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EXOTIC CLASTS OF ORGANODETRITIC ALGAL LIMESTONES FROM LITHOSOMES OF THE BABICA CLAY, SKOLE UNIT (OUTER FLYSCH CARPATHIANS, POLAND)

Jacek RAJCHEL & Jolanta MYSZKOWSKA

Zakład Geologii Ogólnej i Matematycznej, Wydział Geologii, Geofizyki i Ochrony Środowiska Akademii Górniczo-Hutniczej im. Stanisława Staszica, al. Mickiewicza 30, 30-059 Kraków

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Abstract: The paper deals with exotic clasts of Lithothamnium calcarenites and calcirudites occurring in the central part of the Skole Unit. The clasts are confined exclusively to those lithosomes of the Babica Clay (upper Paleocene) which occur within the Variegated Shale Formation, overlying the Bircza Lithothamnium Limestone Bed (BLLB). The exotic clasts represent fragments of talus deposits, formed due to degradation of algal reefs which were situated along the northern margin of the Skole basin. They were transported into the basin by dense cohesive flows that built pebbly mudstones lithosomes of the Babica Clay. Exotic clasts of calcarenites contain silicified cores formed after clast deposition. The age of exotic rocks was determined as the turn of the Early and Late Paleocene basing on foraminifers.

Abstrakt: Scharakteryzowano grupę litotamniowych, kalkarenitowych i kalcyrudytowych egzotyków, z centralnej części jednostki skolskiej. Występują one tylko w tych litosomach iłów babickich (późny paleocen), które usytuowane są w obrębie formacji pstrych łupków, powyżej warstwy litotamniowego wapienia z Birczy /wt/. Egzotyki te są fragmentami stożków nasypowych, formujących się z degradacji raf glonowych usytuowanych wzdłuż północnej krawędzi zbiornika tej jednostki. Ich transport w głąb zbiornika odbywał się w gęstych, kohezyjnych spływach żwirowców ilastych formujących litosomy iłów babickich. Egzotyki kalkarenitowe posiadają zsylifikowane jądro, utworzone po ostatecznej depozycji egzotyka. Na podstawie zawartej w egzotykach mikrofauny otwornicowej określono ich wiek na przełom wczesnego i późnego paleocenu.

Key words: Skole Unit, Babica Clay, organodetritic exotic clasts, calcareous algae, silicification, cherts, Paleocene, Outer Flysch Carpathians.

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INTRODUCTION

The object of this study are clasts of organodetritic algal limestones which fall into the category of exotic rocks (*cf.* Jaroszewski *et al.*, 1985). The clasts have been found in lithosomes of the Babica Clay occurring in the central part of the Skole Unit (Fig. 1), between Rzeszów and Ustrzyki Dolne (Rajchel, 1976a, 1989, 1990). The lithosomes with exotic rocks occur only above the Bircza Lithothamnium Limestone Bed (BLLB; Gucik, 1961; Kotlarczyk, 1978; Rajchel, 1976a, 1989; *cf.* Figs. 2, 3).

The Babica Clay represents strongly differentiated deposits of the pebbly mudstone type. They have been distinguished first by Kropaczek (1917a, b) near Babica village on the Wisłok River, and later described under this name from numerous sites of Upper Cretaceous–Lower Palaeogene strata in the Skole Unit. At present, the name "Babica Clay" is applied exclusively to those deposits of this type which occur in lense-like lithosomes within Paleocene strata of the Wola Korzeniecka Member, Ropianka Formation, and in the Paleocene sequence of the Variegated Shale Formation of the Skole Unit (Kotlarczyk, 1978; Rajchel, 1990).

The majority of exotic rocks studied do not show close resemblance to the older allodapic limestones of the BLLB (Rajchel & Myszkowska, *in press*). Some specimens resemble, in turn, carbonate conglomerates from the top of the Ropianka Fm, occurring in the north-eastern and central parts of the Skole Unit (Fig. 2; *cf.* Rajchel, 1976a, 1989; Kotlarczyk, 1988a).

The aim of our paper is to characterise the lithology of exotic rocks and to compare them with deposits of similar type and age. Such a comparison could help in documenting differences in appearance and mode of sedimentation of these deposits, as well as to confirm the exotic character of the clasts studied. Basing on foraminifer tests preserved within exotic rocks, the age of parent rocks has also been

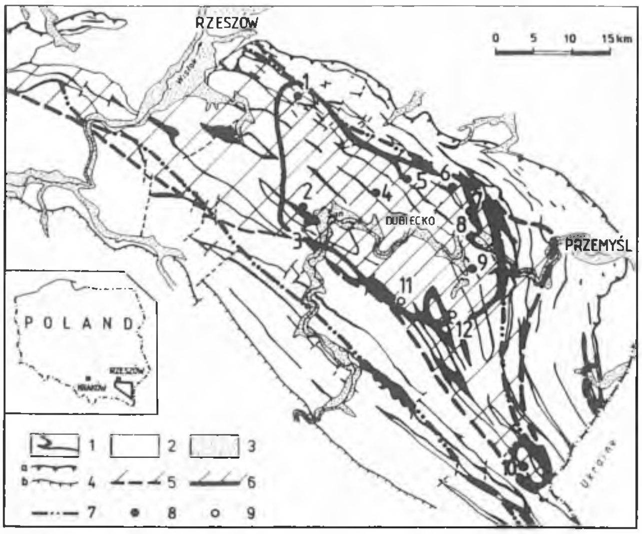

Fig. 1. Locations of exotic clasts of organodetritic Lithothamnium limestones in the Skole Unit (after Świdziński, 1958 and Rajchel, 1990; simplified and modified). *1* – Variegated Shale and Hieroglyphic Fm, *2* – Spas Shale Fm, Dołhe Fm, Ropianka Fm, Menilite Fm and Krosno Fm, *3* – Quaternary sediments, *4* – principal thrusts: *a* – Carpathian over thrust, *b* – other thrusts, *5* – extent of the Babica Clay lithosomes at the base of the Variegated Shale Formation, *6* – extent of exotic organodetritic limestones within lithosomes of the Babica Clay, weathering regolith, colluvia and alluvia, *7* – extent of the Bircza Lithothamnium Limestone Bed, *8-9* – outcrops of exotic clasts of organodetritic limestones: *8* – *in situ*, *9* – within weathering regolith. Sites: 1 – Zabratówka Wieś, 2 – Siodmówka, 3 – Przedmieście Dynowskie, 4 – Kosztowa, 5 – Drohobyczka Dolna, 6 – Skopów, 7 – Skopów Buczacz, 8, 9 – Bachów, 10 – Jureczkowa, 11 – Żohatyn, 12 – vicinities of Bircza

determined.

