The Eocene Hieroglyphic Beds of the Silesian Nappe in the Western Polish Carpathians – their development and foraminiferal record

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The sedimentation of Hieroglyphic Beds of the Silesian Nappe took place from the Early Eocene up to Late Eocene within the Carpathian Silesian Basin. These beds are dominated by thin-bedded flysch containing – at various stratigraphic positions – thick sandstone-free complexes with variegated shales or bentonite laminae developed during a limited supply of material from the land. Their variability and boundary sequences are presented. In general, their lithological heterogeneity is connected by the ratio of sandstones and shales, thickness of layers and occurrence of different types of shales. The Hieroglyphic Beds are underlain by the Ciężkowice Sandstone or by the Istebna Beds and overlain by the Globigerina Marls or directly by the Menilite Beds. In the Ypresian, during the sedimentation of Hieroglyphic Beds, foraminiferal associations with numerous small-sized Trochammina developed in the Silesian Basin after the PETM crisis. Since the Lutetian, more diverse associations occurred in slightly more favourable conditions, with Reticulophragmium amplectens (Grzybowski), Dolgenia latus (Grzybowski), and Reticulophragmium gerochi Neagu et al., which preferred cool waters, and are index fossils for stratigraphy. The Hieroglyphic Beds developed during a period of gradually cooling global climate. The gradual decrease in temperature stimulated the transfer of species. The thermophilous forms, whose optimum development took place in the Late Cretaceous–Paleocene, disappear during Lower and Middle Eocene and new species that preferred cold boreal waters commonly occur in Middle and Late Eocene. A profound restructuring of foraminiferal assemblages took place in the Priabonian, when massive numbers of calcareous benthic and planktonic forms were deposited.

Key words: Hieroglyphic Beds, Silesian Nappe, Outer Carpathians, Eocene, foraminifera, lithostratigraphy.

INTRODUCTION

The Eocene was a time of tectonic reorganization in the Tethys Ocean. In the western part of the Tethys this reorganization was associated with changes in the configuration and bathymetry of the Carpathian sedimentary basins (e.g., Książkiewicz, 1962,1965, 1972, 1977; Mahef, 1974; Unrug, 1979; Cieszkowski et al., 1985, 2009; Ślązka and Kaminski, 1998; Lexa et al., 2000; Ryko, 2004; Golonka et al., 2006, 2008, 2013; Olszewska and Malata, 2006; Oszczyko et al., 2006; Słomka et al., 2006; Ślązka et al., 2006; Golonka, 2011). At that time, thin-bedded flysch deposits formed in the Carpathian basins, covering large areas of the sea-floor. Some of them constitute the so-called Hieroglyphic Beds composing a complex of turbidite formations, generally with predominant shales. Great numbers of hieroglyphs can be found on the bottom surfaces of thin-bedded sandstones, which are the characteristic feature of these layers (e.g., Paul and Tietze, 1879; Świdziński, 1948; Książkiewicz, 1951; Geroch et al., 1967; Czaplicka et al., 1968; Paul, 1993).

Under this name, the division functions as an informal lithostratigraphic unit in separate Carpathian tectonic units, i.e., in the Silesian, Skole, and Subsilesian nappes, and in the Fore-Magura group of nappes (e.g., Świdziński, 1948; Książkiewicz, 1951; Geroch et al., 1967; Jurkiewicz, 1967; Ślązka, 1971; Burtan, 1978; Morgiel and Szymakowska, 1978; Golonka et al., 1979, 2013; Rajchel, 1990; Neščieruk et al., 1996; Ryko, 2004; Golonka and Waśkowska-Oliwa, 2007). In the Silesian Nappe, this type of deposits occurs beneath the Globigerina Marls and Menilite Beds, and above the Ciężkowice Sandstone and Istebna Beds. The Hieroglyphic Beds represent a standard lithostratigraphic unit, depicted as a separate unit in cartographic works (e.g., Skoczylas-Ciszewska, 1954; Burtan and Szymakowska, 1964; Książkiewicz, 1974a, b; Golonka, 1981; Szymakowska and Wójcik, 1981,1992; Cieszkowski et al., 1991; Paul et al., 1996) or in combination with Green and/or Variegated Shales (e.g., Żytko, 1963; Nowak, 1963, 1964; Sikora, 1963, 1964; Burtan, 1964a, b; Burtan and Skoczylas-Ciszewska, 1964a, b, c; Szymakowska and Żytko, 1964; Golonka et al., 1979; Neščieruk et al., 1995). Despite the common use of this lithostratigraphic unit, it still lacks any wider documentation, apart from general characteristics (e.g., Geroch, 1960; Bieda et al., 1963; Geroch et al., 1967; Neščieruk et al., 1996; Ryko, 2004; Cieszkowski et al., 2006a;
Chodyń and Waśkowska-Oliwa, 2006; Waśkowska et al., 2008). Micropalaeontological data pertaining to the Hieroglyphic Beds of the Silesian Nappe (e.g., Jurkiewicz, 1959, 1979; Geroch, 1960; Bieda et al., 1963; Geroch et al., 1967; Książkiewicz, 1974b; Geroch and Koszarski, 1988; Cieszkowski, 1992; Szymakowska and Wójcik, 1992; Chodyń and Waśkowska-Oliwa, 2008; Waśkowska, 2012, 2014a, b, c; Waśkowska and Cieszkowski, 2014) are still scarce. The majority of references mention only characteristic forms, or refer to single foraminiferal species and constitute only minor parts of comprehensive biorstratigraphic-lithostratigraphic accounts of the deposits of the Silesian Nappe. The sedimentation of the Hieroglyphic Beds occurred in deep-water sedimentary zones of the Carpathian Basin during essential palaeoclimatic changes linked with intense climatic cooling (e.g., Coxall et al., 2005; Agnini et al., 2006; Bijl et al., 2010; Galazzo et al., 2013 and papers cited therein). Therefore, studying the variability within continuous profiles of the Hieroglyphic Beds seemed to be an issue worthy of detailed investigation. This was the motivation behind undertaking more detailed analyses based on already published data. In recent years, changes have taken place within the taxonomy of foraminifera. Apart from redefinitions of species, new forms have also been described, identified in samples from the Hieroglyphic Beds (Waśkowska-Oliwa, 2008; Waśkowska, 2014a, b, c). Branches of palaeoecology have developed to provide possibilities for wider interpretations.

The present study focuses on the lithological development and its heterogeneity in the Hieroglyphic Beds of the Silesian Nappe in the western sector of the Outer Carpathians, as well as on the variability in the foraminiferal record:

STUDY AREA

Studies were conducted within the Outer Carpathians, which are composed predominantly of turbidite deposits developed in basins of the North-Western Tethys. The Carpathian deposits are chiefly of a deep-water type and developed during the Mesozoic and Cenozoic times. One of the Tethys basins is the Silesian Basin sensu lato, which evolved during its 150 million years of existence, changing its extent, morphology and configuration (e.g., Książkiewicz, 1962, 1965, 1972, 1977; Unrug, 1979; Cieszkowski et al., 1983; Słomka, 1993; Ślązka and Kaminski, 1998; Ślązka et al., 2006; Golonka et al., 2006, 2013; Olszewska and Malata, 2006; Oszczypko, 2006; Ryłko, 2004; Słomka et al., 2006; Golonka and Waśkowska-Oliwa, 2007). The Jurassic–Lower Cretaceous sediments were deposited in one of the two main Carpathian basins, called the Protosilesian Basin. This basin includes early stages of deep-sea basin development. The Upper Cretaceous–Lower Paleogene deposits accumulated in the Silesian Basin sensu stricto, which emerged as a result of geotectonic reorganization via dividing the basin from the Protosilesian Basin. On the other hand, the Late Paleogene and Early Neogene formations were deposited in the Krosno-Menilite Basin, which – after the next reorganization of the architecture of the Carpathian basins, associated with the disappearance of cordilleras – represents the declining phases of the evolution. In the Miocene, a complicated process of orogeny resulted in the disappearance of the Carpathian basins, and the deposits accumulated in the basins became the constituents of the Carpathian nappes that subsequently emerged.

The Outer Carpathians have a nappe-type structure (e.g., Nowak, 1927; Świderski, 1948; Książkiewicz, 1962, 1965, 1972, 1977; Geroch et al., 1967; Mahé, 1974; Eliaš, 1979; Cieszkowski et al., 1985; Żyko et al., 1989; Słomka, 1995; Ślązka and Kaminski, 1998; Golonka and Waśkowska, 2007; Golonka et al., 2013, Fig. 1). Among the Outer Carpathian nappes, the central position is occupied by the Silesian Nappe. Its deposits were accumulated mainly in the Silesian Basin sensu lato.

The Hieroglyphic Beds were studied in the area between the Ropa River valley to the east, and the Olza River valley to the west. The study covers four sectors in the Silesian Nappe. Starting from the east, these are: the Beskid Niski Mountains, Rožnów Foothills, Wiśnica Foothills, and the Beskid Śląski Mountains (Fig. 1). Representative, fairly complete profiles of the Hieroglyphic Beds were selected from each sector, having original lower and upper boundaries with the under- and overlying divisions preserved. In the eastern sector, the complete profile is situated in the town of Gorlice, in the Sękówka River valley (Fig. 2). Next, in the Rožnów Foothills area, the Hieroglyphic Beds and Green Shales occur in an area adjacent to the eastern shore of Rožnów Lake. In this area, the outcrops of Hieroglyphic Beds were analysed in the Gródek-Lipie area, whereas a profile in the Szczecinówka Stream valley was selected for detailed study (Fig. 2). In the Wiśnica Foothills, outcrops located between Zegartowice and Szczyrzyc were analysed. A detailed analysis was carried out on a complete profile situated in the valley of the Stradomka River and its tributaries in Krzeslawice and Pogorzany (Fig. 2). In the westemmost sector, which included outcrops in the Beskid Śląski Mountains, the Hieroglyphic Beds were analysed in the Jasnówice, Istebna, and Kamesznicza areas. A complete profile is available in the Olecka Stream valley, in the border zone between Poland and the Czech Republic (Fig. 2).

METHODS AND MATERIALS

The research was based on field work which consisted of prospecting, detailed profiling and micropalaeontological sampling of the Hieroglyphic Beds in the selected regions described above. Material for micropalaeontological analysis was prepared according to standard procedures, involving maceration in an aquatic solution of Glauber’s salt, and washing on 0.068 mm sieve meshes. From the subsequent portions of residue obtained in this way, all microfossils were separated from the terrigenous material and subjected to verification. For the purpose of micropalaeontological study, 105 samples from the Hieroglyphic Beds were selected. The microfossils were dominated by foraminifera, including mainly agglutinated forms, whereas fish teeth occurred as an accessory component. In calcareous deposits, echinoid spines and fragments of mollusc shells were found. The faunal specimens were in a fairly good preservation state. The microfaunal analysis pertained only to the foraminiferal group.

