The Middle Miocene of the Fore-Carpathian Basin
(Poland, Ukraine and Moldova)

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**deceased 7 January 2016

ABSTRACT:

Wysocka, A., Radwański, A., Górka, M., Bąbel, M., Radwańska, U. and Złotnik, M. 2016. The Middle Miocene of the Fore-Carpathian Basin (Poland, Ukraine and Moldova). *Acta Geologica Polonica*, **66** (3), 351–401. Warszawa.

Studies of Miocene sediments in the Fore-Carpathian Basin, conducted by geologists from the University of Warsaw have provided new insights on the distribution of the facies infilling the basin, particularly in the forebulge and back-bulge zones. The origin of the large-scale sand bodies, evaporitic deposits and large-scale organic build-ups is discussed, described and verified. These deposits originated in variable, shallow marine settings, differing in their water chemistry and the dynamics of sedimentary processes, and are unique with regard to the fossil assemblages they yield. Many years of taxonomic, biostratigraphic, palaeoecologic and ecotaphonomic investigations have resulted in the identification of the fossil assemblages of these sediments, their age, sedimentary settings and post-mortem conditions. Detailed studies were focused on corals, polychaetes, most classes of molluscs, crustaceans, echinoderms, and fishes.

Key words: Lithofacies; Fossil assemblages; Middle Miocene; Fore-Carpathian Basin; Poland; Ukraine.

INTRODUCTION (A. Radwański, A. Wysocka and M. Górka)

This paper reviews and updates the investigations of researchers from the Faculty of Geology in Warsaw on the mid-Miocene of the Fore-Carpathian Basin in southern Poland, western Ukraine and Moldova. In palaeogeographic terms, the studied area belonged to the northern compartment of the Central Paratethys that extended, in mid-Miocene times, from Moravia, through Poland and Ukraine, to Moldova and Romania (Text-fig. 1A, B).

The investigations into the Miocene of the Fore-Carpathian Basin began at the end of the 18th century with the paper by Jaśkiewicz (1787), who reported molluscan shells from the Korytnica Clays, and concluded on their marine origin. The palaeontological assemblages have been studied gradually, until the 1920's, when the period of more intense work on faunal assemblages of the Miocene, which lasts till the present, commenced (see chapter 'Overview of selected taxonomic groups'). The palaeontological groups treated in the literature range from leaf flora and microfossils, through numerous invertebrates, to large marine mammals. Not only the taxonomic composition but also the interspecific relations (e.g., symbiosis, commensalism, parasitism) and the eco-taphonomic history among the described organisms have been reported.

Besides their stratigraphic importance, the numerous taxa and/or organic assemblages appear to be

perfect tools for the reconstruction of environmental conditions in the Miocene sea. Some of these groups, some quite "exotic", are briefly presented in this paper. The present authors' research has focused on the palaeogeography, palaeoenvironments, palaeontology, and behavioural palaeobiology. All these research areas have been conducted in the Faculty of Geology, University of Warsaw, both in the area of the Fore-Carpathian Basin (Radwański 1964, 1965, 1968, 1969, 1973, 1974; Bałuk and Radwański 1968, 1977, 1979,

1984a,b, 1991, 1996, 1997; Bałuk 1971, 1972, 1974, 1975, 1977, 1984, 1995, 1997, 2003, 2006; Gutowski, 1984; Radwańska 1984, 1987, 1992, 1994a,b, 2003; Radwańska and Radwański 1984; Bąbel 1986, 1987, 1991, 1996, 1999a,b, 2002a,b, 2004a,b, 2005a,b, 2007a,b; Musiał 1987; Drewniak 1994; Bąbel *et al*. 1999, 2011, 2015; Radwański and Wysocka 2001, 2004, 2006; Roniewicz and Wysocka 2001; Złotnik 2001, 2003; Górka 2002, 2006; Wysocka 2002, 2006; Ceranka and Złotnik 2003; Bąbel and Becker 2006;
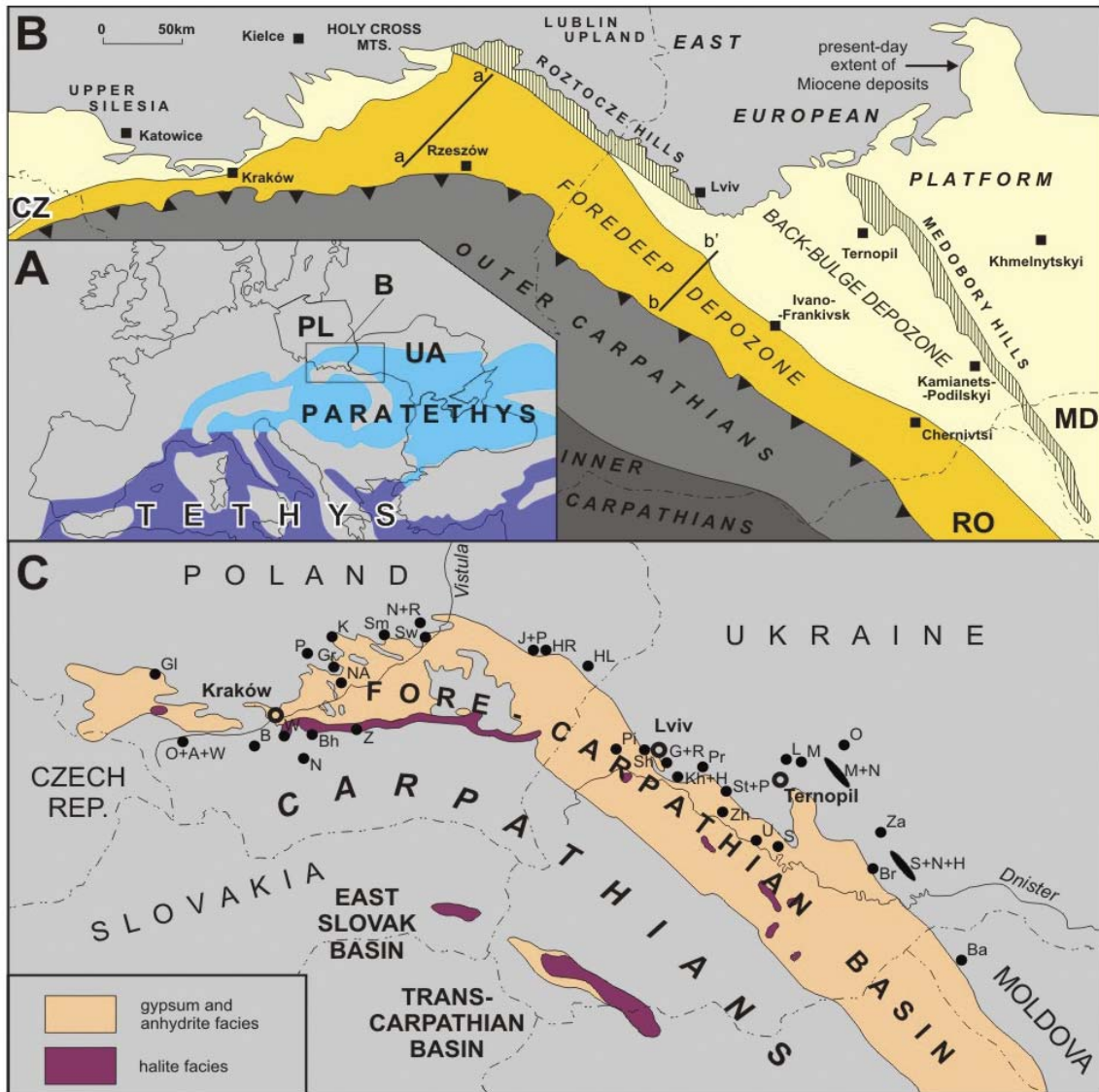
Text-fig. 1. A – Sketch map of the Mediterranean Tethys and Paratethys bioprovinces in Europe (after Rögl and Steininger 1983); **B** – the present-day extent of the Middle Miocene deposits of the Fore-Carpathian Basin in Poland and western Ukraine (foredeep depozone – deep yellow, back-bulge depozone – light yellow); **C** – the present-day distribution of the Badenian evaporites, without carbonate facies (after Khrushchov and Petrichenko 1979, and other sources) with the location of the exposures described in the text (Poland: B – Bęczyn (=Benczyn), Bh – Bochnia, Gl – Gliwice, Gr – Grobie, HL – Huta Lubycka, HR – Huta Różaniecka, J+P – Józefów and Pardysówka, K – Korytnica, N – Niskowa, NA – Nida area, N+R – Nawodzice and Rybnica, O+A+W – Oświęcim, Andrychów, Wadowice, P – Pińczów, Sm – Smerdyna, Sw – Świniary, W – Wieliczka, Z – Zgłobice; Ukraine: Br – Bridok, G+R – Glebiviti and Romaniv, Kh+H – Khorosno and Hlukhivets, L – Lozova, M – Mohyla, M+N – Maksymivka and Halushyntsi, O – Ohryzkovtsi, Pi – Pisky, Pr – Peremyshlany, S – Skoviatyn, Sh – Sykhiv, St+P – Stratyn and Pukiv, S+N+H – Sakhkamin, Nihyn, Humentsi, U – Ustechko, Za – Zakupne, Zh – Zhalybory; Moldova: Balatina)

Górka *et al*. 2006, 2012; Radwański *et al*. 2006, 2011, 2012, 2014; Wysocka *et al*. 2006, 2011, 2012; Bąbel and Bogucki 2007; Ceranka 2007a,b; Czarniecka 2011) and inside the Carpathians (Bałuk 1966, 1970; Łoziński *et al*. 2015, 2016). The staff of the Faculty were joined in their researches by their associates, students, friends, and a number of colleagues from the Polish Geological Institute, Polish Academy of Sciences, Jagiellonian University and University of Science and Technology (e.g., Jakubowski and Musiał, 1977, 1979a,b; Studencki 1979, 1988a,b; Studencka 1986, 1987, 1994, 1999, 2015; Studencka and Studencki 1988; Peryt and Peryt 1994, 2015; Peryt *et al*. 1995, 2012; Gedl 1996; Oszczypko 1996, 2006; Peryt 1996, 2001, 2002, 206a,b, 2013; Jasionowski 1997, 2006; Studencka *et al*. 1998; Krzywiec 1999, 2001; Olszewska 1999; Porębski *et al*. 2002; Jasionowski *et al*. 2003, 2005, 2006; Krzywiec *et al.* 2005, 2008; Oszczypko *et al.* 2006; Oszczypko and Oszczypko-Clowes 2011; Studencka and Jasionowski, 2011; Peryt 2013a,b; Peryt *et al.* 2014; Jankowski and Margielewski 2015; Leszczyński and Nemec 2015; Bojanowski *et al.* 2016; Gedl *et al.* 2016) as well as from Ukraine, Austria, Czech Republic, Hungary, Germany, and The Netherlands.

The present account is organized as a series of separate chapters (or subchapters), prepared by different authors, to present selected aspects of the lithofacies, evolution, palaeontology and palaeoecology of the Fore-Carpathian Basin.

FORE-CARPATHIAN BASIN *VS*. CARPATHIAN FOREDEEP (A. Radwański and A. Wysocka)

The Miocene Fore-Carpathian marine domain is usually treated as a basin. It has been named and understood, however, either as the Fore-Carpathian Basin, or the Carpathian Foredeep. These two terms, in various papers, are treated either as synonymous or as distinct units. Short comments to both of these terms are given below.

The Fore-Carpathian Basin is defined herein as a palaeogeographic unit, a Middle Miocene marine domain whose water stretched out from the Carpathian margin. In Poland, it ranged as far as the belt of the present-day Central Polish Uplands. In Ukraine, it reached to the south-eastern margin of the Podolian Platform (a part of the East-European Craton) (Text-fig. 1B). The basin was underlain by topographically diversified land, and characterized by variable depths.

On the contrary, the Carpathian Foredeep is a geotectonic term, a circum Carpathian basin, in which the sediments, marine or non-marine, accumulated due to geotectonic subsidence of its basement (Text-fig. 1B). The sediments may have attained remarkable thicknesses masking completely the topography of the substratum. In the latter case, the basin could have been facies-uniform. So defined, the Carpathian Foredeep corresponds to the Outer Foredeep *sensu* Oszczypko (2006, see also Oszczypko and Oszczypko-Clowes 2011).

In terms of the nomenclature used for the foreland basin system (after DeCelles and Giles 1996), a foreland basin system is defined as consisting of: (1) a wedge-top, (2) foredeep, (3) forebulge, and (4) back-bulge depozones. The type and thickness of sediments occupying these depozones depends on their location at the time of deposition, rather than their geometrical relationship with the thrust belt (DeCelles and Giles 1996). During the latest stages of the Carpathian thrust-and-fold belt development, the Fore-Carpathian foredeep depozone was formed as a result of the immense load of the growing nappes stacking one on the other, moving outwardly from the depocentre. This caused a high subsidence rate just in front of the orogenic front with the progressive movement of the depocentre to the north. The Carpathian forebulge belt was formed as an isostatic response to the subsidence in the foredeep, fringing the foredeep well north of the Carpathian front. In recent topography, the Carpathian forebulge is marked by the Upper Silesian High, Cracow Upland, Miechów Upland, the Holy Cross Mountains (Text-fig. 1B) (e.g., Kutek and Głazek 1972; Radwański 1974; Marcinowski and Radwański 1983), and the Lublin Upland with the Roztocze Hills ranging as far as Lviv in the Ukraine (Text-fig. 1B) (Wysocka 2002, 2006; Jankowski and Margielewski 2015). The situation in the Ukrainian and Moldovian part of the fore-Carpathian region is less clear, as no distinct forebulge zone may be recognised (although it may be supposed that the Medobory Hills could have originated as such). Consequently, the vast area covered by Miocene deposits outside the Fore-Carpathian foredeep and forebulge depozones, should be treated as the Fore-Carpathian back-bulge basin (Text-fig. 1B). According to De-Celles and Giles (1996), this zone should be characterised by shallow water sediments accumulated in a broad zone of flexural subsidence cratonward of the forebulge. The Fore-Carpathian forebulge depozone is expected to be a site of local unconformities, condensations, stratal thinning, fault-controlled depocentres, as well as synsedimentary and postdepositional block faulting, e.g., in the sandy sequences of the Opole Minor in the Ukraine (Pazdro 1953; Wysocka *et al*. 2012, fig. 2).
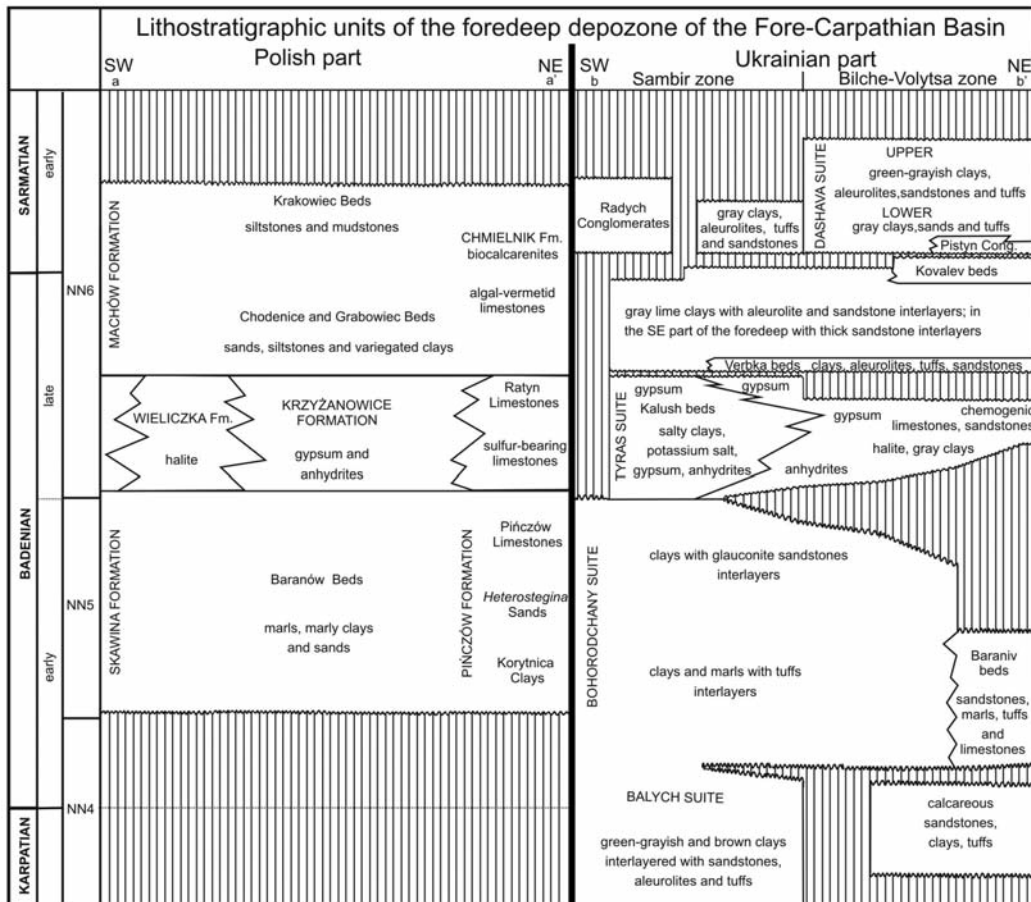
Text-fig. 2. Stratigraphic schemes for the foredeep depozone of the Fore-Carpathian Basin, Polish (line a-a' in Text-fig. 1B) and Ukrainian (line b-b' on Text-fig. 1B) sectors (based on Jasionowski 1997; Oszczypko *et al*. 2006; Andreyeva-Grigorovich *et al*. 2008 and Petryczenko *et al*. 1994)

LITHOFACIES OVERVIEW (A. Wysocka)

For almost two centuries, the geological record of the Fore-Carpathian Basin has attracted geological studies (e.g., Staszic 1815; Alth 1850; Hilber 1882; Łomnicki 1897, 1898; Teisseyre 1900; Nowak 1938; Pazdro 1953; Kudrin 1966; Ney *et al*. 1974). Numerous new geological and geophysical studies, related to prospecting for hydrocarbon sources, started recently (e.g., Oszczypko 1996, 2006; Krzywiec 1999; Dziadzio 2000; Porębski *et al*. 2002; Krzywiec *et al*. 2005, 2008; Mastalerz *et al*. 2006; Popadyuk *et al*. 2006; Ślączka *et al*. 2006; Pietsch *et al.* 2010; Warchoł 2011; Lis and Wysocka 2012; Gozhyk *et al.* 2015).

The Miocene succession of the Fore-Carpathian Basin starts with transgressive siliciclastics, occasionally with thin coaly interbeds, clays and marls of Karpatian (Garecka and Jugowiec 1999) or Early Badenian age (Text-fig. 2). Typical transgressive lithostratigraphic units are the Baranów (Baraniv in Ukraine) Beds as well as Skawina and Pińczów Formations. These shallow-water, high-energy deposits do not exceed 100 m in thickness (e.g., Wysocka 2002; Mastalerz *et al*. 2006), are overlain by regionally persistent evaporitic beds (Text-fig. 2) and referred to as the Wieliczka and Krzyżanowice formations (Tyras suite in Ukraine). They correspond to the lower part of nannoplankton zone NN6 (Peryt and Peryt 1994). The relatively low basin diversity marked by the evaporitic beds suggests the intermittent lack of basin diversification into the foredeep, forebulge, and back-bulge depozones. The return to the basin subdivision into the three zones is well revealed by the supra-evaporitic deposits of the Machów Formation (Dashava Fm. in Ukraine), exceeding 2000 m in thickness in the axial zone of the foredeep (over 5000 m in the Ukrainian foredeep) (Text-fig. 3; and Table 1).

The large-scale sandy-bodies, evaporitic beds and large-scale carbonate build-ups of the forebulge and back-bulge depozones of the Fore-Carpathian Basin are discussed in the following chapters.

Large-scale sandy-bodies of the forebulge and back-bulge depozones of the Fore-Carpathian Basin (A. Wysocka and A. Radwański)

The Middle Miocene sandy and organodetrital deposits of the Roztocze, Opole Minor and Ternopil area cover c. 45,000 km². Recently, these deposits have been studied intensively (see e.g., Radwański and Wysocka 2001; Wysocka 2002; Górka *et al.* 2006; Radwański *et al.* 2006; Wysocka and Jasionowski 2006; Górka *et al.* 2012; Peryt *et al.* 2012a; Radwański *et al.* 2012; Wysocka *et al.* 2012; Radwański *et al.* 2014, and Table 1), and the results are shortly summarized below.

The sandy and organodetrital deposits are easily accessible in huge quarries and sand-pits revealing their 3-D facies geometry (e.g., Radwański and Wysocka 2001; Wysocka *et al.* 2012; Radwański *et al.* 2014). However, their facies interpretation and correlation are insufficient because of the lack of new and reliable cartographic and stratigraphic data. Consequently, there is no single general stratigraphic scheme for the entire area of the Fore-Carpathian Basin (Text-figs 2, 3). Based on published schemes, the investigated lithofacies are correlated with the Lower Badenian Baraniv, Mykolaiv, and Naraiv beds, and with the Upper Badenian Pidhirtsi, Ternopil, and Buhliv beds, as well as with the Lower Sarmatian sands (Text-fig. 3). The large-scale sandy-bodies of the forebulge and back-bulge depozones of the Fore-Carpathian Basin are individualized in the Roztocze and Opole Minor (Lviv area) and in the Ternopil area (Text-fig. 3). In these areas, several tens of exposures show a variability of sedimentary structures and a diverse biotic content (Text-fig. 3 and Table 2).

The sandy sequence of the Roztocze and Opole Minor (the so-called Mykolaiv Sands, see Wysocka *et al.* 2012) extends along the south-western margin of the East European Craton and rests upon a Laramide basement of Upper Cretaceous (Maastrichtian) marls, the topography of which was determined by Palaeogene erosion and denudation. The resultant topography, having been locally exposed today, allows the estimation of the pre-Miocene morphological denivelations (Pazdro 1953; Wysocka *et al.* 2012). All have been filled more or less completely with a mass of sands, the thickness of which ranges, consequently, from a dozen metres to nearly nil. The petrographic content of these sands is very monotonous, as they are composed of quartz, with a variable but minor admixture of glauconite, clay minerals, as well as calcareous dust and bioclasts. All bioclasts are calcitic, as the aragonitic ones have been completely leached out du-
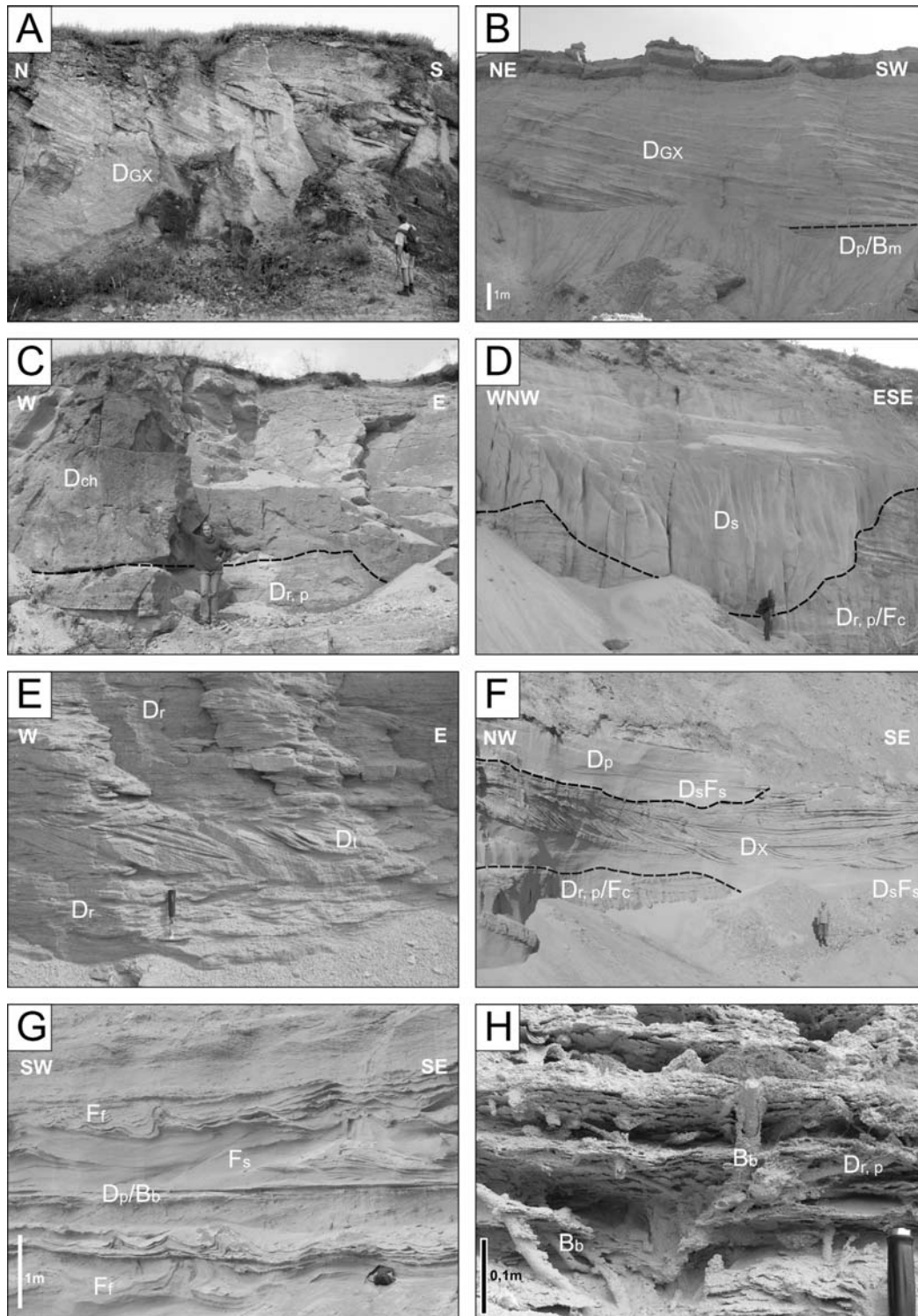
ring diagenesis. Typically, the larger bioclasts are heavily armoured with sand grains due to pressure-solution processes (Radwański and Wysocka 2001; Radwański *et al.* 2012).

A big variety of different sedimentary structures is typical of this sandy-sequence. Within the particular sets, both depositional and deformational structures of variable scale are present (Table 2), and are commonly burrowed (Text-fig. 4) (Wysocka 2002; Wysocka *et al.* 2012). These sandy bodies are interpreted as migrating megaripples of various kinds, sand bars, slumps, and/or delta-slope bodies. An uneven bottom morphology controlled the current directions (Wysocka 2002) until this

Section	Most important bibliography, including older reference data
Polish territory	
Skotniki	Radwański 1969, 1973
Smerdyna	Rutkowski 1976; Laptaś 1992; Roniewicz and Wysocka 2001; Leszczyński and Nemec 2015
Nawodzice	Bałuk and Radwański 1968; Nosowska 1997
Świniary	Kowalewski 1929; Błaszak 1965; Pawłowski 1965; Radwański 1973; Kenig and Wysocka 1996; Radwański and Wysocka 2004
Korytnica	Bałuk 1974; Bałuk and Radwański 1977, 1984a, b
Opatówka Valley	Czapowski 1976; Czarniecka 2011
Pińczów-Busko area	Radwański 1969; Studencki 1988a, b
Chmielnik region	Rutkowski 1976; Czapowski and Studencka 1990; Leszczyński and Nemec 2015
Roztocze Hills	Areń 1959; Jaroszewski 1977; Jakubowski and Musiał 1979; Musiał 1987; Wysocka 2002, 2006; Wysocka and Jasionowski 2006; Jankowski and Margielewski 2015
Ukrainian territory	
Gleboviti	Radwański and Wysocka 2001; Wysocka 2002; Radwański and Wysocka 2006
Stradch	Łomnicki 1898; Wysocka 2002; Wysocka and Jasionowski 2006
Lozyna	Wysocka 2002
Birky	Wysocka 2002
Yasnyska	Wysocka 2002
Sykhiv	Teisseyre 1938; Wysocka 2002
Pidjarkiv	Jahn 1937; Malicki and Jahn 1937; Szörényi 1953
Pukiv	Radwański et al. 2014
Stratyn	Radwański et al. 2012
Romaniv	Wysocka et al. 2012
Khorosno	Wysocka et al. 2012
Mohila	Wysocka et al. 2006
Ohryzkovtsi	Jasionowski et al. 2006
western Ukraine	Kudrin 1957, 1966; Vialov 1970

(Left side labels: Roztocze Hills (Ukrainian part, close to Lviv) — Gleboviti, Stradch, Lozyna, Birky, Yasnyska, Sykhiv, Pidjarkiv; Opole Minor — Pukiv, Stratyn, Romaniv, Khorosno; Ternopil area — Mohila, Ohryzkovtsi, western Ukraine)

Table 1. Summary of selected published geological data on the sandy and organodetritic lithofacies in the forebulge and backbulge depozones of the Fore-Carpathian Basin

topography was smoothed by sedimentation to form an extensive offshore zone. As long as the topographic relief remained, slumping and liquefaction, or even seismic shocks, were locally important to produce homogenized sand bodies up to 15 m thick (Wysocka 2002; Wysocka *et al*. 2012). Later, the sand bodies were influenced by storm agents (with scouring and residual lags), or by waves and currents, to produce sand bars of variable heights (up to 4, rarely to 10–15 m).

A poorly known, large-scale sand-body is exposed in the Ternopil area, in the huge Mohila sand-pit and the small, unexploited Lozova sand-pit. It occurs to the south west of the Medobory reefal-complex and is separated from the back-reef sandy facies (Jasionowski e*t al*. 2006). In the Ternopil area, the sandy-complex is characterised by a progradational set of large-scale tabular cross-stratification. It is covered by a sandy unit with structures indicative of extremely shallow-water environments (Wysocka *et al*. 2006). Another unusual feature that has attracted attention in the Lozova section is a large-scale landslide of biogenic material, transported from the Medobory reefal-complex (Wy-

Text-fig. 3. Position of the studied sections in Ukraine against the regional (as used traditionally) and standard zonations (compiled from Petryczenko *et al*. 1994; Andreyeva-Grigorovich *et al*. 2008 and Górka *et al*. 2012)

Text-fig. 4. Selected sedimentary features of the large-scale sedimentary complexes of the Roztocze, Opole Minor and Podolia; for symbol explanations see Table 2. **A** – progradational set of large-scale tabular cross-stratification (Smerdyna, PL); **B** – progradational set of large-scale tabular cross-stratification, downlapping on plane-stratified sands (Sykhiv, UA); **C** – large-scale channel-like structures (Dch, underline by dashed line) cut in ripple cross-stratified calcarenites (Dr, p) (Józefów, PL); **D** – large-scale cross-section of a giant scour (underline by dashed line) filled with structureless sands (Hlukhivets, UA); **E** – cosets of ripple, trough and tabular cross-stratified calcarenites (Pardysówka, PL); **F** – channel-like infills (base out-lined) cut into cosets of tabular and trough cross-stratified sands (Khorosno, UA); **G** – cosets of synsedimentary deformed layers (Khorosno, UA); **H** – strongly bioturbated, ripple cross-stratified sands (Dr) with numerous burrows of callianassid decapods (Bb) (Romaniv, UA)

socka *et al.* 2006), pointing to a high bottom relief during sedimentation and the isochroneity of sandy and reefal facies in the area (Text-fig. 3). To the north east of the Medobory reefal-complex, a sandy sequence is exposed e.g., in the Ohryzkovtsi section, a very remarkable section (Jasionowski *et al.* 2006) that is terminated by oolitic sands. Undoubtedly, the sandy sequence in the Ternopil area should be intensively investigated in the future.

All sandy bodies discussed above are intriguing because of the huge mass of pure quartz-sands lying on a nonclastic basement and representing a regional accretion prism which, in the Ukrainian part of the Fore-Carpathian Basin, had carpeted the pre-Miocene topography at the margin of the East-European Craton, and having been gradually downthrown south-westerly towards the foredeep depozone. This prism had been dependant on the pre-Miocene topography of the region, the synsedimentary tectonics, as well as the dynamic conditions of the transgressive Middle Miocene (Badenian) overflood. The supply of a huge, terrestrial sand-mass is inferred to have successively been continued from the Palaeogene wastes of the East-European hinterland of Podolia and Volhynia (Wysocka *et al.* 2011; Radwański *et al.* 2014). The mode of its delivery remains as yet unknown: neither fluviatile or aeolian transport, nor deltaic spread may be recognised by the sedimentary structure of the sand sequences studied. All display a variety of structures typical of shallow- to very shallow-marine, high-energy bottom conditions.