Our study makes it possible to reconstruct sedimentary environment of the northern margin of the Skole basin in Late Paleocene times, i.e. before its closing due to the Early Styrian orogenic movements (Kotlarczyk, 1988a).

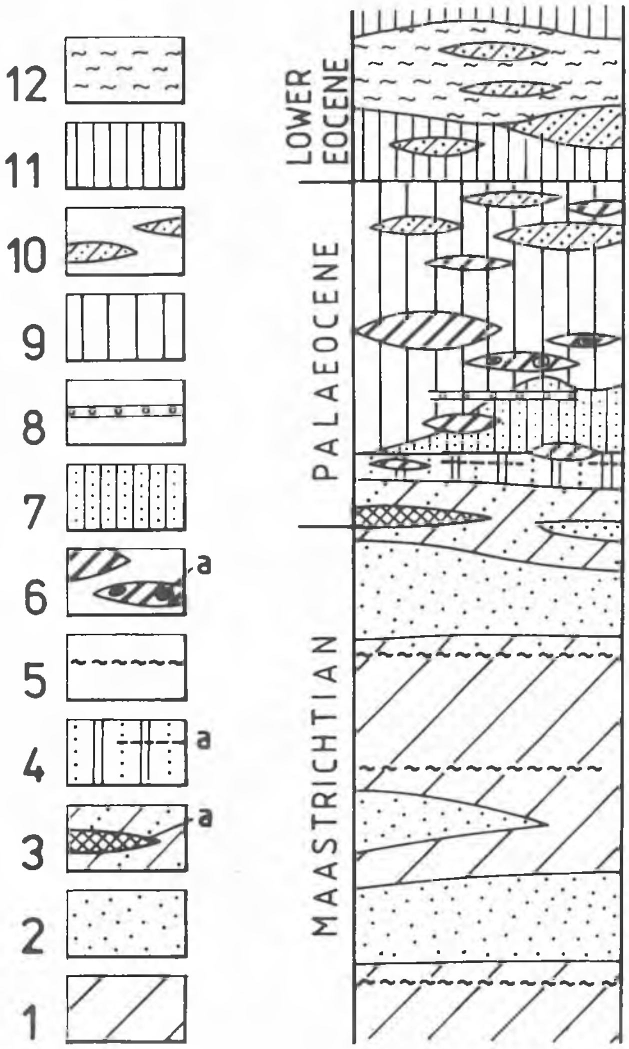

Fig. 2. Schematic lithostratigraphy of upper part of the Ropianka Fm and Variegated Shale Fm of the central part of Skole Unit (after Kotlarczyk, 1978 and Rajchel, 1990; modified and supplemented, not to scale). *1-5* – Ropianka Fm: *1* – thin-bedded sandstones and calcareous shales, *2* – thick-bedded calcareous sandstones, *3* – thin- and medium-bedded sandstones with intercalations of conglomerates and submarine slump deposits, *a* – Baculites marls, *4* – thin-bedded brittle sandstones and noncalcareous shales, *a* – Lithothamnium calcareous conglomerates and calcirudites, *5* – variegated shales markers, *6* – Babica Clay, *a* – exotic clasts of organodetrital limestones, *7-12* – Variegated Shale Fm: *7* – Boguszówka Sandstone Member, *8* – Bircza Lithothamnium Limestone Bed, *9* – Żohatyn Variegated Shale Member, *10* – Kosztowa Sandstone, *11* – variegated shales of the Lower Eocene, *12* – Trójca Variegated Shale Member

BABICA CLAY LITHOSOMES: CHARACTERISTICS

Lithosomes of the Babica Clay were formed due to cohesive flows shed from the northern slope of the Skole basin (Bukowy, 1957a, b; Gucik *et al.*, 1962; Kotlarczyk & Śliwowa, 1963), wherefrom only the largest flows could have reached the axial part of the basin (Fig. 1; *cf.* Rajchel, 1990, fig.8). Moreover, the western part of the Skole Unit bears traces of the Babica Clay flows, derived from the southern basin margin (Szymakowska, 1961; Jasionowicz, 1962; Gucik *et al.*, 1962). The dispersive phase of such flows was usually composed of strongly sandy, black, carbonate clayey substance. Their dispersed phase, in turn, were lithologically differentiated exotic rocks, as well as rocks eroded from the base of the flow, occurring in variable proportions and showing different sizes. The dispersive phase usually dominates over the dispersed one, although the reverse situation can also be encountered (Fig. 3). The Babica Clay deposits rarely contain olistoliths.

The submarine slump origin of the Babica Clay results in the presence of irregularly spaced lense-like lithosomes of variable size and thickness up to 30 m.

The petrographic inventory of exotic rocks comprised in the Babica Clay can be reconstructed on the basis of numerous papers (Bukowy, 1956, 1957a, b; Kotlarczyk, 1961;

