Acta Geologica Polonica, Vol. 53 (2003), No. 2, pp. 101-122

The Aquitanian marine deposits in the basement of Polish Western Carpathians and its palaeogeographical and palaeotectonic implications

NESTOR OSZCZYPKO & MARTA OSZCZYPKO-CLOWES

Jagiellonian University, Institute of Geological Sciences, Oleandry 2a, 30-063 Kraków, Poland.
E-mail: nestor@geos.ing.uj.edu.pl, u3d09@geos.ing.uj.edu.pl

ABSTRACT:

OSZCZYPKO, N. & OSZCZYPKO-CLOWES, M. 2002. The Aquitanian marine deposits in the basement of Polish Western Carpathians and its palaeogeographical and palaeotectonic implications. *Acta Geologica Polonica*, **53** (2), 101-122, Warszawa.

Early Miocene mudstones and conglomerates were discovered in the Andrychów 6 borehole, beneath the Polish Western Carpathians. These dark grey mudstones contain calcareous nannoplankton belonging to the Aquitanian NN1 zone, which can be correlated with the Egerian Stage of the Central Paratethys. The marine mudstones are underlain by conglomerates and sandy-silty deposits of Oligocene age, which overlapped the Early Palaeozoic-Precambrian platform basement. The conglomerates display features of fan delta deposits, and were supplied with material derived from erosion of the uplifted part of platform basement (Cieszyn-Slavkov Ridge). The Egerian mudstones from the Andrychów 6 borehole, and the Eggenburgian Zebrzydowice Formation known from the Karvina and Cieszyn area, reflect a progressive flooding of the European Platform during the Egerian/Eggenburgian transgression. The Egerian-Oligocene mudstones and conglomerates, as well as the Zabrzydowice Formation are equivalents of the youngest flysch deposits in the Outer Carpathians. The Egerian deposits from the Andrychów area and the Eggenburgian Zebrzydowice Formation from the Cieszyn and Ostrava areas are relicts of a broad marine embayment which flooded southern Poland and linked the terminal flysch basin and the adjacent European shelf.

The sub-thrust Aquitanian (Egerian) to Langhian (Early Badenian) deposits in the Andrychów-Zawoja-Cieszyn area recorded a sedimentary-tectonic evolution of the southern edge of the European Platform. This time span covers the Egerian-Eggenburgian/Ottnangian marine deposition, the Late Ottnangian overthrust of the Outer Carpathians, the Karpatian alluvial fan deposition, uplift of the Cieszyn-Slavkov Ridge, the Late Karpatian-Early Badenian marine transgression and the subsequent Late Badenian to Sarmatian telescopic thrusting of the Outer Carpathians.

Key words: Paratethys, Carpathian Foredeep, Early Miocene, Palaeogeography, Paleotectonics.

INTRODUCTION

The Palaeogene time was traditionally regarded as a period of intensive inversion and erosion in the Carpathian foreland area. According to KUTEK & GŁAZEK (1972), the Mesozoic and Palaeozoic cover was removed from the Lower San High during that time, while the material resulting from the erosion was transported by rivers southward into the flysch basin (see also KSIĄŻKIEWICZ, 1962). This concept has been modified following discovery of Palaeogene and Early Miocene marine autochthonous deposits at the base of the Early Miocene to Middle Miocene molasse (PICHA 1979, 1996; PICHA & STRANIK 1999; MORYC 1995; JURKOVA & *al.* 1983; GARECKA & *al.* 1996; GEDL 2000). Simultaneously, the Early Miocene age of the youngest flysch deposits of the Outer Carpathians was documented in calcareous nannoplankton studies (KOSZARSKI & *al.* 1995, ŚLĘZAK & *al.* 1995, ANDREYEVA-GRIGOROVICH & *al.* 1997, CIESZKOWSKI 1992, GARECKA & OLSZEWSKA 1998, OSZCZYPKO & *al.* 1999, OSZCZYPKO-CLOWES 2001, OSZCZYPKO & OSZCZYPKO-CLOWES 2002). Recent biostratigraphical studies of the youngest deposits from the Outer Carpathians, as well as the Oligocene-Miocene deposits of the Carpathian foreland, reveal a link between these areas. The geological results of the Andrychów 6 borehole provide the impulse for a new palaeogeographical reconstruction. In this paper, we would like to present the results of our sedimentological and calcareous nannoplankton studies of the core material obtained from the Andrychów 6 borehole and their regional context, with a special emphasis on the Egerian/Eggenburgian palaeogeography of the Outer Carpathian, residual, flysch basin and the European shelf.

PREVIOUS WORK AND THE GEOLOGICAL SETTING

Lower Miocene autochthonous deposits have been known from the basement of the Flysch Western Carpathians in Poland (Text-figs 1-2) since the late 1970s. These deposits were documented in the following deep boreholes: Bielsko 4, Sucha IG-1, Zawoja 1, Lachowice 1, 2, 3a, 7, Cieszyn IG-1, Bielowicko IG-1 and Zebrzydowice 13 (ŚLĄCZKA 1977; BUŁA & JURA 1983, MORYC 1989; POŁTOWICZ 1995). For further reading connected with this area of research interest see OSZCZYPKO (1996, 1997, 1998).

According to MORYC (1989), the oldest Lower Miocene deposits belonging to the Zawoja Formation were discovered in the Zawoja 1 borehole (south of Sucha Beskidzka, Text-figs 1-2). The age of this formation was recently discussed by OSZCZYPKO & *al.* (2000), who assigned the formation to the Oligocene. The Zawoja Formation is overlapped by the Sucha Formation, which was identified in the following boreholes: Sucha IG-1, Zawoja 1, Lachowice 1, 2, 3a, 7, and Stryszawa 1K (see BARAN & *al.* 1997, PIETSCH & *al.* 1997). This formation is an olistoplaque up to 370 m thick (ŚLĄCZKA 1977, MORYC 1989, POŁTOWICZ 1995), composed of Lower Cretaceous to Paleocene flysch olistholiths, derived from the Sub-Silesian and Silesian successions, and their Early Miocene matrix (POŁTOWICZ 1995, LASKOWICZ 1997, GEDL 1997). In the Sucha-Zawoja area, the flysch olistoplaque is cov-

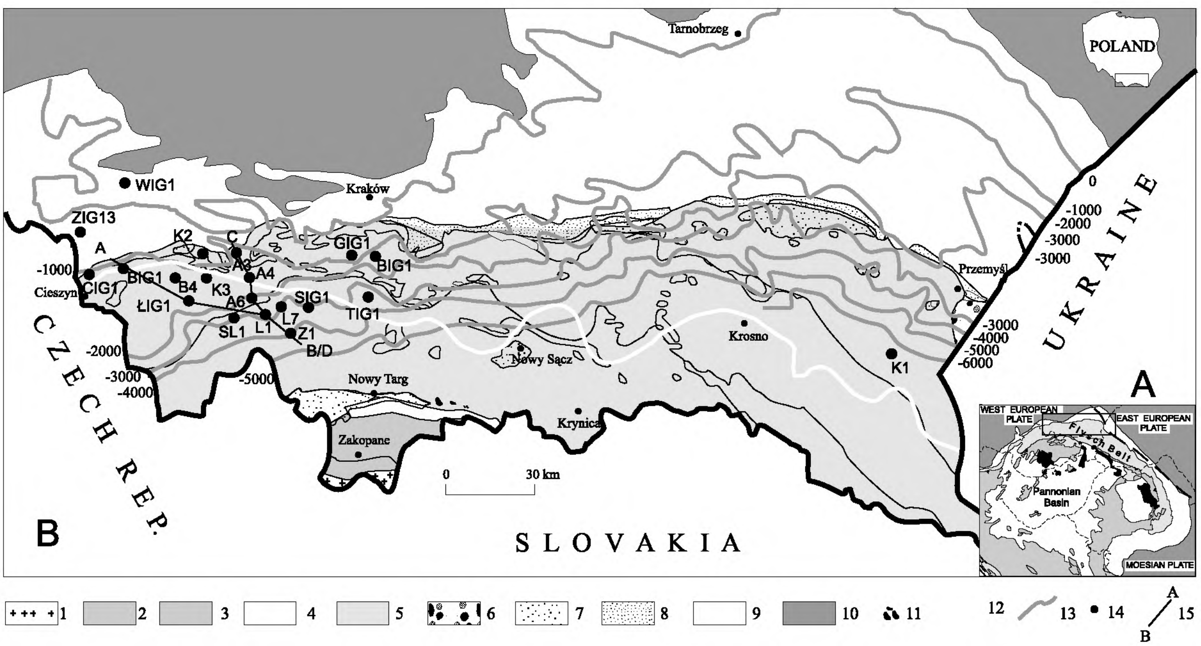


Fig. 1. A. Position of the Polish Carpathian Foredeep in the the Carpathian - Pannonian region. B. Sketch-map of the Polish Carpathians and their foredeep (after OSZCZYPKO 1997, supplemented); 1 – crystalline core of Tatra Mts., 2 – high and sub - Tatra units, 3 – Podhale Flysch, 4 – Pieniny Klippen Belt, 5 – Outer Carpathians, 6 – Stebnik Unit, 7 – Miocene deposits upon Carpathians, 8 – Zgłobice Unit, 9 - Miocene of the foredeep, 10 – Mesozoic and Palaeozoic foreland deposits, 11 – andesites, 12 – northern extent of Lower Miocene, 13 – isobath of Miocene substratum, 14 – boreholes, 15 – geological cross-section. Abbreviations; boreholes: A 3 – Andrychów 3, A 4 – Andrychów 4, A 6 – Andrychów 6, B 4 – Bielsko 4, BL G 1 – Bielowicko IG1, B IG1 – Borzęta IG1, C IG1 – Cieszyn IG1, G IG1 – Głogoczów IG1, K 2 – Kęty 2, L 1 – Lachowice 1, L 7 – Lachowice 7, Ł IG1 – Łodygowice IG1, SL 1 – Ślemień 1, T IG1 – Trzebunia IG1, W IG1 – Woszczyce IG1, Z 1 – Zawoja 1, Z IG13 – Zebrzydowice IG13

ered by coarse, clastic deposits of the Stryszawa Formation up to 566 m thick (ŚLĄCZKA 1977, MORYC 1989).

The lower portion of the Stryszawa Formation is composed of polymictic conglomerates (ŚLĄCZKA 1977, MORYC 1989), up to 229 m thick (Lachowice 2). The conglomerate pebbles and cobbles are dominated by: sandstones, mudstones, carbonates, quartzites, fragments of metamorphic rocks and granites, which were derived from both the Carpathian Flysch belt and the Palaeozoic basement. These conglomerates pass into the upper part of the Stryszawa Formation, which is composed of grey, olive-green and variegated mudstones with intercalations of coarse-grained sandstones and conglomerates with carbonate and anhydrite-gypsum cement (OSZCZYPKO & LUCIŃSKA-ANCZKIEWICZ 2000). The Stryszawa Formation contains a relatively common microfauna of Early Cretaceous – Early Miocene age, recycled from the Carpathian Flysch (OSZCZYPKO 1998). From this formation, Ottnangian-Karpatian calcareous nannoplankton (NN 4 Zone) has also been reported by GARECKA & *al.* (1996). The upper part of the Stryszawa Formation reveals features of alluvial fan deposits. In the Sucha IG-1(SIG1) and Lachowice 1 boreholes this formation passes upwards into the Dębowiec Conglomerate (ŚLĄCZKA 1977, MORYC 1989).

In the Bielsko area, the basal portion of the Lower Miocene deposits revealed a different development from that described above. The oldest deposits are light grey sands of the Hałcnów Formation, up to 100 m thick, with a 19.5 m packet of dark mudstones (? Eggenburgian/Ottnangian, see KUCIŃSKI & NOWAK, 1975; KUCIŃSKI & *al.* 1975). Higher up in the section the Karpatian Bielsko Formation was penetrated (KUCIŃSKI & *al.* 1975). This formation is represented by a 77 m thick series of green-greyish mudstones with intercalations of conglomerates with blocks of Carboniferous rocks. The same deposits

