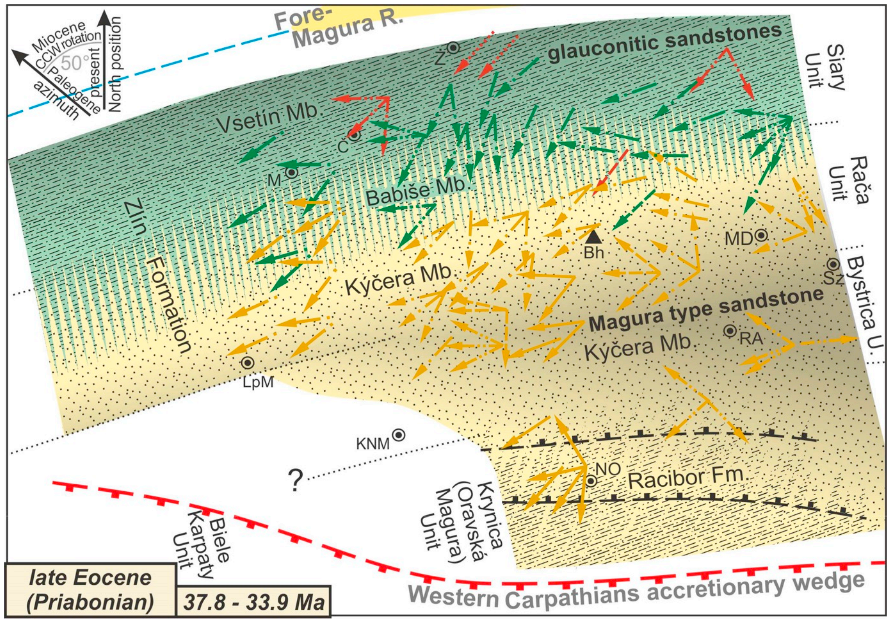

Fig. 10. Paleogeographic scheme of the western and central part of the Magura Basin during the late Eocene (Priabonian) (50° CCW Miocene rotation into present position was applied; modified after Pivko, 2000 and Teťák, 2005, 2008, 2016) (explanations are in Fig. 5).

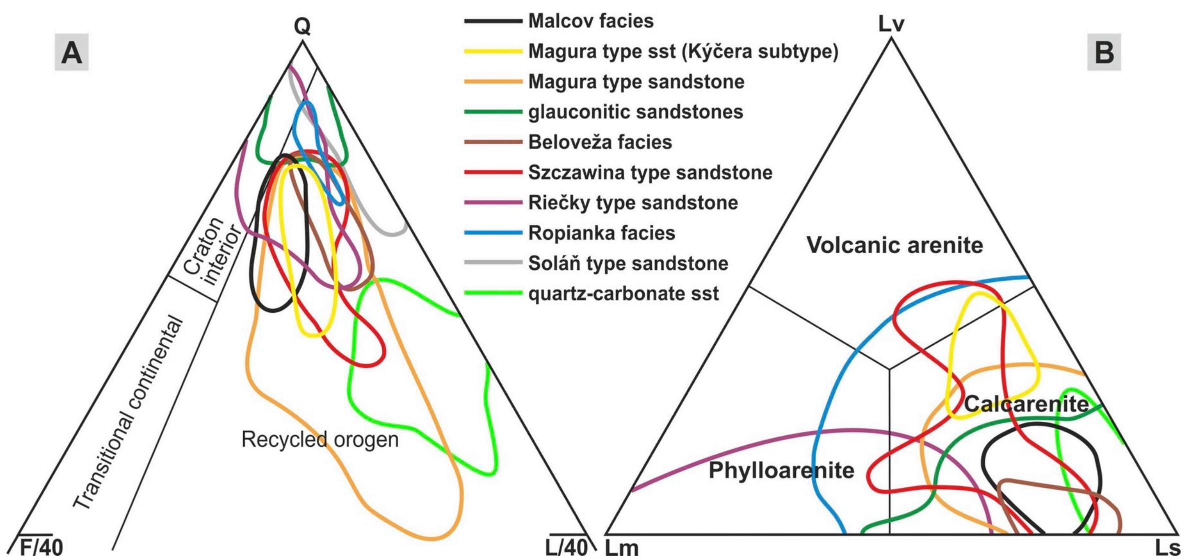

Fig. 11. Petrographic characteristics of the sources of fundamental lithotypes and lithofacies from central and western part of Magura Nappe (based on Teťák, 2008; Laurinc and Teťák, 2017). A – The discrimination diagram interpreting the tectonic nature of the source areas of sandstone (Dickinson, 1985); B – Classification of sandstones based on the lithic clasts content (Pettijohn et al., 1972). (*Q – Quartz total, F – Feldspar, L – Lithics, Lv – magmatic and volcanic lithic fragments, Lm – metamorphic lithic fragments, Ls – sedimentary lithic fragments*).

granitoid and volcanic clasts (Javorina, Drietomica, Chabová Mbs. and Jarmuta and Proč Fms.). As it was mentioned above, the southern edge of the Magura Basin was tectonically complicated thrust belt built of the different Pieniny Klippen Belt units (Sub-Pieniny, Pieniny, Klape, Fatric), which supplied various material, also recycled from the Veporic-Gemeric-Meliatic-Silicic collisional orogenic belt including the Upper Jurassic – Upper Cretaceous subduction-related magmatism with chromian spinels (Mišík et al., 1991a, b; Mišík, 1996; Winkler and Ślączka, 1994; Plašienka, 1995, 1996, 2012; Madzin et al., 2019).

5.2. Deposition in the Magura Basin

Several factors have a decisive influence on the deposition in siliciclastic basin. Namely they are: (1) source area – size, topography, geological structure, tectonic activity, weathering, climate, (2) transport of detrital material – granularity and amount of material, dynamics of current, sorting, (3) deposition conditions in the sedimentary basin – tectonic activity, deposition depth, CCD, local or global variations of sea level, burial and diagenetic processes, bottom currents influenced by connection with ocean. These factors had a crucial effect on the provenance, value, grain size and distribution of clastic sediments within the basin. The interplay between the above-mentioned factors has been intensively investigated by generations of geologists also in the Western Carpathians in the past.

The deposition environment of the Outer Western Carpathian nappes represented facies of the internal troughs (Magura and Fore-Magura/Dukla Basins) and external basins (Pouzdřany-Ždánice-Waschberg, Sub-Silesian, Silesian and Skole Basins). The Upper Cretaceous to Paleogene sediments of the Outer Western Carpathians were deposited on an attenuated continental and/or oceanic crust of the

Northern Penninic realm and on the passive margin of the Northern European Platform and/or Bohemian Massif (Kováč et al., 2016). The Magura Basin, as an SW part of the Western Carpathian flysch basins realm, was opened by *syn*-rift extension during the Upper Jurassic to Lower Cretaceous (Poprawa and Malata, 2006; Golonka, 2011) according to the oldest deposits in the Morava (Eliáš et al., 1996) and in Slovakia – Poland (Šariš, Grajcarek Unit, Plašienka, 2012; Oszczypko et al., 2015; Jurewicz, 2018). Sedimentation of carbonates dominated in the Magura Basin during the Upper Jurassic to Lower Cretaceous (Picha et al., 2006; Oszczypko et al., 2015; Plašienka, 2012). The Magura Basin was not separated basin, but it was interconnected with neighboring basins (Rhenodanubian and Dukla Basins). The Magura Basin was a NE prolongation of the Piemont-Liguria Ocean (Schmid et al., 2008). Since the Lower Cretaceous, the Magura Basin was also connected with the Valais Ocean through Rhenodanubian Basin (Schmid et al., 2008; Oszczypko et al., 2015).

The Silesian Basin, as a NE part of the Western Carpathian flysch basins, was individualized during the Lower Cretaceous by the Silesian Ridge uplift. Significant uplift of the Silesian Ridge, as a thrust belt with mountain topography, was caused by compression tectonics from the Turonian up to early Paleocene (Poprawa and Malata, 2006; Cieszkowski et al., 2012).

Even the oldest preserved sediments of The Magura Basin have the character of deep-sea sedimentation. Upper Jurassic to Lower Cretaceous carbonates, marls and “flyschlike” deposits form Kurovice tectonic klippen and Cetechovice and Lukoveček olistoliths (Pícha et al., 2006). The deposits of the Outer Western Carpathian units are mostly composed of synorogenic flysch deposited in the deep-marine environment. These deposits are represented by a variety of gravity-driven currents (turbidites, debris flows and olistoliths). The sedimentation took place in diverse depositional environments from the steep slopes of the ridges to the deep-water environment in the central part of the basin. Prevailing monotonous hemipelagic and thin-bedded flysch sedimentation was disrupted by several depositional fans penetrating hundreds of kilometers deep into the basin. Several sandstone depositional deep-sea fans could be defined based on detailed facial and petrographic research and paleocurrent measurements (Table 1; e. g. Laurinc and Teťák, 2017).

Detritic material was supplied either from the southern or northern margin of the basin or from the intrabasinal sources. The gravity currents deposited wide wedge (Soláň and Mutne type sandstones) or smaller fans (Riečky, Skawce, and Mrázovce type sandstones) along the northern passive margin of Magura Basin. Several smaller fans formed a wedge along with the southern active Western Carpathian accretionary wedge (quartz-carbonate sandstones). Afore-mentioned fans and lobes penetrated into the more or less stable and smooth plain environment with thin-bedded and/or variegated mudstones sedimentation. Especially the bodies of huge lobes of Magura and glauconitic sandstones penetrated deeper into the Magura Basin. Shortly active intrabasinal source arises in the center of the basin (Szczawina type sandstone) during the Maastrichtian and Paleocene (Oszczypko and Salata, 2005; Teťák et al. 2016).

The deposits of basin-fill were gradually (from the south) scraped off their basement and stacked in fold-and-thrust system of the accretionary wedge during the Paleogene to early Miocene subduction (e.g. Kováč et al., 2016). The subduction of an active southern margin caused the progressing reduction and disintegration of sedimentation space. Deposition culminated in the basin during the late Eocene to (?) early Miocene – Malcov Fm. (Teťák et al. 2016).

5.2.1. Santonian – Campanian

The early “Senonian” to Campanian (Fig. 12) was a period of increased tectonic activity in the Central Carpathians (Plašienka, 2012; Pelech et al., 2016). However, this activity culminated in the area of the Pieniny Klippen Belt. The sedimentary sequences of the Magura Basin from this period present only low tectonic activity connected with high sea level. Magura Basin bottom was approximately in the depth of 2.5 to almost 4 km (Poprawa et al., 2002). Basin was separated from the Silesian Basin by Silesian Ridge in the NE (Cieszkowski et al., 2012). The deposition of variegated mudstones and claystones accompanied by thin-bedded lithofacies unified the whole deposition area of the Magura Basin during the Santonian to Campanian. The supply of detrital material was insignificant. No notable depositional fan was active. Only the marginal parts and, in particular, the southern edge of the Magura Basin, which was under the influence of the tectonic activity of the Western Carpathian accretionary wedge, were exceptions.