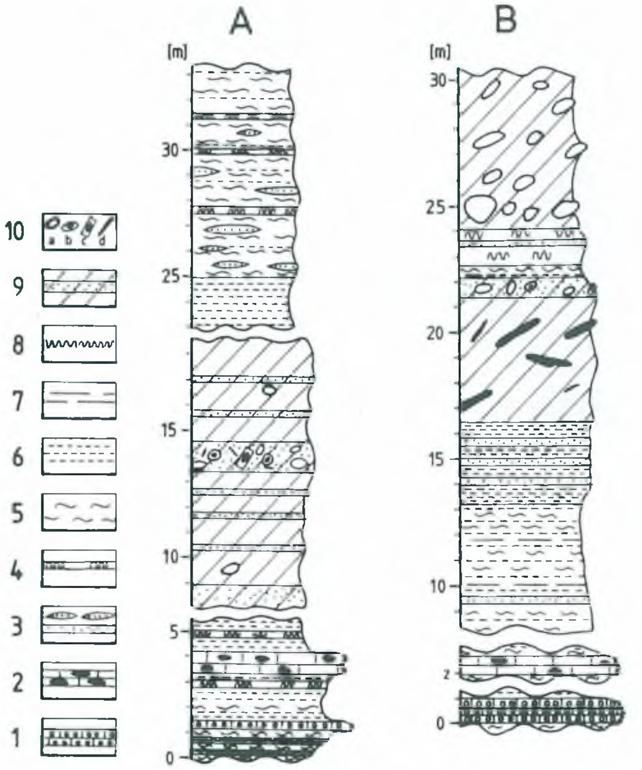

Fig. 3. Detailed lithostratigraphy of the lower part of the Variegated Shale Fm bearing lithosomes of the Babica Clay with exotic clasts of organodetrital Lithothamnium limestones: A – site 4 (Kosztowa), B – site 10 (Jureczkowa). *1-2* – layers associated with the Bircza Lithothamnium Limestone Bed: *1* – limestones with a high admixture of inorganic material, as well as sandstones and conglomeratic sandstones with large proportion of calcareous material, *2* – chert-bearing limestones with low admixture of noncalcareous material; *3* – very fine-grained white sandstones, *4* – ash-coloured-green mudstones, *5* – greyish red clayey shales, *6* – green clayey shales, *7* – grey clayey shales, *8* – deep-blue clayey shales, *9* – Babica Clay: black, calcareous, sandy shales with interlayers of clayey sandstones, *10a* – exotic clasts of organodetritic limestones, *10b* – clasts of limestones derived from the Bircza Lithothamnium Limestone Bed, *10c* – clasts of black shales, *10d* – other exotic rocks

Geroch & Kotlarczyk, 1963; Kotlarczyk & Śliwowa, 1963; Nowak, 1963; Dżułyński *et al.*, 1979; Skulich, 1986; Rajchel, 1989, 1990). The Štramberk-type limestones are the dominant component. Dolomites, marls, phyllites, porphyres, andesites, granites and other igneous rocks occur subordinately, alongside with clasts derived from the substratum, *i.e.* sandstones, shales and marls of the Ropianka Fm, and limestones originated from the BLLB. Exotic sandstones, conglomerates, quartzites and metamorphic rocks, as well as fragments of Carboniferous coal occur more rarely. These exotic rocks display highly variable sizes and diversified degree of roundness. The Babica Clay deposits also contain unusually abundant macrofauna of bivalves, gastropods, bryozoans, and corals, as well as fragmented and sometimes not dismembered Lithothamnium rodoliths.

LITHOLOGY OF EXOTIC ORGANODETRITIC LIMESTONES

The object of our study is a set of several tens of exotic rocks representing algal calcarenites and calcirudites. These clasts are usually prolate or circular, 10 to 30 cm in diameter. Most of them do not show any regular arrangement of components. Singular specimens (Kosztowa, site 4) display poorly marked horizontal lamination or grading. Infrequent specimens bear hollows of different depth and diameter (Fig. 4 & 5), left by boring organisms.

The population studied is dominated by calcarenite-type exotic rocks, the majority of which contain a central cherty core (Fig. 4). Carbonate components of these exotics are beige in colour algal biocalcarenites of variable content of sand fraction (Czermiński, 1955) (Fig. 6). Such a sedi-

Fig. 4. Polished slab of an exotic organodetritic Lithothamnium limestone of calcarenitic type. Irregular outer surface is visible along with central cherty core which reflects the shape of the surface and contain equally-spaced enclaves of unsilicified rock (arrowed). Site 4 (Kosztowa); bar scale in centimetres

Fig. 5. Section through exotic rock built up of highly psamitic, organodetritic calcarenite. Clast pierced by borings produced by organisms (a), 6 cm deep and 1.5 cm in diameter, as well as a tunnel (b) of similar diameter. On the left – asymmetric silicification area (c), postdating the borings. Site 12 (vicinity of Bircza); from collection of Prof. Dr. J. Kotlarczyk; bar scale in centimetres

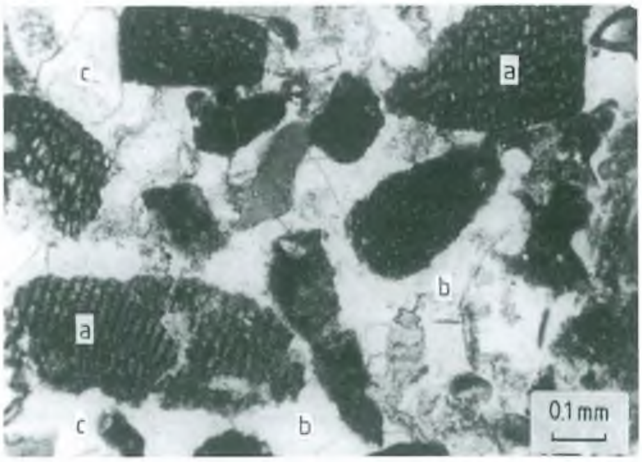

Fig. 6. Exotic clast of biocalcarenite from Kosztowa, site 4. Rounded fragments of coralline algae (a), cemented by calcite blocky cement (b), with isolated quartz grains (c). Thin section; 1 N

Fig. 7. Polished slab of an exotic clast of organodetritic Lithothamnium calcirudite. a – clasts of different limestones, b – psefitic clasts of Lithothamnia, c – quartz and rock fragments. Site 4 (Kosztowa); bar scale in centimetres

ment is usually well-sorted (diameters from 0.1 to 0.6 mm, sometimes up to 2.3 mm), its principal component being fragments of calcareous red algae from Corallinaceae, rarely Squamariaceae families, which make up 30 to 50% of all the fragments. Algal remains show well-preserved internal microstructure, although they are usually strongly fragmented. This fragmentation preclude identification, even at the genus level. The remaining, non-algal organodetritic material constitutes up to 10% of the rock mass, and included fragments of echinoderms (crinoids, echinoids), bryozoans and polychaetes (*Serpula* and *Ditrupa*), as well as planktonic and benthic foraminifers. Fragments of brachiopods and thick-shelled bivalves occur sporadically. All the above elements are preserved as oval grains of rounded edges, more rarely as angular grains.

The content of terrigeneous material, mostly quartz, varies from 2.7 to 27% of the rock. Its poorly rounded grains are 0.1 to 0.5 mm, rarely up to 1.5 mm in diameter. They are accompanied by clasts of organodetritic limestones, gneisses, and granitoids (0.1–0.8%).

Blocky calcite cement dominates, although the majority of samples contain also syntaxial cement growing around echinoderms, as well as scalenohedral and isopachous cement. The latter occurs in incipient intragrain voids, mostly within bryozoan zoecia and foraminiferal tests, rarely outside the tests.