The material was analysed under a NIKON VL100POL binocular microscope at the Department of General Geology and Geotourism of the Faculty of Geology, Geophysics and Environmental Protection, AGH University of Science and Technology (WGGiOŚ AGH), and a FEI QUANTA 200 FESEM scanning microscope at the Scanning Microscopy Laboratory of WGGiOŚ in Kraków.

The analysed materials have been deposited in the author’s collection at the Department of General Geology and Geotourism of the Faculty of Geology, Geophysics and Environmental Protection, AGH University of Science and Technology in Kraków.
Lithology. The Hieroglyphic Beds occur between the Ciękówice Sandstone and the Globigerina and Menilite Beds (Sikora, 1964; Szymakowska, 1979), attaining a thickness of more than 200 m (Waśkowska, 2014a; Fig. 3). Their base is sharp and the natural transition into the Hieroglyphic Beds is distinctly marked in the profile. The boundary interval consists of the last compact complex of thick- and very thick-bedded noncalcareous Ciękówice-type sandstones, above which occurs a shale complex with single beds of laminated sandstones. Szymakowska (1979) described the variegated shales between the Ciękówice Sandstone and the Hieroglyphic Beds in the Gorlice area. In the lower part of the section, the sandstones are medium-bedded, fine-grained, and towards the top, the beds gradually decrease in thickness and the shale complexes are interbedded by several centimetre thick layers of sandstones. The shales have a dark grey colour. They are laminated by grey shales of lighter colours, and are strongly bioturbated. Sandy shales with muscovite, or harder massive siltstones occur as intercalations. The complex with sandstones reaches a thickness of ca. 60 m. Above it, the Hieroglyphic Beds continue exclusively as sandstone-free deposits represented initially dark-grey and grey bioturbated shales which subsequently pass into grey-green ones with a slightly increased proportion of clay (Fig. 4). In the upper part, some 40 m from the top, there is a 15 metre thick complex of variegated shales with red shales laminated by green shales containing cream-coloured bentonites (Figs. 3 and 4). In the middle part of the profile, a submarine slump is found with plastically deformed clasts of grey-green shales within the disturbed Hieroglyphic deposits. The transition of Hieroglyphic Beds into the overlying...
Globigerina and Menilite Beds is distinctly marked in the profile (Fig. 4). Among the grey-green shales, characteristic of the Hieroglyphic Beds, there are thin layers of brown shales that are characteristic for Menilite Beds, which completely supersede the Hieroglyphic-type shales over ca. one metre of the profile. The first thin beds of grey marls/marly Globigerina-type limestones are found at this level.

**Foraminiferal record and biostratigraphical age.** The lower part of the Hieroglyphic Beds contains an uncharacteristic fauna comprised predominantly of cosmopolitan and long-ranged forms (Fig. 3). The most numerous are tubular foraminifera, i.e., *Bathyssiphon, Psammosiphonella, Rhabdamina*, as well as the genera *Recruvoides, Thalmananammina, Paratrochamminoides* and *Trochamminoides*. The foraminiferal assemblages from the lowermost part of the Hieroglyphic Beds contains an increased proportion of *Trochammina* species, and their quantity fluctuates around 20% of all foraminifera in the assemblage. Single individuals of *Caudammina ovula* (Grzybowski), *C. excelsa* (Dylążanka) and *Annectina grzybowskii* (Jurkiewicz) appear (Fig. 5), which had their last occurrences in the Early Eocene (e.g., Jurkiewicz, 1967; Jednorowska, 1968; Bąk, 2004; Kaminski and Gradstein, 2005; Waśkowska, 2011a, b, 2015a). There is also *Popovia beckmannii* (Kaminski et Gerchok) known from the Paleocene to the Middle Eocene (Kaminski and Gerchok, 1987; Kaminski and Gradstein, 2005). From the lower part of the Hieroglyphic Beds, *Bieda* (1946) reported *Nummulites planulatus* Lamarrck, therefore documenting the Lower Eocene age of this part of the unit. The samples from the upper part, underlying the Hieroglyphic Beds of the Cieżkowice Sandstone, contain assemblages of *Glomospira Acme* type, with the proportion of *Glomospira* forms reaching up to 50%. In the deposits of the Outer Carpathians, such assemblages have been found in the Lower Eocene (e.g., Jurkiewicz, 1959, 1967; Morgiel and Szymakowska, 1978;
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Fig. 3. Biostratigraphy of the Hieroglyphic Beds against schematic lithological logs
Olszewska, 1980, 1984, 1997; Morgiel and Olszewska, 1981; Bąk et al., 1997; Wałkowska-Oliwa, 2000, 2005; Bąk, 2004; Cieszkowski et al., 2006b), and their presence may constitute a reference to time frames of the sedimentation of the Hieroglyphic Beds.

More taxonomically diversified assemblages providing the basis for subdividing relevant biostratigraphic zones in the Hieroglyphic Beds occur only in half of the thickness of the shale complex. The first of the distinguishable zones is the Reticulophragmium amplexectens zone (Fig. 3). In foraminiferal assemblages, the index taxon co-occurs with Egerelloides propinquus (Brady), Praesphaerammina subgaleata (Vasieck), Haplophragmoides nauticus Kender, Kaminski et Jones, Buzasina pacifica (Krasheninnikov) (Fig. 5) and Ammolagen a clavata (Jones et Parker). The sedimentary interval with the Reticulophragmium amplexectens zone contains point occurrences of deposits with redeposited fauna representing an assemblage that is transferred from variegated deposits. Rede;posited forms constitute an admixture to the typical Hieroglyphic-type assemblage. Against the grey tests occurring commonly in surrounding deposits, it distinguishes itself by the presence of tests with a characteristic reddish colouration. The redeposited forms include mainly foraminifera with round-shaped tests, e.g., Glomospira and Recurvoides, as well as the species Caudammina gigantea Geroch, not known to occur in the Eocene, but found in older intervals. In the upper part of the Hieroglyphic Beds, beginning from the level with variegated shales, the index species for the next biostratigraphic zone Ammodicus (Dolgenia) latus Grzybowski is a common element (up to 10% of the foraminiferal assemblage; Figs. 3 and 5). Among typical Eocene foraminifera, Pseudonodosinella elongata (Grzybowski), and single individuals of Eratidus gerochi Kaminski et Gradstein and Bulbobaculites goralculus Wałkowska (Wałkowska, 2014a) are identified. In the topmost part of the profile, Spirosigmoilinella compressa Matsunaga (Fig. 5) and planktonic foraminifera appear. Large Subbotina specimens, typical of the Eocene, are represented in greatest numbers. Also identified were Thurammina species that are relatively rare in the Carpathian assemblages. The characteristic feature of the assemblages of the upper part of the Hieroglyphic Beds is an increased proportion of Reophax, which fluctuates around 10% of the assemblage.

ROŻNÓW Foothills – ROŻNÓW Lake Area

Lithology. Between the Ciężkowice Sandstone and Globigerina and Menilite Beds, there is a complex of deposits made up predominantly of shales (Fig. 3). Above the
Ciężkowice Sandstone complexes, there are ca. 20 m thick shale-sandstone deposits of the Hieroglyphic Beds with grey laminated sandstones (Fig. 6). They are at first medium- and thin-bedded, then thin-bedded and becoming increasingly rarer until they gradually disappear (Waśkowska, 2014b). Shales are dark grey, at some places partly sandy, and are laminated with paler grey shales. They rarely contain siderite concretions. Above the complex of classic Hieroglyphic Beds there are deposits devoid of sandstone, known as the Green Shales (Figs. 3, 6–8). In the Lipie area, these are ca. 150 m thick grey and grey-green shales, laminated by darker shales in the lower part, and grading towards the top into grey-green deposits with a distinct increase in the content of clay grains. Among them, single thin layers of bentonite sporadically occur (Waśkowska, 2014b; Fig. 6). The Green Shales includes submarine slump deposits with oval blocks up to 2 m in diameter, composed of “septarian limestones” in a silty matrix (Cieszkowski, 1992; Cieszkowski and Waśkowska, 2013a, b; Figs. 6 and 8). In the Hieroglyphic-Green Shale Beds of the Rożnów Lake area, there is an extended olistostome. Its presence results in the increased thickness of this unit locally up to 350 m (Waśkowska and Cieszkowski, 2014). The contact between the Green Shales and the overlying Globigerina Marl is fairly distinct (Fig. 7) and placed beneath the first bed of grey marly lime-

stones typical for Globigerina Marl, or upon the complex of grey-green marly shales if the limestone beds are absent.

**Foraminiferal record and biostratigraphical age.** The Hieroglyphic Beds and the lower part of the Green Shales contain fauna typical of the Lutetian Reticulophragmium amplexectens zone (Fig. 3). The commonly occurring diagnostic taxon, Haplophragmoides nautilus (Kender, Kaminski et Jones), is accompanied by Popovia beckmanni (Kaminski et Geroch), Adercotryma agterbergi Gradstein et Kaminski, Buzasina pacifica (Krasheninnikov) and Insculptarenula aff. subvesicularis (Hanzliková) (Fig. 5) known from the Eocene (Waśkowska, 2014b). In the lower part of this biozone, the last occurrences of Caudammina ovula (Grzybowski) and Hormosiná velascoensis (Cushman) are observed (Fig. 5). Sandstone from the upper part of the Ciężkowice Sandstone of the Rożnów Lake area contains nummulitic limestone clasts with Nummulites laevigatus (Bruguière) of the Middle Eocene (Cieszkowski 1992). Next, the middle part of the Green Shale section contains assemblages of the Ammodiscus (Dolgenia) latus zone with Eggerellidoides propinquis (Brady) and Bulboculites gorgilicensis Waśkowska, Buzasina pacifica (Krasheninnikov) (Figs. 3 and 5). An increase in the abundance of Reophax is observed in its middle part. In the topmost part of the Green Shales, Reticulophragmium gerochii Neagu et al. ap-

**Fig. 5. Distribution of selected foraminiferal species within the Hieroglyphic Beds**
Fig. 6. Lithological logs of the Hieroglyphic Beds – examples

Lowermost part: A – Lipie section; B – Stradomka section; C – Olecka section; D – lower part, Stradomka section; E – middle part, Olecka section; F – upper part, Olecka section; grain size: A – silt, C – coarse sand, F – fine sand, M – medium sand, P – clay
pears ephemerally, therefore marking the Prabonian Reticulophragmium rotundidorsatum (=geroci) zone (Fig. 3). In the uppermost part of the Green Shales, the abundance and diversity of planktonic foraminifera belonging mainly to the genus *Subbotina*, as well as of the calcareous benthos of *Eponides-Cicicides* morphotypes increase dramatically (Waśkowska, 2014b).