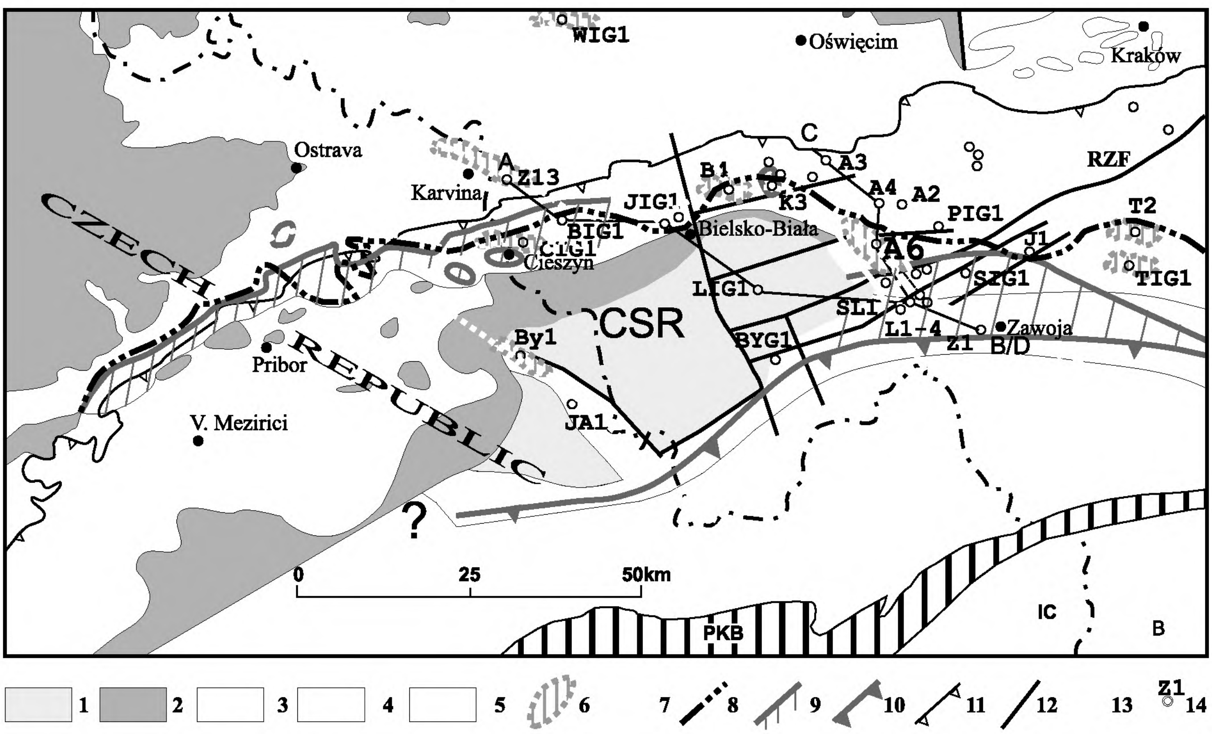


Fig. 2. Distribution of the Miocene autochthonous deposits in Northern Moravia and the Cieszyn-Zawoja areas (after JURKOVA 1971, JURKOVA & *al.* 1983, OSZCZYPKO & *al.* 1989, PALENSKY & *al.* 1995 and OSZCZYPKO & LUCIŃSKA-ANCZKIEWICZ 2000); Platform basement: 1 – Proterozoic-Lower Palaeozoic, 2 – Upper Palaeozoic, 3 – Mesozoic; Carpathian Foredeep: 4 – Karpatian, 5 – Lower-Middle Badenian, 6 – boundary of the Zebrzydowice Fm. (Eggerian - Early Burdigalian), 7 – northern boundary of the Paleogene autochthonous deposits, 8 – northern boundary of the Karpatian deposits, 9 – northern boundary of the "Old Styrian" overthrust, 10 – Late Ottnangian front of the Outer Carpathians, 11 – present-day front of the Outer Carpathians, 12 – fault, 13 – palaeovalley, 14 – borehole. Abbrevations: CSR – Cieszyn-Slavkov (Příbor) Ridge, PKB – Pieniny Klippen Belt, IC – Inner Carpathians, RZF – Rzeszotary fault, AZP – Andrychów-Zawoja Palaeovalley, BSP – Bloldovice-Skoczów Palaeovalley, JP – Jablunkov Palaeovalley, PDP – Pilchowice Palaeovalley, SP – Strumień Palaeovalley; boreholes: A 2 – Andrychów 2, A 3 – Andrychów 3, A 4 – Andrychów 4, A 6 – Andrychów 6, By 1 – Bystrica 1, BYG1 - Bystra IG1, B 4 – Bielsko 4, B IG1 – Bielowicko IG1, C IG1 – Cieszyn IG1, J 1 – Jachówka 1, Ja 1 – Jablunkov 1, J IG1 – Jaworze IG1, K 3 – Kęty 3, L 1-4 – Lachowice 1-4, Ł IG1 – Łodygowice IG1, P IG1 – Potrójna IG1, S IG1 – Sucha IG1, SL 1 – Ślemień 1, T IG1 – Trzebunia IG1, T 2 – Trzebunia 2, W IG1 – Woszczyce IG1, Z 1 – Zawoja 1, Z IG13 – Zebrzydowice IG13

were also found in the Tokarnia IG-1, and Trzebunia 2 boreholes (SZOTOWA 1975, POŁTOWICZ 1995). In the Bielsko 4 borehole the Bielsko Formation passes upwards into a layer of conglomerates, 97 m thick (Komorowice Formation, after KUCIŃSKI & *al.* 1975). Higher up in the profile occur 115 m of mudstones and the Dębowiec Conglomerate. These mudstones contain a microfauna with *Praeorbulina*, which is typical for the basal part of the Lower Badenian. The same profiles were penetrated in the Tokarnia IG-1 and Trzebunia 2 boreholes (see POŁTOWICZ 1995).

In the Cieszyn area, between the Lower Miocene Zebrzydowice Formation and the Dębowiec Conglomerate, flysch olistoplaque (Zamarski Member), composed of elements of the Sub-Silesian Unit were discovered by BUŁA & JURA (1983). The Zamarski olistoplaque (25-150 m thick), is preserved in the central part of the Skoczów palaeo-valley (at least 50 sq. km), beneath the frontal part of the Carpathian thrust (Text-fig. 2). An isolated fragment of the Sub-Silesian Unit was also found in the sub-thrust position in borehole K 3 near Bielsko-Biała (Text-figs 1-2, see also MORYC 1970). According to OSZCZYPKO & LUCIŃSKA-ANCZKIEWICZ (2000), the Zamarski olisthoplaque from the Cieszyn area can be correlated with the Sucha olistoplaque from the Sucha-Zawoja area, as well as with the "Old Styrian overthrust" from Northern Moravia (JURKOVA 1971). All of these buried flysch outliers developed probably during the Ottnangian-Karpatian as an olistoplaque or a gravitational nappe, which slid from the front of the contemporaneous Flysch Outer Carpathians.

In the Cieszyn area the Dębowiec type conglomerates can be subdivided into two different lithosomes (see JAWORSKA 1998, OSZCZYPKO & LUCIŃSKA-ANCZKIEWICZ 2000). The lower lithosome is represented by a 10-110 m thick layer of variegated, poorly sorted, conglomerates composed of flysch-derived clasts. These conglomerates resemble those of the Stryszawa Formation from the Sucha-Zawoja area (OSZCZYPKO & LUCIŃSKA-ANCZKIEWICZ 2000). The upper lithosome is composed of a 40-90 m thick complex of transgressive Dębowiec Conglomerate, which is composed of Upper Carboniferous clasts. This conglomerate passes upwards into the Skawina Formation. The new sedimentary cycle begins with the deposition of marly mudstones with *Praeorbulina* or with the Dębowiec Conglomerate and sandstones. In the Cieszyn area, according to GARECKA & *al.* (1996), the Dębowiec Conglomerate, as well as the lowermost portion of the Skawina Formation, belong to the Late Karpatian (GARECKA & *al.* 1996). The upper portion of the Skawina Formation belongs to the Badenian NN5 and NN6 zones (GARECKA & *al.* 1996, ANDREYEVA-GRIGOROVICH & *al.* 1999; PERYT 1997, 1999). In the Cieszyn-Bielsko area the thickness of the Skawina Formation reaches 1100 m (POŁTOWICZ 1995, JURA 2001).

According to GARECKA & OLSZEWSKA (1998), the oldest Miocene marine deposits in the basement of the Polish Outer Carpathians belong to the Early Burdigalian (Eggenburgian). Eggenburgian deposits were discovered as erosional outliers near Karvina (NE Moravia) and in a few boreholes SE of Cieszyn (JURKOVA & *al.* 1983). These deposits are represented by littoral clastics and neritic mudstones. Calcareous coarse-grained sands with molluscs and foraminifers dominate. The transgressive sands, overlying the crystalline basement and covered by Carpathian nappes, were penetrated in the Bystrice 2 borehole south of Cieszyn and also in a few boreholes near Karvina (Text-fig. 2). In the Karvina area these deposits occur in the Detmarovice Palaeovalley, which deepens towards the SE. The palaeovalley is 10 km long, up to 1 km wide, and extends to Poland, to the Zebrzydowice 13 borehole (BUŁA & JURA 1983). These deposits were found beneath Lower Badenian deposits at a depth between −665 m and −838 m below sea level (JURKOVA & *al.* 1983). The Lower Badenian deposits consist of polymictic sands, granule conglomerates and cobbles, covered by dark grey claystones up to 42 m thick. The conglomerate beds (0.2-0.8 m thick) are intercalated with fine- to medium-grained sandstones. The clasts of the conglomerate are well rounded and up to 5-8 cm in diameter; they are composed of Kulm sandstones and mudstones, Upper Carboniferous sandstones and also mudstones with coalified plants, as well as subordinate quartzite and limestones. In borehole NP738, rich Early Burdigalian (Eggenburgian and Ottnangian ?) calcareous nannoplankton belonging to zones NN2-NN3 were found in the dark green claystones (JURKOVA & *al.* 1983). Towards the SE, in Poland, these deposits were identified in the Zebrzydowice 13 borehole, where they are up to 130 m thick, and are known as the Zebrzydowice Formation (BUŁA & JURA 1983). This formation has also been found at a depth interval of 1251-1306 m in the Cieszyn IG-1 borehole (JAWORSKA 1998). In this borehole the Zebrzydowice Formation onlapped Upper Carboniferous regoliths, and is composed of dark grey claystones at the base of the formation and green-greyish claystones with sporadic intercalations of laminated sandstones in the upper part of the formation. This formation is overlain by a flysch olistoplaque belonging to the Zamarski Member. On the basis of the small foraminifers and the calcareous nannoplankton, the age of the Zebrzydowice Formation in the Cieszyn area has been determined as Eggenburgian-Ottnangian (NN2/NN3) (GARECKA & *al.* 1996, GARECKA & OLSZEWSKA 1998).

PRELIMINARY RESULTS OF THE ANDRYCHÓW 6 BOREHOLE

In 1999 the Polish Oil and Gas Mining Company (Polskie Górnictwo Naftowe i Gazownictwo SA) drilled the Andrychów 6 borehole. The borehole was situated 10 km south of Andrychów (Text-figs 1-2) and was serviced geologically by the OBG Geonafta Warszawa - "Ośrodek Regionalny Geonafta Południe w Jaśle" - Sekcja, Kraków. According to the unpublished FINAL REPORT (2000) the Andrychów 6 exploration borehole reached a depth of 2550 m and penetrated the following profile: 0-1 m – Quaternary deposits, 1-1955 m – flysch deposits of the Silesian Unit, 1955-2538 m – Miocene deposits and 2538-2550 m – Precambrian deposits. Samples were taken from the following core intervals: R1 – 2135-2143 m (100 %), R2 – 2213-2229 m (57%), R3 – 2324-2333 m (100 %) and R4 – 2541-2547 m (50 %). The stratigraphical log of the Miocene deposits was prepared by U. BARAN, T. KUŁAGA, J. MORYC and R. FLOREK, as well as by the borehole geological service team. The results of this research were as follows: 1955-2128 m – Lower Badenian mudstones, 2128-2236 m – Lower Badenian conglomerates, 2236-2538 m – Karpatian conglomerates. More information about the Miocene deposits was given in the "Report on microfauna from samples taken from the Andrychów 6 borehole" by L. BOBREK (FINAL REPORT 2000). In detritical samples, from depths of 1960.0, and 1980.0 m a Lower Badenian microfauna was determined, whereas foraminifers redeposited from the flysch belt were found in the following intervals: 2000.0 and 2010.0 m – Paleocene-Eocene, 2030.0 m and 2040.0 m – Maastrichtian and at depths of 2070.0 and 2080.0 m – Lower Cretaceous. In all of these samples contamination with Miocene taxa was found. According to L. BOBREK (FINAL REPORT 2000) the presence of mixed Miocene and older microfaunas can be related to the flysch olistostromes in the Lower Miocene conglomerates. Completely different microfaunas were determined in the samples taken from the core interval R3 (2324-2333 m), where a few dozen Oligocene-Miocene specimens, and sporadic Lower Cretaceous specimens were found. Among the Miocene taxa which L. BOBREK found were there: *Cibicides borislavienis* AISENSTAT, *Bolivina plicatella mera* CUSHMAN & PONTON and *Globigerinella evoluta* SUBBOTINA, which are characteristic of the Early Miocene up to the Karpatian. Taking this data into account the core from the depth interval 2236-2238 m was assigned to the Karpatian.

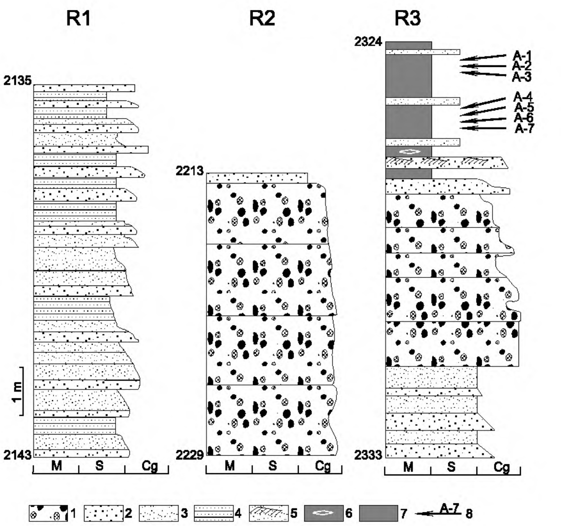


Fig. 3. Sedimentological logs of core intervals of the Andrychów 6 borehole: R1 (2135-2143 m) – Dębowiec Conglomerate, R2 (2213-2229 m) – Stryszawa Formation, R3 (2324-2333 m) – Zebrzydowice and Andrychów formations; 1 – pebble conglomerate, 2 – granule conglomerate, 3 – sandstone, 4 – parallel laminated sandstone, 5 – cross laminated sandstone, 6 – siltstone with hamocky cross lamination, 7 – siltstone, 8 – samples for nannoplankton research

According to geological interpretations of the seismic section 13-12-96 K (see Text-fig. 3, in FINAL REPORT 2000), the Andrychów 6 borehole penetrated beneath the Carpathians a narrow graben filled with Middle and Lower Miocene coarse clastic deposits. This NW-SE trending graben, 5 to 7 km wide, is bounded by normal faults, with Devonian-Carboniferous deposits in the footwall.

In the autumn of the year 2000, we had the opportunity of studying the core material of the Andrychów 6 borehole and took a few samples for the purpose of nannoplankton analysis.