Exotic rocks of the calcirudite structure are gray or white, do not contain siliceous cores (Fig. 7), and are poorly sorted. Bimodal distributions of grain size are frequently observed. One of grain size classes is represented by clasts 1 to 6 cm in diameter which are usually rounded fragments of gray and beige, micritic and fine-sparitic limestones (Fig. 7). Another class is represented by white, angular clasts of limestones, a fraction of a millimetre to 3–5 mm across, dominated by the remains of coralline algae (40–45%). The latter belong mainly to the genus *Lithothamnion* (formerly *Lithothamnium*; vide Studencki, 1988; Bosence, 1991), rarely *Archaeolithothamnium*. They are accompanied by single specimens of algae from the Squamariaceae family, represented by *Peysonnelia* and *Ethelia* genera. Apart from psammitic grains of algae of unidentified growth form, psefitic fragments were observed of branching and crustose thalli, with borings filled either by cement or organodetritic material. Fragments of algal-bryozoan biolites are also frequent. Grains of organic origin comprise as well the remains of bryozoans, echinoderms (crinoids, echinoids), worm tubes (*Serpula* and *Ditrupa* genera), foraminifers and isolated fragments of calcareous sponges. The above grains, comprising a few percent of the total number of grains, are rounded, oval or circular in cross-section, sometimes also irregular.

The admixture of non-carbonate grains varies from 6 to 7%. These are relatively frequent aggregates of glauconite, as well as of terrigeneous material, mostly quartz and feldspars, rarely lithic grains (dolomite-bearing glauconitic claystones, quartzites, micritic and organodetritic limestones, rarely intermediate and mafic igneous rocks). The terrigenic material shows a broad spectrum of grain sizes, from a fraction of a millimetre to a few millimetres. Psefitic components are better rounded.

Exotic clasts of calcirudites contain cement types similar to those of calcarenites. Intergranular cavities are filled with blocky cement, accompanied by syntaxial cement. Intragranular voids comprise, in turn, scalenohedral and isopachous cement.

SILICIFICATION OF CALCARENITIC EXOTIC ROCKS

Siliceous cores forming the interior of exotic clasts of calcarenites usually reflect the outer shape of the latter. The size of cores vary in relation to the diameters of exotic rock, and usually occupies 1/2 to 3/4 of the surface of the greatest section of the clast (Fig. 4). Completely silicified exotics, found in alluvia, probably represent cherty cores separated due to recent weathering. Cherts are always dark-beige or brown showing planar or conchoidal fracture, rough, some-

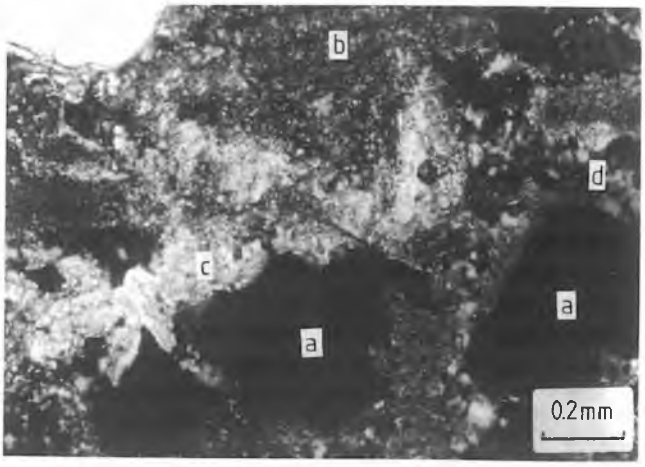

Fig. 8. Poorly silicified exotic clast of a calcarenite; site 11 (Żohatyn). Quartz grains (a), unsilicified organodetritic grains (b), cemented by calcite (c) and partly by silica (d) visible. Thin section, N X

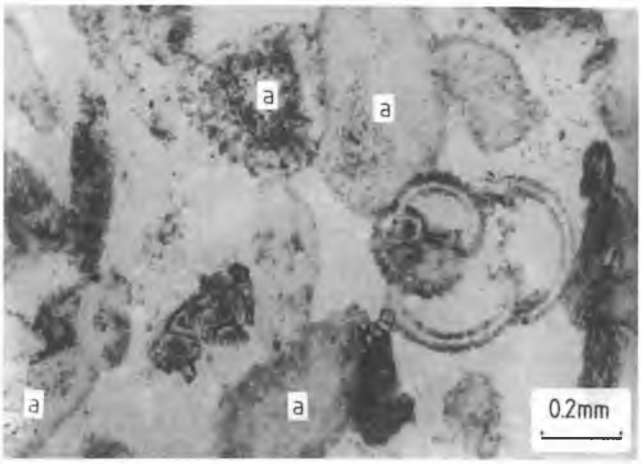

Fig. 9. Cherty core of an exotic calcarenite. Site 5 (Drohobyczka). Strongly silicified rock with relics of organic grains (a), visible as shadows. Thin section, 1 N

times splintery, earthy or smooth, with transparent splinters.

The cherts usually contain macroscopically visible, single, non-silicified carbonate grains, as well as irregular enclaves of unsilicified parent rock, several millimetres in diameter. The surfaces of cherty cores show sometimes hollows filled with carbonate material. A characteristic feature is the lack of silicification within borings resembling those left by boring organisms (Fig. 5).

The features mentioned above suggest that silicification postdates both cementation of the sediment and the borings, the latter probably formed in the littoral zone (Radwański, 1969). This silicification represents a metasomatic process prograding from the centre of exotic rock outwards, without remobilising the silicified material. The central position of cherty cores, which adjust their shape to clast surface, testifies to their formation after rounding and deposition within a lithosome of the Babica Clay. This silicification proceeded due to changes in pH, modified by the decay of organic matter present both in exotics and in surrounding clays (Kwiatkowski, 1996).

A similar type of pebble silicification has been described from the central part of the Skole Unit, within limestones clasts derived from the Dynów Marl Member. The limestones rest within a sand flow, immediately overlying the member (Rajchel, 1976a).

The silicification shows variable advancement within the individual clasts, as shown by the presence of different number of carbonate grains or by the occurrence of concentric zones showing slightly different silica contents (Kosztowa, site 4; Drohobyczka Dolna, site 5; Bachów, site 8; Jureczkowa, site 10; Żohatyn, site 11).

In poorly silicified exotic rocks (Żohatyn, site 11), the of replacement affects mainly the matrix (Fig. 8). Organic remains preserve their original composition and contain sometimes only small impregnations of silica. Within exotics of macroscopically visible silicification (*cf.* Kosztowa, site 4; Drohobyczka Dolna, site 5; Jureczkowa, site 10) the silica replaces, besides matrix, most of the organic remains (Fig. 9). Calcite occurs only as relics, reflecting some features of the internal grain structure. Only fragments of echinoderms and isolated foraminifers, together with surrounding syntaxial and isopachous cement, remain unchanged. At the more advanced level of silicification (Kosztowa, site 4; vicinity of Bircza, site 12), the process of replacement of parent rock by chalcedony affects both the matrix and the clasts, except fragments of echinoderms. The internal microstructure of skeletal elements becomes destroyed. In extreme cases their identification becomes impossible. Despite strongly advanced silicification, depositional structures are still visible due to the presence of inclusions which mark primary grain margins (Fig. 9), and owing to differences in crystallinite of silica. Original carbonate grains are, hence, replaced by microcrystalline chalcedony, whereas intergranular voids are filled with spherulites.

