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Exotic clasts, debris flow deposits and their significance for reconstruction of the Istebna Formation (Late Cretaceous–Paleocene, Silesian Basin, Outer Carpathians)

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Abstract: The different types of calcareous exotic clasts (fragments of pre-existing rocks), embedded in the Paleocene siliciclastic deposits of the Istebna Formation from the Beskid Mały Mountains (Silesian Unit, Western Outer Carpathians), were studied and differentiated through microfacies-biostratigraphical analysis. Calcareous exotics of the Oxfordian–Kimmeridgian age prevail, representing a type of sedimentation comparable to that one documented for the northern Tethyan margin. The Tithonian exotic clasts (Štramberk-type limestones), which are much less common, were formed on a carbonate platform and related slope. The sedimentary paleotransport directions indicate the Silesian Ridge as a main source area for all exotics, which were emplaced in the depositional setting of the flysch deposits. The exotics constitute a relatively rare local component of some debrites. Proceedings of the sedimentological facies analysis indicate that these mass transport deposits were accumulated en-masse by debris flows in a deep-water depositional system in the form of a slope apron. Exotics prove that clasts of the crystalline basement and, less common, fragments of the sedimentary cover, originated from long-lasting tectonic activity and intense uplift of the source area. Mass transport processes and mass accumulation of significant amounts of the coarse-grained detrital material in the south facial zone of the Silesian Basin during the Early Paleogene was due to reactivation of the Silesian Ridge and its increased denudation. Relative regression and erosion of the emerged older flysch deposits were also forced by this uplift. These processes were connected with the renewed diastrophic activity in the Alpine Tethys.

Key words: Flysch Carpathians, Silesian Nappe, Istebna Formation, Silesian Ridge, Silesian Basin, debris flows, apron, limestone exotic clasts.

Introduction

The clasts of crystalline and sedimentary rocks constitute characteristic components of some detrital Carpathian rocks (e.g., Wieser 1948; Książkiewicz 1951). Pebbles, cobbles, boulders and klippes of metamorphic and igneous rocks as well as the Upper Jurassic and Lower Cretaceous limestones are noted in the Carpathian deposits since the earliest history of the geological study of this area. They are known as exotic blocks (ger. „Exotische Bloecke") (*sensu* Hohenegger 1861) or just exotics (e.g., Burtanówna et al. 1937; Raymond 1984). Exotics are remnants of the source areas (parent rocks), which alimented the sedimentary basins (e.g., Unrug 1968), but they also may have come from erosion and redeposition (recycling) of the older sedimentary formations (e.g., Słomka 1986, 2001; Matyszkiewicz & Słomka 1994). Inter- and intra-basinal elevations identified during the early stages of the paleogeographic reconstructions as the so-called cordilleras (Książkiewicz 1953), as well as the marginal continental borders of these basins (e.g., Książkiewicz 1962, 1965; Unrug 1963, 1968; Ślączka 1986; Olszewska & Wieczorek 2001; Poprawa et al. 2002, 2004; Golonka et al. 2008a, b) might have constituted such alimentary areas delivering clastic material for the Carpathian sub-basins. The inter-basinal Silesian Ridge situated between the Silesian Basin on the north and the Magura Basin on the south, and the Subsilesian Ridge, intra-basinal elevation within the proto-Silesian Basin, were such source areas (e.g., Unrug 1968; Eliáš 1970; Golonka et al. 2008b). Fragments of these areas served as the main source supplying the Silesian Basin with detrital material for almost 125 million years (cf. Burtanówna et al. 1937).

Exotics represent one of the most important sources of information about these no longer existing Carpathian alimentary areas, indirectly indicating the type of their parent rocks as well as the type of geological structure and its geotectonic history.

Generally exotics constitute a relatively rare component of the siliciclastic deposits of the Silesian Series, although locally relatively large concentrations are observed (e.g., Burtan et al.

1984; Chodyń et al. 2005; Cieszkowski et al. 2016). They occur as macroscopically distinguishable, but usually single, dispersed in matrix detrital grains. Boulder-sized exotic clasts, most often chaotically scattered in the clastic mass of matrix, are sometimes also called olistoliths (*sensu* Abbate et al. 1970; e.g., Szymakowska 1976). Deposits built of gravel-sized clasts dispersed within detritic matrix (supporting phase) form debrites.

Mass-transported and mass-sedimented debris flow deposits are products of slope sedimentary gravity-driven processes, also triggered by tectonics, seismic activities, meteorological and/or eustatic factors (Shanmugam 2000, 2006, 2015, 2016; see also Strzeboński 2005, 2013, 2015; Festa et al. 2010, 2016; Strzeboński et al. 2013; Szydło et al. 2014; Łapcik et al. 2016). Such deposits containing outsized clasts in matrix are also called olistostromes (Flores 1959; Abbate et al. 1970; Szymakowska 1976; see also e.g., Jankowski 2007; Cieszkowski et al. 2009, 2012; Festa et al. 2010; 2016; Ślączka et al. 2012). In the broad descriptive and rather not genetic sense, the general term "chaotic complex" (*sensu* Jankowski 1997, 2007) describing matrix-supported disorganized deposits, usually built of differentiated gravel-sized clasts scattered in matrix, is also used for this kind of slope gravity flow debrites. Although, this designations, preceded by "chaotic", "chaotically" in names, are also applied for mappable mixed masses (clast-in-matrix types), but also with composite tectono-sedimentary implications, or for such clastic bodies/units which have mainly tectonic origin, namely diverse mélanges or broken formations (cf. e.g., Starzec et al. 2015). However, some of the widely understood mélanges (e.g., Raymond 1984) were interpreted as ancient submarine deposits formed by different gravity-driven mass transport processes (cf. e.g., Festa et al. 2010, 2016), namely deep-water slides, slumps, and debris flows (*sensu* Shanmugam 2006; 2016). Such deposits were termed sedimentary mélanges to provide a distinction from mélanges in the strict sense, meaning those of tectonic origin (Hsü 1974), and/or olistostromes, which are known especially from the collisional Alpine-to-Himalayan orogenic systems (e.g., Festa et al. 2010, 2016). According to such origin, assigned to them by Festa et al. (2010, 2016), these deposits may consequently be interpreted as products of the above-mentioned critical sedimentary processes. They can be referred to slide, slump or debrite types respectively, depending on the visible features of internal fragmentation and disorganization (see also Strzeboński 2015). In this case deposits forming amalgamated lithosomes, affected by sedimentary multiple events and multi-stage disorders, could be termed directly: slide-, slump- and/or debrite bodies/units/series/complexes, etc., or generally mass transport deposits/complexes (MTDs/MTCs *sensu* Shanmugam 2015, 2016).

The Istebna Beds of the sedimentary Silesian Series (*sensu* Burtanówna et al. 1937), also called the Istebna Formation (*sensu* Menčík 1983; Wójcik et al. 1996; see also Picha et al. 2006), constitute one of the most important lithostratigraphic divisions with exotics in the tectonic Silesian Unit of the Outer Carpathians (Figs. 1, 2). The Istebna Formation (Istebna Fm.) has been studied by numerous geologists starting with Hohenegger (1861), who identified them as a separate unit and proposed their name. Liebus & Uhlig (1902) and Burtanówna et al. (1937) clarified the stratigraphy and division of the unit. Other researchers developed the research methodology and contributed further details on the deposits of the Istebna Fm. (Książkiewicz 1951, 1962; Geroch 1960; Unrug 1963, 1968; Eliáš 1970; Peszat 1976; Menčík 1983; Menčík & Tyráček 1985; Ślączka 1986; Picha et al. 2006; Ślączka et al. 2006, 2012; Cieszkowski et al. 2009, 2012; Uchman 2009; Rajchel & Uchman 2012).

The previous studies of the exotics from the Istebna Fm. were focused mostly on the crystalline rocks often constituting nearly 100 % of the exotic population (e.g., Wieser 1948; Książkiewicz 1951, 1953, 1962; Unrug 1963, 1968; Peszat & Wieser 1999; Poprawa et al. 2004). Another area of research concerned microfacies-biostratigraphic and paleoecological analyses based on clasts of the exotic sedimentary rocks (e.g., Burtan et al. 1984; Tomaś et al. 2004; Chodyń et al. 2005; Strzeboński et al. 2013).

The paper presents results of the analysis of the exotic calcareous clasts and the exotic-bearing debrites, and their application for the reconstruction of the sedimentation and development of the Silesian Basin.

Database, methods, and terminology

The results of the present sedimentological analysis are based on field investigations of the outcrops of the Istebna Fm. in the Beskid Mały Mts. (IFmBM). Litho-sedimentological logging was carried out on the topographic sections totalling almost 1400 metres in a true thickness. Data were collected from exposures in 22 riverbeds, exposures along the shoreline of Jezioro Żywieckie dam lake, several natural rocky forms, and two quarries.

Methods of facies analysis (see in general e.g., Ghibaudo 1992; Słomka 1995; Shanmugam 2006; Mulder 2011; Talling et al. 2012; Strzeboński 2015; Prekopová et al. 2017) were used for: qualitative distinction of lithotypes, sub-lithotypes and lithotype associations (visual assessment), approximation of lithosome shapes, as well as interpretation of depositional lithofacies origin (transport−transformation−depositional mechanisms), sequences and depositional complexes, and, last but not least, types of both depositional environment and sub-environments, as well as kinds of depositional system. Additionally, data such as lithofacies types were also treated quantitatively and statistical analysis of selected parameters was performed, including thickness share (percentage of the thickness expressed in terms of the % by volume), frequency share (percentage of the quantities referred as the % by frequency), and variability range of bed thickness. In the exotic study, in addition to the classically used frequency analysis (percentage by frequency), innovative volumetric analysis (expressed as a volume per cent, volume range and average volume) were used.

