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# High-resolution petrography of marls from Goleszów (Polish Outer Carpathians, Upper Jurassic, Vendryně Formation)

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In the Ghibaudo (1992) classification, the Upper Jurassic Lower Cieszyn Shales (Vendryně Formation) exposed in Goleszów (southern Poland) show sedimentological features typical of the MyG (muddy gravel beds) facies. Two lithic components of this facies have been petrographically studied: calcareous shales, which are principal constituent of the olistostrome matrix, and the rocks displaying field characteristics of marls, which occur as olistoliths. Two factors controlling the mode of intrabasinal redeposition have been recognized: the primary depositional environment, and the presence of calcareous nannofossils in the original sediments. Because the rocks occurring as olistoliths and those forming the matrix are compositionally similar but differ in grain size and clay abundance, it is reasonable to assume that the matrix rocks were originally deposited in quieter water conditions than the future olistoliths. Despite post-sedimentary modification, FESEM/BS imagery of the marls from the olistoliths reveals coccoliths in their groundmass, which are hold together with calcite overgrowth cement; this feature is eogenetic. Thus, the presence of coccoliths appears to be the crucial factor that made possible early hardening of the sediments and subsequently their redeposition as lithic blocks. This process in the starting sediments for the olistostrome matrix was inhibited by clay. Thus, they remained unconsolidated and were then redeposited as muds.

Key words: Lower Cieszyn Shales *vel* Vendryně Formation, olistostrome, marls, dirty chalk facies, diagenesis, FESEM/BS imagery.

## INTRODUCTION

Olistoliths of various ages are known in the Outer Carpathians, and those from the Lower Cieszyn Shales are of particular interest. One reason for this is that they are related to the rifting stage of the northern domain of Tethys at the Jurassic/Cretaceous transition, and so considered as the geological record of shelf sedimentation during the opening of the Outer Carpathian Basin. Upper Jurassic deposits are lithologically variable and not well-exposed in the Polish part of the Outer Carpathians. The most valuable insight into the early stages of the Outer Carpathians geological history is provided by lithological, petrographic and sedimentological studies of the Lower Cieszyn Shales cropping out in the Nowa Marglownia Quarry near Goleszów (Fig. 1A, GPS: 49°44'38''N, 18°43'49''E). Geological investigations in this quarry were initiated by Peszat (1968) and Nowak (1968). Peszat (1968, 1971) appears to have been the first to draw attention to the redepositional characteristics of the Lower Cieszyn Shales exposed at Goleszów. Quarrying activity has made sedimentological features of these rocks increasingly visible, and Słomka (1986) reported that the Lower Cieszyn Shales at Goleszów are a product of submarine mass movements transporting material in general towards the south, and can be regarded as typical olistostrome. The redepositional mechanisms visible in this exposure were latter studied in detail by Malik (1994).

This paper is a provenance study of the marls that occur particularly as olistoliths within the Lower Cieszyn Shales exposed in the Nowa Marglownia Quarry. One should note, though, that the Lower Cieszyn Shales showing depositional features of olistostrome are reported only from that quarry. This paper analyses the factors which led to these sediments being hardened early and consequently redeposited as olistoliths, and explores the factors controlling redeposition. Therefore, combined lithological, sedimentological, and petrographic studies have been carried out. Petrographic examinations of the Outer Carpathians marls are relatively rare (see Bromowicz and Górniak, 1988; Górniak, 2011). Because of their fine grain size, the components in these rocks are difficult to study with an optical microscope. Petrographic study of the marls from the Lower Cieszyn Shales was reported only by Peszat (1968, 1971). In this paper, for the first time, petrographic study of marls from olistoliths exposed at Goleszów have been performed using both conventional optical microscopy and field emission electron microscopy, which can resolve micrometre-sized components in thin section-sized samples. An important goal of the electron microscopy study of these marls was use of their compositional signatures as clues to ancient environments and processes.

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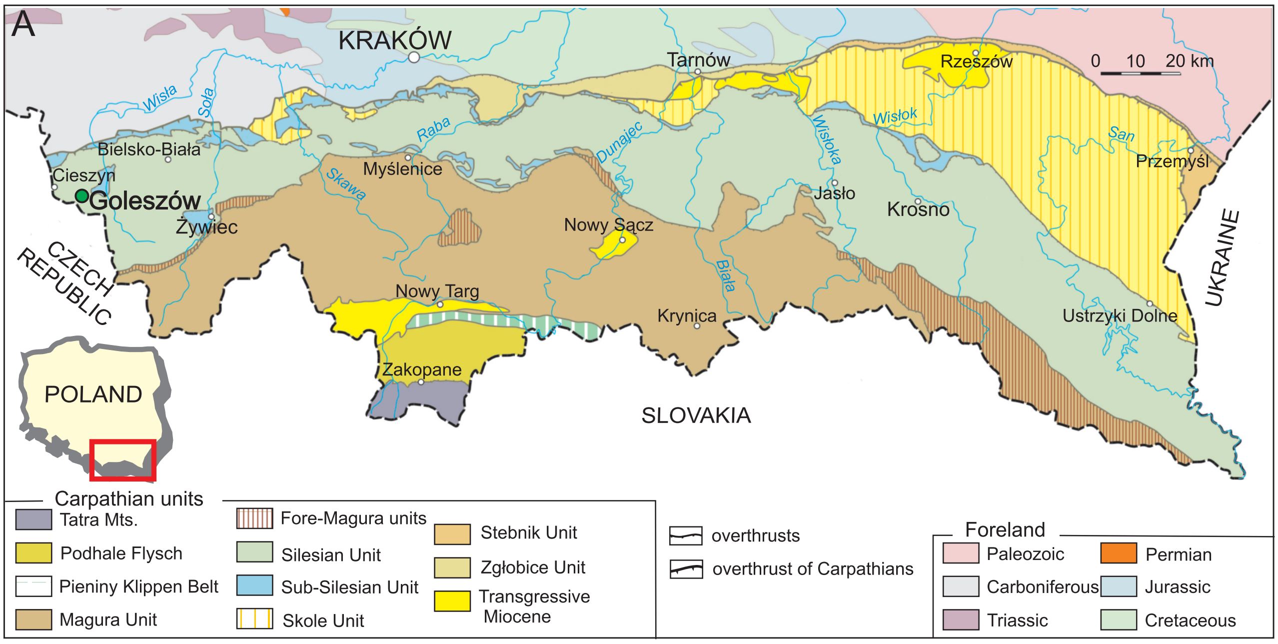


