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Where was the Magura Ocean?

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ABSTRACT:

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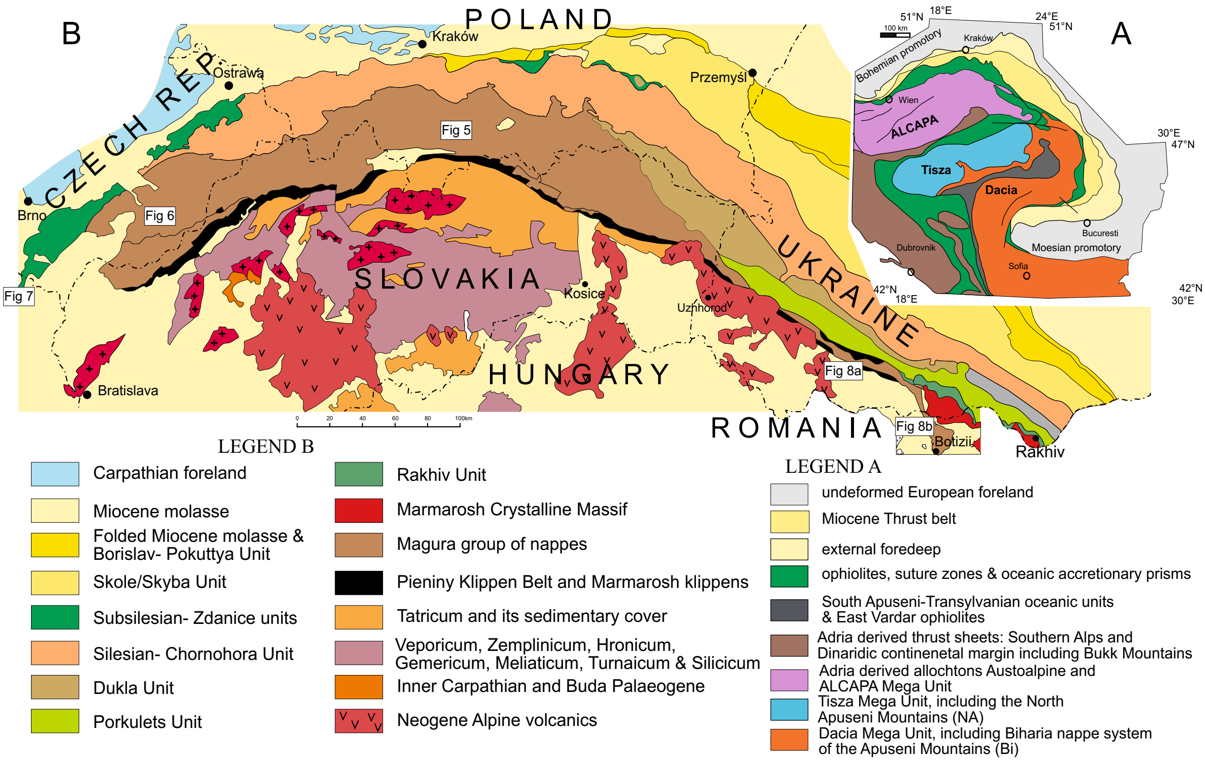
In the Late Jurassic to Early Cretaceous palaeogeography of the Alpine Tethys the term Ocean is used for different parts of these sedimentary areas: eg. Ligurian – Piedmont and Penninic, Magura, Pieniny, Valais and Ceahlau-Severins oceans. The Magura Ocean occupied the more northern position in the Alpine-Carpathian arc. During the Late Cretaceous–Paleogene tectono-sedimentary evolution the Magura Ocean was transformed into several (Magura, Dukla, Silesian, sub-Silesian and Skole) basins and intrabasinal source area ridges now incorporated into the Outer Western Carpathians.

Key words: Cenozoic, Outer Western Carpathians; Palaeogeography; Intrabasinal ridges; Basin development.

INTRODUCTION

The term Magura Ocean, understood as the eastern prolongation of the Ligurian – Piedmont and Penninic Ocean (eg. Puglisi 2009; 2014), is often used in the palaeogeographic and palaeotectonic reconstructions of the Outer Western Carpathians (Channell and Kozur 1997). More often the Magura Ocean is considered as the eastern extension of the Valais Ocean / North Pennic domain (Schmid *et al*. 2004; Sandulescu 2009; Ustaszewski *et al*. 2008; Schmid *et al*. 2008), although the presence of the Valais Ocean is also debatable (see Schmid *et al.* 2004). The concept of the Magura Ocean is usually used in reference to the Late Jurassic and Early Cretaceous (Birkenmajer 1986), but it is also used for the Late Cretaceous and even for the Paleogene (Frontzheim *et al*. 2008; Plašienka 2014; Kovač *et al*. in press). At the same time, terms such as the Magura Basin, Magura Nappe or the Magura Superunit are commonly used. Sometimes, the Magura Ocean and the Magura Basin are used interchangeably, causing confusion of their concepts. Whereas the terms Magura Basin and Magura Nappe are sufficiently well-defined, the spatial and temporal coverage of the Magura Ocean has not been defined in more detail.

The southern margin of the Magura Ocean is designated as the northern boundary of the Pieniny Klippen Belt (PKB), which separates the Central Western Carpathians (CWC, Cretaceous accretionary wedge) from the Outer Western Carpathias (OWC, Paleogene-Early Miocene accretionary wedge). The PKB is a 650 km long suture zone, but only a few kilometres wide (Text-figs 1A, B). Within the PKB, the northern edge of the CWC belonged to the Czorsztyn Unit (Ridge), while the Grajcarek Unit represented the



Text-fig. 1. A – Tectonic sketch-map of the Alpine–Carpathian-Pannonian area (after Schmid *et al.* 2008); B – Tectonic sketch-map of the Western Carpathians and adjacent Ukrainian Carpathians with location of lithostratigraphic logs of the Magura Nappe in Poland, Western Slovakia and Czech Republik (based on Oszczypko *et al.* 2005b)

southern, transitional (to the PKB basin), margin of the Magura Basin (Ocean). The aim of this study is to discuss what the Magura Ocean was and its location in space and time. As a benchmark, we chose the Małe Pieniny Mts in the Polish Outer Carpathians, where the transition zone between the Magura and PKB basins (Birkenmajer 1977, 1986) was first well-documented. In the study, we used our observations from the Outer Carpathians, from the Rhenodanubian Flysch Zone, as well as our recent results from the studies of the PKB.

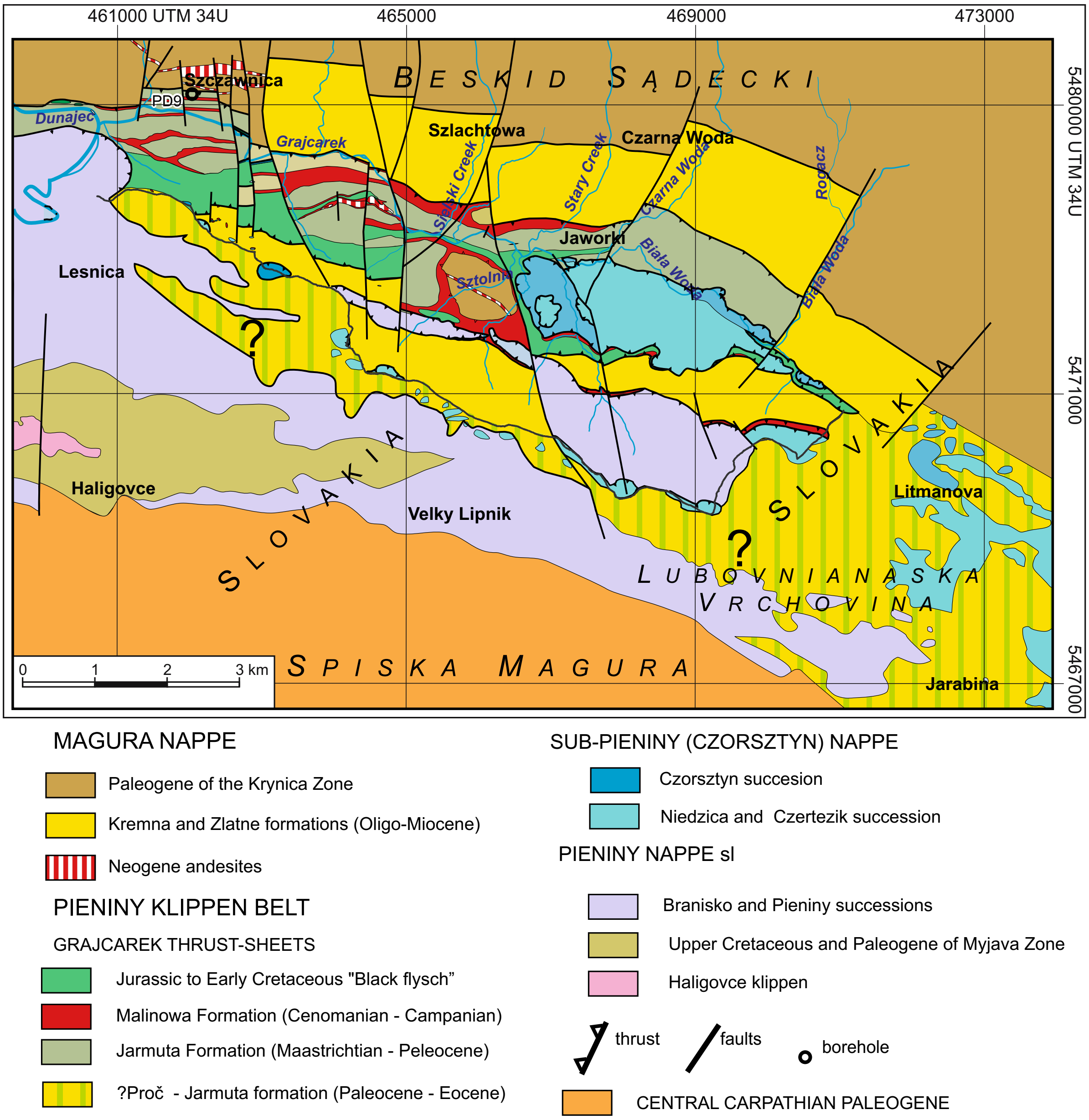
GRAJCAREK UNIT OF THE MAŁE PIENINY MTS (POLAND)

The Małe Pieniny Mts of the Polish Western Carpathians are located between the Dunajec River Valley to the west and the Polish/Slovak state boundary to the east (Text-fig. 2). In this area, the PKB is composed (from north to south) of the Grajcarek Unit and the Czorsztyn, Niedzica-Czertezik, Branisko and Pieniny klippen units of the PKB (Text-fig. 3). The Jurassic–Lower Cretaceous klippen units have a common mid-Upper Cretaceous sedimentary cover (Birkenmajer 1970, 1977, 1986).

The lower part of the Grajcarek succession (Text-fig. 4) is represented by manganiferous as well as red and green radiolarites, as known from the Szczawnica sections (Sikora 1971a, b). In these radiolarites, Nowak (1971) recognized two microfossil assemblages: (1) an older one, with *Nannoconus* ex gr. *steinmanni* Kamptner (late Tithonian) without lower Tithonian stomiosphaerids and calpionellids; and (2) a younger one (?Valanginian–Hauterivian), with *Nannoconus* div. sp. and *Cadosina* aff. *olzae* Nowak. Birkenmajer (1977, 1979, 2001) included the radiolarites into the Sokolica and Czajakowa formations (Bathonian–Oxfordian), followed by (very condensed) red Aptychus Marls of the Czorsztyn Formation (Kimmeridgian–Tithonian), cherty limestones of the Pieniny Formation (Tithonian–Barremian), spotty marls of the Kapuśnica Formation, and black marly shales of the Wronine Formation (Aptian–Cenomanian). Our recent studies (Oszczypko *et al.* 2012a; Oszczypko and Oszczypko-Clowes 2014, and references therein), based on foraminifers, documented that the Szczawnica-Zabaniszcze Upper Jurassic–Lower Cretaceous condensed deposits are overlain by the black flysch of the Szlachtowa Formation (Aptian–Albian). Completely different opinions are represented by Birkenmajer *et al.* (2008, and reference therein) and Gedl (2013, and references therein) who consider the Szlachtowa Formation as of Toarcian–Bajocian age.