Deposition in the Magura Basin during the early “Senonian” was represented mainly by variegated (red and green) mudstones and marlstones irregularly interlayered with thin layers of sandstones. Despite the monotony of sediments, a number of lithostratigraphic units have been defined: Cebula Fm., Malinowa Shale, Haluszowa Fm., Ondrášovec Mb., Púchov Mb., Kaumberg Fm. Sedimentation of red mudstones (Cebula Fm.) below the CCD prevails over rare turbidity currents deposits in the central part of the basin. Variegated marlstones were more abundant at the margins of the basin (Birkenmajer and Oszczypko, 1989; Potfaj, 1993; Faupl, 1996; Teťák et al. 2016).

The deposition of the Cebula Fm. continued by deposition of variegated hemipelagic mudstones, marls and with slowly increasing amounts of turbidity currents derived probably from mildly uplifted Fore-Magura Ridge during the Campanian (Poprawa and Malata, 2006). The thin-bedded “flysch” deposits gradually overlapped most of the Magura Basin. Green laminated thin-bedded sandstones alternated with non-calcareous green and red mudstones. Several minor depositional fans have interfered with the red mudstones. The deep-sea hemipelagic deposits of the Cebula Fm. are the earliest deposits in the Orava region.

5.2.2. Maastrichtian – early Paleocene

This ca. 10 Myr long period was characterized by increased tectonic activity and relatively long-term sea level decrease (Fig. 13). The Magura Basin depth was about 2 to 3.5 km (Poprawa et al., 2002). Mentioned conditions had an influence on the increased supply of clastic material into the basin and on facial heterogeneity of deposits. Clastic sedimentation of gravity currents dominated in the Magura Basin since Maastrichtian. The higher tectonic activity was caused by folding and thrusting of the Central Western Carpathians and PKB over the southern edge of the Magura Basin. The southern margin of the Magura Basin (Grajcarek/Šariš Unit represented by Jarmuta and Proč Fm.) got to the foreland position at the front of the Central Western Carpathian accretionary wedge (Plašienka, 2012, 2014; Oszczypko et al., 2015; Jurewicz, 2018; Madzin et al., 2019).

Since the Maastrichtian, possibly as well earlier, the Fore-Magura Ridge mildly uplifted and separated Fore-Magura Basin from the Magura Basin (Poprawa and Malata, 2006; Cieszkowski et al., 2007). The Fore-Magura Ridge was responsible for the supply of the proximal turbidites of the Mutne sandstone Mb. (Cieszkowski et al., 2007). At the same time, the Hostýn Ridge supplied the clastic material of the Soláň Fm. (Eliáš, 1963; Pesl, 1968) and Altlengbach Fm. (Faupl, 1996) from the NW. In general, upward coarsening debris flows and slump sandstones to conglomerates of the Soláň Fm. formed a large wedge (ramp) of coarse clastic sediments and olistoliths along the edge of the ridge. Soláň type sandstone contains a high proportion of grains and pebbles of Jurassic limestones and fragment of coralline algae. Soláň type sandstone shows many similarities with the Istebna type sandstone (Picha et al., 2006). Hostýn Ridge was related to the Fore-Magura Ridge.

The Southern edge of the Magura Basin was bounded by a thrust belt as a result of the Maastrichtian collision of the lower plate Czorsztyn Ridge (Oravic) ribbon continent with the upper plate of the Tatric (Austroalpine-Slovakocarpathian) margin. The overriding Pieniny Nappe supplied the Sub-Pieniny Unit with Gregorianka Breccia. During the Paleocene, the Sub-Pieniny Unit was detached from its

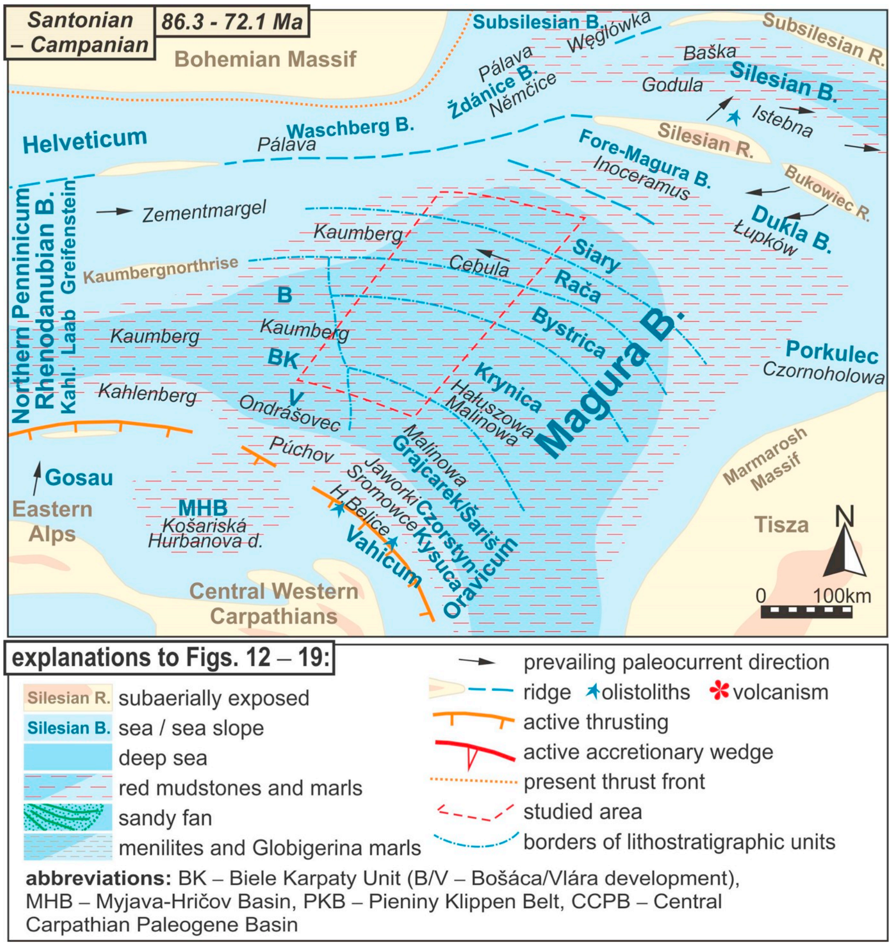

Fig. 12. Palinspastic map of the Santonian to Campanian. A – Scheme displays the Magura Basin and adjacent areas (based on Kováč et al., 2016; Książkiewicz, 1962; Picha et al., 2006; Oszczypko and Salata, 2005; Oszczypko and Oszczypko-Clowes, 2009; Faupl, 1996; Golonka, 2011). Red marls and mudstones overlapped most of the Magura Basin. The supply of sedimentary material was limited. Active thrusting took place in the Central Western Carpathians (Plašienka, 2012). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

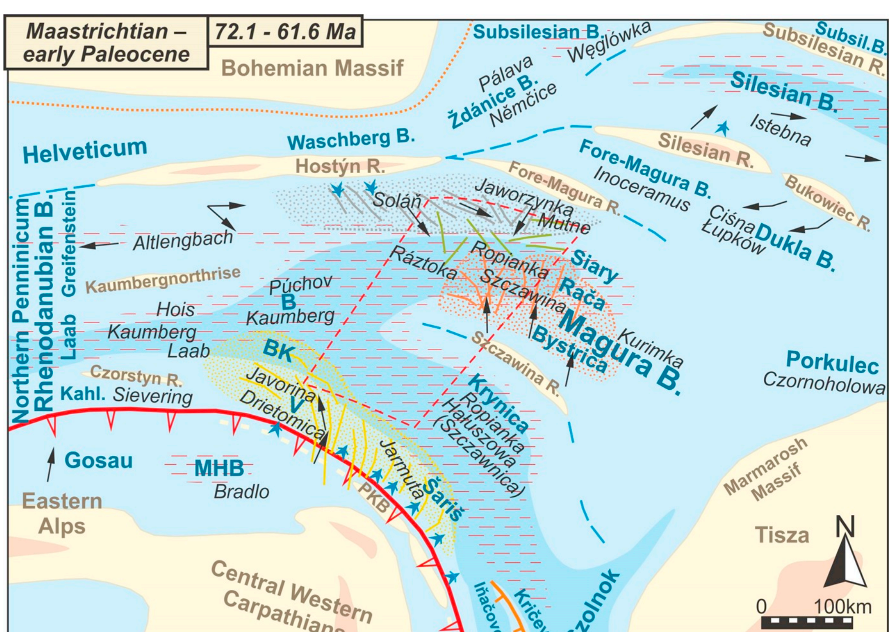

Fig. 13. Palinspastic map of the Maastrichtian to early Paleocene. Scheme displays the Magura Basin and adjacent areas (based on Kováč et al., 2016; Książkiewicz, 1962; Oszczypko and Salata, 2005; Oszczypko and Oszczypko-Clowes, 2009; Faupl, 1996; Golonka, 2011). Fan of the Szczawina type sandstone spread from the short-existing Szczawina Ridge situated somewhere between the Bystrica and Krynica area. A huge wedge of the Soláň and Mutne type sandstones spread along the northern basin margin (explanations are in Fig. 12).

basement substratum and thrusted over the frontal quartz-carbonate sandstones of Jarmuta and Proč Fms. (later Šariš Unit, Plašienka, 2012; Madzin et al., 2019).

A new ridge was uplifted in the center of the Magura Basin, which is called Szczawina Ridge according to Szczawina type sandstone that originated here and was transported northward to the Bystrica and Rača part of the basin. The existence and location of the ridge could be deduced from facial distribution and differences between the Krynica and Bystrica Units due to shortening of space. Oszczypko and Salata (2005) already mentioned small local intrabasinal ridge, which supplied clastic material of the Szczawina type sandstone and could have appeared on the boundary between the Krynica and Bystrica Units. It is not known whether any deposits from the southern edge of the Szczawina Ridge would be preserved. If so, they are not preserved on the present surface.