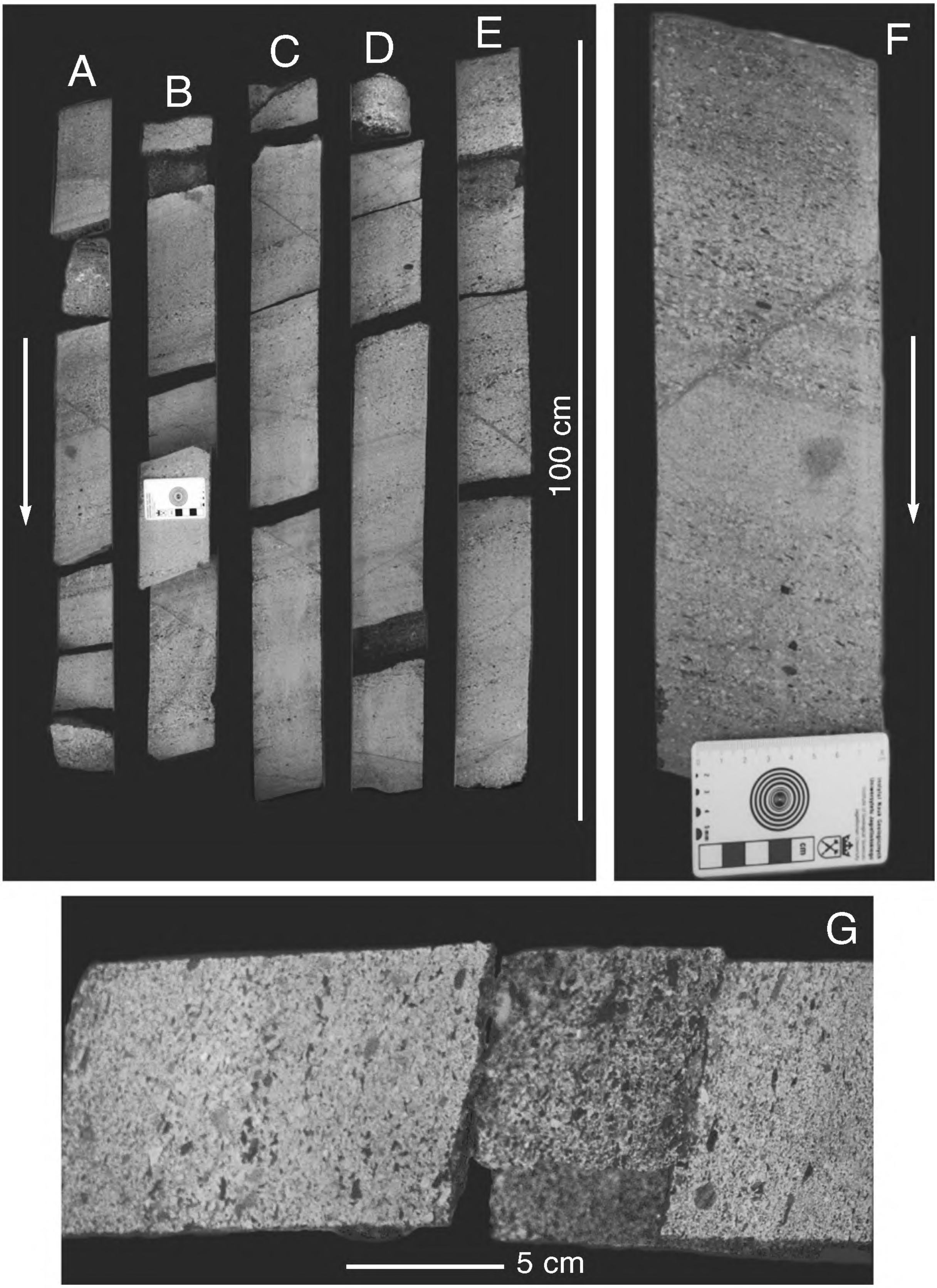
DESCRIPTION OF THE CORE MATERIAL

R1 (2135-2143 m)

Box (S I). Fine-grained, thin- to medium-bedded (10-15 cm) lithoclastic conglomerates with calcareous cement (Text-figs 3, 4A). The grey conglomerates are composed of imbricated (12-20°) flat pebbles and granules, 2-8 mm in diameter. The clasts are dominated by limestones, dark mudstones and very fine, parallel-laminated sandstones, as well as small coal clasts. These conglomerates passed upwards into the coarse (C) and very coarse-grained (VC) sandstone intervals with parallel lamination. The thin-bedded (3 to 5 cm thick) granule conglomerate and planar laminated, graded-bedded VC to C-grained sandstone is cut through by a low-angle (40°), early diagenetic reverse fault (Text-fig. 4F)

Box (S II). Medium-bedded (10-20 cm) fine to medium-grained conglomerates with 2-3 cm intercalations of medium, coarse- and very coarse-grained sandstones with

Fig. 4. Andrychów 6 borehole – core interval 2135-2143 m. Granule conglomerarates and coarse- to very coarse-grained sandstones of the Dębowiec Conglomerate. A – box (S I), B – box (S II), C – box (S III), D – box (S IV), E – box (S V), F – Thin-bedded granule conglomerate and planar laminated, graded-bedded, very coarse to coarse-grained sandstone, cut through low-angle, early diagenetic inverse fault (detail from box (S I), G – Small scale imbrication of the granule conglomerate, detail from box (S V)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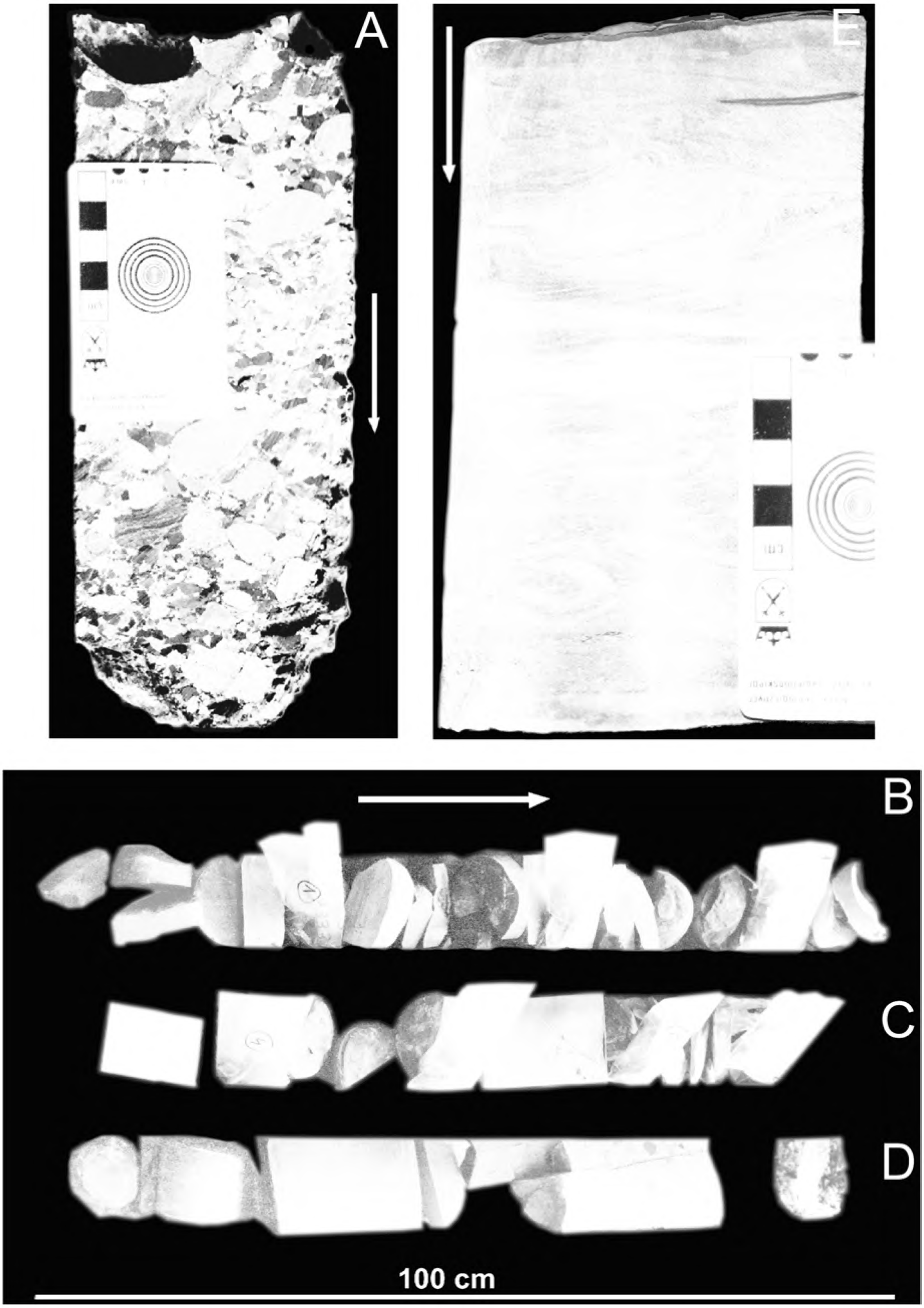
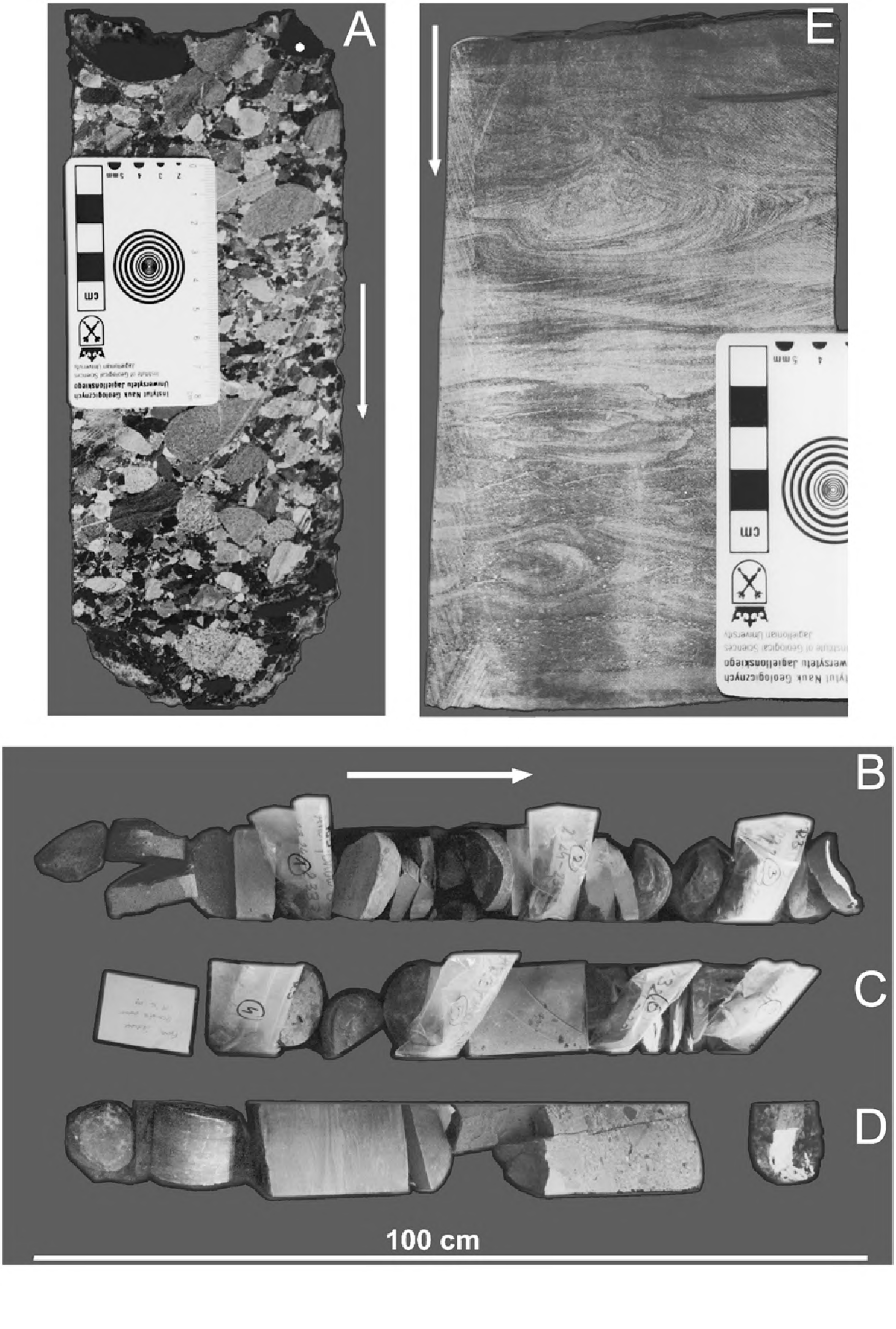


Fig. 5 A. Polimictic pebble conglomerate of the Stryszawa Fm. (core interval 2213-2219 m), box (S IV), B, C – Basal portion of sampled, dark grey, marly mudstones of the Zebrzydowice Formation (core interval 2324-2333), boxes (I, II), D – Pebbly conglomerate of the Andrychów Formation onlaped by the mudstones of the Zebrzydowice Formation, box (S III), E – Hydroplastic deformed silty mudstones, erosively covered by siltstone couplets with hummocky-cross lamination and convolution at the top (detail from box (S III)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flaser? bedding (Text-fig. 4B). The thin section reveals sandstone composed of granulated quartz, alkaline feldspars, light micas, sporadic biotite, glauconite and fragments of micaceous quartz-chlorite slates, gneisses, micrite limestones, dolomites and phyllites, as well as discrete laminated claystones, rich in organic matter.