Summing up, the lateral and vertical facies succession in the vast area of the forebulge and back-bulge depozones of the Fore-Carpathian Basin point to a full transgressive-regressive cycle, controlled by the evolution of the Carpathians during the Badenian-Sarmatian times. The problems of detailed correlation as well as the synchroneity/diachroneity of the particular facies still remain unsolved. The next fascinating and unsolved problem is the influence of the Middle Miocene Climatic Optimum, followed by the subsequent drastic cooling, on the facies pattern as well as on the biotic diversity (for preliminary discussion see Wysocka *et al.* 2012 and Radwański *et al.* 2014).

Badenian evaporites [Maciej Bąbel]

The evaporitic event that took place in the Central Paratethys in Badenian time has been referred to as the Badenian salinity crisis by analogy to the famous Messinian crisis in the Mediterranean area (Peryt 2002,

2006a). The widespread deposition of Ca-sulphates, Na-chlorides and, locally, KMg-salts took place at that time in several apparently interconnected basins or areas: the Fore-Carpathian Basin, the Slovak Basin, the Intra-Carpathian Basin and the Transylvanian Basin (Liszkowski 1989; Peryt 2006a) (Text-fig. 1C). Among these basins, the Fore-Carpathian Basin was the largest, and its northern part is the best studied. In this area, the primary evaporite gypsum deposits are excellently exposed, particularly in the Ukraine. The halite facies as well as a large part of the carbonate facies with native sulphur deposits are hidden in the subsurface (Aleksenko 1967; Gąsiewicz 2000b; Garlicki 2008; Bukowski 2011).

This short review attempts to present the main new ideas concerning evaporite sedimentology and stratigraphy developed during the last few decades of studies conducted in the northern part of the Fore-Carpathian Basin, mainly in the gypsum depositional zone. Great progress in the studies of Badenian evaporites was initiated by the publications by Kwiatkowski (1972) and Garlicki (1979). The halite facies are only briefly mentioned, and the extensive geochemical and isotopic studies are not reviewed at all.

Analyses of the Badenian gypsum facies

At the end of the last century, an older view that the large gypsum crystals occurring in the Badenian deposits are a primary evaporite sediment (Kreutz 1925; Gaweł 1955), was fully established (Bąbel 1986, 1987; Kasprzyk 1991, 1993a,b; Peryt 1996; Petrichenko *et al.* 1997). At that time it was also proved that the large (several metres in size; Text-fig. 5A) domal structures composed of such gypsum crystals, recorded in the Badenian, are also primary structures that formed on the evaporite basin floor (J. Tokarski in Flis 1954, p. 21; Koltun and Roskosh 1969; Bąbel 1986, 2005b, 2007a; Kasprzyk 1993a, b; Kasprzyk *et al.* 1999; Pokalyuk *et al.* 2009).

Deposits composed of large primary gypsum crystals (> 2 mm in size) are called selenites (Warren 1982; Bąbel 2004a) and represent a significant part of the Badenian sulphate evaporites. Application of the facies analysis methodology to these and other primary deposits in the Fore-Carpathian Basin (Polish part) has revealed a novel and more detailed picture of evaporitic environments in the marginal zone of the basin (Kasprzyk 1991, 1993a,b; Bąbel 1999a,b, 2005b). Further sedimentological and facies studies conducted in the Ukraine, Moldova and in the Czech Republic (Peryt 1996, 2001; Peryt *et al.* 1997; Petrichenko *et al.*

Table 2. The main sedimentary features of the clastic facies of the back-bulge depozones of the Fore-Carpathian Basin (Wysocka et al. 2012; extended)

Structures	Characteristics	Interpretation
Depositional (D)		
Giant-scale high-angle foreset stratification D_{GX}	Medium- to coarse-grained sands, occasionally gravels; average thickness of single set about 4-10 m	Fault scarp-attached bar formed by the avalanching of littoral sediments
Large-scale tabular cross-stratification, occasionally in form of clinoforms D_x	Medium- to coarse-grained sands; average thickness of single set about 2-4 m, maximum up to 10-15 m; commonly of diagonal and tangential type	Migration of straight-crested bars or progradation of a delta slope; high-energy shallow-water environment
Trough cross-stratification D_t	Medium- to coarse-grained sands; set thickness from 10 to 50 cm	Migration of curved-crested ripples; high-energy shallow-water environment
Ripple cross-lamination D_r	Fine-grained sands; heights of individual ripples range between 2 and 10 cm; dominate asymmetrical and climbing (ripple laminae-in-phase and ripple laminae-in-drift) ripples, occasionally wavy and flaser lamination	Migration of wave and wave-formed current ripples; shallow-water environment, (?) up to intertidals
Plane bedding D_p	Various sands; thickness of sets rarely exceeds 10 cm	Lower- or upper-stage plane beds; low- to high-energy shallow-water environment
Large-scale scours D_s	Large-scale elongated scours filled with fine-grained, well-sorted sands; depth up to 10 m, widths range up to 20 m; concave sharp and erosional bottom surface; basal part massive, top parts with traces of lamination and numerous fold and diapir deformations	Grain flow in the form of underwater slump-scours; sediment movement caused by overloading of slope, rapid drawdown and destruction of frontal part of a delta body, and/or by seismic shock
Channel-like fills D_{ch}	Channel-like elongated forms filled with massive fine- to coarse-grained sands and/or organodetrital material; sharp concave lower boundaries, depth up to 3 m, width to 5 m	Storm surge channels, locally filled by lag deposits
Biogenic (B)		
Individualised burrows B_b		Syn- or post-depositional activity of echinoderms (echinoids and sea-stars), shrimps and crabs, as well as undetermined sea-anemones, bivalves, and holothurians
Maze of 'burrow-ghosts' of various size, totally blurring primary depositional structures B_m		Total destruction of depositional structures, formed by long-termed activity of over-populated mass-abundant bottom dwellers
Deformational (F)		
Slump (fold and diapir) structures F_f	Highest parts of scour infills, vertical or overturned anticlines and synclines, commonly detached, with strongly deformed bend zones; up to 2 m height	Caused by collapse of large-scale bars or delta slopes and/or by seismic shock
Convolute bedding F_c	Small-scale fold deformations underlain or overlain by non-deformed deposits; deformed layer thickness up to 30 cm; anticlinal parts are steep and chevron-like, synclinal are flat and blunt	Result of reversed density gradient or sediment liquefaction; caused by overburden by overlying deposits, seismic shock and/or movement of liquefied sediment
Pseudonodule structures F_p	Disturbed bedding in form of ovate or spherical masses surrounded by massive sands	Fluid-loss structures, produced by escaping water, breaking upward through a primary lamination; caused by gravity mass movement or deformational shear of currents
Structureless F_s	Sands completely devoid of any sedimentary structures; bodies up to 15 m thick	Homogenisation caused by rapid sedimentation, total bioturbation, redeposition, and/or liquefaction

1997; Bąbel 2005b, 2007b) have shown that at the stage of Ca-sulphate deposition the evaporite basin was a very shallow, flat and broad platform occupied by a system of more or less (5-20 m) deep saline pans, dominated by the deposition of coarse and giant-crystalline selenites, and semi-emerged evaporite shoals where the selenite deposition was associated with fine-grained gypsum precipitation, as well as with the formation of gypsum microbialite and/or stromatolite deposits.

The Badenian gypsum facies were shown to be very similar to the famous Messinian gypsum facies (e.g., Lugli *et al.*, 2010), with the exception of some facies, which are very specific and typical of the Badenian. They include the giant gypsum intergrowths facies (Text-fig. 5B, C; Bąbel 1987, 1999a, b; Peryt 1996), never recorded outside of the Badenian basins and widespread microbialite and stromatolite facies (Text-fig. 5D, Kwiatkowski 1970, 1972; Kasprzyk 1993c; Peryt 1996; Bąbel 2005b, 2007b; Bąbel *et al.*
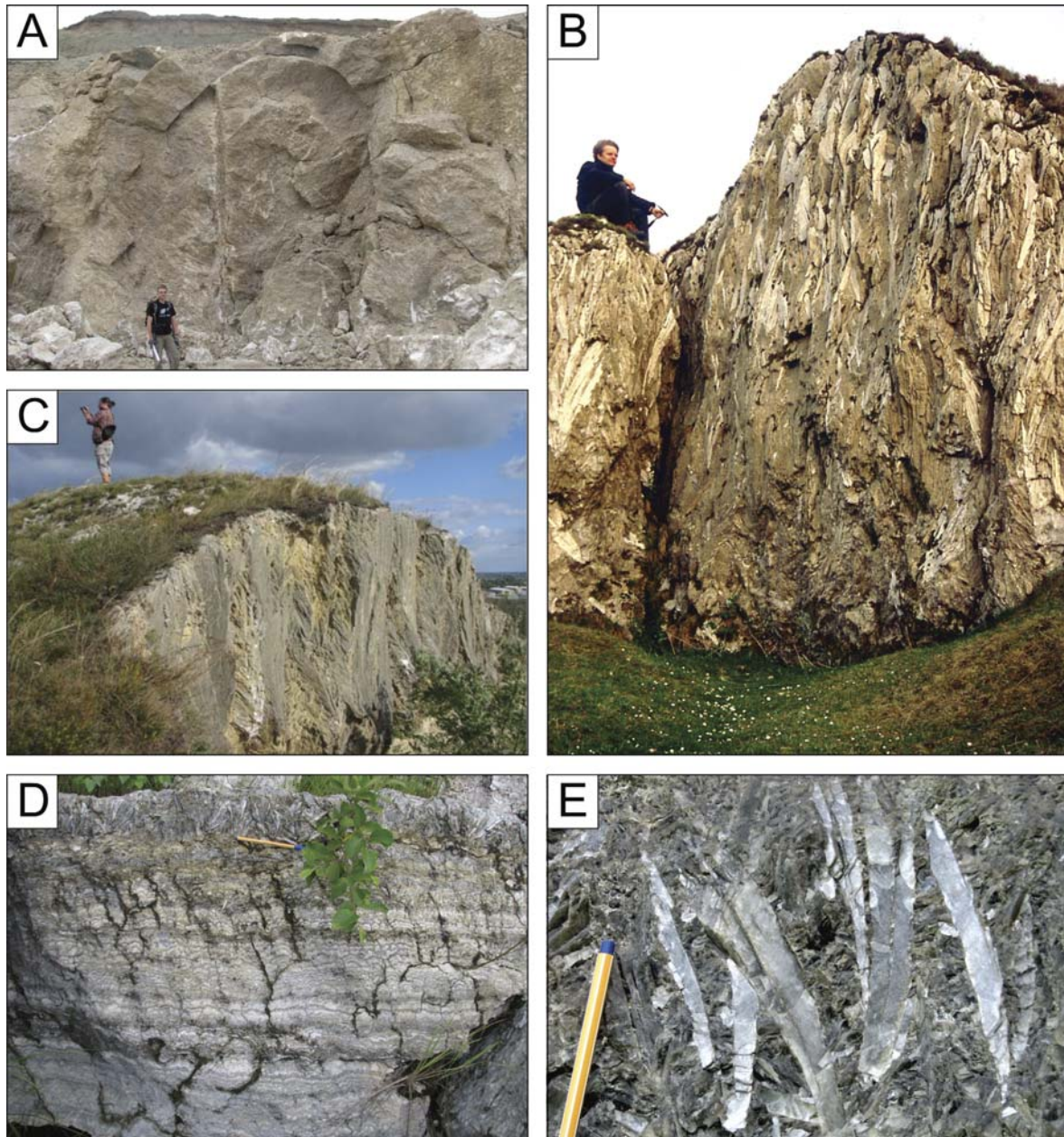
Text-fig. 5. Gypsum facies. **A** – primary selenite dome (Skoviatyn Quarry, UA); **B** – giant gypsum intergrowths facies (Zhalybory, UA); **C** – giant gypsum intergrowths facies (Gacki, PL); **D** – gypsum microbialite facies passing upward into the grass-like selenite facies (Pisky Quarry, UA); **E** – sabre gypsum facies with conformably oriented selenite crystals (Ustechko, UA)

2011), rarely met in other evaporite basins (Allwood *et al*. 2013).

Selenite facies – controlling factors

The selenite facies are very specific. They are created by the *in situ* growth of gypsum crystals on the bottom of the evaporite basin, and hence are classified as autochthonous evaporites (Vai and Ricci-Lucchi 1977). Although the mechanism of sediment accretion is clear and seemingly simple (Bąbel 2007a, b), the selenite deposits display a great variability of facies, sometimes drastically different and incomparable (Ortí 2011). The main visual difference is that within every facies or evaporite bed the gypsum crystals reveal a characteristic crystal morphology, create different types of twins, form specific crystal aggregates or crystalline constructions such as for example domes (Ortí and Shearman 1977; Rodríguez-Aranda *et al*. 1995; Lugli *et al*. 2010).

Undoubtedly the differences exhibited by the selenite facies depend on some environmental factors that influence or control the morphology of the growing crystals (such as pH, deviations from stoichiometry, degree of supersaturation, temperature, or foreign admixtures in the solution, and some physical factors such as flow of solution). It seems that the most important factor in the shaping of the morphology of the growing gypsum crystals was the presence of various specific organic substances in the solution (see Cody and Cody 1989, 1991; and reviews in Bąbel 1991; Rodríguez-Aranda *et al*. 1995; Vogel *et al*. 2010). It was experimentally proved that even very slight differences in the listed environmental parameters and the presence of only minor amounts of some specific organic compounds in the brine can produce a drastically different gypsum crystal habit observed in various selenite facies. So far, however, these parameters and compounds remain poorly recognized.

Palaeocurrent analysis

In the case of some selenite facies, one factor was recognized as crucial for the creation of the specifically oriented arrangement of crystals or crystal texture, i.e. the flow of brine. As originally suggested by Dronkert (1977, 1978, 1985), in case of the Messinian selenites, the gypsum crystals could grow in an oriented manner, under the influence of a bottom brine current supersaturated with gypsum, with the apices predominantly turned upstream (Pawlikowski 1982; Bąbel 1986; Lugli *et al*. 2010). This interpretation was fully supported by field studies and statistic measurements of the orientation of crystal apices in the Badenian basin

within the laterally continuous sabre gypsum facies beds (Text-fig. 5E). These studies revealed the counter clockwise pattern of brine flow in the basin, interpreted as cyclonic circulation typical of the closed and semiclosed basins of the northern hemisphere (Bąbel 1996, 2002b; Bąbel *et al*. 1999, 2011, 2015; Bąbel and Becker 2006; Bąbel and Bogucki 2007). The Badenian basin is possibly the only ancient example where the cyclonic basinal water flow pattern has been detected.

Stratigraphy

The halite Wieliczka Formation is the only formally defined lithostratigraphic unit in the entire Fore-Carpathian Badenian (Garlicki 1994). Wala (1980) attempted to introduce a formal stratigraphic subdivision for the Badenian gypsum deposits of the Nida area and even presented stratotype sections during the conference field trip in 1980. However, his proposal was described only in limited conference materials and remains practically unknown. It was Alexandrowicz *et al*. (1982) who coined the name Krzyżanowice Formation as the term for the Badenian gypsum evaporite unit in Poland and this name is now widely accepted and used in spite the fact that the formation has not been defined formally. In Ukraine, the coeval evaporite deposits are referred to the Tyras Suite.

Wala (1961, 1963, 1980, and unpublished materials) recognised that the Badenian gypsum deposits of the Nida area in Poland are composed of a set of thin layers showing a nearly perfect correlation, and lettered them alphabetically from **a** at the base to **n** at the top. Most of these layers represents selenite beds. Subsequent investigations showed that this sequence of layers is detected in a much larger area of the basin (Kasprzyk 1989, 1991, 1993a), and is also recognisable in Ukraine (Kasprzyk 1995). Kubica (1992, 1994b) working on core material from the northern part of the Fore-Carpathian Basin recognised seven laterally continuing thin lithostratigraphic units within the gypsum sections and marked them with capital letters from A to H. Later this subdivision was recognised in a much larger area of the basin and supplemented by Bąbel (2005a).

Investigations of a number of sections in the entire basin revealed that some of the layers are exellent marker beds. Further sedimentological studies indicated that these beds can be connected with important basin-scale events and interpreted as isochronic or near isochronic. The event-stratigraphy methodology was successfully applied to the Nida Gypsum area (Bąbel 1996, 1999a, b) and to the entire sulphate marginal part

of the evaporite basin (Peryt 2001, 2006a, 2013; Bąbel 2005a).

Models of the evaporitic basin

Before 2000 several more or less justified models of Badenian evaporite basins had been presented. Many authors suggested that the basin was a saline lagoon type (e.g., Kwiatkowski 1972). Garlicki (1979) adopted the so-called "saturation shelf" concept of Richter-Bernburg (1955) and presented the comprehensive model of brine flow in the basin. According to this model, the deposition of evaporite facies was controlled by depth – Ca-sulphates in shallower and Na-chlorides in deeper parts of the basin. This idea was also accepted by Połtowicz (1993), Bukowski (2011), and Głuszyński and Aleksandrowski (2016). Similarly Bąbel and Bogucki (2007), who applied limnological terminology to the evaporite basin, suggested a meromictic lake model for the basin, in which halite deposition was restricted to the deepest monimolimnion zone. It was assumed that the selenite deposits were formed only in the well oxygenated and Ca-sulphate saturated mixolimnion zone, on the marginal platform or shelf only. In both models the halite deposition in relatively deep subbasins could be connected with the shallowing and emersion of the surrounding shelves (Bąbel and Bogucki 2007; cf. Bukowski 2011). Liszkowski (1989) introduced the model of non-evaporitic deposition for the Ca-sulphates and Na-chlorides assuming that the entire mass of salts derived from the formational brines was expelled to the foreland basin from the tectonically squeezed flysch deposits during the thrust movements of the Carpathian nappes.

Analyses of Badenian sulphate facies integrated with geochemical studies led to the introduction of a new basin model. The marine salina model, formerly mentioned by a few authors, was suggested for the Fore-Carpathian Basin, particularly for its northern Ca-sulphate margin by Peryt *et al.* (1995), Peryt (2001, 2006a), Bąbel (2004b, 2007b) and Cendón *et al.* (2004). This model assumes that the basin is a depression separated from the sea by a topographic barrier, and is supplied with seawater seeping through it or overflowing this barrier, occasionally in the form of short-term marine transgressions. The water level in the basin is situated below the seawater level and the basin is in fact a saline lake supplied with marine water.

Gypsum depositional models

The western part of the Ca-sulphate basin (Poland and the Czech Republic) shows different development of the gypsum facies than in the eastern and east-southern part. In the west zone of the basin the sections commonly contain clay intercalations and large pore structures are present between the selenite crystals. Some subfacies, such as skeletal palisade subfacies of the giant gypsum intergrowths, are present only the west (Bąbel 1987, 1999a, b). The giant selenite domes composed of the flat-lying variety of sabre crystals occur only to the east (Text-fig. 5A). It seems that climate and supply of meteoric water to the basin were the main control of these "megafacies" features and Schreiber *et al.* (2007) suggested the dry shore and wet shore model of evaporite deposition for these two zones.

Carbonate facies

Carbonate facies associated with Badenian gypsum deposits commonly form separate bodies. Among many varieties of limestone two are apparently the most important: the so-called Ratyn Limestone and the sulphur-bearing limestone, both representing a petrological puzzle.

During the earliest studies, the limestones associated with gypsum were called "supra-gypsum limestone" because they were commonly found in the topmost part of the gypsum successions (Alth and Bieniasz 1877), although in many sections they also form a lateral equivalent of gypsum. Łomnicki (1897) introduced the term Ratyń limestone (Ratyń – in Polish, Ratyn – in Russian, Ukrainian and English spelling) for a variety of such a limestone occurring at Ratyn Hill and its environs in Lviv (see Peryt 2006b). Later the term was expanded to embrace other types and varieties of limestones associated with the Badenian gypsum deposits. The Ratyn Limestone facies is difficult to define precisely because the deposits include numerous varieties of limestone, generally chemical in character (massive, dense, and cavernous, commonly without macrofauna, although with outstanding exceptions) and of an unclear origin (see review of the meanings of Ratyn Limestone in Peryt *et al.* 2012b).

The Ratyn Limestone occurs mostly in Ukraine in a belt of exposures situated north of the Badenian gypsum extent, as well as appearing in the topmost part of the Badenian gypsum commonly covering a karstified surface. The recent petrological and geochemical study of the Ratyn limestone from several representative outcrops in Ukraine by Peryt *et al.* (2012b) indicates that the limestones are mostly the product of meteoric (vadose-phreatic) diagenesis of a primary evaporitic peloidal carbonate, containing *in situ* grown lenticular gypsum crystals, deposited in a saline lagoon (or possibly a salina environment; Peryt and Kasprzyk

1992; Olszewska-Nejbert *et al.* 2009). The diagenesis of these deposits included intensive calcitization of gypsum. Other varieties of the Ratyn limestone, commonly covering the top of the gypsum deposits or occurring in karst cavities within them, and containing a marine fauna, represent marine deposits (Peryt and Peryt 1994).

The sulphur-bearing limestone represents an economically important facies forming large native sulphur deposits both in Poland and Ukraine. There are two opposite views concerning the origin of these sediments (Kwiatkowski 1966), one assuming an entirely post-sedimentary, so-called epigenetic origin via replacement of primary gypsum deposits during burial, and the other suggesting a primary origin at the bottom of the evaporite basin or during very early diagenesis. Most Polish authors accept the epigenetic hypothesis strongly supported by the presence of pseudomorphs after gypsum crystals as well as unchanged gypsum blocks ("gypsum islands") within the ore bodies, coupled with isotopic data (Pawłowski *et al.* 1979; Pawlikowski 1982; Kubica 1994a; Parafiniuk *et al.* 1994; Parafiniuk 2002). However, Gąsiewicz (2000a, b, 2010) and Olchowy (2015) were recently able to support the syngenetic theory proving that most of the sulphur-bearing limestones show sedimentary structures different from those observed in the gypsum deposits, which are difficult to explain by the epigenetic theory. According to these authors, the sulphur-bearing limestone represents the sedimentary to early diagenetic environment of a Badenian evaporite shoal.

Other discoveries

During studies of the Badenian gypsum facies several rare geological phenomena were discovered. They include the finding of gypsum ooids in core material from the environs of Smerdyna in Poland (Text-fig. 1C) (Kasprzyk and Bąbel 1986; Bąbel and Kasprzyk 1990), known only from a few occurrences in the world (Tekin *et al*. 2008; and references in Bąbel and Kasprzyk 1990), the recognition of an uncommon type of gypsum intergrowth (Bąbel 1987, 1991), and the findings and documentation of the largest natural crystals so far recorded in Poland (Bąbel 2002a; Bąbel *et al*. 2010).

Large-scale build-ups of the back-bulge depozone of the Fore-Carpathian Basin (A. Radwański, A. Wysocka and M. Górka)

A peculiar coralgal facies is recognised in the area between Ternopil and Kamianets Podilskyi (Ukraine),

up to Balatina (Moldova), crossing the Moldova-Romanian border as well. It extends for over more than 300 km, within an up to 40 km wide zone in the centre of the forebulge depozone of the Fore-Carpathian Basin. It is subparallel to the north-eastern margin of the foredeep depozone. The bodies of this facies that are the build-ups ('*bioherms*' or '*reefs*') once formed slightly elevated monadnocks that protruded above an almost flat-shaped landscape. Their patchy range has long been known as the Medobory Hills (Text-figs 1 and 6) available for studies in plenty of natural and artificial exposures. The dominant components of the Medobory Hills include the Upper Badenian coralline algal reefs associated with bioclastic, marly and rhodoid facies (Korolyuk 1952; Jasionowski *et al*. 2005, 2006; Radwański *et al*. 2006, 2011; Studencka and Jasionowski 2011; Górka *et al*. 2012). The coralgal facies from the territory of Moldova was also briefly analysed (Janakevich 1969a,b, 1977).

A typical sequence of the large-scale build-ups is exposed e.g., in the Maksymivka, Nihyn, Humentsi, and Haluschyntsi quarries in the vicinity of Ternopil (Text-fig. 1). These are huge (c. 1 km long and some tens of metres deep) open-pits, located along the topographic crest. The exposed build-ups have been referred to as the Medobory Biohermal Complex (Radwański *et al*. 2006). The complex is an up to 60 m thick biogenic sequence composed of coralline algal colonies of various shapes and sizes (Text-fig. 6D). Isolated coral colonies, mostly of *Tarbellastrea* and *Porites*, occur with usually low frequency in some parts of the build-ups (Górka *et al*. 2012).

The coralgal build-ups vary in size, from the centimetres of rodolith forms to hummocks several metres high (Text-fig. 6A, C). They are developed either as isolated masses, or overlapping each other and are separated by calcarenites or calcirudites (Text-fig. 6A, C and E). In some cases, the fabric of the biohermal structures was soft during their growth (Radwański *et al*. 2006). As a result, the build-ups are often densely burrowed by alpheid shrimps. Particular burrows are filled with a clayey material full of bioclasts, especially crab remains and echinoid tests. Some build-ups are riddled by borings of the bivalve *Lithophaga*, whose internal moulds not only of borings, but also of shells are commonly preserved (Studencka and Jasionowski 2011). This points to an extremely shallow, high-energy environment, in which early diagenetic, beachrock-type cementation occurred. The high-energy dynamics of the Maksymivka environment is thought to have been caused by storm agitation, tidal or pseudotidal waves, or gusts of landborne winds.

In the Polish part of the Fore-Carpathian Basin, the faunal content of an open-marine, normal salinity environment typical of the large-scale build-ups of the back-bulge depozone is constant throughout all regions, upon which the Middle Miocene (Badenian) transgression had progressed. Very diverse faunal assemblages, in facies ranging from clays (Bałuk and Radwański 1977), through sands (Radwański 1970; Radwański and Wysocka 2004), to pure limestones of the 'Leithakalk' type known as the Pińczów Limestones (Radwański 1965; Studencki 1988a), indicate open-marine conditions, with influx from the Indo-Pacific bioprovince (e.g., Radwański 1974; Hoffman 1977; Förster 1979a, b). Consequently, the studied coralgal facies and other deposits with an open-marine fauna in Ukraine and Moldova are all correlated with those present in Poland (Roztocze area), and are regarded to be coeval in general terms. However, there are still some open questions on the correlation between the Polish and Ukrainian part of the Fore-Carpathian Basin (compare e.g., with Studencka *et al.*, 1998). Moreover, a temporal shift cannot be excluded, as resulting from the two Badenian transgressions spread propagating from the west and south-west (e.g., Bałuk and Radwański 1977; Kovač *et al.* 2007).

The uppermost parts of the coralgal build-ups are eroded and covered by the Lower Sarmatian serpulid-microbialite reefs (Text-fig. 6C, F). Moreover, these Sarmatian reefs are located also at the south-western foot of the Medobory Hills where they build a few tens of meters high rocky hills called the *toutra* mounds (Text-fig. 6A, B). They are usually arranged in curvilinear chains oriented approximately perpendicular to the orientation of the Medobory Hills (Text-fig. 6B). Such a geometric pattern is still unexplained and awaiting further sedimentological/structural investigations. Additionally, the change in the composition of the organic community and the type of build-ups is interpreted as related to the restricted conditions in the Paratethys during the Early Sarmatian and resulting palaeoenvironmental changes (Pisera, 1996; Jasionowski *et al.* 2002, 2003, 2006; Jasionowski 2006; Studencka and Jasionowski 2011).

OVERVIEW OF SELECTED TAXONOMIC GROUPS

Some of the sediments infilling the Fore-Carpathian Basin yield unique and very rich faunal assemblages. Many years of meticulous studies have enabled the analysis of their precise taxonomic and stratigraphic position. The relationships between the particular

groups of organisms and their eco-taphonomic significance have also been studied. Many of the analysed groups have turned out to be perfect tools to reconstruct the particular sedimentary settings in the Miocene sea. A brief overview of selected groups of organisms, including corals, polychaetes, molluscs, crustaceans, echinoderms, and fish otoliths is presented below.

All specimens illustrated herein, except *Notocochlis tigrina* Röding, 1798 of Text-fig. 11Q, which is from the private collection of P. Degórski, are housed in the S.J. Thugutt Geological Museum (prefix MWGUW) of the Faculty of Geology of the University of Warsaw.

Miocene corals from the Fore-Carpathian Basin (M. Górka)

Corals from the Fore-Carpathian Basin were first described by Pusch (1837), Zejszner (1845), and Reuss (1847, 1871). Eichwald (1853) stated the number of the known coral species to be three, but soon after this number quickly increased to over 20 (Siemiradzki 1918; Friedberg 1928; Kowalewski 1930). These early reports were summarized by Dembińska-Różkowska (1932), who reported 42 species and subspecies. The corals from Korytnica were described by Stolarski (1991) and Roniewicz and Stolarski (1991).