The highest activity of the Szczawina Ridge was during the Maastrichtian and it continued to the late Paleocene. The activity of the ridge decreased during the Paleocene and the ridge terminated the supply of the detritus probably by higher sea level during the late Paleocene. Based on the geological mapping and paleocurrent measurements, could be identified at least 4 submarine fans, which material was derived from this ridge (Sikora and Żytko, 1959; Książkiewicz, 1962, 1966; Ryłko, 1992; Pivko, 2002; Oszczypko and Salata, 2005; Teťák et al. 2016). The age of deposition of the Szczawina type sandstone in the Bystrica and Rača Unit in the Beskid Wyspowy and Gorce Mts. (Beskid Wyspowy fan) is the Maastrichtian, eventually the Campanian (Oszczypko et al., 2005a). Large composite fan (North Orava fan) was developed across the Bystrica and Rača Unit in Babia hora and Pilsko Mts. area during the Maastrichtian. Small fan of the Beskid Żywiecki reached only the Rača Unit. During the Paleocene, North Orava and Beskid Wyspowy fans occurred only in the Bystrica Unit. The most eastern occurrence of the Szczawina type sandstone is the Grybów area (Oszczypko and Salata, 2005).

Deposits were not triggered by eustatic changes. Long-term eustatic curve fluctuated 30–60 m in the Maastrichtian, 30–100 m in the Danian and 30–70 m in the Seladian (Haq, 2014). Together 18 fluctuations in short-term curve with up to 130 m change were not as important for the input of clastics as tectonic uplift. Short-term cycles have been manifested in about 8 grain size cycles inside the Szczawina type sandstone in the Rača Unit (Pivko, 1998).

The Fore-Magura and Szczawina Ridges were not as significant as the Hostýn Ridge. Uplift of several ridges caused that material for the Ropianka facies and Szczawina type sandstone was derived from several sources (Figs. 5 and 13). Dispersed paleocurrent directions of the Ropianka Fm. support this presumption (Fig. 4). Szczawina Ridge could be considered as their main source. Facially the thin-bedded deposits represent distal "flysch" facies (Fig. 3A) derived from the Szczawina, Fore-Magura and Hostýn Ridges. Szczawina Ridge reflected in the examined terrain by paleocurrents to NW or SW (new measurements – Fig. 5), to NW (Oszczypko and Salata, 2005; Książkiewicz, 1966) or to NE (Książkiewicz, 1962; Ryłko, 1992). Other types of sandstones (e.g. glauconitic and biotite sandstones) also occur sporadically in Ropianka Fm. except for Szczawina type sandstone. These could be the source of contradictory paleocurrent directions (to S or SE). Locating the Szczawina Ridge between Bystrica and Krynica unit seems to be the best solution with current knowledge. Discussion and further information will be necessary to solve this problem.

5.2.3. *Late Paleocene – early Eocene*

The global temperature and sea level have risen according to the long-term curve in this period (Haq et al., 1987; Zachos et al., 2008). The Magura Basin was affected by flexural subsidence (Poprawa and Malata, 2006). The basin depth was approximately 2.5 to almost 4 km (Poprawa et al., 2002; Kender et al., 2005). Mentioned conditions culminated in the middle Eocene and they were represented by the deposition of hemipelagic plain red mudstones and plain thin-bedded "flysch" facies mainly in the central and northern part of the Magura Basin (starting with Ropianka Fm. through Łabowa Fm. to Lower Beloveža Mb.; Birkenmajer and Oszczypko, 1989; Teťák et al., 2016, Figs. 14 and 20). Prevailing thin-bedded facies point out that the Fore-Magura, Hostýn and Szczawina Ridges were not much active. The supply of detritus from Szczawina Ridges terminated probably during the late Paleocene.

Even in this relatively calm period, short-term eustatic decrease enables crop out and erode the Fore-Magura and Hostýn Ridges. Erosion has resulted in the deposition of the significant deep-sea fans of Skawce (Ciężkowice) and Riečky type sandstones along the northern edge of the basin. Likewise, Grybów Ridge could supply Mrázovce Mb. (defined in Kováčik et al., 2012; Bónová, 2018).

The southern edge of the Magura Basin formed a constantly active thrust belt composed of the Pieniny and other tectonically affiliated units. The mentioned units with various geological composition supplied quartz-carbonate and exotic material for the Proč Fm. as well as for Milpoš Breccia, Svodnica Fm. and Chabová Mb (Fig. 11). The Milpoš Breccia contains recycled exotic clasts described above. Some klippen of the Pieniny Klippen Belt originated as olistoliths fallen into the Proč Fm. deposits (Plašienka, 2012, 2018; Teťák, 2016).

5.2.4. *Early – middle Eocene*

The global temperature and long-term sea level culminated in this period (Haq et al., 1987; Zachos et al., 2008). The Magura Basin was treated with continual flexural subsidence (Poprawa and Malata, 2006) and its depth was approximately 2.5 up to 4 km (Poprawa et al., 2002). The northern sources (Silesian, Hostýn and Fore-Magura Ridges) were little active in material supply into the Magura Basin (besides Altlengbach Fm. in Rhenodanubian Basin, Faupl, 1996). Typical facies was the thin-bedded "flysch" facies of the Beloveža Fm. (Figs. 3B and 9).

The pressure of advancing Western Carpathian accretionary wedge probably triggered uplift of the intrabasinal Southern-Magura Ridge, which produced large amount of material for Magura type sandstone fan. That was one of the largest and one of the longest producing deep-sea fan of the Outer Western Carpathians, permanently until the early Oligocene (Oszczypko et al., 2005a; Teťák et al., 2016). The Magura type sandstone was interbedded with thin-bedded "flysch" facies mainly at the distal part of fan (Zábava Fm. – Fig. 3C, D).

The sedimentation along the southern edge of the Magura Basin (in Šariš/Grajcarek Unit and Vlára development of the Biele Karpaty Unit) terminated gradually during the early and middle Eocene (e.g. Kováč et al., 2016). It suggests that the mentioned units were incorporated into the advancing front of the Western Carpathians accretionary wedge (compare Figs. 15 and 16). The edge of the wedge gradually reached the fan of Magura type sandstone.

5.2.5. *Middle Eocene*

A large part of the sediments preserved in the Magura Nappe deposited during the Middle Eocene. In the period, the long-term sea level declined and global temperature with short-lived peak decreased (Haq et al., 1987; Zachos et al., 2008). The Magura Basin was treated with continual flexural subsidence (Poprawa and Malata, 2006) and its depth was approximately 2.5 up to 4 km (Poprawa et al., 2002).

The conditions during this period were linked with a decrease in sea level and uplift of the new source areas. Less mature sands of the Magura type sandstone was derived from the intrabasinal Southern-Magura Ridge, which was uplifted during the middle Eocene (Poprawa and Malata, 2006). The extensive depositional fan of the Magura type sandstone run into the basin and it flowed along the axis of the basin (Figs. 16 and 17). The fan was composed of several lobes which migrated laterally initially only in the southern half of the basin, but later lobes prograded in to the northern part of the basin (Kýčera Mb.). Sedimentological analyses helped to interpret the complex system of multiple lobes with channels, levies and sea plain facies (Cieszkowski et al., 1998; Teťák, 2010; Teťák et al., 2016).

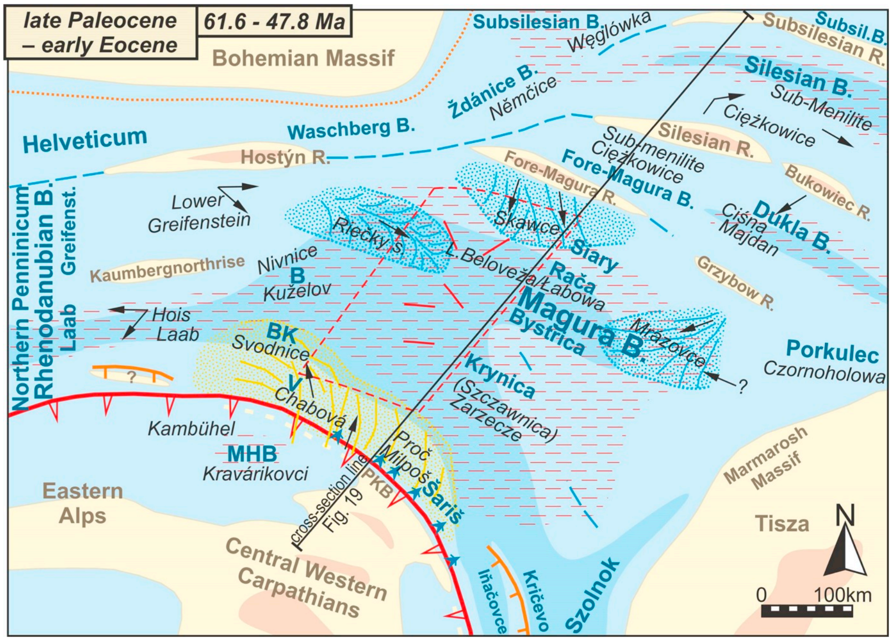

Fig. 14. Palinspastic map of the late Paleocene to early Eocene. A – Scheme displays the Magura Basin and adjacent areas (based on Kováč et al., 2016; Książkiewicz, 1962; Oszczypko and Salata, 2005; Oszczypko and Oszczypko-Clowes, 2009; Faupl, 1996; Golonka, 2011). Fans of the Riečky and Skawce (Ciężkowice) type sandstones overlapped the variegated mudstones and thin-bedded "flysch" (explanations are in Fig. 12).

During the Lutetian, the Fore-Magura Ridge started to supply the material for massive quartz glauconitic sandstones (Pasierbiec and Osielec type sandstones) often combined with calcareous mudstones to marls (Łącko and Bystrica Mb. – Fig. 3E). Glauconite and large foraminifera originated from a shallow shelf of Fore-Magura Ridge, but a high amount of calcareous mud was formed on a deeper shelf. The fan was composed of several depositional lobes. The diversity of fan reflected in the numerous facies and in paleocurrent measurements. The paleocurrent directions tend to the west or south-west up to south-east (recent directions after Miocene rotation). The quartzy sandstones and conglomerates with glauconite prevail in proximal part but the calcareous mud prevails in distal part. Some individual beds with mudstone dominance have a character of megaturbidites with thickness over 10 m. The glauconitic sandstones are interbedded with the Magura type sandstone in the south of the Bystrica Unit (Oravské Veselé Mb.). The amount of glauconitic sandstones decreased during the Bartonian. They have been partly pushed out by the Riečky sandstone fan supplied from the Hostýn Ridge (Upper Luhačovice Mb.). The glauconitic sandstones were interbedded with thin-bedded "flysch" facies especially at the edge of the fan (Vychylovka Fm., Hieroglyphic Fm.).