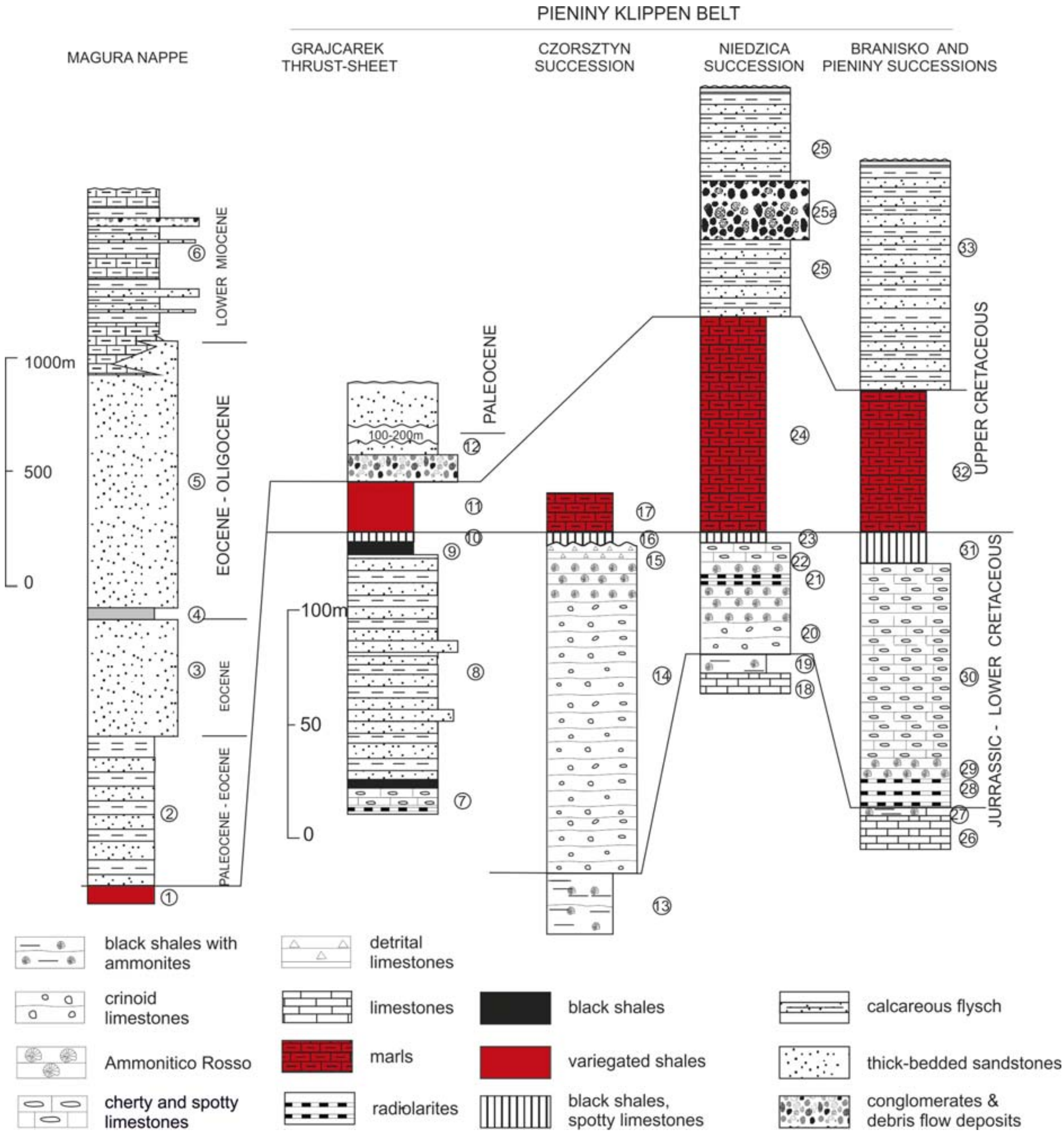
The total thickness of the Szlachtowa Formation is up to 220 m (Birkenmajer 1977; Birkenmajer *at al.* 2008), but in the PD-9 borehole, in Szczawnica (Birkenmajer *et al.* 1979), the partial thickness of the “Black Flysch” was about 310 m (120 m and 190 m of the Szlachtowa and Bryjarka formations, respectively). The Szlachtowa Formation is composed of turbiditic sandstones with intercalations of black and dark grey marly mudstones and shales. It is overlain by 10 to 16 m thick packets of light grey spotty shales and marls with pyrite concretions and sideritic limestone intercalations belonging to the Opaleniec Formation of Albian–Cenomanian age (Oszczypko *et al.* 2004, 2012a).

Between the Opaleniec and Malinowa formations, Oszczypko *et al*. (2012a) recognized red and green radiolarites followed by spotty limestones and marls with rare Late Albian calcdinocysts (*Colomisphaera* aff. *pokornyi* Řehánek, Oszczypko *et al*. in preparation) with intercalations of black and green shales followed by 1 m thick red and green shales (Bonarelli Horizon, Uchman *et al*. 2013). These strata, 3–10 m thick, were previously described by Sikora (1962, 1971a, b) as the “Cenomanian Key Horizon” (CKH) (Text-fig. 4).



Text-fig. 2. Geological sketch-map of the Małe Pieniny Mts and Lubovnianska Vrchovina Range with location of lithostratigraphic logs (based on Oszczypko *et al.* 2010 and Oszczypko and Oszczypko-Clowes 2014)

In Małe Pieniny, except for the Upper Jurassic/ Lower Cretaceous radiolarites and limestones of the Szczawnica section, there are several sections with radiolarites and cherty limestones without clear stratigraphical position. The majority of them have been interpreted (Birkenmajer 1977, 1979; Birkenmajer and Pazdrowa 1968) as tectonic blocks of Jurassic radiolarites, and of Tithonian–Barremian cherty limestone of the Pieniny Limestone type, derived from the Branisko Unit of the PKB. Our studies document that part of these small klippens belongs to the

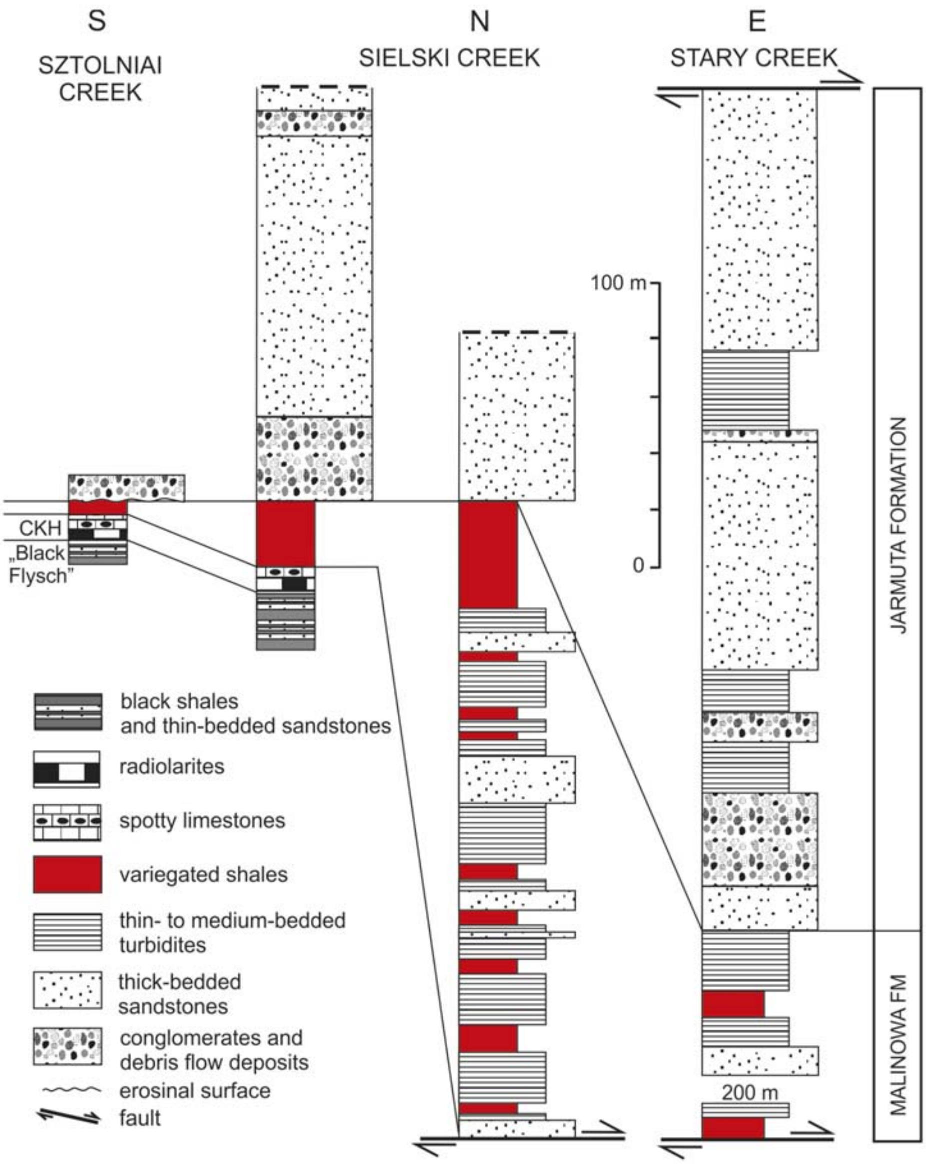


Text-fig. 3. Lithostratigraphic log of the Małe Pieniny Mts (based on Oszczypko and Oszczypko-Clowes 2014). Magura Nappe: (1) Malinowa Shale Formation, (2) Szczawnica and Zarzecze formations, Magura Formation; (3) Piwnicza Ss. Member, (4) Mniszek Shale Member, (5) Poprad Ss. Member, (6) Kremná Formation; Grajcarek thrust-sheets: (7) Czajakowa and Sokolica Rad. formations, Czorsztyn and Pieniny lms. formations, and Kapuśnica and Wronine formations, (8) Szlachtowa Formation, (9) Opaleniec Formation, (10) Cenomanian Key Horizon, (11) Malinowa Shale Formation, (12) Jarmuta Formation; Klippen successions (partly after Birkenmajer, 1977): Czorsztyn Succession: (13) Skrzypne Sh. Formation, (14) Smolegowa Lm. Formation and Krupianka Lm. Formation, (15) Czorsztyn, Dursztyn, Lysa and Spis limestones formations, (16) Chmielowa and Pomiedznik formations, (17) Jaworki Marls; Niedzica Succession: (18) ?Krempachy Marl Formation, (19) ?Skrzypne Shale Formation, (20) Smolegowa, Krupianka and Niedzica limestones formations, (21) Czajakowa Rad. Formation, (22) Czorsztyn and Dursztyn Limestone formations, Pieniny Limestone Formation, (23) Kapuśnica Formation, (24) Jaworki Marl Formation, (25) Sromowce Formation, (25 a) Bukowiny Gravelstone Member; Branisko and Pieniny successions: (26) ?Krempachy Marl Formation, (27) ?Skrzypny Shale Formation, (28) Czajakowa and Sokolica Rad. formatios, (29) Czorsztyn Lm. Formation, (30) Pieniny Limestone Formation, (31) Kapuśnica Formation, (32) Jaworki Marl Formation, (33) Sromowce Formation

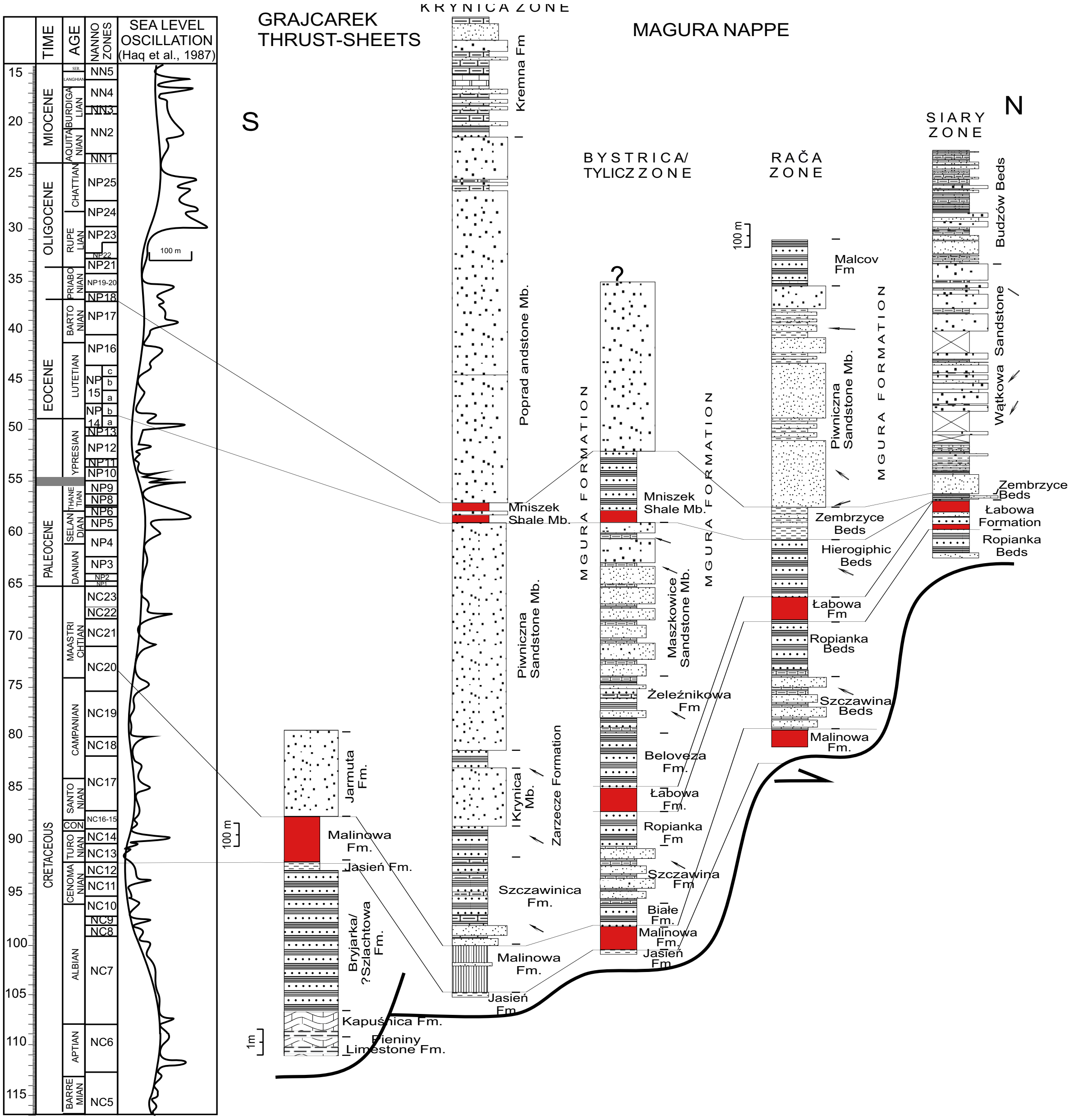
CKH of the Grajcarek Unit (Oszczypko *et al*. 2012a; Oszczypko and Oszczypko-Clowes 2014).