**Lithology.** As in other sections, the Hieroglyphic Beds, up to 200 m thick, occur above the Ciężkowice Sandstone (Fig. 3). Their lower boundary is distinct. A ca. 3 m thick transitional series occurs under the last compact complex of thick-bedded sandstones of the Ciężkowice type. It starts with medium- and thin-bedded sandstones, followed by thin-bedded grey sandstones (Waśkowska, 2015b; Fig. 6). The lower part of the Hieroglyphic Beds, which constitutes ca. one-third of the profile, consists of deposits devoid of sandstone, represented by strongly bioturbated grey-green shales with intercalations of red shales (Fig. 9), rarely and irregularly distributed in the profile. Above it, there are thin- and medium-bedded quartzose sandstones, with parallel or wavy lamination and numerous hieroglyphs, mainly trace fossils. In the lower part, two complexes of variegated shales as well as a 10 m thick subaqueous slump were found (Waśkowska, 2015b; Figs. 3, 6 and 9). Clasts of shales, sandstones similar to those from the Istebna Beds, and thin-bedded flysch deposits occur in the matrix. Within the shale-sandstone profile, there is a ca. 20 m thick complex of predominantly brown and brown-grey shales laminated by grey-green shales (Figs. 3 and 9). Its characteristic feature is the presence of numerous thin layers of cream-coloured bentonites, maybe of pyroclastic origin. This complex has the characteristics of “the Black Eocene-type” deposits (Waśkowska, 2015b). Above it, sporadic carbonate concretions are observed in shale-sandstone deposits. The transition into the overlying deposits of the Globigerina Beds is evident. The transition zone has a thickness of ca. 1.5 m. Within this zone, single thin beds of grey marly Globigerina limestones are present, with the co-occurrence of dark shales characteristic of the Menilite Beds (Fig. 7).

**Foraminiferal record and biostratigraphic age.** The lower and middle parts of the Hieroglyphic Beds (shale complex and thin-bedded flysch beneath “the Black Eocene-type” deposits) contain a nondiagnostic cosmopolitan deep-water foraminiferal assemblage (Fig. 3). It occurs in the deposits corresponding to the Lower and Middle Eocene. Identification of foraminiferal zones is difficult in this interval because of the presence of chiefly long-ranged species and the lack of index species that determine adequate biostratigraphic intervals in accordance with the zonal definitions. The estimated Early and Middle Eocene age is predetermined by the presence of forms whose biostratigraphic ranges reach the Early Eocene, namely *Annectina grzybowskii* (Jurkiewicz) (e.g., Jurkiewicz, 1967; Jednorowska, 1968; Bąk, 2004; Kaminski and Gradstein, 2005; Waśkowska, 2011a, b, 2015a), and species that occur in Carpathian deposits from the Early Eocene, i.e., *Reticulophragmium amplexans* (Grzybowski), *Subbotina
Fig. 8. Deposits of the Hieroglyphic Beds and Green Shales in the Lipie section

A – hieroglyphic-type deposits in uppermost part of the Ciężkowice Sandstones; B – thin-bedded flysch deposits of the Hieroglyphic Beds; C, E – deposits of the Green Shales; D – white bentonite layers within the Green Shales; F – calcareous concretions from chaotic deposits of the Green Shales
hornibrooki (Brönnimann), Eratidus gerochi Kaminski et Gradstein, Haplophragmoides nauticus Kender, Kaminski et Jones and Pseudonodosinella elongata (Grzybowski) (e.g., Morgiel and Olszewska, 1981; Geroch and Koszarski, 1988; Olszewska et al., 1996; Olszewska, 1997; Kaminski and Gradstein, 2005; Cieszkowski et al., 2006b; Pearson et al., 2006; Wałkowska-Oliwa, 2008; Wałkowska, 2011a, b). The age of the assemblage is further supported by the superposition in the profile. Within the part of the profile with the cosmopolitan fauna, there is a distinct sequence of deposits containing crisis assemblages with numerous and small-sized Trochammina whose age was determined to be Early Eocene, based on planktonic and agglutinated foraminifera. Within the Lower Eocene variegated deposits, an increase in the number of Glomospira is observed (Wałkowska, 2015a).

The foraminiferal assemblages from the middle and upper parts of the thin-bedded flysch are characteristic of the Ammodiscus (Dolgenia) latus zone (Fig. 3) sensu Olszewska (1997), defining the Bartonian interval. The characteristic forms include Haplophragmoides parvulus Blaicher, Buzasina pacifica (Krasheninnikov), Ammomarginulina aubertae Gradstein et Kaminski, Eggerelloides propinquis (Brady), Insculptarenula aff. subvesicularis (Hanzlíková) and Bulbobaculites gorlicensis Wałkowska. In the upper part,
SpirosigmaLinella compressa Matsunaga appears (Waśkowska, 2015b; Fig. 5). In the lower part of "the Black Ecoene-type" complex, the assemblage contains calcareous foraminifera redeposited from Eocene deposits of shallower parts of the Silesian Basin. In the topmost part of the section, the assemblages are characteristic of the Priabonian Reticulophragmium rotundidorsatum (=gerochi) zone (Fig. 3) within which the index species occasionally occurs. In the near-top parts of the profile, the numbers of planktonic and calcareous benthic foraminifera, whose assemblages point to its Priabonian age, rise dramatically (Waśkowska, 2015b).

**Lithology.** In this area, the Hieroglyphic Beds, with a thickness of up to ca. 130 m, occur as thin-bedded shale-sandstone flysch (Fig. 3). In the bottom part, bioturbated shales of grey-green colouration are laminated with slightly darker grey shales (Fig. 6). Sandstone beds are minor constituents, with an average thickness of up to several centimetres. They are grey and laminated, with muscovite on their uppermost surfaces (Fig. 10). In the Kamesznica area, the lower part of the Hieroglyphic Beds is represented by grey and grey-green bioturbated shales with muscovite and spherosiderites. In the middle part of the section, there is a complex devoid of sandstones, ca. 25 m in thickness, composed of green soft shales. In the central part of the section, it contains variegated shales – green shales with red laminae (Figs. 3, 6 and 10). In this complex, intercalations were identified as small cream-coloured bentonites. The upper, shale-sandstone part of the profile contains complexes with more numerous thin sandstone beds, as well as complexes in which sandstones are rare. It is difficult to delineate the lower contact. The Hieroglyphic Beds are underlain by the Upper Istebna Shales and form thin-bedded flysch predominantly made up of dark grey sandy shales with muscovite. Spherosiderites are an accessory component of the profile, except for the part of the profile where sandstones are absent. The natural transition into the overlying deposits is gradual (Fig. 6). The proportions of grey-green shales typical of the Hieroglyphic Beds successively increase and abundant...
bioturbation also appears. The Hieroglyphic Beds successively grade into the Menilite Beds. Dark brown shales, characteristic of the Menilite Beds, appear in the profile: first as intercalations and then replacing the shales of the hieroglyphic-type. The quantity and thickness of sandstones also increase dynamically. The transition zone to the Menilite Beds is several metres thick.

Foraminiferal record and biostratigraphic age. The foraminiferal assemblages from the Hieroglyphic Beds are cosmopolitan (Fig. 3). In the lower part of the section, foraminifers are relatively abundant, whereas in the upper part of the profile, above the complex devoid of sandstones, the numbers drop rapidly. The Hieroglyphic Beds occur above the Upper Istebna Shales of Paleocene age, and the poorly taxonomically differentiated foraminifer assemblages contain a typical Paleogene species of Rzehakina fissistomata (Grzybowski) (Fig. 3). In the lower part of the Hieroglyphic Beds, there is a distinct increase in the number of Trochammina, and monospecific assemblages predominantly of dwarfed forms are found, denoting crisis-feature assemblages (Waszkowska, 2012, 2015a). In the lower part of the complex with the Trochammina assemblages, an increased proportion of Glomospira is observed, among which Glomospira charoides (Jones et Parker) predominates. In the assemblages of cosmopolitan and long-ranging species, Caudammina ovula (Grzybowski), Glomospira diffundens Cushman et Renz and Buzasina pacifica (Krasheninnikov) are sporadically found (Figs. 3 and 5). These species are most commonly found in the Senonian and Paleocene. Single occurrences of these species are also recorded in the Early Eocene. In turn, a typical Eocene species, also sporadically recorded in the lower part of the Hieroglyphic Beds is Eraulites gerochii Kaminski et Gradstein. Praesphaerammina subgaleata (Vasicek) is common. The foraminiferal assemblages from the middle Hieroglyphic shale complex with variegated shales have a slightly different character. They are characterised by increased taxonomic diversity, including the presence of Saccamminoides carpathicus Geroch, which has a relatively short stratigraphic range. This species occurs in the Carpathians exclusively in the Lower Eocene (e.g., Geroch, 1955, 1956, Geroch et al., 1967; Jurkiewicz, 1967; Morgijel and Szymakowski, 1978; Olzewska, 1980, 1981, 1997; Geroch and Nowak, 1984; Geroch and Koszarz, 1988; Rajchel, 1990; Waszkowska-Oliva, 2000; Bak, 2004; Olzewska et al. 2006; Waszkowska, 2011a, b) and allows establishing the age of this part of the profile.

In turn, the assemblages occurring within the thin-bedded shale-sandstone flysch above the shale complex with variegated deposits are taxonomically uniform. They contain only cosmopolitan, long-ranged forms typical for the Cretaceous and Paleogene. The most numerous group is comprised of the tubular forms Bathysiphon, Psammospironella and Rhabdammina, followed by Paratrochamminoides, Trochamminoides and Recurvoides, and then accompanying components like Ammodiscus, Ammosphaeroidina, Halophragmacea, Glomospira, Karrenula, Saccammina and Trochammina. There are very few species of biostratigraphic significance in this interval, so it cannot be sub-divided into zones based on agglutinated foraminifers. Spirosigmillina compressa Matsunaga, found in one of the samples from the topmost part of the profile (Fig. 5), is known to range from the Middle/Late Eocene in the boreal seas (Charnock and Jones, 1990; Kaminski and Gradstein, 2005; Kaminski and Ortiz, 2014) and may suggest a Late Eocene age for this part of the profile. Similarly, poor assemblages were found in the lower part of the Menilite Beds. In this region, the lack of Globigerina Marls, which are an isochronous level in the Carpathians, poses difficulties in accurately marking the upper contact of the Hieroglyphic Beds. The foraminiferal assemblages lack the planktonic forms which commonly occur in the near-top parts of the Hieroglyphic Beds in areas east of Istebna.