The source of such abundant silica supply is still uncertain. It cannot be represented by the exotic material itself, because it contains no siliceous organisms. The quartz grains cannot be considered either, since they show negligible corrosion. Most probably, the source of silica was provided by siliceous organisms, mainly radiolarians, occurring within the matrix of the Babica Clay deposits and within the surrounding variegated shales (Morgiel & Szymakowska, 1978). It is also possible that part of silica might have been derived from pelitic fraction of the Babica Clay (Gaweł, 1951).

AGE OF EXOTIC ORGANODETRITIC LIMESTONES

Stratigraphic position of the exotic rocks studied here indicates that they are older than host lithosomes of the Babica Clay. The Paleocene age is commonly accepted, on the basis both of foraminiferal microfauna (Morgiel, 1959; Szczechura & Pożaryska, 1974; Morgiel & Szymakowska, 1978) and the macrofauna (Krach, 1963). Some other opinions resulted from erroneous assignment of the Babica Clay lithosomes to the lithologically similar Eocene Czudec Clay

Table 1

Foraminifers from exotic Lithothamnium limestones and their stratigraphic ranges (based on Olszewska *et al.*, 1996)

foraminifers	Late Cretaceous	Early Paleocene	Late Paleocene	Early Miocene	Middle Miocene
Rzehakina cf. *fissistomata* (Grzyb.)		■	■		
Spiroplectinella aff. *dentata* (Alth)	■	■			
Planorbulina cf. *cretae* (Marsson)	■	■	■		
Lobatula cf. *carinata* (Terquem)		■	■	■	■
Dorothia cf. *crassa* (Marsson)	■	■			
Discocyclina sp.			■	■	■
Parasubbotina pseudobulloides (Plummer)			■		
Eoglobigerina cf. *spiralis* (Bolli)			■		
Acarinia ex gr *angulata* (White)		■			
A. aff. *intermedia* Subbotina		■	■	■	
A. cf. *nitida* (Martin)		■	■	■	
Subbotina triloculinoides (Plummer)		■	■	■	
S. trivalis (Subbotina)		■	■		
Igorina pusilla (Bolli)		■	■		

(Rajchel, 1990) or to Upper Maastrichtian–Lower Paleocene lithosomes of the Makówka slump debrite (Kotlarczyk, 1978, 1988a, b).

An attempt of direct dating these exotic rocks, basing on foraminifers, has been made by B. Olszewska. Taking into account the compactness and silicification, the determinations have been made in the microscopic thin sections. The following foraminifer species (Table 1) and genera have been identified: *Bolivina* sp., *Gavelinella* sp., *Haplophragmoides* sp., *Cibicides* sp., *Ammobaculites* sp., *Gaudryina* sp., *Polymorphinidae* sp., *Discocyclina* sp., as well as fragments of large foraminifers.

Irrespectively of variable lithology, the age of exotic rocks, deduced from foraminiferal microfauna, can be assigned to the turn of the Early and Late Paleocene. This assemblage is stratigraphically younger in respect to the *in situ* occurring deposits of the BLLB (Rajchel, 1990).

EXOTIC ORGANOGENIC LITHOTHAMNIUM LIMESTONES IN OTHER OUTER CARPATHIAN UNITS

Exotic clasts of organodetritic Lithothamnium limestones from the Babica Clay of the Skole Unit show petrographic similarity to numerous exotic rocks of the other Outer Carpathian units, both Paleocene and younger in age.

The closest analogues are organodetritic rocks of the Krosno Beds, at the Bystre slice, in the south-eastern part of the Silesian Unit. These exotics are, however, not silicified. They are embedded together with other exotic rocks within submarine slump deposits, similar to that of the Babica Clay. Some of them represent fragments of a Lithothamnium-bryozoan reef. The source area of these exotics were cordilleras situated farther to the south-east (Ślączka, 1959).

The other, similar to the above-described, exotic clasts of biosparitic and biomicritic limestones with coralline algae and minor rhodolites occur in pebbly mudstones and conglomerates of the Ciężkowice sandstone (Paleocene–Early Eocene), of the Silesian Unit. They display comparable size and chaotic texture, although showing no silicification phenomena (Leszczyński, 1978).

Exotic organodetritic Lithothamnium-bryozoan-nummulitic limestones of Palaeogene age have also been described from numerous sites throughout the western part of the Magura Unit. They were encountered in the upper part of the Ropianka beds, as well as in the Magura Beds, Pasierbiec Sandstone and Ciężkowice Sandstone. Their source areas were situated on both margins of the Magura basin. Exotic Lithothamnium limestones are also known from the Krynica zone of the Magura Unit, from the Hieroglyphic Beds of Early Eocene age that are exposed near Stary Sącz (Oszczypko, 1975) and which have been transported from the south-eastern margin of the Magura basin.

The Fore-Magura zone also contains exotic clasts of Senonian–Palaeogene organodetritic limestones with calcareous red algae and bryozoans that have been shed from the Silesian cordillera (Burtan *et al.*, 1984).

LITHOLOGICAL PROPERTIES OF ORGANODETRITIC EXOTIC ROCKS AND AUTOCHTHONOUS PALAEOGENE LIMESTONES OF THE SKOLE UNIT: A COMPARISON

The exotic rocks studied show some resemblance to the older, autochthonous carbonates of the Skole Unit.

Exotics of calcarenites are similar to some of the limestones derived from the BLLB (Gucik, 1961; Kotlarczyk, 1961). The main difference consist in the turbiditic origin of the latter, whereas similarities refer to the character and origin of detrital material. The principal component of the two types of rocks are the remains of coralline algae. Echinoderms, foraminifers, fragmented bryozoans and polychaetes are also present. In contrast, the BLLB limestones are white or white-greenish due to significant admixture of glauconite and clasts of green glauconitic claystones. Moreover, they show grading and characteristic horizontal lamination, whereas the exotic limestones are massive. Organic remains of the BLLB limestones show poorer roundness, as compared to analogous grains from exotic rocks; they also contain a more differentiated spectrum of terrigenic material, including quartz, feldspars, micas, glauconitic claystones, granitoids, gneisses, and schists (Rajchel & Myszkowska, *in* *press*). Differences in chert structure are also noticeable. Cherts derived from the BLLB limestones show traces of horizontal lamination, are usually carbonate-free and display lense-like shapes.