The CKH passes upwards into the Malinowa Formation (Text-fig. 4), composed of non-calcareous red and green argillaceous shales, sometimes replaced by massive red marls (in the Sztolnia sections; Oszczypko *et al*. 2012a). The thickness of the Malinowa Formation varies from a few metres on the southern slope of the Jarmuta Mt., 20–70 m in the Grajcarek Creek sections, up to 220–250 m in the Sielski and Stary creeks (Text-fig. 4). This formation, of Turonian–Campanian age (Oszczypko *et al*. 2012a), was deposited beneath the CCD level, at a depth of around 4 km (Uchman *et al*. 2006).

The Malinowa Formation is overlain by coarse-clastic deposits of the Jarmuta Formation (Birkenmajer 1977, see also Text-figs 2–4), distributed along the northern edge of the PKB. Locally the variegated shales are intercalated with Jarmuta-type sandstones and conglomerates. The typical Jarmuta Formation is represented by thick-bedded turbidites (0.5–5 m thick), conglomerates and sandstones with subordinate intercalations of grey marly shales. In the mouth of the Sielski and Grajcarek creeks and along the lower reaches of Czarna Woda Creek (Oszczypko *et al.* 2012a) the basal portion of the Jarmuta Formation contains debris flow paraconglomerates with clasts of red shales, and blocks of limestones and radiolarites. Fine-grained



Text-fig. 4. Lithostratigraphic logs of the Grajcarek Unit in the Małe Pieniny Mts (based on Oszczypko and Oszczypko-Clowes 2014)



Text-fig. 5. Lithostratigraphic logs of the Magura Nappe in Poland (based on Oszczypko and Oszczypko-Clowes 2010, supplemented)

conglomerates comprise clusters of dark ?Upper Cretaceous limestones as well as of Triassic and Jurassic dark organodetrital limestones.

An extremely rich set of clasts of Mesozoic rocks of the PKB is known from exposures near the church in Jaworki (Birkenmajer 1979, 2001). These rocks can be correlated with coarse-grained mass-flow deposits with huge slide block of the Milpoš Breccia of the Šariš (Grajcarek) Unit in the Litmanova–Jarabina area (Text-fig. 2; see Plašienka and Mikuš 2010; Plašienka 2012).

According to Birkenmajer and Wieser (1990), the Jarmuta conglomerates from the Biała Woda section are dominated by volcanic rocks and carbonates as well as sedimentary clastics. In the Szczawnica and Biała Woda sections, heavy mineral assemblages of the Jarmuta Formation contain a relatively high content of chromian spinels of ophiolite provenance (Oszczypko and Salata 2005). The thickness of the formation varies widely from about 100 metres north of the Grajcarek Valley, to several tens of metres in the Grajcarek Valley, and up to 400 metres north of this valley. The Jarrmuta Formation is regarded as of Maastrichtian–Middle Paleocene age (Birkenmajer 1977; Birkenmajer *et* *al*. 1987). Palaeocurrent analysis of the Jarmuta Formation turbidites shows the supply of clastic material to have come from the SE, whereas the clasts of the debris flow conglomerates came directly from the PKB erosion (Laramian uplift).

THE MAGURA NAPPE (POLAND)

The Magura Nappe is the biggest and innermost tectonic unit of the Outer Western Carpathians. The width of the Magura Nappe in Poland is around 50 km. Its northern boundary is erosional and its southern boundary, along the PKB, is tectonic. The Magura Nappe, completely uprooted from its basement, is thrust sub-horizontally over the more external flysch units, which also appear in tectonic windows. The amplitude of the overthrust is not less than 55 km. The Magura Nappe, up to 2 km thick, is composed mainly of Maastrichtan–Paleogene siliciclastic flysch deposits (Text-figs 3, 5). This nappe is sub-divided into five facies/tectonic sub-units. From south to north, these are: the Krynica, Sącz (Bystrica), Rača and Siary sub-units (Text-fig. 5). The basal portion of the Magura Nappe consists of Turonian–Campanian red and green shales of the Malinowa Formation, equivalent of the Malinowa Formation of the Grajcarek Unit. In the Polish sector of the Magura Nappe, deposits older than the Turonian, represented by 5–10 m thick green and black shales (? Albian–Cenomanian), are known only from a few places, located mainly around the Mszana Dolna tectonic windows (Oszczypko *et al*. 2005a).

The youngest deposits of the Magura Nappe are Oligocene to Early Miocene flysch (Oszczypko-Clowes and Oszczypko 2004). Associated facially with the Magura succession is the succession of the southern Fore-Magura scale, exposed in front of the Magura Nappe, west of Żywiec (Burtan and Sokołowski 1956). This scale, only several hundred metres wide, was included by Książkiewicz (1977) in the Magura Nappe. The same facies development is also shown in the so-called Łużna and Harklowa outliers, near the town of Gorlice. Consequently, they are regarded as a prolongation of the Fore-Magura Unit.

THE MAGURA NAPPE (WESTERN SLOVAKIA AND CZECH REPUBLIC)

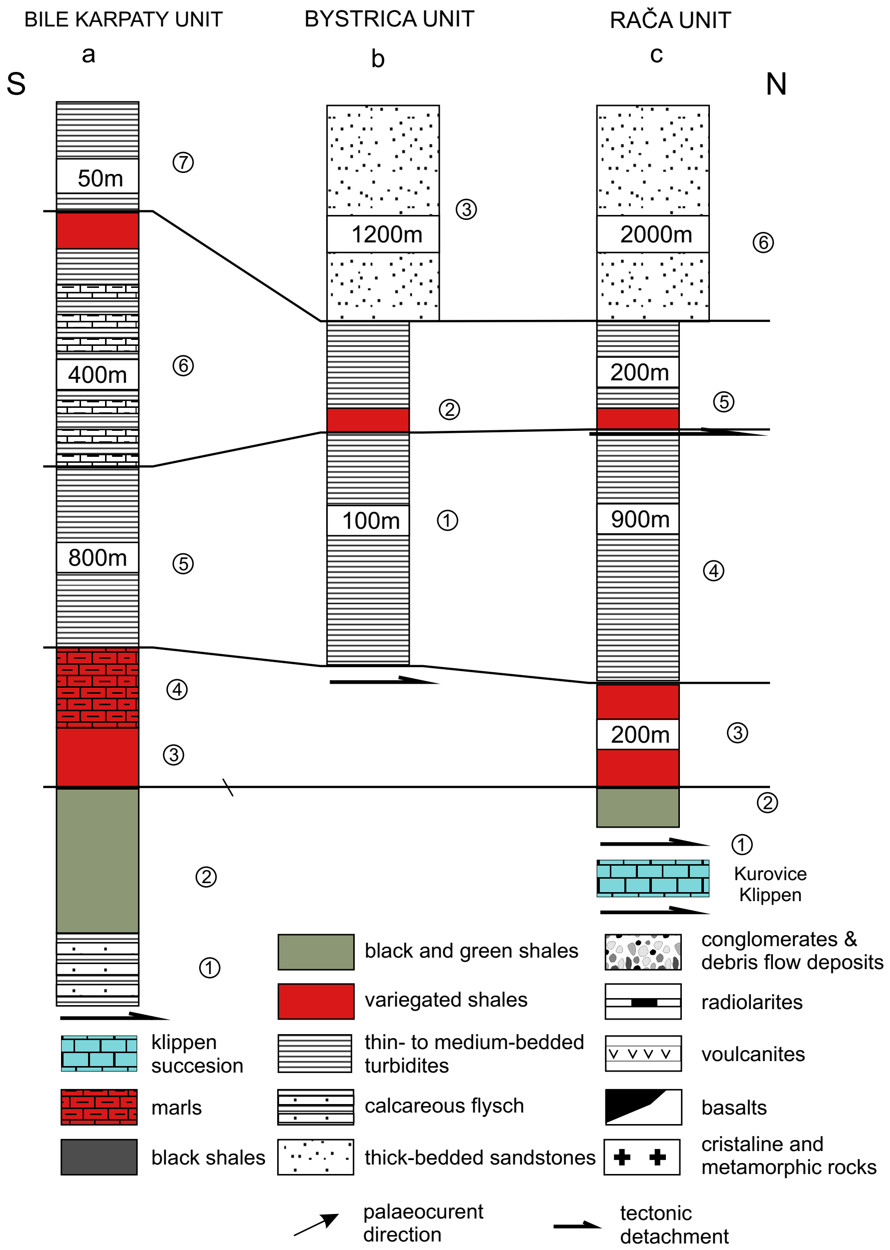
Towards the west, the width of the Magura Nappe oscillates around 40–50 km. Only at the meridian of Žilina is it reduced to 25 km. Similarly as in Poland, several flysch facies-tectonic units, uprooted from their basement, are distinguished within the Magura Nappe. From south to north these are the Bile Karpaty, Orava-Krynica, Bystrica and Rača units (Lexa *et al*. 2000; Picha *et al*. 2006; Kovač in print, and refererences therein). The Bile Karpaty Unit is located at the front of the PKB (Text-figs 1B, 6a). The oldest deposits of this unit are known as the the Hluk Formation (Barremian–Albian), not less than 120 metres thick (Lexa *et al*. 2000; Picha *et al*. 2006). There are carbonate turbidites (T_{ab}) occuring in 30–30 cm beds with intercalation of black shales. Upward in the succession, there are dark green shale formations of the Gault Formation (Aptian / Albian) with a thickness of about 200 m. The uppermost part of this succession is represented by red and green shales intercalated with fine-grained, thin sandstones of the Kaumberg Formation (Cenomanian–Turon), variegated marls of the Puchov (Gbely) Formation (Campanian–Maastrichtian), thick-bedded sandstones and conglomerates of the Svodnica Formation (Paleocene) with fragments of granites, phyllites and volcanic rocks of diabase type (Potfaj 1993), the Niwnice Formation (thin- and medium-bedded turbidites) and the Kuzelov Member (Cuisian), dominated by variegated shales with thin-bedded sandstones. The inclusion of the Puchov Formation into the Bile Karpaty succession is debatable (see Bubik 1995; Švabenicka *et al*. 1997; Picha *et al.* 2006). The palaeocurrent analysis shows that clastic material was derived from the south, probably from the Central Carpathians (Potfaj 1993). Facies development and age of the Bile Karpaty succession suggest its more external position in the basin relative to the Grajcarek succession. The Bile Karpaty Unit is thrust over the Oligocene deposits of the Bystrica Unit.

In the more external units (Krynica / Orava, Bystrica and Rača), the basal detachment of the Magura Nappe is usually located within the Lower Cretaceous (Albian) flysch, followed by red and variegated shales of the Kaumberg / Malinowa Formation (Turonian–Campanian) and Upper Cretaceous / Paleogene (up to Oligocene) flysch (Text-figs 6b–d).

Additionally known from the Rača Unit (Picha *et al.* 2006) are other Late Jurassic and Early Cretaceous sediments: the Kurovice limestones (Oxfordian / Tithonian), dark Tlumačov Marls (Tithonian / Berriasian), and the Rajnochovice black flysch (Barremian / Albian). In the Fore-Magura Unit of northern Moravia, deposits older than Paleocene–Eocene are unknown. In this unit the block of ophicalcites with neptunian dykes of Jurassic limestones (Sotak *et al.* 2002) was found.

RHENODANUBIAN FLYSCH ZONE (LOWER AUSTRIA)

The Rhenodanubian Flysch Zone (RdFZ) of Lower Austria is widely considered to be a direct western prolongation of the Magura Nappe (Text-fig. 1A) of the Outer Western Carpathians (Eliaš *et al.* 1990; Lexa *et al*. 2000; Froitzheim *et al*. 2008; Ustaszewski *et al*.2008). However, correlation of facies / tectonic units of the Magura Nappe (Rača, Bystrica, Krynica, Bile Karpaty) and nappes of the RdFZ is still under discussion (Prey 1979; Faupl and Wagreich 1992; Faupl 1996; Oberhauser 1995; Schnabel 1997, 2002; Trautwein *et a*l. 2001; Mattern and Wang 2000; Picha *et al.* 2006; Egger and Wessely 2014).



Text-fig. 6. Lithostratigraphic logs of the Magura Nappe in Western Slovakia and Czech Republic (based on Lexa *et al*. 2000 and Picha *et al*. 2006); a – Bile Karpaty Unit: (1) Hluk Formation (Barremian–Albian), (2) Gault Flysch (Albian), (3) Kaumberg Formation (Cenomanian–Campanian), (4) Puchov Marls (Maastrichtian), (5) Svodnice Formation (Maastrichtian–Paleocene), (6) Nivnice Formation (Paleocene), (7) Kuželov Formation (Eocene); b – Bystrica Unit: (1) Solan Formation (Maastrichtian–Paleocene), (2) Beloveza Formation (Eocene), (3) Bystrica Formation (Eocene); c – Rača Unit: (1) Kurovice Klippen (Jurassic–Lower Cretaceous), (2) Gault Flysch (Albian), (3) Kaumberg Formation (Cenomanian–Campanian), (4) Solan Formation (Maastrichtian–Paleocene), (5) Beloveza Formation (Paleocene–Eocene), (6) Zlin Formation (Eocene–Oligocene)

The RdFZ is located between the European Palaeozoic Platform to the north and the front of the Northern Calcareous Alps (NCA) to the south. It is generally 10 km in width, reaching up to 20 km only in the area of Vienna and Salzburg. The Rhenodanubian flysch is overthrust by the NCA, and thrust over the Helvetic Zone and the North Alpine Molasse Basin.