**B – The stratigraphy of the study area**

| | | | Well-established names | | Formal units | |
|---|---|---|---|---|---|---|
| | | | Hohenegger (1861) | | Wójcik et al. (1996) | Eliáš et al. (2003), Golonka et al. (2008) |
| CRETACEOUS | Cieszyn Beds | | Upper Cieszyn Shales | Cieszyn Formation | Upper Cieszyn Shales Member | Hradiště Formation; Cisownica Shale Member |
| CRETACEOUS | Cieszyn Beds | | Cieszyn Limestones | Cieszyn Formation | Cieszyn Limestones Member | Cieszyn Limestone Formation |
| JURASSIC / CRETACEOUS | Cieszyn Beds | Berriasian–Tithonian | **Lower Cieszyn Shales** ? | Cieszyn Formation | **Goleszów Marly Shales Member** ? | **Vendryně Formation** ? |

**Fig. 1A – location map of the Lower Cieszyn Shales (Vendryně Formation) outcrop studied; geological map of the Polish Carpathians by Żytko et al. (1989), simplified; B – stratigraphy of the study area: old views and new insights**

## GEOLOGICAL SETTING

The Lower Cieszyn Shales (Berriasian–Tithonian: Olszewska, 2005; Olszewska et al., 2008) were first described by Hohenegger (1861). These deposits, known only in the western part of the Outer Carpathians, in Poland are exposed in scarce outcrops between Cieszyn, Bielsko-Biała and Żywiec (Fig. 1A). The Lower Cieszyn Shales occur at the bottom of the Cieszyn Beds (*sensu* Hohenegger, 1861; Książkiewicz, 1972), which form the lower part of the Silesian Unit, separated during the folding of the Carpathians and called by Książkiewicz (1972) the Cieszyn Nappe.

The thickness of the Lower Cieszyn Shales in the Polish Outer Carpathians is up to 300 m (Słomka et al., 2006). Their lithology is highly variable and they consist mostly of dark calcareous shales, limestones (detrital, organodetrital and pelitic in appearance), marls, and also muddy conglomerates, which occur in the top part of the sequence (Bieda et al., 1963; Nowak, 1973). The Lower Cieszyn Shales tectonically overlie the Cretaceous and Paleocene succession of the Sub-Silesian Unit or the Miocene deposits of the Carpathian Foredeep, and are overlain by calcareous flysch deposits, about 550 m thick, including the Cieszyn Limestones Formation (Berriasian–Valanginian) and the Upper Cieszyn Shales (Valanginian–Hauterivian) (Nowak, 1973; Słomka et al., 2006; Olszewska et al., 2008). The Cieszyn Beds are intruded by teschenite bodies.

In the formal stratigraphic subdivision by Wójcik et al. (1996) the Cieszyn Beds are distinguished as the Cieszyn Formation, containing the Lower Cieszyn Shales called the Goleszów Marly Shales as a member. Recently, in the formal stratigraphic subdivision proposed by Eliáš et al. (2003) for Moravia and by Golonka et al. (2008) for Poland, the Lower Cieszyn Shales were renamed the Vendryně Formation (Fig. 1B).

The Lower Cieszyn Shales *vel* Vendryně Formation are the oldest deposits of the Polish Outer Carpathians (Bieda et al., 1963; Nowak, 1973). They have been considered to represent pelagic sediments containing redeposited partly consolidated shelf deposits (olistoliths; Peszat, 1968; Nowak, 1973; Słomka, 1986). This redeposition was inferred from the presence, in the calcareous shales, of mixed microfaunal assemblages from different environments (planktonic and benthic foraminifera and radiolaria, diatoms, coccoliths, tintinnids, ostracods), as well as macrofaunal fragments (e.g., corals, bryozoans, molluscs, aptychi, echinoderms, and fish teeth) (Bieda et al., 1963; Vašiček, 1971; Szydło, 1997; Szydło and Jugowiec, 1999). Recently, the Lower Cieszyn Shales were considered to have been deposited in a rifted sedimentary basin, in which sediment-gravity-flow processes such as debris-flow have operated locally (Ślączka et al., 2006). It is generally agreed that during the Late Jurassic/Early Cretaceous transition (Neo-Cimmerian tectonic activity), rifting of the southern part of the North European Platform caused the formation of the proto-Silesian Basin, called also Severin-Moldavidic Basin, in the area where the Western Outer Carpathians presently are located (Golonka et al., 2000; Oszczypko, 2004; Ślączka et al., 2006). This basin was gradually filled with dark, calcareous muds containing olistoliths of limestone and marl, redeposited mainly from the northern shelf of Tethys, and originated from the destroyed carbonate platform (Słomka et al., 2006; Ślączka et al., 2006). Teschenites that occur within the oldest strata of this basin are thought to represent the injections of basic magma related to rift phenomena in the proto-Silesian Basin (Narębski, 1990). According to Słomka et al. (2006) the low sedimentation rate and resulting small thickness of deposits from the beginning of sedimentation to the Cenomanian indicate that this basin was starved. Recently, based on palaeogeographic studies, the Vendryně Formation are thought to represent basinal facies, which were deposited in the western part of the Severin-Moldavidic Basin (proto-Silesian) distinguished as the Godula facies zone. The sediment source area was located in the north and considered to be shelf-related parts of uplifted fragments of the North European Platform (e.g., Picha et al., 2006; Słomka et al., 2006).