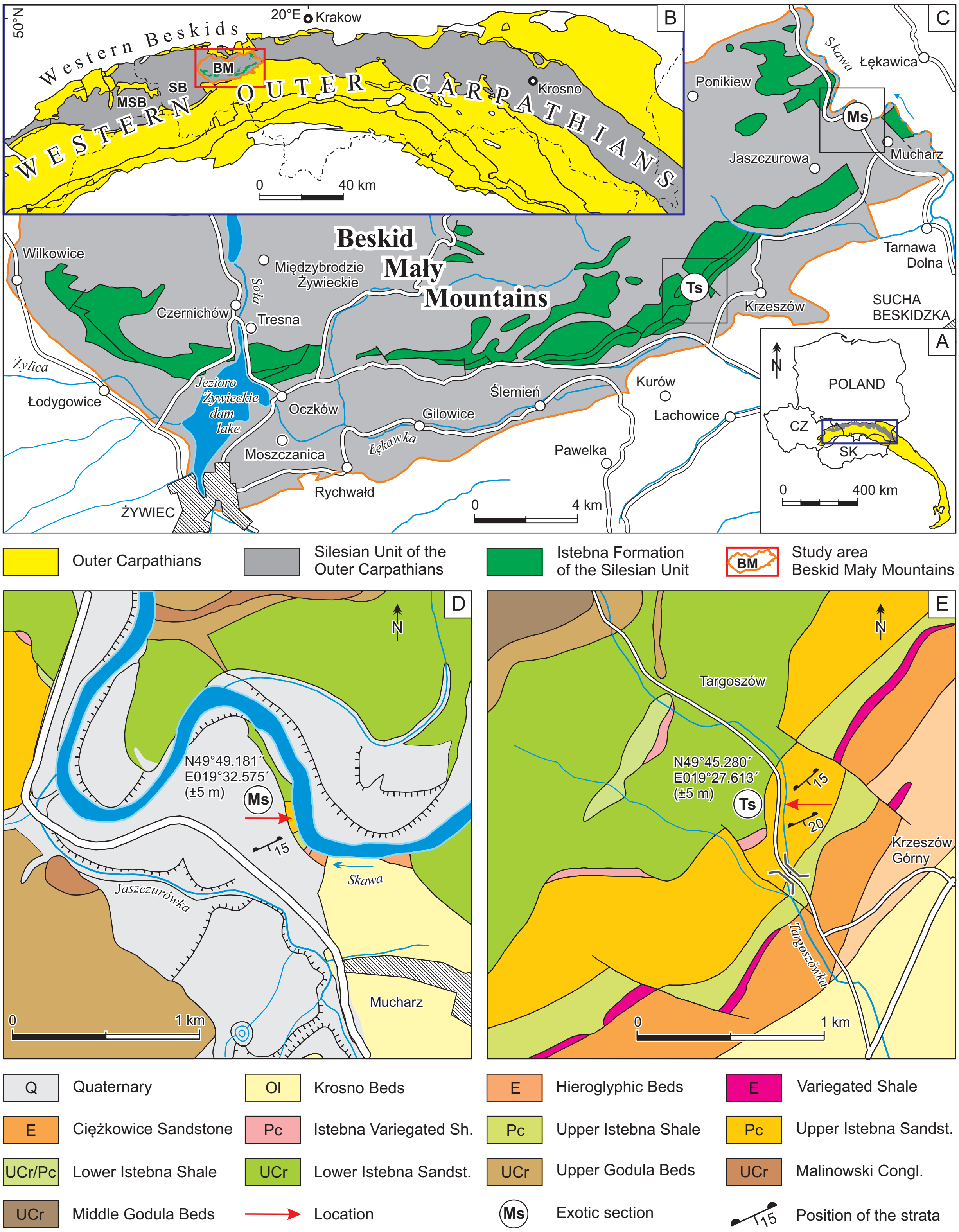


Fig. 1. A — Position of the Outer Carpathians and Silesian Unit relative to part of the contour map of Europe, CZ – Czech Republic, SK – Slovakia; **B** — Location of the Beskid Mały Mts. (BM), the Silesian Beskid Mts. (SB) and the Moravskoslezské Beskydy Mts. (MSB) areas on the background of the Silesian Unit of the Western Outer Carpathians; **C** — Occurrence of the Istebna Formation in the Beskid Mały Mts., Ms – Mucharz section, Ts – Targoszów section; **D** — Details of the geological map with localization of the Mucharz section; **E** — Details of the geological map with localization of the Targoszów section (based on: Nowak 1964; Książkiewicz 1973; Golonka et al. 1981; Żytko et al. 1989; Lexa et al. 2000; Cieszkowski et al. 2012; simplified and partly modified). Stratigraphy: E – Eocene, Ol – Oligocene, Pc – Paleocene and UCr – Upper Cretaceous deposits.

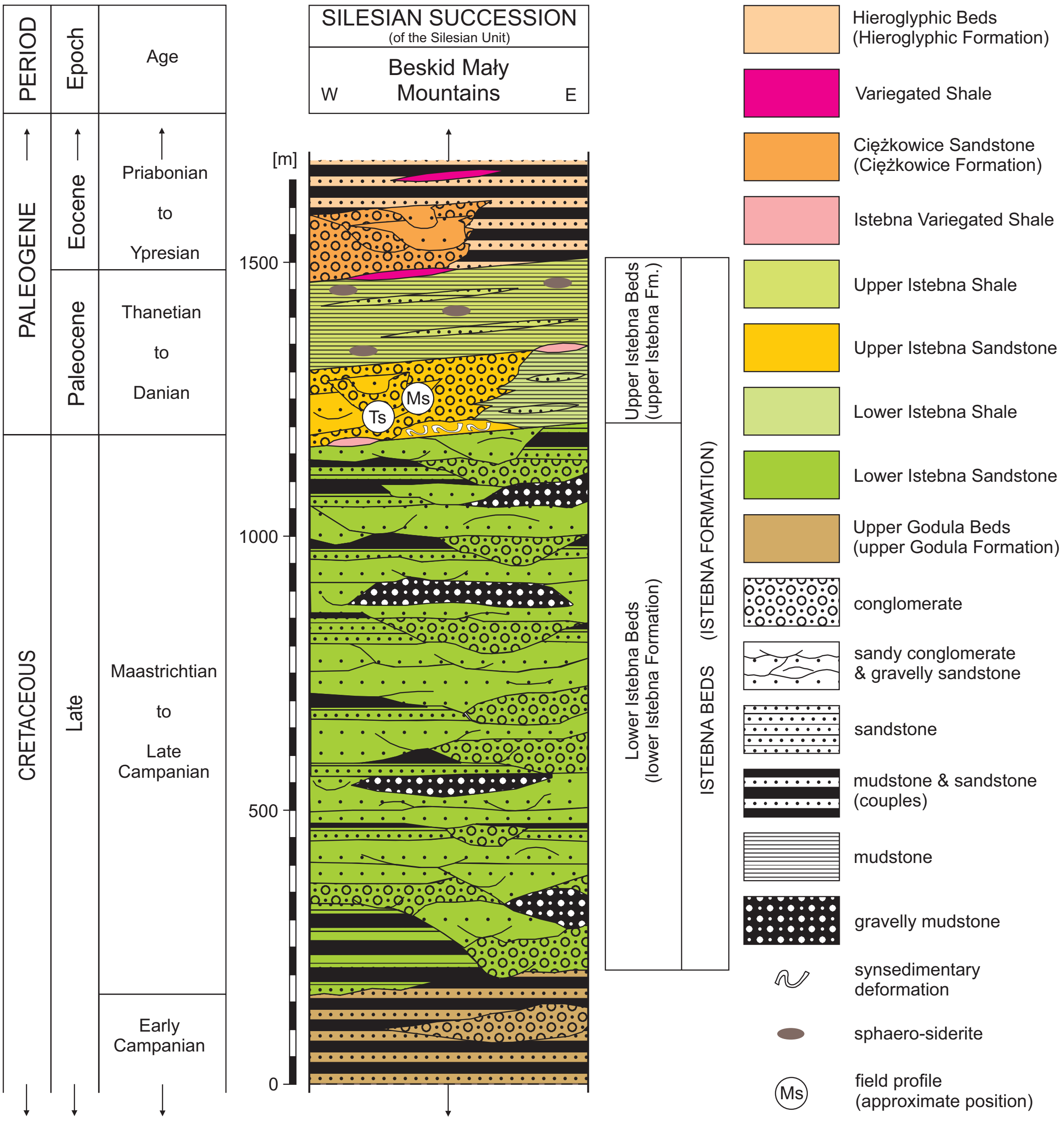


Fig. 2. An integrated lithostratigraphical scheme of the Silesian Series in the Beskid Mały Mts. showing position of the studied logs (after: Burtanówna et al. 1937; Książkiewicz 1951; Geroch 1960; Szydło et al. 2015; Strzeboński 2005; partly changed).

Another aspect of the present research was microfacies-biostratigraphical analysis of calcareous clasts, very rarely occurring among exotics. Samples were taken from the best exposed and relatively richest in calcareous exotic material sections (Figs. 1D, E and 3), which are described in detail in this article. A total of 20 samples of the calcareous exotic clasts were collected in Mucharz and 18 samples in Targoszów. Afterwards samples were cut and examined macroscopically. A total of 24 standard thin sections were prepared of the chosen exotics. The micropaleontological studies of thin sections were carried out under a Nikon Eclipse LV100 POL polarizing microscope and the microfacial studies under a Nikon SMZ1000 stereomicroscope. Dunham's (1962) classification of carbonate rocks was used for limestones and Mount's (1985) classification for calcareous rocks with siliciclastic admixture.

The general term calcariclastic (portmanteau of calcarious and clastic) is used in a manner analogous to a designation commonly accepted in sedimentology: siliciclastic (coined by combining silicious and clastic). The name of calcariclastics (syn. calcareclastics, in terms of the above-mentioned) is applied to clastic carbonate sedimentary deposits containing predominantly resedimented calcium carbonate-bearing detritic material of diverse origin, age, and fractions (pellite-to-psephite in size), and formed by inorganic, gravity-forced processes. Depending on the predominance of debris flows or turbidity currents, debritic calcariclastics (debrites rich in limestone clasts and calcareous matrix) and turbiditic calcariclastics (calcarious-bearing turbidites) can be distinguished, in a similar way to the case of siliciclastics.

Geological background

Overview of stratigraphic successions with exotics

Distinct lithotype diversity and irregular distribution of exotics, especially calcareous ones, is observed in the lateral and vertical occurrence in the western part of the Silesian Series.

Calcareous resediments (i.e., calcariclastics) are generally rare in the flysch series (*sensu lato*) of the Outer Carpathians (e.g., Leszczyński & Malik 1996). However, they include the oldest known calcariclastic deposits of the Silesian Series, the so-called Cieszyn Beds (*sensu* Bieda et al. 1963; Słomka 1986): Vendryně Fm., Cieszyn Limestone Fm., and Cisownica Shale Mb. (e.g., Waśkowska-Oliwa et al. 2008). These beds belong to the flyschoidal (flysch-type) basinal series predominantly composed of redeposited, originally shallow-water, calcareous clastic material. They constitute, however, a small amount of the Silesian Series taking under consideration their thickness (locally to ca. 15 % by volume of the Upper Jurassic–Paleocene deposits) and stratigraphic range (ca. 17 % for the Tithonian–Maastrichtian interval) (cf. Burtanówna et al. 1937).

Successive formations of the Silesian Series, starting from the Hradiště Fm. (*sensu* Wójcik et al. 1996), are already dominated by flysch series *sensu stricto*, meaning those composed mainly of siliciclastics, such as siliceous turbidites and debrites (e.g., Słomka 1995; Strzeboński 2015). In general, occurrence of these calcareous exotics is not abundant in the Carpathian siliciclastic flysch deposits. In relation to its whole mass it could be estimated at less than 1 %. Calcareous clasts appear there only locally and sporadically, as in the case of local accumulations of the Ostravice Mb. of the Godula Fm. (Słomka 1995; Cieszkowski et al. 2016).

Exotics also occur in some debris flow deposits (exotic debrites) of the Istebna Formation (IFm). The distribution of calcareous exotics in the Istebna Fm. of the Beskid Mały Mts. (IFmBM) is laterally and vertically non-homogenous. Generally in the IFmBM calcareous exotics are relatively more common (by volume and frequency) than in the areas situated farther west, namely in the Moravskoslezské Beskydy Mts. and Silesian Beskid Mts. areas (e.g., Książkiewicz 1951; Strzeboński 2005), and on the other hand much less common than in the areas situated farther east, especially in the Lanckorona Foothills (e.g., Książkiewicz 1951; Kowal-Kasprzyk 2016).

Geological setting of the Istebna Formation

The sedimentary succession of the Istebna Fm. belongs to the Silesian Unit of the Western Outer Carpathians, exposed in the Beskid Mały Mts. (Figs. 1, 2). The Istebna Fm. crops out in the south part of this allochthonic tectonic unit, also known as the Silesian Nappe. Outcrops of the formation extend from the Moravskoslezské Beskydy Mts. in Slovakia and the Czech Republic in the west, through the Silesian Beskid Mts. and Beskid Mały Mts. in Poland, altogether referred to a set of mountain ranges called the Western Beskids (Fig. 1B,C), to the region of Krosno city in the east (within the Polish borders), thus forming an essential part of the Silesian Unit (Żytko et al. 1989; Lexa et al. 2000).

The Beskid Mały Mts. is one of the geographical regions of the occurrence of exotics in deposits of the Istebna Fm. (Fig. 1B,C). The Istebna Fm. in the Beskid Mały Mts. reaches up to 1300 m in thickness (Fig. 2). Lithofacies development of the IFmBM is similar to that known from the adjacent Beskids (i.e., Moravskoslezské Beskydy Mts. and Silesian Beskid Mts.), and differences are mostly in the thickness and frequency of the particular lithotypes (e.g., Strzeboński 2005).

In the studied area the Istebna Fm. is underlain by the Godula Beds (*sensu* Burtanówna et al. 1937; Słomka 1995) (Fig. 1D,E), also called the Godula Fm. (Fig. 2) (Menčík 1983; Wójcik et al. 1996; see also Picha et al. 2006), and overlain by the Ciężkowice Fm. (cf. Wójcik et al. 1996) — the so-called Ciężkowice Sandstone (Figs. 1D,E and 2) (see Burtanówna et al. 1937; Leszczyński 1981) interbedded with the variegated shales or by the Hieroglyphic Beds (see Burtanówna et al. 1937), also named the Hieroglyphic Fm. (cf. Wójcik et al. 1996), with the variegated shales intercalations (Fig. 2) (see also Książkiewicz 1951).