The RdFZ is divided into several major lithostratigraphic units (Oberhauser 1968, 1995) with partially different characters of sedimentary successions of deep-water deposits. They are regarded as the eastern part of the Penninicum and generally represent the time span from the Early Cretaceous up through the Middle Eocene. Part of the Rhenodanubian flysch was deposited on a platform composed of Upper Triassic continental quarzites (St Veit Klippen Zone). The southern part of the RdFZ was deposited on the Late Jurassic oceanic crust, as preserved in the Ybbsitz Klippen Zone (Decker 1990; Schnabel 1992; Voigt and Wagreich *et al*. 2008; Ślączka *et al.* 2014).

The Ybbsitz Klippen Zone (YbKZ) has a special position within the RdFZ where the sedimentary sequence is floored by ultrabasic rocks. This sequence is sometimes considered as a prolongation of the Grajcarek Unit (Schnabel 1992). The oldest deposits in this area are exposed on both sides of the river Ybbs. On the right side of the river the exposures are located in the place known as “Wald Kappelen” (WP 62: N47 56 25.9 E14 54 15.9, Text-fig. 7.1a), below the thrust of the the Frankenfeld Nappe of the Northern Calcareous Alps (NCA). These rocks are represented by YbKZ pillow-lava beds with sedimentary breccia, with quartz and feldspar, overlain by red and green radiolarites and dark grey and reddish-pink Kimmeridgian limestones with a mass occurrence of *Globochaete alpina* and numerous *Saccocoma* sp. These limestones belong to the well known Lombardian Ammonitico Rosso biofacies. The top of the section is terminated by Upper Cretaceous red shales of the Ybbsitz Formation (WP 63: N47 56 31.8’ E14 54 36.2’).

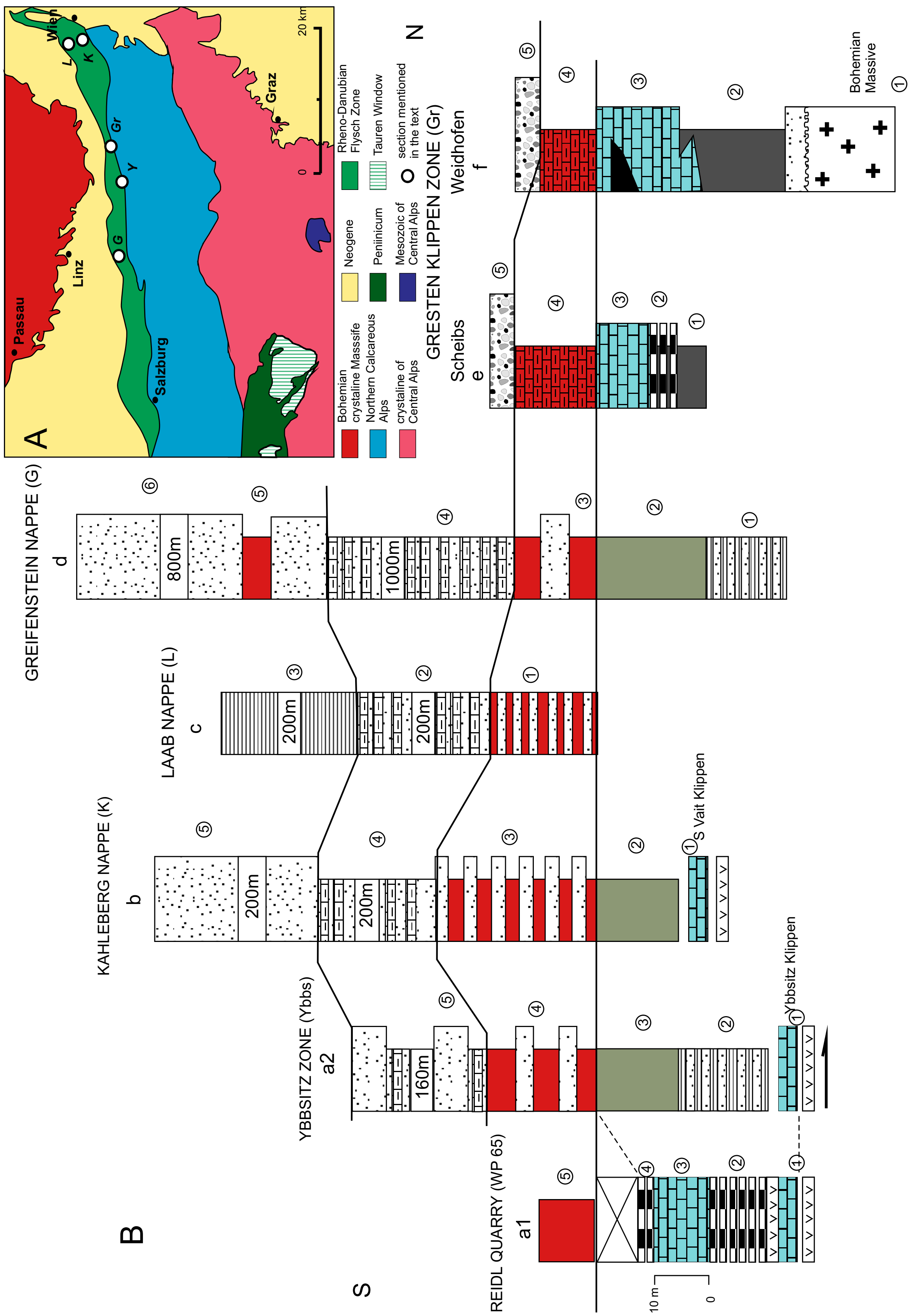
The basal portion of the YbKZ is also known from the Reidl Quarry (Text-fig. 7), on the left side of the Ybbs valley, 3 km W of Ybbsitz. The lowest part of the succession is represented by a 3-m thick package of green and red shales with manganese concretions and tuffite intercalations. Higher up, the succession is composed of: green and red radiolarites (9 m), red bioturbated marls (2 m), spotty *Globochetae / Aptychus* micritic limestones (our sample WP 68: N47 56 17.2’ E14 51 47.1’), pale pink and greenish limestones (1 m), and sedimentary breccia of green and red radiolarites (0.5 m), covered by 5 m of cherty limestones. Sample WP 68 contains calpionellids [*Crassicollaria* sp., *Calpionella alpina* Lorenz, *Tintinnopsella* cf. *longa* Colom], and calcareous dinocysts [*Colomisphaera carpathica* (Borza), *Schizosphaerella minutissima* Colom], which indicate a Late Tithonian–?Berriasian age. Above the micritic limestones, with a break in exposures, Upper Cretaceous red shales of the Ybbsitz Formation are exposed. This section is really very similar to the basal portion of the Grajcarek Unit (Szczawnica / Zabaniszcze section, Poland, see Birkenmajer 1977, 1979; Oszczypko *et al*. 2012a).

In the village of Ederlehen, the micritic *Calpionella* limestones (Rotenberg Beds, 20 m thick) are intruded by a 2 m thick basaltic sill with thermal contacts (polymetallic mineralization). The *Calpionella* limestones are followed (Homayoun and Faupl 1992) by a set of deep-water marly limestones, calcareous sandstones and grey and dark grey shales and marls (Glosbach Formation, c. 250 m thick).

The succeeding Albian sediments are represented by a sequence of anoxic black siliceous shales and grey marls with intercalations of calcareous and siliceous sandstones and sporadic fine-graded calcirudites (Haselgraben Formation, c. 130 m thick). Heavy mineral assemblages are represented mainly by garnet, zircon, tourmaline, apatite and a small amount of chromium spinel. The Haselgraben Formation is followed by a complex of thick-bedded, massive sandstones interbedded by laminated calcareous sandstones and red and green shales (Ybbsitz Formation, ?Cenomanian–Coniacian; Schnabel 1979; Homayoun and Faupl 1992). Observed paleocurrent directions are from W to E. Heavy minerals are represented by garnet, zircon, tourmaline and apatite. Chromium spinel content ranges from 0 up to 12 %. The Ybbsitz succession is terminated by the Kahlenberg Formation.

From the north to the south, the RdFZ is composed of the Northern Zone (Tulbingerkogel Schuppe), Greifenstein Nappe, Kahlenberg Nappe with the St. Veit Klippen at the base, Laab Nappe and the Ybbsitz Klippen Zone (Schnabel 1997, 2002; Egger and Wessely 2014). The Laab and Kahlenberg nappes disappear towards the west, and the Greifenstein Nappe continues as the Main Nappe.

The Rhenodanubian flysch successions (Text-fig. 7 a2–d) begin generally with carbonate turbidites (Wolfpassing and Tristel formations) followed by Albian black shales and siliciclastic, glauconitic turbidites (Gault, ?Rehbreingraben? formations, Glosbach Formation). Intercalation of hemipelagic claystones, occurring in the majority of successions, indicate deposition below the local calcite compensation depth, probably at >3000 m (Wagreich *et al*. 2008). Locally intercalations appear of sedimentary breccias (slump de-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Scheibs
e
Weidhofen
f
Bohemian Massive
10 m
0

posits) with blocks of variegated limestones, micaschists, phyllites, and quartzites. North of Salzburg (Haunsberg Wildflysch Formation) there is an olistostrome within Early Cretaceous sediments, which contain blocks of granitoids, crystalline schists, lower Permian conglomerates with melaphyre pebbles, ?Triassic grey dolomites, and Jurassic–Neocomian deep and shallow water limestones derived from the NEP (Frasl 1987

Big blocks of serpentinites occur within the Wolpassing Formation, in the vicinity of the village of Kilb (Prey 1977). Chromium spinels, which occur in the serpentinites, indicate their derivation from a mantle peridotite of harzburgite character (Cieszkowski *et al* 2006)

Sedimentation of variegated shales and marls, with intercalations of sandstones (Seisenburg Formation, Lower Variegated Marls, Kaumberg Formation, Hütteldorf Formation, Reiselsberg Formation), started in the Cenomanian and lasted till the Early Campanian. In the Cenomanian sandstones of the St. Veit Klippen Zone picrites has been recognized.

The Early to Middle Campanian part is dominated by turbiditic calcareous sandstones and calcturbidites (Zementmergel Beds, Kahlenberg Formation, lower part of the Hois Formation; Text-fig. 7b–d).

The higher part of the Cretaceous and the Lower Paleogene are represented by several thick-bedded complexes of turbiditic sandstones (Altlengbach and Greifenstein formations, Kahlenberg and Sievering formations, upper part of the Hois Formation; Text-fig. 7). Sedimentation terminated by complexes of thin- and medium-bedded sandstones and shales during the early Eocene (Irenental Formation and Agsbach Formation).

The primary positions of the above-described nappes are still debatable. According to Prey (1979), Faupl and Wagreich (1992) and Faupl (1996) the Laab Nappe, regarded as the prolongation of the Bile Karpaty Unit (Elias *et al*. 1990), was situated originally between the Greifenstein and Kahlenberg Nappes. However, other authors (Oberhauser 1995; Trautwein *et al.* 2002 and Mattern and Wang 2008) state that the Laab Nappe was originally north of the Greifenstein Nappe. Recently, Egger (in Egger and Wessely 2014) included the Kahlenberg Nappe in the Greifenstein Nappe as the Kahlenberg and Satzberg digitations (?recumbent folds) and the Northern Zone (Tulbingerkogel unit), similarly to Grün *et al.* 1972, he regarded as a marginal part of that nappe (Egger and Wessely 2014). Schnabel (2002) connected the Northern Zone with the Kahlenberg Nappe (Schnabel 2002). Also debatable is the position of the St. Veit Klippen Zone. It was variously regarded as a substratum of a part of the the Kahlenberg flysch succession (Schnabel 1997) or of the Greifenstein one (Egger and Wessely 2014), but Wagreich *et al* (2012) state that it was not established beyound doubt. The St. Veit Klippen Zone is also considered to be an eastern continuation of the Ybbsitz Zone (Faupl and Wagreich 2000; Wagreich *et al*. 2008; Egger and Wessely 2014) and Lexa *et al.* (2000) consider it as a prolongation of the Pieniny Klippen Belt with affinities to the Lower Austroalpine-Fatric elements (Wagreich *et al.* 2012).