## MATERIAL AND METHODS

Fieldwork in the Nowa Marglownia Quarry near Goleszów was carried out in 1998. Representative samples of olistostrome for laboratory analyses were collected from exposures located in the eastern (Fig. 2) and western parts of the quarry. Three olistoliths of marl, which differ in depositional textures, were sampled in detail. The laboratory analyses include observations of sample components and their relationships by optical and electron microscopy and mineral identification by X-ray diffraction.

Microscopy was used to study the rocks in their natural state. Thin sections and their polished equivalents have been examined with optical and electron microscopy, respectively. Petrographic studies of thin sections with an *Amplival* (Carl Zeiss, Jena) instrument were focused mostly on microfacial analyses. A FEI *Quanta 200* field emission scanning electron microscope (FESEM) equipped with an EDAX energy-dispersive spectrometer *Genesis 4000* was used for high-resolution petrographic study. The FEI *Quanta 200* FESEM is equipped also with a *Backscattered Electron* (BS) *Centaurus Detector* that can resolve 0.05 micrometre size grains. FESEM/BS petrographic studies of the polished equivalents of the thin sections were focused mostly on the micromorphology of the rock components, their relationships and alteration. The samples were examined in backscattered electron mode (BS) at working distance (WD) = 9.9 mm, accelerating voltage (HV) = 15.0 kV and silicon strip detector (SSD).

X-ray diffraction was used to examine bulk rocks and the fine clay fraction (<0.2 μm) in monoionic state isolated from carbonate-depleted samples. XRD analyses were performed using a *Philips APD X'Pert PW 3020* diffractometer with CuK radiation and a graphite monochromator. The XRD patterns were recorded for 1 s per 0.05° 2 step from random powder back-loaded specimens and oriented preparations of the fine clay fraction in air-dried state and solvated with ethylene glycol. External standards obtained from selected Outer Carpathian marl samples were applied to accomplish semi-quantitative mineralogy which was conducted following the procedure of Schultz (1964) and Moore and Reynolds (1997).

## RESULTS

Because the quarry was abandoned in 1982, the olistostrome exposure at the time of the author's field study described in detail elsewhere (Górniak, 2011), was similar to that described previously by Słomka (1986). In the eastern, >30 m high wall of the quarry it was possible to observe dark-coloured chaotic deposits with four preferentially oriented lenticular olistoliths several metres in length, which were easily visible in the middle part of the exposure (Fig. 2). In the western wall only one partially exposed olistolith has been found. Within the olistostrome matrix, composed of shales with leaf-like partings disturbed to various degrees, limestone intercalations irregularly distributed and variable in thickness were observed. Scarce, usually disrupted, thin (about 1 cm) limestone layers with sharp basal and top surfaces were found to occur beneath the olistoliths. Above the olistoliths, more numerous and thicker (10–15 cm) limestone beds showing transition to shales were observed.

### LITHOLOGICAL VARIATION IN THE QUARRY

**Olistostrome matrix**. Two lithologies have been distinguished: shales and limestones. The shales, black or beige-black in colour, with coarse leaf-like partings, strongly calcareous, silt-lean, and faintly parallel laminated (Fig. 2A, B), correspond to the aleuritic fissile marls of Peszat (1968). Limestones, classified as intrasparites, are hard, grey in colour with a distinct steel-grey tint, and cross-laminated when they occur in thicker beds.

**Olistoliths**. Olistolith lithologies have been grouped into two categories: limestones and marls. One lithological variety of limestone and two varieties of marl were distinguished. The limestones, intrasparitic in texture, steel-grey in colour, occur as two olistoliths located in the eastern wall of the quarry, beneath two other olistoliths composed of lumpy marl with granular texture, coal-black and brownish when weathered. These marls correspond to the psammitic lumpy marls of Peszat (1968) (Fig. 2A, C). The bedded marls, brownish-grey in colour, locally showing indistinct parallel lamination, occur as an olistolith exposed in the western wall of the quarry. These marls correspond to the psammitic bedded marls of Peszat (1968).