The Istebna Beds (*sensu* Burtanówna et al. 1937) are traditionally divided into the Lower Istebna Beds and Upper Istebna Beds (Fig. 2). The lowest subdivision is also called the Lower Istebna Sandstone, whereas the upper part is tripartite: the Lower Istebna Shale, the Upper Istebna Sandstone, and the Upper Istebna Shale (Fig. 2) (see also Książkiewicz 1951).

The previously mentioned stratotype division of the Istebna Beds, proposed for the Silesian Series in the Beskid Śląski Mts., cannot always be applied during field work in the Beskid Mały Mts. Sometimes in the investigated area the Lower Istebna Shale disappears and the Lower Istebna Sandstone directly passes into the Upper Istebna Sandstone (Fig. 2). In some cases the Upper Istebna Sandstone is pinched out as well and then the Lower Istebna Sandstone is overlain by the Lower Istebna Shale coalesced (amalgamated in a broad sense) with the Upper Istebna Shale (Fig. 2) (see Książkiewicz 1951).

The age of the IFmBM was determined as Late Cretaceous–Paleocene (Fig. 2) based on the micropaleontological study (e.g., Geroch 1960; see also Szydło et al. 2015).

Depositional lithofacies

The IFmBM includes mainly siliciclastic material, originally of terrigenous provenance, which is mineralogically mature and represented mostly by quartz, subordinately silicate minerals: feldspar- and muscovite flakes, and accessory heavy minerals (e.g., Unrug 1968; Grzebyk & Leszczyński 2006). Texturally this material is moderately mature−moderately sorted and subrounded-to-rounded, with the exception of feldspars, which may even be subangular. Carbonized plant

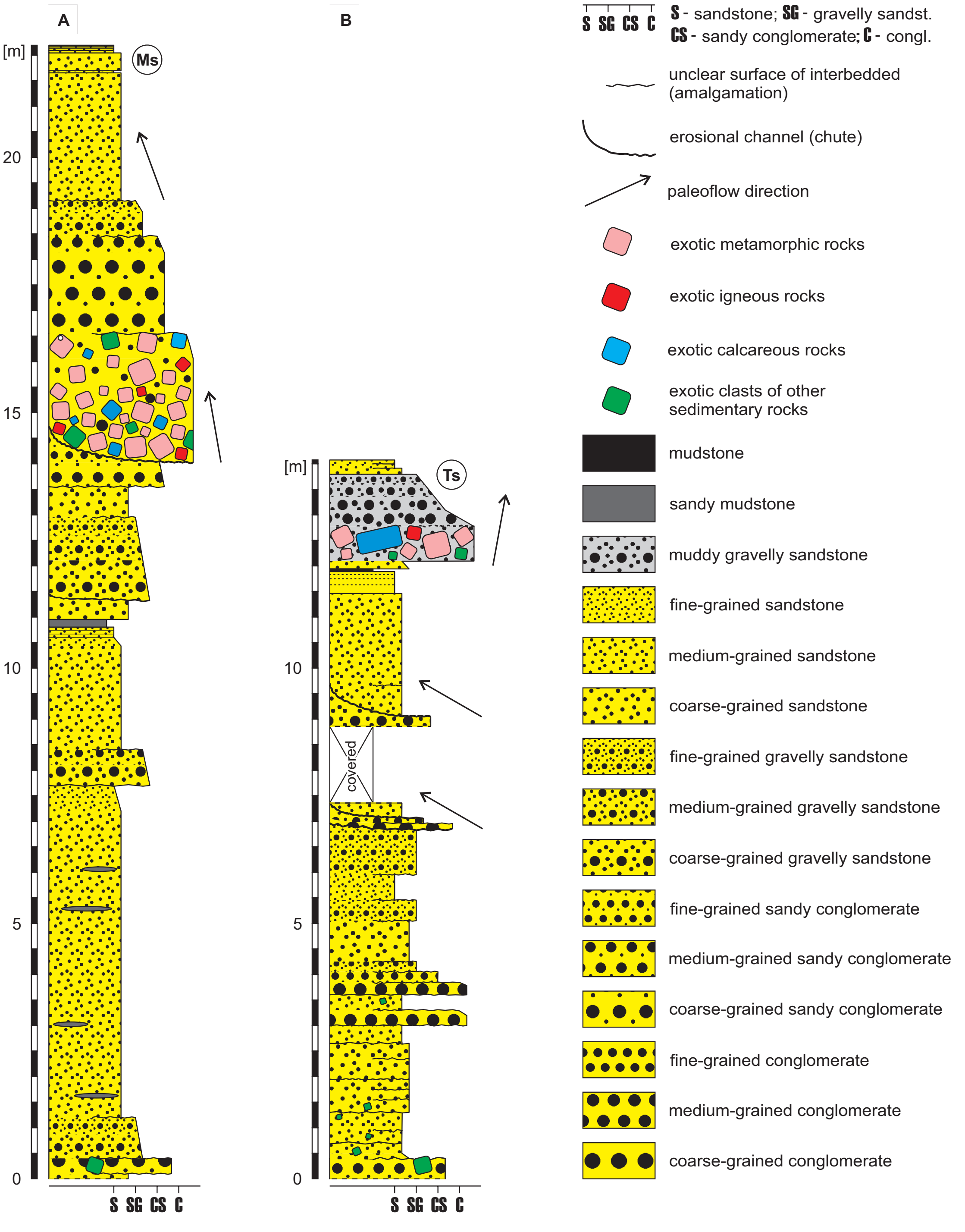


Fig. 3. Schematic lithological-sedimentological logs of the studied sections. **A** – Mucharz section (Ms); **B** – Targoszów section (Ts). For advice on general position of the profiles see Figs. 1 and 2.

detritus constitutes an additional component, especially of sandy mudstone and muddy sandstone lithotypes (cf. Strzeboński & Uchman 2015).

The IFmBM includes detrital sedimentary rocks represented by the following siliciclastic lithotypes: 1 — sandstone, 2 — gravelly sandstone, 3 — sandy conglomerate, 4 — conglomerate (1–4 represent sandstone-to-conglomerate association, with deposits sometimes containing clasts of exotic rocks), 5 — sandstone with mudstone couplet, 6 — mudstone (sometimes accompanied by sphaerosiderite concretions), 7 — gravelly mudstone (in the broad sense than pebbly mudstone *sensu* Crowell 1957, i.e. granule gravel-to-boulder gravel), sometimes with exotics (Fig. 2).

Among the basic lithotypes some sub-lithotypes can be distinguished according to their structural features, for example, massive conglomerate–debritic conglomerate (i.e., gravelly debris flow deposit) or normally graded sandstone – turbiditic sandstone (i.e., sandy turbidity current deposit) (Strzeboński 2015).

These lithotypes are sometimes disturbed to varying degrees, by being involved in ripped-fold structures, which were caused by synsedimentary gravity-forced deformations (slump deposits) (Fig. 2).

The siliciclastics of the IFmBM, especially of the Lower Istebna Sandstone and the Upper Istebna Sandstone (Fig. 2), are predominantly characterized by the irregularly developed beds with horizontally variable thickness, patchy top surfaces, depositional and erosional pinch-outs. Additionally, thick- and very thick bedded, mainly amalgamated massive sandstone-to-conglomerate bodies with interbeds of massive gravelly mudstone, without regular mudstone intercalations, occur.

Studied sections with calcareous exotic clasts

Mucharz section

The Mucharz section is situated in the orographic left bank of the Skawa river bend, near the Mucharz village in the Beskid Mały Mountais, on the area of the future dammed-water Świnna Poręba reservoir (Fig. 1B–D) (GPS coordinates: N 49°49.181'; E 19°32.575'; ±5 m). Exotic conglomerate belongs to the Upper Istebna Sandstone (Paleocene) (Fig. 2) (see Książkiewicz 1973). The examined exotic-bearing deposit has a maximum thickness of 230 cm (Fig. 3A), and forms a tongue-shaped lithosome with basal half-lenticular cross section (255–75°), clearly showing an irregular, erosional bottom surface. Exotics occur as clasts of diverse, primarily crystalline rocks, randomly scattered within the siliciclastic, non-calcareous matrix (matrix-supported conglomerate). The matrix is poorly sorted, predominantly sand-sized and without a macroscopically visible significant amount of clay- and silt-sized particles (without the dark grey colour of a fine-grained background). The exotic clasts reach up to 25 cm in length along the longest axis, and several centimetres in diameter. In the uppermost part of the body they are more dispersed in the matrix then in the lower part (Fig. 4A–C). Among the calcareous exotics, light grey and dark grey micritic limestones and calcareous rocks with clay and silt admixtures, limestones and silty limestones are the most common, while light grey organogenic and organodetritic limestones (Štramberk-type limestones) are rare. According to Wieser (1948) exotics of the crystalline rocks, collected from this location, are dominated by diverse varieties of gneiss and granulite (56.5 and 13 % by frequency respectively), while the igneous rocks are infrequent (total of 7.5 % freq.), and other rocks (sedimentary rocks and vain quartz clasts) have 23 % freq. (op. cit., p. 143 — table 7).

Paleotransport directions were estimated on the basis of the positioning of the long axes of clasts (flow lineation), clast overlaps ("imbrications"), geometry of the lithosome, wash-outs, and chutes (longer axis of the scour-and-fill structures). The paleotransport directions indicate that the clastic material with exotics was distributed nearly from S to N (not considering the orogenic rotation of the Carpathian tectonic units; cf. e.g., Rauch 2013), and SSE to NNW in the overlain deposit comprising finer-grained clastic material (Fig. 3A). Directions observed in the surrounding area, for example, in non-exotic, thin- to medium-bedded and fine- to medium-grained sandstones, based on directional sole structures in the form of tool marks and flute casts, indicate the sedimentary transport also from SSW and SW to NNE and NE.

A massive coarse-clastic deposit rich in a sandy matrix and exotic material can be considered as exotic conglomerate with a matrix-support structure. A matrix-supported exotic conglomerate could be interpreted as a "clean" exotic-bearing conglomerate debrite, meaning a debritic conglomerate with exotic clasts and low concentration of pelitic and aleuritic fractions (*sensu* particle size). This pebble-sandy debris flow deposit constitutes filling of the disposable ephemeral channel — small, single-filled chute (Fig. 3).

Targoszów section

The Targoszów section is a new exotic position located in the orographic left bank of the Targoszówka stream, near the Krzeszów Górny and Targoszów villages, in Stryszawa District in the Beskid Mały Mts. (Fig. 1B,C and E) (GPS coordinates: N 49°45.280'; E 19°27.613'; ±5 m). Deposits with exotics belong to the Upper Istebna Sandstone (Fig. 2) (Nowak 1964). The observed exotics reveal a great variety of petrographic types (Table 1) and occur in a massive conglomerate approx. 60 cm in thickness (Figs. 3B and 4D–F). The deposit forms a flat in base lithosome without a visible erosional bottom surface. The matrix of the deposit is rich in sandy-muddy material, with numerous chaotically scattered quartz granules. Common exotic clasts are randomly distributed in the matrix and their concentration is 40–60 % by volume of the debrite. The largest outsized clast was 43×35×22 cm (limestone with cherts), however, the longest axis of the average clast reaches no more than 10 cm, and their average volume is ca. 400 cm^3 (Table 1). Clasts of crystalline rocks prevail (53 % vol. and 89 % freq.) (Table 1). Calcareous exotics are not abundant in frequency (4.7 %) and similar to those described from the Mucharz section. Nevertheless, the present study proved that in terms of volume they have a very large share (41.5 % vol.) (Table 1).

In the upper part of the profile there is an indistinct, probably amalgamated, transition to normally graded muddy gravelly sandstone. Medium-to-fine pebbles and granules are scattered in massive sandstone rich in a muddy matrix, but exotics are not present (Fig. 3B).

Paleotransport of the clastic material with exotics, determined on the basis of similar indicators like in the Mucharz section, indicates distribution from SSW to NNE, and close to the direction from SE to NW in the non-exotic deposits occurring just below exotic conglomerate (Fig. 3B). These directions are repeated laterally in the surrounding area.