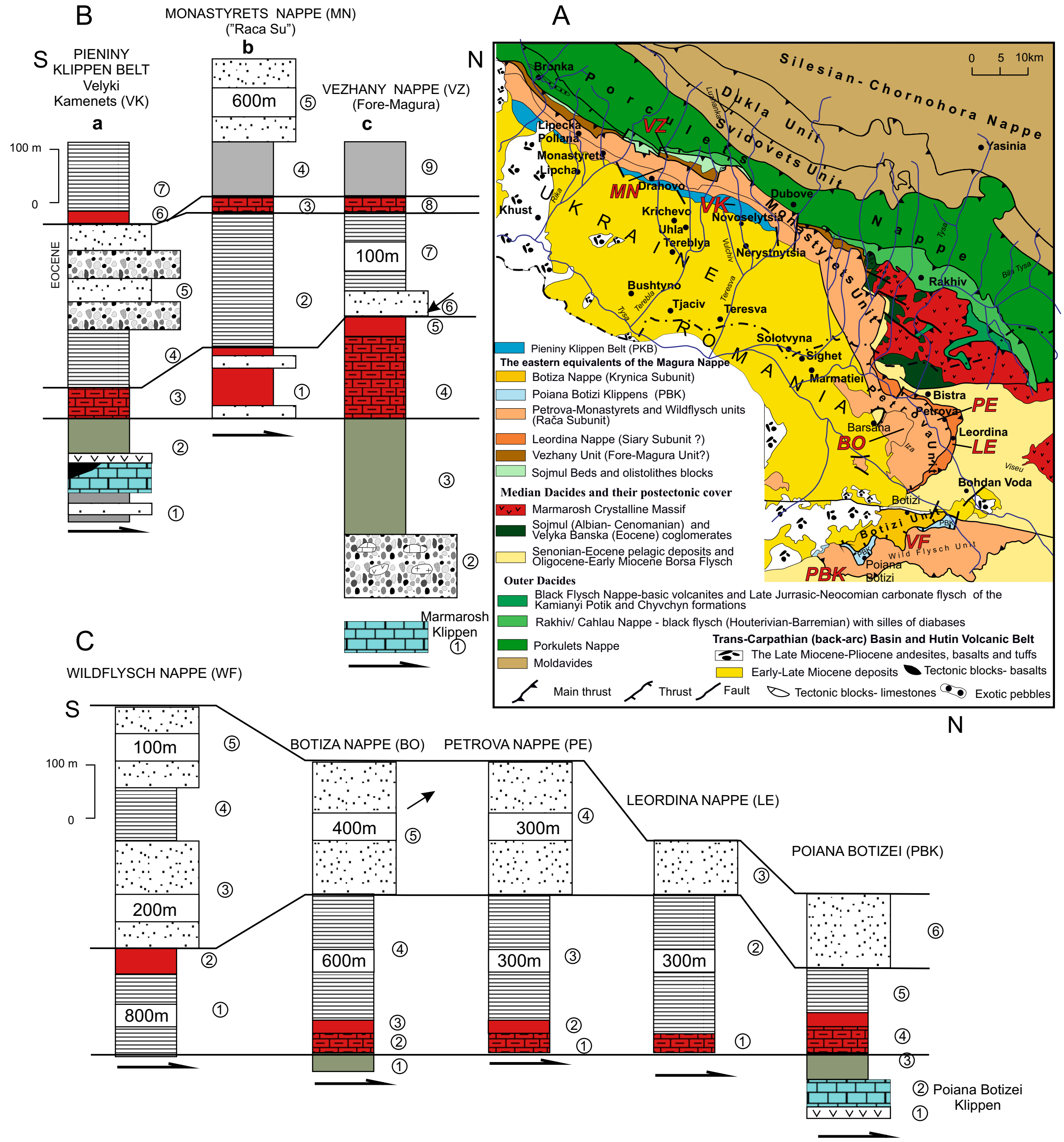
Yet another structural division of the NCA foreland has been presented by Voigt and Wagreich *et al*. (2008). These authors distinguished: the Middle and South Pennic Zone: Metamorphic Pennic Bündnerschiefer of the Tauern Window, Middle Pennic Tasna and Sulzfluh nappes, Arosa Zone; Rhenodanubian Flysch: Ybbsitz Zone and Kahlenberg Nappe; Greifenstein and main nappe; Helvetic units: Ultrahelvetic Gresten Klippen Zone, Helvetic units; Washberg Zone.

HELVETICUM (AUSTRIA)

During the Mesozoic and Paleogene the Helvetic palaeogeographic domain developed on the southern border of the Western European Platform (WEP). In this domain, the Late Jurassic pelagic carbonates are followed by shallow water carbonates of the Early Cretaceous, and higher by characteristic variegated pelagic and hemipelagic marls and shales (Buntmergel Serie) of Cenomanian–Middle Eocene age.

The southern slope of the WEP and base-of-slope zone (the Ultra-Helvetic domain) are represented by the Gresten Klippen Zone and the Main Klippen Zone. The

Text-fig. 7. A – Geological sketch-map of the Rhenodanubian Flysch Zone and adjacent areas (based on Beck-Mannagetta 1960, simplified); B – Lithostratigraphic logs of the Rhenodanubian Flysch in Lower Austraia (based on Schnabel 1992 and Lexa *et al*. 2000): **a1** – Reidl Qurry: (1) green and red shales, (2) green and red radiolarites, (3) spotty limestones, (4) cherty limestones, (5) Ybbsitz Formation); **a2** – Ybbsitz Zone: (1) Ybbsitz Klippen (Middle Jurassic–Valanginian), (2) Neocomian Flysch (Valanginian–Aptian), (3) Gault Flysch (Albian), (4) Ybbsitz Formation (Cenomanian–Santonian), (5) Zement marl Formation (Campanian); **b** – Kallenberg Nappe: (1) St.Veit Klippen, (2) Gault Flysch (Albian), (3) Ybbsitz Formation (Cenomanian–Santonian), (4) Kahlenberg Formation (Campanian–Maastrichtian), (5) Sievering Formation (Mastrichtian–Paleocene); **c** – Laab Nappe: (1) Kaumberg Formation (Companian–Maastrichtian), (2) Hois Formation (Paleocene), (3) Aggsbach Formation (Eocene); **d** – Greifenstein (Main) Nappe: (1) Neocomian Flysch (Barremian–Aptian), (2) Gault Flysch (Albian), (3) Kaumberg Formation (Cenomanian–Maastrichtian), (4) Zementmergiel Formation, (5) Uppermost variegated shales, (6) Atlenbach and Greifenstein formations; Gresten Klippen; **e** – Scheibs facies: (1) Middle Jurassic clastics, (2) Radiolarites (Malm), (3) Tithonian/Neocomian limestones, (4) Late Cretaceous/ Paleogene – variegated marls, (5) Paleogene conglomerates; **f** – Waidhoffen facies: (1) Bohemian crystalline Massif, (2) Jurassic conglomerates, sandstones and mudstones, (3) Jurassic–Early Cretacecous limestones, (4) Late Cretaceous/Paleogene variegated marls, (5) Paleogene conglomerates. Lithology explained on Fig 6.



Text-fig. 8. **A** – Geological sketch-map of the Eastern Carpathians (PKB and Marmarosh Flysch Zone, Transcarpathian Ukraine and Romania, based on Oszczypko *et al.* 2005b. supplemented); **B** – Lithostratigraphic logs of the PKB and Marmarosh Flysch Zone (Magura Nappe) of the Trancarpathian Ukraine: a)Velyki Kamenets and Vilchovchyk section of the PKB (based on Oszczypko *et al*. 2012): (1) Aalenian, (2) Bajocian–Early Cretaceous Czorsztyn/Niedzica carbonate sequence, (3) Puchov Marls (Turonian–Campanian), (4) "Jarmuta beds" (Maastrichtian–Paleocene), (5) Vilchovchic conglomerates (Eocene), (6) Red shales (Eocene), (7) ?Malcov beds (Oligocene), b) Monastyrets Unit (Rača Zone of the Magura Nappe): (1) Kalyna beds (Late Cretaceous/Paleocene), (2) Schopurka beds (Eocene), (3) ? Sub-Menilite Globigrina Marls (Late Eocene–Oligocene), (4) Dusina Marls (Oligocene), (5) Drahovo Sandstone ? Oligocene), c) Vezhany (Fore-Magura) Unit: (1) Marmarosh Klippens (Triassic–Early Cretaceous), (2) Sojmul Conglomerates (? Albian), (3) Sojmul Beds (Albian–Cenomanian), (4) Red marls of Puchov type (Turonian–Santonian), (5) Red shales of the Malinowa Fm type (Campanian), 6) "Jarmuta" type conglomerate sandstones (Maastrichtian/Paleocene), (7) Metove beds (Eocene), (8) Sub-Menilite Globigerina Marls (Late Eocene/ Oligocene, (9) Łuh beds (Oligocene). Lithology explained on Fig 6; **C** – Lithostratigraphic logs of the Northern Maramuresh flysch Units / Magura Nappe (Romania), (based on Aroldi 2001; Żytko 1999: a) Wild Flysch Nappe: (1) Roaia Fm. (Lutetian–Priabonian), (2) Red shales, (3) Magura-Perciu-Pintenul Sandstone (Rupelian–Chattian), (4) Thin-bedded flysch, (5) Magura-Perciu-Pintenul Sandstone (Rupelian–Chattian), b) Botiza Nappe: (1) Scaglia Cinerea (Albian/Cenomanian), (2) Red marls (Late Cretaceous), (3) Red shales (Paleocene), 4) Tocila Formation (Ypresian–Lutetian), (5) Secu Sandstone (Lutetian–Bartonian), c) Petrova Nappe: (1) Red marls (Late Cretaceous), (2) Red shales (Paleocene), (3) Petrova Formation (Lutetian–Early Priabonian), (4) Stramtura Sandstone (Priabonian), d) Leordnina Nappe: (1) Red marls (Late Cretaceous), (2) Rozleva Formation (Thanetian–Early Rupelian), 3) Veronicu Sandstone (Middle Rupelian–Chattian), e) Poiana Botizei Klippen, (1) Jurassic–Early Cretaceous carbonate sequence, 2) Scaglia Cinerea (Albian–Cenomanian), (3) Red Marls (Late Cretaceous), (4) Red Shales (Paleocene), (5) Hieroglyphic beds (Eocene), (6) Secatura sandstone (Oligocene). Lithology explained on Fig 6

Gresten succession is divided into the “Klippen” and the “Envelopes” (Text-fig. 7e, f). The former consists of continental to marine sediments ranging in age from Early Jurassic to Early Cretaceous (Widder 1988; Hoeck *et al*. 2005). The “Envelope” is developed as variegated marls (Buntmergel) ranging from the Late Cretaceous to the Eocene.

Also regarded as part of the Ultra-Helvetic Domain are successions with mafic rocks (diabase, gabbro, serpentine, ophicalcite) associated with Kimmeridgian–Tithonian radiolarites and variegated limestones, known from the tectonic windows of Strobl and St.Gilgen (Plöchinger 1964; 1982). These successions show that a rift zone developed also along part of the northern margin of the Penninic Ocean

TRANSCARPATHIAN UKRAINE

In the Ukrainian Carpathians, the PKB runs as a discontinuous belt, with a width up to 5 km, from the vicinity of Uzhhorod in the west to the Tereblia-Teresva rivers in the east (Text-fig. 1B); separate klippens are located at Perechyn (NE of Uzhhorod), near Svaliava, Priborzhavske and Drahovo-Novoselytsia. It is trangressively overlain from the south by the Miocene of the Transcarpathian Basin (Text-figs 1B, 8A). NE from Uzhhorod, it was overthrust at a low angle onto the Magura Nappe, and, farther to the east, onto the Monastyrets’-Petrova thrust-sheet of the Marmarosh Klippen Zone Nappe (see Oszczypko *et al*. 2005b).

Velyki Kamenets section

The easternmost exposure of the PKB is known from the Velykyi Kamenets’ quarry (GPS N48°10’48,9”, E3°44’05,4”), located near the village of Novoselytsia in Trans-Carpathian Ukraine (Text-fig. 8A, Ba). In this area the PKB, up to 3 km wide, is composed of Jurassic through to Upper Cretaceous pelagic deposits, transgressively overlain by the Paleocene/Eocene Vilkhivchyk conglomerates (Smirnov 1973). Towards the north, the PKB is thrust at a low angle over the Drahovo Sandstones of the Monastyrets Unit (Smirnov 1973; Kruglov in Ślączka *et al*. 2006). To the south these klippens contact with the Neogene deposit of the Transcarpathian Depression (Oszczypko *et al*. 2005b; 2012b).

Recently, the Velyki Kamenets has been intensively studied (Krobicki *et al*. 2003; Lewandowski *et al*. 2005; Rehakova *et al*. 2011; Oszczypko *et al*. 2012b. The 80-m thick succession of the Kamenets quarry is represented by the Czorsztyn/Niedzica type of lithofacies (Rehakova *et al*. 2011). The succession begins with Gresten-type conglomerates and sandstones, up to 28 m thick, followed by a 55 m thick sequence of Bajocian to Middle Berriasian limestones with a 6 m thick basaltic lava flow at the top.

Additionally a 6–9 m thick pyroclastic breccia in the lower Tissalo beds (? Albian-Cenomanian) was recognised in the old, Malyi Kamenets’ quarry, and in the section of the Vilkhivchyk Stream. The rocks are typical of oceanic island arc alkali basalts and pyroclastics belonging to intraplate volcanism (Oszczypko *et al*. 2012b). Higher up in the succession, these are followed by variegated marls of the Púchov Formation (Turonian–Campanian), by the Jarmuta Formation (Maastrichtian/Paleocene) and the Vilkhivchyk Formation (Lower–Middle Eocene, Smirnov 1973). In the Puntski Brook in Novoselytsia, the Vilchivchyk conglomerates transgressively overlie the Púchov Marls. The Vilchovchyk Formation, up to 300 m thick, represents a fining- and thining-upwards sequence, from fan delta coarse conglomerates, through thick and thin turbidites to hemipelagic red shales.

Marmarosh Klippen Zone (Ukraine)

Monastyrets Unit

The oldest deposits of the Monastyrets Unit (Text-fig. 8A, 8B, b) belong to Upper Cretaceous red and variegated shales, equivalent of the Malinowa Formation (Oszczypko *et al.* 2005b), followed by Upper Cretaceous–Paleocene thin- to medium-bedded turbidites overlain by Eocene variegated shales and thin bedded flysch of the Shopurka beds. The upper part of this succession belongs to the Drahovo thick-bedded sandstone, up to 1 km thick. These sandstones are not older than Late Eocene (Oszczypko *et al*. 2005b). The Vezhany Unit is overthrust by the Monastyrest Unit, which contacts the PKB along a sub-vertical fault. The Vezhany and Monastyrest units can be correlated with the Fore-Magura (Grybów) Unit and the Rača Unit of the Magura nappe respectively (Oszczypko *et al*. 2005; see also Żytko 1999).