During the Lutetian, sedimentation of quartz-carbonate sandstones was replaced with the glauconitic and Magura type sandstones in the southwestern part from the Magura Basin (Biele Karpaty Unit; Teťák, 2016). Subduction of the southern edge of the Magura Basin has initiated by accretion of the Biele Karpaty Unit and Rhenodanubian flysch into the ALCAPA orogenic wedge during the late Lutetian (compare Kováč et al., 2016; Faupl, 1996). The deposition in Rhenodanubian Basin and Biele Karpaty Unit gradually finished from the SW (Faupl, 1996).

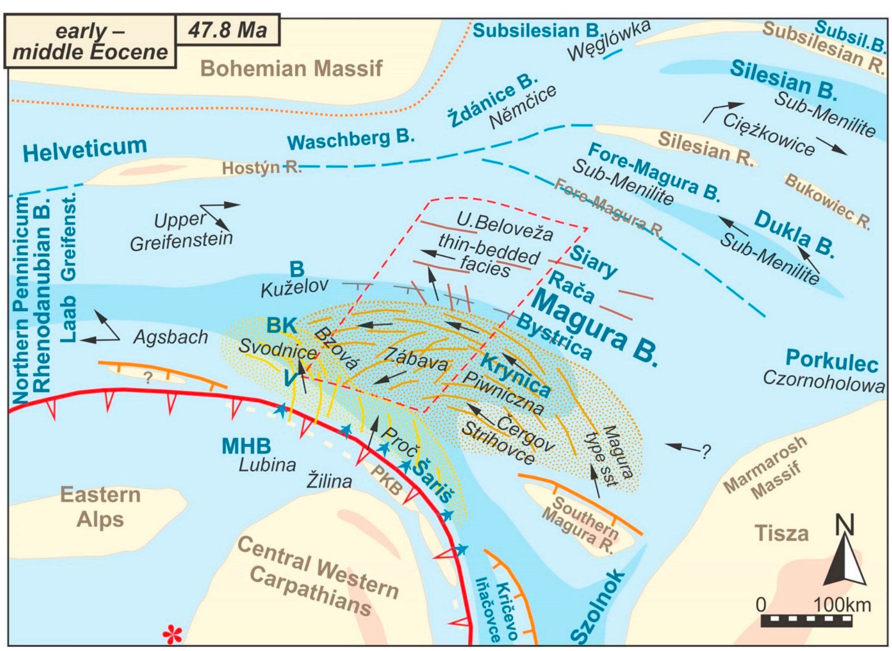

Fig. 15. Palinspastic map of the early to middle Eocene. A – Scheme displays the Magura Basin and adjacent areas (based on Kováč et al., 2016; Książkiewicz, 1962; Oszczypko and Salata, 2005; Oszczypko and Oszczypko-Clowes, 2009; Faupl, 1996; Golonka, 2011). Quartz-carbonate and Magura type sandstones fans interbedded with thin-bedded "flysch" deposits (explanations are in Fig. 12).

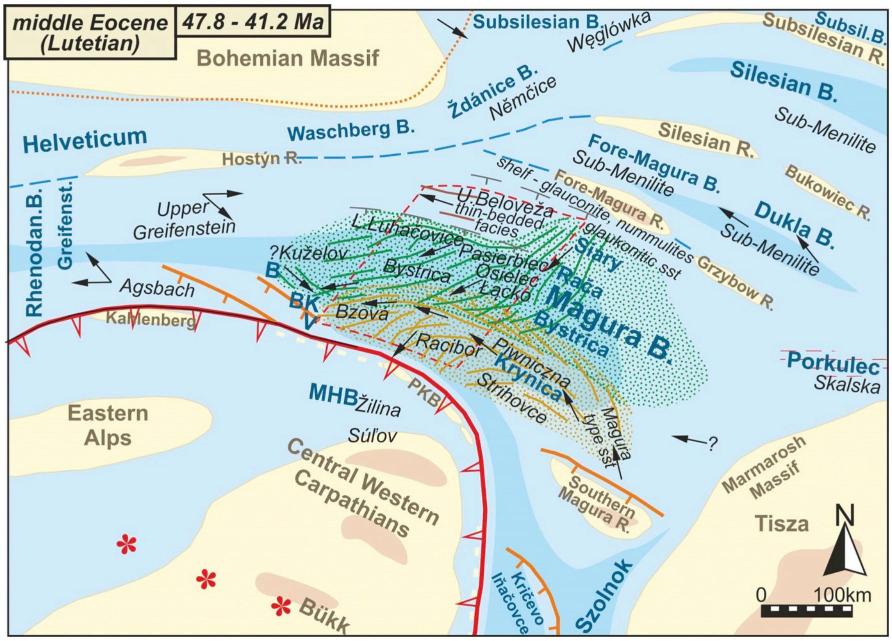

Fig. 16. Palinspastic map of the middle Eocene (Lutetian). Scheme displays the Magura Basin and adjacent areas (based on Kováč et al., 2016; Książkiewicz, 1962; Oszczypko and Salata, 2005; Oszczypko and Oszczypko-Clowes, 2009; Faupl, 1996; Golonka, 2011). Glauconitic and Magura type sandstones fans were overlapping and interbedded each other. Thin-bedded "flysch" deposition was shifted to the northern part of the Magura Basin. Active Western Carpathian accretionary wedge progressed further into the basin and consumed the Šariš Unit (explanations are in Fig. 12).

5.2.6. Late Eocene to early Miocene

In the period, the global temperature and long-term sea level decreased (Haq et al., 1987; Zachos et al., 2008). The Magura Basin was affected by continual flexural subsidence (Poprawa and Malata, 2006) and its depth was approximately 2.5 up to 4 km (Poprawa et al., 2002). Maximal depositional rates were achieved during the Priabonian, triggered by tectonic movements (Poprawa et al., 2002, 2006), (Figs. 18 and 19). The front of the Western Carpathians accretionary wedge progressed northwards and incorporated southern margin of the Magura Basin. After the middle Eocene, the Iňačovce-Kričevo Unit was connected to the accretion wedge and Southern-Magura Ridge was joined as well at the end of Eocene (Sotak et al., 2000; Olszewska and Oszczypko, 2010; Salata and Oszczypko, 2010). Advancing edge of the orogen and the subsiding northern part of the Magura Basin resulted in a northward progradation of the glauconitic and Magura type sandstones fans. Large depositional fan of Magura type sandstone shifted from Bystrica Unit to Rača Unit. The Magura type sandstone fan interfingered with glauconitic sandstones fan on the Siary-Rača Units border (Babiše Mb.). The basin floor was disintegrated due to compressional stresses during the middle Eocene. The increase of slump sedimentation in the southern part of the basin was a consequence of the collision of the southern Magura Basin edge with Western Carpathian accretionary wedge. An increased amount of slumps is typical for the Racibor Fm. as well as Malcov Fm. (Fig. 3G, H; Teťák, 2010; Teťák et al., 2016).

The Malcov Fm. was deposited in smaller limited sub-basins parallel with the shortening Magura Basin from Priabonian to Rupelian (Figs. 3H and 19). The period was influenced by the increase of compression. The Magura Basin got the character of residual piggy-back basins above the Outer Western Carpathian accretionary wedge up to the early Miocene. Initiation of massive subduction of the southern edge of the Magura Basin floor migrated from the west (Biele Karpaty Unit – Lutetian) to the

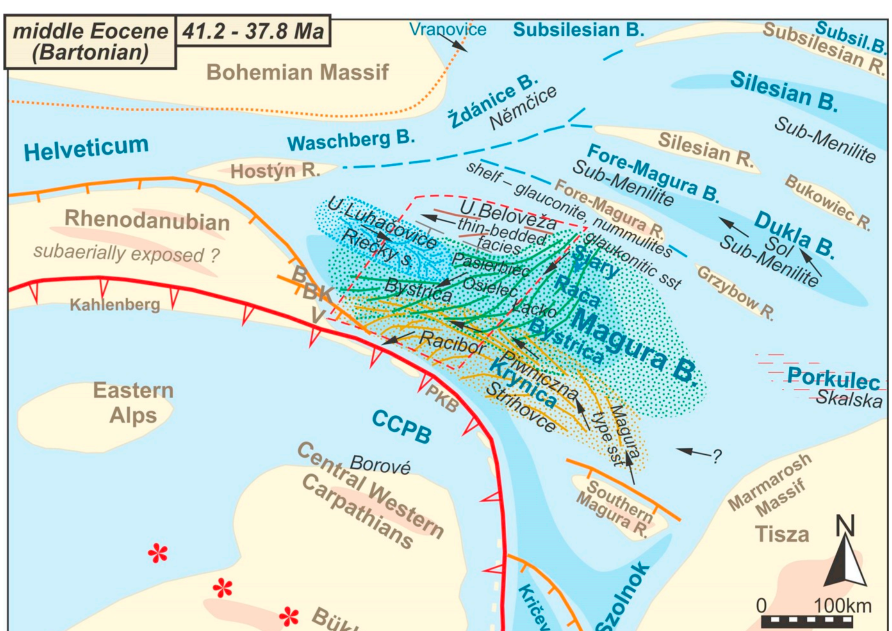

Fig. 17. Palinspastic map of the middle to late Eocene. Scheme displays the Magura Basin and adjacent areas (based on Kováč et al., 2016; Książkiewicz, 1962; Oszczypko and Salata, 2005; Oszczypko and Oszczypko-Clowes, 2009; Faupl, 1996; Golonka, 2011; Bónová, 2018). The Lutetian paleogeography continued during the Bartonian. The Riečky type sandstones fan run into the basin from the northwest (explanations are in Fig. 12).

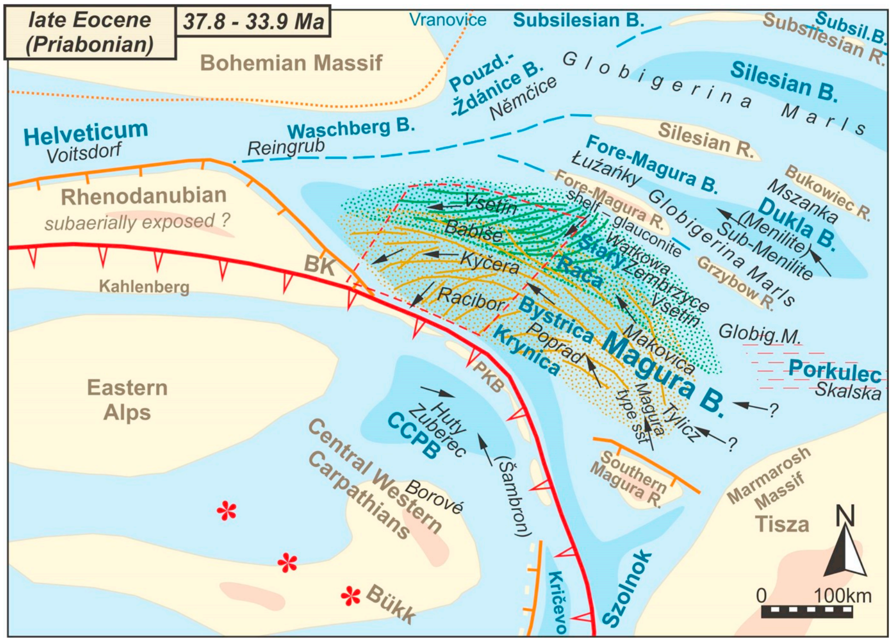

Fig. 18. Palinspastic map of the late Eocene (Priabonian). A – Scheme displays the Magura Basin and adjacent areas (based on Kováč et al., 2016; Książkiewicz, 1962; Oszczypko and Salata, 2005; Oszczypko and Oszczypko-Clowes, 2009; Faupl, 1996; Golonka, 2011; Bónová, 2018). Active Western Carpathian accretionary wedge progressed further into the basin. The subsided northern part of the Magura Basin has resulted in a northward progradation of the glauconitic and Magura type sandstones fans (explanations are in Fig. 12).