Prior to the paper by Studencki (1979), who reported on a small Early Badenian coral patch-reef in Grobie (discovered by Ryszard Wrona), no coral build-ups were recorded from the Miocene of the Holy Cross Mts. area. The reef was briefly mentioned by Müller (1984), who later described it as the northernmost coral reef in the Neogene and presented its coral assemblage (Müller 1996). Further studies on the coral build-up in Grobie were conducted by Górka (2002), who concluded that its most important coral component was the hermatypic species *Tarbellastraea reussiana* (Milne-Edwards and Haime, 1850) (Text-fig. 7A) supported by *Porites collegniana* Michelin, 1842. This particular taxonomic composition of the coral assemblage, dominated by only two species, is a typical phenomenon in the reefal build-ups of the Fore-Carpathian Basin (e.g., Müller 1996; Radwański *et al.* 2006; Górka *et al.* 2012). Miocene coral reefs are more common in the Roztocze area (e.g., Pisera 1978, 1985; Müller 1996). The reefs of Roztocze are coeval with a large system of barrier reefs stretching across western Ukraine, north-western Moldova, down to Romania (e.g., Korolyuk 1952; Janakevich 1977; Pisera 1996; Radwański *et al.* 2006; Studencka and Jasionowski 2011; Górka *et al.* 2012). This Late Badenian barrier reef is well seen in morphology where it forms the hilly range known as the Medobory Hills. When com-
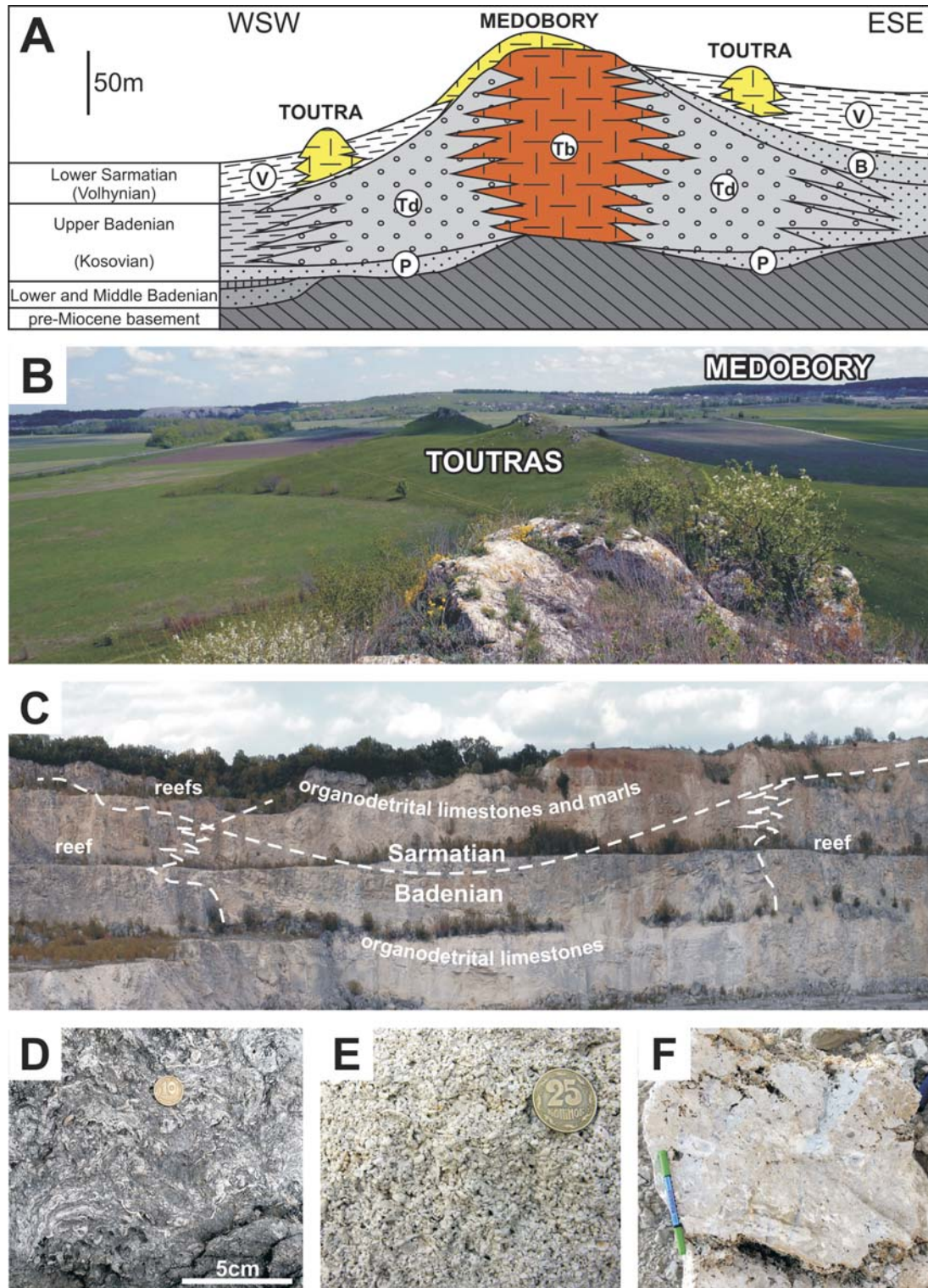
Text-fig. 6. Spatial relationships of the biohermal facies in the Medobory area, and details of their lithology and main frame-builders. **A** – Schematic geological cross-section through the Medobory area. Abbreviations: P – Pidhirtsi Beds, Tb – Ternopil Beds (**biohermal facies**), Td – Ternopil Beds (detrital facies), B – Vyshhorodok Beds and Buhliv Beds, V – Volhyn Beds (**biohermal facies in yellow**), after Jasionowski *et al*. 2006; **B** – Overall view of the vicinity of Nihyn, to show the spatial relationship between the Medobory Hills and the toutry chain; **C** – Panoramic view of the north-eastern wall of the Humentsi Quarry to show the spatial distribution of the lithofacies; **D** – massive and laminar thalli of coralline algae (Upper Badenian, Humentsi, UA); **E** – fine-grained organodetrital limestones from the interbiohermal area (Upper Badenian, Humentsi, UA); **F** – microbialite limestone with a high content of bivalve shells, serpulid tubes, and numerous growth caverns (Lower Sarmatian, Humentsi, UA)

pared to Roztocze, it becomes obvious that the dimensions of the reefal bodies grow significantly to the south; in Ukraine the thickness of the bioherms reaches almost 100 m. Nevertheless, the taxonomic composition of the coral assemblages is only slightly modified; *T. reussiana* and *Porites* (in this case *P. vindobonarum prima* Kühn, 1925) still predominate (Text-figs 7B, C and 8A-C). Also noticed are *Siderastrea* cf. *italica* (Defrance, 1826) (Text-fig.7D) and ?*Montastrea* sp. (Text-fig. 8D). The taxonomic composition of the coral assemblage shows a significant similarity with other Miocene coral reefs of the Tethys (Esteban *et al*. 1996; Hayward *et al*. 1996) and Paratethys (Friebe 1991, 1993; Müller 1996; Riegl and Piller 2000; Górka 2002).

The shapes of the coral colonies (see Korolyuk 1952; Radwański *et al*. 2006; Górka *et al*. 2012) vary from massive, lamellar, through knobby, to branching and/or platy forms (Text-fig. 7B). Large quantities of *Porites*

may also indicate a significant influx of suspended material of terrigenous origin (see Müller 1984; McCall *et al*. 1994; Esteban 1996; Jasionowski *et al*. 2005, 2006).

The important role played by hermatypic corals in the ecosystem is particularly emphasized by the presence of diversified borings and/or pits formed by numerous groups of organisms inhabiting the cenosteum. Aragonitic skeletons are regarded as a hard substrate, ideal for settling. With the exception of organisms that inhabited the coral colonies only due to their hardness but could also settle on inanimate hard substrates (boring bivalves of the genera *Lithophaga*, *Gastrochaena*, and *Jouannetia* (Text-fig. 8C); see Radwański *et al*. 2006; Studencka and Jasionowski, 2012; Górka *et al*. 2012; Text-fig. 7C, D), there were also animals closely connected to corals, probably due to some kind of interspecific relations: the cirriped crustaceans of the genus *Creusia* (Bałuk and Rad-
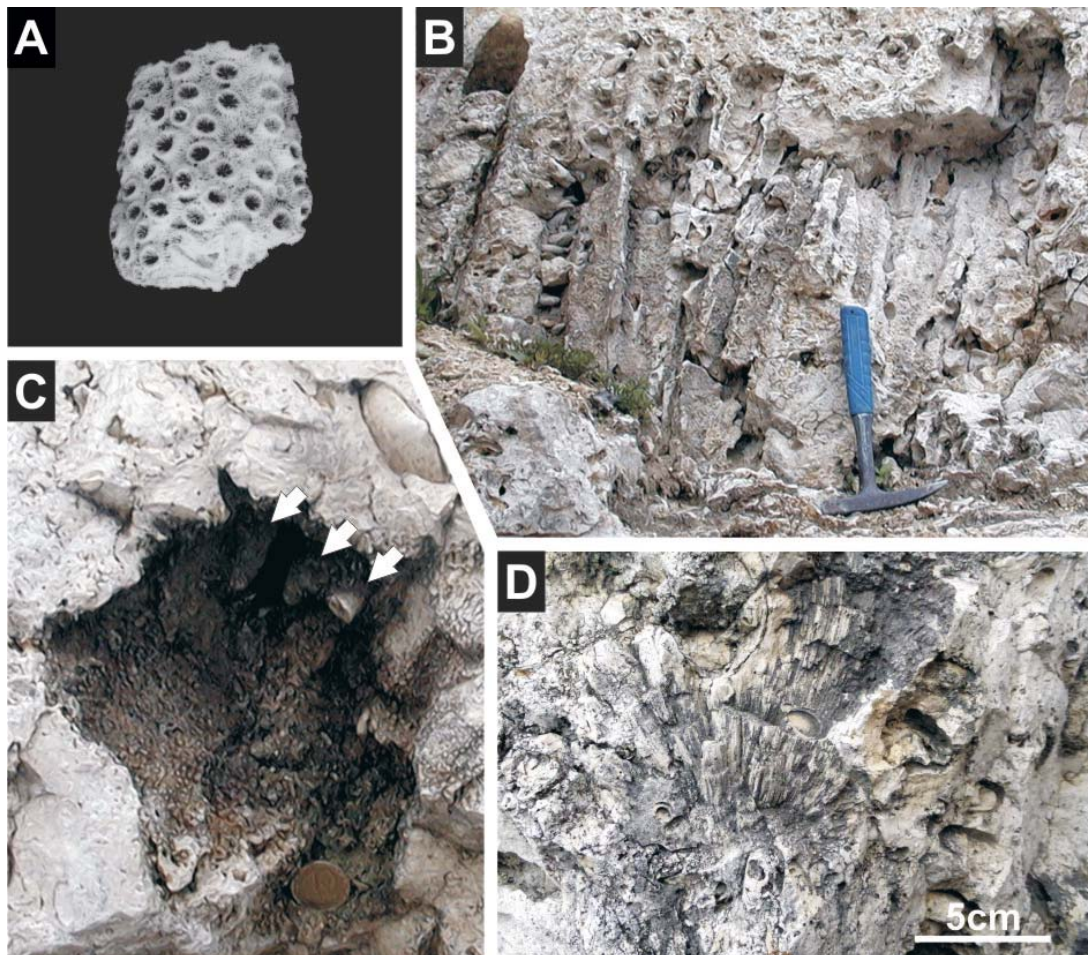
Text-fig. 7. Hermatypic corals from the Fore-Carpathian Basin. **A** – Fragment of stick-like colony of *Tarbellastraea reussiana* (Milne-Edwards and Haime, 1850) from the vicinity of Grobie, Lower Badenian, Poland (taken from Górka 2012, Pl. 1, fig. 4b), natural size; **B** – Field photo of a large, branched 'organ-pipe' colony of *Tarbellastraea reussiana* (Upper Badenian, Maksymivka, UA); **C** – *Tarbellastraea reussiana* colony, intensely bored (*arrowed*) by *Lithophaga lithophaga* (Linnaeus, 1758) (Upper Badenian, Maksymivka, UA); **D** – *Siderastrea* cf. *italica* (Defrance, 1826) with bivalve borings (Upper Badenian, Demkivtsi, UA). Photograph A taken by S. Kolanowski, B-D by M. Jasionowski

wański 1967; Wysocka *et al.* 2012) and the micropolychaetes *Josephella commensalis* (Bałuk and Radwański 1997).

In a similar manner to the other invertebrate groups of the Fore-Carpathian Basin, corals were ubiquitous during the Early Badenian climatic optimum (see Müller 1996; Górka 2002; Radwański *et al.* 2006) and disappeared with the advent of the salinity crisis. They re-appeared with the return of open-marine conditions in the latest Badenian. The presence of corals is evidence of at least warm-temperate or even subtropical waters during the Middle Miocene of the Fore-Carpathian Basin (Radwański *et al.* 2006; Górka *et al.* 2012).

Polychaetes from the Korytnica Basin (U. Radwańska)

The vast majority of polychaete worms are marine, being one of the most common components of present-day shallow-marine communities (Bianchi 1981; Jäger 1983). Based on the mode of life, the Class Polychaeta Grube, 1850 is subdivided into two orders: the Sedentarida Lamarck, 1818, and the Errantida Audouin and Milne-Edwards, 1832. Representatives of sedentary polychaetes live usually permanently in a more or less lithified tube, rarely in burrows or borings, and their fossil potential is relatively high.

Most of the tube-dwelling polychaetes are suspension feeders, and thus they require permanent water mobility to keep the branchial crown free from the sediment. Others have feeding tentacles extending from the tube opening and creeping along the mud, picking up organic particles. Favourable bathymetric conditions for most of the present-day genera are referenced as littoral, usually inter- or shallow subtidal; some, however, are found at bathyal depths (Hayward 1977; Bianchi 1981; Jäger 1983; Radwańska 1994a).

The first tube-dwelling polychaetes from the Ko-
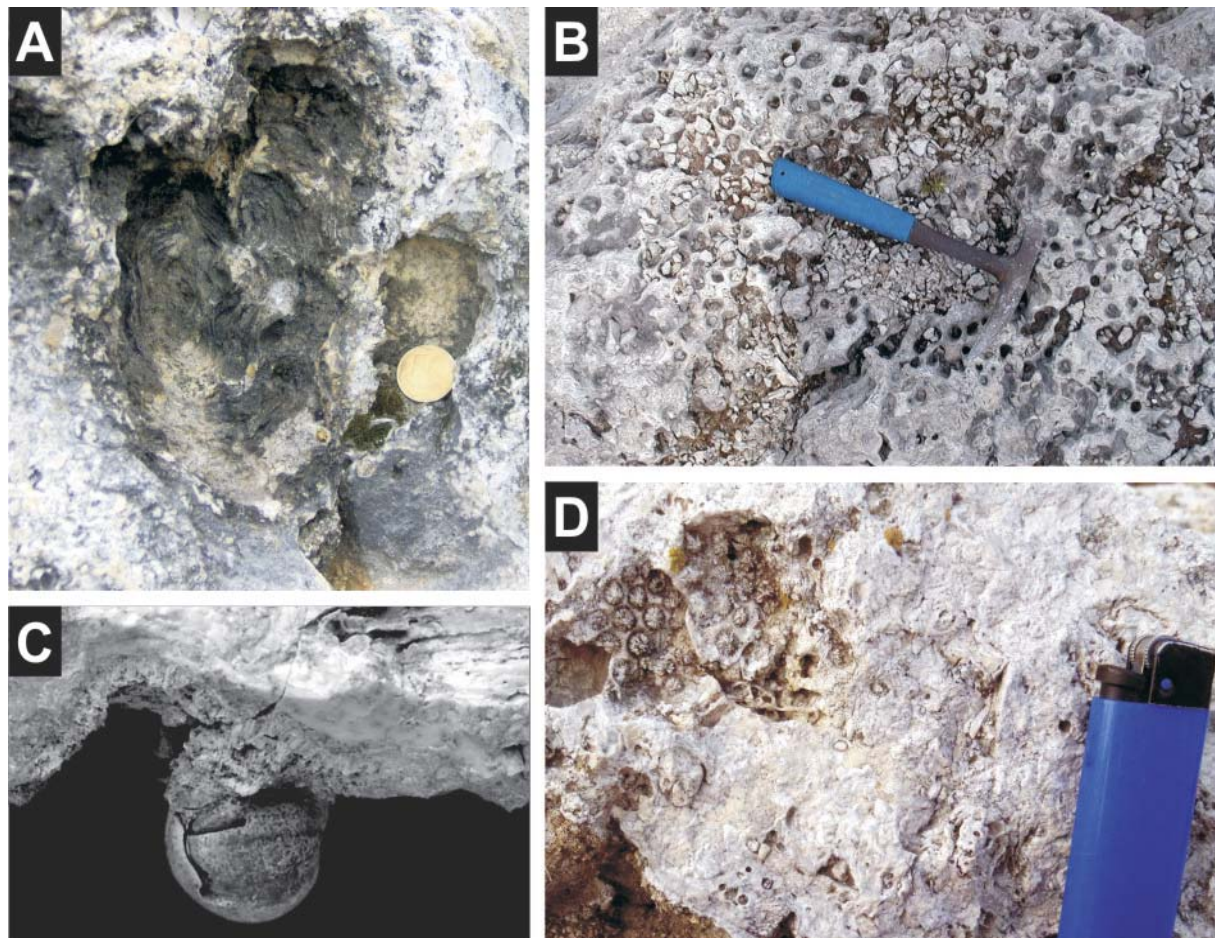
Text-fig. 8. Hermatypic corals from the Fore-Carpathian Basin. **A** – Field photo, to show a hollow after dissolution of a *Porites vindobonarum prima* Kühn, 1925 colony (Upper Badenian, Maksymivka, UA); ´0.3; **B** – Mass-occurrence of branching colonies of *Porites vindobonarum prima* (Upper Badenian, Sakhkamin, UA); **C** – *Jouannetia semicaudata* DesMoulins, 1828; mould of the shell in the boring within *Porites vindobonarum prima* colony, MWGUW ZI/79/082, side view (Upper Badenian, Maksymivka, UA), ´2; **D** – Mould of *Montastrea* sp. (Upper Badenian, Zakupne, UA). Photograph B taken by M. Jasionowski

rytnica Clays were reported by Pusch (1837, p. 181). Subsequently, various materials from Poland, Volhynia and Podolia were studied by Dembińska (1924), and more recently the group was monographed by Jakubowski and Musiał (1977, 1979a, 1979b); Radwańska (1994a, 1994b); Bałuk and Radwański (1997) and Radwański and Wysocka (2004).

Sedentary polychaetes from the Korytnica Clays

The most diversified sedentary polychaete assemblage was recognised from the Korytnica Clays, which comprises 32 species- or genus-level taxa (Radwański 1964, 1969, 1970; Radwańska 1994a, b; Bałuk and Radwański 1997). They are represented by rock-boring forms of the family Spionidae and Sabellidae, tube-dwelling forms (Radwańska 1994a), as well as commensal micropolychaetes (Bałuk and Radwański 1997) and unique, opercular caps (Radwańska 1994b). Also reported was the ichnofossil *Helicotaphrichnus commensalis* Kern, Grimmer and Lister, 1974, occurring within the columellae of some gastropods, and attributed to borings of present-day spionid polychaetes that are commensal to the hermit crabs occupying empty gastropod shells (Kern 1979; Bałuk and Radwański 1984b; Radwańska 1994a). Another ichnofossil, *Tibikoia sanctacrucensis* Bałuk and Radwański, 1979, being aggregates of faecal pellets, was ascribed to the life activity of the present-day species *Heteromastus filiformis* (Claparède, 1864).

Tube-dwelling polychaetes: This is most abundant group among sedentary polychaetes (Text-fig. 9). Variable tube morphology, mode of coiling, sculpture, and relation to the substrate are the basis of their species-level taxonomy. Particular species reveal phyletic relationships either to Late Mesozoic or to modern polychaete faunas.

The studied polychaete assemblage includes also very peculiar material consisting of tiny calcareous tubes, observable under SEM-magnifications (Bałuk and Radwański 1997), settled within the calyxes of some colonies of the scleractinian coral *Tarbellastraea reussiana*. These tubes are ascribed to the life activity of micropolychaetes commensal to this coral and are accommodated into the extant genus *Josephella* Caullery and Mesnil, 1896 to represent a separate species *Josephella commensalis* Bałuk and Radwański, 1997.

Opercular caps: This is a very unique group among the tube-dwelling polychaetes (Radwańska 1994b; Text-fig. 10), representing isolated parts of the opercular system closing the tubes of some polychaetes.

The group was described, in open nomenclature, as opercular caps comparable to those of the present-day species of the genus *Vermiliopsis* Saint-Joseph, 1894. Ten Hove and Nishi (1996) considered these caps to belong to the serpulid genera *Spirobranchus* Blainville, 1818 and/or *Pomatoceros* Philippi, 1844. Unfortunately, tubes of these genera have not been found in the Korytnica Clays (Radwańska 1994a), nor were the opercula found *in situ*.

Rock-boring polychaetes: These polychaetes contain three species: *Polydora ciliata* (Johnston, 1838), *P. hoplura* (Claparède, 1869), and *Potamilla reniformis* (O.F. Müller, 1771). All of the taxa recorded are adapted to live permanently in their characteristically shaped borings. These polychaetes mostly inhabited abrasion surfaces along the rocky seashores of the Korytnica Basin, zones affected by strong waves and currents, and on any skeletal material available within the Korytnica Clays (Radwański 1964, 1969, 1970; Radwańska 1994a).

*Distribution of sedentary polychaetes in the Korytnica Basin*

Sedentary polychaetes are relatively rare in the Korytnica Basin, both in the rocky-shore facies of the oyster shell bed and within the clay facies. In both facies, polychaete tubes were found either isolated, probably having been detached from any soft substrate, or as epibiontic forms encrusting skeletal material (primarily, coral colonies and mollusc shells). The former ones, except for the free-living species *Ditrupa cornea* (Linnaeus, 1767) and the commensal micropolychaete *Josephella commensalis*, were certainly attached to such soft substrates as e.g., sea plants, or to some soft-bodied animals. In the clay facies, the tube-dwelling polychaetes usually occur as gastropod epizoans, and are rarely represented by single specimens of spirorbids or serpulids.

Gastropods (M. Złotnik)

Gastropods are the most diversified invertebrates recognised from the Middle Miocene deposits of the Fore-Carpathian Basin. Besides bivalve molluscs (see Friedberg 1934–1936, 1938; Krach 1947, 1954, 1981; Kazakova 1952; Zelinskaja *et al*. 1968; Bałuk 1970; Voloshina 1973; Hoffman and Szubzda 1976; Jakubowski and Musiał 1977, 1979a,b; Janakevich 1977, 1980, 1993; Hoffman and Szubzda-Studencka 1982; Studencka 1986; 1987, 1994, 1999, 2015; Studencka and Studencki 1988a; Jakubowski *et al*. 1996; Stu-
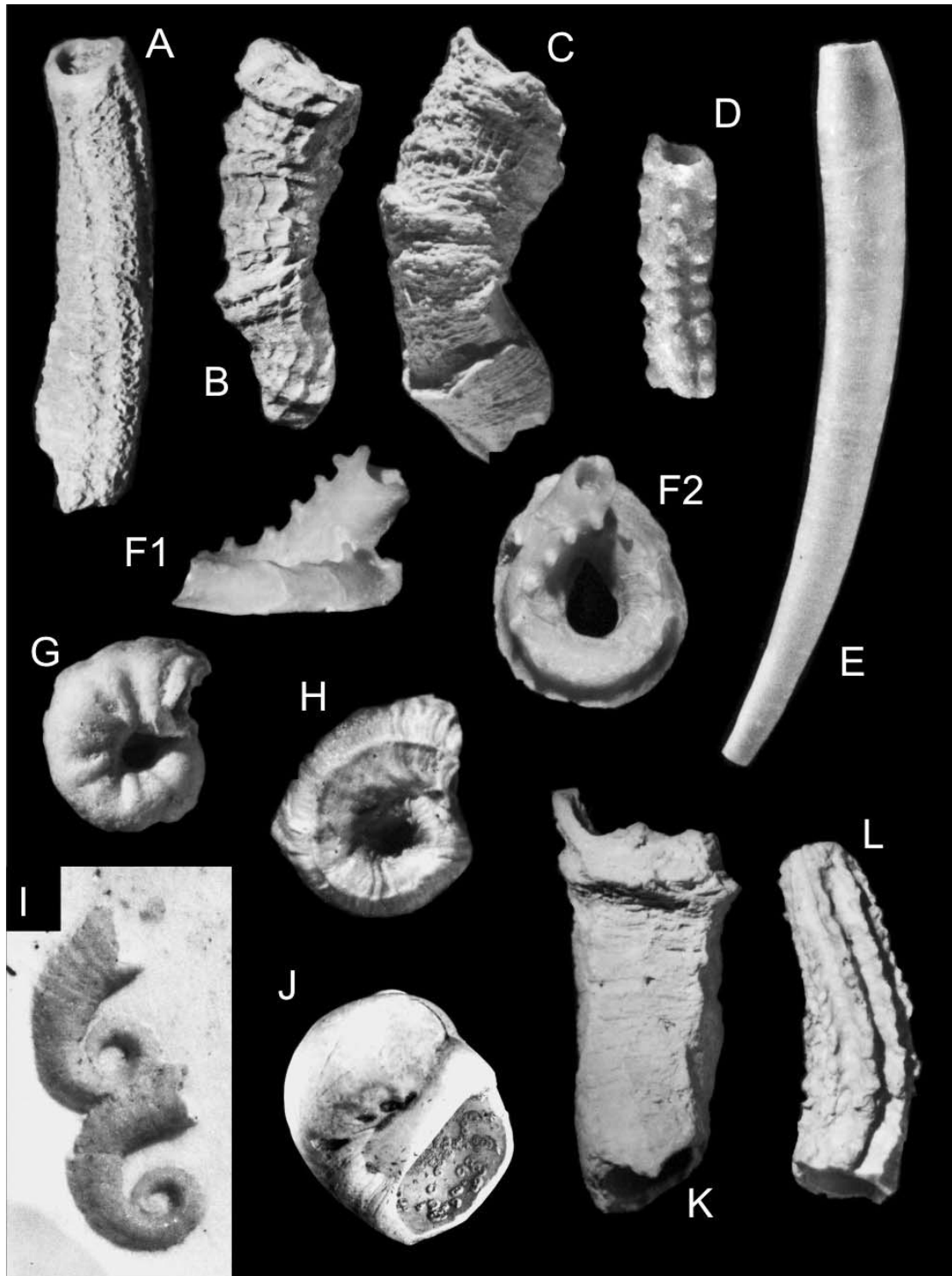
Text-fig. 9. Tube-dwelling polychaetes from the Korytnica Clays. **A** – *Hydroides vesicularis* Radwańska, 1994 (holotype, MWGUW PK-011), × 10; **B** – *Vermiliopsis quinquesignata* (Reuss, 1860), MWGUW PK- 042, × 15; **C** – *Vermiliopsis* sp., MWGUW PK-057, × 15; **D** – *Vepreculina* sp., MWGUW PK-052, × 20; **E** – *Ditrupa cornea* (Linnaeus, 1767), MWGUW PK- 061, × 10; **F** – *Placostegus echinatus* Radwańska, 1994 (holotype, F1 – lateral view of the tube, F2 – top view of the tube, MWGUW PK-065, × 10; **G** – *Protolaeospira strophostoma* (Boettger, 1907), MWGUW PK-075, × 15; **H** – *Pileolaria inflata* Radwańska, 1994 (holotype, MWGUW PK-089, × 20; **I** – *Pileolaria korytnicensis* Radwańska, 1994 (paratypes, two specimens in the shell of *Ancilla glandiformis* (Lamarck, 1810), MWGUW PK/GS-02, × 20; **J** – *Pileolaria korytnicensis* Radwańska, 1994, growing gregariously in the circum-apertural parts of the shell of *Natica* (*Polinices*) *redempta* Michelotti, 1847, MWGUW PK/GS-05, general view, × 1.5; **K** – *Vermiliopsis monodiscus* Zibrowius, 1968, MWGUW PK-039, × 10; **L** – *Metavermilia? semicostata* (Boettger, 1901), MWGUW PK-033, × 15. Photographs by L. Łuszczewska
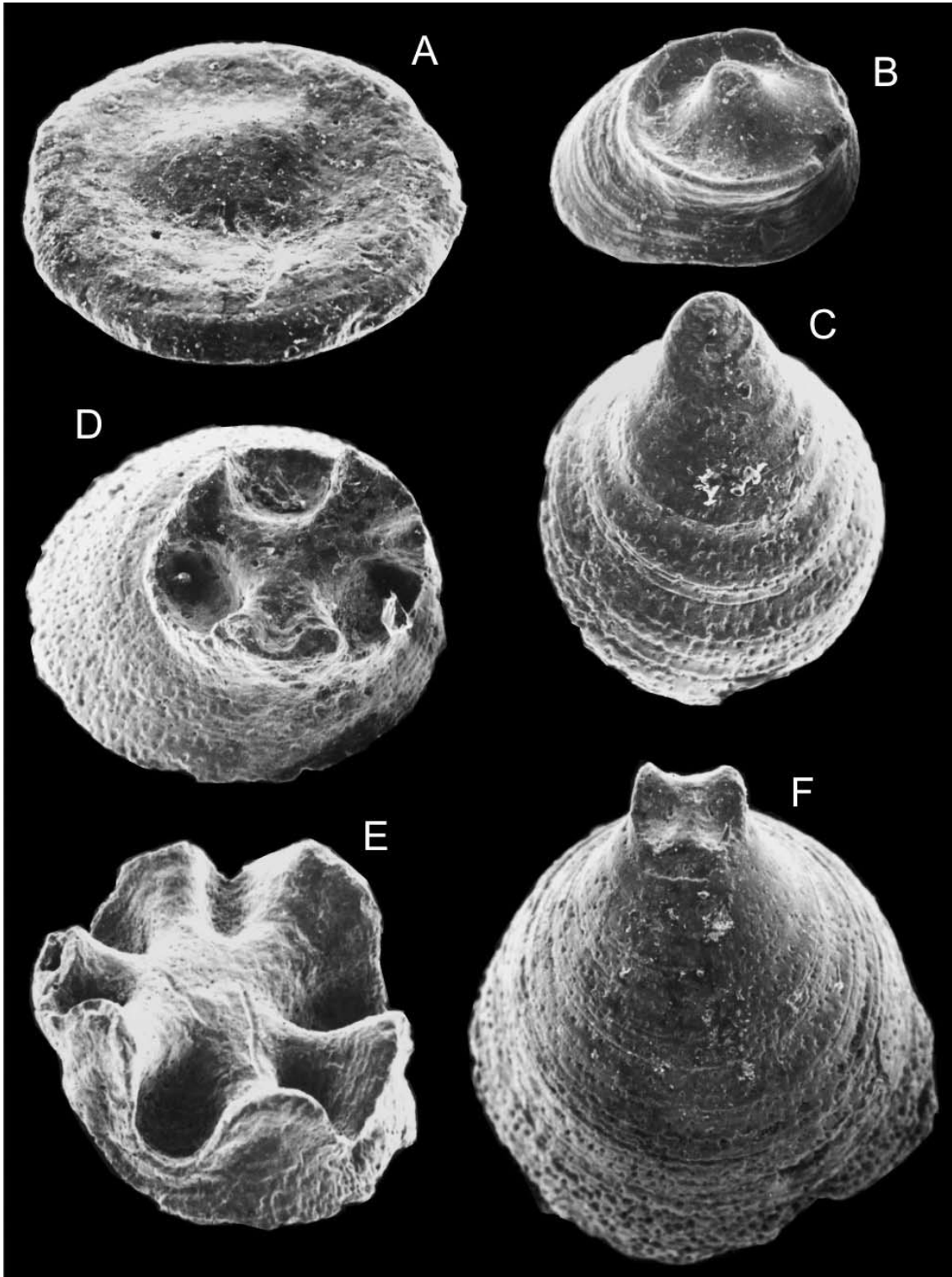
Text-fig. 10. Middle Miocene (Badenian) opercular caps of the tube-dwelling polychaetes *Vermiliopsis* Saint-Joseph, 1894 from the Korytnica Clays. **A** – Cap comparable to those of the present-day species *Vermiliopsis monodiscus* Zibrowius, 1968, outer view, MWGUW PK-096; SEM × 50; **B-C** – Caps comparable to those of the present-day species *Vermiliopsis infundibulum* (Philippi, 1844), **B** – outer view of a low-conical specimen, MWGUW PK-097, **C** – outer view of a high-conical specimen, MWGUW PK-098; SEM × 50; **D-F** – Caps comparable to those of the present-day species *Vermiliopsis labiata* (O.G. Costa, 1861), **D, E** – outer view of low-conical specimens, D - MWGUW PK-099, E – MWGUW PK-100; SEM × 30; **F** – outer view of a high-conical specimen with a small cross, MWGUW PK-101; SEM × 50. Photographs by C. Kulicki

dencka and Popov 1996; Studencka *et al.* 1998, 2012) they are usually the most abundant macrofossils occurring in the sandy and especially in the clay facies. Gastropod shells, or rarely their internal moulds, were reported from numerous exposures of the entire Fore-Carpathian Basin, e.g., from Niskowa (Bałuk 1970), Andrychów (Krach and Nowak 1956) and Benczyn (Krach and Książkiewicz 1949), Miechów (Krach 1947), Przeciszów (Alexandrowicz and Krach 1963), Gliwice Stare (Krach 1954), to Korytnica (Friedberg 1911-1928; Kowalewski 1930; Bałuk 1975, 1995, 1997, 2003, 2006), numerous localities in Roztocze Hills area (Jakubowski and Musiał 1977, 1979a,b, Krach 1981, Pisera 1985) and Ukraine (Friedberg 1911-1928, Anistratenko 2009, Scarponi *et al.* 2016). Some of the gastropods are a very useful tool for the stratigraphy of the Miocene deposits. Among them the planctic pteropods (see Krach 1981, Janssen and Zorn 1993) and nassarids (see Złotnik 2003) are the most important taxa.

The most diversified gastropod fauna was recognised from the Korytnica Clays (Radwański 1969; Bałuk 1975, 1995, 1997, 2003, 2006; Bałuk and Radwański 1977). Calcareous nannoplankton and dinoflagellate cysts locate the Korytnica Clays in the lower Middle Badenian (Upper Langhian to Lower Serravalian – see Martini 1977 and Gedl 1996, respectively). A somewhat earlier dating (Lower Badenian, which correlates with the Langhian Stage) was suggested by benthic foraminifera (Rögl and Brandstätter 1993).

Gastropods from the Korytnica Clays – taphonomy, taxonomy, abundance and mortality patterns

Most gastropods from the Korytnica Clays are characterised by an exceptionally good preservation state. The shell surface is usually shiny, and the details of the sculpture are perfectly preserved. The protoconch is usually present and easily distinguishable from the teleoconch (Text-fig. 11R, S). In a few cases the colour pattern is also preserved. This is well recognisable in *Neritina picta* Férrusac, 1825 or *Notocochlis tigrina* (Röding, 1789) (=*Natica tigrina in* Bałuk 1995*)* (Text-fig. 11L and Text-fig. 11Q1, respectively). On the other hand, some gastropod shells are corroded and/or bear bioerosional traces, a record of the activity of clinid sponges, boring pelecypods and polychaetes. The shell surface may also be altered by encrusting and etching organisms: polychaetes, barnacles and bryozoans (Bałuk and Radwański 1977).