Vezhany Unit

The Vezhany Unit is well exposed in the Terebla river section, between the Zabrid in the north and Drahovo in the south (Text-figs 8A, 8B, c). The basal (Albian), 100–200 m thick, portion of the Vezhany succession belongs to an olistostrome, composed of blocks of Urgonian limestones, serpentinites, basal volcanites, granitoids and metamorphic rocks (Smirnov 1973; Oszczypko *et al.* 2005b). This portion is overlain by a 200 m thick unit of Cenomanian grey marly mudstones, with intercalation of thin-bedded sandstones, of the Sojmul Beds (Dabagyan *e al.* 1989; Oszczypko *et al*. 2005b), followed by a 180 m thick succession of Turonian–Campanian red marls of the "Puchov Beds" (Dabagyan *et al*. 1989; Sotak 2004; Oszczypko *et al.* 2005b). In the Polish Carpathians this type of deposit is known from the Sub-Silesian and Fore-Magura units (Burtan and Sokołowski 1956) and the PKB (Birkenmajer 1977). In the Terebla section the variegated marls pass upwards into 30 m thick red and green shales of Maastrichtian age (Dabagyan *e al*. 1989).

The Paleogene begins with thick-bedded sandstones of the lower Metove beds, 100 m thick, with intercalations of Paleocene–Early Eocene grey and red marls (Smirnov 1973). The upper 70-80 m thick part of these beds is represented by grey and red marls of Early–Late Eocene age (Smirnov 1973). The uppermost, up to 150 m thick, part of the succession in the Zabrid section is represented by Early Oligocene medium- to thick-bedded sandstones with intercalations of dark massive marls of the "Dusino type" (NN 23-24 Zone, Oszczypko *et al.* 2005b). A similar succession is also known from Poland, from the northern thrust-sheet of the Fore-Magura Unit near Żywiec (Burtan and Sokołowski 1956), the Grybów Unit (Oszczypko-Clowes and Ślączka 2006), and from the Fore-Magura Unit in Moravia (Czech Republic; Picha *et al*. 2006).

Observations from the Terebla valley clearly indicate that before the Paleogene the Marmarosh flysch / Fore Magura flysch zone was a part of the Magura Basin, which continued at least to the Latorica valley of Transcarpathian Ukraine. The separation of these sub-basins into the Krosno and Magura lithofacies took place probably in the Late Eocene. Further extension of the northern edge of the Magura Basin to the west is almost completely obliterated by younger Eocene–Oligocene sediments.

FLYSCH OF THE NORTHERN MARAMURESH (ROMANIA)

In the Maramures (Romania) area between the Middle Dacides (Marmarosh Massif, Ukraine) and the Inner Dacides (Bihor Unit) there occurs a tectonic group of several units: the Botiza, Petrova, Leordina and Wildflysch, belonging to the Magura Nappe (Sandulescu *et al.* 1981; Bombita *et al*. 1992: Aroldi 2001; Żytko 1999). According to Żytko (1999), the Monastyrets–Petrova and Leordina nappes are prolongations of the Rača sub-Unit, the Botiza Nappe is an equivalent of the Bystrica sub-Unit, and the Wildflysch Nappe is a prolongation of the Krynica sub-Unit. The original position of the Wildflysch Nappe within the Magura Basin is still hotly debated (see different opinions of Żytko 1999 and Aroldi 2001). The differences stem from different interpretations of the position of the Poiana Botizii Klippen, which according to Żytko (1999) were situated at the northern edge of the Magura Basin (see also Bombita *et al*. 1992; Oszczypko *et al*. 2005), and which according to Aroldi (2001) were a prolongation of the PKB (see also Schmid *et al*. 2008).

According to Żytko (1999), the Wild Flysch succession (Text-fig. 8C, Wf), is the equivalent of the Krynica facies zone of the Magura Nappe, and was deposited in the southernmost part of the Magura Basin. In the current tectonic situation both the PBK and the Wildflysch Nappe are situated south of the Bohdan Woda strike-slip fault (BVF) and both are overthrust backward upon the paraautochthonous strata of the Median Dacides. The Wild Flysch Nappe, up to 2000 m thick (8C, WF), is composed of Middle Eocene to Oligocene thin- to medium-bedded flysch with massive turbidite sandstones (Text-figs 8C, WF). The basal portion of the succession is represented by up to 800 m thick (Aroldi 2001), fine- to medium-grained, thin- to medium-bedded, coarsening- upward, turbidites of the Roaia Formation (Rupelian–Priabonian). The Roaia Formation is followed by the at least 800–1000 m thick, thick-bedded Magura Perciu-Pentenul Sandstone (Rupelian–Chattian). The Wild Flysch Nappe is thrust southward over the post-tectonic Miocene cover of the Median Dacides (Text-fig. 8A). Jankowski *et al*. (2009) regarded the Wild Flysch deposits as the Podhale type of Eocene / Oligocene post-tectonic cover of the Median Dacides

The succession of the Botiza Nappe, up to 800 m thick (Text-fig. 8C, BO), begins with the Lower Cretaceous Scaglia Cinerea, followed by Upper Cretaceous marls (ca 50 m), and Paleocene variegated shales. The upper part of the succession is dominated by a coarsening-upwards turbiditic sequence (Ypresian–Priabonian), up to 1200 m thick. The flysch sequence is terminated by Oligocene calcareous flysch, up to 600 m thick (Żytko 1999; Aroldi 2001).

The up to 1000 m thick Petrova-Monastyrets Nappe, the largest flysch nappe of the Northern Maramuresh (Text-figs 8A, 8CF, PE), is located north of the BVF and along the Ukrainian – Romanian boundary (Żytko 1999; Aroldi 2001). The basal portion of the successsion, similarly as in the Botiza Nappe, consists of red marls of the Dumbrowa Formation ("Puchov" marls) (Upper Cretaceous), and Paleocene–Lower Eocene variegated shales. Higher in the succession, the Petrova Formation, up to 600 m thick, is represented by thin-bedded flysch (Lutetian–Early Priabonian). The upper part of the succession is represented by thick-bedded sandstones (up to 500 m) of the Stramtura Sandstone (Priabonian). The lower and thinner tectonic units of the North Maramuresh flysch succesion are represented by the Leordina Nappe, distributed north of the BVF (Żytko 1999; Aroldi 2001). This succession begins (Text-figs 8A, 8C, LE) with the Dumbrava marls Formation (Upper Cretaceous) followed by the 500 m thick Rozlava Formation (Thanetian–Early Rupelian) and the ca. 100 m thick Veroniciu Sandstone (Middle Rupelian).

Poiana Botizii Klippen (NE Maramuresh, Romania)

In the middle of the 20th century, several small outcrops of Tithonian–Neocomian Pieniny type limestones were found near the village of Poiana Botizii (Bombita *et al.* 1992, and references therein), along the northern margin of the Transylvanian Basin. Initially, these klippens were recognized as equivalents of the Grajcarek Unit of the PKB in Poland (Bombita and Pop 1991; see also Sandulescu *at al.*1981; Aroldi 2001, and references therein). Subsequent studies (Bombita *et al*. 1992) showed, however, that the Poiana Botizii rocks form two successions (Text-figs 8A, 8C, PBK). The lower succession is composed of the following units: Callovian blocks of red violet pyroclastics and cinerites/sandstones with basaltic and andesitic clasts, Callovian/Oxfordian striped greenish-red radiolarites, Oxfordian detrital turbiditic limestones with ophiolitic grains and light grey limestones (Petricea Formation); Kimeridgian–Lower Tithonian (Varastina Formation) spotty and cherty limestones, lenticular breccia, red *Aptychus* shales with intercalation of nodular calcarenites, Ammonitico Rosso-type limestones, and Lower Tithonian/Upper Berriasian Biancone (Maiolica) limestones. The upper succession consists of Hauterivian, Barremian and Lower Aptian black pelites of the Scaglia Cinerea type (Poiana Botizi Formation, 40–50 thick), previously regarded as the Tissalo Beds, and of Lower Cenomanian–Lower Paleocene, up to 100 m thick red marls of the Piatra Rosie Formation (Couches Rouges type), with a tuffite horizon at the base. These are followed by Eocene flysch of the Tocila/Petrova formations. The lack of Upper Albian deposits is interpreted as a result of the Austrian tectogenesis.

Bombita *et al*. (1992) concluded that the Poiana Botizi succession represents the basement of the Magura Basin, located in an external position with respect to the Grajcarek succession. It means that during the Early Cretaceous the Grajcarek and Poiana Botizi successions were located on opposite banks of the Magura Basin. The opinion of Bombita *et al* (1992) was supported by the NW thrust of the Magura Nappe over the Poiana Botizi Klippen, which at the same time are thrust over the Middle Dacides (Marmarosh Massif) and its post-tectonic cover. This suggests that the position of the Poiana Botizii Klippen is more or less the same as the position of the Marmarosh Klippen in Ukraine, located between the Marmarosh Massif to the north and the Magura Nappe and the PKB to the south (Oszczypko *et al*. 2005b).

PRESENT BOUNDARIES OF THE MAGURA NAPPE

Southern Boundary

The southern boundary of the Magura Nappe is tectonic. In Lower Austria this boundary is marked by the thrust of the Northern Calcareous Alps over the Rhenodanubian Flysch Zone (Text-fig. 1A). Farther to the east (Czech Republic, Western Slovakia, Poland and Eastern Slovakia), the Magura Nappe contacts the Central Carpathians to the south through a narrow zone of the Pieniny Klippen Belt (Żytko *et al.* 1989).

The tectonic slices of the Magura Succession, incorporated in the Polish PKB, are known as the Hulina (Sikora 1971a, 1974) or Grajcarek Unit (Birkenmajer 1977, 1986). The best exposures of this unit are located in the Małe Pieniny Mts. In the East Slovakian PKB the southern boundary of the Magura Nappe is marked by the Faklovka Unit (Oszczypko *et al*. 2010) or the Šariš Unit (Plašienka and Mikuš 2010; Plašienka 2012; Plašienka *et al*. 2012). The Klippen units and the Saris Unit of the PKB continue to the vicinity of Prešov. Farther to the east, the Jurassic and Lower Cretaceous rocks disappear and the Šaris Unit is represented by the Late Cretaceous Puchov Marls and the Paleogene Jarmuta-Proč formations (Lexa *et al.* 2000).

In the Ukrainian PKB the Grajcarek / Šaris Unit has not been documented, albeit isolated Jurassic and Lower Cretaceous rocks of the PKB are known from Perechyn (NE of Uzhhorod), from near Svaliava, Priborzhavske, Drahovo and Novoselytsia in the Teresva valley; these approximately mark the southern boundary of the former Magura Ocean.

Northern boundary

The northern boundary of the Magura Nappe is directly defined by its flat thrust over its foreland. In the Austrian sector, west of Vienna, it is manifested by the Greifenstein Unit of the RdFZ which overthrust the marly deposits of the Helveticum or the Allochthonous Molasse. To the north of Vienna, the direct foreland of the Magura Nappe belongs to the Washberg and Ždánice units. To the east the foreland of the Magura Nappe is occupied by the sub-Silesian Unit, Silesian Unit (Czech Republic and Poland) and, south of Gorlice (E Poland), the Dukla units, and the Fore-Magura Zone and Vezhany Unit in the Ukraine.

The northern boundary of the Magura Nappe in the Ukrainian Carpathians is represented by a tectonic contact between the Monastyrets and Vezhany units in the Terebla River valley. This boundary is traced westward up to the Latorica River. West of the Latorica River, the Monastyrets Unit of the Magura Nappe disappears. Its position is occupied by the Paleogene beds of the Vezhany Unit (Dusino Formation and variegated marls of of the Fore-Magura Unit). A very narrow belt of the Magura Nappe still appears c. 30 km east of the Slovakian – Ukrainian boundary. Westward of the Polish – Slovakian border the Magura Nappe expands and contacts the Fore-Magura (Grybów) Unit or the Dukla unit (Lexa *et al.* 2000). West of Gorlice, to the town of Zlin (Northern Moravia, Czech Republic), the Magura Nappe commonly contacts directly with the youngest deposits of the Silesian Nappe, less commonly, through a narrow band of the Fore-Magura Unit (eg. Żywiec area (Burtan and Sokołowski 1956). West of Vienna, the equivalent of the Magura Nappe is the thrust of the Greifenstein [Nappe?] over the marly deposits of the Helveticum or the thrust of the Ultra-Helveticum (Hauptklippen Zone) over the Allochthonous Molasse. To the west of Vienna, Greifenstein Nappe as the equivalent of the Magura is thrust over the marl deposits belonging to Helveticum, Ultra - Heveticum (Haupklippen Zone) or directly over the Allochtchonous Molasse.

GEOMETRY OF THE MAGURA NAPPE

The Magura Nappe and the RdFZ (its western prolongation) stretches nearly 800 km from Salzburg in Austria to the valley of the Terebla River in Transcarpathian Ukraine (Text-fig. 1). The Magura Nappe is widest in Poland and in Western Slovakia, where it reaches 50–55 km. Westward (in Austria) it is 10 to 20 km wide, and in the Ukrainian Carpathians it narrows to several kilometres and locally disappears completely (Text-fig. 1). The reasons for this changing width can be both the primary nature of the basin and its association with bending of the lower plate and the amplitude of the thrusting. In general, in the Magura Nappe there are no major tectonic thrusts or repetitions, with the exception of its western and eastern terminations. During the Oligocene–?Early Miocene nappe movements, the Magura Nappe has the largest tectonic reduction in the Austrian and Ukrainian sectors and, to a lesser extent, in the Czech, West Slovakian and Polish sectors. At the time of nappe movements, the Magura Nappe was deeply uprooted in the Austrian and Czech sectors and shallowest in the the Polish and Ukrainian sectors.