DISCUSSION

LITHOLOGICAL DEVELOPMENT

Lower boundary. The position of the base of the Hieroglyphic Beds depends on the development of the underlying lithostratigraphic units (Fig. 3). The Ciężkowice Sandstone is widely distributed in the Western Carpathians within the Silesian Nappe. It occurs as a series of large lenses predominantly made up of thick-bedded sandstones occurring within deposits with prevalent shales (Leszczyński, 1981). The Ciężkowice Sandstone forms the thickest and best-developed complex around its stratotype area (Leszczyński, 1981; Cieszkowski et al., 1991; Leszczyński and Radomski, 1994). At its maximum extent, the uppermost part reaches the Lutetian in the Reticulophragmum amplispinatum zone. Eastward and westward, a gradual reduction of the Ciężkowice Sandstone is observed. It is marked by the thinning of sandstone lenses, reduction in their number, as well as their greater fragmentation and dilution (Leszczyński, 1981). West of the Ciężkowice area, the relatively compact outcrops of the Ciężkowice Sandstone lose their continuity. This phenomenon is recorded from as far as Mszana Dolna and Sucha Beskidzka (e.g., Książkiewicz 1974a, b; Burtan, 1978) and continues up to the areas of Istebna (Burtanówna et al., 1937; Burtan et al., 1956; Burtan, 1972, 1973, 1978) and Moravia (e.g., Menčík and Tyraček, 1985; Ryko, 2004; Bubik, 2007). Additionally, the stratigraphic range of the Ciężkowice Sandstone on the peripheries of its distribution is successively shorter; its uppermost part is dated as Early Eocene or it descends to the Paleocene/Eocene boundary. The contact zone with the Hieroglyphic Beds is clearly marked in the profiles (Figs. 3 and 6). The transitional complexes, which constitute a gradual transition between the Ciężkowice Sandstone and the Hieroglyphic Beds, are relatively thin with the thickness of up to several metres. They are characterised by the presence of grey or grey-green shales of the Hieroglyphic type, along with dark shales typical for the Ciężkowice Sandstones. They are interbedded by grey and beige sandstones whose layers thin up the section of the complex, whilst simultaneously the frequency of their occurrence decreases. It can be assumed that the sedimentation of the Ciężkowice Sandstone terminated with the last compact complex of thick-bedded sandstones with a characteristic beige colouration.

The Hieroglyphic Beds occur above the Ciężkowice Sandstone, and in case of its absence directly above the Istebna Beds. Such a situation takes place in the western part of the area (Figs. 3 and 6), and it continues in the Czech part of the Outer Carpathians (Eliaš, 2001; Bubik, 2007). The uppermost part of the Istebna Beds (Upper Istebna Shales) is represented by thin-bedded flysch predominantly composed of dark shales. The sedimentary transition from the Upper Istebna Shales into the Hieroglyphic Beds is gradual (Burtan, 1936; Burtanówna et al., 1937; Geroch, 1960; Fig. 6), and the contact between them is conventionally marked in the profile where the grey or grey-greenish shales typical of Hieroglyphic Beds prevail over the dark grey Istebna Shales with muscovite. Shales of the Hieroglyphic Beds contain abundant bioturbation that can be used as an additional criterion for marking the
boundary. In many places, at the contact between the Hieroglyphic Beds and the underlying divisions, variegated shales appear (e.g., Burtan et al., 1956; Burtan, 1972, 1973; Szymakowska, 1979; Leszczyński, 1981; Wójcik et al., 1993a, b; Leszczyński and Radomski, 1994) although they are not always present (Figs. 3 and 6).

**Upper boundary.** The Hieroglyphic Beds contact with the Globigerina Marls, and, if the latter are absent, directly with the Menilite Beds (Figs. 3 and 7). The Globigerina Marls occur widely in the Outer Carpathians and their sedimentation lasted a short period from the latest Eocene to the Oligocene (e.g., Blaicher, 1970; Olszewska, 1983, 1984; Leszczyński, 1997). Their thickness within the Silesian Nappe is estimated at several metres (e.g., Geroch et al., 1967; Leszczyński, 1988, 1997). The Globigerina Marls are a complex of pelagic carbonates characterised by the presence of marly limestones and cream-coloured marls with a rich planktonic foraminiferal fauna, interbedded by grey and light green marls and marly shales (Geroch et al., 1967; Blaicher, 1970; Olszewska, 1983, 1984; Leszczyński, 1996, 1997). The transition zone between the Hieroglyphic Beds and the overlying unit is relatively thin, up to 1 m. In the uppermost part of the Hieroglyphic Beds, the carbonate content increases dramatically, and Menilite-type shales occur as interbeds (Fig. 7). Leszczyński (1996) marked this contact on the first green marly shale underlying a light-coloured marl that is the discriminating feature of the Globigerina Marls.

Locally, the Globigerina Marls do not form a separate complex but constitute intercalations within dark brown shales characterising the Globigerina Marls complex. These components of the thin-beded flysch. Authigenic structural material of the Globigerina Marls was diluted by terrigenous material. Such a situation occurs, e.g., in the Gorlice area (Szymakowska, 1979; Figs. 3 and 7), as well as in the Grybów, Bochnia, Limanowa, Wieliczka, Myślenice, Lachowice, Sucha-Beśkidzka, Bielsko-Biała and Istebna sections (e.g., Burtan, 1936, 1964a, 1973; Burtanówna et al., 1937; Nowak, 1963, 1964; Sikora, 1963; Burtan and Skoczylas-Ciszewska, 1964a, b; Szymakowska, 1964; Paul, 1993). In these areas, the separation of the Globigerina Marls from the Menilite Beds is not possible. The contact between the Hieroglyphic Beds and Menilite Beds is then transitional.

**Lithology.** The Hieroglyphic Beds in the Silesian Nappe are a complex of the Hetero- or the and Menilite Beds—components of the thin-beded flysch. Authigenic structural material of the Globigerina Marls was diluted by terrigenous material. Such a situation occurs, e.g., in the Gorlice area (Szymakowska, 1979; Figs. 3 and 7), as well as in the Grybów, Bochnia, Limanowa, Wieliczka, Myślenice, Lachowice, Sucha-Beśkidzka, Bielsko-Biała and Istebna sections (e.g., Burtan, 1936, 1964a, 1973; Burtanówna et al., 1937; Nowak, 1963, 1964; Sikora, 1963; Burtan and Skoczylas-Ciszewska, 1964a, b; Szymakowska, 1964; Paul, 1993). In these areas, the separation of the Globigerina Marls from the Menilite Beds is not possible. The contact between the Hieroglyphic Beds and Menilite Beds is then transitional.

Lithological heterogeneity within the Eocene deposits defined as the Hieroglyphic Beds sensu lato is very obvious (Figs. 3, 6 and 7). It pertains primarily to the thickness and frequency of sandstone beds in profiles. Grey quartzose sandstones with silica cement predominate. Greenish sandstones with glauconite are also widespread. The zones of predominant dark shales are characterized by the appearance of brown sandstones with abundant muscovite. As a rule, these are very fine- or fine-grained sandstones grading upwards into shales (Figs. 7–9). They occur as single very thin or thick beds, with the thickness fluctuating from 1 to 5 cm, although there are some sections with medium-thick beds. The sandstones are laminated and massive. The beds commonly show parallel and wavy lamination, more rarely—cross-lamination. The number of sandstone beds in the profiles is very variable, and most of the units are predominantly made up of shales. The sand/shale ratio in the thin-beded flysch complexes varies from about 10 to 30%. Sandstones occur within the complexes of grey-green, non-calcareous laminated shales with variable proportions of individual colour variants. The presence of abundant bioturbation is a characteristic feature of these shales (Fig. 9).

Thick, lithologically relatively uniform, sandstone-free (or with minor quantities of thin-beded sandstones) complexes are known as the Green Shales and are distinguished above the Hieroglyphic Beds either as a separate informal lithostratigraphic unit, or as a main component of the Hieroglyphic deposits. The Green Shales function as a lithostratigraphic unit chiefly in the eastern sector of the Polish Outer Carpathians, marked in stratigraphic works from the areas of Męcina, Rożnów Lake, Ciężkowice, Rzepienicki, Jasło and Pilżno (Burtan and Skoczylas-Ciszewska, 1964a; Koszarski et al., 1964; Kuciński, 1965; Koszarski, 1966; Koszarski and Zykto, 1966; Cieszkowski et al., 1991; Cieszkowski, 1992; Wójcik et al., 1993a, b; Leszczyński and Radomski, 1994; Waśkowska, 2014b). In the Gorlice area, the Green Shales have not been found to date (Szymakowska, 1979), although the sandstone-free complex is known to occur at various stratigraphic positions; an example is the Szczyrzyc Foothills, where 70 m of the profile above the topmost part of the Ciężkowice Sandstone is composed of grey-green shales resembling Green Shales (Waśkowska, 2014a, c, 2015b; Figs. 3, 6 and 9). In the Beskid Śląski Mountains (Jasnowice area), a 25 m thick sandstone-free complex dominated by grey-green shales occupies the middle part of the Hieroglyphic Beds (Figs. 3, 6 and 10). In turn, in the Istebna area, the lower part of the Hieroglyphic Beds is almost sandstone-free (Waśkowska, 2015a). Wójcik et al. (1993b) noted sandstone-free green shale complexes from the lower part of the Hieroglyphic Beds in the Jasło area.

Other shale units are also in use as regards Eocene deposits corresponding to the Hieroglyphic Beds. A note on the shale nature of the complex between the Ciężkowice Sandstone and Menilite Beds was made by Świdziński (1950) who distinguished variegated shales in the Grybów area, describing them as “claystone shales or shale clays, greenish, interbedded by...
characteristic brown-purple shales”. At present, the term “variegated shales” is traditionally applied in the Polish geological nomenclature to sandstone-free deposits containing red shales as its most characteristic component. In the mid-twentieth century, this term regarded the prevalence of variously coloured laminated shales, although red shales were not a necessary component. Therefore, in many cartographic divisions of that time, the variegated shales were separated in place of the Hieroglyphic Beds (developed as thin-beded flysch) or as a variant name (e.g., Nowak, 1963; Sikora, 1963; Żytko, 1963; Burta, 1964b, c; Burta and Skoczylas-Ciszewska, 1964a, b, c; Skoczylas-Ciszewska, 1964), suggesting the presence of laminated, sandstone-free or nearly sandstone-free complexes. These deposits most often occur above the Ciężkówice Sandstone or Istebna Beds where they form a characteristic “layer cake” of lighter grey and/or green shales with darker ones. A large quantity of dark shales causes them to be very similar macroscopically to the shales of the Istebna Beds, especially because the latter complexes contain spheroiderites, like the Istebna Beds (Książkiewicz, 1974b; Burta, 1978; Wójcik and Rączkowski, 1994; Ważowska, 2015a). Locally, the Hieroglyphic Beds include complexes with a major proportion of sandstones, or made up predominantly of sandstones. Książkiewicz (1974b) reported that the sandstone/shale ratio in the lower part of the Hieroglyphic Beds might be 1:1. East of Gorlice, a 50–75 m thick complex containing thick-beded sandstones with intercalations of green-grey and dark grey shales was reported in the topmost part of the Hieroglyphic Beds. In their upper part, there are calcareous shales, above which the Glocz is widespread in the east of the basin (Wojnicz, 1991). In turn, in the Wojnicz area, thick-beded sandstone occurs within the Middle Eocene Hieroglyphic Beds (Kozarski and Kuciński, 1965).

The lithological development depends on the configuration of the sedimentation system, including the distribution and activity of source areas, as well as on the dynamics of gravitational processes and morphological conditions. Thus, the alternative occurrence of thin-beded shale-sandstone, and sandstone-free deposits is a natural consequence of the geometry of the sedimentation cone. However, the analysis of data from reference sources pertaining to the Hieroglyphic Beds indicates that sandstone-shale deposits are replaced by shale deposits, a phenomenon which is widespread in the eastern part of the study area and provides the basis for subdividing a lithostratigraphic unit now informally called the Green Shales. After formalisation, this division should operate at the rank of member, whereas the Hieroglyphic Beds should be a superior unit.