Box (S III). Medium-bedded (16-25 cm) fine-grained conglomerates with 2-5 cm thick intercalations of coarse- and very coarse-grained sandstones (Text-fig. 4C).

Box (S-IV). Conglomerate bed with sporadic, dispersed pebbles (1-2 cm) of fine-grained sandstones, dark muscovite mudstones and small coal clasts (Text-fig. 4D).

Box (S V-VI). Medium to thick-bedded conglomerates (up to 35 cm), with 1-2 cm thick intercalations of coarse- and very coarse-grained sandstones with a small scale granule imbrication (Text-fig. 4E). The maximum diameter of the pebbles reached 2.5 cm (grey quartzitic sandstones). In this box frequent small-scale early diagenetic faults were observed.

Box (S VII-VIII). Fine conglomerates with very rare thin sandstone intercalations.

Remarks: This sequence probably represents shallow marine (littoral), high-energy depositional environments related to the Late Karpatian-Early Miocene marine transgression.

R2 (2213-2229 m)

Box (S I-IV). Massive dark grey, coarse-grained, thick-bedded (35-100 cm) conglomerates with a few dozen cm of fine-grained, grey conglomerates at the top (box S I). These conglomerates are composed of mosaic coloured, spindle-shaped pebbles, 3-5 cm in diameter (Text-figs 3, 5A). The pebbles are predominantly dark grey, medium to coarse-grained, parallel-laminated, calcareous sandstones, with calcite veins. Pale, fine-grained, quartzitic sandstones are less common. There are also subordinate pale creame-coloured marls, limestones and dark mudstones. In box (S III) the clasts of dark mudstones are more common. Larger pebbles and cobbles, up to 9 cm, are found in box (S II).

Remarks: These massive conglomerates, composed of both platform-derived, as well as the flysch-derived gravels and cobbles, were probably deposited by the mass alluvial fan flow.

R3 (2324-2333 m)

Box (S I). Dark marly mudstones with an intercalation of very thin-bedded (2 cm) medium-grained sandstones with coalified? flakes (Text-figs 3, 5B). At the top the sandstones pass into laminated mudstones, composed of monocrystalline and aggregated quartz, alkaline feldspars and micas, as well as rare grains of micrite limestones and shale clasts.

Box (S II). Dark mudstones with two intercalations of grey, thin-bedded (5-10 cm), medium-grained sandstones (Text-fig. 5C)

Box (S III). At the base there are at least 30 cm of light-coloured, fine conglomerate with sporadic pebbles (3-4 up to 6 cm in diameter) of calcareous sandstones, marly mudstones, limestones and dark and green mudstones (Text-fig. 5D) This conglomerate passes upwards into thin-bedded, pale colored, coarse-grained sandstone, and higher up into dark grey marly mudstones, with a hydroplastic deformation at the top. This interval is capped by a 5 cm layer of coarse-grained siltstones with a hummocky cross-lamination and convolution (Text-fig. 5E). The sandstone-conglomerate member is cut by a sub-vertical extensional joint (Text-fig. 5D).

Box (S IV). 100 cm of a grey, fine conglomerate with carbonate cement. In the middle part of the bed there is a concentration of pebbles and cobbles of fine and very fine, cross-laminated sandstones (Text-fig. 6F).

Box (S V). Coarse conglomerate at the top, and a fine conglomerate at the base (Text-fig, 6A).

Box (S VI). Fine- to coarse-grained, size-graded conglomerate (Text-fig. 6B, G) dominated by imbricated pebbles and cobbles, up to 7.5 cm in diameter, of well rounded laminated sandstones and small pebbles of white-greyish limestones.

Box (S VII). 50 cm coarse conglomerate. Sandstone pebbles up to 6 cm in diameter (Text-fig. 6C). There are grey and pale-coloured calcareous sandstones, composed of mono- and poly-crystalline quartz, alkaline feldspars, micas and granules of quartz-glauconite sandstones, limestones, gneisses and slates.

Box (S VIII). Fine conglomerates with a thin intercalation of coarse- and very coarse-grained carbonate sandstones with dispersed ellipsoidal and spindle-shaped pebbles of calcareous sandstones, up to 7 cm in diameter (Text-fig. 6D).

Box (S IX). Fine- to medium-grained, thick-bedded conglomerate (40 cm) with an intercalation of 20 cm of parallel-laminated coarse-grained sandstones (Text-fig. 6E). The pebbles and cobbles are dominated by pale-coloured laminated sandstones.

Remarks: The core material from this interval is represented by 3 m of dark marly mudstones of shelf origin underlain by 6 m of conglomerates and pebbly sandstones. These are deposited by a high density gravitational flow of the marine fan delta (see READING & al. 1996), which was supplied with coarse clastic material derived from the uplifted platform basement.

R4 (2541-2547 m)

Box (S I-II). Strongly brecciated, pale-beige quartzitic sandstones. At the top brown, fine breccia, capped by iron pan, probably of weathering origin.

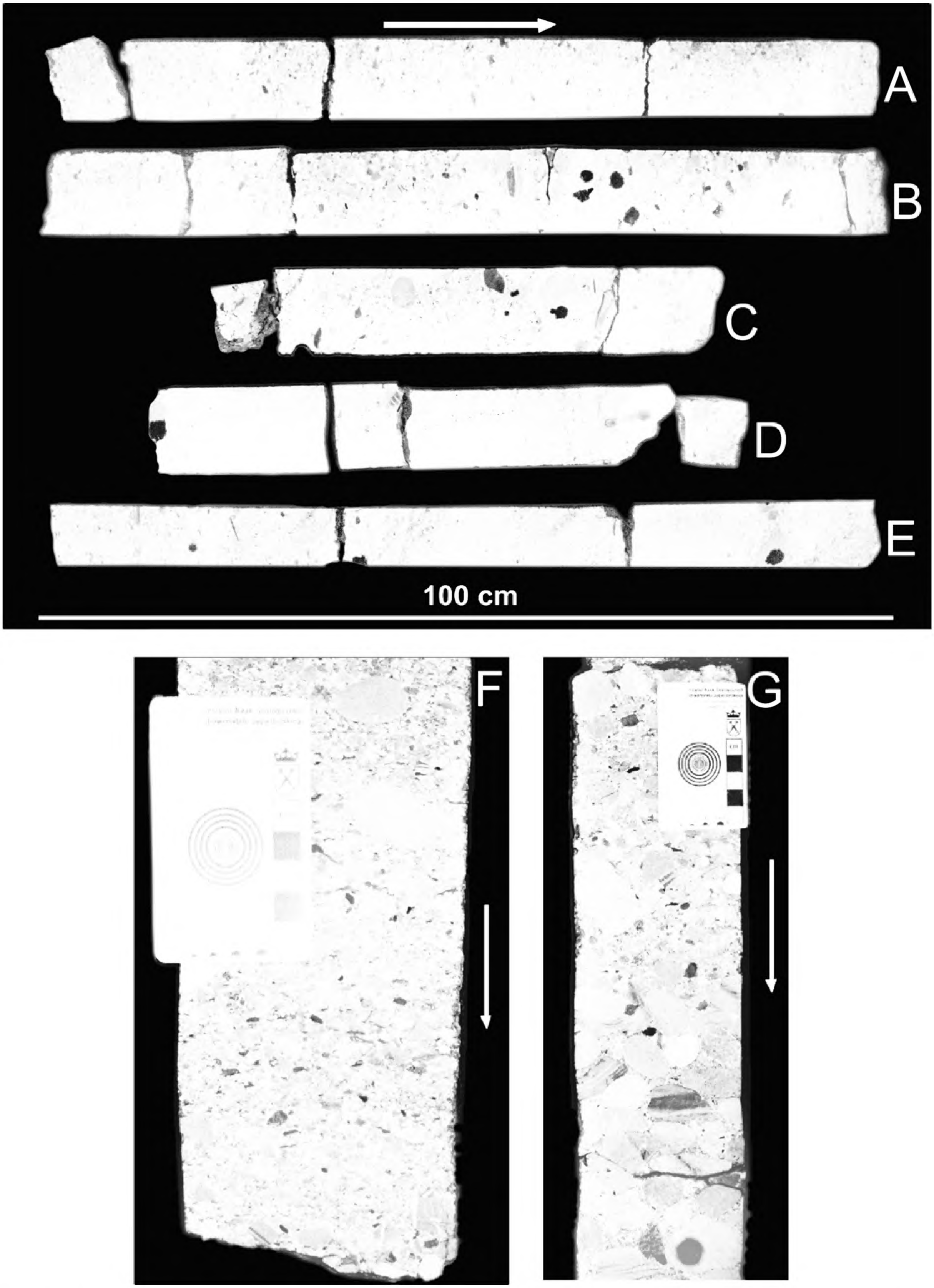
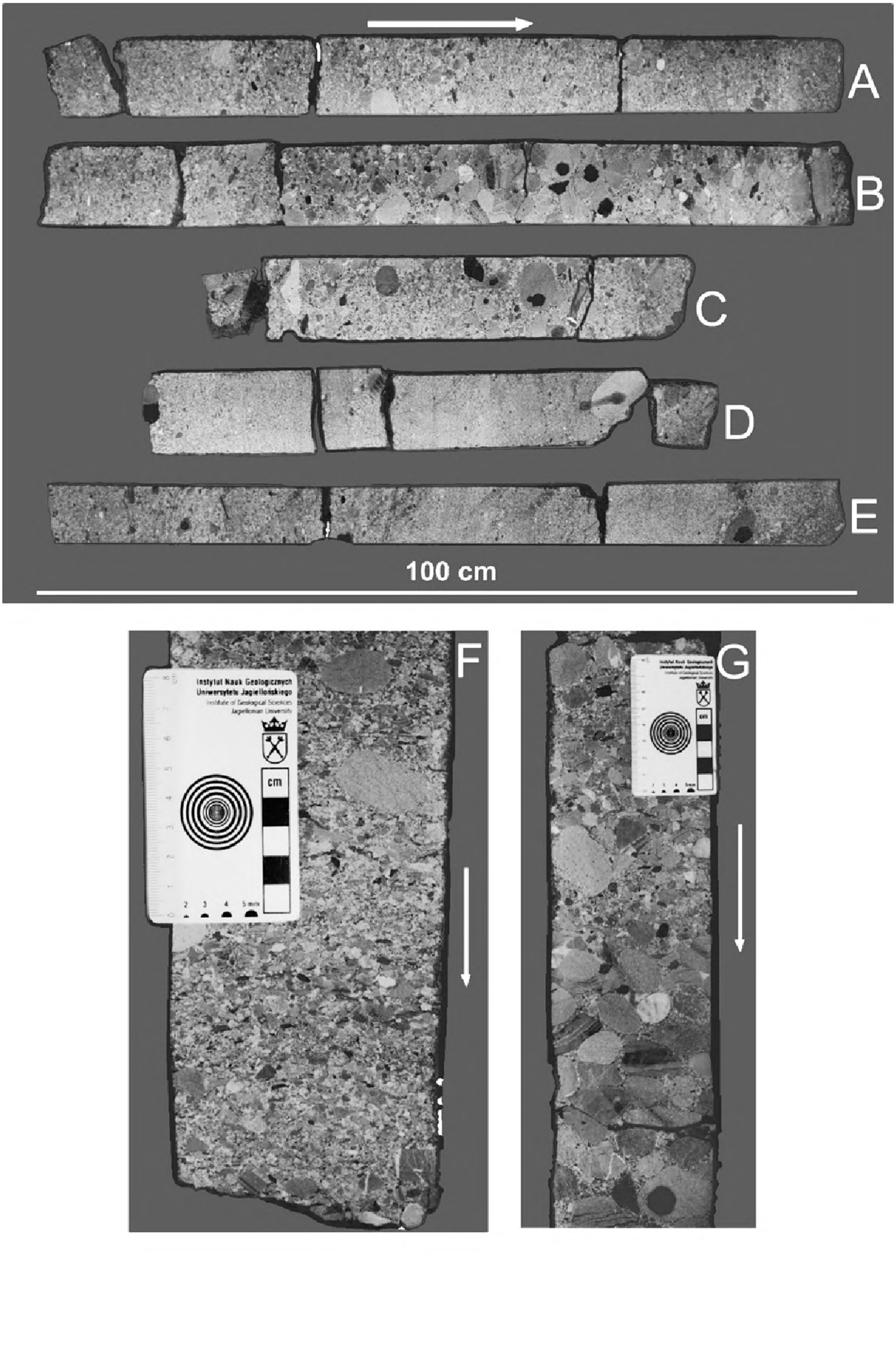


Fig. 6A, B, C, D, E – Massive pebbly conglomerarates and coarse-grained pebbly sandstones of the Andrychów Formation (core interval 2324-2333 m, boxes (S V, VI, VII, VIII, IX), F – Pebbly conglomerate with dispersed pebbles of quartzitic sandstones, box (S IV), G – Upwards transition of polimictic pebble conglomerate to granule conglomerate with dispersed pebbles (detail from box S VI)


A
B
C
D
E
100 cm
F
Instytut Nauk Geologicznych
Uniwersytetu Jagiellońskiego
Institute of Geological Sciences
Jagiellonian University
cm
2 3 4 5 mm
G

CALCAREOUS NANNOPLANKTON BIOSTRATIGRAPHY

These samples were taken from the core interval R3 (2324-2333 m), from boxes S 13, 14 and 15 (Text-fig. 3). All samples were prepared using the standard, smear slide technique for light microscope (LM) observations. The investigation was carried out under LM (Axilab/Carl Zeiss Jena) at a magnification of 1000x using parallel and crossed nicols. Several of the specimens photographed in LM are illustrated in Plate 1.