In the palinspastic reconstructions of Nemčok *et al*. (2006) and Gągała *et al*. (2012), based on the balanced cross-sections Kraków–Nowy Targ and Przemysl–Uzhhorod, the original width of the Magura Basin was estimated at 85 and 116 km respectively. These estimates do not take into account that Lower Peninic units, equivalents of the Magura Nappe, occur in the Hohe Tauern and Rechnitz tectonic windows of the NCA (Text-fig. 7A, see also Schmid *et al*. 2004; Ustaszewski *et al*. 2008). In this case, the width of the Rhenodanubian (North Peninic units) can be estimated at c. 80 km. A similar conclusion can be drawn for the eastern end of the Magura flysch (Ukraine and Romania), where the width of the Magura nappe is reduced to a few km. Taking into account the tectonic windows of the Uzhhorod (Text-fig. 8A, Ukraine) and Baja Mare (Romania), the reconstructed width of the Magura Nappe will be at least 60 km (Bombtita *et al*. 1992; Żytko 1999; Sandulescu 2012). These are values close to those obtained from the balanced cross-sections in the Outer Western Carpathians.

FROM THE MAGURA OCEAN TO THE MAGURA BASIN

The time of the opening of the Magura Ocean is still under discussion. Traditionally an Early–Middle Jurassic age is accepted (Birkenmajer 1986; Oszczypko 1992, 1999; Golonka *et al*. 2000, and references therein) that is essentially coeval with the opening of the South–Penninic–Piedmont–Ligurian Ocean (Schmid *et al*. 2004). Alternatively, Plašienka (2002) suggests an Early Cretaceous opening for the Magura Ocean (Text-fig. 9). According to this scenario, the Early Cretaceous opening of the Magura Ocean was accompanied (?) by thermal uplift of the Czorsztyn Ridge and post-rift thermal subsidence of the Magura Ocean, resulting in uniform deposition of pelagic and hemipelagic shales below the Calcium Compensation Depth (CCD). The latter scenario is compatible with the concepts of Schmid *et al.* (2005, 2008) that link opening of the Magura Ocean with the Late Jurassic–Early Cretaceous opening of the Valais-Rhenodanubian (North Penninic) oceanic Basin.

In several palaeogeographic reconstructions, the Magura Ocean opened during the Tithonian–Berriasian times, as a NE prolongation of the Ligurian–Piedmont Ocean (Chanel and Kozur 1997; Golonka *et al*. 2000, 2006; Ślączka *et al.* 2014, and references therein).

Schmid *et al*. (2008) correlated the Valais Ocean with the Rhenodanubian Flysch, accreted to the Alpine nappes during the Eocene. Its equivalent in the Outer Western Carpathians would be the Magura Flysch, accreted to the Central Carpathians during the Oligocene–Miocene. Taking into account the much larger size of the Magura Nappe in comparison to the Rhenodanubian Flysch Zone, we believe that the term Magura Ocean is fully justified (Text-fig. 9).

For the Early Cretaceous, the term Magura Ocean is sometimes attributed to all Outer Carpathian basins (cf. Chanel and Kozur 1997; Puglisi 2009, 2014). Accordingly, the Magura Ocean was limited by the European shelf to the north and it passed into the Ceahlau-Severin Ocean towards the SE. To the south it was bordered by the Northern Calcareous Alps in the west, and by the Czorsztyn Ridge, separated from the Central Carpathians by the Pieniny Ocean, in the east (Text-fig. 9).

The following ophiolites, marking the suture zones of Alpine Tethys were distinguished in the Carpathian sedimentary system (Ustaszewski *et al*. (2008) (Text-fig. 1A): (1) Ceahlau-Severin, (2) Valais, (3) Rhenodanubian-Magura, and (4) Pieniny Klippen Belt.

The opening of the Magura Ocean in the Late Jurassic was accompanied by submarine volcanism. Traces of that volcanism have been preserved at both the southern and northern edges of the Ocean. At the southern edge, pillow-lava beds, overlain by red and green radiolarites, followed by Kimmeridgian Globochaete / Saccocoma limestones, are known from Ybbsitz KZ (Wald Kapelen and Reildl Quarry, Text-fig. 7a1), and from the Grajcarek Succession. In Eastern Slovakia serpentinitic sandstone has been recognized in the Krichevo-Šambrone Zone (Sotak and Bebej 1996). At the northern edge, the mafic rocks (diabase, gabbro, serpentine, ophicalcite) occur within the radiolarites and Kimmeridgian–Tithonian variegated limestones of the Strobl and St.Gilgen (Wolfgangseefenster) tectonic windows. These rocks known from the Ultra-Helvetic Domain (Plochinger 1964) and Fore-Magura Unit in Moravia (Sotak *et a*l. 2002) were developed in the rift zone, along the southern margin of the North European Platform (Text-fig. 7e, f).

In the Ukrainian sector of the Eastern Carpathians Jurassic volcanism is known from the northern margin of the the Marmarosh Klippen Zone. The Callovian–Oxfordian radiolarites are intruded by diabase, and terminal ophiolitic volcanism took place during the latest Jurassic (Chernov 1972). In the Romanian sector of Maramuresh Jurassic volcanism is known from the Poiana Botizi Klippens (Text-figs 8A, 9; Bombita *et al*. 1992). In this area, violet pyroclastics and basaltic/ andesitic clasts have been recognized in the sandstones at the the base of the Callovian–Oxfordian green and red radiolarites.

In the valley of the Terebla River at the front of the Marmarosh Klippen Zone and Marmarosh Massif, the Rakhiv and Porkulets (Burkut) nappes are distinguished. These units are thrust over Lower Cretaceous flysch of the Charnohora Nappe (Kruglov and Cypko, 1988). The Rakhiv and Porkulets Nappes contain blocks of volcanic rocks and Upper Jurassic limestones (Rogoziński and Krobicki 2006). Farther to the west these nappes disappear at the front of the Magura Nappe. The Rakhiv and Porkulets nappes of the Ukrainian Carpathians are correlated with the Black Flysch Nappe of Romania (Kruglov and Cypko 1988; Sandulescu 2009). According to Sandulescu (op. cit) the Black Flysch Nappe of the Romanian Maramuresh shows similarity to the Grajcarek Unit in Poland. In our interpretation the Grajcarek Unit was derived from the southern edge of the Magura Basin (Ocean), while the Black Flysch Unit of Romania and the Rakhiv and Porkulets (Burkut) nappes of Ukraine were derived from the Ceahlau / Severin oceanic domain, connected to the west with the northern edge of the Magura Basin (Ocean).

Early Cretaceous volcanism is known both from the southern and northern margin of the Magura Ocean. At the southern margin, alkali basalts and pyroclastics, typical of an oceanic island arc, have been recognized in the Ukrainian sector of the PKB (Oszczypko *at al*. 2012b) and in the Slovakian sector of the PKB (Spišiak *et al*. 2011). It is also known from sedimentary blocks in the Grajcarek succession in Poland (Birkenmajer and Wieser 1990; Oszczypko *et al*. 2012b) where it represents intraplate volcanism (Oszczypko *et al*. 2012b). At the northern margin of the Magura Nappe (RdFZ and the Gresten Klippens – Text-figs 7, 8), Early Cretaceous volcanism is distributed much wider than the Late Jurassic volcanism. Basalts, long known as teschenites, occur in the Silesian Nappe of Poland and the Czech Republic (Golonka *et al*. 2000; Lucińska-Anczkiewicz et al. 2002; Grabowski *et al*. 2004). The teschenite-picrite dating of the main magmatic phase in the Silesian Nappe (Poland and Czech Republik) indicated 128–120 Ma (Barremian-Aptian). In this area Tithonian pillow lavas are also known.

Estimations of the pre-orogenic width of the Polish sector of the Outer Carpathian Basin vary. According to palaeogeographic reconstruction it was estimated as 175 km by Książkiewicz (1956), however, Sikora (1976), based on plate tectonic concepts, estimated the Late Cretaceous–Paleocene width of the basin as 700–1000 km. Birkenmajer (1985, 1988) claimed that the Early Cretaceous Magura Basin (Ocean), the precursor of subsequent Outer Carpathian basins, was up to 400 km wide (300 km according to the Channel and Kozur 1997 estimation). Golonka *et al*. (2006) and Ślączka *et* *al*. (2014) estimated the width of the Early Cretaceous Outer Carpathian Basin as 1000 km, with a 200 km width suggested for the Magura sub-Basin.

According to palaeomagnetic measurements, the northern edge of the PKB Basin (Czorsztyn Ridge) (= southern edge of the Magura Basin), at the meridian of Kraków, was located at the palaeolatitudes 22° (Grabowski *et al*. 2008) and 27.3 ° ± 1.3 ° (Marton *et al*. 2013) in the Late Jurassic and the late Cretaceous, respectively. This gives a 5.3° (= ca. 580 km) northward tectonic shift of the PKB during the interval. So in the Late Cretaceous, the southern edge of the Magura Basin could thus have been 12° (ca. 1400 km) south of the palaeo-position of Kraków. This allows estimation of the width of the Late Cretaceous Outer Carpathian basin as 1000–1300 km, values which correspond to those given by Sikora (1974; see also Golonka *et al.* 2014).

The Outer Western Carpathians form a curved arc to the north, and their tectonic units reach the front of the orogen obliquely (Text-fig. 1). As a consequence, higher and higher tectonic units join the Outer Western Carpathians frontal zone from east to west. This phenomenon has been described by Nowak (1927) as tectonic *discrepantion*, and can be explained as shifting of orogenic folding from south to north and from west to east. The higher tectonic units, occurring to the south and west, were folded and uplifted earlier than the lower units, which gradually joined the front of the Carpathians, as a result of subduction of the foreland plate beneath the flysch nappes.

During the Late Jurassic–Early Cretaceous the palaeobathymetrically variable Magura Ocean was dominated by carbonate sedimentation. In the eastern part of the Magura Ocean (Marmarosh) the Early/Middle Jurassic was manifested by folding and coastal uplift (Chernov 1972). Marine sedimentation was renewed during the Callovian, and continued to the Hauterivian. Sedimentation started with the Callovian–Kimeridgian radiolarites and cherty limestones followed by the Tithonian–Hauterivian flysch. After the Late Hauterivian folding the southern part of the basin was occupied by Late Barremian barrier reef limestones and clastic sediments. At the same time, the NE part of the Marmarosh area was uplifted into the Marmarosh Ridge, which was a source area of clastic material to the East Carpathian flysch basins (Chernov 1972; Smirnov 1973). South of the ridge, the coastal conglomerates of the Sojmul Formation (Aptian/Cenomanian) were deposited initially, followed by the Puchov Marls (Cenomanian–Maastrichtian) and Paleogene flysch of the Vezhany and Monastyrest units.

Sedimentation proceeded differently in the western part of the Magura Ocean. In this area, the Late Jurassic–Early Cretaceous is characterized by deep water radiolarites, cherty limestones and calcareous flysch, followed by dark-green pelitics of the Gault Formation (Albian, Text-figs 6, 7).

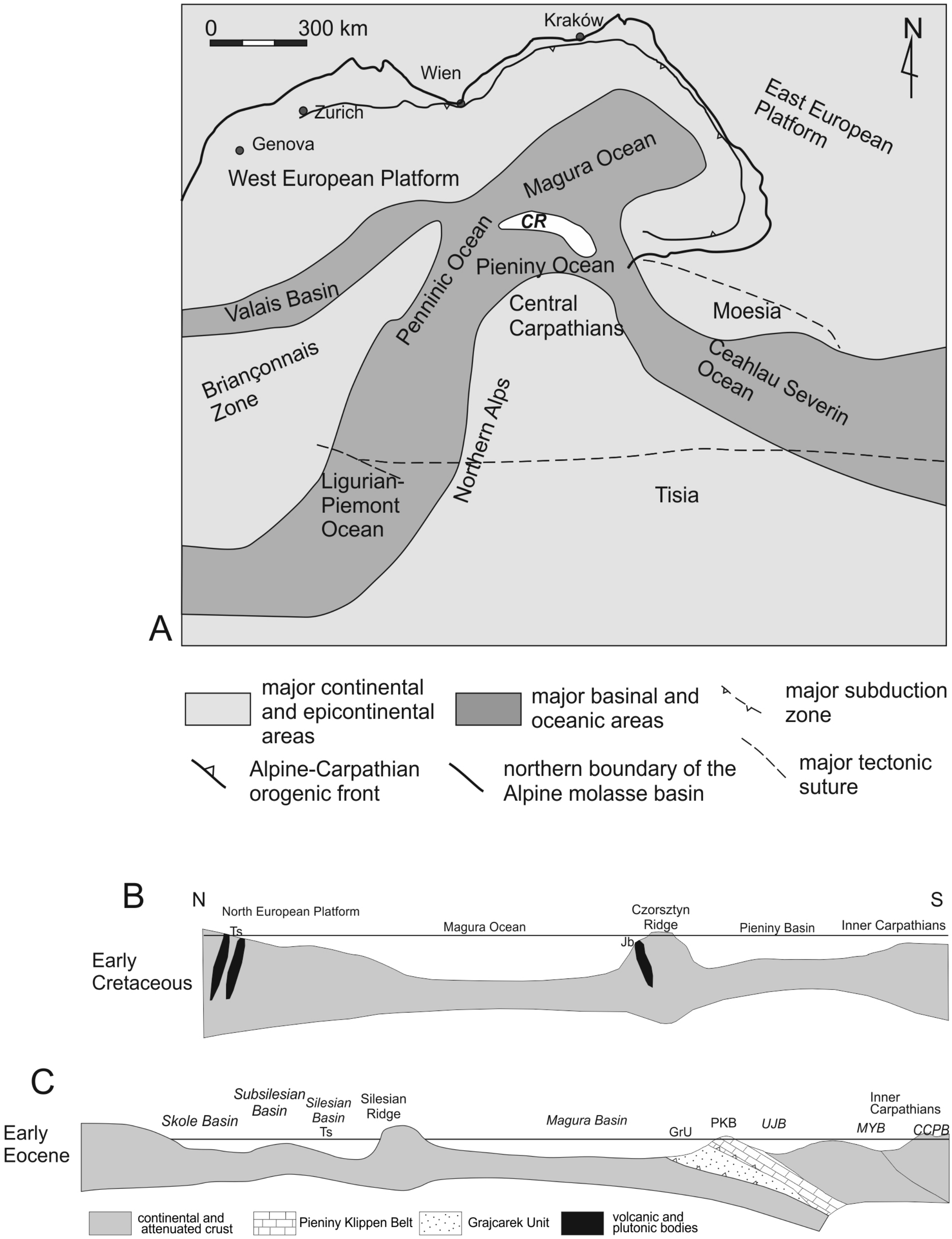
In the Voigt *et al*. (2008) model, during the Early Cretaceous and up to the Early Campanian, only one deepwater (Magura/Silesian) basin existed in the Outer Western Carpathian domain (Text-fig, 9a, b). This basin was bounded by the Bohemian Massif shelf to the north and the submerged Czorszyn Ridge to the south. According to these authors, the Aptian–early Campanian sedimentation in this basin was controlled by the rising sea level and the greenhouse climate.