Exotic clasts of calcirudites are macroscopically similar to the carbonate conglomerate (breccia) which occurs in the Skole Unit near Przemyśl, in the upper part of the Ropianka Fm. This conglomerate is composed of clasts of the Štramberk-type limestones, quartzites, green phyllites, as well as flysch-derived marls and shales, cemented by carbonate matrix made up of dismembered green shales (Wójcik, 1907; Bukowy & Geroch, 1957; Dżułyński *et al.*, 1979). Stratigraphic position of the conglomerate is not precisely determined, its age being established from the presence of Maastrichtian to Early Paleocene microfauna (Bukowy & Geroch, 1957; Dżułyński *et al.*, 1979; Kotlarczyk, 1988a).

Another type of rock, similar to exotic calcirudites, is represented by locally exposed, isolated beds of breccias or conglomerates in the top of the Ropianka Fm (Rajchel, 1976a, 1989, 1990). The psefitic carbonate material is composed here mainly of fragments of Lithothamnium colonies, up to 2 cm in diameter or larger, as well as of clasts of green shales of comparable size. The psammitic fraction is dominated by quartz with variable admixture of glauconite. Coarse-grained varieties of these conglomerates, particularly the chaotic ones, are similar to exotic clasts of calcirudites. This similarity consists mainly in grain-size composition and texture. The conglomerates in question are organodetritic grainstones, comprising as a main component fragments of calcareous red algae from the Corallinaceae family. The coexisting assemblage of skeletal grains is analogous to that described from the exotic limestones of the Babica Clay, and contain relict of bryozoans, echinoderms, polychaetes and foraminifers, as well as fragments of algal-bryozoan biolites. Poor sorting is another common property. Similarly to exotic calcirudites, clasts of the conglomerates in question range in size from the aleuritic to psefitic fraction, although carbonate clasts several centimetre across are lacking. The conglomerates described differ also in higher and more differentiated admixture of terrigeneous material (quartz, quartzites, glauconitic claystones, chlorite-quartzose and quartz-muscovitic schists, acid and igneous rocks) and glauconite.

In the light of the above comparison one can infer that none of the autochthonous rocks described can be considered as a potential source rock for the studied exotic clasts.

SEDIMENTARY ENVIRONMENT AND SOURCE AREAS OF EXOTIC ORGANODETRITIC LIMESTONES

Sediments of the Carpathian geosyncline became enriched in phytogenic carbonate material in different areas and at different stages of development (Alexandrowicz *et al.*, 1966). This material, transported by turbidity currents, was dispersed together with terrigeneous material. Only exceptionally larger accumulations of Lithothamnium detritus could have been formed, and on extremely rare occasions this detritus could build carbonate rocks. A few examples are provided, *i.e.* by the Skalnik limestone occurring in Menilite Fm of the Dukla Unit (Małecki, 1963; Ślączka, 1971; Ślączka & Walton, 1992), and by the Bircza limestone (Gucik, 1961; Kotlarczyk, 1961, 1978). The phytogenic algal material is also a component of the above-mentioned exotic clasts which occur in Palaeogene and older strata of the Flysch Carpathians (Ślączka, 1959; Leszczyński, 1978; Burtan *et al.*, 1984).

It can be proposed that in the Paleocene, and particularly in its younger part, a regional trend to the widespread development of calcareous red algae and the formation of shallow-water organodetritic limestones in the marginal parts of flysch basins occurred. The climax of development of calcareous algae, however, took place in the final stage of the Carpathian orogen evolution, on the northern margin of the Badenian sea which filled the foredeep (Radwański, 1969, 1973), as well as on the southern margin of the nearly completely formed orogen (Rajchel, 1976a, b; Golonka, 1979, 1981).

Normally, the environment for calcareous red algae growth is the littoral zone and the upper part of the neritic one, down to a depth of a few tens of metres. This zone became an alimentary area for carbonate phytogenic detritus which was accumulated in the middle and lower parts of the neritic zone. Both these zones could have been situated upon deformed and tectonically uplifted parts of the geosyncline, as e.g. in the margins of the Tatra island in the Eocene (Małecki, 1956; Roniewicz, 1969). More frequently, however, such accumulation proceeded upon banks associated with geosynclinal cordilleras, even up to 15 km wide (Unrug, 1979). Such occurrences were described, for example, from the southern part of the Magura Unit, at its contact with the geanticlinally uplifted Pieniny Klippen Belt. Lithothamnium detritus occurs here both in the Złatne sandstone, belonging to the Pieniny Klippen Belt (Birkenmajer, 1979), and in coeval sandstones of the Magura Unit, known from Krościenko and Ochotnica (Alexandrowicz *et al.*, 1966; Golonka, 1974).

The Silesian cordillera played a similar role of alimentary centre during Palaeogene times (Książkiewicz, 1951; Gucik *et al.*, 1962). This centre supplied Lithothamnium detritus both southwards, to the Magura basin, and northwards, to the Silesian basin (Leszczyński, 1978; Ślączka & Walton, 1992). Another, minor centre was located over the Andrychów Klippes swell (Książkiewicz, 1951). The latter was a source of the Lithothamnia-rich Szydłowiec Sandstone of the Subsilesian Unit. The lithostratigraphy of the klippes zone includes bryozoan-Lithothamnium limestones at the turn of the Cretaceous and Tertiary. These limestones were deposited in a very shallow sea (Książkiewicz, 1951). The other Lithothamnia-rich deposits in the Subsilesian Unit are represented by the sandstones exposed in the Żywiec tectonic window, coeval with the Szydłowiec Sandstone (Geroch & Gradziński, 1955).