Due to their exceptional preservation state and extremely high taxonomic diversity, the group has been the subject of intensive investigation for over 200 years (Pusch 1837; Kontkiewicz 1882; Friedberg 1911-

1928, 1928; Kowalewski 1930). Eichwald (1853), Hörnes (1856), and Hoernes and Auinger (1879) included the Korytnica gastropods into their classic monographs on the Miocene malacofauna. The most recent Bałuk's (1975, 1995, 1997, 2003, 2006) monographs include over 550 prosobranch species representing 65 families, with 33 new species recognised (Bałuk 1975, 1995, 1997, 2003, 2006; Bałuk and Jakubowski 1968). The highest taxonomic diversity is noted among the Turridae (101 species). However, 20 species or more, are noted also among the Muricidae, the Nassaridae, the Mitridae, the Cerithidae, and the Rissoidea. The total number of gastropod species from the Korytnica Clays exceeds 800 species, including more than 250 opistobranch species (Bałuk, in preparation). According to Bałuk, the gastropods from the Korytnica Clays reveal the strongest affinity to the gastropods from the Vienna Basin (see Hörnes 1856; Hoernes and Auinger 1879; Harzhauser and Kowalke 2002).

The relative abundance of gastropods varies in the succession. The relative number of gastropod shells ranges from 10% to 85% of all invertebrate macrofossils. The lowest and highest frequencies were recognised from deposits predominated by corbulid bivalve molluscs [*Corbula gibba* (Olivii, 1792)] and those predominated by turritellid gastropods (*Turritella badensis* Sacco, 1895), respectively. The relative biovolume of the turritellids recognised from the latter deposits reaches up to 70% of the total biovolume of all infaunal macrofossils (Hoffman 1977).

The gastropod taxonomic composition varies between particular parts of the Korytnica Basin. Its littoral zone is occupied mostly by *Nassarius limatus* (Chemnitz, 1786), *Petaloconchus intortus* (Lamarck, 1818), *N. korytnicensis* (Bałuk, 1997), *N. restitutianus* (Fontannes, 1879), *Alvania spp.*, *Caecum sp.* and cerithids (see Bałuk and Radwański 1977; Hoffman 1977; Złotnik 2003). The coastal swamps (Radwański 1969; Hoffman 1977), located in the southern part of the basin and recognised only from a single locality, were dominated, i.a., by *Neritina picta*, *Nassa schoenni* (Hoernes and Auinger, 1882), *Melanopsis sp.*, *Turitella erronea* Cossman in Friedberg 1914, *Terebralia sp.* and *Natica pseudoredempta* Friedberg, 1923 most of which are rare or absent from other parts of the basin.

The major off-shore part of the Korytnica Basin was dominated by *Nassarius korytnicensis*, *N. restitutianus*, *N. styriacus* (Auinger in Hilber, 1897), *Turritella badensis*, *Turboella spp.*, cerithids, *Odostomia spp.*, *Eulima sp.* and *Notocochlis tigrina* (=*Natica tigrina* in Bałuk 1995). *Nassarius korytnicensis*, *T. badensis* and *N. styriacus* dominate the upper and/or uppermost part of the succession and the latter species
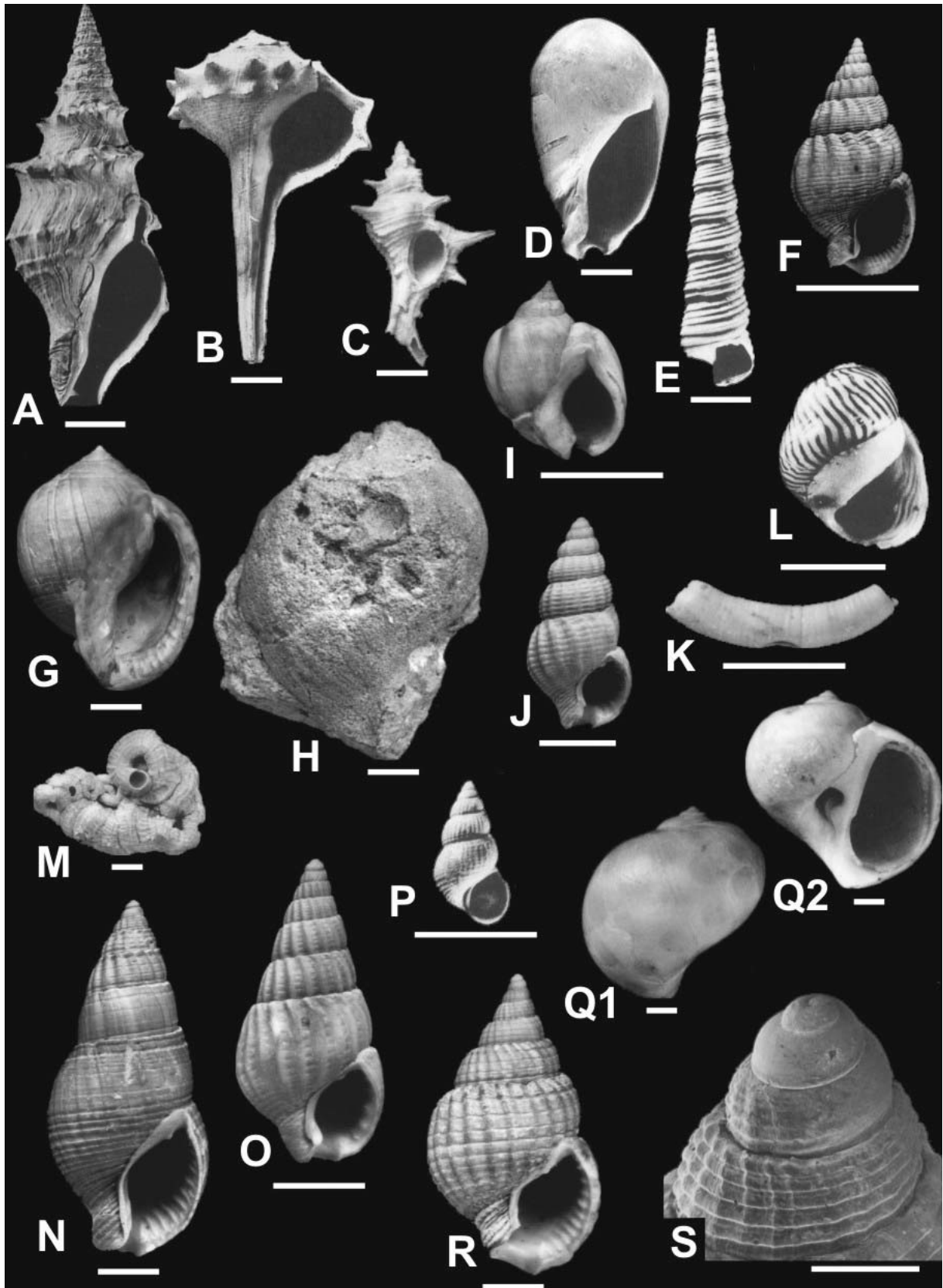
frequently occurs only in the central part of the basin (see Bałuk and Radwański 1977; Hoffman 1977; Złotnik 2003).

Besides small and medium-sized species, which predominate in both abundance and biovolume in the bulk samples, many large-sized gastropods were collected, although their relative abundance in the bulk samples is usually low. Some of these large gastropods are important components of the trophic web (Hoffman 1977) and diagnostic of the distinguished palaeocommunities (see Bałuk and Radwański 1977). Among them, *Clavatula polonica* (Pusch, 1837), *Murex friedbergii* Cossman and Peyrot, 1924, *Ancila glandiformis* (Lamarck, 1810), *Tudicla rusticula* (Basterot, 1825) and *Semicassis miolaevigata* Sacco, 1890 are the most abundant (see Text-fig. 11).

The mortality patterns of some Korytnica gastropods were studied by Hoffman (1976) and Kowalewski (1990). The investigations show remarkable differences between the studied species. The mortality rates of *Murex friedbergi*, *Nassius restitutianus*, *Notocochlis tigrina* and *Pyrgulina indistincta* (Montagu, 1808) are nearly constant for their postlarval life. A very high proportion of individuals dying in the early stages was observed for *Turritella badensis*. *Raphitoma hispidula* (Jan in Bellardi 1847) and *Turbonilla scala* (Eichwald, 1853) are characterised by a relatively high juvenile mortality, followed by a plateau of adult vigour, when the mortality was very low. In gerontic stage, the probability of death rapidly increases for these species (Hoffman 1976). The analysis of the contribution of predatory boring gastropods to the mortality of the Korytnica gastropods demonstrates that, generally, the mortality patterns do not depend on the predation by muricid and/or naticids, even when the predation pressure was very high (Hoffman 1977; Kowalewski 1990).

Nassarid gastropods and local stratigraphy of the Korytnica Clays

The Korytnica Clays lie almost horizontally (also confirmed by geophysical data - see Szymanko and Wójcik 1982). Representatives of the family Nassaridae, the most abundant gastropods in the Korytnica Clays (see Bałuk and Radwański 1977; Hoffman 1977; Kowalewski 1990; Złotnik 2003), are crucial for local stratigraphy (Złotnik 2003). Based on five nassariid assemblages (*Nassarius restitutianus*, *N. restitutianus-korytnicensis*, *N. korytnicensis*, *N. korytnicensis-limatus* and *N. schoenni*), the Korytnica Clays succession was subdivided into five ecostratigraphic units: Lower *restitutianus*, Lower *restitutianus-korytnicensis*, Upper *restitutianus*, *korytnicensis*, and Upper *restitutianus-korytnicensis*. The entire sequence reflects temporal changes in the relative size of two large gastropod populations: of *N. restitutianus* and of *N. korytnicensis* (Złotnik 2003). This nassariid-based stratigraphy applies to almost the entire Korytnica Basin with the exception of the littoral zone, characterised by the *schoenni* and *korytnicensis-limatus* assemblages (Złotnik 2003, text-fig. 7). The nassariid-based correlation was confirmed by many geological and palaeobiological data.

The appearance of the *korytnicensis* assemblage in the upper part of the succession seems to be the most significant ecological event hitherto recognised from the entire sequence of the Korytnica Clays. The co-occurrence of several strictly tropical faunal elements and their broad correlation with the most taxonomically diversified community III of Bałuk and Radwański (1977), suggest that the appearance of this assemblage was caused by a warming event. If this preliminary hypothesis (Złotnik 2003) is correct, then the entire succession of nassariid assemblages could be interpreted as a record of climatic fluctuations that took place in the early Middle Miocene.

Palaeoecology of the Korytnica gastropods

The gastropods represent almost all members of the trophic web, viz. predators (e.g., *Notocochlis*, *Murex*, *Clavatula*, *Raphitoma*), scavengers (*Nassarius*), browsers (e.g., *Turboella*, *Alvania*, cerithids), parasites (e.g., *Odostomia*, *Eulima*), and suspension feeders (*Turri-*

Text-fig. 11. Selected species of the most common gastropods from the Korytnica Basin. **A** – *Clavatula polonica* (Pusch, 1837), MWGUW BkK-G897, in apertural view; **B** – *Tudicla rusticula* (Basterot, 1825), MWGUW BkK-G759, in apertural view; **C** – *Murex friedbergi* Cossman and Peyrot, 1924, MWGUW BkK-G524, in apertural view; **D** – *Ancila glandiformis* (Lamarck, 1810), MWGUW BkK-G733, in apertural view; **E** – *Turritella badensis* Sacco, 1895, MWGUW BkK- G176, in apertural view; **F** – *Nassarius limatus* (Chemnitz, 1786), MWGUW ZI/32/015, in apertural view; **G, H** – *Semicassis miolaevigata* Sacco, 1890. **G** is MWGUW ZI/32/002 in apertural view, **H** is internal mould MWGUW ZI/32/003, in abapertural view; **I** – *Nassarius schoenni* (Hoernes and Auinger, 1882), MWGUW ZI/32/011 in apertural view; **J** – *Nassarius striaticosta* (Boettger, 1906). Shell MWG/ZI/32/014 in apertural view; **K** – *Caecum trachea* (Montagu, 1803), MWGUW BkK-G1176, in side view; **L** – *Neritina picta* Férrusac, 1825, MWGUW BkK-G89, in apertural view; **M** – *Petaloconchus intortus* Lamarck, 1818, MWGUW BkK-G1170; **N** – *Nassarius restitutianus* (Fontannes, 1879), MWGUW ZI/32/016, in abapertural view; **O** – *Nassarius styriacus* (Auinger in Hilber 1879), MWGUW ZI/32/013, in apertural view; **P** – *Alvania tenuicostata* Bałuk 1975, MWGUW BkK-G130, in apertural view; **Q** – *Notocochlis tigrina* Röding, 1798, private collection of P. Degórski, in abapertural and apertural views; **R, S** – *Nassarius korytnicensis* (Bałuk, 1997), R is MWGUW ZI/32/017, in apertural view; **S** – Protoconch and the earliest teleoconch whorls of MWGUW 009747. All specimens, except H, which is from the *Heterostegina* Sands, are from the Korytnica Clays. Scale bars – 1 cm (A-I), 0.25 cm (J-R), and 0.5 mm (S). Photographs A-E, L, P taken by B. Drozd, F-K, M-O, R by B. Malinowska, Q by P. Degórski, and S by C. Kulicki

tella, *Petaloconchus*) (Hoffman 1977). The group is the member of the trophic nucleus within 4 out of 5 macrobenthic assemblages recognised from the Korytnica Basin by Hoffman (1977). Nassarids, turritellids, *Turboella*, *Pyrgulina*, *Odostomia*, *Turbonilla*, *Alvania*, and naticids are members of the trophic nucleus in the *Turboella-Loripes* assemblage; *Nassarius* and turritellids – in the *Corbula*-spatangoid assemblage; turritellids – in the turritellid assemblage; and *Clavatula* – in the *Pteromeris*-coral assemblage.

Noteworthy, the dominant gastropod taxa recognised by Bałuk and Radwański (1977) from the clay succession differ from those recognised by Hoffman (1977) or Złotnik (2003). These differences reflect different sampling and sieving methods discussed earlier in this paper.

Both the overall character of the gastropod fauna and the occurrence of gastropods typical of warm waters indicate tropical/subtropical conditions during the sedimentation of the Korytnica Clays. According to Bałuk and Radwański (1977), the occurrence of such genera as *Terebra*, *Rostellaria*, *Architectonica*, and large-sized species of the genera *Cypraea*, *Conus*, *Strombus*, *Triton*, and *Galeodes* indicate tropical conditions. The same is true for the genus *Parastrophia* represented in the Korytnica Clays by *Parastrophia radwanskii* (cf. Bałuk 1975). The subtropical/tropical conditions of the clay sedimentation are also confirmed by the occurrence of the bivalved gastropod *Berthelinia* (see Bałuk and Jakubowski 1968; Bałuk and Radwański 1977). Finally, the extremely high taxonomic diversity of the Korytnica gastropods also indicates warm climatic conditions, as in recent communities biodiversity is positively correlated with temperature (Weiner 1999). Warm climatic conditions (tropical and/or subtropical) are also suggested by the non-gastropod animal groups recognised from the Korytnica Clays (for review see Bałuk and Radwański 1977 and references therein; see also Schultz 1977; Radwańska 1984, 1992; Rögl and Brandstätter 1993). Warm water, subtropical conditions in the Central Parathethys realm in the Badenian are also confirmed by the results of Studencka *et al.* 1998, Studencki 1999 and Harzhauser *et al.* 2003. According to Sitár and Kováčová-Slamková 1999, Böhme 2003 and Kvaček *et al.* 2006, the Badenian climate of the Central Paratethys realm represents a part of the Miocene Climatic Optimum.

The Korytnica Clays sequence and the overlying members were interpreted by Bałuk and Radwański (1977) as formed in a progressively shallowing basin with depths changing from c. 60 m at the beginning of sedimentation to almost 0 m at its end. Normal marine

salinity is confirmed by the occurrence of corals (Dembińska-Różkowska 1932; Bałuk and Radwański 1984b; Stolarski 1991), echinoids (Mączyńska 1977, 1987), asteroids (Kaczmarska 1987), crinoids (Radwańska 1987), and some benthic foraminifera (Walkiewicz 1975, 1977b; Rögl and Brandstätter 1993).

Drilling gastropods from the Korytnica Basin

Three major groups of gastropod drillers were recognised from the Korytnica Basin, viz. naticid, muricid and cassid drillers. Drill holes in the mollusc shells attributed to the predatory activity of naticid and/or muricid gastropods were reported from the Korytnica Clays by Hoffman *et al.* (1974), Kowalewski (1990), and Złotnik (2001). Drill holes on echinoid tests attributed to cassids were recognised from both the Korytnica Clays (Ceranka and Złotnik 2003) and from the overlying *Heterostegina* Sands (Ceranka and Złotnik 2003; Złotnik and Ceranka 2005), the deposits of which filled the basin in the terminal stage of its development (see Bałuk and Radwański 1977; Gutowski 1984). The fossil remains of the drillers and traces of their predatory activity usually co-occur; however, in some cases the number and/or size of the shells of the drillers remain in evident contrast with the number and/or size of the drill holes (see Ceranka and Złotnik 2003). Examples of the drilling activity of predatory gastropods from the Korytnica Basin are presented in Text-fig. 12A–C.

The detailed quantitative analysis of the drill holes has provided many important data on the palaeobiology of the drillers. Among 122 species of prey attacked by naticids and/or muricids, the highest drilling frequencies were recognised for the gastropods *Pyrgulina interstincta* (Montagu, 1808) (41%) and *Tornatina truncatula* (Bruguière, 1792) (40%), and for the bivalves *Meretrix* sp. div. (43%) and *Glycymeris deshayesi* (Mayer, 1868) (40%). On the other hand, some gastropods [e.g., *Ficus* sp. div., *Ranella marginata* (Martini, 1777)] have been attacked neither by naticid nor muricid drillers (Hoffman *et al.* 1974). According to the latter authors, the naticids had more frequently attacked bivalve molluscs whereas the muricids preyed mostly upon gastropod prey. This result is, however, disputable, because the use of drill hole morphology as a criterion for distinguishing between naticid and muricid drillers (applied by Hoffman *et al.* 1974) has been undermined by Złotnik (2001). The correlation between the size of the predator and the size of the prey predicted by Kitchel's *et al.* (1981) model of predator – prey interaction was not a rule in the case of naticid drillers from the Korytnica Basin. A strong correlation between the size of the prey and the size of the preda-

tor was recognised for naticid drillers preying upon the gastropod *Nassarius restitutianus*. The lack of any correlation between the discussed variables was noted for naticids preying on the bivalves *Corbula gibba* (Olivi, 1792) and *Venus nux* Gmelin, 1791 (= *Venus multilamella,* Lamarck, 1818) (Kowalewski 1990).

Kowalewski (1990) indicated that naticids were at least in some cases size-selective drillers. The central region of the shell of the bivalve *Corbula gibba* and the two last whorls of *Nassarius restitutianus* (= *Nassa hoernesi* in Kowalewski 1990) were drilled by naticids preferentially. Złotnik (2001) showed that the predatory behaviour of naticid drillers can change during the driller ontogeny. Larger naticids chose a more attractive (gastropod) prey, and when preying upon bivalves (*Corbula gibba*), they also displayed a stronger site selectivity.

Both naticid and murid attacks were very effective, with more than 95% of all drill holes complete (*sensu* Kitchel *et al.* 1981), enabling prey consumption (Hoffman *et al.* 1974; Kowalewski 1990; Złotnik 2001).

Patterns of drilling predation of cassid gastropods on echinoids from the Korytnica Basin were recognised by Złotnik and Ceranka (2005). Echinoid prey, re-presented by three species of *Echinocyamus* (*E. linearis* Capeder, 1906, *E. pusillus* Müller, 1776 and *E. pseudopusillus* Cotteau, 1895) were drilled presumably by one cassid species, *Semicassis miolaevigata* (Ceranka and Złotnik 2003; Złotnik and Ceranka 2005). The drilling predation intensities varied among the prey species and ranged from 3.4% for *E. linearis* up to 36% for *E. pusillus*. An intermediate value of drilling predation (15%) was recognised for *E. pseudopusillus*. The intensities of drilling predation recognised for some of the prey species (*E. pusillus*) varied also between (but never within) the sublithofacies of the investigated deposits (*Heterostegina* Sands). Drilling predation of cassids was both size- and site-selective. Larger individuals of *E. linearis* and *E. pusillus* were attacked more frequently and the aboral side of the test of all *Echinocyamus* species was drilled preferentially. An extremely high concentration of drill holes was observed in the apical disc and petals. Results obtained for the most abundant prey (*E. linearis*) indicate that the predatory behaviour of large cassids was somewhat different from those typical of small cassids. Large cassids drilled and consumed their prey
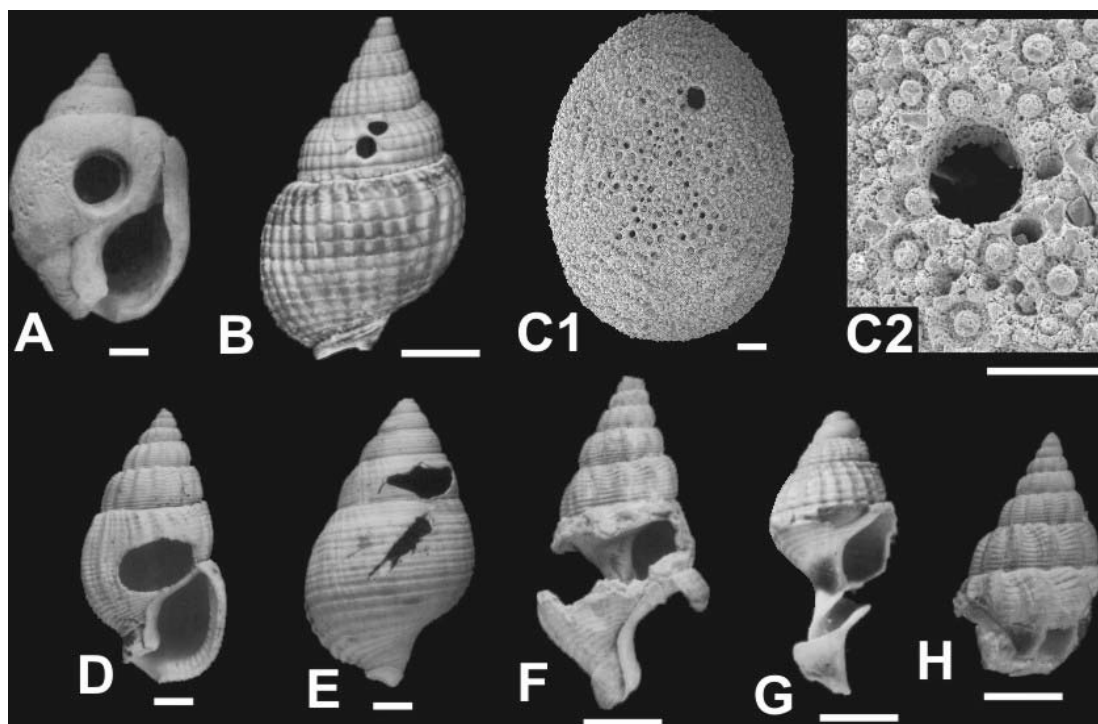
Text-fig. 12. Traces of gastropod drilling predation on gastropods (**A-B**) and echinoids (**C**) and traces of arthropod predation upon the Korytnica gastropods (**D-H**). **A** – muricid/naticid drill hole in the shell of *Nassarius schoenni* (Hoernes and Auinger, 1882), MWGUW-009748; **B** – A double naticid/muricid drill hole in the shell of *Nassarius korytnicensis* (Bałuk, 1997), MWGUW-009749; **C1-C2** – cassid drill hole in the test of *Echinocyamus linearis* Capeder, 1906. **C1** – Aboral side of test, **C2** – Close up of a drill hole, MWGUW ZI/32/005; **D** – Sub-circular damage attributed to stomatopods in the shell of *Nassarius limatus* (Chemnitz, 1786), MWGUW 009750; **E** – Elongate damages attributed to stomatopods in the shell of *Nassarius rosthorni* (Partsch in Hörnes, 1856), MWGUW 009751; **F-H** – Successive stages of shell destruction caused by hermit crabs, **F** – *Nassarius limatus* (Chemnitz, 1786), MWGUW 009752, G – *Nassarius restitutianus* (Fontannes, 1879), MWGUW 009753, **H** – *Nassarius limatus* (Chemnitz, 1786), MWGUW 009754. All specimens, except C, which is from the *Heterostegina* Sands, are from the Korytnica Clays. Scale bar is 0.25 cm. Photographs A-B, D-H taken by B. Malinowska, C by C. Kulicki

almost always individually, whereas small cassids sometimes preyed upon the urchins in a group. Large cassids displayed also a higher site-selectivity. Cassids from the *Heterostegina* Sands were extremely efficient drillers, as all drill holes are complete and unrepaired. This means that all attacks on the echinoids were successful (Złotnik and Ceranka 2005).

Cassid drill holes in *Echinocyamus* from the *Heterostegina* Sands significantly complement the information on the size and structure of cassid populations recorded by body fossils. The high number of small drill holes recognised from the sands indicates the occurrence of a large number of small individuals in the cassid population, although neither small shells nor small internal moulds of cassids were preserved in the fossil record of the Korytnica Basin (Ceranka and Złotnik 2003).

Crustacean predation upon gastropods

Many gastropod shells bear traces of crustacean predation. The predatory activity of hermit crabs has been reported by Radwański (1969) and Bałuk and Radwański (1977). Traces of stomatopod predation upon the Korytnica gastropods have been described and analysed by Bałuk and Radwański (1996). According to Bałuk and Radwański (1977), "particular species of Korytnica gastropods were attacked by hermit crabs to a very variable extent. Of the long siphonated forms, the most common two *Clavatula* species, *C. laevigata* (Eichwald, 1853) and *C. asperulata* (Pusch, 1837), became the prey in very low percentage, whereas very uncommon *Tudicla rusticula* was damaged in most specimens collected. A low percentage of damage is also noted in a common species *Ancilla glandiformis* whose shell may be however nipped completely". These preliminary results may indicate that hermit crabs were very selective when they chose their gastropod prey, however, it should be emphasized that the suggested species-selectivity, although very probable, should be treated as only a preliminary hypothesis. This is because the investigation of Bałuk and Radwański (1977) focused only on a few, selected gastropod species and no numerical data have been presented. My field observations evidently indicate that many other gastropods (mainly nassarids) were also frequently attacked by crabs (Text-fig. 12F–H).

Stomatopod predation upon gastropods was the subject of more detailed studies. The percentage of the attacked individuals varied distinctly between 31 investigated species of prey and ranges from 0.6% for *Notocochlis tigrina* to 54.4% for *Nassarius dujardini* (Deshayes, 1844) (=*Sphaeronassa dujardini* in Bałuk

and Radwański 1996). Stomatopod predation upon gastropods was site-selective. Based on the different morphology of the traces they were attributed to two different stomatopod families: Gonodactylidae and Squillidae (Bałuk and Radwański 1996). Some of the shells bearing traces of crab or stomatopod predation are evidently repaired (see Bałuk and Radwański 1977 and 1996 for crabs and stomatopods, respectively). This indicates that gastropods could have sometimes survived attacks of crustacean predators, both crabs and stomatopods.

Traces of stomatopod predation observed on the gastropod shells (circular to sub-circular holes and elongate scars – see Text-fig. 12D, E) are, in fact, the only record of the occurrence of stomatopods in the Korytnica Basin, as no remains of these low mineralized crustaceans were preserved in the fossil record of the discussed deposits.

Scaphopods, chitons and cephalopods (M. Złotnik)

Fossil scaphopods are common in the Middle Miocene deposits of the Fore-Carpathian Basin. Although the number of their species does not exceed 20, their shells were reported from numerous exposures located in a broad area extending from the Silesia Upland to the Roztocze Hills, e.g., from Andrychów (Krach and Nowak 1956) and Benczyn (Krach and Książkiewicz 1949) near Wadowice, Gliwice Stare (Friedberg 1911–1928; Krach 1954), Brzeźnica near Bochnia (Krach 1960), Zgłobice (Friedberg 1938), Wieliczka (Reuss 1867), Małoszów (Krach 1947), Niskowa (Skoczylasówna 1930; Bałuk 1965, 1970), and Korytnica near Kielce (Friedberg 1911–1928; Kowalewski 1930; Bałuk 1972, 1984). They were also reported from the Ukrainian part of the Carpathian Foredeep Basin (Friedberg 1928, 1938).

The most diversified scaphopods were recognised from the Lower/Middle Badenian Korytnica Clays, a unique facies deposited in a shallow bay during the transgression of the Parathethys sea onto the southern slopes of the Holy Cross Mts. in Central Poland (see Radwański 1969; Bałuk and Radwański 1977 for geological setting; Martini 1977; Dudziak and Łuczkowska 1991; Rögl and Brandstätter 1993, Gedl 1996; for stratigraphic position). Among 13 scaphopod species (including 4 new ones) recognised in the clays, *Dentalium fossile* Schroeter, 1783 and *Fustiaria miocaenica* (Boettger, 1901) are the most abundant taxa (Bałuk 1972). In some parts of the clays, the relative biovolume of the latter species reaches up to 10% of the total biovolume of all invertebrate fossils (Hoffman 1977). The pattern of geographic distribution of particular scaphopod species recognised by Bałuk (1972)

shows that *Dentalium fossile*, *D. badense* Partsch in Hörnes, 1856, and *Entalina tetragona* (Brocchi, 1814) were the most widespread scaphopods across the Polish part of the Parathetys Sea.

Chitons were recognised from Niskowa (Bałuk 1965), Korytnica (Bałuk 1971, 1984), Gieraszowice Rybnica1, Rybnica2 and Nawodzice (Studencka and Studencki 1988b), Monastyrz and Trzęsiny (Jakubowski and Musiał 1977, 1979a) and from numerous localities in Ukraine (Studencka and Dulai 2010). The most diversified assemblage was recognised from the Korytnica Clays. Among 17 species of chitons (including 5 new ones) recognised from the Korytnica Clays, *Chiton denudatus* Reuss, 1860 and *Lepidopleurus decoratus* (Reuss, 1860) are the most abundant species (Bałuk 1971). The latter species occurs also in the much less diversified chiton assemblage from Niskowa (Bałuk 1965). The results of Studencka and Studencki (1988b) show that taxonomic diversity of chitons declines during Badenian.

Cephalopods are represented by a single, endemic cuttlefish species, *Sepia sanctacrucensis* Bałuk 1977, reported only from the Korytnica Clays. Fragmented parts of the sepions ("os sepiae") are the only remains of this species preserved in the fossil record (Bałuk 1977, 1984). Both chitons and *Sepia* occur in Miocene deposits very rarely (Bałuk 1971, 1977). Selected representatives of all discussed molluscs are presented in Text-fig. 13.

Scaphopods and chitons from the Korytnica Clays are very similar to those recognised from the Miocene deposits of the Vienna Basin (Bałuk 1971, 1972). The occurrence of the genus *Sepia* in the Parathetys has been discussed broadly by Bałuk (1977), who concluded that *Sepia,* due to its relatively low fossilization potential, is very rarely present in the fossil record.

The occurrence of scaphopods, chitons and cephalopods indicates normal marine conditions (salinity) during the sedimentation of the Korytnica Clays. Chitons, reported exclusively from the upper and uppermost parts of the clays, indicate very shallow depths of the sea during the late stage of the development of the Korytnica Basin (Bałuk 1971; Bałuk and Radwański 1977). Finally, the occurrence of representatives of the polyplacophoran genera *Craspedochiton* and *Cryptoplax* recognised from the clays by Bałuk (1971) is considered as indicative of tropical conditions by Bałuk (1971) and Bałuk and Radwański (1977). All these palaeoecological interpretations are in agreement with the results obtained from the investigations of many other animal groups, which inhabited the Korytnica Basin in the Middle Miocene (for review see Bałuk and Radwański 1977 and chapter "Gastropods" in this paper).

Crustaceans of the Fore-Carpathian Basin (M. Górka)

The first decapod remains were found in Wieliczka (Reuss 1867) and it was concluded at that time that crustaceans are present in very diverse lithofacies, from coarse-grained cliff conglomerates, through sands, clays, to carbonates, of Early and Late Badenian age.