The variable sedimentation regime determines the lithological types. In the inventory of the Hieroglyphic Beds, besides the typical deposits of grey-green shales and thin-beded sandstones, the majority of which are turbidites, there are deposits testifying to the considerable effect of hemipelagic sedimentation. The most significant among them are the green shales that constitute a widely distributed facies in the Silesian Basin, and testify to a regional-scale reduction in terrigenous material supply. The complexes with red and dark shales, and complexes with bentonites should also be listed among other Hieroglyphic deposits developed under conditions of the quiet sedimentation regime.

The complexes with red shales are customarily termed “variegated shales”. Their characteristic property is the occurrence of red or cherry soft shales with intercalations of green-grey shales (Figs. 4, 9 and 10). In the Hieroglyphic Beds, the red shales are predominantly clayey deposits, made of finer material than the typical grey-green shales (Ważowska, 2015a). They occur in different lithostratigraphic positions within the Hieroglyphic Beds (e.g., Burtanówna et al., 1957; Książkiewicz, 1974b; Burta, 1978; Paul, 1993; Wójcik et al., 1993b; Leszczyński and Radomski, 1994; Wójcik and Rączkowski, 1994; Ważowska, 2014c, 2015a) and mostly do not show lateral continuity in the western part of the Outer Carpathians except for the variegated deposits underlying the Hieroglyphic Beds and overlying the Ciężkówice Sandstone (e.g., Burta et al., 1956; Burta, 1972, 1973; Szymakowska, 1979; Leszczyński, 1981; Wójcik et al., 1993a, b; Leszczyński and Radomski, 1994). The variegated deposits within the Hieroglyphic Beds usually occur as thick shale complexes (Figs. 3 and 6). As a rule, they are surrounded by grey-green shales, whereas sandstones in these zones are rare or disappear. In the Hieroglyphic Beds, variegated shale complexes have thicknesses from several to several tens of metres. In the Brzesko and Bochnia region, they are markedly thicker, and variegated deposits replace the thin-beded flysch typical for the Hieroglyphic Beds (Skoczylas-Ciszewska, 1952, 1954) or constitutes a thick shale complex occurring beneath the Menilite Beds (Skoczylas-Ciszewska and Burta, 1954). In the Jasło area (eastern region), the variegated deposits are a permanent component characteristic of the Hieroglyphic Beds. They constitute intercalations within the thin-beded flysch or they are a predominant component. In the latter case, thin-beded sandstones are relatively rare (Szymakowska and Wójcik, 1981, 1992). The variegated Eocene shales have the nature of oceanic red beds containing deep-water agglutinated foraminiferal assemblages. They are very widespread not only in the Silesian Basin, but are known as well from other Carpathian basins which developed from the ProtoSilesian Basin. They are also developed on a large scale in the neighbouring Magura Basin where they are formally distinguished as the Labowa Shale Formation.

The Middle Eocene complexes of Hieroglyphic Beds contain concentrations of bentonites (Fig. 3). They form thin layers usually with a thickness of about several millimetres, with white, cream or pinkish colouration (Chodyń and Ważowska-Oliwa, 2006; Ważowska-Oliwa et al., 2008; Ważowska, 2014b). The preservation of fine pyroclastic material in deep-sea conditions, supplied to the basin first by air, then successively transported in a column of water, is possible only under conditions of calm sea. In the eastern region, the amount of material that reaches together with a diminished supply of terrigenous material. Bentonites occur within the sandstone-free or nearly sandstone-free deposits developed as grey-green shales laminated with darker grey ones (Fig. 3). Alternatively, they also occur within shales dominated by dark deposits, showing similarities with the “Black Eocene-type” deposits known from the areas where there are units of the Fore-Magura group (e.g., Burta, 1978; Olszewska, 1981; Cieszkowski et al., 1985; Połowicz, 1985; Cieszkowski, 1986; Paul and Ryko, 1987; Osyczkpo and Wójcik, 1993). They are also recorded in areas of variegated shale deposits. The bentonite-bearing deposits occur in the lower and middle parts of the Hieroglyphic Beds. They are found in Lower Eocene deposits of the Kamesznica area, and in Middle Eocene deposits of the Szczyrzyc Depression. The Early Eocene bentonites correspond lithologically to the Glichów horizon in the Subsilesian Nappe (Cieszkowski et al., 2006b; Ważowska, 2011a), and have a stratigraphic position similar to the bentonites known from variegated deposits of the Magura Nappe (Cieszkowski et al., 2011), although the stratigraphic and geochemical similarities were not confirmed by detailed analyses.

The lithological component that accompanies nearly sandstone-free zones is sideritic concretions (Fig. 3). They occur ex-
clusively in grey shales or grey shales laminated with darker ones. The sidersites are loaf shaped, usually with diameters of several tens of centimetres, or stretched out flattened concretions, thinning or pinching out laterally at a scale of 3–4 m. They are composed of dark grey sideritic pellite and their surfaces are covered by limonitic substances.

The sandstone-free complexes are associated with the occurrence of subaqueous slumps (Fig. 3). These were recorded near the Roźnów Lake, in the Szczyczyr Foothills (e.g., Cieszkowski, 1992; Cieszkowski and Waśkowska, 2013a, b, 2014; Waśkowska, 2014b) and in the Gorlice region. The dimensions of these slumps vary from several metres to several hundred metres, and depend on the amount of material shifted. Their development is also heterogeneous. In the Gorlice area, the clasts of redeposited material are represented exclusively by grey shales. The samples collected in the nearby area contain – apart from the autochthonous fauna – forms redeposited from Cretaceous variegated deposits. In the Szczyczyr Foothills, the slump mass contains sandstone and shale clasts reminiscent of deposits of the Istebna Beds (Waśkowska, 2015b). The olistostome outcropping in the Roźnów Lake area is tripartite and contains diverse Eocene–Late Cretaceous deposits (Waśkowska and Cieszkowski, 2014). The submarine gravitational mass-movement deposits are found in the middle part of the Hieroglyphic Beds. The micropaleontological data indicate that the shifts took place in the Middle Eocene and point to increased geotectonic activity at that time.

The Hieroglyphic Beds *sanctu* late developed chiefly after the main deposition phases of a great sedimentation cycle marked by the intensive deposition of coarse-grained clastics in the Silesian Basin, from the Late Cretaceous through the Early Eocene. The complexes corresponding lithologically to the Hieroglyphic deposits also occur within the Ciężkowice Sandstone, and have been distinguished there as a facies associated with the Hieroglyphic Beds that feature turbidite characteristics (Leszczyński, 1981). They occur chiefly in the surroundings of thick-bedded Ciężkowice Sandstones. They differ from the typical Hieroglyphic Beds by the increased proportion of sandstones, and by the occurrence of dark grey shales and white sandstones. These sandstones feature Ciężkowice-type characteristics, and they have the same palaeotransport directions, whereas grey hieroglyphic sandstones with glauconite were probably supplied from other source areas (Leszczyński, 1981).

FORAMINIFERAL RECORD

Majority of agglutinated foraminifera living in deep flysch basins are long-ranged forms, and therefore have limited use in stratigraphic dating. In these habitats, the evolutionary mechanisms, depending on environmental stimuli prompting taxonomical differentiation, proceed slowly. Therefore, the dating of deposits based on deep-water agglutinated forms is not very precise (Waśkowska-Oliwa, 2007; Waśkowska, 2011b). The foraminiferal assemblages from the Hieroglyphic Beds show little taxonomical diversity (Figs. 11–13), therefore age dating based on this group of fossils brings about certain diagnostic difficulties. Planktonic and benthic calcareous foraminifera are occasional components of the assemblages whereas those occurring in the lower parts of the Hieroglyphic Beds are usually redeposited. They occur en masse in the topmost part of the Hieroglyphic Beds/Green Shales, as well as in the overlying Globigerina Marls.

The Hieroglyphic Beds are characterised by a differentiated foraminiferal record, although foraminifer tests are a common component of shales, indicating that the foraminiferal associations were permanently developing during the sedimentation of these deposits. The stratigraphic range of the Hieroglyphic Beds is variable; their upper boundary is almost isochronous whereas the lower boundary depends on the development of the Ciężkowice Sandstone (Fig. 3). Thus, the lower boundary of the Hieroglyphic Beds in the regions of maximum thickness of the Ciężkowice Sandstone lenses (e.g., the Roźnów Lake and Ciężkowice areas) occurs within the Lutetian, while towards the west, it successively descends to the Early Eocene, or to the Paleocene/Eocene boundary.

**Ypresian assemblages.** Analyses of the sections and published data indicate that the lower part of the Hieroglyphic Beds usually contains undiagnostic assemblages of agglutinated foraminifera, predominantly comprised of cosmopolitan forms known from the Cretaceous and Paleogene from many different regions of the world. The unification of Ypresian and Lutetian foraminiferal assemblages in the Hieroglyphic Beds is a common phenomenon, but the lack of index forms makes biostratigraphic determinations difficult. Data from publications pertaining to the fauna of this part of the Hieroglyphic Beds are scarce, and their little usefulness for biostratigraphy has been emphasised (Książkiewicz, 1974b). In lithostratigraphic studies, chiefly the diagnostic microfauna is cited from only upper parts of the profile (e.g., Książkiewicz, 1974b; Szymakowska, 1979; Cieszkowski, 1992; Leszczyński and Radomski, 1994).

In integrated biostratigraphical subdivisions of the Early Eocene in the Outer Carpathians, the assemblages with numerous *Glomospira*, followed by those with *Saccamminoides carpaticus* Geroch, *Saccamminoides diagnosticus* and *Saccamminoides striatulatus* Morget and Olszewski, 1981; Olszewska et al., 1996; Olszewski, 1997). In the material analysed, increased quantity of *Glomospira* from the Lower Eocene interval was found only in the Istebna region (Fig. 3). In the Szczyczyr section, this lithostratigraphic interval contains assemblages with undiagnostic fauna, and the amount of *Glomospira* increases dynamically only in the variegated shales (Waśkowska, 2015a). In the Silesian Nappe, *Glomospira* Acme assemblages are relatively common, occurring widely in the variegated complexes separating the Ciężkowice Sandstones (e.g., Jurkiewicz, 1959, 1967; Geroch, 1960; Cieszkowski, 1992). There is no palaeontological data on this type of fauna from the regions where the Ciężkowice Sandstones are absent or where the Hieroglyphic Beds are in direct contact with the Istebna Beds. The presence of species *Saccamminoides carpaticus* Geroch in the assemblages is very sporadic, except for samples obtained from variegated shales where specimens of this species are common (several specimens per sample). On the Czech side, the Roznov Beds (Eliaš, 2001; Golonka and Waśkowska-Oliwa, 2007), which are lateral equivalents to the Hieroglyphic Beds, descend to the Paleocene (Bubik, 2007).