The source area for studied exotic clasts has not been preserved. This zone was probably situated north of the geosynclinal Skole basin. Along the recent Carpathian arc, at least between the Dębica Uplift and the Rzeszów area, the zone was the marginal cordillera. (Gucik *et al.*, 1962; Książkiewicz, 1975; Unrug, 1979; Bromowicz, 1986). Farther to

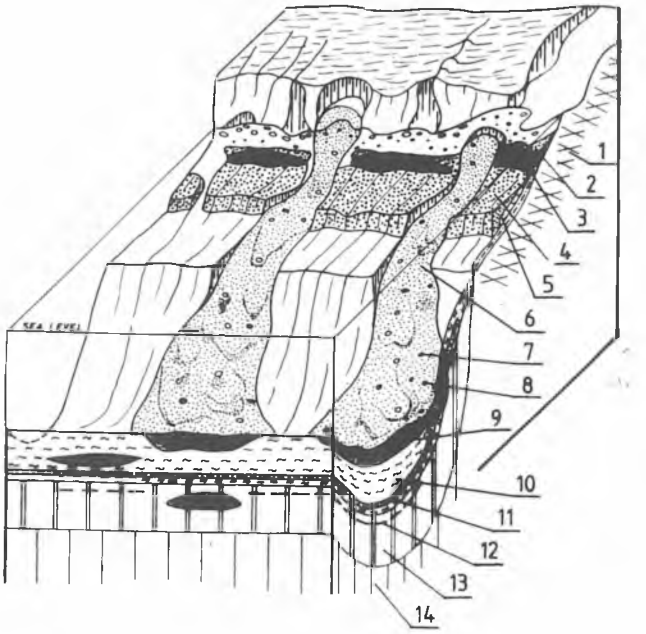

Fig. 10. Reconstruction of the northern margin of the Skole basin in Late Paleocene times (not to scale). 1 – basement, 2 – sandy-clayey sediments of the littoral and neritic zones, 3 – algal reef, 4 – talus of algal calcarenite, 5 – talus of algal calcirudite, 6 – gravity cohesive flow (lithosomes of the Babica Clay), 7 – exotic clasts of organodetritic limestones, 8 – other exotic rocks derived from the littoral zone, 9 – limestone clasts derived from the Bircza Lithothamnium Limestone Bed, 10 – Żohatyn Variegated Shale Member, 11 – Bircza Lithothamnium Limestone Bed, 12 – Lithothamnium breccia or conglomerate from the top of the Ropianka Fm, 13 – Wola Korzeniecka Member, 14 – Leszczyny Member

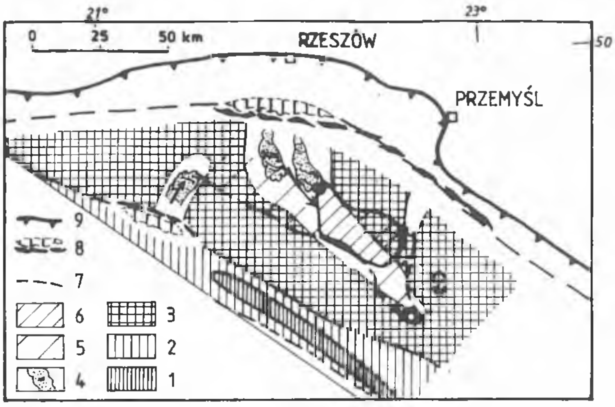

Fig. 11. Palaeogeographic sketch of the Skole basin at the turn of Early and Late Paleocene (after Gucik *et al.*, 1962; modified). *1* – variegated marls, *2* – variegated and green shales, *3* – Inoceramian beds grading upwards into variegated shales, *4* – Babica Clay, *5* – occurrences of the Babica Clay lithosomes within the Variegated Shale Fm, above the Bircza Lithothamnium Limestone Bed, *6* – extent of exotic clasts of organodetritic Lithothamnium limestones, *7* – boundary of the Skole basin, *8* – cordilleras and Lithothamnium reefs, *9* – recent Carpathian margin

the east, near Przemyśl, the continental slope with shelf zone were developed (Kotlarczyk, 1988a).

The exotic clasts were transported as fragments of preliminarily lithified rock perpendicularly to the northern margin of the Skole basin (Figs. 10, 11). They were moved in dense gravity flows of the Babica Clay, down to the axial zone of the basin (Bukowy, 1957a; Gucik *et al.*, 1962; Kotlarczyk & Śliwowa, 1963; Rajchel, 1990). The western part of the source zone supplied loose, clastic, phytogenic material that now builds the BLLB, and was transported NW–SE i.e. along the basin (Gucik *et al.*, 1962; Bromowicz, 1974; Kotlarczyk, 1978, 1988a, b).

The limestone from which exotic clasts were derived, have originated from accumulations of fragmented benthic organisms, dominated by calcareous red algae. The detrital grains were fragments of single thalli of coralline algae. Occasionally branching thalli and fragments of crustose thalli were be identified.

The organodetrital grains which form the exotic clastsdo not contain corals, contrary to recent reefs where corals coexist with calcareous red algae, playing the role of bounding, cementing and encrusting organisms (Wray, 1977). This may indicate that the studied material was derived from an area dominated by bryozoan-algal facies (McKenzie *et al.*, 1978). This facies recently proceeds south and north of the tropical zone, and outside the coral-algal facies domain. According to this model, the mass growth of different organic forms depends on surface water temperature which is a function of depth and latitude. Calcareous red algae are cosmopolitic forms and coexist abundantly with corals only in low-latitude seas. Outside the tropical zone, the number of corals decreases markedly. The reverse relationship is true for bryozoans, which show maximum development in colder waters at higher latitudes.

An equivalent of the bryozoan-algal facies in the Mediterranean Sea is the "coralligene" facies (Bosence, 1983, 1985), composed of bottom-stabilising sea organism which shown considerable species differentiation, and dominated by calcareous red algae (Bosence, 1983; Studencki, 1988). The resulting buildups occur in littoral and sublittoral zones, down to 160 m (Bosence, 1985). They are up to 4 m high and 50 m in diameter. At their base, carbonate sands and gravels derived from reef disintegration are accumulated. Such reefs are cavernous structures; and include tunnels and galleries that form suitable ecological niches for numerous penetrating, burrowing and encrusting organisms (Bosence, 1985).

The fragmentation of algae that build the exotic clasts indicates that, at a certain stage of development, the reef entered the range of destructive activity of waves or currents. Bioerosion must have been also important. As a result of such processes, bioclastic material of variable size was produced and accumulated upon the talus formed at shallow depth, at reef base. This is indicated by microborings, adapted to the littoral zone conditions (Radwański, 1969). This material was then recycled on the bottom by waves and currents, and consolidated during early diagenesis in shallow, marine, phreatic environment. The resulting material was fragmented into clasts of variable size which, after rounding and subsequent borings, became incorporated into gravity flows of the Babica Clay.

CONCLUSIONS

1. The exotic clasts described in this study represent fragments of organodetritic Lithothamnium limestones which originated as talus deposits around small algal reefs. The reefs developed upon the shelf of the northern margin of the Skole basin.