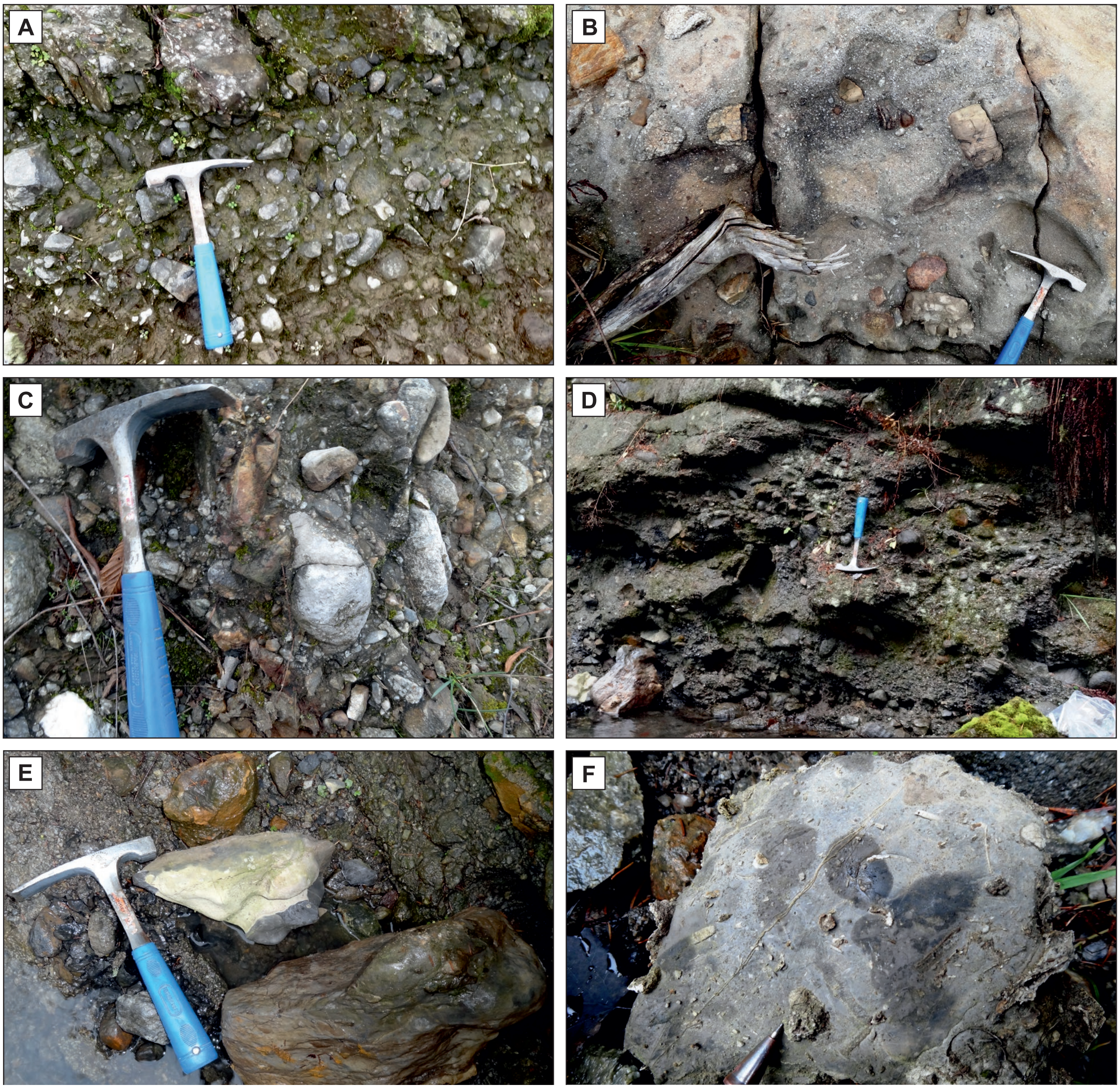


Fig. 4. Exotic clasts in the siliciclastic-type debrites with prevalence of siliceous and silicate grain material. Mucharz section: **A** — debrite represented by matrix-supported conglomerate containing exotic clasts, showing generally a disorganized structure (chaotic dispersed, floating in sandy matrix quartz granules and exotics), on the left side the slight inverse grading is visible. **B** — massive gravelly sandstone type debrite, outsized exotics floating in matrix are clearly visible. **C** — debrite in the form of clast-supported to matrix-supported exotic conglomerate, generally massive, partly inversely graded with randomly scattered outsized clasts. Targoszów section: **D** — massive muddy conglomerate debrite containing exotic clasts, partly with irregular pockets richer in sandy-granule matrix. At the top part irregular surface with amalgamated non-exotic muddy gravelly sandstone occurs. **E** — lower part of the debrite from picture D: shows outsized exotic clasts. **F** — outsized clast of organodetritic limestone from debrite described in photo D.

The massive, coarse-clastic deposit, composed of sandy matrix rich in mud (clay- and silt-sized material), as well as in quartz granules and outsized exotics, can be considered as an exotic matrix-supported conglomerate rich in unsorted sandy-muddy matrix.

An exotic-bearing deposit developed in such a way could be interpreted as a "dirty" conglomerate debrite, that is a debritic conglomerate with exotics and with a sandy matrix rich in high content of fine-sized particles (mud), or as a specific case of exotic-bearing gravelly mudstone debrite, meaning a debritic gravelly mudstone with exotics and quartz granules rich in a sandy matrix, but relatively poor in fine-sized particles (mud). Presumably it originated from siliciclastic gravelly-sandy-muddy debris flow and formed an apron-type cover lithosome (linearly supplied) with no signs of basal erosion, indicated by a flat base. This debrite, coalesced with the surrounding clastic bodies, is interpreted as a component of the slope-apron depositional settings.

Table 1: Percentage composition of the petrographic type clasts, based on a set of 256 specimens, pebble-to-boulder in-size, occurring in the Upper Istebna Sandstone (Paleocene) of the Istebna Formation (Silesian Series of the Outer Carpathians). The exotic position in the Targoszów section from the Beskid Mały Mountains as an example.

Rock type		Petrographic type	Volume per cent [%]			Frequency per cent [%]			Volume range [cm³]	Average volume [cm³]			
Crystalline	Metamorphic	Gneisses	36.9	50.3	53.2	26.9	54.3	88.6	1–7900	525	355	230	384
		Quartzites	5.9			12.9			15–1411	176			
		Muscovite-biot. sch.	2.1			5.6			< 1–936	146			
		Sericite-chlor. sch.	0.9			2.3			17–476	153			
		Granulites	4.5			6.6			6–1428	255			
	Igneous	Porphyries	0.8	1.0		1.5	3.5		66–338	210	114		
		Aplites	< 0.1			1.2			< 1–22	12			
		Granites	0.2			0.8			39–109	74			
	Vein quartz		1.9			30.8			< 1–245	23			
Sedimentary		Sandstones	2.5	46.8		5.1	11.4		42–706	191	1588		
		Limestones	41.5			4.7			31–23177	3399			
		Mudstones	2.8			0.8			14–2415	1214			
		Cherts	<0.1			0.8			29–49	39			

Results

Exotic clasts in the Istebna Formation of the Beskid Mały Mts.

Deposits with macroscopically discernible crystalline and sedimentary exotics are rare in the IFmBM (approx. up to 3 % by volume and up to 0.5 % freq.). They appear mainly in the Lower Istebna Sandstone (especially at its border with the Upper Godula Beds) and in the Upper Istebna Sandstone (especially at the beginning of this sedimentary succession) (Fig. 2) (e.g., Książkiewicz 1951). Exotic clasts constitute a component of some siliciclastic deposits (siliceous-silicate debrites). The most exotics are associated with debritic conglomerates, debritic sandy conglomerates and debritic gravelly mudstones (Figs. 3 and 4), and to a lesser extent with debritic gravelly sandstones. The qualitative and quantitative results, based on the authors' own analysis, are outlined below and the volumetric relations (percentage by volume) together with the frequency of occurrence (frequency per cent) of the petrographically diversified clasts are shown in Table 1.

Statistical description of the siliciclastic deposits

Gravelly mudstone debrites make up 7.0 % vol. of the total thickness of the IFmBM, while conglomerate debrites and sandy conglomerate debrites, which are chiefly related to the occurrence of exotics, make up together only 6.6 % vol. of the thickness in total. Gravelly sandstone debrites, which form a relatively large bulk of the IFmBM (10 % by volume), only occasionally contain some exotic rocks. In the sandstone debrites, despite their dominance in the formation (51.4 % vol. and 33.4 % by frequency), no exotics were observed macroscopically. In the other lithotypes, exotics were also not found.

Conglomerates with exotic clasts constitute 34 % vol. and 32 % of the frequency (amount) of all the assessed conglomerates (2.8 % vol. and 0.7 % by frequency of the IFmBM). Exotic sandy conglomerates had a 7 % thickness share and a 6 % frequency share in all the investigated sandy conglomerate lithotype (3.8 % vol. and 1.3 % freq., IFmBM). Occasionally, single specimens of exotics were also present as outsized clasts in gravelly sandstones. Exotic gravelly mudstones made up 15 % by volume and 7 % by frequency among gravelly mudstones.

In the Targoszów section (Figs. 1C,E and 3B) exotics are associated with the siliciclastic deposit having transitional characteristics relative to the above-mentioned "clean" debrite types. They occur in conglomerate, but with a macroscopically visible sandy- and mud-rich matrix (dark grey colour of a fine-grained background).

Among all the observed exotic debrites, namely rocks containing exotic clasts and considered as debris flow deposits, debrites represented by exotic conglomerates made up 38 % of the thickness and 62 % of the frequency, while debrites in the form of sandy conglomerates with exotics made up 10 % vol. and 23 % by frequency. Therefore, they constitute the dominant exotic debrite association (48 vol. %, 85 freq. %). For debrites developed as exotic gravelly mudstones the shares were 42 % and 8 %, respectively, and for debrites classified as exotic "mudded" sandy conglomerate deposits: 10 % and 7 %.

Metamorphic rocks prevail among the exotics of the Upper Istebna Sandstone (>50 % by volume and frequency). Usually there are various types of gneiss, mostly porphyroblastic with feldspars and micas, and sometimes migmatitic (40 % vol. and 30 % freq.), quartzites (6 and 13 % respectively), crystalline schists (3 and 8 %), and rare granulites (4 and 7 %) (Table 1). Clasts of igneous rocks are the least common at most sites (typically less than 5 % vol/freq., Table 1), rarely up to 20 %, but only in the Lower Istebna Sandstone (cf. Wieser 1948). They are usually represented by various granitoids and intrusive rocks. Quartz pebbles, probably of vein origin, are relatively numerous and may account for up to 31 % freq., but only 2 % by volume (Table 1). Clasts of sedimentary rocks are usually rarely observed in the exotic populations. Nevertheless, some local exceptions appear, and then their volume reaches from a few to a dozen percent. Sandstones and dark cherts, such as lydites, are predominant in the frequency among the clasts of sedimentary rocks (6 % freq.), but their volume share is quite subordinate (about 2 % vol.). Calcareous rocks, including limestones, are relatively rare (locally up to 5 % freq.), but they can appear as single large blocks, reaching more than 40 % by volume, which makes this lithological type exceptional in this locality (Table 1).

Exotic calcareous rocks

A total of 24 thin sections were prepared from the exotic calcareous rocks sampled at the studied localities. Four of them were determined as Tithonian in age, one sample as Tithonian or alternatively Berriasian in age, one sample as latest Kimmeridgian or earliest Tithonian in age, one sample as Cretaceous (not older than Albian) in age, two of them did not give enough data to enable age determination, and the rest of them represent the Oxfordian–Kimmeridgian. Generally the Oxfordian–Kimmeridgian limestones represented different microfacies (MF) to the Tithonian limestones (Fig. 5), but some exceptions were noted (MF-1, MF-3). Table 2 presents the described calcareous microfacies. Tables 3 and 4 show lists of the most important microfossils noted in the limestones, as well as their known ranges, while Fig. 6 illustrates chosen microfossils.

Conceptual scenario for sedimentation development

During the Late Jurassic–Early Cretaceous diastrophic activity in the Alpine Tethys realm, the southern margin of the North European Platform was reshaped by the northward advancing, marginal breakdown (partitioning) of the continental plate and its edging (e.g., Golonka et al. 2000; Olszewska & Wieczorek 2001). The accommodation space of the proto-Silesian Basin was formed as a result of geotectonic processes which took place in the northernmost province of the Outer Carpathian Tethys (Ślączka 1986; Słomka 2001; Ślączka et al. 2006; Golonka et al. 2008b).