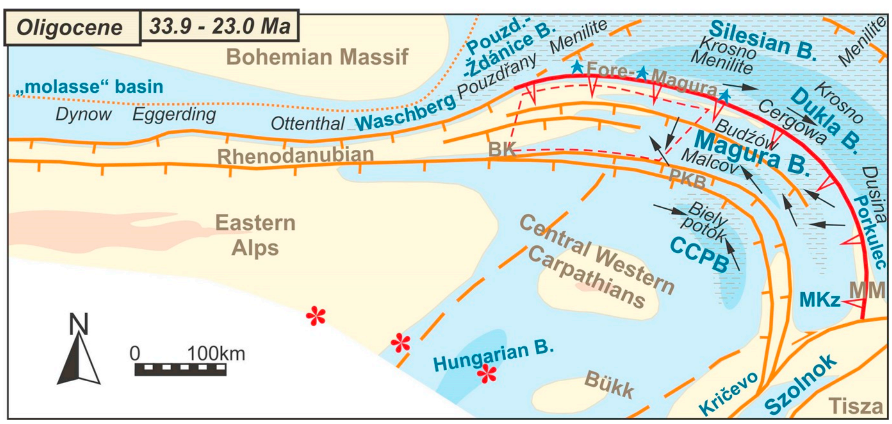

Fig. 19. Palinspastic map of the Oligocene. Scheme displays the Magura Basin and adjacent areas (based on Kováč et al., 2016 and Bónová, 2018). The Western Carpathian accretionary wedge progressed and the active thrusting edge shifted to the front of the Magura Basin. The Magura Basin got the character of residual piggy-back basins. (MM – Marmarosh Massif, MKz – Marmarosh Klippen zone, next explanations are in Fig. 12).

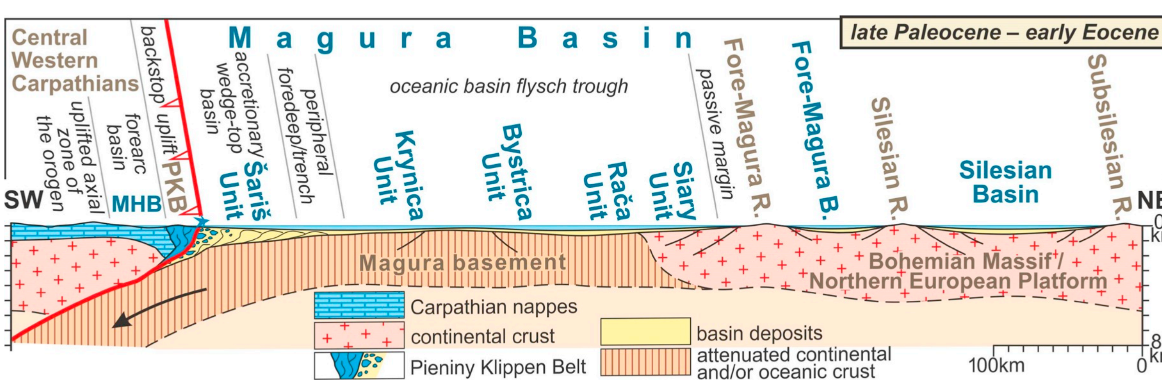

Fig. 20. Palinspastic cross-section displays the tectonic position of the basins in the Western Carpathian orogenic system during the late Paleocene to early Eocene (the cross-section line position is displayed in Fig. 14; based on Kováč et al., 2016; Picha et al., 2006).

east (Bartonian and Priabonian). The vanishing Magura subduction was accompanied by continuous growth of the fold-and-thrust system with maximum shortening during the Oligocene (Kováč et al., 2016 and references therein). Most of these youngest deposits were later removed by erosion. Malcov Fm. deposits were preserved mainly in the decreased areas such as the Orava – Nowy Targ Basin and in a narrow tectonically affected zone along the Pieniny Klippen Belt.

6. Conclusions

The main purpose of the research was the interpretation of the filling history and tectonic activity of the Magura Basin during the Upper Cretaceous to Oligocene. Sedimentological and petrographic methods were used for this purpose.

1) Sedimentary sequences of the Magura Nappe were divided into fundamental lithofacies and lithotypes during detailed geological mapping and sedimentological research in the Orava region.
2) A total of 1164 paleocurrent measurements were measured. They were assigned to lithotypes and lithostratigraphic units.
3) Acquired paleocurrent and sedimentological data were integrated with already published data especially from the central and western part of Magura Nappe.
4) Presented palinspastic maps are the summary of cited and new findings and, at the same time, the main benefit of the research. The maps propose the interpretation of the geological, structural and depositional history of the deep-sea "flysch" realm demonstrated on the example of the Magura Basin during the Upper Cretaceous to Oligocene.
5) From the discussion follows the proposition for the paleogeographic reconstruction of the Magura Basin as well as the surrounding areas. We propose the discussion about the character of the basin filling, source areas, about the definition of regional paleogeographic terms (e.g. Szczawina, Southern-Magura and Hostýn Ridges), about the location of the Fore-Magura Ridge and its clear definition with intent to avoid confusion with the Silesian and Hostýn Ridges.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.palaeo.2019.109250.

Acknowledgments

This research was supported by the Slovak Research and Development Agency under the contract APVV-14-0118. Authors are thankful to the Ministry of Environment of the Slovak Republic for funding large regional geological projects and contributing by this way to progress in geological knowledge. The authors wish to express their gratitude to Ondrej Pelech, and anonymous reviewers for useful comments, consultation and advice.