Cirripeds: Badenian crustaceans were first reported by Bałuk and Radwański (1967), who described a new cirriped species, *Creusia sanctacrucensis* Bałuk and Radwański, 1967, that inhabited coral colonies (see also Bałuk and Radwański 1984a). Subsequently, they described another species of a cirriped crustacean, *Trypetesa polonica* Bałuk and Radwański, 1991, considered as an obligate commensal to the hermit crabs (Bałuk and Radwański 1991). Diverse reworked cirriped species from the Lower Badenian Mykolaiv sands of Ukraine were described by Wysocka *et al*. (2012), who reported abundant barnacles *Balanus* sp., goose barnacles *Scalpellum* sp., and unique specimens of *Creusia* sp. (Text-fig. 14A).
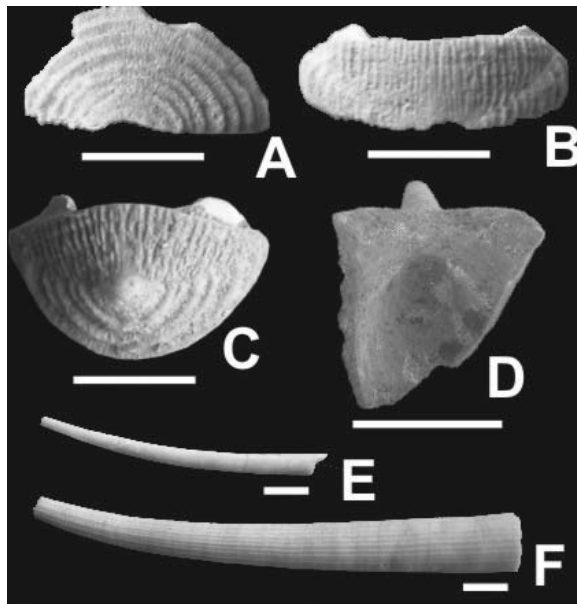
Text-fig. 13. Selected species of chitons (**A-C**), cuttlefish (**D**) and scaphopods (**E-F**) from the Korytnica Clays. **A-C** – *Lepidopleurus decoratus* (Reuss, 1860); Head (**A**), intermediate (**B**) and tail (**C**) valves. A is MWGUW 009755, B is MWGUW 009756, and C is MWGUW 009757; **D** – *Sepia sanctacrucensis* Bałuk, 1977. Fragmented sepion of MWGUW 009758; **E** – *Fustiaria miocaenica* (Boettger, 1901), MWGUW 009759; **F** – *Dentalium fossile* Schroeter, 1783, MWGUW 009760. Scale bars are 0.25 cm. Photographs A-C, E, F taken by M. Ginter, D by M. Wróbel
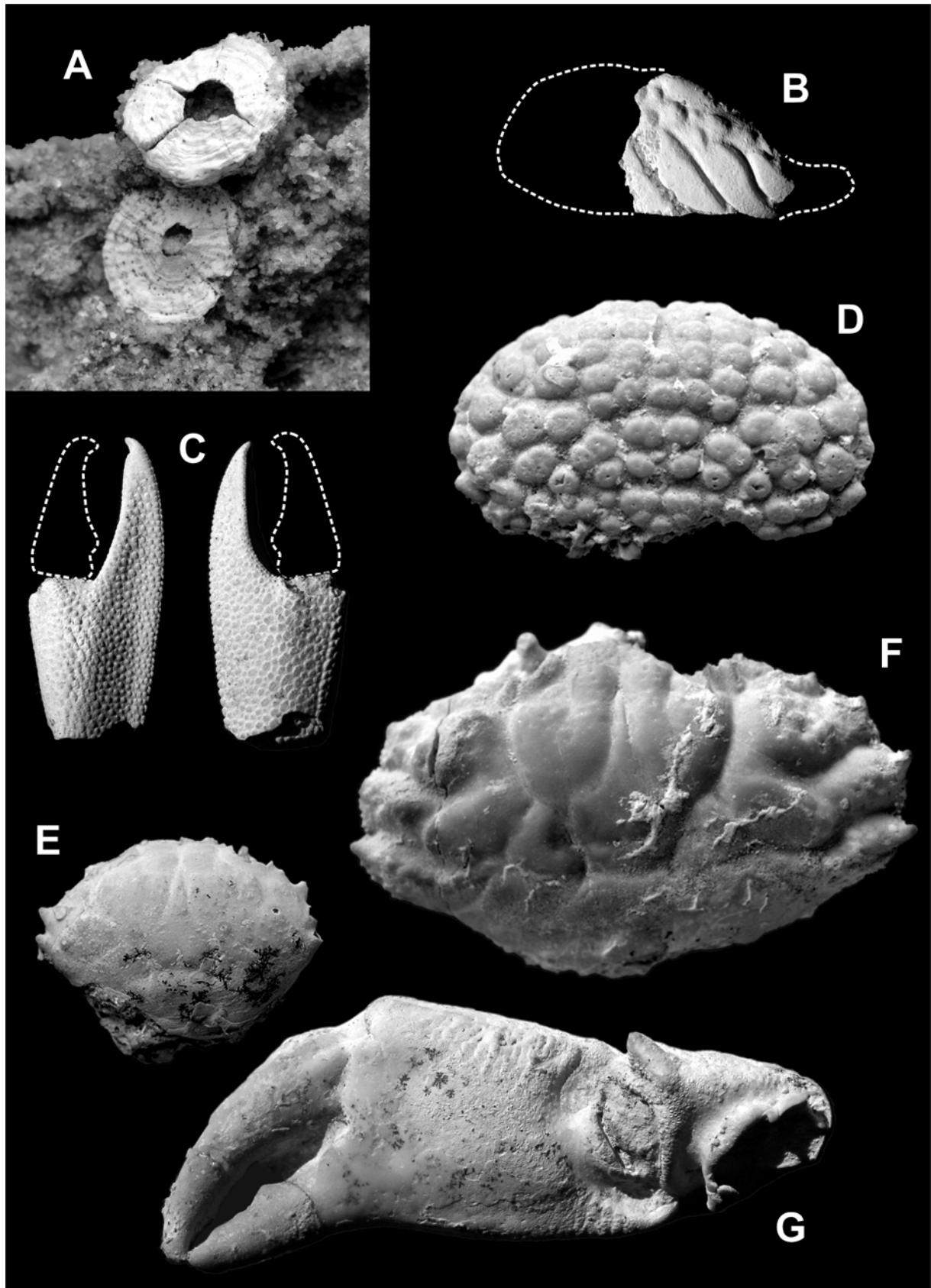
Decapods: The studies on decapods intensified in the 1970's with the continuous works of Wacław Bałuk and Andrzej Radwański (Radwański 1967; Bałuk and Radwański 1968; Bałuk 1970) in the south-eastern parts of the Holy Cross Mts. Radwański (1973) reported the remains of a *Callianassa* shrimp from the Lower Badenian sands of the Holy Cross Mts. area and attributed numerous *Ophiomorpha nodosa* Lungdgren, 1891, burrows to it. Later, he published on decapod-attributable burrows from various Miocene sites from western Ukraine: burrows attributed to the shrimp *Alphaeus* sp. from the reefal deposits of Upper Badenian limestones of the Ternopil Beds (Radwański *et al*. 2006); the burrows *O. nodosa* attributed to the *Callianassa* shrimp and *Psilonichnus* ichsp., attributed to the ghost crab *Ocypode* sp., from the Lower Badenian Mykolaiv Beds (Radwański *et al*. 2012; Wysocka *et al*. 2012).

The first monographic descriptions of the Polish Badenian decapods appeared in 1979, with Förster's (1979a) publication on Miocene crabs from southern Poland. It was followed by a paper devoted exclusively to the decapod assemblage of the Lower Badenian deposits of the Korytnica Basin (Förster 1979b), in which 23 forms representing at least 10 genera were recorded. Förster's designations were reviewed and revised by Müller (1984, 1996). The latter of these papers (Müller 1996) must be treated as the most extensive and up-to-date for the recognition of decapods from the Polish part of the Fore-Carpathian Basin. It presents 36 species from different parts of the basin – not only from the biohermal (reefal) deposits on the southern slopes of the Holy Cross Mts. (see Górka 2002) and the Roztocze area, but also from other lithofacies, varying from clayey, through muddy, to sandy deposits. It also states that decapod assemblages were present in reefal facies in two chronostratigraphic levels – in the Lower Badenian (predominantly the Holy Cross Mts. area) and the uppermost Badenian (Roztocze). The taxonomic composition of these assemblages is almost identical to the assemblages recorded in other reefal deposits of Miocene (Müller 1984, 1993; Radwański *et al*. 2006; Gatt and de Angeli 2010; Ósso and Stalennuy 2011; Górka *et al*. 2012) or younger (Pliocene/Pleistocene) age (see Karasawa 2000). Only one additional species, *Dardanus hungaricus* (Lőrenthey, 1929), was later recorded by Górka (2002) in the reefal facies of the well-known Grobie site (Text-fig. 14B) that supplements Müller's report (see Müller 1996).

Practically the same decapod assemblage, consisting of taxa almost exclusively related to reefal conditions was recorded in the Upper Badenian Ternopil Beds from the Medobory Hills in western Ukraine (Górka 2006; Radwański *et al*. 2006). These first reports were soon followed by the effects of regular exploration of the Maksymivka Quarry near Ternopil (Ósso and Stalennuy 2011). These authors reported 12 taxa, among them the new species *Bathynectes muelleri* Ósso and Stalennuy, 2011. Field work along the Medobory Hills, stretching further south into Moldovan territory are still ongoing. Their results enable the statement that this assemblage of decapods (Text-fig. 14C–G), dominated by the characteristic species *Daira speciosa* (Reuss, 1871), *Petrolisthes magnus* Müller, 1984, *Pilodius vulgaris* (Glaessner, 1928), *Pilumnus mediterraneus* (Lőrenthey,1897), and *Xantho moldavicus* (Janakevich, 1977), is typical of the entire range of the Medobory Hills (see Górka *et al*. 2012; also Janakevich 1969a, 1977).

In the Fore-Carpathian Basin, crustaceans became a quite reliable tool in palaeoenvironmental studies. Their taxonomic diversity is evidence of open-marine conditions during (and shortly after) the Early Badenian transgression. It becomes obvious that the salinity crisis, which started in the early Late Badenian (see Peryt 2006a; Studencka *et al*. 1998; Studencka and Jasionowski 2011; Śliwiński *et al*. 2012) wiped out the crustaceans from the basin. After their re-appearance in the latest Badenian, during the deposition of the Ternopil Beds (Müller 1996; Górka 2006; Radwański *et al*. 2006; Ósso and Stalennuy 2011), they finally disappeared due to the decisive environmental changes at the Badenian/Sarmatian boundary (Studencka and Jasionowski 2011; Górka *et al*. 2012).

Miocene Echinodermata of Poland (U. Radwańska)

The Echinodermata are relatively common in the Middle Miocene of the Polish part of the Fore-Carpathian Basin and are represented by five classes: Holothurioidea, Crinoidea, Asteroidea, Echinoidea, and Ophiuroidea (not described yet).

The most diversified echinoderms are known from the Korytnica Clays (e.g., Mączyńska 1977, 1987; Walkiewicz 1977a; Kaczmarska 1987; Radwańska 1987; Ceranka 2007a), of the Korytnica Basin, and from the sands of Nawodzice (Bałuk and Radwański

Text-fig. 14. Crustaceans from the Badenian of southern Poland and western Ukraine. **A** – Two specimens of the cirripede *Creusia* sp., top view (Stratyn, UA), MWGUW ZI/79/138, × 5; **B** – *Dardanus hungaricus* (Lőrenthey, 1929), fragment of right propodus, oblique-lateral view (Grobie, PL), MWGUW ZI/81/012, × 5; **C** – *Petrolisthes magnus* Müller, 1984, left palm with dactylus: a – inner surface, b – outer surface (Sakhkamin, UA); MWGUW ZI/79/051, both × 1.5; **D** – *Daira speciosa* (Reuss, 1871), carapace, dorsal view (Maksymivka, UA), MWGUW ZI/79/049, × 2.5; **E** – *Pilumnus mediterraneus* (Lőrenthey, 1897), carapace, dorsal view (Maksymivka, UA), MWGUW ZI/52/039, × 2.5; **F** – *Xantho moldavicus* (Janakevich, 1977); large carapace (Maksymivka, UA), MWGUW ZI/79/043, × 2.5; **G** – *Xantho moldavicus* (Janakevich, 1977); right chela and carpus, inner view (Haluschyntsi, UA), MWGUW ZI/79/019, × 2.5

1968; Nosowska 1997) and Świniary of the Raków-Klimontów area (Radwański 1973; Mączyńska 1988; Radwański and Wysocka 2004; Ceranka 2007a) on the southern slopes of the Holy Cross Mts.

Holothurioidea: Holothurian sclerites have only been described from the Korytnica Clays (Walkiewicz 1977a). The assemblage comprises 32 forms belonging to the Stichopitidae, Calclamnidae, Theeliidae, and Synaptitidae. The indirect proof of the presence of free moving holothurians in the Korytnica Clays are the otoliths of fishes of the family Carapidae (Radwańska 1992), which, in the majority, are commensals to these holothurians. Sclerites with a circular outline (Theeliidae, Synaptitidae) recognised in the Korytnica Clays should be ascribed to burrowing holothurians, whereas sclerites developed as perforated plates (Calclamnidae) and elongated perforated rods (Stichopitidae) presumably belong to free moving species (Walkiewicz 1977a).

Free-living crinoids: The free-living crinoids have been described from Pińczów (Radwański 1977), Łagiewniki near Busko (Tasakowski 2013), and Korytnica (Radwańska 1987, 2003). In the "Leithakalke" type limestones at Pińczów only one centrodorsal with a radial ring of *Discometra rhodanica* (Fontannes, 1879) has hitherto been reported by Radwański (1977). The relatively rich assemblage of free living crinoids (Text-fig. 15) of the order Comatulida A.H. Clark, 1908, was described from the littoral facies of the Korytnica Basin (Radwańska 1987). This assemblage comprises *Sievertsella polonica* (Radwańska, 1987) of the family Comasteridae A.H. Clark, 1908 (Text-Fig. 1/1a–1c), and members of the family Himerometridae A.H. Clark, 1908; *S. polonica* was also described from Łagiewniki (Tasakowski 2013).

All recent genera of the subfamily Comasterinae and the family Himerometridae, are regarded as subtropical and tropical (Clark 1931), with both recent and
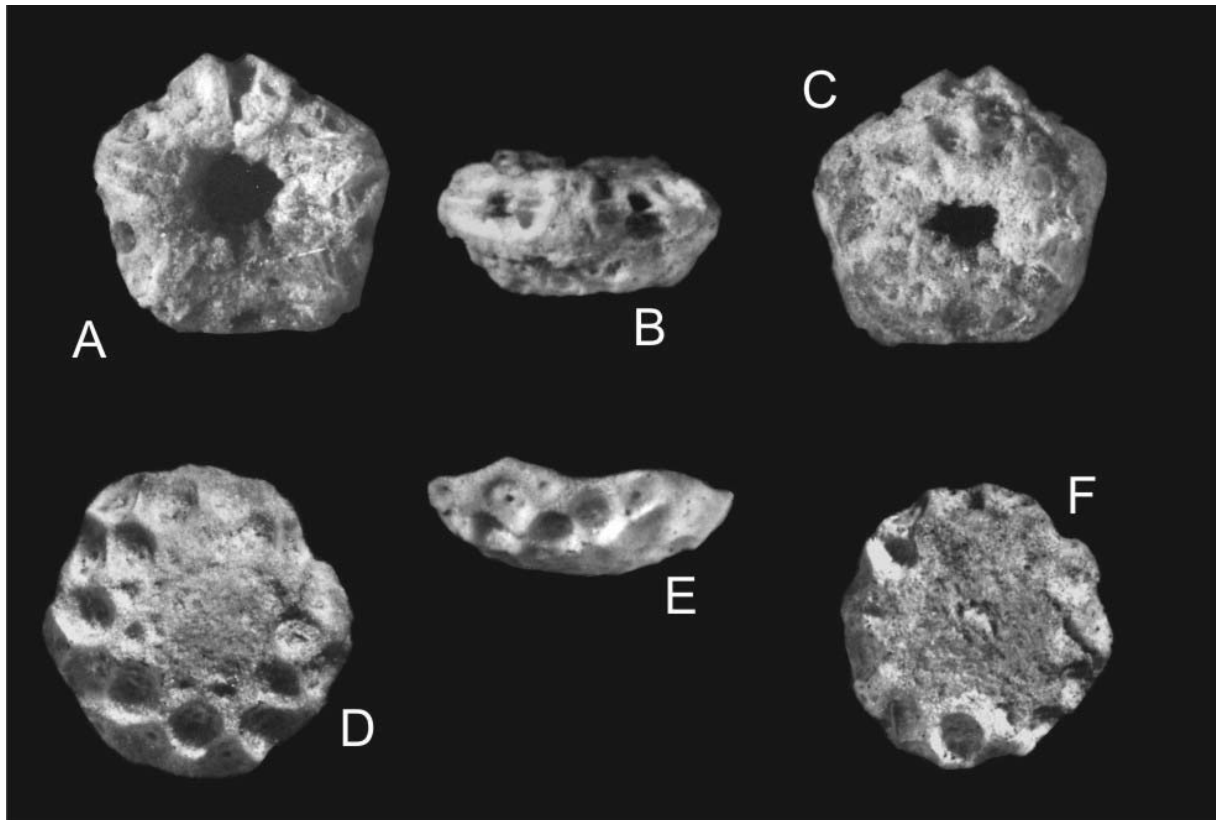
Text-fig. 15. Middle Miocene (Badenian) free-living crinoid *Sievertsella polonica* (Radwańska 1987) from the Korytnica Clays. Holotype, centrodorsal with radial ring (**A** – ventral, **B** – lateral, **C** – dorsal view), A-C is MWGUW ZI/56/330; Paratypes, centrodorsals (**D, E** – dorsal views, D is MWGUW ZI/56/331, E is MWGUW ZI/56/332, **F** – lateral view of MWGUW ZI/56/333). Photographs by L. Łuszczewska

Text-fig. 16. Middle Miocene Asteroids from the Nawodzice Sands. **A-C** – *Astropecten navodicensis* Nosowska, 1997; **A, B** specimen with aborally bent arms, nearly a tulip-like form (**A** – lateral view of the arms, **B** – oral view of the disc), MWGUW ZI/56/334 ; **C** – specimen with outspread arms, aboral view; MWGUW ZI/56/335; × 3; **D-F** – *Ceramaster polonicus* Nosowska, 1997; **D** – **holotype**, aboral view of the specimen with outspread arms, × 3; E – fragment of the arm of MWGUW ZI/56/336; × 2; **F** – abactinal ossicles (**F1** – oral view, **F2** – lateral view) of MWGUW ZI/56/337; × 10. Photographs by E. Nosowska
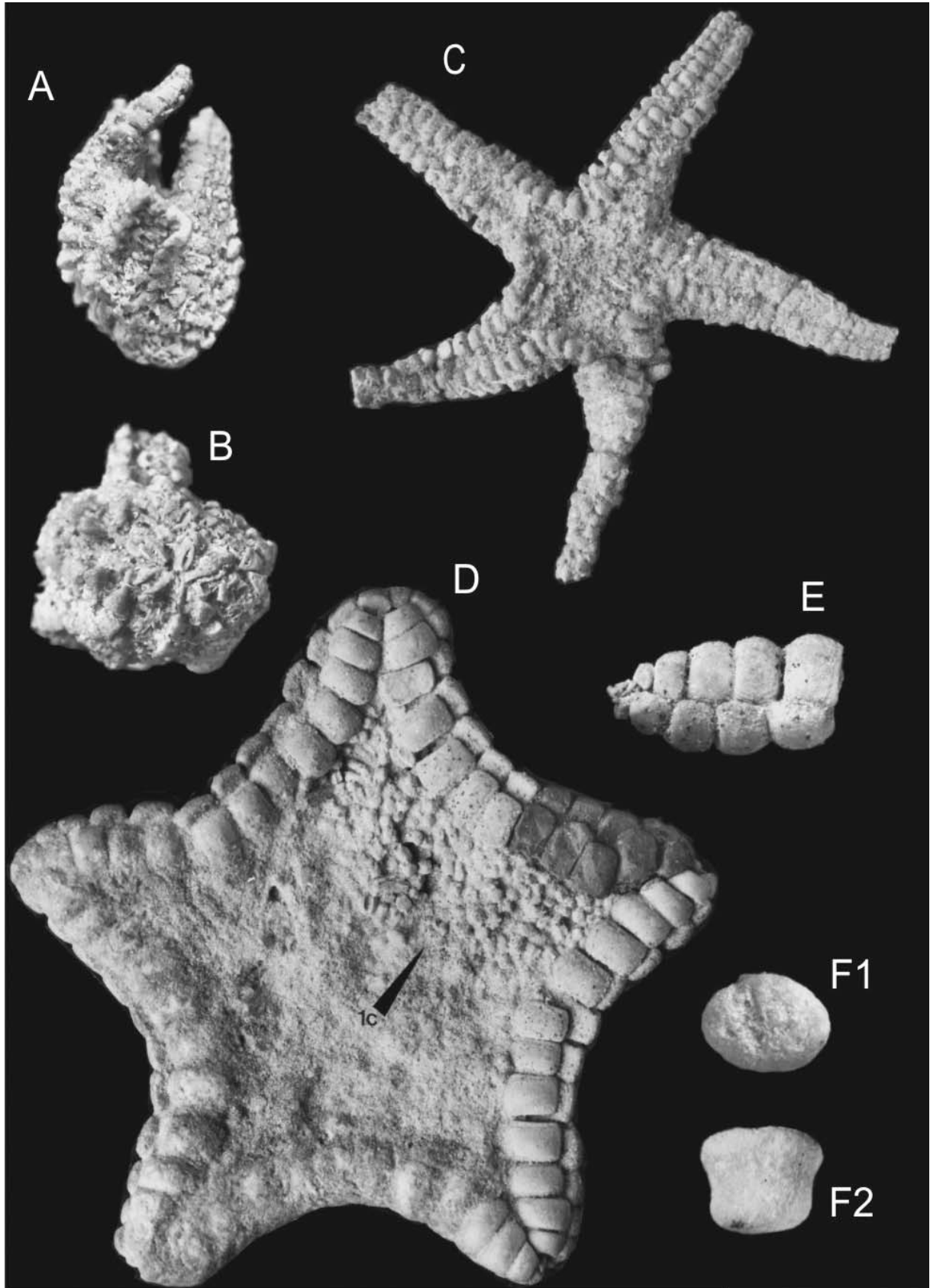
fossil representatives of these groups (Clark 1931; de Castro Manso and Souza-Lima 2017) confined to the Indo-Pacific realm. This general statement matches well the hitherto recognised tropical and/or subtropical conditions prevailing during the Middle Miocene (Badenian) development of the Korytnica Basin (e.g., Bałuk and Radwański 1977, 1979; Radwańska and Radwański 1984).

Asteroidea: Asteroids are relatively common in the Middle Miocene of the Fore-Carpathian Basin. They were reported from Nawodzice (Bałuk and Radwański 1968; Nosowska 1997), Świniary (Radwański 1973; Radwański and Wysocka 2004), Korytnica (e.g., Kowalewski 1927; Bałuk and Radwański 1977; Kaczmarska 1987), and from Niskowa near Nowy Sącz (Bałuk 1970). Most of the asteroids (Text-fig. 16) are represented by isolated ossicles (see Kaczmarska 1987; Nosowska 1997), but entirely preserved skeletons (*Astropecten navodicensis* Nosowska, 1997 and *Ceramaster polonicus* Nosowska, 1997) have been reported from Nawodzice (see Bałuk and Radwański 1968; Radwański 1973; Nosowska 1997), and interpreted as being buried in life position (Bałuk and Radwański 1968).

The assemblages (Kaczmarska 1987; Nosowska 1997) described from the Nawodzice Sands and the Korytnica Clays compare well with the environmental conditions recognised in the Middle Miocene (Badenian) area, typified by shallow, open-marine, and/or subtropical waters, and show certain affinities to the recent asteroid fauna of the Indo-Pacific area.

Echinoidea: Echinoids (Text-fig. 17) represent the most diversified and numerous group of Echinodermata recognised from the Middle Miocene of the Fore-Carpathian Basin. They were first reported by Roemer (1870), and subsequently studied by Kowalewski (1930), Radwański (1973), Bałuk (1975), Mączyńska (1977, 1979, 1987, 1988, 1993, 1996), and Ceranka (2007a).

In the rich material, consisting of over 37,000 complete tests and almost 10,000 fragments, Ceranka (2007a) recognized 20 species of 16 genera, 11 families and 7 orders. The assemblage is dominated by irregular forms of the genera *Clypeaster* Lamarck, 1801 and *Echinocyamus* van Phelsum, 1774, of the order Clypeasteroida. Fairly common are representatives of the order Spatangoida, such as *Schizaster* L. Agassiz, 1835 and *Spatangus* Gray, 1825. Among regular forms, the commonest are the Cidaroida, of the genus *Eucidaris* Pomel, 1883, and Echinoida, of the genera *Tripneustes* L. Agassiz, 1841, *Schizechinus* L. Agassiz, 1841, and *Psammechinus* L. Agassiz et Desor, 1846.

Among all echinoid localities, noteworthy is the Świniary locality (see Radwański and Wysocka 2004), with its echinoid species *Psammechinus dubius* (L. Agassiz, 1840) occurring gregariously (Text-fig. 17E) preserving spine canopies and Aristotle's lanterns in position. All echinoids were jumbled together in haphazard positions, some of them inverted on the sole, showing that some were dead, but others still alive, when the layer was deposited (see Radwański and Wysocka 2004, text-fig. 5). Such taphonomic premises indicate that the echinoids were transported in a huge mass of sand, from which live specimens could escape only occasionally (Radwański and Wysocka 2004).

The Middle Miocene echinoids of the Fore-Carpathian Basin comprises widely distributed forms. Their ecological requirements (particularly the occurrence of the genera *Clypeaster* and *Echinolampas*) indicate warmer seas, including the tropical zone, and well-marked affinities with the Indo-Pacific bioprovince.

### Miocene Echinodermata of Ukraine (M. Górka)

The first notes on Ukrainian echinoderms were by Niedźwiedzki (1879), Hilber (1882) and Łomnicki (1897, 1898). More serious studies started later, in the 1950s, on the echinoids by Szörényi (1953) and the asteroids by Kudrin (1957). More recently, Ukrainian echinoderms were studied by Radwański and Wysocka (2001), Kroh (2005), Radwański *et al.* (2006), Górka *et al.* (2012), and Wysocka *et al.* (2012), and a monographic description of the group was published by Radwański *et al.* (2014).

The Lower Badenian sandy deposits of the Mykolaiv Beds have yielded the most ubiquitous assemblage of echinoderms from western Ukraine. This facies is distributed in the vicinity of Lviv (see Wysocka 2002) and stretches to the south as far as the Dnister valley and to the east where it reaches the town of Pere-