**Sedimentation**. Based on the Ghibaudo's (1992) classification scheme designed for gravity flow deposits, the above-reported lithological and sedimentological features of the Lower Cieszyn Shales visible in the Nowa Marglownia Quarry near Goleszów correspond to matrix-supported MyG facies. A characteristic feature of this facies is the presence of large clasts, which in the exposure studied, are represented by olistoliths of limestone and marl. The marl olistoliths are psammitic showing variable partings (lumpy and bedded marls). The olistoliths are scattered in the matrix, which is dominated by aleuritic fissile marls. The l (laminated beds) subfacies, in which parallel lamination in silt (depositional interval d) have been recognized, is common in the olistostrome matrix (Górniak, 2011).

### MINERALOGY AND PETROGRAPHY

**Thin-section petrography**. Three lithological varieties of marl, which differ in grain size and partings, were studied petrographically in detail: aleuritic fissile marls creating the olistostrome matrix and psammitic lumpy and bedded marls occurring as olistoliths.

In thin section the aleuritic fissile marls show faint parallel lamination defined by fine (<0.2 mm) bioclastic and siliciclastic material (Fig. 2D). Parallel lamination is present with laminae as thin as 0.2 mm. Bioclasts and siliciclastic material occur also as grains disseminated in a brown-stained matrix where they are preferentially oriented. Bioclasts show only partial retention of fossil outlines. Calcareous dinocysts, foraminifers and cal-

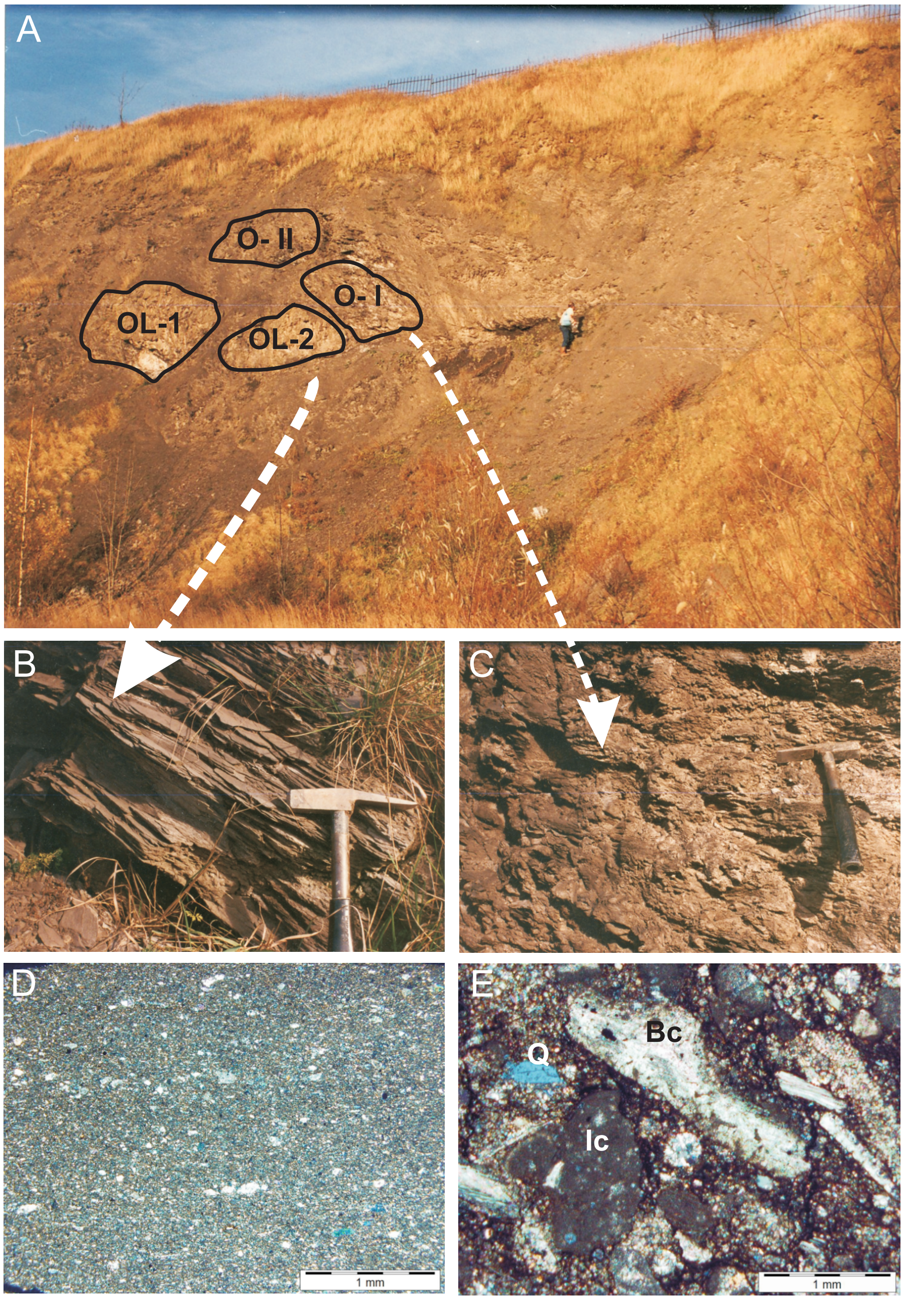


**Fig. 2. Lithological variation of the Lower Cieszyn Beds (Vendryně Formation) in the Nowa Marglownia Quarry at Goleszów**

**A** – facies MyG uncovered in the eastern wall of the quarry at Goleszów in the autumn of 1998; OL – olistoliths of limestone, O-I and O-II – olistoliths of marl; **B** – field characteristics of aleuritic fissile marls from the matrix of olistostrome; **C** – field characteristics of psammitic lumpy marl from olistolith O-I; **D** – thin section image of the aleuritic fissile marls showing faint parallel lamination defined by fine bioclastic and siliciclastic material (crossed polars, sample Go/1); **E** – thin section image of the psammitic lumpy marls showing intra-bioclast-bearing depositional textures (crossed polars, sample Go/9); Bc – bioclast, Ic – intraclast, Q – quartz

cite-replaced sponge spicules are recognizable. Siliciclastic material is scarce and present dominantly as quartz grains and mica flakes; some biotite flakes show alteration to chlorite.