References

Alexandrowicz, S.W., Cieszkowski, M., Golonka, J., Kutyba, J., Oszczypko, N., Paul, Z., 1984. The stratigraphy of the Krynica zone of the Magura nappe in the Polish Flysch Carpathians (in Polish, English summary). Biuletyn Państwowego Instytutu Geologicznego 340, 23–43.
Bieda, F., 1946. La stratigraphie du Flysch des Karpates centrales polonaises basée sur les grands Foraminiferes (in Polish, French summary). Ann. Soc. Geol. Pol. 16, 1–54.
Birkenmajer, K., Oszczypko, N., 1989. Cretaceous and Palaeogene lithostratigraphic units of the Magura Nappe, Krynica Subunit, Carpathians. Ann. Soc. Geol. Pol. 59, 145–181.
Bónová, K., 2018. Heavy Minerals in Sandstone Formations of the Magura Zone (Eastern Slovakia) – Provenance and Palaeogeographic Implications (in Slovak, English Summary). University of P. J. Šafárik, Košice, 168 p.
Bónová, K., Bóna, J., Kováčik, M., Laurinc, D., 2016. Heavy minerals from sedimentary rocks of the Malcov Formation and their palaeogeographic implications for evolution of the Magura Basin (Western Carpathians, Slovakia) during the Late Eocene – Late Oligocene. Geological Quarterly 60 (3), 675–694.
Bónová, K., Spišiak, J., Bóna, J., Kováčik, M., 2017. Chromian spinels from the Magura Unit (Western Carpathians, Eastern Slovakia) – their petrogenetic and palaeogeographic implications. Geological Quarterly 61 (1), 3–18.
Bónová, K., Bóna, J., Kováčik, M., Mikuš, T., 2018. Heavy minerals and exotic pebbles from the Eocene flysch deposits of the Magura Nappe (Outer Western Carpathians, Eastern Slovakia): their composition and implications on the provenance. Turk. J. Earth Sci. 27, 64–88.
Bónová, K., Bóna, J., Pańczyk, M., Kováčik, M., Mikuš, T., Laurinc, D., 2019. Origin of deep-sea clastics of the Magura Basin (Eocene Makovica sandstones in the Outer Western Carpathians) with constraints of framework petrography, heavy mineral analysis and zircon geochronology. Palaeogeography, Palaeoclimatology, Palaeoecology, Elsevier 514, 768–784.
Bromowicz, J., 1992. Basen sedymentacyjny i obszary źródłowe piaskowców magurskich. Geologia, 54, Akad. górn.-hutn., Kraków, 116 p.
Budzyń, B., Dunkley, D.J., Kusiak, M.A., Poprawa, P., Malata, T., Skiba, M., Paszkowski, M., 2011. SHRIMP U-Pb zircon chronology of the Polish Western Outer Carpathians source areas. Ann. Soc. Geol. Pol. 81, 161–171.
Cieszkowski, M., 1979. Warstwy z Kowańca w podjednostce krynickiej płaszczowiny magurskiej – nowa definicja. Geological Quarterly 23 (2), 501–502.
Cieszkowski, M., 1992. Marine Miocene deposits near Nowy Targ, Magura Nappe, Flysch Carpathians (South Poland). Geol. Carpath. 43, 339–346.
Cieszkowski, M., 2002. Fore-Magura Zone in the polish sector of the Outer Carpathians. XVII. Congress of Carpathian-Balkan Geological Association, September 1st – 4th 2002, Bratislava, vol. 53.
Cieszkowski, M., Olszewska, B., 1986. Malcov beds in Magura nappe near Nowy Targ, Outer Carpathians, Poland. Ann. Soc. Geol. Pol. 56, 53–71.
Cieszkowski, M., Waśkowska-Oliwa, A., 2001. Skawce Sandstone Member – a New Litostratigraphic Unit of the Labowa Shale Formation (Paleocene – Eocene: Magura Nappe, Siary Subunit) Polish Outer Carpathians. Bulletin Polish Academy of Sciences. Earth Sci. 49 (2), 137–149.
Cieszkowski, M., Zuchiewicz, W., Schnabel, W., 1998. Sedimentological and tectonic features of the Poprad sandstone Member, Eocene, Magura Nappe: Case study of the Klikuczowa quarry, Outer West Carpathians, Poland. Bulletin Polish Academy of Sciences. Earth Sci. 46 (1), 55–74.
Cieszkowski, M., Schnabel, W., Waśkowska-Oliwa, A., 1999. Development and stratigraphy of the Paleocene-Early Eocene thick-bedded turbidites in the north-western zone of the Magura nappe, Outer Carpathians, Poland. Geologica Carpathica, Bratislava 50, 20–21.
Cieszkowski, M., Golonka, J., Waśkowska-Oliwa, A., Chrustek, M., 2006. Geological structure of the Sucha Beskidzka region - Świnna Poręba (Polish Flysch Carpathians). (in Polish, English summary). Kwartalnik AGH Geologia 32, 155–201.
Cieszkowski, M., Golonka, J., Waśkowska-Oliwa, A., Chodyń, R., 2007. Type locality of the Mutne Sandstone Member of the Jaworzynka Formation, Western Outer Carpathians. Ann. Soc. Geol. Pol. 77 (3), 269–290.
Cieszkowski, M., Golonka, J., Ślączka, A., Waśkowska, A., 2012. Role of the olistostromes and olistoliths in tectonostratigraphic evolution of the Silesian Basin in the Outer West Carpathians. Tectonophysics 568-569, 248–265.
Dickinson, R.W., 1985. Interpreting provenance relations from detrital modes of sandstones. In: Zuffa, G.G. (Ed.), Provenance of Arenites. Reidel, Dordrecht, pp. 333–361.
Eliáš, M., 1963. Způsob sedimentace soláňských vrstev v západní oblasti magurského flyše v ČSSR. Věstník Ústř. Úst. geol. 38, 253–260.
Eliáš, M., Martinec, P., Reháková, D., Vašíček, Z., 1996. Geologie a stratigrafie kurovických vápenců a tlumačovských slínovců v kurovickém lomu (svrchní jura, spodní křída, Vnější Západní Karpaty, Česká republika), [Geologyand stratigraphy of the Kurovice Limestone and Tlumačov Marl Formation at the Kurovice quarry (Upper Jurassic – Lower Cretaceous, Outher Western Carpathians, Czech Republic]. Věstník Českého geologického ústavu, 71, 3, 259–276.
Faupl, P., 1996. Exkursion A2. Tiefwassersedimente und tektonischer Bau der Flyschzone des Wienerwaldes. Exkursionsführer 11. Sedimentologentreffen. Geologische Bundesanstalt, Berichte, 33, (32 p).
Fossen, H., 2010. Structural Geology. Cambridge University Press, New York, 463 p.
Gągała, Ł., Vergés, J., Saura, E., Malata, T., Ringenbach, J.C., Werner, P., Krzywiec, P., 2012. Architecture and orogenic evolution of the northeastern Outer Carpathians from cross-section balancing and forward modeling. Tectonophysics 532-535, 223–241.
Gavęda, A., Golonka, J., Waśkowska, A., Szopa, K., Chew, D., Starzec, K., Wieczorek, A., 2019. Neoproterozoic Crystalline Exotic Clasts in the Polish Outer Carpathian Flysch: Remnants of the Proto-Carpathian Continent? Springer, International Journal of Earth Sciences, pp. 1–19.
Golonka, J., 2011. Evolution of the Outer Carpathian Basin. In: Bąk, M., Kaminski, M.A. & Waśkowska, A. (eds), Integrating Microfossil Records from the Oceans and Epicontinental Seas. Grzybowski Foundation Special Publication, 17, 3–14.
Golonka, J., Malata, E., 1977. Stratigraphy of the Magura Unit in Żywiecki Beskid between Babia Góra and Pilsko. Proceedings of the XI Congress of the Carpathians-Balkan Geological Association. Kiev, Naukova Dumka, 31–32.
Golonka, J., Krobicki, M., Oszczypko, N., Ślączka, A., Słomka, T., 2003. Geodynamic evolution and palaeogeography of the Polish Carpathians and adjacent areas during Neo-Cimmerian and preceding events (latest Triassic-earliest Cretaceous). Geol. Soc. Lond., Spec. Publ. 208, 137–158.
Golonka, J., Krobicki, M., Matyszkiewicz, J., Olszewska, B., Ślączka, A., Słomka, T., 2005. Geodynamics of ridges and development of carbonate platform within the Carpathian realm in Poland. Slovak Geological Magazine 11, 5–16.
Golonka, J., Ślączka, A., Waśkowska, A., Krobicki, M., Cieszkowski, M., 2013. Budowa geologiczna zachodniej części polskich Karpat zewnętrznych. In: Krobicki, M., Feldman-Olszewska, A. (eds). Głębokomorska sedymentacja fliszowa: sedymentologiczne aspekty historii basenów karpackich: V Polska Konferencja Sedymentologiczna POKOS 5′2013, Żywiec: abstrakty referatów i posterów oraz artykuły: przewodnik do wycieczek, 11–61.
Hanžl, P., Schnitter, F., Finger, F., Krejči, O., Burianková, K., Stránik, Z., 2000. Petrography, geochemistry and age of granitic pebbles from the Moravian part of the Carpathian Flysch. Pol. Tow. Mineral. Prace Spec. 17, 156–158.
Haq, B.U., 2014. Cretaceous eustasy revisited. Glob. Planet. Chang. 113, 44–58.
Haq, B.U., Hardenbol, J., Vail, P.R., 1987. Chronology of fluctuating sea levels since the Triassic (250 million years ago to present). Science 235, 1156–1167.
Hrouda, F., Krejčí, O., Potfaj, M., Stráník, Z., 2009. Magnetic fabric and weak deformation in sandstones of accretionary prisms of the Flysch and Klippen Belts of the Western Carpathians: mostly offscraping indicated. Tectonophysics 479, 254–270.
Jankowski, L., Kopciowski, R., 1999. Correlation of the Magura and Dukla units of the Polish-Slovak border area. Biuletyn Państwowego Instytutu Geologicznego, Warszawa 387, 106–114.
Jucha, S., Kotlarczyk, J., 1958. Próba nowego podziału stratygraficznego serii menilitowej i warstw krośnieńskich. Nafta 14, 205–207.
Jurewicz, E., 2018. The Šariš Transitional Zone, revealing interactions between Pieniny Klippen Belt, Outer Carpathians and European platform. Swiss J. Geosci. 111, 245–267.
Kaczmarek, A., Oszczypko-Clowes, M., Cieszkowski, M., 2016. Early Miocene age of Stare Bystre Formation (Magura Nappe, Outer Carpathians, Poland) indicated by the