The examined samples yield well-preserved and moderately diverse calcareous nannoplankton assemblages that are dominated by placoliths, and are typical of an outer offshore (shelf) environment. The autochthonous assemblage contains abundant *Coccolithus pelagicus*, *Cyclicargolithus floridanus* and *Reticulofenestra minuta*, whereas *Sphenolithus conicus, Sphenolithus dissimilis* and *Helicosphaera carteri* are relatively rare (Table 1). In addition, sample A3 contained *Helicosphaera perchnielseniae*. The zonal assignment of the samples is based on the co-occurrence of *Sphenolithus conicus, Sphenolithus dissimilis*, *Helicosphaera perchnielseniae* and *Helicosphaera carteri*. The species *Dictyococcites bisectus,* whose LO defines the Oligocene/Miocene boundary at higher latitudes (PERCH-NIELSEN 1985; BERGGREN & *al.* 1995; FORNACIARI & *al.* 1996; BOWN 1998), was not observed. The rare occurrence of *Sphenolithus conicus* as well as the lack of *Sphenolithus delphix* suggest that the nannofossil assemblage may belong to the highest part of the NN1 Zone. According to YOUNG (YOUNG *in* BOWN 1998), *Sphenolithus delphix* is characteristic of only the upper part of NN1, though AUBRY (1986) reported this taxon from NP25 and NN1. In addition, this assemblage did not contain the species *Sphenolithus disbelemnos* and *Discoaster druggii*, which are typical of NN2.

	A 7	A 6	A 5	A 4	A 3	A 2	A 1
Blackites spinosus	X		-			X	
Coccolithus eopelagicus	X	X	-	X	X	X	X
Coccolithus pelagicus	X	X	-	X	X	X	X
Coronocyclus nitescens	X		-				
Cyclicargolithus abisectus	X	X	-	X	X		X
Cyclicargolithus floridanus	X	X	-	X	X	X	X
Discoaster deflandrei	X						
Ericsonia fenestrata	X		-		X		X
Helicosphaera carteri		X	-		X		X
Helicosphaera compacta	X	X	-	X			
Helicosphaera euphratis	X		-				X
Helicosphaera perch-nielseniae					X		
Pontosphaera multipora	X	X	-	X			X
Pontosphaera plana	X		-				
Pontosphaera rothi	X		-	X			
Reticulofenestra daviesii			-		X		X
Reticulofenestra dictyoda	X		-	X	X		X
Reticulofenestra lockerii		X	-	X			X
Reticulofenestra minuta	X	X	-	X	X		X
Sphenolithus calyclus	X		-				X
Sphenolithus capricornutus			-			X	
Sphenolithus conicus	X		-	X	X	X	X
Sphenolithus dissimilis	X		-	X		X	X
Sphenolithus moriformis	X	X	-				X
Sphenolithus predistentus	X	X	-				
Transversopontis obliquopons	X		-				
Transversopontis pulcheroides			-			X	
Triquetrorhabdulus cf. challengeri		X	-				
Zygrhablithus bijugatus	X	X	-				

Table 1. Calcareous nannoplankton from Andrychów 6 borehole; core interval: R3 (2324-2333 m)

Lower Miocene calcareous nannofossil assemblages are well documented from the following localities: Carpathian Foreland – NE Moravia (borehole Raj NP738, see JURKOVA & *al.* 1983), and the Cieszyn area (Zebrzydowice Formation, see GARECKA & *al.* 1996; GARECKA & OLSZEWSKA 1998), S Moravia (Pouzdrany and Zdanice Units, see KRHOVSKY & *al.* 1995), Silesian (KOSZARSKI & *al.* 1995) and Skole nappes (ŚLĘZAK & *al.* 1995; GARECKA & OLSZEWSKA 1998), Magura Nappe (Zawada Formation see OSZCZYPKO & *al.* 1999; OSZCZYPKO-CLOWES 2001; OSZCZYPKO & OSZCZYPKO-CLOWES 2002) and the Podhale Flysch Basin (STAREK & *al.* 2000).

The nannoplankton assemblages from the Andrychow 6 borehole can be best compared and correlated with those of the Zawada Formation, Uherčice and Zdanice-Hustopeče Formations. The calcareous nannofossil association from the lowermost part of Zawada Formation, includes *Cyclicargolithus abisectus, Cyclicargolithus floridanus, Sphenolithus conicus, Sphenolithus dissimilis*, *Sphenolithus delphix* and *Triquetrorhabdulus carinatus.* Such an association, in the absence of *Dictyococcites bisectus*, is believed to be indicative of NN1. KRHOVSKY (*in* KRHOVSKY & *al.* 1995) identified an NN1 assemblage in the Pouzdřany units containing: *Cyclicargolithus abisectus, Cyclicargolithus floridanus, Helicosphaera scissura, Helicosphaera euphratis, Helicosphaera kamptneri, Pyrocyclus hermosus* and *Triquetrorhabdulus carinatus*. The upper part of the Zawada Formation was assigned to the NN2 Zone. Eggenburgian assemblages were also determined by KRHOVSKY & *al.* (1995) in the Boudky Formation (Pouzdřany Unit) and by JURKOVA & *al.* (1983) from the Karvina area. The samples of the Boudky Formation contained diversified nannofossil assemblages with *Helicosphaera ampliaperta*, *Helicosphaera kamptneri, Helicosphaera mediterranea, Sphenolithus conicus, Reticulofenestra pseudoumbilica* and were placed by KRHOVSKY in the NN2 Zone. The association described by JURKOVA & *al.* (1983) did not contain any species of *Helicosphera*, but instead included *Calcidiscus* cf. *leptoporus*, *Umbilicosphaera rotula*, *Discoaster druggii*. In both cases the assemblages contained *Reticulofenestra excavata* which is a typical Eggenburgian species (LEHOTAYOVA 1975). The Zebrzydowice Formation in the Zebrzydowice 13 borehole was assigned to the NN3 Zone (GARECKA & *al.* 1996, GARECKA & OLSZWSKA 1998).

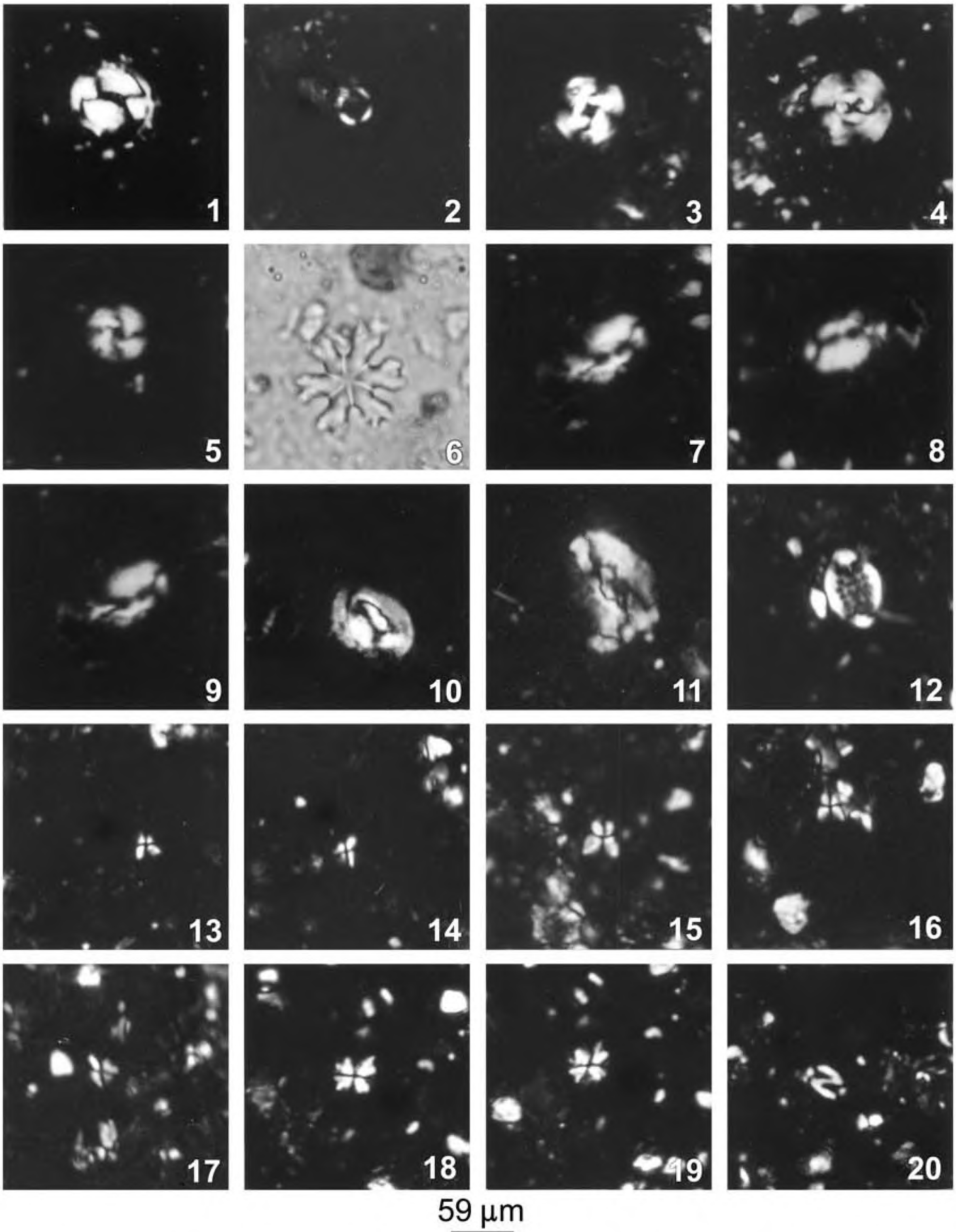


Plate 1. LM microphotographs of calcareous nannofossils from the Andrychów 6 borehole

1 – *Coccolithus eopelagicus* (Bramlette & Riedel) sample A 3 (crossed nicols), 2 – *Coronocyclus nitescens* (Kamptner) sample A 7 (crossed nicols), 3 – *Cyclicargolithus abisectus* (Miller) sample A 6 (crossed nicols), 4 – *Cyclicargolithus abisectus* (Miller) sample A 7 (crossed nicols), 5 – *Cyclicargolithus floridanus* (Roth & Hay) sample A 7 (crossed nicols), 6 – *Discoaster deflandrei* Bramlette & Riedel, sample A 7 (parallel nicols), 7 – *Helicosphaera carteri* sample A 6 (crossed nicols), 8 – *Helicosphaera carteri* sample A 6 (crossed nicols), 9 – *Helicosphaera carteri* (Wallich) sample A 6 (crossed nicols), 10 – *Helicosphaera compacta* Bramlette & Wilcoxon sample A 4 (crossed nicols), 11 – *Helicosphaera euphratis* Haq, sample A 1 (crossed nicols), 12 – *Pontosphaera multipora* (Kamptner) sample A 4 (crossed nicols), 13 – *Sphenolithus conicus* Bukry sample A 7 (crossed nicols), 14 – *Sphenolithus conicus* Bukry sample A 2 (crossed nicols), 15 – *Sphenolithus conicus* Bukry sample A 2 (crossed nicols), 16 – *Sphenolithus conicus* Bukry sample A 2 (crossed nicols), 17 – *Sphenolithus conicus* Bukry sample A 2 (crossed nicols), 18 – *Sphenolithus dissimilis* Bukry & Percival sample A 2 (crossed nicols), 19 – *Sphenolithus dissimilis* Bukry & Percival sample A 2 (crossed nicols), 20 – *Transversopontis obliquipons* (Deflandre) sample A 7 (crossed nicols)

The youngest deposits and the most complete Miocene sequence of the Polish Flysch Carpathians are known from the Skole Nappe. ŚLĘZAK & *al.* (1995) distinguished the following nannofossil zones from the Krosno Beds: NP24/25, NN1, NN2, NN3 and NN4. In contrast the Krosno Beds from the Silesian Nappe were placed in the NN1, NN2 and NN3 zones only (KOSZARSKI & *al.* 1995).

INTERPRETATION

The geological records of the Andrychów 6 borehole (see FINAL REPORT 2000) supported by our sedimentological and calcareous nannoplankton studies, open up a new area for biostratigraphic and palaeogeographic investigations, which will enable a better understanding of the early stages of the Carpathian Foredeep development.

In contrast to the FINAL REPORT (2000), we propose the following reinterpretation of the stratigraphic profile of the Andrychów 6 borehole (Text-fig. 7):

1) The low resistivity interval (1955-1986 m) containing Early Badenian foraminifers should be included in the Skawina Formation.

2) The depth interval 1986-2108 m, which is composed of sandy-clay deposits of Cretaceous and Paleocene/Eocene age, can be included in the Sub-Silesian Unit. In our opinion, these deposits can be compared with the mélange-type deposits described at the front of the Silesian Unit (SE of the Czaniec, and 3 km west of the Andrychów 4 borehole) as the Domaczka olistostrome (WÓJCIK & *al.* 1999).

3) The core from depth interval 2108 to 2219 m is represented mainly by fine-grained conglomerates and sandstones, which we have included into the Dębowiec Conglomerate of the Early Badenian-?Karpatian age. Our suggestion is based on the lithological similarity between the investigated cores and the characteristics of the Dębowiec Conglomerate as given by BUŁA & JURA (1983) and JURA (2001).

4) The depth interval 2220-2290 m is composed of polymictic pebble and gravel conglomerates which can be compared to the Stryszawa Formation (Karpatian, see ŚLĄCZKA 1977, MORYC 1989, POŁTOWICZ 1995, OSZCZYPKO 1997 1998, OSZCZYPKO & LUCIŃSKA-ANCZKIEWICZ 2000).

5) The dark shelf mudstones in the core interval 2290-2327 m should be included in the Zebrzydowice Formation of Egerian/Eggenburgian age. This supposition is based on the same stratigraphical position, and the lithological similarity of the Eggenburgian strata from the Karvina area, the Zebrzydowice Formation (Zebrzydowice 13 and Cieszyn IG-1 boreholes), and the deposits penetrated at 2324-2327 m depth in the Andrychów 6 borehole. The dark mudstones from this borehole belong to the NN1 Zone, whereas the NN2 and NN3 zones were found in mudstones from Karvina and the Zebrzydowice 13 borehole respectively (see also JURKOVA & *al.* 1983, GARECKA & *al.* 1996). This can be explained by the progressive marine transgression from the south to the north.