In thin section both varieties of psammitic marls (lumpy and bedded) show intraclast-bioclast-bearing depositional textures (Fig. 2E). They consist of brown-stained microsparite and micrite groundmass with abundant, often large, bioclasts (up to 3 mm in size) and intraclasts, less common coated grains (about 1 mm across), as well as occasional siliciclastic grains (up to 0.5 mm across) and rare glaucony. These marls display a bedding-plane fabric due to preferred orientation of elongated particles ranging from weak (lumpy variety) to distinct (bedded variety). The psammitic marls contain microstylolites showing drape amplitude of up to 0.5 mm and thickness of up to 0.2 mm, which are oriented either parallel or at various angles to bedding (Fig. 3A–D). The microstylolite seams are accompanied by euhedral dolomite rhombs (Fig. 3D) and pyrite. Skeletal grains are mixed. They consist of calcareous dinocysts (stomio-

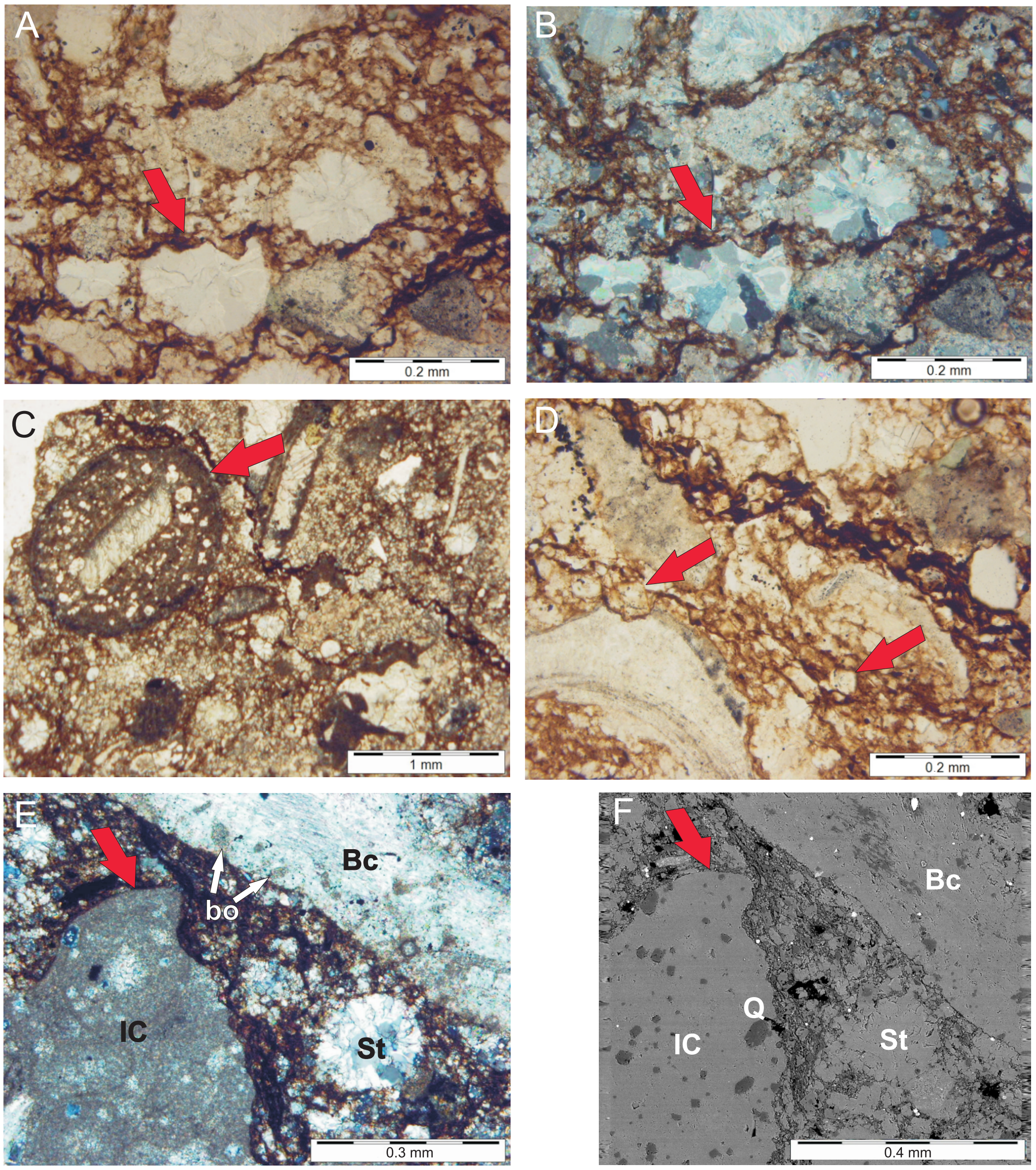


**Fig. 3. Thin section petrography of psammitic lumpy marl from olistolith O-I (sample Go/9)**

**A**, **B** – pressure-solution of stomiosphaerids at the microstylolite seams (arrow); A – plane polarized light, B – crossed polars; **C** – pressure-solution of coated grain at the microstylolite seams (arrow); note micro-sized quartz crystals within cortex; plane polarized light; **D** – microstylolite seams accompanied by euhedral dolomite rhombs (arrows); plane polarized light; **E**, **F** – intraclast referred to as aggregate grain (arrow) as shown by thin section micrograph (crossed polars) – FESEM/BS image pair (E and F respectively); Bc – bioclast, bo – microborings, Ic – intraclast, St – stomiosphaerid calcisphere, Q – quartz