calcareous nannoplankton. Geological Quarterly 60, 341–354.
Kázmér, M., Dunkl, I., Frisch, W., Kuhlemann, J., Ozsvárt, P., 2003. The Palaeogene forearc basin of the Eastern Alps and Western Carpathians: subduction erosion and basin evolution. J. Geol. Soc. Lond. 160, 413–428.
Kender, S., Kaminski, M.A., Cieszkowski, M., 2005. Foraminifera from the Eocene Variegated Shales near Barwinek (Magura Unit, Outer Carpathians), the type locality of Noth (1912) revisited. Ann. Soc. Geol. Pol. 75, 249–272.
Koszarski, L., Sikora, W., Wdowiarz, S., 1974. The Flysch Carpathians. Polish Carpathians. In: Maheľ, M. (Ed.), Tectonics of the Carpathian-Balkan Regions. Geologický Ústav Dionýza Štúra, Bratislava, pp. 180–197.
Kováč, M., Plašienka, D., Soták, J., Vojtko, R., Oszczypko, N., Less, G., Ćosović, V., Fügenschuh, B., Králiková, S., 2016. Paleogene palaeogeography and basin evolution of the Western Carpathians, Northern Panonian domain and andjoined areas. Glob. Planet. Chang. 140, 9–27.
Kováčik, M., Bóna, J., Gazdačko, Ľ., Kobulský, J., Maglay, J., Žecová, K., Derco, J., Zlinská, A., Siráňová, Z., Boorová, D., 2012. Explanation to the Geological Map of the Nízke Beskydy Mts. – Western Part at Scale 1: 50,000. Bratislava, Slovakia, SGÚDŠ.
Krs, M., Krsová, M., Chvojka, R., Potfaj, M., 1991. Palaeomagnetic investigations of the flysch belt in the Orava region, Magura Unit, Czechoslovak Western Carpathians. Geologické práce, Správy 92, 135–151.
Książkiewicz, M., 1953. Karpaty flyszowe między Olzą a Dunajcem. Reg. Geol. Pol., Karpaty, Tektonika 1, 2, Pol. Tow. Geol., Krakow, 305–360.
Książkiewicz, M., 1958. Stratygrafia serii magurskiej w Beskidzie Średnim. Stratigraphy of the Magura series in the Średni Beskid (Carpathians) (in Polish, English summary). Biuletyn Instytutu Geologicznego 135, 43–96.
Książkiewicz, M. (ed.), 1962. Atlas geologiczny Polski. Zagadnienia stratygraficzno-facjalne. Zeszyt 13, Kreda i starszy trzeciorzęd w polskich Karpatach zewnętrznych. 1: 600 000. Instytut Geologiczny, Warszawa.
Książkiewicz, M., 1965. Les Cordilléres dans les mers crétacées et paleogenes des Carpathes du Nord. Bull. Soc. Géol. France 7, 443–455.
Książkiewicz, M., 1966. Geologia Regionu babiogórskiego. Przewodnik XXXIX. zjazdu Polskiego Towarzystwa geologicznego, Babia Góra, Warszawa, Wydawnictwa Geologiczne, pp. 5–58.
Książkiewicz, M., 1974. Objaśnienia do Szczególowej mapy geologicznej Polski w skali 1:50 000, ark. Sucha Beskidzka, Wydawnictwa Geologiczne, Warszawa.
Książkiewicz, M., 1975. Bathymetry of the Carpathian Flysch Basin. Acta Geol. Pol. 25 (3), 309–367.
Książkiewicz, M., 1977. Trace fossils in the flysch of the Polish Carpathians. Acta Palaeontol. Pol., 36, 208 p.
Laurinc, D., Teťák, F., 2017. Petrographic evaluation of sandstones from the Biela Orava region (Magura Group of Nappes, Outer Western Carpathians) (in Slovak). Geologické práce, Správy 130, 29–46.
Leško, B., Samuel, O., 1968. Geológia východoslovenského flyšu – Vydavateľstvo Slovenskej akademie vied, Bratislava, 245 p.
Lexa, J., Bezák, V., Elečko, M., Mello, J., Polák, M., Potfaj, M., Vozár, J., 2000. Geological map of Western Carpathians and adjacent areas 1: 500 000. Geological Survey of Slovak Republic.
Madzin, J., Plašienka, D., Méres, Š., 2019. Provenance of synorogenic deposits of the Upper Cretaceous-Lower Palaeogene Jarmuta-Proč Formation (Pieniny Klippen Belt, Western Carpathians). Geol. Carpath. 70 (1), 15–34.
Marschalko, R., 1975. Sedimentologický výskum paleogénnych zlepencov bradlového pásma a prilahlých tektonických jednotiak a prostredie ich vzniku: Východné Slovensko. Náuka o Zemi, Séria Geológia, 9, 148 p.
Marschalko, R., Potfaj, M., 1982. Sekvenčná analýza, paleoprúdenie a prostredie uloženia spodnoeocénneho flyšu Oravskej Magury a bradlového pásma. Geologické práce, Správy 78, 97–122.
Marschalko, R., Mišík, M., Kamenický, L., 1976. Petrographie der Flysch-Konglomerate und Rekonstruktion ihrer Ursprungazonen (Paläogen der Klippenzone und der angrenzenden tektonischen Einheiten der Slowakei). Západné Karpaty, Geológia 1, 7–124.
Márton, E., Grabowski, J., Tokarski, A., Túnyi, I., 2015. Palaeomagnetic results from the fold and thrust belt of the Western Carpathians: an overview. In: Pueyo, E. L., Sussman, A. J., Oliva-Urcia, B., Cifelli, F. (eds): Palaeomagnetism in fold and thrust belts: New Perspectives. Geological Society, London, Special Publications 425, 259–276.
Matějka, A., Roth, Z., 1952. Zpráva o výzkumu magurského flyše v povodí Bílé Oravy. Věstník Ústř. Úst. geol., 27, Praha, 212–216.
Matějka, A., Roth, Z., 1956. Geologie magurského flyše v severním povodí Váhu mezi Bytčou a Trenčínem. S mikrobiostratigrafickou statí Evy Hanzlíkové. V Praze, Nakladatelství Československé akademie věd, 332 p.
Mišík, M., 1996. O sedimentačnom priestore klapskej jednotky (in Slovak). Mineralia Slovaca 28 (1), 73–75.
Mišík, M., Sýkora, M., Jablonský, J., 1991a. Strihovské zlepence a Juhomagurská Kordilera. Západné Karpaty, Série Geológia 14, 7–72.
Mišík, M., Sýkora, M., Mock, R., Jablonský, J., 1991b. Paleogene Proč Conglomerates of the Klippen Belt in the West Carpathians, material from Neopieninic Exotic Ridge. Acta Geologica et Geographica Universitatis Comenianae, Geologica 46, 9–101.
Mutti, E., Rocci-Lucchi, F., 1972. Turbidites of northern Apenines: introduction to facies analysis. Int. Geol. Rev. 20, 125–166.
Nemčok, M., Nemčok, J., Wojtaszek, M., Ludhová, L., Klecker, R. A., Sercombe, W. J., Coward, M. P. and Keith, J. F., 2000. Results of 2D balancing along 20o and 21o30´ longitude and pseudo-3D in the Smilno tectonic window: Implications for shortening mechanisms of the West Carpathian accretionary wedge. Geologica Carpathica, 51, 5, Bratislava, 281–300.
Olszewska, B., Oszczypko, N., 2010. The geological position, sedimentary record and composition of the Tylicz Conglomerate (Late Eocene–Oligocene): stratigraphical and paleogeographical implications (Magura Nappe, Polish Outer Carpathians). Geol. Carpath. 61, 39–54.
Oszczypko, N., 1991. Stratigraphy of the Paleogene deposits of the Bystrica Subunit (Magura Nappe, Polish Outer Carpathians). Bulletin of the Polish academy of sciences, Earth sciences 39 (4), 415–433.
Oszczypko, N., 1992. Zarys stratigrafii plaszczowiny magurskiej (Stratigraphy of the Magura Nappe, Polish Flysch Carpathians). Przewodnik LXIII zjazdu PTG, Krakow, pp. 11–29.
Oszczypko, N., 2006. Late Jurassic-Miocene evolution of the Outer Carpathian fold-and-thrustbelt and its foredeep basin (Western Carpathians, Poland Geological Quarterly, 50, 1, 169–194.
Oszczypko, N., Oszczypko-Clowes, M., 2009. Stages in the Magura Basin: a case study of the Polish sector (Western Carpathians). Geodin. Acta 22 (1–3), 83–100.
Oszczypko, N., Salata, D., 2005. Provenance analyses of the Late Cretaceous Palaeocene deposits of the Magura Basin (Polish Western Carpathians) – evidence from a study of the heavy minerals. Acta Geol. Pol. 55, 237–276.
Oszczypko, N., Malata, E., Bąk, K., Kędzierski, M., Oszczypko-Clowes, M., 2005a. Lithostratigraphy and Biostratigraphy of the Upper Albian-Lower/Middle Eocene Flysch deposits in the Bystrica and Rača Subunits of the Magura Nappe; Western Carpathians (Beskid Wyspowy and Gorce Rages, Poland). Ann. Soc. Geol. Pol. 75, 27–69.
Oszczypko, N., Oszczypko-Clowes, M., Golonka, J., Marko, F., 2005b. Oligocene-Lower Miocene sequences of the Pieniny Klippen Belt and adjacent Magura Nappe between Jarabina and the Poprad River (East Slovakia and South Poland): their tectonic position and palaeogeographic implications. Geological Quarterly 49 (1), 307–402.
Oszczypko, N., Oszczypko-Clowes, M., Salata, D., 2006. Exotic rocks of the Krynica Zone (Magura nappe) and their palaeogeographic significance (in Polish). Geologia, 21, 32, 1, 21–45.
Oszczypko, N., Ślączka, A., Oszczypko-Clowes, M., Olszewska, B., 2015. Where was the Magura Ocean? Acta Geol. Pol. 65 (3), 319–344.
Oszczypko, N., Salata, D., Konečný, P., 2016. Age and provenance of mica-schist pebbles from the Eocene conglomerates of the Tylicz and Krynica Zone (Magura Nappe, Outer Flysch Carpathians). Geol. Carpath. 67 (3), 257–271.
Panaiotu, C., 1998. Paleomagnetic constraints on the geodynamic history of Romania. In: Monograph of Southern Carpathians (J. Sledzinski, ed.), Warsaw Univ. Tech., Rept. Geodesy, 7, 37, 205–216.
Paul, Z., 1980. Description to the Detailed Geological Map of Poland in scale 1: 50 000 (in Polish). Sheet Łącko (1034). Wyd. Geol., Warszawa, 1–58.
Pelech, O., Hók, J., Havrila, M., Pešková, I., 2016. Structural position of the Upper Cretaceous sediments in the Považský Inovec Mts. (Western Carpathians). Acta Geologica Slovaca 8 (1), 43–58.
Pešková, I., Hók, J., Potfaj, M., Vojtko, R., 2012. Structural interpretation of the Varín and Orava segment of the klippen belt (in Slovak). Geologické práce, Správy 120, 51–64.
Pesl, V., 1964. Litofaciální zhodnocení paleogenních sérií vnitřních jednotek magurského flyše. Závěrečná zpráva, Československé naftové doly – Výzkumný ústav Brno, Manuskript – archív Geofondu, ŠGÚDŠ, Bratislava 86.
Pesl, V., 1968. Litofacie paleogénu v magurské jednotce vnějších flyšových karpat na území ČSSR a PLR (in Czech, English summary). Sborník geologických vied – ZK 9, 71–118.
Pesl, V. (edit), 1981. Vysvětlivky k základní geologické mapě ČSSR 1 : 25 000, 25-212 Fryšták. Manuscript, Geofond, Praha.
Pettijohn, F.J., Potter, P.E., Siever, R., 1972. Sand and Sandstones, New York Springer-Verlag, 618 p.
Picha, F.J., Stráník, Z., Krejčí, O., 2006. Geology and Hydrocarbons Resources of the Outer Carpathians and their foreland, Czech Republic. In Golonka, J., Pícha, F.J. (eds.), The Carpathians and their foreland: Geology and hydrocarbon resources. American Association of Petroleum Geologists, Memoir, 84, 49–175.
Pickering, K.T., Stow, D., Watson, M., Hiscott, R.N., 1986. Deep water facies, processes and models: a reviev and classification scheme for modern and ancient sediments. Earth Sci. Rev. 23, 75–174.
Piotrowski, J., Piotrowska, K., 2004. Słownik jednostek litostratygraficznych Polski, wersja podstawowa. Tom III: jednostki formalne mezozoiku i kenozoiku. docplayer.pl/14038220-Slownik-jednostek-litostratygraficznych-polski.html.
Pivko, D., 1998. Cycles of different scale in the turbidites of the Magura nappe on the northern Orava, Western Carpathians (Campanian – Upper Eocene). Slovak Geological Magazine 4 (2), 95–106.
Pivko, D., 2000. Geologická stavba a vývoj územia okolia Pilska na severnej Orave (in Slovak). Manuscript, Katedra geológie a paleontológie, Prírodoved. fakulta UK Bratislava, 131 p. Pivko, D., 2000. Litostratigraphic and facies division of the Flysch units, Outer Western Carpathians (northern Orava, Slovakia). Slovak Geological Magazine 6 (2–3), 158–164.
Pivko, D., 2002. Geology of Pilsko mountain and surroundings (Flysch belt on northern Orava). Acta Geologica Universitatis Comenianae 57, 67–94.
Pivko, D., Beňuška, P., Korábová, K., Kováčik, M., Potfaj, M., Siráňová, Z., Vranovská, A., 1991. Explanatory notes to Geological map of Pilsko Mts. surroundings 1: 25 000 on 26-142 Mútne and 26-231 Oravské Veselé sheets (in Slovak). Research report, Manuscript GÚDŠ, Bratislava, 78 p.
Plašienka, D., 1995. Mesozoic evolution of Tatric units in the Malé Karpaty and Považský Inovec Mts.: implication of the Klape and related units in Western Slovakia. Geol. Carpath. 46 (2), 101–112.
Plašienka, D., 1996. Kryptické chrbty, alebo kolízne orogénne pásma? (in Slovak) Mineralia Slovaca, 28, 1, 75–79.
Plašienka, D., 2012. Jurassic syn-rift and Cretaceous syn-orogenic, coarse-grained deposits related to opening and closure of the Vahic (South Penninic) Ocean in the Western Carpathians – an overview. Geological Quarterly 56 (4), 601–628.
Plašienka, D., 2014. The Šariš Unit in the structure and evolution of the Pieniny Klippen