Within the Early Eocene assemblages, there is a marked increase in the proportions of *Trocchammina* (Figs. 3 and 13) that is considered a cosmopolitan form and occurs universally in the foraminiferal assemblages of flysch basins of the Outer Carpathians, but it is normally an accessory component. In the Early Eocene, the quantity of *Trocchammina* in the Hieroglyphic Beds increased dramatically to several tens of percent, sometimes constituting the majority of the assemblage (Waśkowska, 2012, 2015a). The characteristic feature of the assemblages with numerous *Trocchammina* is, on the one hand, the increased number of foraminifera, and – on the other hand – the occurrence of dwarfed individuals. Such assemblages were identified in the Gorlice, Szczyczyr and Istebna areas (Fig. 3). Their Ypresian age was determined based on agglutinated and planktonic foraminifera (Waśkowska, 2012, 2015a). In the
The Eocene Hieroglyphic Beds of the Silesian Nappe in the Western Polish Carpathians...

Fig. 11. Foraminifera from the Hieroglyphic Beds of the Silesian Nappe

A – Bathysiphon sp. (sample Gorlice 22/6/13); B – Bathysiphon sp. (Gorlice 23/8/13); C – Nothia sp./Bathysiphon sp. (Gorlice 22/6/13); D – Nothia sp./Bathysiphon sp. (Olecka 134/20/09); E – Psammophilina cylindrica (Glassner) (Gorlice 23/8/13); F – Psammophilina discreta (Brady) (Gorlice 23/8/13); G – Rhizammina sp. (Gorlice 23/8/13); H – Saccamminoides carpathicus (Schubert) (Olecka 132/17/19); I – Placentammina placenta (Grzybowski) (Gorlice 18/26/13); J – Ammodiscus peruvianus Berry (Gorlice 19/15/12); K – Ammodiscus peruvianus Berry (Gorlice 27/7/12); L – Ammodiscus (Dolgenia) latus Grzybowski (Gorlice 27/7/12); M – Ammodiscus (Dolgenia) latus Grzybowski (Gorlice 17/4/12); N – Ammodiscus clevelandus (Reuss) (Gorlice 27/7/12); O – Glomospira serpens (Grzybowski) (Gorlice 17/4/12); P – Glomospira diffundens Cushman et Renz (Olecka 51/6/09); R – Glomospira charoides (Jones et Parker) (Olecka 108/25/09); S – Glomospira charoides (Jones et Parker) (Gorlice 19/15/12); T – Glomospira charoides (Jones et Parker) (Olecka 108/25/09); U – Glomospira glomerata (Grzybowski) (Gorlice 19/15/12); V – Glomospira glomerata (Grzybowski) (Gorlice 19/15/12); W – Glomospira gordialis (Jones et Parker) (Gorlice 19/15/12); Y – Dolgenia sp. (Olecka 108/25/09); Z – Thurammina sp. (Gorlice 22/6/13); AB – Saccamminoides carpathicus Geroch (Olecka 116/41/06); AC – Saccamminoides carpathicus Geroch (Olecka 137/23/09); AD – Spirosigmoilinella compressa Matsunaga (Gorlice 27/7/12); AE – Caudammina excelsa (Dylązanka) (Gorlice 15/2/12); AF – Caudammina ovula (Grzybowski) (Olecka 133/18/09); scale bar 100 µm
Fig. 12. Foraminifera from the Hieroglyphic Beds of the Silesian Nappe

A – Subrepohax scalaris (Grzybowski) (sample Gorlice 17/4/12); B – Pseudonodosinella elongata (Grzybowski) (Gorlice 27/7/12); C – Reophax pilulifer Brady (Gorlice 19/15/12); D – Reophax sp. (Gorlice 18/26/13); E – Reophax pilulifer Brady (Gorlice 19/15/12); F – Reophax duplex Grzybowski (Gorlice 18/5/12); G – Reophanus berrgreni Gradstein et Kaminski (Gorlice 27/7/12); H – Paratrochamminoides deflexiformis (Noth) (Gorlice 27/7/12); I – Trochamminoides proteus (Karrer) (Lipie 79/13/09); J – Trochamminoides cf. dubius (Grzybowski) (Olecka 108/25/09); K – Trochamminoides subcoronatus (Grzybowski) (Olecka 108/25/09); L – Trochamminoides cf. dubius (Grzybowski) (Lipie 19/15/12); M – Paratrochamminoides sp. (Olecka 108/25/09); N – Ammobaculites sp. (Gorlice 14/1/12); O – Ammobaculites sp. (Stradomka 29/45/06); P – Ammobaculites agglutinans d’Orbigny (Olecka 132/17/09); R – Ammomarginulina aubertae Gradstein et Kaminski (Lipie 85/19/09); S – Ammomarginulina aubertae Gradstein et Kaminski (Stradomka 1/str/03); T – Buzasina pacifica (Krasheninnikov) (Stradomka 69/53/05); U – Buzasina pacifica (Krasheninnikov) (Stradomka 69/53/05); V – Buzasina pacifica (Krasheninnikov) (Lipie 81/15/09); W – Eratidus gerochi Kaminski et Gradstein (Olecka 134/20/09); Y – Eratidus gerochi Kaminski et Gradstein (Gorlice 14/22/13); Z – Eratidus gerochi Kaminski et Gradstein (Gorlice 17/4/12); AB – Haplophragmoides porrectus Maslakova (Olecka 116/41/09); AC – Haplophragmoides walteri (Grzybowski) (Gorlice 19/15/12); AD – Haplophragmoides cf. walteri (Grzybowski) (Gorlice 19/15/12); AE – Haplophragmoides sp. (Lipie 86/20/09); AF – Haplophragmoides kirki Wikenden (Gorlice 17/4/12); AG – Haplophragmoides eggeri Cushman (Stradomka 25/44/06); AH – Praesphaerammina subgaleata (Vasicek) (Gorlice 14/22/13); scale bar 100 μm
Fig. 13. Foraminifera from the Hieroglyphic Beds of the Silesian Nappe

A – *Haplophragmoides excavatus* Cushman (sample Lipie 82/15/09); B – *Haplophragmoides nauticus* Kender, Kaminski et Jones (Lipie 82/15/09); C – *Ammosphaeroidina pseudopauciloculata* (Mjatliuk) (Gorlice 18/5/12); D – *Ammosphaeroidina pseudopauciloculata* (Mjatliuk) (Olecka 108/25/09); E – *Thalmannammina subturbinata* (Grzybowski) (Gorlice 19/15/12); F – *Recuroides anomis* Mjatliuk (Gorlice 10/18/13); G – *Thalmannammina subturbinata* (Grzybowski) (Lipie 86/20/09); H – *Trochammina* sp. (Olecka 133/18/09); I – *Trochammina* sp. (Olecka 133/18/09); J – *Insculptarenula aff. subvesicularis* (Hanzlíková) – central side (Stradomka 1/str/03); K – *Insculptarenula aff. subvesicularis* (Hanzlíková) – dorsal side (Stradomka 1/str/03); L – *Spiroplectammina spectabilis* (Grzybowski) (Olecka 132/17/09); M – *Spiroplectammina spectabilis* (Grzybowski) (Gorlice 10/18/13); N – *Karrerulina conversa* (Grzybowski) (Gorlice 19/15/12); O – *Karrerulina conversa* (Grzybowski) (Gorlice 19/15/12); P – *Karrerulina hornis* (Mjatliuk) (Gorlice 19/15/12); Q – *Karrerulina sp.* (Olecka 108/25/09); R – *Karrerulina conformis* (Grzybowski) (Olecka 108/25/09); S – *Reticulophragmium gerochi* Neagu et al. (Stradomka 64/58/05); T – *Reticulophragmium gerochi* Neagu et al. (Lipie 79/13/09); U – *Reticulophragmium amplectens* (Grzybowski) (Gorlice 17/4/12); V – *Reticulophragmium amplectens* (Grzybowski) (Gorlice 19/15/12); W – *Reticulophragmium amplectens* (Grzybowski) (Gorlice 7/4/12); AB – *Popovia beckmanni* (Kaminski et Geroch) (Stradomka 65/46/06); AC – *Popovia beckmanni* (Kaminski et Geroch) (Gorlice 19/15/12); AD – *Eggerelloides propinquus* (Brady) (Gorlice 19/15/12); AE – *Eggerelloides propinquus* (Brady) (Stradomka 27/26/08); scale bar 100 µm
Istebna area, the increased number of *Trochanamminula* accompanies the assemblages of Glomospira Acme type (Fig. 3). Thus, the monospecific assemblages with *Trochanamminula* developed in the Silesian Basin since the Early Ypresian.

In the Early Eocene, a taxonomic restructuring of foraminiferal assemblages took place (e.g., Tjalsma and Lohman, 1983; Miller et al., 1987; Kaminski et al., 1989; Pak and Miller, 1992; Thomas and Shackleton, 1996; Thomas, 1998). In the Early or Middle Eocene, the species common in the Late Cretaceous and Paleocene had their last occurrences. These are, e.g., *Caudammina ovula* (Grzybowski), *Annectina grzybowskii* (Jürkiewicz), *Caudammina excelsa* (Dyļąžanka), *Hormosina velascoensis* (Cushman) and *Glomospira diffundens* Cushman et Renz, recorded as sporadic forms in the Ypresian part of the Hieroglyphic Beds (Fig. 5). Their occurrences within undiagnostic assemblages of agglutinated foraminifera are carriers of biostatigraphic information. Because of the widespread occurrence of assemblages with cosmopolitan and long-ranging species in the lower part of the Hieroglyphic Beds, biostatigraphic assignments are possible only by analysing faunal variability in a continuous sequence of samples.

**Lutetian assemblages.** Beginning from the Middle Eocene, there is a record of gradual changes successively expressed chiefly as an increase in taxonomical diversity and gradual reduction in uniform uncharacteristic foraminiferal assemblages. The Lutetian assemblages mark a transitory interval between taxonomically poor Ypresian assemblages, and the more diversified Bartonian and Priabonian assemblages. A characteristic feature of the Lutetian interval is the relatively numerous occurrence of *Reticulophragmium amplaectens* (Grzybowski) (Figs. 3 and 13), continuing from the Lutetian and defining the biostatigraphic zone for which this species is an index taxon (e.g., Morgiel and Olszewska, 1981; Geroch and Nowak, 1984; Olszewska et al., 1996; Olszewska, 1997). The widespread and numerous occurrence of *Reticulophragmium amplaectens* (Grzybowski) in Carpathian assemblages coincides with the disappearance of *Saccaamnoides carpaticus* Geroch, with these two species co-occurring only in the late Ypresian (Olszewska et al., 1996; Olszewska, 1997; Kaminski and Gradstein, 2005; Waśkowska, 2011b). Assemblages with uncharacteristic cosmopolitan foraminifera also occur in the Lutetian interval of the Hieroglyphic Beds (e.g., Stradomka, Olecka profiles). Determination of the boundary between the Ypresian and Lutetian based on foraminiferal assemblages is difficult. As a rule, in the Hieroglyphic Beds where the Ypresian interval is represented by thin-bedded flysch, foraminiferal assemblages are less diversified, sometimes making determination of the Ypresian zone impossible. In thick beds of shale intervals, the diversity increases markedly and the assemblages have features characteristic of the *Reticulophragmium amplaectens* zone.