sphaerids) (Figs. 2E and 3A, B), fragments of echinoderm plates, bryozoans, algae, brachiopods, corals and ostracods, which are rounded to various degrees, and foraminifers, radiolarians and sponge spicules. Microborings in the surfaces of some skeletal grains are observed (Fig. 3E). Calcareous fossils are usually partially replaced by silica whilst originally siliceous species (radiolarians and sponge spicules) occur as calcareous pseudomorphs. Intrabiotic cement, principally calcareous, has been found to occur. Intraclasts variable in size (up to 3 mm) and shape, often with sutured outlines, are abundant. Some of them i.e. those composed of coated grains cemented by micrite, are referred to as aggregate grains (Fig. 3E, F) or lumps. Isolated coated grains, less than 2 mm across, with micro-sized quartz crystals embedded in their cortices are less common. The presence of euhedral to subhedral quartz micro-crystals is also a specific characteristic of some intraclasts. Siliciclastic grains are composed principally of quartz with minor biotite. Quartz grain content, determined from point-count analysis, is about 5%. Rare apatite is also present.

**X-ray diffraction**. The bulk samples of aleuritic fissile marls are composed of carbonates (45–46% calcite, 3% dolomite) and clay minerals (34–38%) with small amounts of quartz (10–12%), plagioclase (2%), pyrite (3%) and organic matter (2%). The bulk samples of psammitic marls are dominated by carbonates (73–75% calcite, 1% dolomite), though small amounts of clay minerals (12–19%); quartz (5–8%), plagioclase (1–2%), pyrite (2%) and organic matter (2%) are also present. The clay assemblage particularly in psammitic marls is dominated by illite-smectite. A small amount of kaolinite, illitic material and chlorite is also present in the samples studied (Table 1). The fine clay fraction (<0.2 μm) isolated from psammitic marls is composed of highly illitic illite-smectite. Ethylene glycol solvation indicates the presence of ordered (R1) illite-smectite containing about 80% of illite layers (Fig. 4), which were determined by the Środoń technique (Środoń, 1981).

**FESEM/BS petrography**. The FESEM/BS images show the groundmass of marls from olistoliths to be composed of diagenetically altered coccoliths, clay minerals and less common micrometre size quartz (Fig. 5A–C). Whole coccolith placoliths and their fragments (micarb) have been found to occur. The coccolith placoliths are thickened and hold together due to the formation of calcite overgrowths (Fig. 5B). These grains are amoeboidal in shape and form grain-to-grain contacts that are concave-convex in character (Fig. 5C). Clay minerals and less common micrometre size quartz grains are concentrated in clusters/nests and appear to clog the micro-pore space within welded coccoliths. Non-carbonate components are particularly common in stylolite drapes (Fig. 5D). Clay is often squeezed and drapes over rigid grains. Well-developed intrabiotic cement includes micro-sized calcite and quartz crystals (Fig. 5E), less common pyrite framboids and clay minerals. Phosphatic micronodules, up to several hundred micrometres across, contain relics of micrite and microsparite, quartz grains and sponge spicules and are impregnated by finely dispersed pyrite (Fig. 5F).

**Petrographic classification**. The four components: carbonates (calcareous bioclasts), clay minerals, authigenic silica minerals (micro and nano-quartz) and clastic material (mostly quartz), were used to represent the basic composition of the rocks studied. The basic composition helps to classify mixed sediments in terms of quantitative mineralogy and the origin of constituents. The results are summarized in two ternary classification schemes that deal with mixed carbonate, argillaceous, siliceous and siliciclastic rocks (Fig. 6). These diagrams show that rocks from olistoliths defined on the basis of field characteristics as psammitic marls are allocated to the limestone field whereas aleuritic marls from matrix of olistostrome classified as

Table 1

**Mineralogy of representative samples collected from olistoliths and matrix of the olistostrome exposed at the Nowa Marglownia Quarry in Goleszów**

| Sample | Field characteristics | Whole rock mineralogy [wt.% ] | | | | | | | Clay minerals normalized [%] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Calcite | Dolomite | Total clay | Quartz | Plagioclas | Pyrite | Organic matter | Illite-smectite | Illite, micas | Kaolinite | Chlorite |
| Olistolith I Go/9 | psammitic lumpy marl | 73 | 1 | 12 | 8 | 2 | 2 | 2 | 78 | 5 | 17 | 0 |
| Olistolith II Go/10 | psammitic lumpy marl | 75 | 0 | 13* | 8 | 2 | 2 | nd | 77 | 6 | 17 | 0 |
| Olistolith III Go/I/3 | psammitic bedded marl | 73 | 0 | 19* | 5 | 1 | 2 | nd | 78 | 5 | 17 | 0 |
| Matrix Go/1 | aleuritic shaly marl | 45 | 1 | 38 | 10 | 2 | 3 | 2 | 68 | 10 | 17 | 5 |
| Go/3 | aleuritic shaly marl | 46 | 3 | 34* | 12 | 2 | 3 | nd | 70 | 10 | 17 | 3 |

nd – not determined; * – total clay and organic matter; remark: thermal technique TG/EGA (thermogravimetry/evolved gas analysis) and chemical analyses were used for the semi-quantification of organic matter and the improvement of the clay contents