Text-fig. 17. Middle Miocene Echinoids from the Holy Cross Mountains and Roztocze. **A–C** – *Eucidaris zeamays* (Sismonda, 1842); **A** – primary spin of MWGUW Pi/004, Pińczów; **B** – fragment with preserved interambulacral and ambulacral columns, of MWGUW Szcz/001, Szczaworyż; **C** – fragment with preserved ambulacral column of MWGUW Pi/037; **D** – *Trigonocidaris albida* A. Agassiz, 1869 (D1 – aboral view, D2 – lateral view) of MWGUW Ka/002, Pińczów; **E** – *Psammechinus dubius* (L. Agassiz, 1840) (E1 – aboral view, E2 – oral view) of MWGUW Sw/001, Świniary; **F** – *Schizechinus hungaricus* (Laube, 1869) (F1 – lateral view, F2 – aboral view), MWGUW M/001, Monastyrz; **G** – *Echinocyamus pusillus* Müller, 1776 (G1 – aboral view, G2 – oral view, G3 – lateral view, G4 – close-up view, to show apical disc) of MWGUW KI/048, Korytnica; **H** – *Echinocyamus calariensis* (Lambert, 1097) (H1 – aboral view, H2 – oral view, H3 – lateral view) of MWGUW KI/049, Korytnica; **I** – *Spatangus* sp. (I1 – aboral view, I2 – oral view) of MWGUW Sw/045, Świniary; **J** – *Clypeaster scillae* des Moulins, 1837, aboral view of MWGUW Pi/058, Pińczów. Photographs by T. Ceranka
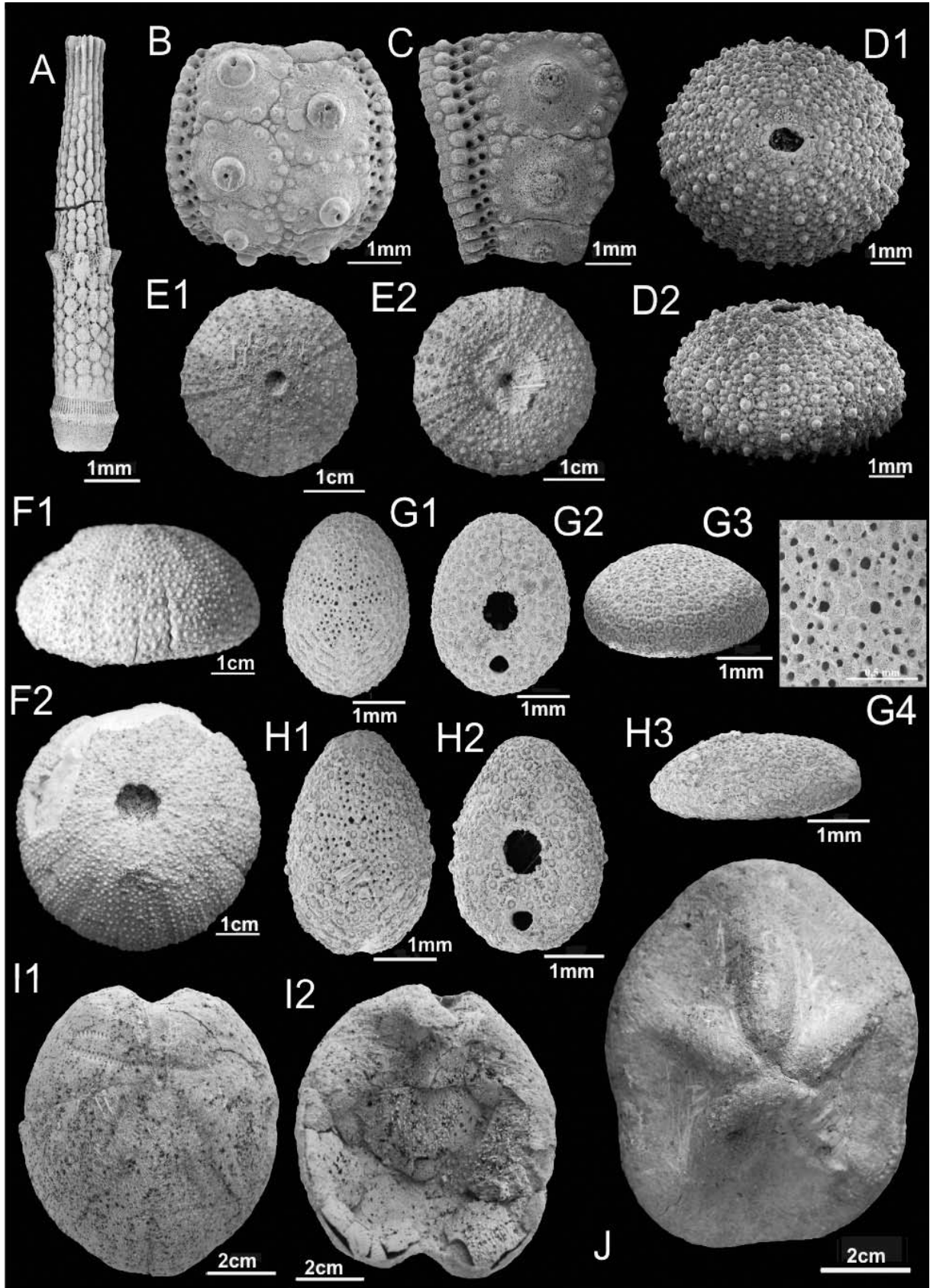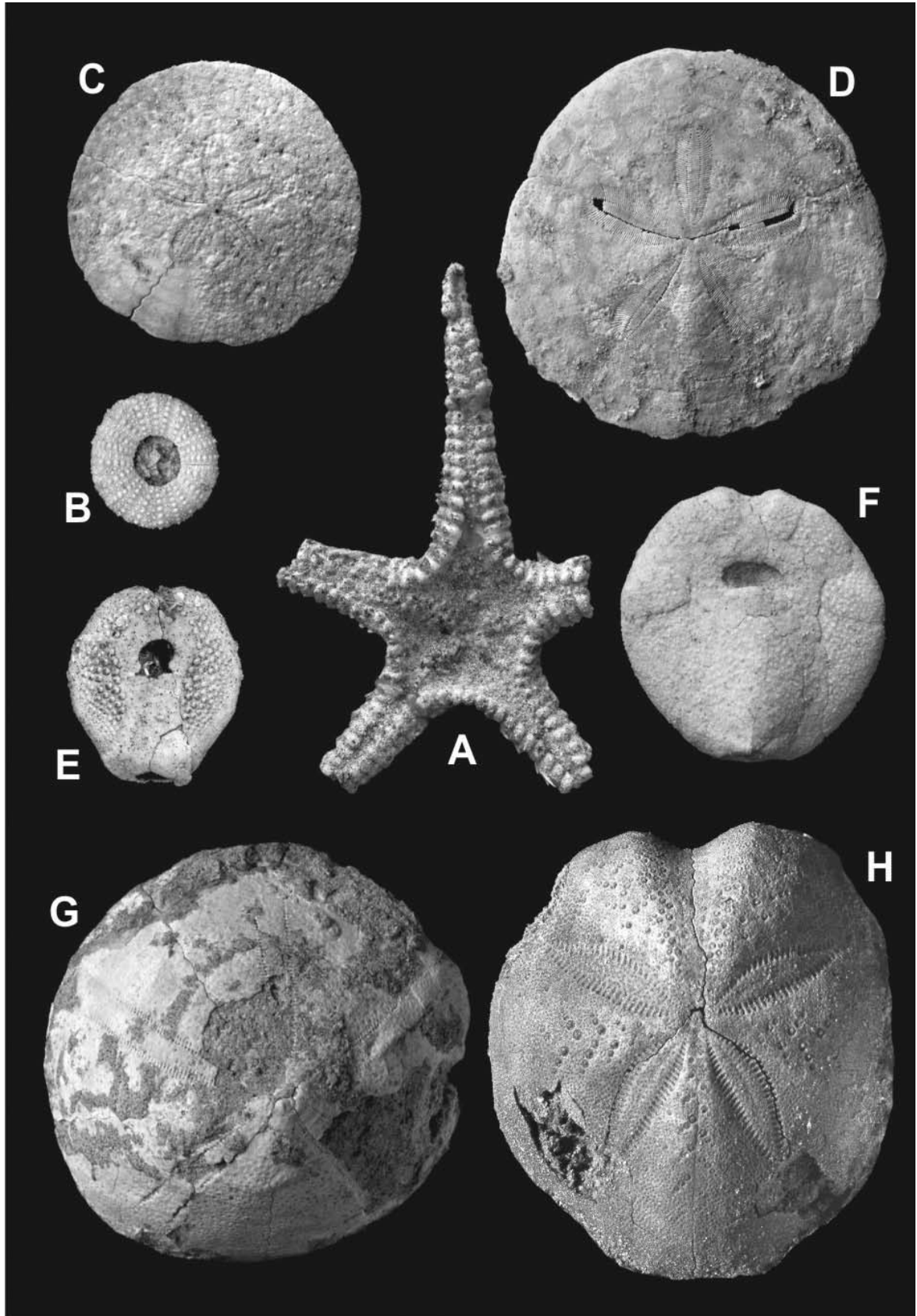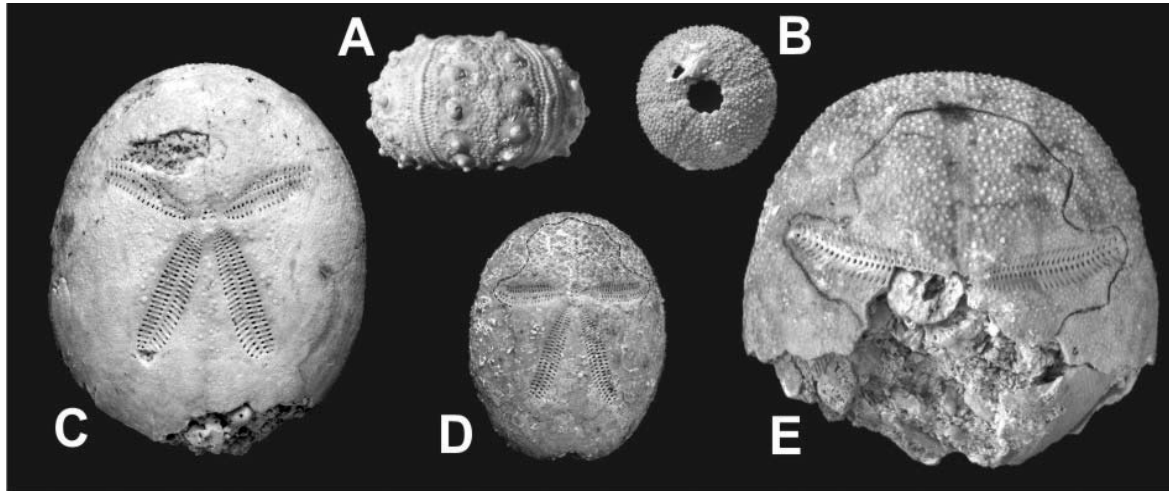
Text-fig. 19. Echinoids from the biohermal facies of Ternopil Beds, Ukraine. **A** – *Eucidaris desmoulinsi* (Sismonda, 1842), side view (Humentsi) of MWGUW ZI/55/006; **B** – *Arbacina* cf. *catenata* (Desor in L. Agassiz and Desor, 1846), aboral view (Maksymivka) of MWGUW ZI/55/024; **C** – *Rhabdobrissus tarnopolensis* Radwański *et al*. 2014, aboral view (Maksymivka) of MWGUW ZI/55/027 (holotype); **D** – *Brissus unicolor* (Leske, 1778), young specimen, aboral view, peripetalous fasciole marked (Maksymivka) of MWGUW ZI/55/039b; **E** – *Brissus unicolor* (Leske, 1778), anterior part of an old specimen (Verbka) of MWGUW ZI/55/049. All specimens are natural size. Pphotographs by M. Nowak.

myshlany (Radwański *et al.* 2012; Wysocka *et al.* 2012). Recorded echinoderms comprise 12 echinoid species and a single species of starfish (Radwański *et al*. 2014).

The Upper Badenian Ternopil Beds are the second echinoid-bearing lithofacies of western Ukraine. Four echinoid species were described from the biohermal (reefal) limestones of this unit, and two species from the biodetrital unit. The same two species are present also in the topmost part of the coeval Pidhirtsi Beds (see Radwański *et al.* 2014).

Starfish: Only one species of starfish, *Astropecten forbesi* Heller, 1858, has been recorded from the My-kolaiv Beds. Although a few relatively well preserved specimens have been collected (Text-fig. 18A), larger remains of starfish, excepting isolated ossicles, are relatively rare (Radwański *et al.* 2014).

Echinoids: The taxonomic composition of the echinoid assemblage is closely related to the facies and age of the investigated strata. The assemblage from the Mykolaiv Beds is dominated by "irregular" echinoids (Text-fig. 18), with 10 species recognised: *Parascutella* cf. *paulensis* (L. Agassiz, 1841), *Parmulechinus* sp., *Echino-*

cyamus sp., *Clypeaster* sp., *Echinolampas* sp*., Conolampas* sp., *Spatangus* cf. *austriacus* Laube, 1871, *Hemipatangus ocellatus* (Defrance, 1827), *Echinocardium leopolitanum* Radwański and Wysocka, 2001, and *Brissus* sp. These taxa are accompanied by 2 "regular" sea urchins: *Stylocidaris*? *polyacantha* (Reuss, 1860) and *Psammechinus dubius* (L. Agassiz, 1840).

On the contrary, the ratio between irregular and regular echinoids is more balanced in the Upper Badenian biohermal Ternopil Beds (Text-fig. 19), in which *Brissus unicolor* (Leske, 1778) and *Rhabdobrissus tarnopolensis* Radwański *et al*., 2014 co-occur with "regular" *Eucidaris desmoulinsi* (Sismonda, 1842) and *Arbacina catenata* (Desor *in* L. Agassiz and Desor, 1846). Only two species have been recorded in the organodetrital Ternopil Beds and in the Pidhirtsi Beds: *Parascutella gibbercula* (De Serres, 1829) and *Spatangus* cf. *austriacus* Laube, 1871.

Fish otoliths [U. Radwańska]

Fish otoliths from the Middle Miocene of southern Poland were reported by Friedberg (1924), then by Chaine and Duvergier (1928), and Kowalewski (1930). Taxonomic studies were later performed by Śmigielska

Text-fig. 18. Echinoderms from the sandy and organodetrital Badenian deposits of western Ukraine. **A** – *Astropecten forbesi* Heller, 1858, Gleboviti, MWGUW ZI/55/139; **B** – *Psammechinus dubius* (L. Agassiz, 1840), oral view (Swirzh) of MWGUW ZI/55/094; **C** – *Parmulechinus* sp.nov., aboral view (Pukiv), of MWGUW ZI/55/110a; **D** – *Parascutella gibbercula* (De Serres, 1829), aboral view (Zalistsi), of MWGUW ZI/55/115; **E** – *Hemipatagus ocellatus* (Defrance, 1827), oral view (Khorosno) of MWGUW ZI/55/068; **F** – *Echinocardium leopolitanum* Radwański and Wysocka, 2001, oral view (Gleboviti), of MWGUW ZI/55/127a; **G** – *Conolampas* sp., aboral view (Vybranivka), of MWGUW ZI/55/106; **H** – *Spatangus* cf. *austriacus* Laube, 1871, aboral view (Bridok), of MWGUW ZI/55/104. All specimens are natural size. Photographs A-B, E-F by M. Nowak.
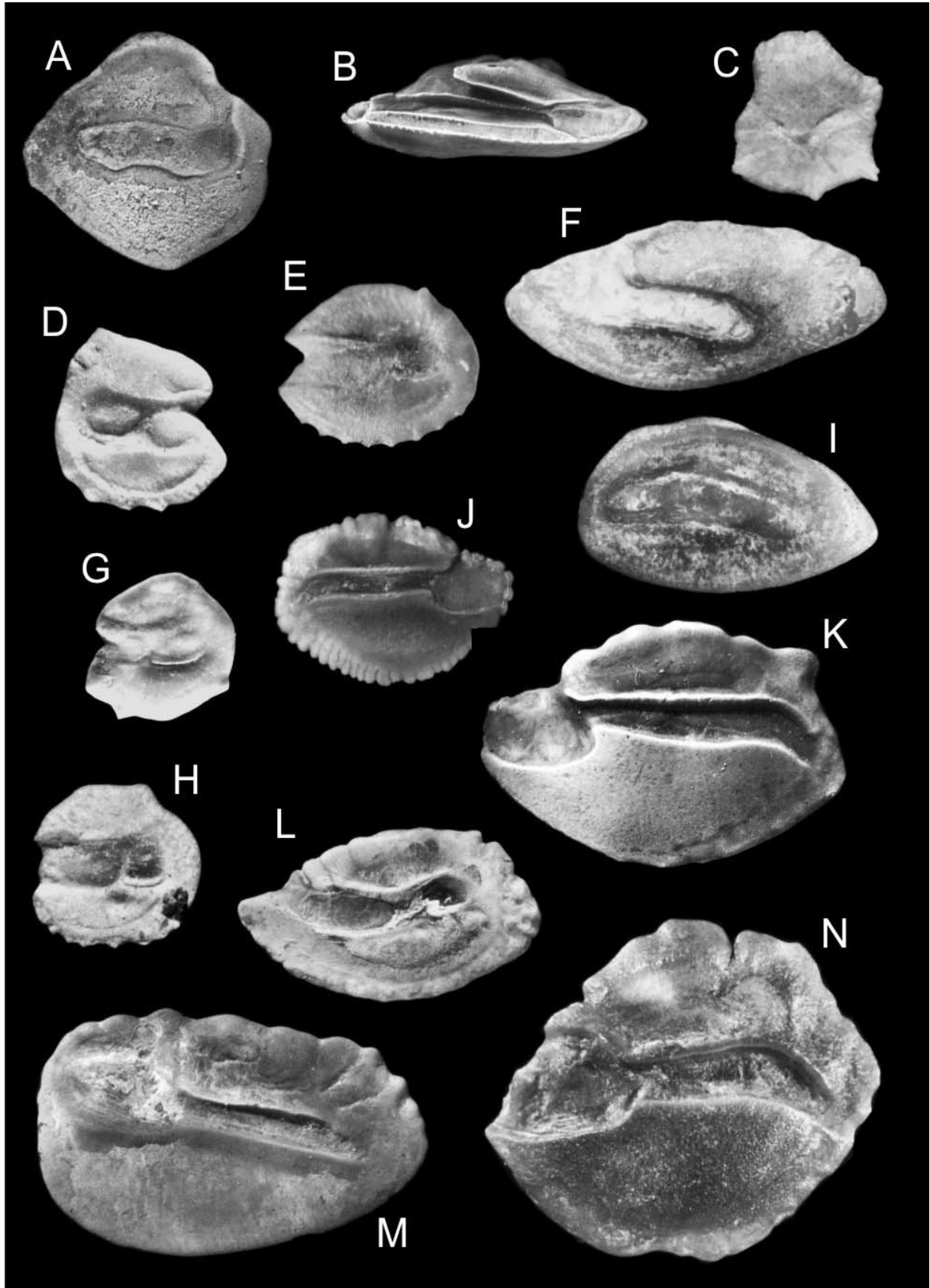
(1966, 1973, 1979), and more detailed research has been undertaken by Radwańska (1984, 1992).

All fish otoliths (Text-fig. 20) from the Middle Miocene of southern Poland belong to the teleosts. Of the three types of paired (left and right) otoliths present in teleost fishes, all but one specimen of the investigated material represent the saccular otoliths, i.e., the sagittae. Radwańska (1992) monographed 147 species representing 50 families. Among the recognised families, the Myctophidae and Sparidae are characterised by high taxonomic diversity (14 species). The Congridae, Gadidae, Crapidae, Triglidae, and Gobiidae are represented by at least 5 species. The total number of otolith specimens exceeds 22,600.

Taxonomically the richest otolith assemblage comes from the Korytnica Basin (Text-fig. 20), where it is represented by 105 species of 47 families (Radwańska 1992), with the majority of species confined to the littoral zone. Noteworthy in the assemblage are ubiquitous fish otoliths of the family Gobiidae Bonaparte, 1832. They were found together with tiny claws, which have recently been reported by Karasawa *et al*. (2014) as those representing the shrimp family Alpheidae Rafinesque, 1815. This co-occurrence suggests a commensal relationship of gobies with snapping shrimps. The second important group in the Korytnica Basin is the family Pomadasyidae, and primarily the species *Brachydeuterus latior* (Schubert, 1906), which is the most numerous (over 3,300 specimens) taxon recognised in the assemblage. This species is an important environmental indicator suggesting tropical and subtropical littoral zones, and tolerant also of nearshore brackish waters (Radwańska 1992). The Korytnica assemblage comprises also other tropical elements, such as otoliths of fishes of the genera *Adioryx* and *Myripristis*, and many others (Radwańska 1992). Otoliths of genera typical of the Indo-Pacific bioprovince, such as *Hoplobrotula*, *Centroberyx*, *Platycephalus*, and *Sillago* also occur. Finally, of importance is the presence of the otoliths of fishes of the family Carapidae, which in the majority are commensals to the holothurians, in the intestines of which they live. The presence of holothurians in the Korytnica Clays was recognised earlier based on isolated sclerites (Walkiewicz 1977a).

The otolith assemblage from Nawodzice is relatively poor, both regarding its abundance and taxonomic diversity (10 species from 7 families). Nawodzice represents an extremely shallow-marine basin, evidently too shallow to be a permanent habitat of any fishes.

Relatively rich is the otolith assemblage from Rybnica (4,106 specimens), although it is taxonomically poorly diversified (33 species of 18 families). The most abundant is the family Gadidae. The ecological requirements of the assemblages from Nawodzice and Rybnica indicate the dominance of otoliths, which belonged to fishes that inhabited littoral waters with a normal salinity, but all the taxa recognised are much tolerant of thermal conditions, and thus cannot give precise information about the climate.

The otolith assemblage representing the deepest setting among the localities studied is the one from Bęczyn. It is a rather monotonous assemblage dominated by otoliths of the fishes of the family Myctophidae, which live currently mainly in warm, open oceanic waters.

Otolith assemblages have been described also from the Łychów area and from Niskowa, representing, however, rather poorly diversified faunas.

Acknowledgements

REFERENCES

Aleksenko, I.I. 1967. Sulphur of the Fore-Carpathians, pp. 1–304. Nedra; Moscow. [In Russian]

Alexandrowicz, S.W. and Krach, W. 1963. Dolny torton w Przeciszowie koło Oświęcimia. *Annales Societatis Geologorum Poloniae*, **33**, 493–515.

Alexandrowicz, S.W., Garlicki, A. and Rutkowski, J. 1982.

Podstawowe jednostki lito- stratygraficzne miocenu zapadliska przedkarpackiego. *Geological Quarterly*, **26**, 470–471.

Allwood, A.C., Burch, W., Rouchy, J.M. and Coleman, M. 2013. Morphological biosignatures in gypsum: diverse formation processes of Messinian (~6.0 Ma) gypsum stromatolites. *Astrobiology*, **13**, 870–886.

Alth, A. 1850. Geognostisch-paläontologische Beschreibung der nächsten Umgebung von Lemberg. *Haidingers Naturwissenschaften*, **3**, 171–279.

Alth, A. and Bieniasz, F. 1887. Atlas Geologiczny Galicyi. Tekst do zeszytu 1, pp. 1–79. Komisya Fizyograficzna Akademii Umiejętności; Kraków.

Andreyeva-Grigorovich, A. S., Oszczypko, N., Ślączka, A., Oszczypko-Clowes, M., Savitskaya, N. and Trofimovicz, N. 2008. New data on the stratigraphy of the folded Miocene Zone at the front of the Ukrainian Outer Carpathians. *Acta Geologica Polonica*, **58**, 323–353.

Anistratenko, V. 2009. A new rissoid gastropod with lecithotrophic development from the Miocene of Paratethys. *Acta Geologica Polonica*, **59**, 261–267.

Areń, B. 1959. Results of researches on the Roztocze Lubelskie (Lublin Upland). *Przegląd Geologiczny*, **7**, 10–14. [In Polish, with English summary]

Bałuk, W. 1965. Chitons from the Tortonian of the Nowy Sącz Depression. *Acta Palaeontologica Polonica*, **10**, 365–378.

Bałuk, W. 1966. Neogene sediments in the Nowy Sącz depression (External Carpathians) and their palaeographical significance. *Bulletin de l'Académie Polonaise des Sciences*, **14**, 181–186.

Bałuk, W. 1970. The Lower Tortonian at Niskowa near Nowy Sącz, Polish Carpathians. *Acta Geologica Polonica*, **20**, 101–157.

Bałuk, W. 1971. Lower Tortonian chitons from the Korytnica Clays, southern slopes of the Holy Cross Mountains. *Acta Geologica Polonica*, **21**, 449–472.

Bałuk, W. 1972. Lower Tortonian scaphopods from the Korytnica Clays, southern slopes of the Holy Cross Mts. *Acta Geologica Polonica*, **22**, 545–571.

Bałuk, W. 1974. Lower Tortonian gastropods from Korytnica (Poland). *Palaeontologica Polonica*, **32**, 1–182.

Bałuk, W. 1975. Lower Tortonian gastropods from Korytnica, Poland; Part. 1. *Palaeontologica Polonica*, **32**, 1–186.

Bałuk, W. 1977. A new species of the cuttlefish from the Korytnica Clays (Middle Miocene; Holy Cross Mountains, Poland). *Acta Geologica Polonica*, **27**, 167–176.

Bałuk, W. 1984. Additional data on chitons and cuttlefish from the Korytnica Clays (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **34**, 281–297.

Bałuk, W. 1995. Middle Miocene (Badenian) Gastropods from Korytnica, Poland; Part II. *Acta Geologica Polonica*, **45**, 1–153.

Bałuk, W. 1997. Middle Miocene (Badenian) Gastropods from Korytnica, Poland; Part III. *Acta Geologica Polonica*, **47**, 1–75.

Bałuk, W. 2003. Middle Miocene (Badenian) Gastropods from Korytnica, Poland; Part IV – Turridae. *Acta Geologica Polonica*, **53**, 29–78.

Bałuk, W. 2006. Middle Miocene gastropods from Korytnica, Poland: Part V. Addenda et Corrigenda ad Prosobranchia. *Acta Geologica Polonica*, **56**, 177–218.

Bałuk, W. and Jakubowski, G. 1968. *Berthelinia krachii* n. sp., a new bivalved gastropod from the Miocene of Poland. *Acta Palaeontologica Polonica*, **13**, 291–302.

Bałuk, W. and Radwański, A. 1967. Miocene cirripeds domiciled in corals. *Acta Palaeontologica Polonica*, **12**, 457–521.

Bałuk, W. and Radwański, A. 1968. Lower Tortonian sands at Nawodzice (southern slopes of the Holy Cross Mts.), their fauna and facial development. *Acta Geologica Polonica*, **18**, 447–471. [In Polish, with English summary]

Bałuk, W. and Radwański, A. 1977. Organic communities and facies development of the Korytnica Basin (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **27**, 85–123.

Bałuk, W. and Radwański, A. 1979. Additional data on the organic communities and facies development of the Korytnica basin (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **29**, 225–238.

Bałuk, W. and Radwański, A. 1984a. Creusoid cirripedes from the Korytnica Clays (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **34**, 271–279.

Bałuk, W. and Radwański, A. 1984b. New data on the Korytnica Basin, its organic communities and ecological relationships between species (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **34**, 179–194.

Bałuk, W. and Radwański, A. 1991. A new occurrence of the fossil acrothoracican cirripedes: *Trypetesa polonica* sp.n. in hermitted gastropod shells from the Korytnica Basin (Middle Miocene; Holy Cross Mountains, Central Poland), and its bearing on behavioural evolution of the genus *Trypetesa*. *Acta Geologica Polonica*, **41**, 1–36.

Bałuk, W. and Radwański, A. 1996. Stomatopod predation upon gastropods from the Korytnica Basin, and from other classical Miocene localities in Europe. *Acta Geologica Polonica*, **46**, 279–304.

Bałuk, W. and Radwański, A. 1997. The micropolychaete *Josephella commensalis* sp.n. commensal to the scleractinian coral *Tarbellastraea* reussiana (Milne-Edwards and

Haime, 1850) from the Korytnica Clays (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, 47, 211–224.

Bąbel, M. 1986. Growth of crystals and sedimentary structures in the sabre-like gypsum (Miocene, southern Poland). *Przegląd Geologiczny*, **34**, 204–208. [In Polish, with English summary]

Bąbel, M. 1987. Giant gypsum intergrowths from the Middle Miocene evaporites of southern Poland. *Acta Geologica Polonica*, **37**, 1–20.

Bąbel, M. 1991. Crystallography and genesis of the giant intergrowths of gypsum from the Miocene evaporites of Poland. *Archiwum Mineralogiczne*, **44**, 103–135. [for 1990]

Bąbel, M. 1996. Wykształcenie facjalne, stratygrafia oraz sedymentacja badeńskich gipsów Ponidzia. In: P.H. Karnkowski (Ed.), Analiza basenów sedymentacyjnych a nowoczesna sedymentologia. Materiały 5 Krajowego Spotkania Sedymentologów, p. B1-B26. Warszawa.

Bąbel, M. 1999a. Facies and depositional environments of the Nida Gypsum deposits (Middle Miocene, Carpathian Foredeep, southern Poland). *Geological Quarterly*, **43**, 405–428.

Bąbel, M. 1999b. History of sedimentation of the Nida Gypsum deposits (Middle Miocene, Carpathian Foredeep, southern Poland). *Geological Quarterly*, **43**, 429–447.

Bąbel, M. 2002a. The largest natural crystal in Poland. *Acta Geologica Polonica*, **52**, 251–267.

Bąbel, M. 2002b. Brine palaeocurrent analysis based on oriented selenite crystals in the Nida Gypsum deposits (Badenian, southern Poland). *Geological Quarterly*, **46**, 49–62.

Bąbel, M. 2004a. Models for evaporite, selenite and gypsum microbialite deposition in ancient saline basins. *Acta Geologica Polonica*, **54**, 219–249.

Bąbel, M. 2004b. Badenian evaporite basin of the northern Carpathian Foredeep as a drawdown salina basin. *Acta Geologica Polonica*, **54**, 313–337.

Bąbel, M. 2005a. Selenite-gypsum microbialite facies and sedimentary evolution of the Badenian evaporite basin of the northern Carpathian Foredeep. *Acta Geologica Polonica*, **55**, 187–210.

Bąbel, M., 2005b. Event stratigraphy of the Badenian selenite evaporites (Middle Miocene) of the northern Carpathian Foredeep. *Acta Geologica Polonica*, **55**, 9-29. (with On-Line Appendix)

Bąbel, M. 2007a. Gypsum domes in the karst relief of Ponidzie region, southern Poland. *Prace Instytutu Geografii Akademii Świętokrzyskiej w Kielcach*, **16**, 71–89. [In Polish with Engish summary]

Bąbel, M. 2007b. Depositional environments of a salina-type evaporite basin recorded in the Badenian gypsum facies in the northern Carpathian Foredeep. In: B.C. Schreiber, S. Lugli and M. Bąbel (Eds), Evaporites Through Space and Time. *Geological Society, London, Special Publications*, **285**, 107–142.

Bąbel, M. and Becker, A, 2006. Cyclonic brine-flow pattern recorded by oriented gypsum crystals in the Badenian evaporite basin of the northern Carpathian Foredeep. *Journal of Sedimentary Research*, **76**, 996–1011.

Bąbel, M. and Bogucki, A. 2007. The Badenian evaporite basin of the northern Carpathian Foredeep as a model of a meromictic selenite basin. In: Schreiber B. C., Lugli S. and Bąbel M. (Eds), Evaporites Through Space and Time. *Geological Society, London, Special Publications*, **285**, 219–246.

Bąbel M. and Kasprzyk A. 1990. Gypsum ooids from the Middle Miocene (Badenian) evaporites of southern Poland. *Acta Geologica Polonica*, **40**, 215–239.

Bąbel, M., Boguckiy, A., Vizna, S. and Yatsyshyn, A. 1999. Reconstruction of brine paleocurrents in the Middle Miocene evaporitic basin of the Carpathian Foredeep. *Biuletyn Państwowego Instytutu Geologicznego*, **387**, 12–13.

Bąbel, M., Olszewska-Nejbert, D. and Bogucki, A. 2011. Gypsum microbialite domes shaped by brine currents from the Badenian evaporites of western Ukraine. In: Reitner J., Quéric N.-V. and Arp G. (Eds), Advances in Stromatolite Geobiology. *Lecture Notes in Earth Sciences*, **131**, 297–320.

Bąbel M., Olszewska-Nejbert, D. and Nejbert, K. 2010. The largest giant gypsum intergrowths from the Badenian (Middle Miocene) evaporites of the Carpathian Foredeep. *Geological Quarterly*, **54**, 477–486.

Bąbel, M., Olszewska-Nejbert, D., Nejbert, K. and Ługowski, D. 2015. The Badenian evaporative stage of the Polish Carpathian Foredeep: sedimentary facies and depositional environment of the selenitic Nida Gypsum succession. In: G. Haczewski (Ed.), Guidebook for field trips accompanying IAS 31st Meeting of Sedimentology held in Kraków on 22nd–25th of June 2015. Kraków, pp. 25–50.

Bianchi, C.N. 1981. Policheti Serpuloidei. Consiglio Nazionale delle Ricerche; Guide per il riconoscimento delle specie animali delle acque lagunari e costiere italiane, **5**, 1–187. Genova.

Bojanowski, M., Jaroszewicz, E., Košir, A., Łoziński, M., Marynowski, L., Wysocka, A. and Derkowski, A. 2016. Root-related rhodochrosite and concretionary siderite formation in oxygen-deficient conditions induced by a ground-water table rise. *Sedimentology*, **63**, 523–551.

Böhme, M. 2003. The Miocene Climatic Optimum: evidence from ectothermic vertebrates of Central Europe. *Palaeogeography,Palaeoclimatology, Palaeoecology*, **195**, 389–401.

Bukowski, K. 2011. Badenian saline sedimentation between Rybnik and Dębica based on geochemical, isotopic and

radiometric research, pp. 183. Wydawnictwa AGH, Kraków. [In Polish, with English summary]

Cendón, D.I., Peryt, T.M., Ayora, C., Pueyo, J.J. and Taberner, C. 2004, The importance of recycling processes in the Middle Miocene Badenian evaporite basin (Carpathian foredeep): palaeoenvironmental implications. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **212**, 141–158.

Ceranka, T. 2007a. The Miocene echinoids from the Holy Cross Mountains and Roztocze area, their taxonomy, ecology and taphonomy. Unpublished Ph. D. thesis; Institute of Geology, University of Warsaw, pp. 1-194. [In Polish]

Ceranka, T. 2007b. Symmetry disorders of the test of the Miocene echinoid *Echinocyamus* from Poland. *Acta Palaeontologica Polonica*, **52**, 503–518.

Ceranka, T. and Złotnik, M. 2003. Traces of cassid snails predation upon the echinoids from the Middle Miocene of Poland. *Acta Palaeontologica Polonica*, **48**, 491–496.

Chaine, J. and Duvergier, J. 1928. Sur des Otolithes fossils de la Pologne. *Annales Societatis Geologorum Poloniae*, **5**, 190–204. [In Polish, with French summary]

Clark, A.H. 1931. A monograph of the existing crinoids, **1** (3). *United States National Museum Bulletin Smithsonian Institute*, **82**, 1–816.

Cody, A.M. and Cody, R.D. 1991. Chiral habit modification of gypsum from epitaxial-like adsorption of stereospecific growth inhibitors. *Journal of Crystal Growth*, **113**, 508-–519.

Cody, A.M., Cody, R.D. 1989. Evidence for micro-biological induction of {101} Montmartre twinning of gypsum ($CaSO_4 \cdot 2H_2O$). *Journal of Crystal Growth*, **98**, 721–730.

Czapowski, G. 1976. Several kinds of carbonate cementations in Miocene sediments in the vicinity of Sandomierz (Holy Cross Mts., Central Poland). *Bulletin de l'Académie Polonaise des Science, Série de Terre*, **24**, 83–92.

Czapowski, G. and Studencka, B. 1990. Sedimentary-palaeontological study of the Lower Sarmatian bar deposits in the Chmielnik area (southern slopes of the Holy Cross Mts.). *Przegląd Geologiczny*, **38**, 117–127. [In Polish, with English summary]

Czarniecka, U. 2011. Microfacies of Miocene siliciclastic-carbonate deposits in the Opatówka Valley (northern marginal zone of the Carpathian Foredeep). *Przegląd Geologiczny*, **59**, 625–632. [In Polish, with English summary]

De Castro Manso, C.L. and Souza-Lima, W. 2017. [in print] The first record of comatulid crinoid and its implications for the Miocene of the Bragança-Viseu Basin, Brasil. *Acta Geologica Polonica*.

DeCelles, P.G. and Giles, K.A. 1996. Foreland basin systems. *Basin Research*, **8**, 105–123.

Dembińska, M. 1924. Les annelids mioceniques de la Po-

logne. *Rozprawy i Wiadomości Muzeum im. Dzieduszyckich*, **9**, 116–131.

Dembińska-Różkowska, M. 1932. Polnische Miozänkorallen. *Annales Societatis Geologorum Poloniae*, **8**, 97–171.

Drewniak, A. 1994. Coralline algae from the Pińczów Limestones (Middle Miocene; southern slopes of the Holy Cross Mountains, Central Poland) as environmental indicators. *Acta Geologica Polonica*, **44**, 117–135.