Basal deposits of the Silesian Series observed in field exposures, such as calcareous-to-marly slumps and debris flow deposits (cf. also Peszat 1968; Słomka 1986, 2001; Górniak 2015), suggest that during the early stages of the basin's evolution, mostly gravity resediments developed. Calcareclastic sedimentation was related to erosion of the calcareous sediments developed on the margins of the proto-Silesian Basin, including the Silesian Ridge. Firstly chaotic flyschoid deposits (proto-flysch−structurally flysch-like succession) were accumulated. Calcareclastic slumps and debrites created the early depositional system in the form of an apron. Afterwards chaotic sedimentation was ordered. Formation of the calcariclastic ramp(s) and more arranged deposition with repeatedly negative sequences continued horizontally, as with siliciclastic submarine fans (*sensu* Reading & Richards 1994; see e.g., Słomka 1986, 2001), as well as sedimentation of early calcareclastic turbidites, dominated in the architectural setting of the proto-basin.

The change from calcariclastics to deposits dominated by siliciclastics, observed in the field sections, may also indicate that progressively the western part of the Silesian Basin (initially proto-Silesian) was intensely supplied with siliciclastic material, which did not favour further development of the autochthonic calcareous sedimentation (Leszczyński & Malik 1996).

A large amount of siliciclastic coarse-grained material, produced especially during the phases of intensified tectonic activity of the Silesian Ridge, were temporarily accumulated in the over-slope zone (shelf-edge/normal fault area) and subsequently redeposited by mass-gravity processes into the deeper basinal environment. Slides and slumps, with increasing fragmentation and downslope acceleration (e.g., Wojewoda 2008), evolved into diverse debris flows with varying participations of particular grain-size fractions of the clastic material (e.g., sand and gravel, mud and sand or mud and gravel etc.). For instance, muddy-gravelly debris flows constituted mass flows of sediment-water mixtures in which gravel-sized clasts were randomly scattered in a predominantly muddy matrix. On the other hand sandy-to-gravelly debris flows were mass flows dominated by a concentrated mixture of sand and gravel grains, disorderly mixing in various proportions, and with low content of a mud matrix.

These slumps and debrites created a depositional system in the form of a siliciclastic slope apron. Subordinately, siliciclastics also filled single relatively small channels. An additional element of the depositional apron architecture was small-scale, but high-relief, lobe-like shaped, coarse-clastic bodies, which were formed at their mouth.

Hydroplastic behaviour and quasi-laminar state of debris flows may be affected by aquaplaning (hydroplaning *sensu* Shanmugam 2006; Festa et al. 2016). In such a case, deconcentrating (dilution) of their incoherent clastic masses would appear as a result. If such mass flows contained, originally or incorporated during transportation, large amounts of clay- and silt-sized particles, hydroplaning process may have contributed to at least partial (superficial) transformation of flows into turbulent suspensions−turbidity currents, and also it may be partly responsible for longer down-slope transport (e.g., Fisher 1983; Shanmugam 2000, 2006, 2016; see also Felix et al. 2009; Mulder 2011; Strzeboński 2015; Festa et al 2016). After stopping the bottom part of sediment gravity flow (debris flow freezing), the upper turbulent part may have been separated and accumulated as individual normally graded turbiditic deposits. Hydroplaning could also lead to elutriation of debris flow matrix and clay-silt particle separation process. This additionally, besides contributing to induce of suspension clouds, could be responsible for "cleaning" of debris flows.

The repeated mass redeposition of clastic materials resulted in the mixing of genetically diverse groups of sediments (including hemipelagic background sediments), and in the obliteration of their individual original characteristics includ-

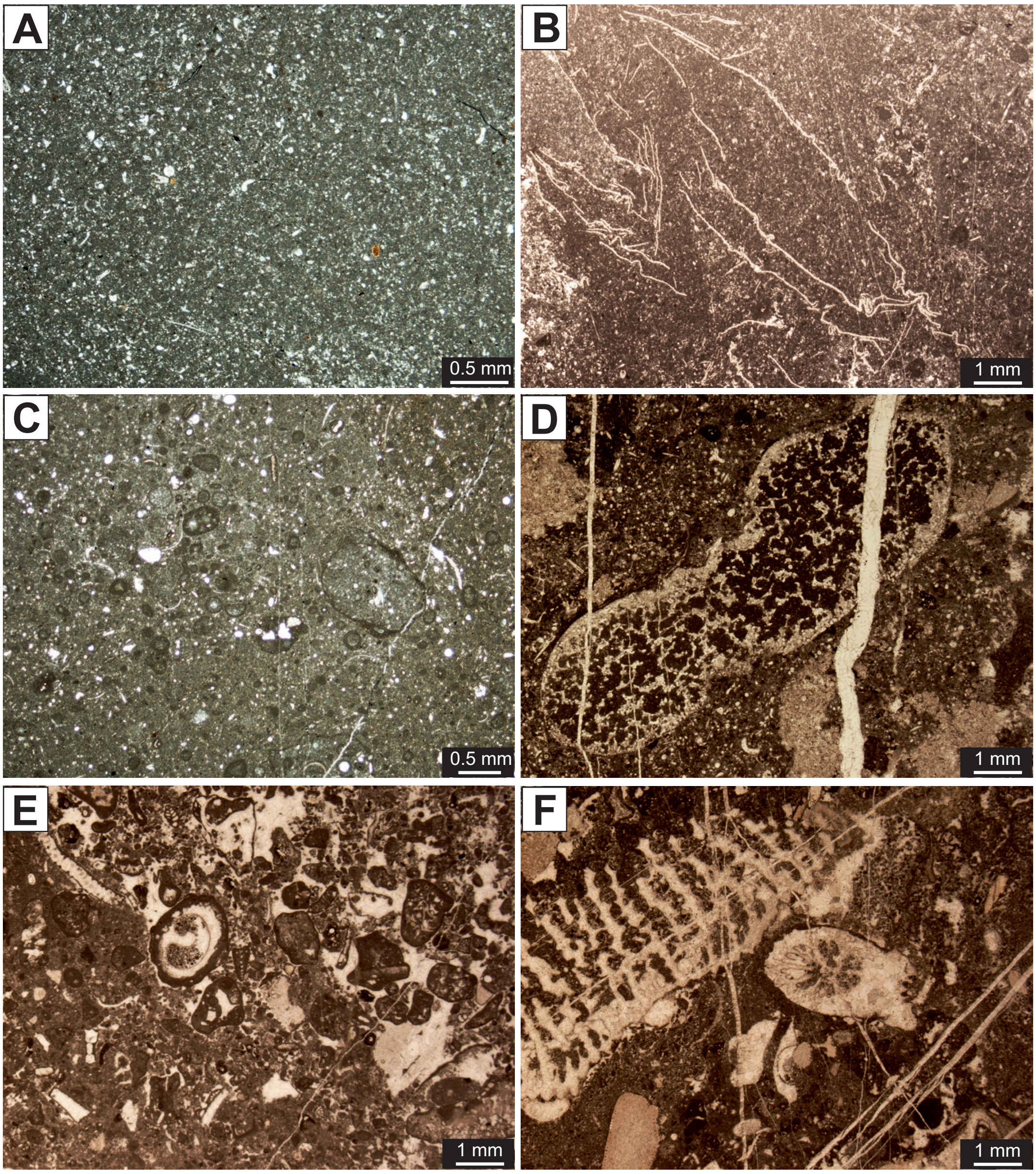


Fig. 5. Examples of the studied exotic limestones (microphotographs; plane polarized light — PPL): **A** — MF-1: Muddy bioclastic micrite (thin section S30/5). **B** — MF-3: Bioclastic wackstone with thin–shelled bivalves (S30/9). **C** — MF-4: Wackstone with bioclasts and non-skeletal grains (S30/2). **D** — MF-5: Wackstone with remnants of siliceous sponges and non-skeletal grains (S29/7). **E** — MF-7: Coated packstone/grainstone (S29/8). **F** — MF-10: Fine-peloidal packstone/grainstone with peri-reefal components (S30/10).

ing their sedimentary structures. As a result, this led to homogenization and development of massive structure and polygenetic nature of the final debris flow deposits (debrites).

Discussion

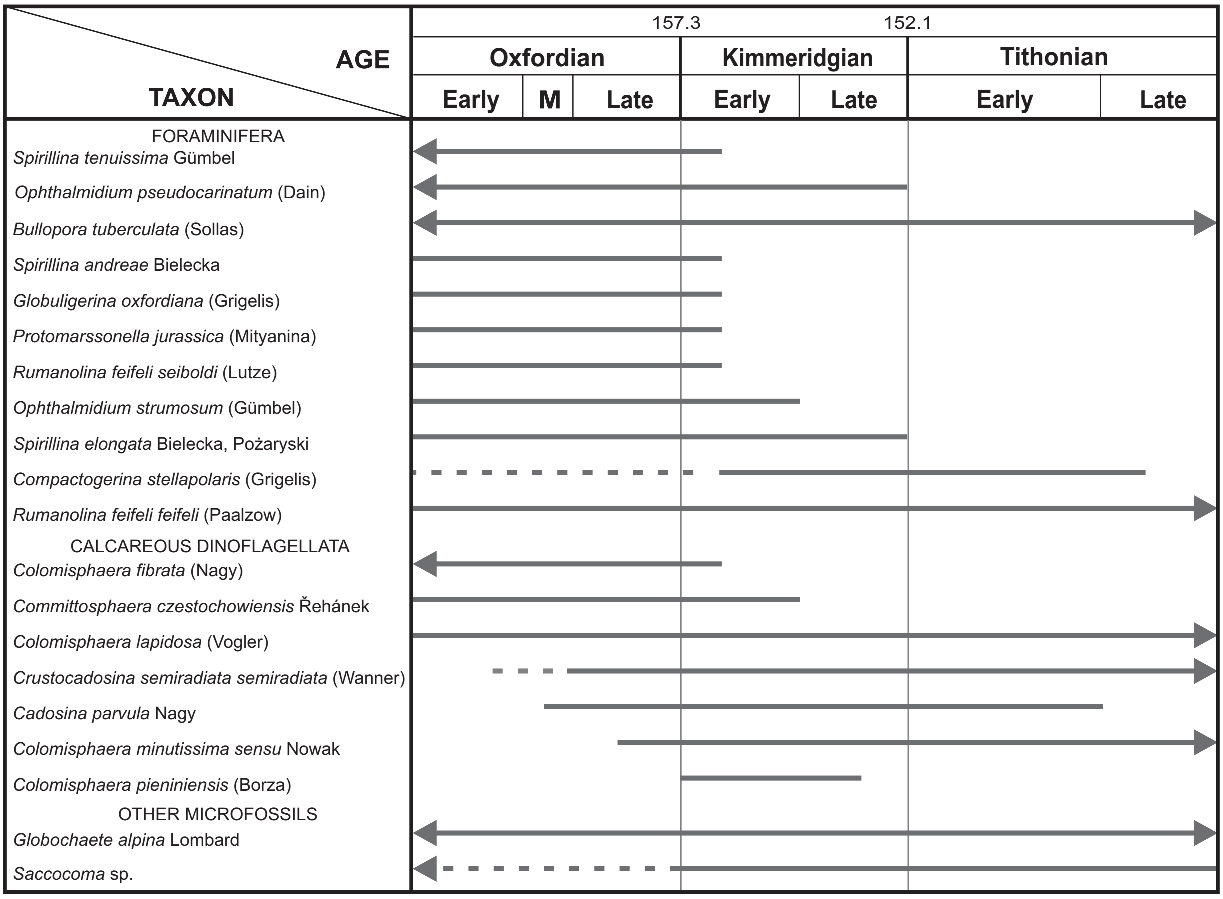
Interpretation of the studied calcareous exotic rocks

Micropaleontological data (mostly based on foraminifera, calcareous dinoflagellata and tintinnids) from the studied samples, indicate that the calcareous exotics from the IFmBM are mostly represented by the Oxfordian–Kimmeridgian rocks and, occasionally, by the Tithonian (and maybe also Berriasian) rocks. The Oxfordian–Kimmeridgian calcareous rocks represent deposits typical for the diverse zones of the carbonate shelf/ramp with the sponge-microbial buildups. It is a type of sedimentation very similar to that known from the northern Tethyan margin — the Carpathian Foredeep basement (e.g., Morycowa & Moryc 1976; Gutowski et al. 2007; Krajewski et al. 2011) and partly the Kraków-Częstochowa Upland (e.g., Matyszkiewicz 1989, 1996). Whereas, the Tithonian limestones can be interpreted as deposits of the diversified zones of

Table 2: Description of the microfacies of the studied exotic calcareous rocks.