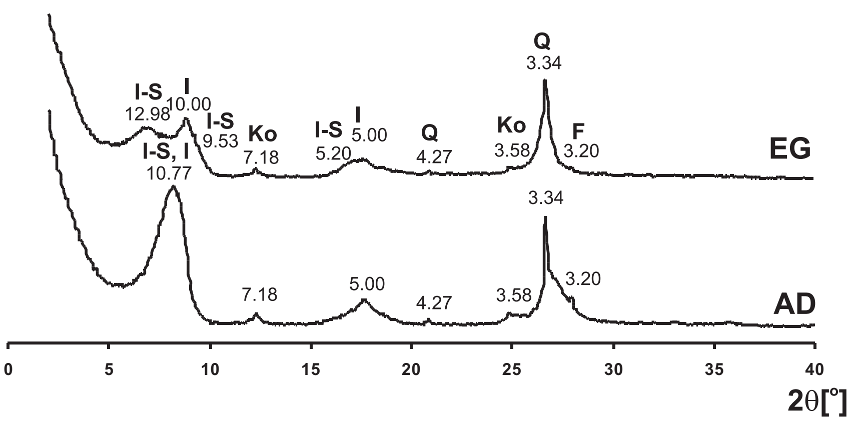


**Fig. 4. Representative X-ray diffraction patterns of the fine clay fraction (<0.2 μm) isolated from psammitic marl (sample GO/9)**

AD – air-dried, EG – ethylene glycol solvated, F – feldspar
I-S – illite-smectite, I – illite, Ko – kaolinite, Q – quartz