Dronkert, H. 1977. The evaporites of the Sorbas basin. Diputación Provincial, Universidad de Barcelona, *Instituto de Investigaciones Geológicas*, **32**, 55–76.

Dronkert, H. 1978. Late Miocene evaporites in the Sorbas basin and adjoining areas. *Societa Geologica Italiana*, **16**, 341–361. [for 1976]

Dronkert, H. 1985. Evaporite models and sedimentology of Messinian and Recent evaporites: *GUA Papers of Geology (Amsterdam)*, *Ser. 1*, **24**, 1–283.

Dudziak, J. and Łuczkowska, E. 1991. Biostratigraphic correlation of foraminiferal and calcareous nannoplankton zones, Early-Middle Badenian (Miocene), Southern Poland. *Bulletin of the Polish Academy of Sciences, Earth Sciences*, **39,** 199–214.

Dziadzio, P. 2000. Depositional sequences in Badenian and Sarmatian deposits in the SE parts of the Carpathian Foredeep (SE Poland). *Przegląd Geologiczny*, **48**, 1124–1138. [In Polish, with English summary]

Eichwald, C.E. 1853. *Lethaea rossica*, ou, Paléontologie de la Russie, **3**, 1–553. Stuttgart.

Esteban, M. 1996. An overview of Miocene reefs from Mediterranean areas: general trends and facies models. In: E.K. Franseen, M. Esteban, W.C. Ward and J.-M. Rouchy (Eds), Models for carbonate stratigraphy from Miocene reef complexes of Mediterranean regions, SEPM Concepts in Sedimentology and Paleontology, **5**, 3–53. Tulsa, Oklahoma.

Esteban, M., Braga, J.C., Martin, J. and de Santisteban, C. 1996. Western Mediterranean reef complexes. In: E.K. Franseen, M. Esteban, W.C. Ward and J.-M. Rouchy (Eds), Models for carbonate stratigraphy from Miocene reef complexes of Mediterranean regions, SEPM Concepts in Sedimentology and Paleontology, **5**, 55–72. Tulsa, Oklahoma.

Flis, J. 1954. Gypsum karst of the Nida Trough. *Prace Geograficzne Instytutu Geografii PAN*, **1**, 9–73. [In Polish, with English summary]

Förster, R. 1979a. Decapod crustaceans from the Middle Miocene (Badenian) deposits of Southern Poland. *Acta Geologica Polonica*, **29**, 89–106.

Förster, R. 1979b. Decapod crustaceans from the Korytnica basin (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **29**, 253–268.

Friebe, J.G. 1991. Carbonate sedimentation within a silici-

clastic environment: the Leithakalk of the Weissenegg Formation (Middle Miocene; Styrian Basin, Austria). *Zentralblatt für Geologie und Paläontologie, Teil I 1990 (11)*, 1671–1687.

Friebe, J.G. 1993. Sequence stratigraphy in a mixed carbonate-siliciclastic depositional system (Middle Miocene; Styrian Basin, Austria). *Geologische Rundschau*, **82**, 281–294.

Friedberg, W. 1911-1928. Mollusca Miocaenica Poloniae, pars I (Gastropoda et Scaphopoda). **1** (1911), 1–112, **2** (1912), 113–240, **3** (1914), 241–360, **4** (1923), 361–440, **5** (1928), 441–561. Musaeum Dzieduszyckianum; Lwów-Poznań.

Friedberg, W. 1924. Études sur le miocène de la Pologne, Partie III. *Kosmos*, **49**, 555–567.

Friedberg, W. 1928. Studja nad formacją mioceńską Polski. *Kosmos*, **53**, 69–81.

Friedberg, W. 1934-1936. Mollusca Mioceanica Poloniae, pars II. (Lamellibranchiata). Polskie Towarzystwo Geologiczne, Kraków, 1 – 283.

Friedberg, W. 1938. Katalog meiner Sammlung der Miozanmollusken pollens. *Mémoires de l'Academie Polanaise des Sciences et des Lettres. Classe des sciences Mathématiques et Naturelles Serie B: Sciences Naturelles,* **12**, 1–164.

Garecka, M. and Jugowiec, M. 1999. Wyniki badań biostratygraficznych miocenu zapadliska przedkarpackiego na podstawie nanoplanktonu wapiennego. *Prace Państwowego Instytutu Geologicznego*, **168**, 29–42.

Garlicki, A. 1979. Sedimentation of Miocene salts in Poland. *Prace Geologiczne, Polska Akademia Nauk, Oddział w Krakowie*, **119**, 1–67. [In Polish, with English summary]

Garlicki, A. 1994. Formalne jednostki litostratygraficzne miocenu - formacja z Wieliczki (fm). *Przegląd Geologiczny*, **42**, 26–28.

Garlicki, A. 2008. Salt mines at Bochnia and Wieliczka. *Przegląd Geologiczny*, **56**, 663–669.

Gatt, M. and de Angeli, A. 2010. A new coral-associated decapod assemblage from the Upper Miocene (Messinian) Upper Coralline Limestone of Malta (Central Mediterranean). *Paleontology*, **53**, 1315–1348.

Gaweł, A. 1955. Złoża gipsów w Polsce południowej. *Cement-Wapno-Gips*, **11/20**, 117–122.

Gąsiewicz, A. 2000a. Comparative study of element geochemistry of gypsum-ghost limestones and selenite lithofacies from the Miocene of northern Carpathian Foredeep: implication to the model of massive replacement of solid sulphates by calcium carbonates. *Chemical Geology*, **164**, 183–218.

Gąsiewicz, A. 2000b. Sedimentology and diagenesis of gypsum-ghost limestones and origin of Polish native sulphur deposits. *Prace Państwowego Instytutu Geologicznego*, **172**, 1–143. [In Polish, with English summary]

Gąsiewicz, A. 2010. Major and minor elemental trends of gypsum-ghost limestones of the Osiek-Baranów Sandomierski native sulphur deposit (northern Carpathian Foredeep, Poland): implications for limestones genesis. *Geological Quarterly*, **54**, 519–532.

Gedl, P. 1996. Middle Miocene dinoflagellate cysts from the Korytnica Clays (Góry Świętokrzyskie Mountains, Poland). *Annales Societatis Geologorum Poloniae*, **66**, 191–218.

Gedl, P., Peryt, D. and Peryt, T. 2016. Foraminiferal and palynological organic matter records of the Upper Badenian (Middle Miocene) deposits at Anadoly (marginal part of the Ukrainian Carpathian Foredeep Basin). *Geological Quarterly*, **60**, 517–536.

Głuszyński, A. and Aleksandrowski, P. 2016. A deep palaeovalley in the floor of Polish Carpathian Foredeep Basin near Pilzno and its control on Badenian (Middle Miocene) evaporite facies. *Geological Quarterly*, **60**, 493–516.

Gozhyk, P., Semenenko, V., Andreeva-Grigorovich, A. and Maslun, N. 2015. The correlation of the Neogene of Central and Eastern Paratethys segments of Ukraine with the International Stratigraphic Chart based on planktonic microfossils. *Geologica Carpathica*, **66**, 235–244.

Górka, M. 2002. The Lower Badenian (Middle Miocene) coral patch reef at Grobie (southern slopes of the Holy Cross Mountains, Central Poland), its origin, development and demise. *Acta Geologica Polonica*, **53**, 521–534.

Górka, M. 2006. Badeńskie dziesięcionogi Miodoborów: ich taksonomia i eko-tafonomia. In: Wysocka, A. and Jasionowski, M. (Eds), Przebieg i zmienność sedymentacji w basenach przedgórskich. Materiały Konferencyjne II Polskiej Konferencji Sedymentologicznej, p. 121.

Górka, M., Jasionowski, M. and Poberezhskyy, A. 2006. Stop V: Humieńce [Humentsi]. In: A. Wysocka and M. Jasionowski (Eds), Przebieg i zmienność sedymentacji w basenach przedgórskich. Materiały Konferencyjne II Polskiej Konferencji Sedymentologicznej, 83–89.

Górka, M., Studencka, B., Jasionowski, M., Hara, U., Wysocka, A. and Poberezhskyy, A. 2012. The Medobory Hills (Ukraine): Middle Miocene reef systems in the Paratethys, their biological diversity and lithofacies. *Biuletyn Państwowego Instytutu Geologicznego*, **449**, 147–174.

Gutowski, J. 1984. Sedimentary environment and synecology of macrobenthic assemblages of the marly sands and red-algal limestones in the Korytnica Basin (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **34**, 324–340.

Harzhauser, M. and Kowalke, T. 2002. Sarmatian (Late Middle Miocene) Gastropod Assemblages of the Central Paratethys. *Facies*, **46**, 57–82.

Harzhauser, M., Mandic, O. and Zuschin, M. 2003.Changes in Paratethyan marine molluscs at the Early/Middle Miocene transition: diversity, palaeogeography and palaeoclimate. *Acta Geologia Polonica,* **53**, 323–339.

Hayward, A.B., Robertson, A.H.F. and Scoffin, T.P. 1996. Miocene patch reefs from a Mediterranean terrigenous setting in Southwest Turkey. In: E.K. Franseen, M. Esteban, W.C. Ward and J.-M. Rouchy (Eds), Models for carbonate stratigraphy from Miocene reef complexes of Mediterranean regions, SEPM Concepts in Sedimentology and Paleontology, **5**, 317–332. Tulsa, Oklahoma.

Hayward, B.W. 1977. Lower Miocene polychaetes from the Waitakere Ranges, North Auckland, New Zealand. *Journal of the Royal Society of New Zealand*, **7**, 5–16.

Hilber, V. 1882. Geologische Studien in den ostgalizischen Miozän-Gebieten. *Jahrbuch der Kaiserlich Königlichen Geologischen Reichsanstalt*, **32**, 193–330.

Hoernes, R. and Auinger, M. 1879. Die Gasteropoden der Meeres-Ablagerungen der ersten und zweiten miöcanen Mediterran-Stufe in der Österreichisch-ungarischen Monarchie. *Abhandlungen der Kaiserlich-Königlichen Geologischen Reichsanstalt*, **12**, 1–382.

Hoffman, A. 1976. Mortality patterns of some gastropods from the Badenian (Miocene) Korytnica Clays, Poland. *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen*, **152**, 293–306.

Hoffman, A. 1977. Synecology of macrobenthic assemblages of the Korytnica Clays (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **27**, 227–280.

Hoffman, A. and Szubzda, B. 1976. Paleoecology of some molluscan assemblages from Badenian (Miocene) marine sandy facies of Poland. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **20,** 307–332.

Hoffman, A. and Szubzda-Studencka, B. 1982. Bivalve species duration and ecological characteristics in the Badenian (Miocene) marine sandy facies of Poland. *Neues Jahrbuch fur Geologie und Paleontologie. Abhandlungen*, **163,** 122–135.

Hoffman, A., Pisera, A. and Ryszkiewicz, M. 1974. Predation by muricid and naticid gastropods on the Lower Tortonian Mollusc from the Korytnica Clays. *Acta Geologica Polonica*, **24**, 249–260.

Hörnes, M. 1856. Die fossilen Mollusken des Tertiaer-Beckens von Wien; I Univalven. *Abhandlungen der Kaiserlich-Koniglichen Geologischen Reichsanstalt*. **3,** 1–176.

Jäger, M. 1983. Serpulidae (Polychaeta sedentaria) aus der norddeutchen höheren Oberkreide – Systematik, Stratigraphie, Ökologie. *Geologische Jahrbuch, Reihe A*, **68**, 1-219.

Jahn, A 1937. Zdjęcie morfologiczne północnej krawędzi Podola i jej przedpola między potokami Koczurowskim i Pohoryleckim. *Kosmos A*, **62**, 549–596.

Jakubowski, G and Musiał, T. 1977. Lithology and fauna from the Upper tortonian sands of Monastyrz and Długi Goraj (Southern roztocze, Poland). *Prace Muzeum Ziemi*, **26**, 63–126. [In Polish, with English summary]

Jakubowski, G. and Musiał, T. 1979a. Lithology and fauna of the Middle Miocene deposits of Trzęsiny (Roztocze Tomaszowskie region, South-eastern Poland). *Prace Muzeum Ziemi*, **32**, 37–70. [In Polish, with English summary]

Jakubowski, G and Musiał, T. 1979b. Middle Miocene sandy and carbonate deposits of Huta Lubycka and Huta Różaniecka (Roztocze Rawskie Region, South-eastern Poland) and their fauna. *Prace Muzeum Ziemi*, **32**, 71–100. [In Polish, with English summary]

Jakubowski, G., Studencka, B. and Urbaniak, J. 1996. Class Bivalvia Linnaeus, 1758. In: L. Malinowska and M. Piwocki (Eds), Geology of Poland, Vol. III. Atlas of Fossils. Part 3a: Cenozoic, Tertiary, Neogene. pp. 663–703. Polska Agencja Ekologiczna; Warszawa. [In Polish]

Janakevich, A.N. 1969a. On the character of crabs from bioherm limestones of north-western Moldavia. *Paleontologichesky Sbornik*, **6**, 25–27. [In Russian]

Janakevich, A.N. 1969b. On paleoecology of reef facies molluscs of the north-west Moldavia. *Paleontologichesky Sbornik*, **6**, 44–51. [In Russian]

Janakevich, A.N. 1977. Middle Miocene reefs of Moldavia, pp. 1–116. Stiinca; Kishinev. [In Russian]

Janakevich, A.N. 1980. Identification book of Mid-Miocene fauna of Moldavia. Shtiintsa; Kishinev. [In Russian]

Janakevich, A.N. 1993. Middle Miocene fauna (Bivalvia) from seas covering the south-western slopes of the East European Platform. Shevchenko University Press; Tiraspol. [In Russian]

Jankowski, L. and Margielewski, W. 2015. Tectonic position of the Roztocze region in the light of the evolution history of the Carpathian Foredeep. *Biuletyn Państwowego Instytutu Geologicznego*, **462**, 7–28. [In Polish, with English summary]

Janssen, A. and Zorn, I. 1993. Revision of Middle Miocene holoplanktonic gastropods, published by the late Wilhelm Krach from Poland. *Geologia Scripta*, *Special Issue*, **2**, 155–236.

Jaroszewski, W. 1977. Sedimentary evidence for Miocene tectonic activity in the central Roztocze. *Przegląd Geologiczny*, **8-9**, 418–427. [In Polish, with English summary]

Jasionowski, M. 1997. Lithostratigraphy of the Miocene deposits in the eastern part of the Carpathian Foredeep. *Biuletyn Państwowego Instytutu Geologicznego*, **375**, 43–60. [In Polish, with English summary]

Jasionowski, M. 2006. Facies and geochemistry of Lower

Sarmatian reefs along the northern margin of the Paratethys in Roztocze (Poland) and Medobory (Ukraine) region: paleoenvironmental implications. *Przegląd Geologiczny*, **54**, 445–454. [In Polish, with English summary]

Jasionowski, M., Górka, M., Studencka, B. and Poberezhskyy, A. 2005. Upper Badenian (Middle Miocene) coralline algal reefs of the Medobory Hills (Paratethys, West Ukraine): preliminary results of palaeontological and sedimentological investigations. 12th Congress R.C.M.N.S., 6-11 September 2005. Patterns and Processes in the Neogene of the Mediterranean Region. Abstracts, pp. 113–115. Wien.

Jasionowski, M., Górka, M., Studencka, B. and Poberezhskyy, A. 2006. Miocene of Medobory Hills (Podillya, west Ukraine). In: A. Wysocka and M. Jasionowski (Eds), Przebieg i zmienność sedymentacji w basenach przedgórskich. Materiały Konferencyjne II Polskiej Konferencji Sedymentologicznej, 53-65. [In Polish, with English summary]

Jasionowski, M., Poberezhskyy, A. Studencka, B. Peryt, D. and Hara, U. 2003. Serpulid–microbialite Lower Sarmatian reefs of the Miodobory Region (Volhyn-Podolian margin of the East–European Platform). *Geologiya i geokhimiya goryuchykh kopalyn*, **2**, 85–91. [In Ukrainian, with English summary]

Jasionowski, M., Studencka, B. and Poberezhskyy, A. 2006. Stop II: Ohryzkowce [Ohryzkovtsi]. In: A. Wysocka and M. Jasionowski (Eds), Przebieg i zmienność sedymentacji w basenach przedgórskich. Materiały Konferencyjne II Polskiej Konferencji Sedymentologicznej, 71–75.

Jaśkiewicz, J. 1787. Dyssertacya na publiczney sessyi Szkoły Głowney Koronney w przytomności Nayjaśnieyszego Pana czytana w Krakowie Dnia 25. Czerwca 1787. Roku.

Kaczmarska, G. 1987. Asteroids from the Korytnica Basin (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **37**, 131–144.

Karasawa, H. 2000. Coral-associated decapod Crustacea from the Pliocene Daito Limestone Formation and Pleistocene Ryukyu Group, Ryukyu Islands, Japan. *Bulletin of Mizunami Fossil Museum*, **27**, 167–189.

Karasawa, H., Kobayashi, N., Goda, T., Ohira, N. and Ando, Y. 2014. A diversity for crabs (Decapoda) from the middle Pleistocene Atsumi Group, Japan. *Bulletin of the Mizunami Fossil Museum*, **40**, 55–73.

Kasprzyk, A. 1989. Lithology of the Miocene sulfate deposits in the Staszów region. *Geological Quarterly*, **33**, 241–268. [In Polish, with English summary]

Kasprzyk, A. 1991. Lithofacies analysis of the Badenian sulfate deposits south of the Holy Cross Mts. *Przegląd Geologiczny*, **39**, 213–223. [In Polish, with English summary]

Kasprzyk, A. 1993a. Lithofacies and sedimentation of the Badenian (Middle Miocene) gypsum in the northern part of the Carpathian Foredeep, southern Poland. *Annales Societatis Geologorum Poloniae*, **63**, 33–84.

Kasprzyk, A. 1993b. Gypsum facies in the Badenian (Middle Miocene) of southern Poland. Canadian *Journal of Earth Sciences*, **30**, 1799–1814.

Kasprzyk, A. 1993c. Stromatolitic facies in the Badenian (middle Miocene) gypsum deposits of southern Poland. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **187**, 375–395.

Kasprzyk, A. 1995. Correlation of sulphate deposits of the Carpathian Foredeep at the boundary of Poland and Ukraine. *Geological Quarterly*, **39**, 95–108.

Kasprzyk, A. and Bąbel, M. 1986. Gypsum ooids from the Miocene deposits of the vicinity of Staszów. *Przegląd Geologiczny*, **34**, 208–210.

Kasprzyk, A., Peryt, T.M., Turchinov, I.I. and Jasionowski, M. 1999. Badenian gypsum in the Ponidzie area, the northern Carpathian Foredeep, Poland. Intern. Conference "Carpathian Foredeep Basin - its evolution and mineral resources", Excursion 5, pp. 1–21. Kraków.

Kenig, K. and Wysocka, A. 1996. Sands and calcite cement-bodies (the Baran6w Beds) from Świniary, eastern margin of the Holy Cross Mts. *Geological Quarterly*, **40**, 203–230.

Kern, J.P. 1979. The ichnofossil Helicotaphriclmus commensalis in the Korytnica basin (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica. Polonica*, **29**, 239–252.

Khrushchov, D.P. and Petrichenko, O.I. 1979. Evaporite formations of Central Paratethys and conditions of their sedimentation. *Annales Géologiques des Pays Helléniques, Tome hors série*, **2**, 595–612.

Kitchell, J.A., Boggs, C.H., Kitchell, J.F. and Rice, J.A. 1981. Prey selection by naticid gastropods: Experimental tests and application to the fossil record. *Paleobiology*, **7**, 533–542.

Koltun, V.I. and Roskosh, I.T. 1969. Conditions of gypsum and anhydrite formations in Sub-Dnester area. *Voprosy Litologii i Petrografii, Lvovskoe Geologicheskoe Obshchestvo*, **1**, 172–176. [In Russian, with English summary]

Kontkiewicz, S. 1882. Sprawozdanie z badań gieologicznych dokonanych w 1880 r. w południowej części guberni Kieleckiej. *Pamiętnik Fizyograficzny*, **2**, 175–202.

Korolyuk, I.K., 1952. Podolian toutras and conditions of their origin. *Trudy Instituta Geologicheskikh Nauk*, **110**, *Geologicheskaya Seria*, **56**, 1–140. [In Russian]

Kovač, M., Andreyeva-Grigorovich, A., Bajraktarević, Z., Brzobohaty, R., Filipescu, S., Fodor, L., Harzhauser, M., Nagymarosy, A., Oszczypko, N., Pavelić, D., Rogl, F., Saft ić, B., Sliva, Ľ. and Studencka, B., 2007: Bade-

nian evolution of the Central Paratethys Sea: paleogeography, climate and eustatic sea-level changes. *Geologica Carpathica,* **58**, 579–606.

Kowalewski, K. 1927. Résultats des recherches sur les sédiments tertiaires de la partie SE de la feuilie Pińczów. *Comptes-Rendus des Séances Service du Gèologique Pologne*, **17**, 22–26.

Kowalewski, K. 1929. Stratygrafia iłów krakowieckich w Świniarach w stosunku do pozostałych obszarów miocenu południowego zbocza G6r Świętokrzyskich oraz ich analogie z utworami solonośnymi Wieliczki. *Posiedzenia Naukowe Państwowego Instytutu Geologicznego*, **24**, 46–50.

Kowalewski, K. 1930. Stratigraphie du Miocéne des environs de Korytnica en comparaison avec le Tertiaire des autres territoires du Massif de S-te Croix. *Bulletin du Service Géologique de Pologne*, **6**, 1–211.

Kowalewski, M. 1990. A hermeneutic analysis of the shell-drilling predation on molluscs in the Korytnica Clays (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **40**, 183–214.

Krach, W. 1947. Miocen okolic Miechowa, stratygrafia i paleontologia. *Bulletin de l'Institute Géologique Poloniae*, **43**, 1–65.

Krach, W. 1954. Nowy profil i fauna miocenu z Gliwic Starych na Górnym Śląsku. Warszawa. *Bulletin de l'Institute Geologique Poloniae*, **71**, 171–176.

Krach, W. 1960. Materiaux pour la connaissance du Miocene de Pologne, II-e partie. *Annales Societatis Geologorum Poloniae*, **30,** 203–211. [In Polish, with French summary]

Krach, W. 1981. Slimaki skrzydłonogi (Pteropoda) w Miocenie Polski i ich znaczenie stratigraficzne, *Prace Geologiczne PAN*, **121**, 116–140. [In Polish]

Krach, W. and Książkiewicz, M. 1949. Dolny torton w Benczynie koło Wadowic. *Annales Societatis Geologorum Poloniae*, **18**, 273–291.

Krach, W. and Nowak, W. 1956. Miocen okolic Andrychowa. *Annales Societatis Geologorum Poloniae*, **25**, 9–54.

Kreutz, S. 1925. Sur la protection de la nature inanimée. *Ochrona Przyrody*, **5**, 58–68. Kraków. [In Polish, with French summary]

Kroh, A. 2005. Echinoidea neogenica. Catalogus Fossilium Austriae, **2**, pp. 1–210. Österreichische Akademie der Wissenschaften; Wien.

Krzywiec, P. 1999. Miocene tectonic evolution of the Eastern Carpathian Foredeep Basin (Przemyśl–Lubaczów) in light of seismic data interpretation. *Prace Państwowego Instytutu Geologicznego*, **168**, 249–276. [In Polish, with English summary]

Krzywiec, P., 2001. Contrasting tectonic and sedimentary history of the central and eastern parts of the Polish Carpathian Foredeep basin – results of seismic data interpretation. *Marine and Petroleum Geology*, **18**, 13–38.

Krzywiec, P., Aleksandrowski, P., Ryzner-Siupik, B., Papiernik, B., Siupik, J., Mastalerz, K., Wysocka, A. and Kasiński, J. 2005. Geological structure and origin of the Miocene Ryszkowa Wola Horst (Sieniawa-Rudka area, eastern part of the Carpathian Foredeep Basin) – Result of 3D seismic data interpretation. *Przegląd Geologiczny*, **53**, 656–663. [In Polish, with English summary]

Krzywiec, P., Wysocka, A., Oszczypko, N., Mastalerz, K., Papiernik, B., Wróbel, G., Oszczypko-Clowes, M., Aleksandrowski, P., Madej, K. and Kijewska, S. 2008. Evolution of the Miocene deposits of the Carpathian Foredeep in the vicinity of Rzeszów (the Sokołów-Smolarzyny 3D seismic survey area). *Przegląd Geologiczny*, **56**, 232–244. [In Polish, with English summary]

Kubica, B. 1992. Lithofacial development of the Badenian chemical sediments in the northern part of the Carpathian Foredeep. *Prace Państwowego Instytutu Geologicznego*, **133**, 1–64. [In Polish, with English summary]

Kubica, B. 1994a. Metasomatism of Badenian sulphates of the Carpathian Foredeep and its palaeogeographic conditions. *Geological Quarterly*, **38**, 395–414.

Kubica, B. 1994b. Lithogeophysical correlation of the Badenian chemical deposits of the Carpathian Foredeep (southern Poland). *Przegląd Geologiczny*, **42**, 759–765. Warszawa. [In Polish, with English summary]

Kudrin, L.N. 1957. Palaeoecological investigations of the lowermost Tortonian deposits from the south-western part of the Russian Platform. *Geologicheskij Sbornik Lvovskovo Geologicheskogo Obshchestva*, **4**, 277–294. [In Russian]

Kudrin, L.N. 1966. Stratigraphy, facies, and ecological analysis of Palaeogene and Neogene faunas of the Fore-Carpathian sequences, pp. 1–174. Lvov University Press, Lvov. [In Russian]

Kutek, J. and Głazek, J. 1972. The Holy Cross area, Central Poland, in the Alpine cycle. *Acta Geologica Polonica*, **22**, 603–653.

Kvaček, Z., Kováč, M., Kovar-Eder, J., Doláková, N., Jechorek, H., Parashiv, V., Kováčová, M. and Silva, L. 2006. Evolution of landscape and vegetation in the Central Paratethys area during the Miocene. *Geologica Carpathica,* **57**, 295–210.

Kwiatkowski, S. 1966. Złoża siarki. Biblioteka Popularnonaukowa, Z geologią na co dzień, pp. 1–53. Wydawnictwa Geologiczne, Warszawa.

Kwiatkowski, S. 1970. Origin of alabasters, intraformational breccias, folds and stromatolites in Miocene gypsum of Southern Poland. *Bulletin de l'Académie Polonaise des Sciences, Sér. Sciences Géologiques et Géographiques*, **18**, 37–42.

Kwiatkowski, S. 1972. Sedimentation of gypsum in the Miocene of southern Poland. *Prace Muzeum Ziemi,* **19**, 3–94. Warszawa. [In Polish, with English summary]

Leszczyński, S. and Nemec, W. 2015. Dynamic stratigraphy of composite peripheral unconformity in a foredeep basin. *Sedimentology*, **62**, 645–680.

Lis, P. and Wysocka, A. 2012. Middle Miocene deposits in Carpathian Foredeep: facies analysis and implications for hydrocarbon reservoir prospecting. *Annales Societatis Geologorum Poloniae*, **82**, 239–253.

Liszkowski, J. 1989. A new halogenetic model for the origin of Lower and early Middle Miocene salt formations of the Carpathian region, eastern Central Paratethys. *Prace Naukowe Uniwersytetu Śląskiego w Katowicach*, **1019**, 1–104. Katowice. [In Polish, with English summary]

Lugli, S., Manzi, V., Roveri, M. and Schreiber, B.C., 2010. The Primary Lower Gypsum in the Mediterranean: A new facies interpretation for the first stage of the Messinian salinity crisis. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **297**, 83–99.

Łaptaś, A. 1992. Giant-scale cross-bedded Miocene biocalcarenites in the northern margin of the Carpathian Foredeep. *Annales Societatis Geologorum Poloniae*, **62**, 149–167.

Łomnicki, A.M. 1897. Atlas Geologiczny Galicyi; Tekst do zeszytu X, Część 1. Geologia Lwowa i okolicy, pp. 1–208. Komisya Fizyograficzna Akademii Umiejętności; Kraków.

Łomnicki, A.M. 1898. Atlas Geologiczny Galicyi; Tekst do zeszytu X, Część 2, Geologia Lwowa i okolicy, pp. 1–167. Komisya Fizyograficzna Akademii Umiejętności; Kraków.

Łoziński, M., Wysocka, A. and Ludwiniak, M. 2015. Neogene terrestrial sedimentary environments of the Orava-Nowy Targ Basin: a case study of the Oravica River section near Čimhová, Slovakia. *Geological Quarterly*, **59**, 21–34.

Łoziński, M., Ziółkowski, P. and Wysocka, A. 2016. Lithofacies and terrestrial sedimentary environments in AMS measurements: a case study from the Neogene of the Oravica River section, Čimhová, Slovakia. *Geological Quarterly*, **60**, 259–272.

Macioszczyk, W. 1988. Polyplacophora from the Badenian deposits of Węglinek, Węglin and Łychów (Western Roztocze, Poland). *Prace Muzeum Ziemi,* **40***, 48–58. [In Polish, with English summary]

Malicki, A. and Jahn, A. 1937. Pochodzenie żwirów, występujących w obrębie północnej krawędzi Podola i południowego Nadbuża. *Kosmos A*, **62**, 597–611.

Marcinowski, R. and Radwański, A. 1983. The mid-Cretaceous transgression onto the Central Polish Uplands. *Zitteliana*, **10**, 65–96.

Martini, E. 1977. Calcareous nannoplankton from the Korytnica Basin (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **27**, 125–133.

Mastalerz, K., Wysocka, A., Krzywiec, P., Kasiński, J., Aleksandrowski, P., Papiernik, B. and Ryzer-Siupik, J. 2006. Miocene succession at the Ryszkowa Wola High (Sieniawa-Rudka area), Carpathian Foredeep Basin: facies and stratigraphic interpretation of wellbore and 3D seismic data. *Przegląd Geologiczny*, **54**, 333–342. [In Polish, with English summary]

Mączyńska, S. 1977. Echinoids from the Korytnica Basin (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **27**, 193–200.

Mączyńska, S. 1979. Echinoids from the Miocene deposits of the Roztocze Region, south-eastern Poland. *Prace Muzeum Ziemi*, **32**, 29–36.

Mączyńska, S. 1987. A supplementary account on the echinoids from the Korytnica Basin (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **37**, 145–153.

Mączyńska, S. 1988. Echinoids from the Middle Miocene (Badenian) sands from southern Poland. *Prace Muzeum Ziemi* , **40**, 59–64.

Mączyńska, S. 1993. Echinoids from Pińczów Limestones (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **43**, 103–114.

Mączyńska, S. 1996. Middle Miocene (Badenian) echinoids from Niechobrz near Rzeszów (southern Poland). *Prace Muzeum Ziemi*, **43**, 39–46.

McCall, J., Rosen, B. and Darrell, J. 1994. Carbonate deposition in accretionary prism settings: Early Miocene coral limestones and corals of the Makran Mountain Range in southern Iran. *Facies*, **31**, 141–178.

Müller, P. 1984. Decapod Crustacea of the Badenian. *Geologica Hungarica. Series Palaeontologica*, **42**, 1–121.

Müller, P. 1993. Neogene Decapod Crustaceans from Catalonia. *Scripta Musei Geologici Seminarii Barcinonensis*, **225**, 1–39.

Müller, P. 1996. Middle Miocene decapod Crustacea from southern Poland. *Prace Muzeum Ziemi*, **43**, 3–16.

Musiał, T. 1987. Miocene of Roztocze (south-eastern Poland). *Biuletyn Geologiczny Uniwersytetu Warszawskiego*, **31**, 5–149. [In Polish, with English summary]

Ney, R., Burzewski, W., Bachleda, T., Górecki, W., Jakóbczak, K. and Słupczyński, K., 1974. Outline of paleogeography and evolution of lithology and facies of Miocene layers on the Carpathian Foredeep. *Prace Geologiczne*, **82**, 1–65. [In Polish, with English summary]

Niedźwiecki, J. 1879. Miocän am Südwest-Rande des galizisch-podolischen Plateaus. *Verhandlungen der Kaiserlich-Königlichen Geologischen Reichsanstalt*, 1879, 263–268.

Nosowska, E. 1997. Asteroids from the Nawodzice Sands (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **47**, 225–241.