6) The fan-delta conglomerates from the interval 2327-2538 m we propose to be established as the Andrychów Formation, as a new lithostratigraphic unit of the Oligocene-Egerian (Aquitanian-?) age. The Andrychów Formation transgressively overlapped the Precambrian-Lower Palaeozoic quartzites (Text-fig. 7).

The well log of the Miocene deposits from the Andrychów 6 borehole was correlated with the well logs of the Zawoja 1 and Lachowice 1 boreholes (Text-fig. 8). The well logs of the Dębowiec Conglomerate and Stryszawa Formation, from different boreholes, revealed similarities (see also MORYC 1989, POŁTOWICZ 1995). The resistivity and gamma ray logs at the depth interval 2219-2290 m in the Andrychów 6 borehole, was similar to the log of the Stachorówka Member. (the Stryszawa Formation in the Zawoja 1 and Lachowie 1 boreholes). In the Andrychów 6 borehole there were no traces of flysch olistoplaque (Sucha Formation), which is very characteristic of the lower part of the Miocene sequences in the Zawoja 1 and Lachowice 1 boreholes. The lower, not sampled, portion the Andrychów Formation, as suggested in the well log is composed of sandstone/mudstone alterations (see VAN WAGONER & *al.* 1992), and revealed some similarity to the Zawoja Formation.

DISCUSSION

The Egerian through Eggenburgian transgression on the European platform margin

The most important result of our studies is the determination of the Egerian (Aquitanian) – ? Oligocene age of autochthonous marine deposits in the basement of the Polish Western Carpathians. The upper part of these deposits revealed a litho- and biostratigraphic similarity to the Eggenburgian Zabrzydowice Formation, whereas the lowermost ones show a similarity to the Zawoja Formation (Eocene-Oligocene, see OSZCZYPKO & *al.* 2000). It is also possible that the Bielsko beds, known from the Bielsko 4, Tokarnia IG-1 and Trzebunia 2 boreholes may represent the upper part of the Zebrzydowice Formation (Text-fig. 2). All these deposits are preserved as ero-

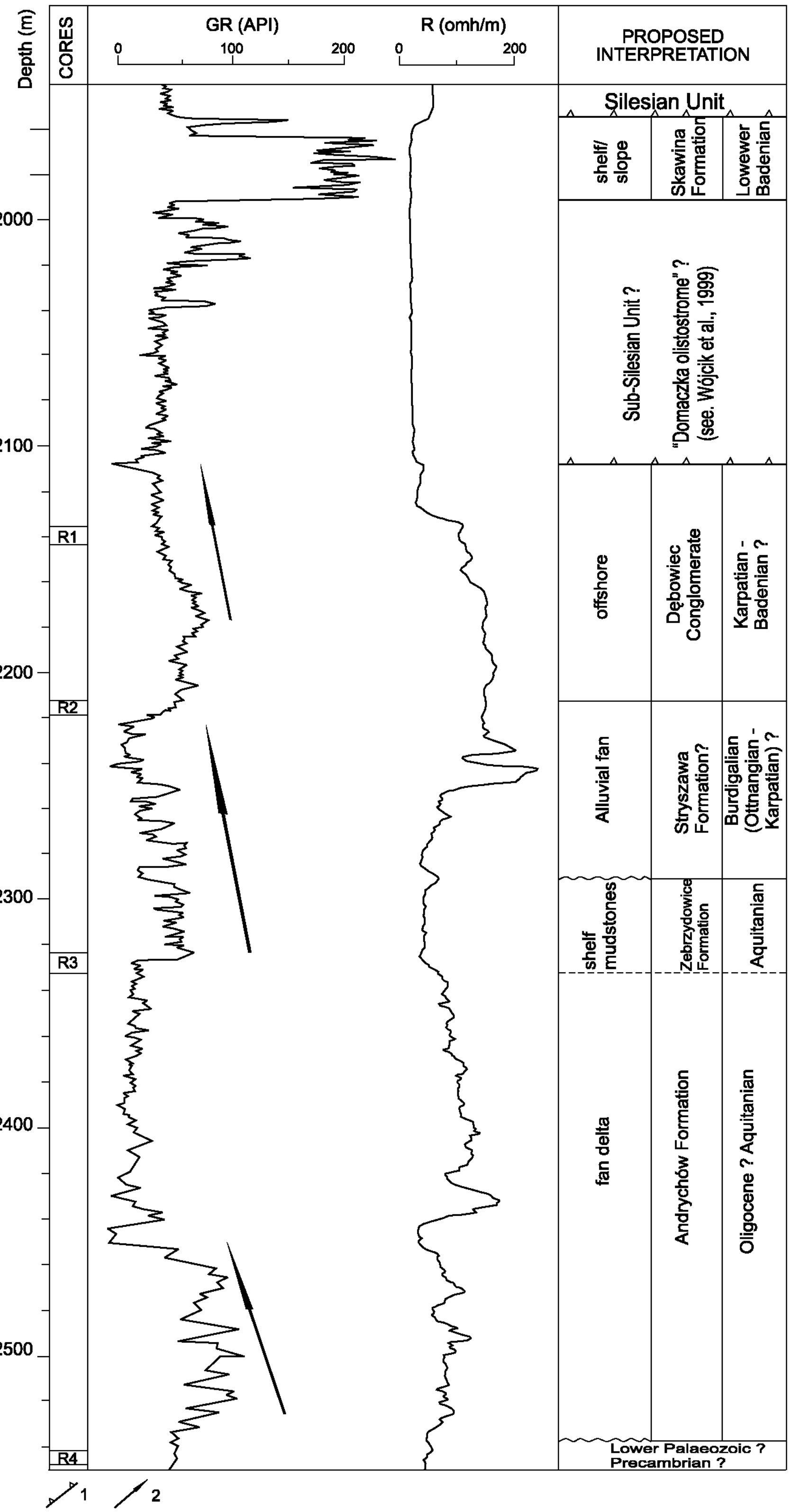


Fig. 7. Lithostratigraphic log of the Andrychów 6 borehole of the Polish Oil and Gas Company (partly after Final Report 2000); 1 – overthrust, 2 – coarsening upwards sequence

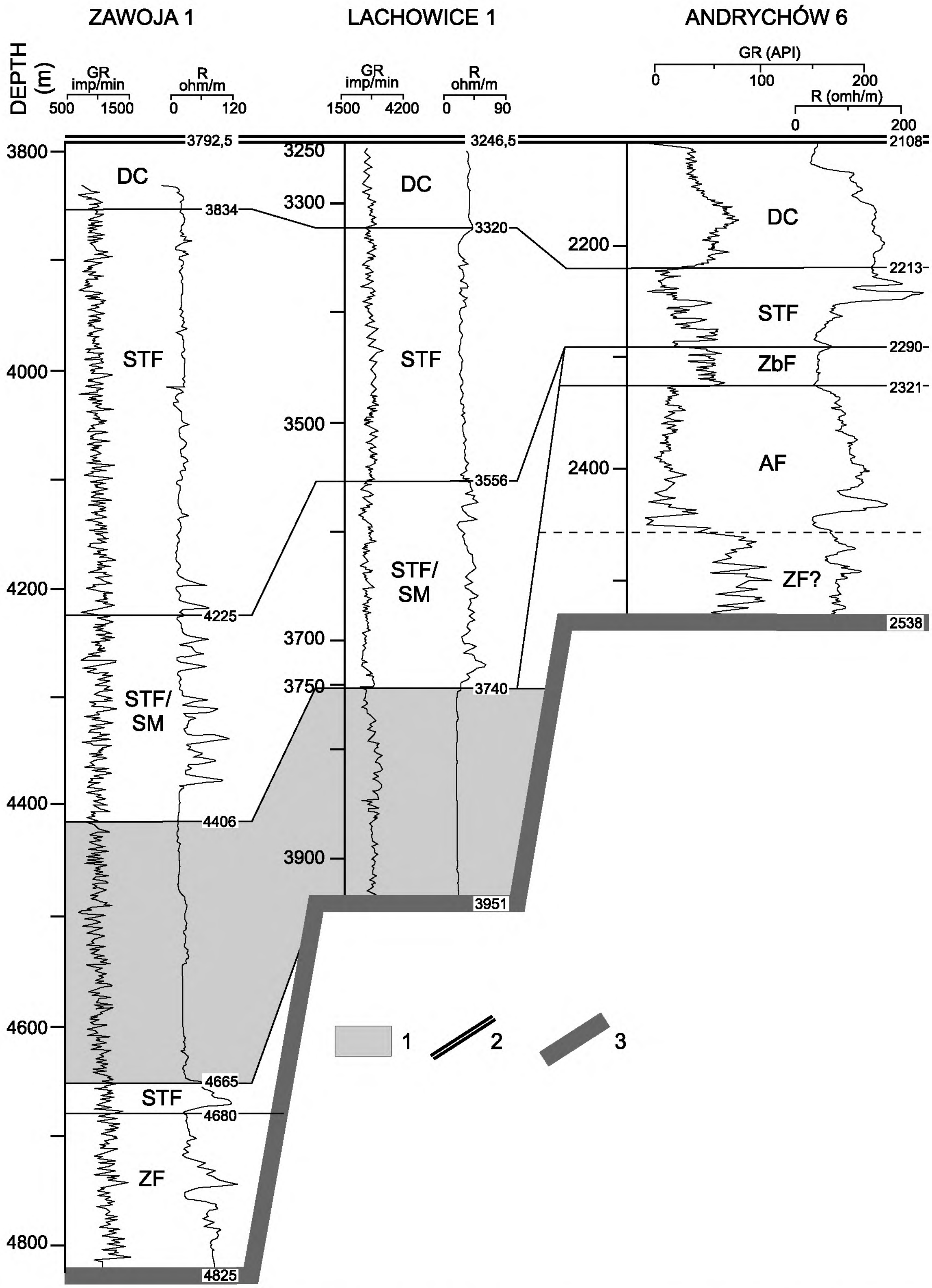


Fig. 8. Log cross-section of the sub-thrust Miocene deposits of the Andrychów – Zawoja area (Polish Western Carpathians); 1 – Sucha Formation (Flysch olistoplaque), 2 – Carpathian sole thrust, 3 – Palaeozoic basement. Abbreviation: DC – Dębowiec Conglomerate, STF – Stryszawa Formation, STF/SM – Stachorówka Member, of the Stryszawa Formation, ZbF – Zebrzydowice Formation, AF – Andrychów Formation, ZF – Zawoja Formation

sional outliers in palaeovalleys (JURKOVA & *al.* 1983, POŁTOWICZ 1995, JURA 2001). These are typical preservation forms of Eggenburgian and Ottnangian deposits in Moravia (see ELIAŠ & PALENSKY 1997). The Oligocene-Egerian through Eggenburgian marine deposits from the basement of the Polish Outer Carpathians are the age equivalents of the youngest deposits of the Outer Carpathians (Text-fig. 9).

The youngest deposits of the Skole, Sub-Silesian and Silesian units belong to the Menilite-Krosno succession, which is up to 3-4 km thick. Since the 1970s the Upper Krosno Formation (above the Jaslo Limestone