Microfacies	**General description**	**Fossils**	**Age**	**Sample(s)**
MF-1 (see Fig. 5A)	Bioclastic wackstone (or, more often, muddy bioclastic micrite).	Fine, broken elements of echinoderms (including planktonic crinoids *Saccocoma* sp.), calcified radiolarians and sponge spicules, carapaces of ostracods, planktonic green algae *Globochaete alpina*, calcareous dinoflagellata (*Cadosina parvula, Colomisphaera lapidosa, Col. carpathica, Col. fibrata, Col. minutissima, Col. pieniniensis, Crustocadosina semiradiata semiradiata, Cr. semiradiata olzae, Committosphaera pulla, Carpistomiosphaera borzai, Stomiosphaera moluccana*), foraminifera (calcareous benthic, i.a., *Spirillina andreae, S. elongata, Rumanolina feifeli seiboldi, R. feifeli feifeli, Ophthalmidium* sp., *Neotrocholina valdensis, Lenticulina* sp., *Nodosarioidea*; rare agglutinated; rare planktonic *Globuligerina oxfordiana*), rare calpionellids – *Crassicollaria* sp. (in the Tithonian sample).	• Latest Oxfordian– earliest (and late?) Kimmeridgian • Kimmeridgian/ Tithonian • Late Tithonian	• S29/11 S29/15 S30/4 S30/5 S30/18 • S29/4 • S29/2
MF-2	Muddy echinoderm-peloidal allochem limestone.	Echinoderms (mostly *Saccocoma* elements), calcified sponge spicules, fragments of thin-shelled bivalves, *G. alpina*, calcareous dinoflagellata (i.e., *Colomisphaera fibrata*), foraminifera (calcareous benthic, i.e., *R. feifeli feifeli, Spirillina* sp., *Lenticulina* sp.; rare agglutinated).	Latest Oxfordian or (more probably) earliest Kimmeridgian	S29/14
MF-3 (see Fig. 5B)	Bioclastic wackstone with thin-shelled bivalves.	Thin-shelled bivalves, calcified sponge spicules, elements of echinoderms (including *Saccocoma*), carapaces of ostracods, *G. alpina*, calcareous dinoflagellata (i.e., *Cadosina fusca fusca, C. parvula, Col. lapidosa, Col. minutissima, Col. pieniniensis, St. moluccana*), foraminifera (calcareous benthic, i.e., *R. feifeli feifeli, Spirillina tenuissima*; rare agglutinated).	• Kimmeridgian • ?Tithonian	• S30/7 S30/9 • S29/6
MF-4 (see Fig. 5C)	Wackstone (or muddy micrite) with bioclasts and non-skeletal grains: peloids, intraclasts, grains of microbial origin, cortoids, small oncoids.	Fragments of bivalve and gastropod shells, elements of crinoids, echinoids and ophiuroids, carapaces of ostracods, calcified radiolarians and remnants of siliceous sponges, few ammonites aptychus, *G. alpina*, calcareous dinoflagellata (i.e., *C. parvula, Col. fibrata, Col. pieniniensis*), foraminifera (calcareous benthic: *Spirillina tenuissima, R.* gr. *feifeli, Ophthalmidium pseudocarinatum, O. strumosum, Cornuspira* sp., *Lenticulina* sp., Nubeculariidea, Nodosarioidea; agglutinated, i.e., *Ammobaculites* sp., *Ammodiscus* sp., *Glomospira* sp., *Reophax* sp.; planktonic foraminifera).	Oxfordian–earliest Kimmeridgian	S29/1 S29/3 S29/12 S30/2
MF-5 (see Fig. 5D)	Wackstone/packstone with remnants of siliceous sponges and non-skeletal grains (like in MF-4).	Calcified remnants of siliceous sponges, fragments of bivalve and gastropod shells, elements of crinoids (including *Saccocoma*), echinoids and ophiuroids, carapaces of ostracods, calcified radiolarians, calcareous dinoflagellata (i.e., *Col. lapidosa, Col. fibrata, Committosphaera czestochowiensis*), *G. alpina*, microproblematica *Koskinobullina socialis*, foraminifera (calcareous benthic, i.e., *S. andreae, Bullopora tuberculata, Lenticulina* sp., *Rumanolina* sp., *Ophthalmidium* sp., Epistominidae, Nodosarioidea, Nubeculariidea; agglutinated, i.e., *Protomarssonella jurassica, Ammobaculites* sp.; planktonic, i.e., *G. oxfordiana*).	Oxfordian–earliest Kimmeridgian	S29/5 S29/7
MF-6	Microoncoid-bioclastic packstone/grainstone with numerous thin-shelled bivalves. Non-skeletal grains: peloids, cortoids, small intraclasts. Bioclasts often constitute nucleuses of microoncoids.	Elements of *Saccocoma* (relatively numerous), other crinoids and holothurians, gastropod shells, carapaces of ostracods, calcified sponge spicules, *G. alpina*, calcareous dinoflagellata (i.e., *C. fusca fusca, Cr. semiradiata semiradiata, Col. pieniniensis*) foraminifera (calcareous benthic, i.e., *R. feifeli feifeli, Spirillina* sp., *Lenticulina* sp., miliolids; less frequent agglutinated; relatively numerous planktonic, i.e., *Compactogerina stellapolaris*).	Kimmeridgian	S30/1
MF-7 (see Fig. 5E)	Coated packstone/grainstone. Non-skeletal grains: cortoids, oncoids, peloids, intraclasts, aggregate grains.	Gastropod and bivalve shells, Dasycladales algae, fragments of bryozoan colonies, elements of crinoids and echinoids, single coral, calcimicrobes, *G. alpina*, microploblematica: *K. socialis* and *Thaumatoporella parvovesiculifera*, calcareous dinoflagellata (i.e., *Cr. semiradiata semiradiata*), foraminifera (calcareous benthic, i.e., *Crescentiella morronensis, Frentzenella odukpaniensis, Mohlerina basiliensis, Coscinoconus alpinus,* miliolids; agglutinated: *Paleogaudryina* sp., *Verneuilina* sp., *Melathrokerion* sp.).	Not older than late Tithonian	S29/8
MF-8	Peloidal-bioclastic-intraclastic packstone/grainstone.	Elements of crinoids and echinoids, fragments of bryozoan colonies, bivalve and gastropod shells, Dasycladales algae, calcareous sponges (*Neuropora*), tubes of serpulid worms, carapaces of ostracods, decapoda *Carpathocancer triangulatus*, calpionellids (*Crassicollaria* sp., *Calpionella alpina*), calcareous dinoflagellata (*Cr. semiradiata semiradiata, C. fusca fusca, Col. carpathica, Col. tenuis*), foraminifera (calcareous benthic, i.e., *C. morronensis, Siphovalvulina variabilis, Neotrocholina* sp., *Protopeneroplis ultragranulata, P. striata, M. basiliensis, Dobrogelina ovidi*, miliolids; agglutinated, i.e., *Uvigerinammina uvigeriniformis, Paleogaudryina* sp.).	Late Tithonian	S29/9
MF-9	Microbial-calcareous sponge boundstone.	Calcareous sponge, incrusting bryozoans, *Saccocoma, G. alpina,* microproblematica *Lithocodium aggregatum*, calcareous dinoflagellata (*Colomisphaera* sp.), rare chitinoidellids, foraminifera (calcareous benthic: i.e., *C. morronensis, Troglotella incrustans, Neotrocholina* sp., *Protopeneroplis* sp., Nubeculariidea, miliolids; agglutinated, i.e., *Valvulina* sp., *Protomarssonella* sp., *Trochammina* sp.).	early/late Tithonian	S29/13
MF-10 (see Fig. 5F)	Fine-peloidal packstone/grainstone with peri-reefal components.	Corals, bivalve and gastropods shells, Dasycladales algae, elements of crinoids and echinoids, carapaces of ostracods, tubes of serpulid worms, *G. alpina*, microproblematica *L. aggregatum* and *K. socialis*, "bacinellid" fabrics, calcareous dinoflagellata (*Cr. semiradiata semiradiata*), rare chitinoidellids, foraminifera (calcareous benthic, i.e., *C. morronensis, T. incrustans, Moesiloculina histri, Trocholina* sp., *Coscinoconus* sp.; agglutinated, i.e., *Coscinophragma cribrosum, Textularia* sp., *Valvulina* sp., Placopsilininae).	early/late Tithonian	S30/10
MF-11	Muddy micrite with rare microfossils.	Calcareous dinoflagellata, planktonic foraminifera (of such genus like *Hedbergella, Globigerinelloides, Heterohelix*).	not older than Albian	S29/16

Table 3: List and known ranges of the most important microfossils from the Oxfordian–Kimmeridgian exotic limestones. Age after Ogg et al. (2016).



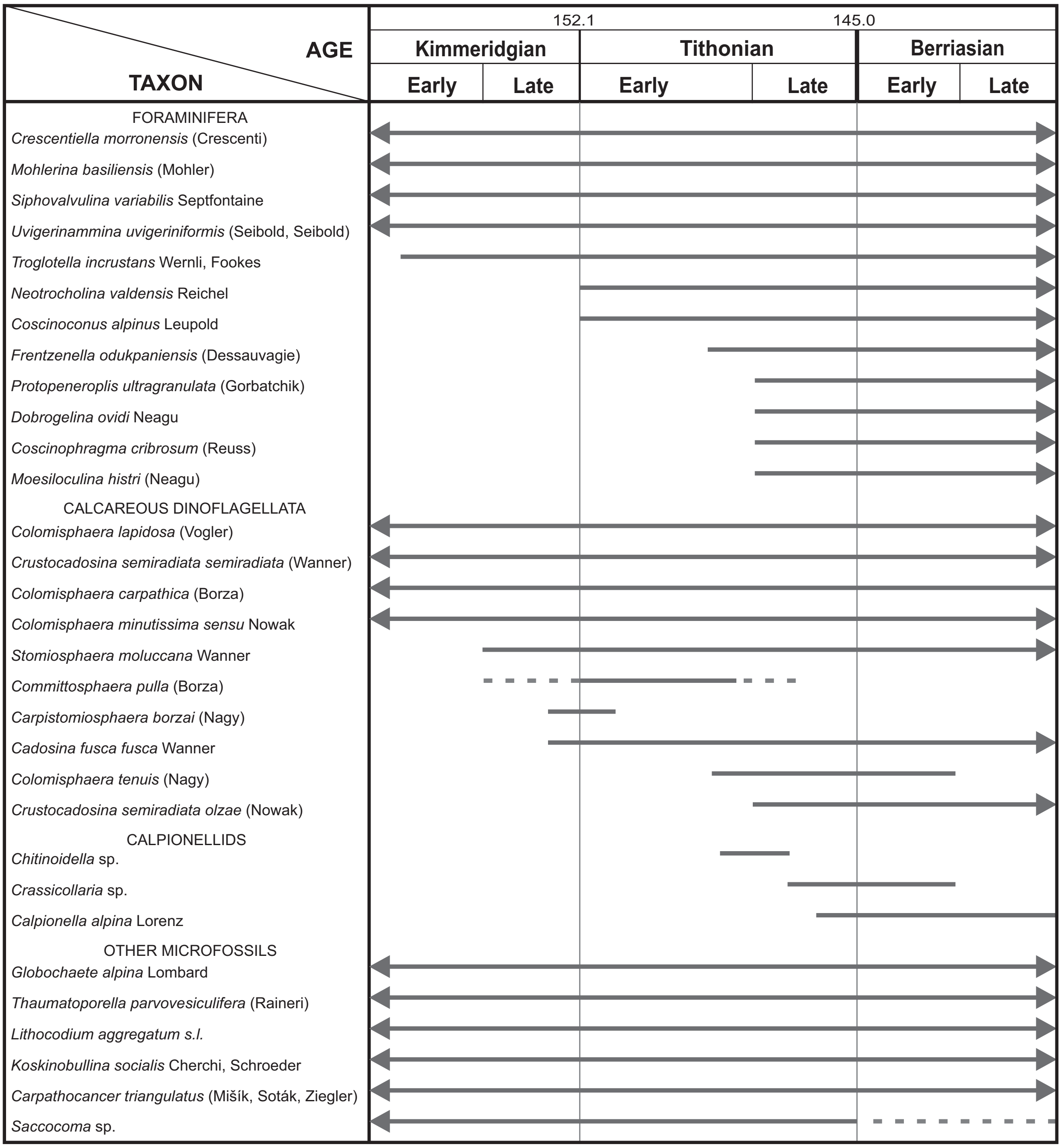
carbonate platforms (so-called Štramberk-type limestones) with reefs built by corals, microbes, and calcareous sponges, less often as deposits of the deeper zones (see also Eliáš & Eliášová 1984; Hoffmann & Kołodziej 2008). Oxfordian–Kimmeridgian sedimentation in the palaeogeographic area of the future Silesian Ridge was probably similar to sedimentation developed in the areas situated northward in the epicontinental basin, while during the Tithonian–Berriasian the Štramberk-type carbonate platform was developed on the Silesian Ridge, and calcareous deposition also took place in the deeper zones.