Belt (Western Carpathians). In: J. Bučová and Ľ. Puškelová (Eds), Conference of Environmental, Structural, and Stratigraphic Evolution of the Western Carpathians 5-7. 11.2014 Abstract Book of 9th ESSEWECA. Prírodovedecká fakulta Univerzita Komenského, Bratislava, 49–51.
Plašienka, D., 2018. The Carpathian Klippen Belt and types of its klippen – an attempt at a genetic classification. Mineralia Slovaca 50, 1–24.
Poprawa, P., Malata, T., 2006. Model późnojurajsko-wczesnomioceńskiej ewolucji tektonicznej zachodnich Karpat zewnętrznych. Prz. Geol. 54 (12), 1066–1080.
Poprawa, P., Malata, T., Oszczypko, N., 2002. Ewolucja tektoniczna basenów sedymentacyjnych polskiej części Karpat zewnętrznych w świetle analizy subsydencji. Prz. Geol. 50 (11), 1092–1108.
Poprawa, P., Malata, T., Pécskay, Z., Banaoe, M., Skulich, J., Paszkowski, M., Kusiak, M., 2004. Geochronology of crystalline basement of the Western Outer Carpathians' sediment source areas – preliminary data. Mineralogical Society of Poland, Special Papers 24, 329–332.
Poprawa, P., Malata, T., Oszczypko, N., Słomka, T., Golonka, J., Krobicki, M., 2006. Tectonic activity of sediment source areas for the Western Outer Carpathian basins – constraints from analysis of sediment deposition rate (in Polish). Prz. Geol. 54, 878–887.
Potfaj, M., 1989. Vychyľovka Formation – new lithostratigraphic unit in Magura flysch (Paleogene of Kysuce and Orava) (in Slovak, English summary). Spr. o geol. výsk., GÚDŠ, Bratislava, pp. 43–49.
Potfaj, M., 1993. Postavenie bielokarpatskej jednotky v rámci flyšového pásma Západných Karpát. Geologické práce, Správy 98, 55–78.
Potfaj, M. (ed.), Šlepecký, T., Maglay, J., Hanzel, V., Boorová, D., Žecová, K., Kohút, M., Nagy, A., Teťák, F., Vass, B., Sandanus, M., Buček, S., Sýkora, M., Köhler, E., Fejdiová, O., Kandera, K., Samuel, O., Bubík, M., Beleš, F., 2003. Vysvetlivky ku geologickej mape regiónu Kysuce 1: 50 000. ŠGÚDŠ, Bratislava, 193 p.
Potfaj, M., Marschalko, R., 1981. Faciálna analýza magurských pieskovcov na Orave. Zborník referátov IV. Slovenskej geologickej konferencie, sekcia 4, zv. 3, SGÚ Dom techniky, Bratislava, 79–83.
Potfaj, M., Samuel, M., Raková, J., Samuel, O., 1991. Geologická stavba Kubínskej hole (Orava). Geologic structure of Kubínska hoľa range (Orava) (in Slovak, English summary). Západné Karpaty, Séria geológia 15, 25–66.
Roth, Z., Benešová, E., Čechovič, V., Eliáš, M., Hanzlíková, E., Chmelík, F., Matějka, A., Pícha, F., 1963. Vysvetlivky k prehľadnej geologickej mape ČSSR 1: 200 000, list M-34-XX list Trstená. Geofond, Bratislava, 7–59.
Ryłko, W., 1992. Litostratygrafia osadów płaszczowiny magurskiej w południowo-wschodniej części Beskidu Żywieckiego (Karpaty Zewnętrzne). Biuletyn Państwowego Instytutu Geologicznego 368, 37–63.
Salata, D., Oszczypko, N., 2010. Preliminary results of provenance analyses of exotic magmatic and metamorphic rock pebbles from the Eocene flysch deposits of the Magura Nappe (Krynica facies zone, Polish Outer Carpathians). Scientific Annals, School of Geology, Aristotle University of Thessaloniki, Proceedings of the XIX CBGA Congress, Special volume 100, 241–248.
Schmid, S.M., Bernoulli, D., Fügenschuh, B., Matenco, L., Schefer, S., Schuster, R., Tischler, M., Ustaszewski, K., 2008. The Alpine-Carpathian-Dinaridic orogenic system: correlation and evolution of tectonic units. Swiss J. Geosci. 101 (1), 139–183.
Schnabel, G.W., 1992. New data on the Flysch Zone of the Eastern Alps in the Austrian sector and new aspects concerning the transition to the Flysch Zone of the Carpathians. Cretac. Res. 13 (5–6), 405–419.
Sikora, W., Żytko, K., 1959. Budowa Beskidu Wysokiego na południe od Żywca. Biuletyn Państwowego Instytutu Geologicznego 141, 60–204.
Ślączka, A., 2005. Bukowiec Ridge: a cordillera in front of the Dukla Basin (Outer Carpathians). Mineralia Slovaca 37, 255–256.
Ślączka, A., Krugłow, S., Golonka, J., Oszczypko, N., Popadyuk, I., 2006. Geology and hydrocarbon resources of the Outer Carpathians, Poland, Slovakia, and Ukraine: general geology. In Golonka, J., Picha, F.J. (eds.), The Carpathians and their foreland: Geology and hydrocarbon resources. American Association of Petroleum Geologists, Memoir, 84, 49–175.
Soták, J., 1990. Study of Mesozoic rocks in flysch zones and its contribution to information about microfacies, paleogeography and paleotectonics of Western Carpathians. Sedimentologické problémy Západných Karpat. Geologický Ústav Dionýza Štúra 45–68.
Soták, J., 1992. Evolution of the Western Carpathian suture zone - principal geotectonic events. Geol. Carpath. 43 (6), 355–362.
Sotak, J., Biroň, A., Prokešová, R., Spišiak, J., 2000. Detachment control of core complex exhumation and back-arc extension in the East Slovakian Basin. Slovak Geological Magazine 6 (2–3), 130–132.
Stráník, Z., 1965. Geologie magurského flyše Čerhovského pohoří a západní části Ondavské vrchoviny. Sborník geologických vied – Západné Karpaty 3, 125–173.
Studer, B., 1827a. Geognostische Bemerkungen über einige Theile der nordlichen Alpenkette. Zeitschrift für Mineralogie 1–46.
Studer, B., 1827b. Notice geognostique sur quelques parties de la chaine de Stockhorn et sur la houille du Siemmenthal, canton Berne. Ann. Sci. Nat. 11, 249–265.
Świdziński, H., 1961. La Serie de Richvald dans les Karpates Flysches. Bulletin of the Polish academy of sciences, Ser. Sci. Geol. Geogr., 9, 2, 109–119.
Teťák, F., 2005. Sedimentácia glaukonitových a kýčerských pieskovcov zlínskeho súvrstvia v západnej časti magurského bazénu (Javorníky, Kysuce) (in Slovak). Mineralia Slovaca 37 (3), 304–306.
Teťák, F., 2008. Paleogene depositional systems and paleogeography of the submarine fans in the western part of the Magura Basin (Javorníky Mountains, Slovakia). Geol. Carpath. 59 (4), 333–344.
Teťák, F., 2010. The gravity flow dynamics of submarine fan sedimentation in the Magura Basin of the Western Carpathians (Magura Nappe, Slovakia). Geol. Carpath. 61 (3), 201–209.
Teťák, F., 2016. Biele Karpaty Unit, geological structure and development west of Veľká Javorina Mt. (in Slovak). Štúdio F, 32 p.
Teťák, F., 2018. Simple processing and retilting of the oriented lineations and its application in paleocurrent analysis. Mineralia Slovaca 50, 47–54.
Teťák, F. (ed.), Kováčik, M., Pešková, I., Nagy, A., Buček, S., Maglay, J., Vlačiky, M., 2016a. Geological map of the Biela Orava region, in scale 1: 50 000. State Geological Institute of Dionýz Štúr, Bratislava.
Teťák, F. (ed.), Kováčik, M., Pešková, I., Nagy, A., Buček, S., Maglay, J., Vlačiky, M., Laurinc, D., Žecová, K., Zlinská, A., Liščák, P., Marcin, D., Žilka, A., Kucharič, Ľ., Gluch, A., Baláž, P., 2016b. Explanations to the geological map of the Biela Orava region in scale 1 : 50 000 (in Slovak, English summary). State Geological Institute of Dionýz Štúr, Bratislava, 217 p.
Teťák, F., Martin, K., Pešková, I., Nagy, A., Buček, S., Maglay, J., Vlačiky, M., Laurinc, D., Žecová, K., Zlinská, A., Liščák, P., Marcin, D., Žilka, A., Kucharič, Ľ., Gluch, A., Baláž, P., 2016c. Geologická mapy regiónu Biela Orava v mierke 1: 50 000 (in Slovak). Záverečná správa, manuskript – archív Geofondu, Št. geol. úst. D. Štúra, Bratislava.
Teťák, F., Cieszkowski, M., Golonka, J., Waśkowska, A., Szczęch, M., 2017. The Ropianka Formation of the Bystrica Zone (Magura Nappe, Outer Carpathians): proposal for a new reference section in northwestern Orava. Ann. Soc. Geol. Pol. 87 (3), 257–272.
Watycha, L., 1976. Objaśnienia do szczegółowej mapy geologicznej Polski, arkusz Nowy Targ 1:50 000. Instytut Geologiczny, Warszawa, 101p.
Winchester, J.A., Pharaoh, T.C., Verniers, J., 2002. Palaeozoic amalgamation of Central Europe: an introduction and synthesis of new results from recent geological and geophysical investigations. Geol. Soc. Lond., Spec. Publ. 201, 1–18.
Winkler, W., Ślączka, A., 1994. A late Cretaceus to Paleogene geodynamic model for the Western Carpathians in Poland. Geologica Carpathica, Bratislava 45 (2), 71–82.
Wójcik, A., Jankowski, L., Kopciowski, R., Malata, T., Marciniec, P., Nescieruk, P., 1995. Opracowanie formalnych jednostek litostratygraficznych Karpat zewnętrznych i zapadliska dla celów Szczegółowej Mapy Geologicznej Polski. Archiwum Państwowego Instytutu Geologicznego, Kraków, 121 p.
Wójcik, E., Zielińska, M., Chybiorz, R., Żaba, J., 2018. Depositional architecture of marginal multiple-source ramp of the Magura Basin (Eocene Flysch formation, Outer Western Carpathians). Geol. Carpath. 69 (4), 347–364.
Zachos, J.C., Dickens, G.R., Zeebe, R.E., 2008. An Early Cenozoic perspective on greenhouse warming and carbon-cycle dynamics. Nature 451, 279–283.