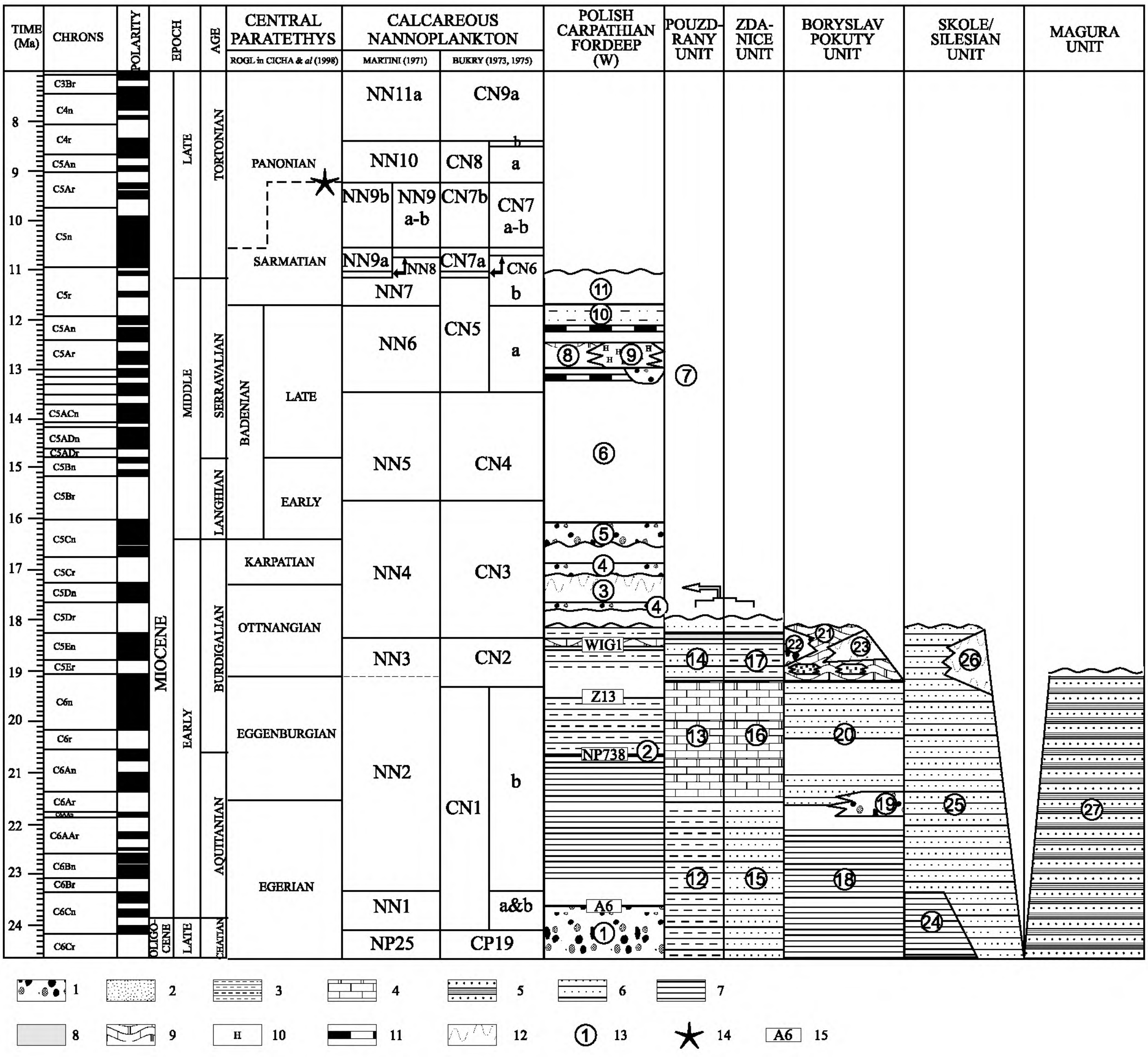


Fig. 9. Regional stratigraphic scheme of the Miocene deposits of the Polish Carpathians and adjacent area. The Miocene time scale after BERGGREN & *al.* (1995) and RÖGL *in* CICHA & *al.* (1995); 1 – conglomerates, 2 – sandstones, 3 – siltstones & mudstones, 4 – marls, 5 – thick-bedded flysch, 6 – Krosno lithofacies, 7 – dark mudstones & Menilite lithofacies, 8 – variegated claystones, 9 – gypsum & anhydrites, 10 – salts, 11 – tuffites, 12– olistostrome, 13 – Lithostratigraphic unit: PCF (W), after OSZCZYPKO (1997, 1998, supplemented): 1 - Andrychów Formation and ? Zawoja Formation, 2 – Zebrzydowice Formation, 3 – Sucha Formation – flysch olistoplaque, 4 – Stryszawa Formation, 5 – Dębowiec Conglomerate, 6 – Skawina Formation, 7 – Sypka Góra Conglomerate, 8 – Krzyżanowice Formation, 9 – Wieliczka Formation, 10 – Chodenice, Grabowiec and Gliwice beds, 11 – Krakowiec and Kędzierzyn beds; Pouzdrany and Zdanice/Sub-Silesian units (after KRHOVSKY & *al.* 1995): 12 – Uherice Formation, 13 – Boudky Formation, 14 – Krepice Formation, 15 – Zdanice-Hustopece Formation, 16 – Sakvice Formation, 17 – Polkowice Formation; Boryslav-Pokuty Unit (after ANDREYEVA-GRIGOROVICH & *al.* 1997): 18 – Upper Menilite beds, 19 – Rushor Conglomerate, 20 – Polanyanytsa Formation, 21 – Vorotyscha Formation, 22 – Sloboda Conglomerate, 23 – Truskavec Conglomerate, Skole/Silesian units (Poland, after GARECKA & OLSZEWSKA 1998): 24 – Menilte beds, 25 – Krosno beds, 26 - Gorlice beds (JANKOVSKI 1997); Magura Nappe: 27 – Zawada Formation (OSZCZYPKO & *al.* 1999, OSZCZYPKO-CLOWES 2001, OSZCZYPKO & OSZCZYPKO-CLOWES 2002), 14 – upper limit of Sarmatian after MARUNTEANU (1999), 15 – cited boreholes

horizon) of the Skole and Silesian units has been assigned to the Lower Miocene. According to nannoplankton studies (ŚLĘZAK & *al.* 1995, ANDREYEVA-GRIGOROVICH & *al.* 1997, GARECKA & OLSZEWSKA 1998) this formation represents the Egerian-Eggenburgian (NN1/NN3 zones). More recently, Egerian-Eggenburgian folded deposits (NN1/NN3) were found in the northern part of the Magura Nappe (OSZCZYPKO & *al.* 1999, OSZCZYPKO-CLOWES 2001, OSZCZYPKO & OSZCZYPKO-CLOWES 2002) at the contact Pieniny Klippen Belt/Magura Nappe (CIESZKOWSKI 1992, MATAŠOVSKY & ANDREYEVA-GRIGOROVICH 2002) and in the Central Carpathian Paleogene (Podhale Flysch) (see STAREK & *al.* 2000). All of these findings enable us to conclude that in the Northern Outer Carpathians and the adjacent part of the European Platform there existed a broad Egerian-Eggenburgian foreland basin (Text-fig. 10).

Late Eocene – Early Miocene palaeogeographic and palaeotectonic evolution of SW Poland

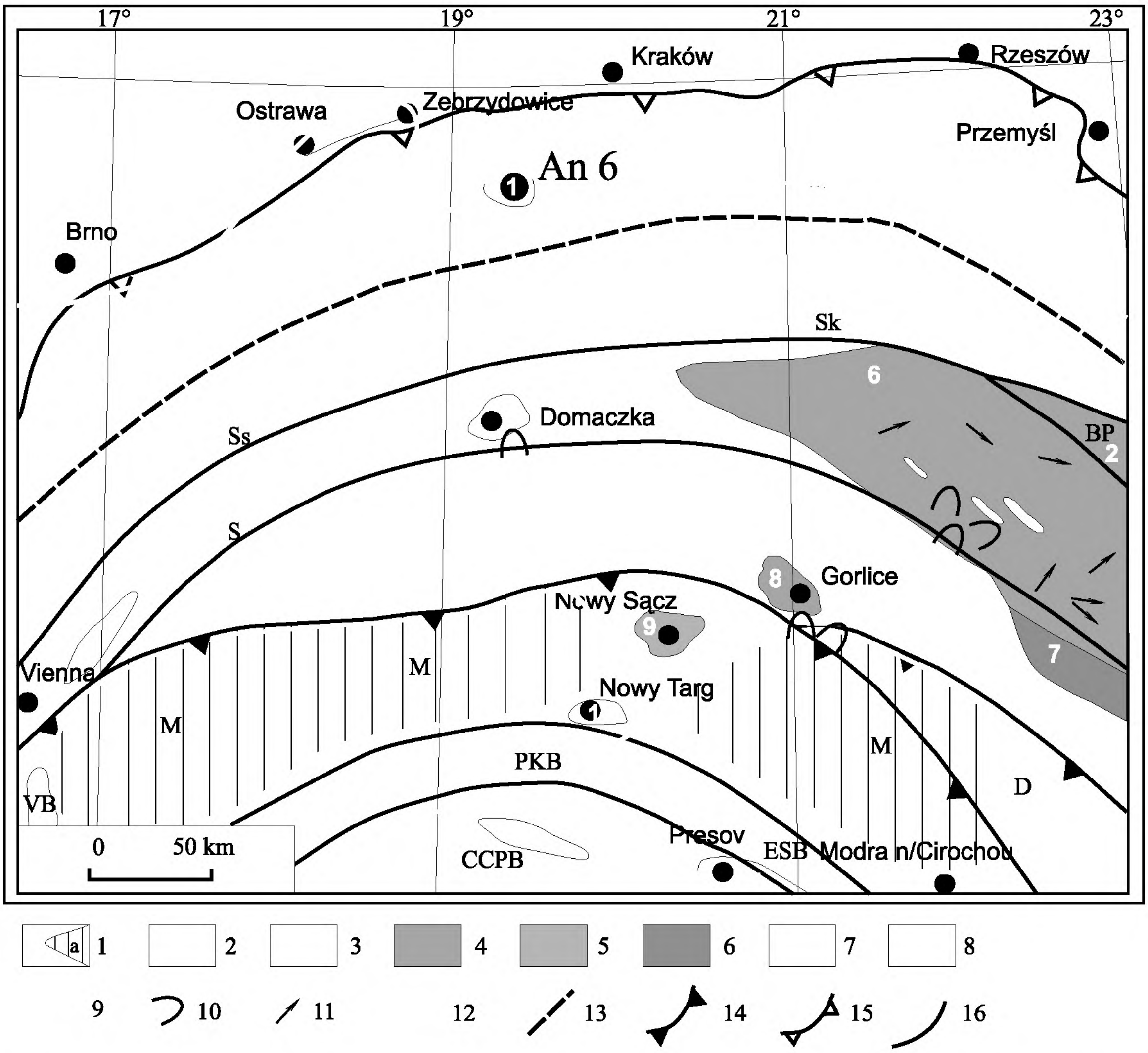


Fig. 10. Early Burdigalian (Eggenburgian) Miocene palaeogeography of the Polish Outer Carpathians [after KSIĄŻKIEWICZ (*Ed.*) 1962, KOVAČ & *al.* 1998, OSZCZYPKO & *al.* 1999, supplemented]; 1 – emerged land, a - islands, 2 – shelf and slope facies, 3 – diatomites; basinal facies: 4 – thin-bedded turbidites, 5 – siliciclastic-carbonate turbidites, 6 – thick-bedded glauconitic turbidites, 7 – thick-bedded turbidites, 8 – presumed extension of the Early Miocene basin, 9 – shoreline, 10 – slumps, 11 – palaeocurrent direction, 12 – seaways, 13 – zero line of Viese's vectors, 14 – tectonic margins, 15 – present-day front of the Carpathians, 16 – northern limit of Boryslav Pokuty (BP), Skole (Sk), Silesian (S), Dukla (D), Magura (M) and Pieniny Klippen Belt (PKB), Central Carpathian Paleogene Basin (CCPB), Vienna Basin (VB) and East Slovakian Basin (ESB) facies. Lithostratigraphic subdivisions: 1 – Zebrzydowice Formation, 2 – Vorotyscha Formation, 3 – Domaczka Formation, 4 – Sakvice Formation, 5 – Presov Formation, 6 – Krosno shaly facies, 7 – Krosno sandstone facies, 8 – Gorlice Beds, 9 – Zawada Formation, 10 – Waksmund Formation, 11 – Biely Potok Formation

The Late Jurassic to Early Miocene Outer Carpathian flysch basin developed along the northern margin of the Neotethys. Like the other orogenic belts, the Outer Carpathians were progressively folded towards the continental margin. During the Late Eocene the Outer Carpathians from the remnant oceanic basin were transformed into a foreland basin (OSZCZYPKO 1999). This was connected with the process of closing of the Neotethys in the course of the Alpine – Himalayan orogenesis (see GOLONKA & *al.* 2000). In the southern part of the Outer Carpathian Basin these movements were manifested by a southward subduction of the thinned crust beneath the Pieniny Klippen Belt/Central Carpathian Block and the development of the Magura accretionary wedge (OSZCZYPKO 1992, 1999). The Late Eocene compression in the Alpine – Carpathian domain coincided with a global glacioeustatic fall of sea level (at least 100 m) (VAN COUVERING & *al.* 1981, HAQ & *al.* 1987).

In the Outer Carpathian basin this resulted in drastic changes in the deposition condition from deep-water conditions, characterized by the occurrence of red and green shales and deep-water turbidites, to conditions represented in the Late Eocene/Oligocene by pelagic *Globigerina* Marls. During the Oligocene these marls were replaced by organic-rich Menilite (Fish) shales, deposited in the restricted basin.

The next important tectonic event took place during the Late Oligocene/Aquitanian, when the Magura Nappe was formed and thrust northwards onto the terminal Krosno flysch basin (see also KOVAČ & *al.* 1998, GOLONKA & *al.* 2000). These movements were almost contemporaneous with those of the Northern Calcareous Alps and Rhenodanubian Flysch. During the Late Oligocene/ Egerian the low stand of sea level in the residual flysch basin resulted in deposition of thick-bedded turbidites, while in the platform area a fan delta system developed (see conglomerates of the Zawoja and Andrychów formations, Text-figs 7-8).

During the Eggenburgian, the front of the Magura Nappe reached the southern part of the Silesian Basin (Text-fig. 10). Parallel to these overthrust movements, the development of the Magura piggy-back basin began. The Silesian basin was supplied both from the eroded front of the Magura Nappe as well as from the uplifted parts of the basin. The restored width of the Egerian – Eggenburgian basin probably measured 100-150 km. The Late Egerian through Eggenburgian global rise in sea level was recorded in the Carpathian foreland basin by an onlap of transgressive deposits of the Zebrzydowice Formation (NN1-3) onto the southern edge of the European Platform (N. Moravia and the S. Upper Silesia Basin, see also PICHA & STRANIK 1999, RÖGL 1999). In the Carpathians this resulted in the deepening of the residual flysch basin and the development of the Egerian – Eggenburgian (NN1/NN3) Magura piggy-back basin, as well as the opening of the sea-way connection with the Vienna Basin (see OSZCZYPKO & *al.* 1999, OSZCZYPKO-CLOWES 2002). At the beginning of the Early Burdigalian (NN3), the Late Krosno basin shifted towards the NE (Skole/Boryslaw Pokuty basin) and finally underwent dessiccation (the Lower Miocene salt formations in the Ukrainian and Romanian Carpathians).

In Upper Silesia this event was probably recorded in the Woszczyce IG-1 borehole (Text-figs 1-2). In this borehole the Menilite-like bituminous shales with fish scales, found at the top of the Upper Carboniferous pass upwards into anhydrite-mudstones, which were transgressively overlapped by the Early Badenian marine transgression (JURA 2001, see also OSZCZYPKO & *al.* 1989).