The age of the oldest analysed calcareous exotics (Oxfordian–Kimmeridgian) agrees with the time interval, when most probably the initial diastrophic processes forming this part of the Alpine Tethys realm took place. Intensification of these processes, as seen in the southern regions of Central Europe, caused the progressive geotectonic-gravity blocky breakdown of the SW periphery of the North European Platform. It forced a subsequent extension of the north province of the Alpine Tethys and formation of a new accommodation space — the early Outer Carpathian sub-basins (e.g., Książkiewicz 1953; Unrug 1968; Ślączka 1986; Słomka 1986; Olszewska & Wieczorek 2001; Poprawa et al. 2002, 2004; Golonka et al. 2008b). The oldest known deposits of the Silesian Series — the Vendryně Formation — are dated as latest Kimmeridgian in age (Olszewska et al. 2008). Nevertheless, it is possible that basal detachment of deposits, which took place during formation of the Carpathian tectonic units (see Paul et al. 1996), may not have been located at the strict bottom of the primary basinal series, and then the beginning of the history of these sedimentary areas may be older.

The younger limestones observed among the studied exotics, dated as Tithonian (possibly also Berriasian) in age can be interpreted as the indicators of the development of calcareous sedimentation in the shallow zone of the newly shaped proto-Silesian Basin. On the other hand, they indicate submarine abrasion of these platforms and resedimentation of their calcareous clastic material (calciruditic-to-calcilutitic sediments) into the deeper basin and its mixing with deposits of the sedimentary background (e.g., Bieda et al. 1963; Peszat 1968; Matyszkiewicz & Słomka 1994; Leszczyński & Malik 1996; Słomka 2001).

A single clast of muddy micrite, determined as not older than Albian in age, is most probably a resedimented fragment of the deposits from the Silesian Series and could constitute an example of the recycling (so-called "cannibalism" *sensu* Matyszkiewicz & Słomka 1994) of the Carpathian sedimentary series.

Table 4: List and known ranges of the most important microfossils from the Tithonian (and alternatively Berriasian) exotic limestones. Age after Ogg et al. (2016).



Origin of the siliciclastics of the Istebna Fm.

The specific features of the IFmBM (see subchapter: *Depositional lithofacies*) show that the south facial zone of the western part of the Silesian Basin was periodically supplied by a large amount of coarse-grained siliciclastic material in the Late Cretaceous–Palaeocene.

It also indicates successive stages of the Silesian Ridge activation, connected with the intensification of the compressive regime in the Outer Carpathian region and the progressive intense denudation of this source area. This type of deposits originated from a large scale of production, resedimentation, as well as mass transport and mass deposition of these clastic materials. It was genetically linked to the syngeotectonically enhanced denudation and the over-covering of shores and offshore of the source areas. Accordingly, a large amount of terrigenic siliciclastics was delivered to the basin and gravitationally poured into the deeper, more distal zones. Finally, disorderly ("chaotic") setting of such series is due to prevalent slumps and debris flows. Therefore intense denudation of the emerged fragments of the Silesian Ridge was the main factor responsible for the origin of such coarse-grained clastics.

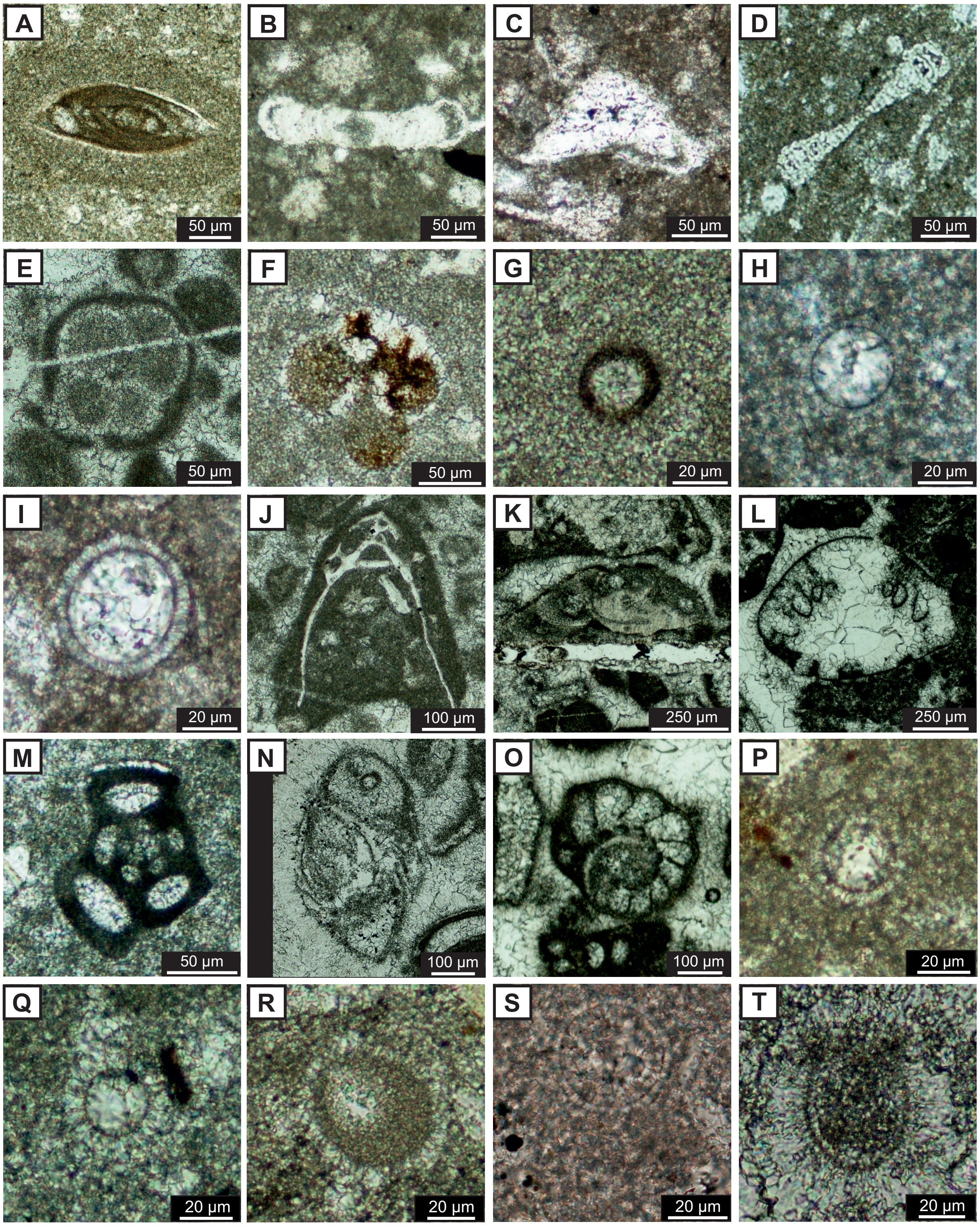


Fig. 6. Examples of microfossils from the Oxfordian–Kimmeridgian exotic limestones: **A** — *Ophthalmidium strumosum* (Gümbel) (S29/3). **B** — *Spirillina andreae* Bielecka (S30/4). **C** — *Rumanolina feifeli feifeli* (Paalzow) (S29/11). **D** — *Spirillina tenuissima* Gümbel (S30/18). **E** — *Compactogerina stellapolaris* (Grigelis) (S30/1). **F** — *Globuligerina oxfordiana* (Grigelis) (S19/32). **G** — *Cadosina parvula* Nagy (S29/3). **H** — *Colomisphaera fibrata* (Nagy) (S29/12). **I** — *Colomisphaera pieniniensis* (Borza) (S29/11). **J** — *Saccocoma* sp. (S30/1). Examples of microfossils from the latest Kimmeridgian/Tithonian–Berriasian exotic limestones: **K** — *Mohlerina basiliensis* (Mohler) (S29/9). **L** — *Frentzenella odukpaniensis* (Dessauvagie) (S29/8). **M** — *Moesiloculina histri* (Neagu), (S30/10). **N** — *Protopeneroplis striata* Weynschenk (S29/9). **O** — *Protopeneroplis ultragranulata* (Gorbatchik) (S29/9). **P** — *Colomisphaera tenuis* (Nagy) (S29/2). **Q** — *Colomisphaera carpathica* (Borza) (S29/9). **R** — *Crustocadosina semiradiata olzae* (Nowak) (S29/2). **S** — *Carpistomiosphaera borzai* (Nagy) (S31/7). **T** — *Chitinoidella* sp. (S29/9).

The uplifted ridge forced relative regression, and resulted in successive exposition of the proximal basinal deposits. In the edge zone of the shelf margin with fronts of prograding clastic bodies (e.g., Porębski & Steel 2006) and the proximal slope zone, the angle of repose was increasing. In such a situation even a slight change of inclination of such zones can cause loss of stability and failure/collapse of a large amounts of accumulated, non-consolidated material. It was another factor causing large-scale mass resedimentation. Described processes contributed to the release of mass wasting, such as slumps, which was responsible for development of slope debris flows (gravelly-sandy and muddy-sandy-gravelly type), including mass flows with exotics. It should be emphasized that such events like catastrophic floods and storms, earthquakes, tsunami or submarine gas escapes etc. (see details in Shanmugam 2016) may constitute additional initial impulses, triggering activation/reactivation of the gravity-powered sedimentary processes. However, we may only speculate in this respect.

Directions repeating in lateral propagation in the IFmBM, created an approximate pattern of parallel pathways for transporting clastic material (in relation to the source area). This indicates that the discussed deposits were accumulated in the siliciclastic cover of a linearly supplied apron depositional system (*sensu* Reading & Richards 1994, see also Słomka 1995).

General lack of ordered "fan" sequences (*sensu* Reading & Richards 1994) indicates that disorganized complexes formed irregular coarse-clastic apron covers, built of amalgamated deposits of slumps and debris flows. Paleotransport directions were parallel to each other and perpendicular to the longer axis of the basin, suggesting linear supply. These observations can suggest development of the linearly sourced apron depositional system.

The Subsilesian elevation, which constituted the northern margin of the Silesian Basin (cf. Książkiewicz 1962; Ślączka 1986), did not have a significant alimentary influence during the sedimentation of the Istebna Fm. Structures indicating paleotransport from the north are observed very rarely.

Origin of the calcareous exotics

During the later (post-Valanginian) phases of the sedimentary filling in the western part of the Silesian Basin, intense calcareous sedimentation was hampered by the previously described processes. Accordingly, shallow-water carbonate sedimentation was not extended in this area, and pure calcareous resediments were not deposited.