2. Algal reefs and related organodetritic deposits cannot be observed at the northern margin of the basin due to tectonic modification.

3. The host rocks for exotic clasts were represented by organodetritic algal limestones of calcarenite and calcirudite types.

4. The littoral provenance of the deposits in question is indicated by the presence of numerous shallow-water organisms within the clasts, as well as by the lack of turbiditic structures.

5. The deposits studied were formed at the turn of Early and Late Paleocene, as indicated by the stratigraphic position of exotic clasts and, first of all, by the preserved foraminifers and – to some extent – the assemblage of calcareous algae.

6. The extensive development of calcareous algae took place somewhat earlier, i.e. during the final stages of deposition of the Ropianka Fm in Early Paleocene times. As a result, individual beds of calcirudites with phytogenic carbonate material were formed in the upper part of this formation.

7. Silicification processes, leading to the formation of cherty cores, affected only exotic clasts of calcarenitic structure, and took place after their deposition within lithosomes of the Babica Clay.

8. The method used in this study allows to reconstruct the environment of marginal zones of geosynclinal basins that were subsequently destructed during orogenic movements.

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Streszczenie

EGZOTYKI ORGANODETRYTYCZNYCH WAPIENI LITOTAMNIOWYCH Z LITOSOMÓW IŁÓW BABICKICH JEDNOSTKI SKOLSKIEJ (KARPATY FLISZOWE, POLSKA)

Jacek Rajchel & Jolanta Myszkowska

Opisano egzotyki organodetrytycznych wapieni glonowych z centralnej części jednostki skolskiej (Fig.1). Występują one tylko w tych litosomach iłów babickich (późny paleocen), które usytuowane są w obrębie formacji pstrych łupków, powyżej warstwy litotamniowego wapienia z Birczy /wt/ (Fig. 2, 3).

Badane egzotyki mają średnicę od 10 do 30 centymetrów i zwykle są kształtu wrzecionowatego lub kulistego (Fig. 5, 7). Ich zewnętrzna powierzchnia posiada nierówności rzędu 2–3 cm, a niekiedy z obecnością wydrążeń (Fig. 5). Biorąc pod uwagę frakcję materiału okruchowego wyróżniono 2 odmiany egzotyków: dominujące biokalkarenity (Fig. 5) i znacznie rzadsze biokalcyrudyty (Fig. 7). Obie odmiany są bezstrukturalne i odpowiadają swym składem wapieniom, ewentualnie wapieniom słabo lub silnie zapiaszczonym.

Egzotyki kalkarenitowe są fragmentami dobrze wysortowanego osadu (Fig. 6), składającego się ze szczątków krasnorostów (rodzina Corallinaceae, Squamariaceae) i towarzyszących im elementów szkieletowych szkarłupni, mszywiołów, wieloszczetów i otwornic. Materiał terygeniczny to głównie kwarc, sporadycznie okruchy skał. Składniki detrytyczne, tworzące zwarty szkielet ziarnowy, spojone są kalcytowym cementem blokowym, lokalnie syntaksjalnym lub skalenoedrycznym-izopachytowym.

Egzotyki kalcyrudytowe reprezentują osad źle wysortowany (Fig. 7), o bimodalnym rozkładzie wielkości ziarn. Jedną klasę stanowią składniki o średnicy od 1 do 6 cm, będące głównie okruchami wapieni. Druga klasa to elementy frakcji psamitowo-aleurytowej reprezentowane najliczniej przez szczątki krasnorostów (rodzina Corallinaceae, Squamariaceae), mszywiołów, szkarłupni, wieloszczetów oraz otwornice, kwarc, a także okruchy biolitytów glonowo-mszywiołowych. Egzotyki kalcyrudytowe wykazują teksturę ziarnową i zawierają analogiczne rodzaje cementu jak odmiana kalkarenitowa.

Egzotyki kalkarenitowe na ogół zawierają centralnie umieszczone krzemienne jądro, odwzorowujące ich zewnętrzne zarysy (Fig. 4). Sylifikacja ta jest procesem późniejszym od cementacji (brak kompakcji ziarn) i od wydrążeń ("omijanie" ich przez sylifikację; Fig. 5). Proces ten zachodził po ostatecznej depozycji egzotyków w litosomach iłów babickich. Potwierdza to m.in. kształt krzemiennego jądra, zgodny z zewnętrznymi zarysami egzotyków (Fig. 4). W poszczególnych egzotykach proces sylifikacji jest różnie nasilony. W próbkach najsłabiej zsylifikowanych spoiwo ulega zastępowaniu w pierwszej kolejności (Fig. 8). Przy bardziej zaawansowanej sylifikacji wypierany jest węglan wapnia budujący ziarna, w miejscu których pozostają brunatnawe wrostki lub relikty węglanu wapnia (Fig. 9). Źródłem krzemionki były prawdopodobnie radiolarie zawarte w iłach babickich i w otaczających je pstrych łupkach (Fig. 2).

Wszystkie egzotyki są fragmentami organodetrytycznych wapieni krasnorostowych, powstałych jako osad stożków nasypowych wokół niewielkich raf glonowych. Budowle te były usytuowane w płytkim środowisku wzdłuż północnej krawędzi zbiornika jednostki skolskiej (Fig. 10, 11). Potwierdzeniem litoralnego miejsca sedymentacji tych utworów jest obecność w badanych egzotykach szczątków szeregu organizmów płytkowodnych, a także brak struktur turbidytowych, charakterystycznych dla wapieni allodapicznych. W wyniku tektonicznej modyfikacji wspomnianej krawędzi, utwory te nie są dostępne współczesnej obserwacji. Transport egzotyków w głąb zbiornika odbywał się prostopadle do jego krawędzi w gęstych, kohezyjnych spływach, docierających do jego osiowej strefy.

Utwory macierzyste dla egzotyków powstały na przełomie wczesnego i późnego paleocenu, na co wskazuje obecna w nich mikrofauna otwornicowa i w pewnym stopniu zespół wapiennych glonów. Są one mniej więcej równowiekowe z warstwą organodetrytycznego, wapienia litotamniowego z Birczy /wt/ (Fig. 2, 10). Rozwój glonów wapiennych, w podobnym usytuowaniu ale na mniejszą skalę, nastąpił w basenie skolskim również nieco wcześniej, czyli pod koniec sedymentacji formacji ropianieckiej /fm/, we wczesnym paleocenie. Doprowadziło to do powstania pojedynczych ławic kalcyrudytowych i zlepieńców z domieszką węglanowego materiału fitogenicznego w stropie tej formacji.