The early stages of the Carpathian foredeep development

The geological results of the Andrychów 6 boreholes, combined with data from older boreholes from the Andrychów-Zawoja-Żywiec-Cieszyn area, allows for a new interpretation of the sedimentary-tectonic evolution of the area. Analyses of the sub-thrust map of the studied area and the regional cross-sections (Text-figs 2, 11, 12) enables us to propose the following scenario of Early/Middle Miocene evolution of this part of the Carpathian foreland:

The Egerian – Ottnangian period of marine deposition in the Carpathian foreland basin (Text-fig. 10) was followed by intra-Burdigalian folding (Late Ottnangian) and the uplift and overthrust of the Outer Carpathians onto the foreland platform (see also OSZCZYPKO 1998, KOVAČ & *al.* 1998). At the beginning of the Ottnangian the front of the Outer Carpathians was located about 50 km south of the present-day position (Text-fig. 2, see also KONIOR 1981, OSZCZYPKO & TOMAŚ 1985, POŁTOWICZ 1995, OSZCZYPKO 1997, 1998). Simultaneously, during the uplift of the Outer Carpathians the sea retreated from its foreland. This was accompanied by the erosion of the Paleogene through Early Miocene deposits on the uplifted blocks of the platform (JURKOVA & *al.* 1883, ELIAŠ & PALENSKY 1997, OSZCZYPKO & LUCIŃSKA-ANCZKIEWICZ 2000). The load of the growing Carpathian accretionary wedge caused a bending of the platform basement and the development of the moat-like flexural depression (inner foredeep, see OSZCZYPKO 1998), which was filled by coarse clastic deposits. This was accompanied by the development of large-scale slides along the frontal part of the Sub-Silesian Nappe. These slides formed olistoplaques and gravitational nappes, which progressively overthrust the subsiding area. In NE Moravia and S. Silesia the thin-skinned Sub-Silesian and Silesian nappes overrode the platform basement and its Paleogene/Early Miocene cover. These overthrusts are known as the "Old Styrian nappes" (JURKOVA 1971) or as the Sucha and Zamarski formations (flysch olistoplaque, see BUŁA & JURA 1981; OSZCZYPKO & TOMAŚ 1985; MORYC 1989; OSZCZYPKO 1997, 1998). In the Cieszyn area this overthrust reached more or less the present-day position of the Carpathians (Text-figs 2, 10, 11). The overthrust developed under terrestrial conditions. This is documented by the alluvial of the original conglomerates of the Stryszawa Formation type, which were found at the base of the overthrust in some boreholes (Bielowicko IG-1, Zawoja 1). The formation of the olistoplaque was followed by the Karpatian period of intensive subsidence and deposition in the inner foredeep, which was filled with coarse clastic sediments of the Stryszawa Formation (GARECKA & *al.* 1996; OSZCZYPKO 1997, 1998). The subsidence and the deposition probably also affected the frontal part of the Carpathian nappes. The Stryszawa Formation was deposited by the alluvial fan, which was supplied by material derived from the erosion of both the Carpathians as well as the emerged platform. The youngest recycled microfauna found in the Stryszawa Formation belong to the Eggenburgian - Ottnangian N5-N6 zone (see STRZĘPKA 1981, OSZCZYPKO 1997). The same origin is also suggested by calcareous nannoplankton of NN 4 Zone found in the Stryszwa Formation (GARECKA & *al.* 1996). These foraminifers and calcareous nannoplankton may have been derived both from the youngest strata of the Outer Carpathians as well as from the Zebrzydowice Formation. Deposition of the Stryszawa Formation was followed by Late Karpatian erosion, which was caused by the uplift of the peripheral bulge (Cieszyn-Slavkov Palaeo-Ridge, see OSZCZYPKO & TOMAŚ 1985, ELIAŠ & PALENSKY, 1997 OSZCZYPKO 1997, OSZCZYPKO & LUCIŃSKA-ANCZKIEWICZ 2000). In Southern Moravia this period of erosion can be correlated with the discordance below

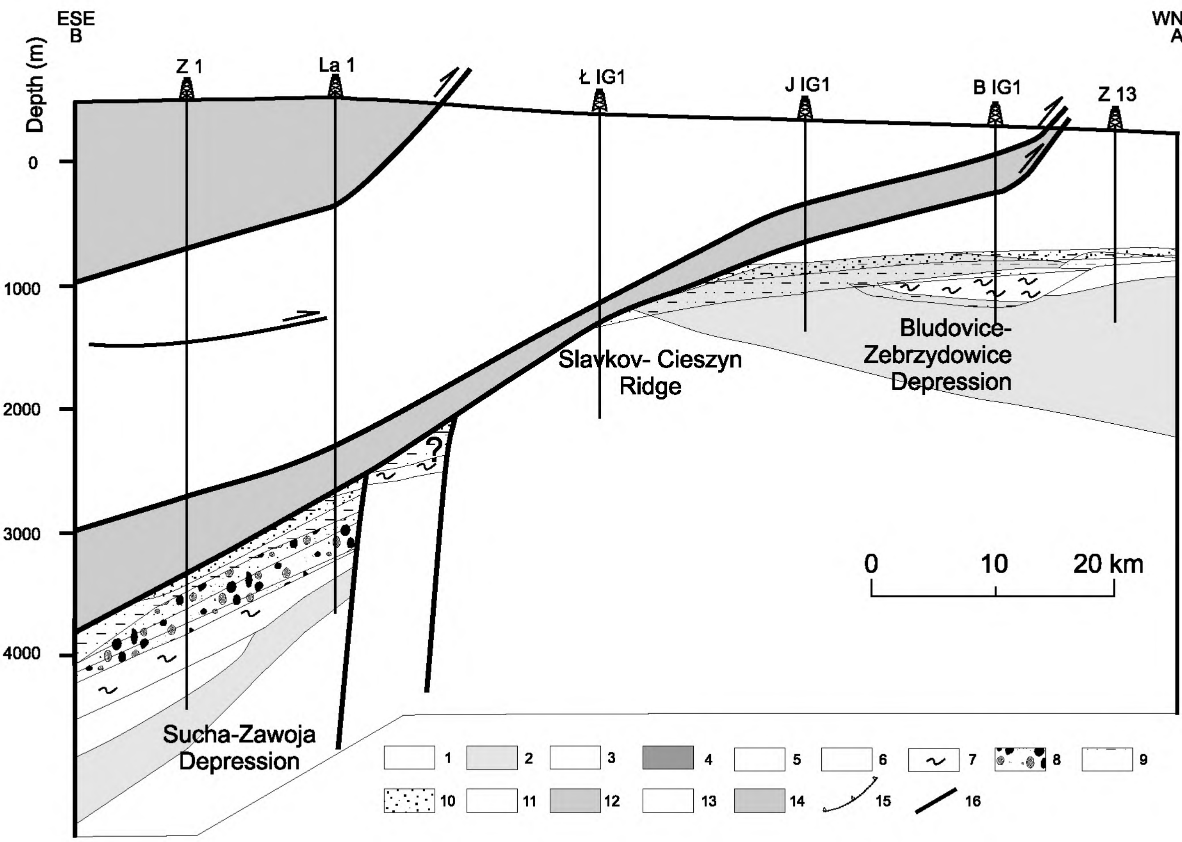


Fig. 11 Geological cross-section Zebrzydowice - Zawoja (Polish Western Carpathians); 1 – crystalline basement, 2 – Palaeozoic undivided, 3 – Devonian – Early Carboniferous, 4 – Late Carboniferous, 5 – Zawoja (Paleogene) and Andrychów formations (Oligocene – Egerian), 6 – Zebrzydowice Formation (Eggenburgian – Ottnangian), 7 – Sucha Formation (olistoplaque), 8 – Stachorówka Member (Karpatian), 9 – Stryszawa Formation (Karpatian), 10 – Dębowiec Conglomerate (Late Karpatian – Early Badenian), 11 – Skawina Formation (Badenian), 12 – Sub-Silesian Unit, 13 – Silesian Unit, 14 – Magura Unit, 15 – overthrust, 16 – faults

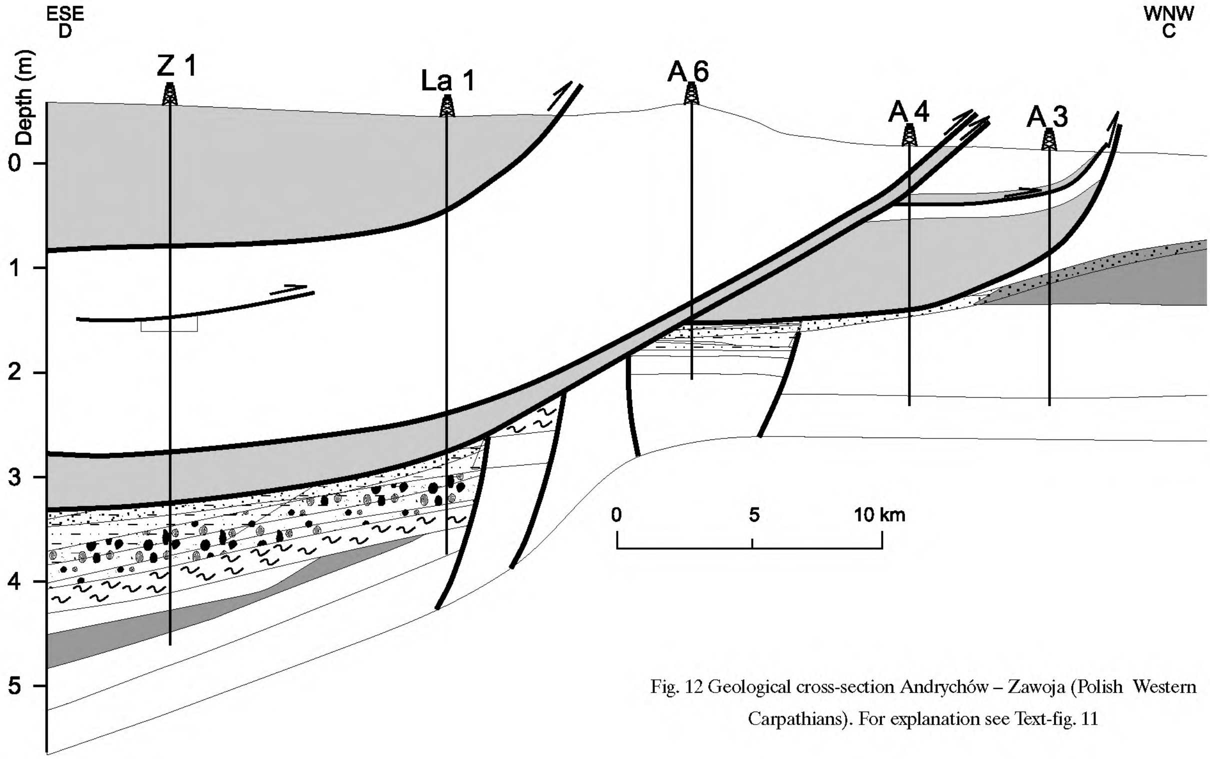


Fig. 12 Geological cross-section Andrychów – Zawoja (Polish Western Carpathians). For explanation see Text-fig. 11

the terminal Karpatian strata (JIRIČEK 1997). Simultaneously, the erosion on the northern flank of the Cieszyn-Slavkov Palaeo-Ridge resulted in the begining of the development of the W-E and NW-SE trending graben (see Text-fig. 2, Bludowice-Skoczów Palaeo-valley) which was bounded by normal faults (see ELIAŠ & PALENSKY 1997, OSZCZYPKO & LUCIŃSKA-ANCZKIEWICZ 2000). During the Late Karpatian – Early Badenian time these subsiding grabens were successively filled with slope deposits (blocks of Carboniferous rocks), the near-shore Dębowiec Conglomerate, and were finally flooded by a relatively deep sea (marly mudstones of the Skawina Formation). This marine transgression invaded both the foreland plate and the Carpathians. During the Badenian the axes of the extensional grabens migrated to the NE (Zawada and Krzeszowice grabens). The Late Badenian drop in sea level and climatic cooling initiated a salinity crisis in the Carpathian foreland basin (see PERYT & *al.* 1997, PERYT 2001, OSZCZYPKO 1998). The shallow (stable shelf) part of the evaporite basin (see POŁTOWICZ 1993) was dominated by sulphate facies, whereas the deeper part, located along the Carpathian front, was occupied by chloride-sulphate facies. After the evaporite deposition the basement of the outer foredeep was uplifted and part of the foredeep was affected by erosion (e.g. Rzeszów Palaeo-Ridge). This event was followed by a telescopic shortening of the Carpathian nappes (Intra Badenian compressive event, see OSZCZYPKO 1997, 1998; KOVAČ & *al.* 1998). This is documented by an at least 12 km movement of the Magura and Fore Magura units against the Silesian unit, as well as the Silesian unit against the Sub-Silesian unit and the tectonic reduplication of the Sub-Silesian unit (Text-figs 11-12). Finally, the present-day position of the Carpathian nappes was reached in post-Sarmatian time (see WÓJCIK & JUGOWIEC 1998, OSZCZYPKO 1998).

Acknowledgments

The authors thank B. G. GEONAFTA (Warszawa-Jasło-Kraków) represented by Mr M. HOFFMAN, Z. BORYS and A. GÓRKA, for their kind permission in allowing us to study and publish data related to the Andrychów 6 borehole. We also extend our thanks to Prof. A. S. ANDREYEVA-GRIGOROVICH from the Universities of Lviv (Ukraine) and Komensky (Slovakia) for her fruitful discussion. The authors are also grateful to David CLOWES for his help in correcting the English text. Finally we would like to thank Prof. M. KOVAČ (Komensky University, Bratislava, Slovakia) and an anonymous reviewer for their thorough and constructive comments.

This paper has been carried out with the financial support of the Polish State Science Foundation (KBN) Project 6P04D 040 19, which was led by N. OSZCZYPKO.

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Manuscript submitted: 10th February 2002
Revised version accepted: 15th December 2002