In the Polish sector of the basin, significant deepening of the basin (to 3.5–4.0 km), took place during the Albian–Cenomanian (Uchman *et al*. 2006). This is documented almost throughout the area, occupied by the Cenomanian green manganese clays correlated with the OA2 Bonarelli level (Oszczypko *et al.* 2012a; Uchman *et al*. 2013), followed by Turonian–Campanian red and variegated shales. Such deep-water sediments, deposited below the local CCD, are known today from oceanic basins.

At the beginning of the Cretaceous, the Outer Western Carpathian sedimentary area was transformed from a remnant oceanic basin into a collision-related foreland basin (Oszczypko 1999).

In the Late Cretaceous–Paleocene, the palaeogeography of the Magura Ocean (Text-fig. 9c) was modified significantly (Oszczypko 1999; 2006). According to Plašienka (2014), these changes could have been caused by folding and thrusting of the Central Carpathians and PKB over the southern edge of the Magura Ocean. Following these tectonic movements, the southern part of the Magura Basin found itself in the foreland position, at the front of the Central Western Carpathian accretionary wedge. The frontal, uplifted part of the orogenic wedge was represented by the PKB, with the Grajcarek/Šariš Unit at the base (Plašienka 2014; Oszczypko and Oszczypko-Clowes 2014). The material eroded from the PKB accumulated as the Jarmuta / Proč conglomerates (Paleocene/Middle Eocene). Under the load of the thrusting accretionary wedge of the Central Carpathians the European Plate underwent sagging and migration of foreland basin towards the north. In our opinion Plašienka's (2014) model may also explain the uplift of the intrabasinal ridges (e.g., Silesian, Marmarosh) as foreland fore-bulges. As a result of these tectonic movements during the Campanian/Paleocene the Magura Ocean was transformed into several Outer Western Carpathian basins (Text fig. 9c).

These basins differed in size and bathymetry. Also variable was the tectonic activity of their source areas. According to Unrug (1968, 1979), the Sub-Silesian



Text-fig. 9. A – Early Cretaceous palaeogeography of the of the Alpine/Carpathian system (based on Chanel and Kozur 1997, Schmid *et al*. 2008, Uchman *et al*. 20013, supplemented). B – Early Cretaceous palinspastic model of the Magura Ocean and Pieniny Basin (based on Oszczypko 2006, modified). Abbreviations: Ts – teschenites, Jb – Jaworki basalts. C – Paleoecene/ Early Eocene palinspastic model of the Western Carpathians, not to scale (based on Oszczypko 2006, modified). Abbreviations: CCPB – Central Carpathian Paleogene Basin, UJB – Ujak Basin, MYB – Myjava Basin, PKB – Pieniny Klippen Belt

Basin, located on the slope of the European continent, passed southwards into the Silesian Basin separated from the Magura Basin by the “Silesian Cordillera” (Ksiażkiewicz 1956), the source of the clastic material for both the Silesian and the Magura basins. The problem of the southern margin of the Magura Basin is still not clear. The concept of the Czorsztyn Ridge of the PKB as its southern source area has never been supported by provenance analyses (no traces of PKB clasts in the Paleocene/Eocene formation in the Krynica facies zone).

The post-Late Cretaceous Magura Basin was the eastern prolongation of the Rhenodanubian basin system. South-east of the Western Outer Carpathians, the Magura Basin was limited to the north by the Marmarosh Palaeo-Ridge, now represented by the Marmarosh Klippen Zone (Smirnov 1973; Żytko 1999; Oszczypko *et al*. 2005b). The southern extension of the Magura Basin in the eastern part of the Transcarpathian Depression is still under discussion. This up to 20 km wide depression is filled with an up to 2.5 km thick cover of Miocene deposits. In this area in both Ukranian and Romanian sites, the Albian–‘Senonian’ marls and limestones of the Inačovce / Krichevo Formation underlying the Miocene are known from several boreholes (Smirnov 1981; Sotak and Bebej 1996; Żytko 1999; Sotak *et al*. 2000, 2002; Aroldi 2001). Farther south, in direct contact with the Inner Dacides, the „basic and ultrabasic eruptive rocks of ophiolitic complex, covered by carbonate oceanic rocks and pelitic sediments of Jurassic age“ have been found in drillings (see Aroldi 2001). This ophiolite sequence is associated with the Main Tethynian Suture of the Late Cretaceous–Miocene Pienides composed of the Babesti Tjachevo, Botiza, Krichevo, PKB and Magura flysch of the Petrova (Monastyrets)-Leordina (Vezhany) and Wildflysch nappes (Text-figs 8B, 8C, 10). In the Transcarpathian Ukraine and Northern Maramush area (Romania), the Magura Basin formed a bay bordered from the east by the Marmarosh Massive and from the south by the northern tip of the Tisza block (Text-fig. 9). Towards the south, the Magura Basin contacted, via the PKB and the Inačovce-Krichevo Zone, with the Sava-Szolnok Basin. Between the Silesian Ridge to the west and Marmarosh Ridge to the east, the northern margin of the Magura Basin was related to the Fore-Magura sub-Marine High (Text-fig. 10, see also Oszczypko *et al.* 2005b; Slączka *et al.* 2006).

Position of source areas

The Outer Carpathian marine basins were supplied with clastic material from the coastal lands and uplifted submarine ridges that appeared at the surface as islands.

During the Late Cretaceous and Paleogene, the Magura Basin was supplied with clastic material from source areas located along the NW and SE margins of the basins (in their present-day geographic position).

In the NW, the Silesian Ridge is commonly regarded as a source area, whereas the position of the SE source area is still under disscussion (Oszczypko and Oszczypko-Clowes 2006). In the Outer Carpathian sedimentary basin system the most important internal source area was the “Silesian Ridge” (Cordillera) (Książkiewicz 1965; Unrug 1968; Golonka *et al.* 2000; Picha *et al,* 2005). According to Unrug (1968), the Silesian Ridge “paralleled the long axis of the flysch trough” and separated the northern Silesian Basin from the southern Magura Basin. The Silesian Ridge could be structurally linked with the Bohemian Massif. In the Eastern Carpathians direct prolongation of the Silesian Ridge is not clear due to the different arangment of the basins. However, the prolongation of its northern part could be the Bukowiec Ridge situated between the Silesian and Dukla basins (Ślączka 2005). In the Eastern Outer Carpathians the position of the Silesian Ridge was occupied by the Marmarosh Massive and Marmarosh Klippen Zone and separated the Magura Basin from the Dukla, Porkulets and Outer Dacides basins.

During the Late Cretaceous–Paleocene the Fore-Magura succession (supplied from the north) was a part of the Magura Basin, whereas during the Late Eocene and Oligocene this succession was a part of the Silesian Basin, supplied from the south (see Unrug 1968; Oszczypko 2006). During the Late Campanian, inversion-related uplift of the Silesian Ridge affected the northern part of the Magura Basin by the onset of intensive clastic flysch deposition. The “exotic” pebbles derived from the Silesian Ridge into the Silesian, Dukla and Magura (Rača Subunit) basins document a Variscan age of the plutonic and metamorphic rocks (Oszczypko 2006). During the Late Cretaceous to Eocene, the clastic material was supplied to the Dukla Basin from the NW (Silesian Ridge). At the end of the Eocene a new source area, which supplied material of the Krosno Menilite series from the SE (Bukowiec Ridge, see Ślączka 1971) was revealed.

Since the Early Eocene, a deep-water submarine fan began to develop in the southern part of the Magura Basin. This is documented by the occurrence of channel-lobe turbidites supplied from SE sources (Krynica succession). The Eocene deposits of the Krynica Zone of the Magura Basin contain fragments of crystalline rocks, derived from a continental crust, and numerous clasts of Mesozoic deep and shallow-water limestones (Olszewska and Oszczypko 2010). In these deposits there are no traces of material derived from erosion of the Czorsztyn Ridge. According to Mišik *et al.* (1991)

exotic material was derived not from the PKB, but from "the basement of the Magura Basin". According to Smirnov (1973), during the Late Cretaceous and Paleocene the Transcarpathian area was ocupied by a relatively shallow marine bay of the Magura Basin. This basin was separated to the south and north by the South Pieniny and Marmarosh and submerged ridges respectively. During the Late Cretaceous/Paleocene, variegated marls (Turonian–Campanian) followed by conglomerates and sandstones of the Jarmuta Formation (Maastrichtian/Paleocene) were deposited in the Marmarosh (Magura) Basin.

During the Early Eocene the Marmarosh Ridge was uplifted and became a source area of metamorphic material (quartzites, sericite/ quartz, muscovite / quartz schists, muscovitic gneisses) to both the Magura-Dukla (Leško and Samuel 1968; Oszczypko *et al*. 2005b) and the Charnohora / Silesian basins. The Middle Eocene deepening of the basin caused reduction in the supply of material from the Marmarosh Ridge and deposition of variegated shales and thin-bedded flysch. The transgression covered the Maramuresh and Northern Transilvania basins with non-flysch Wełyka Bania and Prislop sandstones and conglomerarates, composed of metamorphic rocks, Mesozoic carbonates and subordinate amounts of volcanic rocks. During the Oligocene, significant unification of sedimentary conditions (black marls and curbiocortical flysch) took place in the Marmarosh Basin (Text-fig. 11). During that time the Marmarosh Basin was merged with the Dukla Basin ("disodyl marls" and "curbiocortical flysch").

Relationship of the Dukla Basin to Magura Basin

In the Polish sector of the Magura Basin its northern margin is well marked by the Silesian Ridge. In the Dukla Unit the Late Cretaceous black flysch of the Majdan Formation displays NE–SW palaeotransport direction, suggesting a source area located between the Dukla and Silesian basins (Ślączka and Winkler 1992; Ślączka 2005). At the same time in the Flysch Belt of Eastern Slovakia the activity of the Silesian Ridge is not descernible at all (Korab and Durkovič 1978). Since the Late Cretaceous to the Late Eocene, both the Dukla and Magura sub-basins of the latter area were characterized by the same depositional pattern (Inoceramian facies, Beloveza and lower Zlin formations), with material supply by the same SE to NW longitudinal palaeocurrent system (Leško and Samuel 1968; Korab and Durkovič 1978). At the end of the Eocene, the unification of sedimentary condition in the Dukla and Silesian basins took place; the sediments of the Menilite /Krosno formation were deposited and the pattern continued up to the end of the Oligocene. In Transcarpathian Ukraine, an analogue of the Silesian Ridge was the Marmarosh Ridge (Żytko 1999; Oszczypko *et al*. 2005; Ślączka *et al*. 2006). A shallow isthmus, connecting the Magura Basin and the Outer Dacides and Moldavides Basins, could have existed between the Marmarosh Massive and the Silesian Ridge.

CONCLUSIONS

1. In the Late Jurassic–Early Cretaceous Alpine Tethys there were several large marine basins (so-called remnant oceans) such as: Ligurian– Piedmont, Penninic, Pieniny (Vahicum), Valais, Magura and Ceahlau-Severins.
2. The Magura Ocean was the eastern extension of the Valais Ocean. This up to 1000 km wide (ca 10°) ocean was limited to the north by the West European Platform. Towards the west and east it was connected with the Valais Ocean (North Pennic Ocean) and the Ceahlau / Severin Ocean respectively. To the south the Magura Ocean was bounded by the NW–SE oriented Czorsztyn Ridge.
3. The opening and expansion of the Magura Ocean was accompanied by Late Jurassic and Early Cretaceous volcanism, located along its southern and northern boundaries.
4. The Late Jurassic Magura Ocean was a site of deep water condensed deposition: radiolarites and pelagic limestones followed by Early Cretaceous calcareous and dark distał flysch with the Cenomanian Bonarelli horizon at the top.
5. During the Turonian–Early Campanian this ocean was dominated by deep-water well- oxygenated sediments (known as Oceanic Red Beds). These were mainly red and variegated siltstones deposited below the CCD and red and variegated marls in coastal areas
6. In the course of the Late Campanian–Paleocene tectono-sedimentary evolution, the Magura Ocean was transformed into the several flysch sub-basins: Magura (Rhenodanubian), Dukla, Silesian, Sub-Silesian and Skole / Skyba / Tarcau.
7. This transformation from the remnant Magura Ocean into collision-related foreland basins was coeval with reduction in the southern oceanic space and subsidence of the foreland platform in the north, at the front of the overriding orogen.
8. These newly created basins were supplied with clastic material derived from intrabasinal source areas (ridges) and coastal lands, now incorporated into the Outer Western Carpathians.

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