**Bartonian and Priabonian assemblages.** The Bartonian foraminiferal assemblages are diverse and usually contain biostatigraphically diagnostic forms. The index taxon for the Bartonian and Lutetian is *Ammodiscus* (*Dolgenia*) *latus* Grzybowski (Figs. 3 and 11) whose emergence in the Carpathians was reported from the Bartonian/Lutetian boundary zone (Jürkiewicz, 1967; Morgiel and Olszewska, 1981; Olszewska et al., 1996; Olszewska, 1997). *Ammodiscus* (*Dolgenia*) *latus* Grzybowski occurred until the end of the Eocene in the Outer Carpathians. It was accompanied by fairly large numbers of *Reticulophragmium amplaectens* (Grzybowski). The stratigraphic determinant of the Priabonian is the presence of *Reticulophragmium gerochi* Neagu et al. This species has recently been separated from the Oligocene *Reticulophragmium rotundidorstaum* (Hantken) (Neagu et al., 2011) which until 2011 had appeared under this name in the palaeontological literature. This form is reported from the upper part of the Hieroglyphic Beds or Green Shales from the Gorlice, Sucha Beskidzka, Roźnów Lake, and Ciężkowice areas (Książkiewicz, 1974b; Geroch et al., 1976; Szymkowska, 1979; Cieszkowski, 1992; Fig. 13). While *Reticulophragmium amplaectens* (Grzybowski) and *Ammodiscus* (*Dolgenia*) *latus* Grzybowski are widespread in assemblages and represented by numerous specimens, *Reticulophragmium gerochi* Neagu et al. is found only in taxonomically diversified assemblages, indicating their development under favourable ecological conditions. *Reticulophragmium gerochi* Neagu et al. is usually a minor component in the assemblage. It is ephemeral and relatively rare in the Upper Eocene section. Therefore, in the Hieroglyphic Beds or Green Shales, the Upper Eocene interval is more often represented by the foraminiferal assemblage with *Reticulophragmium amplaectens* (Grzybowski) and *Ammodiscus* (*Dolgenia*) *latus* Grzybowski, and it is not always possible to distinguish the *Reticulophragmium rotundidorstaum* (=gerochi) zone sensu Morgiel and Olszewska (1981), Geroch and Koszarski (1988) and Olszewska (1997). It should be taken into account during the age analysis. Because of great fluctuations in the faunal record of the Hieroglyphic Beds, the dating of these deposits, based on agglutinated foraminifera, provides reliable results only in case of a continuous depositional sequence. Dating of isolated samples can result in errors. In the Bartonian assemblages, and sporadically in the Lutetian assemblages from the Hieroglyphic Beds, foraminifers are rare in the Carpathians, e.g., *Eugyraeaides propinquus* (Brady), *Adocotryma agterbergi* Gradstein et Kaminski, *Buzasina pacifica* (Krasheninnikov), *Insulpentarula aff. subvesicularis* (Hanzliková), *Spiriosigmoilinella compressa* Matsunaga and *Thurammina* occur sporadically (Figs. 5, 12 and 13), but the bulk of the assemblage is composed of species more common in the boreal basins of the Eocene. In the topmost part of the Hieroglyphic Beds/Green Shales, the carbonate content increases successively along with the occurrence of calcareous planktonic and benthic foraminifera. *Subbotina div. sp.*, *Globigerinatheka index* (Finlay), *Catapsydrax dissimilis* Cushman et Bermúdez, *Turborotalia increbescens* (Bandy), *Globigerina officinalis* *Subbotina*, *Globoturborotalia carpathiensis* (Hoür et Wallaës) *Subbotina corpulenta* (Subbotina), *S. linaperta* (Finlay) and *S. yeguaensis* (Weinzierl et Apollin) are widespread (Waśkowska, 2015b).

**PALAEOEOCOLOGICAL IMPLICATIONS**

**Restructuring of assemblages after the Late Paleocene—Early Eocene crisis.** During the Early Eocene, the restructuring of benthic fauna assemblages took place in deep-water basins, which is well-marked in the Outer Carpathians (e.g., Bubik, 1995; Bąk, 2004; Waśkowska-Oliwa, 2005 and papers cited therein). This was a global trend associated with changes in Late Paleocene and Early Eocene palaeoecology, especially thermal conditions (so-called PETM – Paleocene Eocene Thermal Maximum) with the optimum in the Early Eocene (EECO) (e.g., Tjalsma and Lohman, 1983; Miller et al., 1987; Pak and Miller, 1992; Thomas and Shackleton, 1996; Thomas, 1998; Kennett and Stott, 1991; Kahlo et al., 1993, 1996; Pardo et al., 1999; Lourens et al., 2005; Agnini et al., 2009; Stap et al., 2010; Zachos et al., 2010; Påhlke, 2012). These phenomena resulted in a massive extinction of benthic species in deep seas, and this event is recognized as the single largest global extinction of benthic fauna. The Eocene assem-
blages are thus called “new post-crisis fauna” even though they contain many opportunistic long-lived forms functioning since the Cretaceous, which managed to survive the Late Paleocene crisis (Kaminski et al., 1996). In the Carpathian basins, these post-crisis assemblages are characteristic because their taxonomic diversity is lower, with numerous small forms of Glomospira among which two species predominate (e.g., Jurkiewicz, 1967; Bukib, 1995; Bąk et al., 1997; Waśkowska-Oliwa, 2000, 2011a; Bąk, 2004). The assemblages composed predominantly of Glomospira most often accompany hemipelagic, variegated deep-water deposits (e.g., Morgiel and Olszewska, 1981; Waśkowska-Oliwa, 2000; Bąk, 2004; Cieszkowski et al., 2011) in areas of low sedimentation rate (Kaminski et al., 1989). The reorganization of the assemblages structure took place gradually. It was a long-term process, lasting until the Middle Eocene and including gradual diversification of fauna representing various trophic groups that colonised epif- and infaunal niches. The restructuring of benthic fauna assemblages occurred in the late Early Eocene and was characterized by the occurrence of Saccamminoides carpathicus Geroch. The restructuring was not uniform and occurred at variable rates depending on a number of factors. The most important factor is environmental conditions. In the Flysch Outer Carpathians, the Early Eocene represents the Glomospira div. sp. zone which has properties of an acme zone, and the total range zone Saccamminoides carpathicus. Such an Early Eocene biostratigraphic scheme is barely recognizable within the Hieroglyphic Beds because uncharacteristic assemblages or small-sized Trochammina assemblages predominate (Jaskulowska, 2011a, 2011b).

In the Silesian Basin, the fauna stressed by the Late Paleocene crisis diversified very slowly in the Early Eocene. In the material analysed, assemblages characteristic of the Glomospira biofacies were found only in the Hieroglyphic Beds in the Istebna area; the higher proportions of Glomospira in the assemblages occur within the Early Eocene variegated deposits. Trochammina and Glomospira monospecific assemblages occupied similar ecological niches and developed in parallel in the Silesian Basin during the Early Eocene. The poor spread of assemblages with Glomospira could be an effect of the conditions limiting their functioning. They could, therefore, be replaced in the basin by more resistant associations with Trochammina (Jaskulowska, 2011a). Foraminiferal biofacies of the assemblages of the Trochammina biofacies is fairly similar to that of the assemblages of the Glomospira biofacies. They differ chiefly in the type of predominant forms. As a rule, Glomospira monospecific assemblages in the Carpathians are recorded in hemipelagic claystones. These are often variegated deposits.

In turn, Trochammina monospecific assemblages occur in grey-green shales or in thin-bedded flysch deposits characterized by a higher sedimentation rate than the variegated deposits, while in shale sequences the supply of material is permanent. Poorly diversified assemblages with numerous Trochammina specimens are a reflection of the specific conditions on the floor of the Early Eocene Silesian Basin. These assemblages represent the early phases of recolonization that took place after the Late Paleocene crisis, and maintain their form consistently throughout a fairly long time interval until the Middle Eocene. The slowing down of the recolonization process might have been affected, e.g., by sedimentation conditions that limited the diversification of foraminiferal assemblages. The same factors could have an effect on the distribution of assemblages with Saccamminoides carpathicus Geroch in the sedimentary environment of the Hieroglyphic Beds. As an exception, Saccamminoides carpathicus Geroch appears in the Hieroglyphic Beds. It occurs only among taxonomically diversified assemblages. The most numerous specimens are obtained from samples of variegated shales. This species prefers and develops best in environments dominated by hemipelagic sedimentation (Jurkiewicz, 1959, 1967; Geroch and Koszarski, 1988). Jurkiewicz (1959) linked the occurrence of this species with the degree of sanding. The most numerous specimens of this species are found in red deposits within the Ciężkowice Sandstone, whereas in the green shales, they are rare and represented by large and well-developed forms. In turn, they are very rare in sandy shales.

Beginning from the Middle Eocene, more taxonomically diversified assemblages appear in the Hieroglyphic Beds, represented by infaunal and epifaunal morphogroups confirming the improvement of ecological conditions at the sea-floor. To a great extent, the Middle and Late Eocene biostratigraphic zones are based on the first occurrences of forms new to the Silesian Basin, which found favourable living conditions. Also observed is an influx of new species that began to occur in the assemblages from the Middle Eocene.

Foraminiferal assemblages of the Hieroglyphic Beds in the face of long-term Eocene cooling. The Eocene was a time of major climate changes. In the Early Eocene, a climatic optimum (EECO) occurred, typified by the highest temperatures in the Cenozoic, whereas less than 20 million years later, in the Early Oligocene, an ice sheet developed in Antarctica (e.g., Miller et al., 1997; 2005; Coxall et al., 2005; Ortiz and Thomas, 2006; Zachos et al., 2008; Galazzo et al., 2013). In the Eocene, a long-term progressive climate cooling (e.g., Zachos et al., 2001, 2008; Katz et al., 2008; Bijl et al., 2010), called the “doublehouse” state, took place between the “greenhouse” conditions of the early Paleogene and the “icehouse” regime (Galazzo et al., 2013). The trend of global cooling was interrupted by warming episodes, among which the longest and most intensive was the Middle Eocene Climatic Optimum (MECO; e.g., Bohaty and Zachos, 2003; Bohaty et al., 2009; Edgar et al., 2010; Savian et al., 2011; Galazzo et al., 2013; Sluijs et al., 2013). A period of gradual but important faunal turnover associated with climate changes is marked in the world’s ocean beginning from the Middle Eocene (e.g., Corliss, 1981; Keller, 1983a, b; Miller et al., 1987; Miller, 1992; Zachos et al., 2001; Ortiz and Thomas, 2006).