Taking under consideration both the formation time and thickness of the Upper Istebna Sandstone deposits from the Beskid Mały Mts. (assuming 150 m and 5 Ma respectively) (Fig. 2), we can suppose that periodical uplift and denudation of the western part of the Silesian Ridge in Paleocene had to be significantly increased, however, the calculated accumulation rate, ca. 30 m/Ma (delivered to the Silesian Basin) does not properly reflect the real size and power of these geotectonic-sedimentary processes. Dynamic growth of the source area activity corresponds better to the lower Istebna Formation (Late Cretaceous sedimentation) — ca. 100 m/Ma (Fig. 2), though even a much higher value of the ratio would be possible, for example, if compaction or intra-basinal erosion together with large-scale redeposition of the clastic material, were included. It seems possible that before deposition of the Istebna Fm., the Silesian Ridge was deeply denuded and mainly its crystalline base was significantly eroded during deposition of the formation (e.g., Unrug 1968). This agrees with data on the predominance of crystalline exotics in these deposits (almost 90 % by frequency and more than 50 % by volume) (Table 1). Therefore, it is probable that exotic calcareous rocks in the IFmBM come mainly from the secondary sources — from the recycling of the older, thick clastic, flysch deposits, which were eroded, reworked and redeposited. It can be called exotic recycling — re-use of the older exotic clasts.

A larger role of the primary source in the origin of exotic limestones would be possible to some extent, for example, following the model of the synsedimentary anatectic block half-rotations and reverses (cf. Dadlez & Jaroszewski 1994). The fragments of the Silesian Ridge inclined in such a way, with the front slopes covered by the carbonate platform, may have been gradually rotated and exposed. It is probable that during their periodical uplift and emerging (rotation), even in the late, pre- or early orogenic stage of the flysch sediment development, both secondary and primary calcareous material was delivered into the basin. In this case the primary, preserved calcareous material would come from this part of the cover of the Silesian Ridge, which had been semi- or fully submerged until that time. Accordingly, crystalline clasts may have come from the gradually exposed crystalline basement of the Silesian Ridge (primary source), as well as from recycling of the older flysch, and possibly also pre-flysch deposits (secondary source).

Diversified textural maturity of the observed exotic clasts, as well as their petrographic differentiation, microfacies variety, and stratigraphic range, suggest that some of the exotics come directly from the source area, while others are recycled from the older flysch deposits.

Distribution and diversity of the exotic material

As previously mentioned, significant qualitative and quantitative differences are observed in calcareous exotic material between the areas situated farther west and east from the Beskid Mały Mts. In the Beskid Mały Mts. the Oxfordian–Kimmeridgian rocks prevail over the Tithonian–Berriasian ones (Fig. 7). Thus, only a small amount of material coming from erosion of the latest Jurassic–earliest Cretaceous carbonate platforms was delivered to the part of the Silesian Basin corresponding to the Beskid Mały area during the Paleocene deposition, while the amount of fragments (mostly small) of the older, Oxfordian–Kimmeridgian calcareous rocks, was relatively large in the deposits representing the IFmBM.

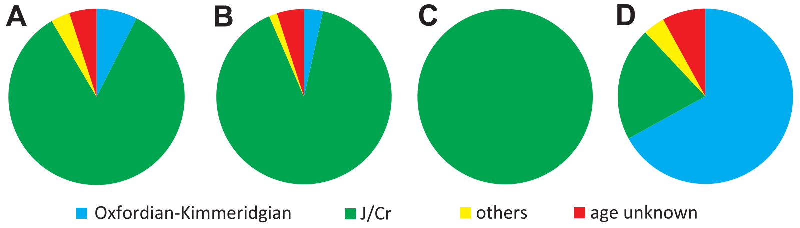


Fig. 7. Comparison of the diversified age of the exotic calcareous rocks from: **A** – diverse formations (Lower Cretaceous–Oligocene) from the western part of the Polish Outer Carpathians (390 exotic clasts); **B** — Lower Istebna Beds: Rożnów, Wiśnicz and Wieliczka Foothills and Beskid Wyspowy Mts. (59 exotic clasts). **C** — Upper Istebna Beds: Tarnawa (Wiśnicz Foothills) (13 exotic clasts). **D** — Upper Istebna Beds: Beskid Mały Mts. (24 exotic clasts). Based on: this work and Kowal-Kasprzyk (2016).

Irregularity and diachronicity of the diastrophic activity in the particular regions of the Carpathian province (e.g., Słomka 1995), should be taken under consideration to explain the diversified distribution of the calcareous clasts in the flysch deposits. These factors had to have influence on both the source and basinal areas: diachronic uplift and emergence of source areas and diversified subsidence and accommodation of sedimentary sub-basins. For that reason, the general tendency for a relatively rare occurrence of calcareous exotics in the Istebna Fm., especially in the western part of the Silesian Nappe, and for a distinct increase of their amount farther east from the Beskid Mały Mts., may be interpreted as a result of a larger reduction of the primary sedimentary cover of the Silesian Ridge in its western part. This might be due to the diachronic activity of fragments of the Silesian Ridge. This means that in the first place "islands" emerged in the western part of the Silesian Ridge, and then, the emergence of the ridge progressed eastward (e.g., Unrug 1968; Matyszkiewicz & Słomka 1994; Słomka 1995). It is also possible that the primary development of the Mesozoic sedimentary cover was diversified in space and thickness. In this context, before the beginning of the Late Cretaceous–Early Paleogene flysch sedimentation, the Upper Jurassic and lowest Cretaceous carbonate cover in the western part of the Silesian Ridge may have been eroded to a large degree, while in the eastern part that cover may have been longer preserved or better developed.

The irregular distribution of exotic clasts could also be influenced by the geometry of the Silesian Ridge. This alimentary area constituted a strongly elongated, probably fragmented tectonic elevation (e.g., Unrug, 1968), with parts in different places that may have been uplifted, submerged, transformationally displaced and half-rotated at different times and with varied intensity. A laterally and vertically diversified denudation would be due to such processes. It would have involved diversification in the volume and fraction-sizes of material delivered to the basin, and development of varied gravity flows, and, as a consequence, development of various depositional systems.

Geotectonic-sedimentary pulses in the development of the Silesian Basin

Very coarse-clastic deposits in the lowest parts of the Lower Istebna Sandstone and Upper Istebna Sandstone, indicate the beginning of the new sedimentary phases of the basin's sedimentary filling. Such intervals reflect especially the pulsar geotectonic activity generating forced regressions: *relative* sea-level falls. A basal position of the coarse-grained, often exotic-bearing accumulations is connected with a relatively rapid and intense beginning of the regional intensification of the compressive tectonic regime. These stages have a significant influence on the sedimentary basin-filling style, lithofacies composition and development of the depositional system architecture.

Generally, non-channelized slope-apron covers, dominated by massive, amalgamated, thick bedded and coarse-grained siliciclastics, occur initially as a consequence of an increase in the diastrophic activity. The intensified tectonic uplift of the source areas after a period of relative calm resulted in the induction of the submarine mass-gravity processes — principally slumps and debris flows (e.g., Słomka 1986, 2001). Diastrophic moderation and formation of preferential, relatively stable ways of transport of the detrital material (channels) induced the formation of the piedmont siliciclastic ramps — multiple, overlapping submarine fans (*sensu* Reading & Richards 1994; see also Słomka 1995).

Distinct exotic enrichment and presence of conglomerate deposits in the lowest part of the Upper Istebna Sandstone, compared with other finer-grained deposits without exotic clasts of the Istebna Fm. in the study region, constitute an additional indicator, suggesting that this interval with coarse-grained siliciclastic sedimentation was a beginning of the next, extremely intense phase of the tectono-sedimentary activity in this part of the Silesian Basin, which was a paleogeographic equivalent of the contemporary Beskid Mały Mts. In this respect, occurrence of conglomerates, exotic conglomerates and synsedimentary disturbed deposits close to the uppermost part of the Lower Istebna Beds (see Fig. 2), can be practically used in the mapping and can be treated as indicators helpful for the separation of the Upper Istebna Sandstone subdivision in the Beskid Mały Mts., especially when coarse-clastic deposits have coalesced (above-mentioned lack of the Lower Istebna Shale). The lithofacies boundary between the Lower Istebna Beds and the Upper Istebna Beds (Fig. 2) may be diachronic (e.g., Szydło et al. 2015). Diachronity of the lower boundary of the Lower Istebna Shale in relation to the Cretaceous/Paleogene boundary (K/Pg) may be a result of the non-simultaneous development of the particular sedimentation types along the whole area of the western part of the Silesian Basin. The boundary between the lower Istebna Fm. and upper Istebna Fm. in the Western Beskids can appear in the time interval between the latest Maastrichtian and the lowest Paleocene (Fig. 2). Determination of the lowest Paleocene biozones which document the K/Pg boundary is problematic (e.g., Jugowiec-Nazarkiewicz & Szydło 2013), and further biostratigraphic study and sedimentological facies analysis are required.

Conclusions

The results, shown in relation to the existing state of knowledge on the history of the Carpathian basinal development, indicate successively:

- Late Jurassic development of the calcareous sedimentation on the south margin of the North European Platform and marginal diversification of this area into the lowered and elevated tectonic zones: the future proto-Silesian Basin and the Silesian Ridge;
- development of the autochthonous calcareous sedimentation in the shallow-water zones of the Silesian Ridge (mostly during the Tithonian–Berriasian);
- uplifting and emerging of the fragments of the Silesian Ridge, contributing to erosion of the older deposits, and development of the large-scale, gravity-driven sedimentary mass processes (slumps, debris flows) on the slope, causing mass redeposition of calcareous materials;
- exposing (tectonically and/or eustatically) the older flysch deposits and incorporating their materials into the newly developing basinal successions (flysch recycling processes);
- subsequent geotectonic–quasi-eustatic pulses in this area, meaning recurrence of tectonic increase in the activity of the source areas corresponding to tectonically forced regression — development of the mass deep-water siliciclastic-dominated sedimentation (e.g., sandstone-to-conglomerate deposits of the IFmBM, occasionally debrites with exotics).

Analyses of the sedimentological attributes of coarse-grained siliciclastics and the exotic-bearing deposits of the IFmBM, suggest that:

- they originated from the deep-water sediment gravity-induced failures (mostly slumps), progressively evolving, predominantly in diverse submarine debris flows;
- efficient development of such mass-transport- and mass-deposit processes in the basin area was spread from the “shelf”-edge, by the proximal slope to the slope-foot (distal zone);
- usually massive, mainly matrix-supported (clast-in-matrix structure) deposit types formed tongue-shaped, lenticular, laterally discontinuous amalgamated debritic lithosomes;
- disorganized clastic bodies were accumulated in the form of the merging covers of the linearly supplied apron depositional system. Subordinately, they also filled erosional washouts and ephemeral chutes in a form of ordinarily single and unstable relatively small channels.

The calcareous exotics (Oxfordian–Tithonian, and alternatively Berriasian in age) found in the IFmBM most probably originated from:

- sedimentary cover of the southern margin of the North European Platform, deposited before sedimentation of the oldest known deposits from the proto-Silesian Basin (e.g., Vendryně Fm.);
- shallow-water, synsedimentary calcareous deposits developed in the early stage of the alimentary activity of the Silesian Ridge;
- secondary source — erosion of the basinal calcariclastics as well as siliciclastics with calcareous exotics and their redeposition into the younger siliciclastic flysch series.

Relatively infrequent occurrence of the calcareous exotics (mainly Late Jurassic in age) and irregularity of their lateral and vertical distribution in IFmBM may be explained by:

- general polarization of the intense, but variable in time and space elevation of the Silesian paleogeographic area and diversification of its geological structure;
- influence of the intense, but spatially and temporally diversified denudation of the particular uplifted and emerged fragments of the source area — the essential depletion of the Upper Jurassic calcareous source rocks before the Late Cretaceous–Paleocene sedimentation in the discussed paleogeographic area;
- relatively small and irregular distribution of the proto-flysch calcariclastics in the Silesian Series (for a potential re-use);
- lithotype diversification of the Istebna Fm. — deposits with macroscopically distinguishable exotic clasts (conglomerate debrites, sandy conglomerate debrites and gravelly mudstone debrites) are not abundant in this formation;
- faster natural physical and chemical destruction of calcareous clasts compared to clasts of crystalline rocks; accordingly, calcareous material goes into the finer fraction and finally into solution, causing secondary allogenic liminess of siliciclastics;
- recycling of the exotic clasts (exotics of the recycled origin) — their reworking and resedimentation into the younger basinal series.

It is clear, therefore, that the provenance and origin of calcareous exotics are very complex and problematic.

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