Nowak, J. 1938. Der Dniestr Fluss und die tortonen Gipse. *Rocznik Polskiego Towarzystwa Geologicznego*, **14,** 155–194. [In Polish, with German summary]

Olchowy, P. 2015. Środowiska sedymentacji i charakterystyka izotopów trwałych węgla i tlenu w utworach siarkonośnych rejonu złoża siarki rodzimej Osiek-Baranów Sandomierski, zapadlisko przedkarpackie, pp. 1–351. PhD Thesis, Akademia Górniczo-Hutnicza im. St. Staszica, Kraków.

Olszewska, B. 1999. Biostratygrafia neogenu zapadliska przedkarpackiego w świetle nowych danych mikropaleontologicznych. *Prace Państwowego Instytutu Geologicznego*, **68**, 9–29.

Olszewska-Nejbert, D., Bąbel, M., Boguckyj, A. and Jacyszyn, A. 2009. Wykształcenie i sedymentacja utworów miocenu w Skale Podolskiej (Skale Podilskiej), zachodnia Ukraina. In: Lessy najstarsze Podola i Pokucia: problemy genezy, stratygrafii i paleogeografii. Monografia naukowa 16 ukraińsko-polskiego seminarium, Skała Podolska, 13-15 września 2009, pp. 35–77. Wydawnictwo LUN im. I. Franko, Lwów.

Ortí Cabo, F. and Shearman, D.J. 1977. Estructures y fábricas deposicionales en las evaporitas del mioceno superior (Messiniense) de San Miguel de Salinas (Alicante, España). *Revista del Instituto de Investigaciones Geológicas de la Diputación Provincial Universidad de Barcelona*, **32**, 5–54.

Ortí, F. 2011. Selenite facies in marine evaporites: A review. In: G.S.C. Kendall GSC and A.S. Alsharhan (eds.), Quaternary Carbonate and Evaporite Sedimentary Facies and Their Ancient Analogues: A Tribute to Douglas James Shearman. Special Publication of the International Association of Sedimentologists, **43**, 431–464. Wiley-Blackwell, Oxford.

Oszczypko, N. 1996. The Miocene dynamics of the Carpathian Foredeep in Poland. *Przegląd Geologiczny,* **44**, 1007–1019. [In Polish, with English summary]

Oszczypko, N. 2006. Development of the Polish sector of the Carpathian Foredeep. *Przegląd Geologiczny*, **54**, 396–403. [In Polish, with English summary]

Oszczypko, N. and Oszczypko-Clowes, M. 2011. Stages of the Polish Carpathian Foredeep development – a new approach. In: Pipik R., Starek D, Staňová S. (Eds), The 4th International Workshop on the Neogene from the Central and South-eastern Europe. September, 11-16, Banská Bystrica, Slovak Republic, p. 30.

Oszczypko, N., Krzywiec, P., Popadyuk, I. and Peryt, T. 2006. Carpathian Foredeep Basin (Poland and Ukraine): Its sedimentary, structural, and geodynamic evolution. In: Golonka, J. and Picha, F.J. (eds), The Carpathians and Their Foreland: Geology and Hydrocarbon Resources. *American Association of Petroleum Geologists Memoir*, **84**, 393–350.

Ósso, À. and Stalennuy, O. 2011. Description of the first fossil species of *Bathynectes* (Brachyura, Polybiidae) in the Badenian (middle Miocene) of the Medobory Hills (Ukraine, Central Parathetys), with remarks on its habitat ecology. *Treballs del Museu de Geologia de Barcelona*, **18**, 37–46.

Parafiniuk, J. 2002. Skład izotopowy siarki, węgla i tlenu a geneza złóż siarki rodzimej zapadliska przedkarpackiego. *Przegląd Geologiczny*, **50**, 817–818.

Parafiniuk, J., Kowalski, W. and Hałas, S. 1994. Stable isotope geochemistry and genesis of the Polish native sulphur deposits - a review. *Geological Quarterly*, **38**, 473–496.

Pawlikowski, M. 1982. Mineralogical and petrographical study of alteration products of the Miocene gypsum rocks in the Wydrza sulphur deposit. *Prace Mineralogiczne*, **72**, 1–60. [In Polish, with English summary]

Pawłowski, S. 1965. Kopalnia piasków kwarcowych w Świniarach. *Przewodnik 38 Zjazdu Polskiego Towarzystwa Geologicznego*, Tarnobrzeg.

Pawłowski, S., Pawłowska, K., and Kubica, B. 1979. Geology and genesis of the Polish sulphur deposits. *Economic Geology*, **74**, 475–483.

Pazdro, Z. 1953. Tectonic units of the Opole Minor, and phases of their development. *Bulletin of the Geological Survey of Poland* (top secret, for Survey Staff only; unnumbered), pp. 1–114. Wydawnictwa Geologiczne, Warszawa.

Peryt, D. 2013a. Foraminiferal record of marine transgression during deposition of the Middle Miocene Badenian evaporites in Central Paratethys (Borków section, Polish Carpathian Foredeep). *Terra Nova*, **25**, 298–306.

Peryt, D. 2013b. Foraminiferal record of the Middle Miocene climate transition prior to the Badenian salinity crisis in the Polish Carpathian Foredeep Basin (Central Paratethys). *Geological Quarterly*, **57**, 141-164.

Peryt, D. and Peryt, T.M. 2015. Environmental changes prior to and at the beginning of deposition of the Badenian Gypsum (Wschodnia River Region, Northern Part of the Fore-Carpathian Basin). Biuletyn Państwowego Instytutu Geologicznego, **461**, 133-152. [In Polish, with English summary]

Peryt, D., Gedl, P. and Peryt, T.M. 2014. Foraminiferal and palynological records of the Late Badenian (Middle Miocene) transgression in Podolia (Shchyrets near Lviv, western Ukraine). *Geological Quarterly*, **58**, 445-464.

Peryt, T.M. 1996. Sedimentology of Badenian (middle Miocene) gypsum in eastern Galicia, Podolia and Bukovina (West Ukraine). *Sedimentology*, **43**, 571–588.

Peryt, T.M. 2001. Gypsum facies transitions in basinal-marginal evaporites: middle Miocene (Badenian) of west Ukraine. *Sedimentology*, **48**, 1103–1119.

Peryt, T.M. 2002. The onset and the termination of the Badenian salinity crisis in Central Paratethys: the state of

the art. *Geologica Carpathica Special Issue*, **53** C, 6 pp.

Peryt, T.M. 2006a. The beginning, development and termination of the Middle Miocene Badenian salinity crisis in Central Paratethys. *Sedimentary Geology*, **188-189**, 379–396.

Peryt, T.M. 2006b. Odsłonięcie Góra Ratyńska. In: Wysocka, A. and Jasionowski, M. (Ed.), Przebieg i zmienność sedymentacji w basenach przedgórskich. 2 Polska Konferencja Sedymentologiczna, POKOS 2, Zwierzyniec 2006 r. Materiały konferencyjne, 49–52. Arkuszowa Drukarnia Offsetowa, Sp. z o.o., Grodzisk Mazowiecki.

Peryt, T.M. 2013. Palaeogeographical zonation of gypsum facies: Middle Miocene Badenian of Central Paratethys (Carpathian Foredeep in Europe). *Journal of Palaeogeography*, **2**, 225–237.

Peryt, T.M. and Kasprzyk, A. 1992. Carbonate-evaporite sedimentary transitions in the Badenian (middle Miocene) basin of southern Poland. *Sedimentary Geology*, **76**, 257–271.

Peryt, T.M. and Peryt, D. 1994. Badenian (Middle Miocene) Ratyn Limestone in western Ukraine and northern Moldavia: microfacies, calcareous nannoplankton and isotope geochemistry. *Bulletin of the Polish Academy of Sciences, Earth Sciences,* **42**, 127–136.

Peryt, T.M., Chowaniec, J., Jasionowski, M. and Peryt, D. (Eds). 2012a. Geological and hydrogeological studies of the Polish-Ukrainian borderland. *Biuletyn Państwowego Instuytutu Geologicznego*, **449**, 1–216. [In Polish, with English summary]

Peryt, T.M., Durakiewicz, T., Peryt, D. and Poberezhskyy, A. 2012b. Carbon and oxygen isotopic composition of the Middle Miocene Badenian gypsum-associated limestones of West Ukraine. *Geologica Acta*, **10**, 319–332.

Peryt, T.M., Karoli, S., Petrichenko, O.I., Gedl, P., Narkiewicz, M., Durkovičova, J. and Dobieszyńska, Z. 1997. Westernmost occurrence of the Middle Miocene Badenian gypsum in central Paratethys (Kobeřice, Moravia, Czech Republic). *Slovak Geological Magazine*, **3**, 105–120.

Peryt, T.M., Poberezhsky, A.V. and Yasinovsky, M., 1995. Facies of Badenian gypsum of the Dnister river region. *Geologiia i Geokhimiia Goryuchikh Kopalyn*, **1-2/90-91**, 16–27. [In Ukrainian, with English summary]

Petrichenko, O.I., Peryt, T.M. and Poberegsky, A.V. 1997. Pecularities of gypsum sedimentation in the Middle Miocene Badenian evaporite basin of Carpathian Foredeep. *Slovak Geological Magazine*, **3**, 91–104.

Petryczenko, O.J., Panow, G.M., Peryt, T.M., Srebrodolski, B.I., Pobereżski, A.W. and Kowalewicz, W.M. 1994. Zarys geologii mioceński formacji ewaporatowych ukraińskiej części zapadliska przekarpackiego. *Przegląd Geologiczny*, **42**, 734–747.

Pietsch, K., Porębski, S.J. and Marzec, P. 2010. The use of seismostratigraphy for exploration of Miocene gas-gearing reservoirs in the NE part of the Carpathian Foreland Basin (Poland). *Geologia*, **36**, 173–186. [In Polish, with English summary]

Pisera, A. 1978. Reefal Miocene deposits of western Roztocze. *Przegląd Geologiczny*, **26**, 159–162. Warszawa. [In Polish, with English summary]

Pisera, A. 1985. Paleoecology and lithogenesis of the Middle Miocene (Badenian) algal-vermetid reefs from the Roztocze Hills, south-eastern Poland. *Acta Geologica Polonica*, **35**, 89–155.

Pisera, A. 1996. Miocene reefs of the Paratethys: a review. In: E.K. Franseen, M. Esteban, W.C. Ward and J.-M. Rouchy (Eds), Models for carbonate stratigraphy from Miocene reef complexes of Mediterranean regions, SEPM Concepts in Sedimentology and Paleontology, **5**, 97–104. Tulsa, Oklahoma.

Pokalyuk, V.V., Doroshenko, A.N. and Tereschenko, C.I. 2009. Megaspherulites in gypsums of the Dnister Podillia region (origin and influence on speleogenesis). *Mineralogical Journal (Ukraine)*, **33**, 15–24. [In Russian, with English summary]

Połtowicz, S. 1993. Palinspastic palaeogeography reconstruction of Badenian saline sedimentary basin in Poland. Zeszyty Naukowe AGH, No. 1559, *Geologia, Kwartalnik*, **19**, 174–178, 203–233. Kraków. [In Polish, with English summary]

Popadyuk, I., Vul, M., Landyzhensky, G. and Shapak, P. 2006. The petroleum geology of the Ukrainian Carpathian Foredeep. In: Golonka, J. and Picha, F.J. (Eds), The Carpathians and their foreland: Geology and hydrocarbon resources. *American Association of Petroleum Geologists Memoir*, **84**, 443–454.

Porębski, S.J., Pietsch, K., Hodiak, R. and Steel, R.J. 2002. Origin and sequential development of Upper Badenian – Sarmatian clinoforms in the Carpathian Foredeep Basin, SE Poland. *Geologica Carpathica*, **54**, 119–136.

Pusch, G.G. 1837. Polens Paläontologie oder Abbildung und Beschreibung der vorzüglichsten und der noch unbeschriebenen Petrefakten aus den Gebirgsformationen in Polen, Volhynien und den Karpaten. 1–218. E. Schweizerbart's Verlaghandlung; Stuttgart.

Radwańska, U. 1984. Some new fish otoliths from the Korytnica Clays (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **34**, 299–322.

Radwańska, U. 1987. Free-living crinoids from the Korytnica Clays (Middle Miocene, Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **37,** 113–129.

Radwańska, U. 1992. Fish otoliths in the Middle Miocene (Badenian) deposits of southern Poland. *Acta Geologica Polonica*, **42**, 141–328.

Radwańska, U. 1994a. Tube-dwelling polychaetes from the Korytnica Basin (Middle Miocene, Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **44**, 35–81.

Radwańska, U. 1994b. A new group of microfossils: Middle Miocene (Badenian) opercular caps (*calottae*) of the tube-dwelling polychaetes *Vermiliopsis* Saint-Joseph, 1894. *Acta Geologica Polonica*, **44**, 83–96.

Radwańska, U. 2003. *Sievertsella*, a replacement name for *Sievertsia* Radwańska, 1987 (Echinodermata, Crinoidea), preoccupied by *Sievertsia* Smith and Paul, 1982 (Echinodermata, Cyclocystoidea). *Acta Geologica Polonica*, **53**, p. 321.

Radwańska, U. and Radwański, A. 1984. A new species of inarticulate brachiopods, *Discinisca polonica* sp.n., from the Korytnica Basin (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **34**, 253–269.

Radwański, A. 1964. Boring animals in Miocene littoral environments of southern Poland. *Bulletin de l'Academie Polonaise des Sciences, Série des Sciences Géologiques et Géographiques*, **12**, 57–62.

Radwański, A. 1965. A contribution to the knowledge of Miocene Elasmobranchii from Pińczów (Poland). *Acta Geologica Polonica,* **10**, 267–276.

Radwański, A. 1967. Problematyka mioceńskich struktur litoralnych na południowych stokach Gór Świętokrzyskich. *Rocznik Polskiego Towarzystwa Geologicznego*, **37**, 169–175.

Radwański, A. 1968. Lower Tortonian transgression onto the Miechow and Cracow Uplands. *Acta Geologica Polonica,* **18**, 387–445.

Radwański, A. 1969. Lower Tortonian transgression onto the southern slopes of the Holy Cross Mts. *Acta Geologica Polonica*, **19**, 1–164.

Radwański, A. 1970. Dependence of rock-borers and burrowers on the environmental conditions within the Tortonian littoral zone of Southern Poland. In: T.P. Crimes and J.C. Harper (Eds), Trace Fossils, *Geological Journal Special Issue*, **3**, 371–390.

Radwański, A. 1973. Lower Tortonian transgression onto the south-eastern and eastern slopes of the Holy Cross Mts. *Acta Geologica Polonica*, **23**, 375–434.

Radwański, A. 1974. Palaeoecological observations on Miocene communities of Poland. *Bulletin of the Geological Society of Denmark*, **23** (3-4), 336–340.

Radwański, A. 1977. Neogen. In: H. Makowski (Ed.), Geologia historyczna, pp. 731–770. Wydawnictwa Geologiczne, Warszawa.

Radwański, A. and Wysocka, A. 2001. Mass aggregation of Middle Miocene spine-coated echinoids *Echinocardium* and their integrated eco-taphonomy. *Acta Geologica Polonica*, **51**, 295–316.

Radwański, A. and Wysocka, A. 2004. A farewell to Świniary sequence of mass-aggregated, spine-coated echinoids *Psammechinus* and their associates (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **54**, 381–399.

Radwański, A. and Wysocka, A. 2006. Stop II: Piaskownia Chlebowice [Gleboviti]. In: A. Wysocka and M. Jasionowski (Eds), Przebieg i zmienność sedymentacji w basenach przedgórskich. Materiały Konferencyjne II Polskiej Konferencji Sedymentologicznej. 41–49.

Radwański, A., Górka, M. and Wysocka, A. 2006. Middle Miocene coralgal facies at Maksymivka near Ternopil (Ukraine): A preliminary account. *Acta Geologica Polonica*, **56**, 89–103.

Radwański, A., Górka, M. and Wysocka, A. 2014. Badenian (Middle Miocene) echinoids and starfish from western Ukraine, and their biogeographic and stratigraphic significance. *Acta Geologica Polonica,* **64**, 207–247.

Radwański, A., Wysocka, A. and Górka, M. 2011. "Entobia balls" in the Medobory Biohermal Complex (Middle Miocene, Badenian; western Ukraine). *Acta Geologica Polonica*, **61**, 265–276.

Radwański, A., Wysocka, A. and Górka, M. 2012. Miocene burrows of the Ghost Crab *Ocypode* and their environmental significance (Mykolaiv Sands, Fore-Carpathian Basin, Ukraine). *Acta Geologica Polonica*, **62**, 217–229.

Reuss, A.E. 1847. Die fossilen *Polyparier* des Wiener Tertiärbeckens. *Naturwissenschaftliche Abhandlungen von Haidinger*, **2**, 109 pp.

Reuss, A.E. 1867. Die fossile Fauna der Steinsalzablagerungen von Wieliczka in Galizien. *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften in Wien, Mathematisch-Naturwissenschaftlichen Klasse,* **55**, 17–182.

Reuss, A.E. 1871. Die fossilen *Korallen* des österreichischungarischen Miocäns. *Denkschriften der Kaiserlichen Akademie der Wissenschaften, Mathematisch-Naturwissenschaftlichen Klasse*, **31**, 197–270.

Richter-Bernburg, G. 1955. Über salinare Sedimentation. *Zeitschrift der Deutschen Geologischen Gesellschaft*, **105**, 593–645. [for 1953]

Riegl, B. and Piller, W.E. 2000. Biostromal Coral Facies – A Miocene Example from the Leitha Limestone (Austria) and its Actualistic Interpretation. *Palaios*, **15**, 399–413.

Rodríguez-Aranda, J.P., Rouchy, J.M., Calvo, J.P., Ordónez S., and García del Cura, M.A. 1995. Unusual twinning features in large primary gypsum crystals formed in salt lake conditions, middle Miocene, Madrid Basin, Spain – Palaeoenvironmental implications. *Sedimentary Geology*, **95**, 123–132.

Roemer, F. 1870. Geologie von Oberschlesien. pp. 587. Wrocław.

Rögl, F. and Brandstätter, F. 1993. The foraminifera genus *Amphistegina* from the Korytnica Clays (Holy Cross

Mts., Central Poland) and its significance in the Miocene of Parathetys. *Acta Geologica Polonica*, **43**, 121–146.

Rögl, F. and Steininger, F.F. 1983. Vom Zerfall der Tethys zu Mediterran und Paratethys. Die Neogene Palaeogeographie und Palinspastik des zirkummediterranen Raumes. *Annales Naturhistorischen Museum Wien*, **85**, 135–163.

Roniewicz, E. and Stolarski, J. 1991. Miocene Scleractinia from the Holy Cross Mountains, Poland; Part 2 – Archaeocoeniina, Astraeina, and Fungiina. *Acta Geologica Polonica*, **41**, 69–84..

Roniewicz, P. and Wysocka, A. 2001. Remarks on Miocene sedimentation in the area between Szydłów and Smerdyna, southeastern margin of the Holy Cross Mts. (Central Poland). *Przegląd Geologiczny*, **49**, 639–642.

Rutkowski, J. 1976. Detrytyczne osady sarmatu na południowym obrzeżeniu Gór Świętokrzyskich, *Prace Geologiczne PAN*, **100**, 1-77.

Scarponi, D., Della Bella, G., Dell'Angelo, B., Huntley, J.W., and Sosso, M. 2016. Middle Miocene conoidean gastropods from western Ukraine (Paratethys): Integrative taxonomy, palaeoclimatogical and palaeobiogeographical implications. *Acta Palaeontologica Polonica,* **61**, 327–344.

Schreiber, B.C., Babel, M. and Lugli, S. 2007. Introduction and overview. Evaporites Through Space and Time. *Geological Society, London, Special Publications*, **285**, 1–13.

Schultz, O. 1977. Elasmobranch and Teleostei fish remains from the Korytnica Clays (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **27**, 201–210.

Siemiradzki, J. 1918. Katalog systematyczny zbiorów paleontologicznych Muzeum im. Dzieduszyckich we Lwowie. *Rozprawy i wiadomości Muzeum im. Dzieduszyckich we Lwowie*, **3**, 5–13, 22–23, 34–36.

Sitár, V. and Kováčová-Slamková, M. 1999. Palaeobotanical and palynological study of the Upper Badenian sediments from the NE part of the Vienna Basin (locality Devínska Nová Ves). *Acta Palaeobotanica*, *Supplement,* **2**, 373—389.

Skoczylasówna, K. 1930. Beitrag zur Kenntnis der Miozänablagerungen in der Umgebung von Nowy Sącz. *Annales Societatis Geologorum Poloniae*, **6**, 50–72.

Staszic, S.W. 1815. O ziemiorództwie Karpatów i innych gór i równin Polski. pp. 436. Warszawa.

Stolarski, J. 1991. Miocene Scleractinia from the Holy Cross Mountains, Poland; Part 1 – Caryophyllidae, Flabellidae, Dendrophylliidae, and Micrabaciidae. *Acta Geologica Polonica*, **41**, 37–68.

Studencka, B. 1986. Bivalves from the Badenian (Middle Miocene) marine sandy facies of southern Poland. *Palaeontologia Polonica,* **47**, 3–128.

Studencka, B. 1987. The occurrence of the genus *Kelliella* (Bivalvia, Kelliellidae) in shallow-water, Middle Miocene deposits of Poland. *Acta Palaeontologica Polonica*, **32**, 73–81.

Studencka, B. 1994. Middle Miocene bivalve faunas from the carbonate deposits of Poland (Central Paratethys). *Géologie Méditerranéenne*, **21,** 137–145.

Studencka, B. 1999. Remarks on Miocene bivalve zonation in the Polish part of the Carpathian Foredeep. *Geological Quarterly*, **43,** 467–477.

Studencka, B. 2015. Middle Miocene bivalves from the Carpathian Foredeep Basin at the Busko (Młyny) PIG-1 and Kazimierza Wielka (Donosy) PIG-1 boreholes: Stratigraphy and taxonomy. *Biuletyn Państwowego Instytutu Geologicznego*, **461,** 95–114. [In Polish, with English summary]

Studencka, B. and Dulai, A. 2010. Chitons (Mollusca: Polyplacophora) from the Middle Miocene sandy facies of Ukraine, Central Paratethys. *Acta Geologica Polonica* , **60**, 257–274.

Studencka, B. and Jasionowski, M. 2011. Bivalves from the Middle Miocene reefs of Poland and Ukraine: A new approach to Badenian/Sarmatian boundary in the Paratethys. *Acta Geologica Polonica*, **61**, 79–114.

Studencka, B. and Studencki, W. 1988a. Middle Miocene (Badenian) bivalves from the carbonate deposits of the Wójcza-Pińczów Range (southern slopes of the Holy Cross Mountains, Central Poland). *Acta Geologica Polonica,* **38,** 1–45.

Studencka, B. and Studencki, W. 1988b. Polyplacophora from the Badenian (Middle Miocene) marine sandy facies of the Holy Cross Mts. (Central Poland). *Prace Muzeum Ziemi*, **40**, 37–46. [In Polish, with English summary]

Studencka, B. and Popov, S.V. 1996. Genus *Acanthocardia* (Bivalvia) from the Middle Miocene of the Paratethys. *Prace Muzeum Ziemi*, **43**, 17–37.

Studencka, B., Gontsharova, I.A. and Popov, S.V. 1998. The bivalve faunas as a basis for reconstruction of the Middle Miocene history of the Paratethys. *Acta Geologica Polonica*, **48,** 285–342.

Studencka, B., Prysyazhnyuk, V.A. and Ljul'eva, S.A. 2012. The first data on the bivalve species *Parvamussium fenestratum* (Forbes, 1844) from the Middle Miocene of the Paratethys. *Geological Quarterly*, **56,** 513–528.

Studencki, W. 1979. Palaeogeography of Lower Badenian of the Wójcza-Pińczów Range. *Przegląd Geologiczny*, **27**, 10–13. [In Polish, with English summary]

Studencki, W. 1988a. Facies and sedimentary environment of the Pińczów Limestones (Middle Miocene; Holy Cross Mountains, Central Poland). *Facies*, **18**, 1–26.

Studencki, W. 1988b. Red algae from the Pińczów Limestones (Middle Miocene; Świętokrzyskie Mts., Central

Poland). *Acta Palaeontologica Polonica*, **33**, 4–57.

Studencki, W. 1999. Red-algal limestones in the Middle Miocene of the Carpathian Foredeep in Poland: facies variability and palaeoclimate implications. *Geological Quarterly,* **43**, 395–404.

Szörényi, E. 1953. Miozäne Echinoiden aus den westlichen Teilen der Ukraine. *Geologica Hungarica Series Palaeontologica*, **23,** 1–122.

Szymanko, J. and Wójcik, K. 1982. Geology of the Middle Miocene Korytnica Basin (southern slopes of the Holy Cross Mts., Central Poland) in the light of geophysical data and photogeological analysis. *Acta Geologica Polonica*, **32**, 93–108.

Śmigielska, T. 1966. Otoliths of fishes from the Tortonian of Southern Poland. *Annales Societatis Geologorum Poloniae*, **36**, 205–275.

Śmigielska, T. 1973. Fish otoliths from the Lower Tortonian deposits at Niskowa near Nowy Sącz. *Annales Societatis Geologorum Poloniae*, **43**, 1–40.

Śmigielska, T. 1979. Fish otoliths from the Korytnica Clays (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **29**, 295–337.

Ślączka, A., Kruglov, S., Golonka, J., Oszczypko, N. and Popadyuk, I. 2006. Hydrocarbon Resources of the Outer Carpathians, Poland, Slovakia, and Ukraine: General Geology, In: Golonka, J. and Picha, F.J. (Eds), The Carpathians and their foreland: Geology and hydrocarbon resources. *American Association of Petroleum Geologists Memoir*, **84,** 443–454.

Śliwiński, M., Bąbel, M., Nejbert, K., Olszewska-Nejbert, D., Gąsiewicz, A., Schreiber, B.C., Benowitz, J.A. and Layer, P. 2012. Badenian–Sarmatian chronostratigraphy in the Polish Carpathian Foredeep. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **326–328**, 12–29.

Tasakowski, S. 2013. Miocene echinoderm fauna from the outcrop at Łagiewniki near Busko. Unpublished M. Sc. Thesis; Institute of Geology, University of Warsaw. [In Polish, with English summary]

Teisseyre, H. 1938. Quelques observations sur la paléogéographie de Roztocze aux environs de Lwów. *Annales Societatis Geologorum Poloniae*, **14**, 113–154. [In Polish, with French summary]

Teisseyre, W. 1900. Atlas geologiczny Galicji. Zeszyt VIII. Spółka Wydawnicza Polska; Kraków.

Tekin, E., Varol, B. and Ayyildiz, T. 2008. A rare natural gypsum ooide (gypsolites) in an evaporitic playa lake of late Miocene (?) to Pliocene age in Central Anatolia, Turkey. *Carbonates and Evaporites*, **23**, 50–59.

Ten Hove, H.A. and Nishi, E. 1996. A redescription of the Indo-West Pacific *Spirobranchus corrugatus* Straughan, 1967 (Serpulidae, Polychaeta) and an alternative hypothesis on the nature of a group of Middle-Miocene microfossils from Poland. *Beaufortia*, **46**, 83–96.

Vai, G.B. and Ricchi Luchi, F. 1977. Algal crusts, autochthonous and clastic gypsum in a cannibalistic evaporite basin: a case history from the Messinian of Northern Apennines. *Sedimentology*, **24**, 211–244.

Vialov, O.S. 1970. Miocene Buglov beds. Naukova Dumka, Kiev. [In Russian]

Vogel, M.B, Desmarais, D.J., Parenteau, M.N., Jahnke, L.L., Turk K.A. and Kubo M.D.Y. 2010. Biological influences on modern sulfates: Textures and composition of gypsum deposits from Guerrero Negro, Baja California Sur, Mexico. *Sedimentary Geology*, **223**, 265–280.

Voloshina, M. 1973. Late Tortonian bivalves from Moldavia and their living conditions. pp. 192. Shtiitnsta; Kishinev. [in Russian]

Wala, A. 1961. Litologia mioceńskiej serii ewaporatów w okolicy Pińczowa. *Sprawozdania z Posiedzeń Komisji, Polska Akademia Nauk, Oddział w Krakowie*, **1/6**, 275–280.

Wala, A. 1963. Korelacja litostratygraficzna serii gipsowej obszaru nadnidziańskiego. *Sprawozdania z Posiedzeń Komisji, Polska Akademia Nauk, Oddział w Krakowie*, **7/12**, 530–532. [for 1962]

Wala, A. 1980. Litostratygrafia gipsów nidziańskich (fm). In: Sympozjum naukowe "Gipsy niecki nidziańskiej i ich znaczenie surowcowe", 30-31.05.1980 r., pp. 5–10. Kraków.

Walkiewicz, A. 1975. Some examples of ecological interpretation based on foraminifers from the Tortonian of Korytnica. *Przegląd Geologiczny*, **23**, 525–529. [In Polish, with English summary]

Walkiewicz, A. 1977a. Holothurian sclerites from the Korytnica Clays (Middle Miocene; Holy Cross Mountains, Poland). *Acta Geologica Polonica*, **27**, 177–192.

Walkiewicz, A. 1977b.The genus *Palmula* and some other rare Nodosariidae (Foraminiferida) from the Korytnica Clays (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **27**, 135–142.

Warchoł, M. 2011. Przepływy hiperpiknalne i kryteria wyróżniania ich osadów w zapisie kopalnym. Unpublished PhD Thesis, Institute of Geological Sciences, Polish Academy of Sciences, Kraków, 296 pp.

Warren, J.K. 1982. The hydrological setting, occurrence and significance of gypsum in late Quaternary salt lakes in South Australia. *Sedimentology*, **29**, 609–637.

Weiner, J. 1999. Życie i ewolucja biosfery. 1-591. PWN; Warszawa.

Wysocka, A. 2002. Clastic Badenian deposits and sedimentary environments of the Roztocze Hills across the Polish-Ukrainian border. *Acta Geologica Polonica,* **52**, 535–561.

Wysocka, A. 2006. Badenian clastic deposits of the Roztocze Hills area – evolution of sedimentation on the northern outer ramp of the Carpathian Foredeep Basin. *Przegląd Geologiczny*, **54**, 430–437. [In Polish, with English summary]

Wysocka, A. and Jasionowski, M. (Eds) 2006. Przebieg i

zmienność sedymentacji w basenach przedgórskich. Materiały Konferencyjne II Polskiej Konferencji Sedymentologicznej. pp. 1–178.

Wysocka, A., Górka, M. and Radwański, A. 2011. Sedimentological and stratigraphical significance of the Sandy Facies from the northern part of the Fore-Carpathian Depression (Badenian; western Ukraine). The 4-th International Workshop on the Neogene from the central and south-eastern Europe. Abstracts and guide of excursion, 12-16. 2011, 49–50. Banská Bystrica.

Wysocka, A., Radwański, A. and Górka, M. 2012. Mykolaiv Sands in Opole Minor and beyond: Sedimentary features and biotic content of Middle Miocene (Badenian) sand shoals of western Ukraine. *Geological Quarterly*, **56**, 475–492.

Wysocka, A., Szablewski, Ł. and Sujka, G. 2006. Stop I: Piaskownia Góra Mogiła [Mohila]. In: A. Wysocka and M.

Jasionowski (Eds), Przebieg i zmienność sedymentacji w basenach przedgórskich. Materiały Konferencyjne II Polskiej Konferencji Sedymentologicznej. 67–71.

Zejszner, L. 1845. Paleontologia polska, **2**. Warszawa.

Zelinskaja, V. A., Kulitschenko, V. B., Makarenko, D. E. and Sorotshan, E. A. 1968. Guidebook of Paleontology, Volumen 1. Bivalvia from Paleocene and Miocene of Ukraine. 297pp.Scientific Board. Kiev.

Złotnik, M. 2001. Size-related chan ges in predatory behaviour of naticid gastropods from the Middle Miocene Korytnica Clays, Poland. *Acta Palaeontologica Polonica*, **46**, 87–97.

Złotnik, M. 2003. Nassariid assemblages from the Korytnica Clays – a useful tool for local stratigraphic correlation. *Acta Geologica Polonica*, **53**, 359–374.

Złotnik, M. and Ceranka, T. 2005. Patterns of drilling predation of cassid gastropods preying on echinoids from the Middle Miocene of Poland. *Acta Palaeontologica Polonica*, **50**, 409–428.