In the foraminiferal assemblages of the Silesian Nappe sensu lato, fundamental changes associated with global cooling and bathymetrical fluctuations are marked in the Late Eocene. The effects included the development of calcareous Globigerina Marls (e.g., Olszewska, 1983, 1984; Leszczyński, 1996;1997 and papers cited therein) containing fauna dominated by planktonic and calcareous benthic forms (e.g., Bieda, 1946; Bläicher, 1961, 1967, 1970; Olszewska, 1983, 1984), which are utterly different from the assemblages from underlying beds. The period including the sedimentation of the upper part of the Hieroglyphic Beds or Green Shales is a transitional interval within which gradual changes proceeded in foraminiferal assemblages, from the ones exclusively comprised of agglutinated foraminifera into the assemblages composed predominantly of calcareous foraminifera. In the agglutinated assemblages, the quantities of plankton and calcareous benthos increase gradually, which is noticeable in sediments deposited by suspension. The change in the character of assemblages is marked in the uppermost several metres of the analysed subdivisions. In the Upper Eocene deposits, which are dominated by thin-bedded flysch, the Globigerina Marls are missing. This phenomenon can be observed in the western part
of the Polish Carpathians, and in the Czech Republic. In some areas of the Silesian Basin, the foraminiferal assemblages in the mid-Eocene (Gradstein, 1997; Kaminski et al., 2005). In optimum climatic conditions, in the boreal basins, *Ammodiscus (Dolgenia) latus* Grzybowski continued to occur until the Middle and Late Miocene (Osterman and Spiegl, 1996; Kaminski et al., 2005). These species reached their optimum development in the Eocene in the temperate zones of Atlantic and Tethyan basins. In the Oligocene, they were well-developed in the cool climate of boreal basins where they were present for the longest time. In the subarctic region, *Reticuloplagium amplexent* (Grzybowski) and *Ammodiscus (Dolgenia) latus* Grzybowski reached over 2 mm across (Kaminski et al., 1999), while in the warm Carpathian basins, it was less than half that size and they found favourable living conditions in the Eocene during the slow climate cooling. The routes of these migrations, associated with the existence of connections between the Carpathian basins and boreal basins, constitute a separate issue.

In turn, there is a gradual disappearance of species belonging to the genus *Karnerula* in the Eocene deposits of the Carpathians. For example, *Karreruina conformis* (Grzybowski), a typical Eocene species, is progressively less numerous towards the top of the Heterostrophia Beds. *Karreruina convergens* (Grzybowski) which is common in the Late Cretaceous and Paleocene, gradually disappear in the Middle Eocene (e.g., Gradstein and Berggren, 1981; Kaminski and Gradstein, 2005). In the boreal basins, its last occurrence was in the Middle Eocene, whereas in the areas of Trinidad, Morocco, Angola, India, and the South China Sea, it is present until the Oligocene (Kuhnt et al., 2002; Kaminski and Gradstein, 2005; Kender et al., 2008), finding there suitable conditions for life. Beginning in the Middle Eocene, *Buzasina pacifica* (Krasheninnikov) ceases to occur in the Hieroglyphic deposits. Its last occurrence is recorded in the Middle Eocene Ammodiscus (Dolgenia) latus zone. *Kalamopiss grzybowskii* (Dylążanka), widespread in the Cretaceous and Paleogene deposits of the Carpathians, is a minor component in the Hieroglyphic deposits and disappears progressively. In the Oligocene, this species was recorded in the South China Sea (Kuhnt et al., 2002; Holbourn et al., 2013). Another species that prefers warm water is *Halophagromoides nauticus* Kender, Kaminski et Jones. This species is known and described from the Oligocene in Angola (Kender et al., 2006, 2008) and occurs commonly in the Carpathian Eocene (Waśkowska-Oliwa, 2008; Golonka and Waśkowska, 2012), while the Late Paleocene/Early Eocene deposits contain transitional forms between *Halophagromoides nauticus* Kender et al. and *H. walteri* (Grzybowski) (Waśkowska, 2008). The migration of this species to the south is possible although too little is known about its stratigraphical and geographical distribution.

The next manifestation of the Eocene climatic changes is the extinction of forms that had survived the Early Eocene crisis (EECO). *Caudammina ovula* (Grzybowski) and *Hormosina velascoensis* (Cushman), still found in the Early Eocene (e.g., Jurkiewicz, 1967; Bąk, 2004; Waśkowska, 2011a, b, 2015a; Figs. 5 and 11) and Middle Eocene (Kaminski and Gradstein, 2005; Holbourn et al., 2013) deep-water deposits, are also present in the Hieroglyphic deposits. Despite their survival in adverse conditions, they did not rebuild their positions in assemblages and disappeared from the palaeontological record. Such forms should also include *Annectina grzybowskii* (Jurkiewicz), *Glomospira diffundens* Cushman et Renz and *Caudammina exselsa* (Dylążanka), which still occur in the post-crisis Early Eocene assemblages (e.g., Jurkiewicz, 1967; Bąk, 2004; Kaminski and Gradstein, 2005; Waśkowska, 2011a, b, 2015a; Waśkowska and Cieszkowski, 2014).

### Foraminiferal assemblages vs. sedimentation regime

Beginning in the Middle or Late Eocene, the sedimentation regime within the Silesian Basin underwent gradual changes. In part of the basin, the sedimentation of Green Shales occurred, with a major effect of suspension (Waśkowska, 2014b). This is the interval from which diversified assemblages and diagnostic species for age determination are obtained. The sedimentation regime had an enormous effect upon the formation of the agglutinated fauna living on the sea-floor. The flysch sedimentation is coupled with the supply of variously sized clastic material to the basin. It is often associated with the massive deposition of psammitite and pelphite material in the form of concentrated sandstone and conglomerate layers. The deposition of such layers significantly disturbs the conditions in the near-bottom zone and destroys the associations of small organisms which had colonized the sea-floor after the last descent of a suspension current. Apart from the availability of food- and oxygen-providing nutrients, it is the sedimentation regime which is primarily responsible for the development of foraminiferal assemblages in deep-sea conditions. It includes the frequency of suspension currents, their strength, and the quantity of deposited material. The descent of each suspension current is followed by recolonization, and – as proved by the faunal record – it is a short-lasting and well-organised process, even though the frequent disturbances associated with suspension currents, repeated in a quick succession, create constraints on the development of foraminiferal assemblages. Assemblages tolerant to such environmental conditions exist at such times. They are composed of agglutinated, cosmopolitan forms, most often having coarse-grained and massive tests. For this reason, the faunal record is modelled by the sedimentary environment in flysch intervals of the Hieroglyphic Beds. In the areas covered by turbidite shale-sandstone sediments, cosmopolitan assemblages with few characteristic properties were formed, whereas
in the areas of calmer shale sedimentation, there were more diverse assemblages of complex trophic structures.

CONCLUSIONS

In the Silesian Basin, the Hieroglyphic Beds developed from the Early and Middle Eocene until the Late Eocene. Their lower boundary is conditioned by the development of the directly underlying Ciężkowice Sandstone. In the western part of the Polish Carpathians, the Ciężkowice Sandstone disappears progressively and the sedimentation of the Hieroglyphic Beds occurs directly on the upper shales of the Istebna Beds. In these places, its sedimentation took place at least from the Ypresian. The upper boundary in the Bartonian is isochronous. It is marked by the Globigerina Marls horizon. In areas where the Globigerina Marls are absent, as they are locally diluted by flysch-type sedimentation, the Hieroglyphic Beds contact directly with the overlying Menilite Beds. The lower and upper boundary sequences are relatively thin, except in western regions where the transitional complexes are extended, and the boundaries between the units are conventional.

The Hieroglyphic Beds are generally dominated by turbidite shale-sandstone deposits, although there are major lateral differences in their development, not only in terms of variable number and thickness of sandstone intercalations, and diversification within the shales, but also in terms of diverse thick sandstone-free complexes that occur in the eastern part of the study area. They are correlated with one another, occupying similar lithostratigraphic positions (starting from the Bartonian or Lutetian) and are established as a separate subdivision of the Green Shales which disappear towards the western part of the study area. Such complexes are also found in other lithostratigraphic positions in the Lower and Middle Eocene. They usually contain irregularly distributed packets of variegated shales without wide lateral continuity. At some places, there are bentonite laminations testifying to suspension-dominated sedimentation, with a limited supply of terrigenous material.

The foraminiferal assemblages from the Hieroglyphic Beds are dominated by uniform assemblages of agglutinated cosmopolitan species with massive tests. The sedimentation regime had a major effect on their development. The Lower Eocene assemblages contain commonly small and numerous Trochammina, representing post-crise assemblages following the PETM event. These assemblages replace small-sized Glomospira div. sp., as well as assemblages with Saccamminoides carpathicus Geroch commonly developed in the Lower Ypresian in other Carpathian basins. The assemblages dominated by Glomospira colonized areas under suspension-type sedimentation, with a limited supply of material from land, whereas the assemblages with Trochammina lived in conditions involving an increased sedimentation rate as well as a higher supply of terrigenous material. Beginning from the Middle Eocene, the foraminiferal assemblages became more taxonomically diversified. In the Lutetian, the assemblages with Reticulophragmium amplectens (Grzybowski) are common. Beginning from the Bartonian, Reticulophragmium amplectens (Grzybowski) is accompanied by Ammodiscus (Dolgenia) latus Grzybowski, while in the Priabonian there are rare occurrences of Reticulophragmium gerochi Neagu et al. Because of the somewhat ephemeral appearances of Reticulophragmium gerochi Neagu et al. defining the zone, it is not always possible to establish a standard for the Carpathian deposits for which it is an index species.

The assemblages from the Hieroglyphic Beds reveal taxonomic changes associated with the long-term Eocene climatic cooling that stimulated inter-basin migrations of fauna. Warm water-prefering forms, i.e., Karrerulina coniformis (Grzybowski), Karrerulina conversa (Grzybowski), Buzasina pacifica (Krasheninnikov) and Kalamopis grzybowskii (Dylążanka), gradually disappeared in the Eocene assemblages of the Silesian Basin. In turn, the Silesian Basin was colonized by species adapted to life in cool waters, including universal stratigraphic index species, such as Reticulophragmium amplectens (Grzybowski), Ammodiscus (Dolgenia) latus Grzybowski and Reticulophragmium gerochi Neagu et al., as well as rare forms, i.e., Eggerelloides propinquus (Brady), Eratidus gerochi Kaminski et Gradstein, Adercorymya agterbergi Gradstein et Kaminski, Ammomarginulina aubertae Gradstein et Kaminski, Insulptarenula aff. subvesicularis (Hanzlíková), Spirosigmolinella compressa Matsunaga, and Reophanus bergreni Gradstein et Kaminski. The environmental conditions during the gradual climatic changes were not favourable for the restructuring of the foraminiferal associations decayed by the PETM crisis. Caudammina ovula (Grzybowski), Hormosina velascoensis (Cushman), Annectina grzybowskii (Jurkiewicz), Glomospira diffundens Cushman et Renz and Caudammina excelsa (Dylążanka) still occurred in the post-crise Early or Middle Eocene assemblages, and then disappeared from the palaeontological records. The definite restructuring of foraminiferal assemblages within the Hieroglyphic Beds took place in the Priabonian, in the uppermost part overlain by the Globigerina Marls. In the assemblages occupying the last several metres of the profile, there is an evident increase in calcareous benthic and planktonic forms that become predominant components.

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