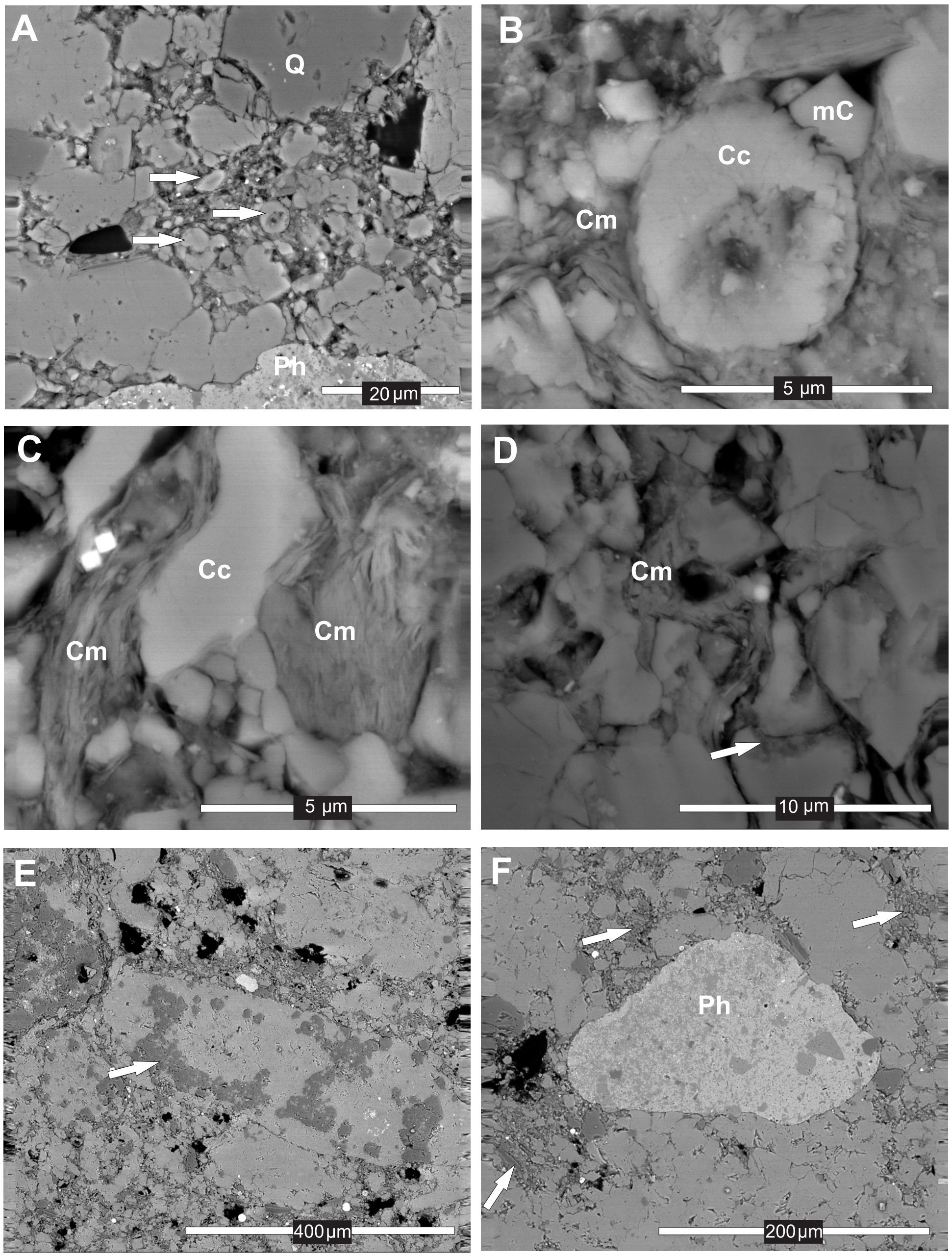


**Fig. 5. FESEM/BS petrography of the psammitic lumpy marl from olistolith O-I (sample G/9)**

**A** – groundmass between amoeboidal calcite microspar composed of coccolith shields (arrow) often fragmented (micarb) and clay minerals (grey); Q – quartz grain, Ph –- phosphate nodule; **B** – close-up; thickened coccolith shield (Cc), micarb (mC) and clay minerals (Cm) in the background; **C** – clay minerals (Cm) between overgrown and welded coccolith shields (Cc); **D** – microstylolite seam composed of clay minerals squeezed between more rigid calcareous grains showing pressure-solution at the contacts (arrow); **E** – intrabiotic calcite and micro-quartz cement (arrow); **F** – phosphate micronodule in groundmass composed of amoeboidal calcite grains; note patchy distribution of clay (arrows)

marls. The thin section reveals that psammitic marls are dominated by petrographic features of limestone due to high contents of calcareous fossils. Background material is relatively scarce. The FESEM/BS petrography shows that the latter can be classified as carbonate-clayey in character. When we try to classify these rocks using classification schemes designed for limestones, they turn out to be floatstones.

## DISCUSSION

Sedimentary conditions attributed to the Ghibaudo's (1992) matrix-rich MyG facies, and can be used to provide a satisfactory explanation for the lithological and sedimentological features of the Lower Cieszyn Shales visible in the Nowa Marglownia Quarry near Goleszów. According to Ghibaudo (1992) the MyG facies results from the redeposition, from a shelf environment into deeper parts of the basin, of either soft sedimentary material or material earlier consolidated to various degrees (clasts). Therefore, the aleuritic fissile marls, which act as the olistostrome matrix, appear to be redeposited as soft sedimentary material. The olistoliths of psammitic lumpy and bedded marls can be regarded as redeposited rigid material, which represents clasts of synsedimentary (intrabasinal) provenance.

The psammitic marls of the olistoliths differ in field characteristics due to variable partings (bedded and lumpy varieties); however, compositionally and in texture they look very alike in thin section. Because the preferred orientation of elongate components is distinct only in the bedded variety of these marls, it is reasonable to assume that they were redeposited in a more rigid form than those showing lumpy partings. Peszat (1968) considered the lumpy psammitic marls to be redeposited when they were weakly consolidated.

The psammitic marls from the olistoliths and aleuritic fissile marls from the olistostrome matrix look different both in overall field appearance (Fig. 2B, C) and when examined petrographically (Fig. 2D, E). However, mineralogically they look very alike and differ only in the relative proportions of similar components, particularly carbonates and clay (Table 1). Therefore, it is reasonable to assume that the source of clay for these rocks was similar.

To avoid erroneous interpretations of petrogenesis, it is necessary to understand as much as possible about the diagenetic processes that affected these rocks. The diagenetic effects visible in the psammitic variety of the rocks studied can be attributed to a mesogenetic stage of diagenesis (see e.g., Boggs, 2009). Mechanical compaction in these rocks is documented by the presence of microstylolite seams (Fig. 3A–D), flattened pyrite framboids, and by deformed clay clusters squeezed between more rigid grains (Fig. 5B, C). The precipitation of material derived from the dissolution at stylolites is documented by intrabiotic pore-filling calcite cement (Fig. 5E). This phenomenon, referred to as chemical compaction related to mesogenetic burial stress, is similar to the case study from the North Sea Chalk of Fabricius and Borre (2007). Also, the presence of ordered highly illitic illite-smectite in the marls studied suggests the stage of illite-to-smectite evolution attributed to late diagenesis (see Moore and Reynolds, 1997). It is of interest that dolomite euhedral crystals visible at the microstylolites (Fig. 3A–D), which are in the North Sea Chalk regarded as a result of dissolution of bioclasts composed of high-magnesian calcite (Fabricius, 2007), in the rocks studied may also be related to the release of magnesium due to smectite-to-illite evolution. These processes consolidated the rocks studied, though, they affected the sediments long after burial. Fortunately, despite the overprint by mesogenetic processes, features related to the early hardening of sediments attributed to an eogenetic stage are still visible in microscopic images.

The critical component of these rocks appears to be calcareous nannofossils (coccoliths) recognizable as a principal constituent of the groundmass. FESEM/BS images have revealed that the coccolith shields are severely diagenetically altered, i.e. thickened due to a heavy calcite overgrowth. Recrystallisation that involves local simultaneous dissolution and overgrowth on coccolith shields is attributed to the eogenetic stage of diagenesis taking place at very shallow depths (a few metres to tens of metres) largely under the conditions of the depositional environment (e.g., Cook and Egbert, 1983), and these processes are thought to have a strong effect on early hardening of newly deposited chalk-type sediments. The hardening is related to joining together coccolith shields by calcite overgrowth cement. Early cementation in chalk sediments, pre-dating regional hardening of the North Sea Chalk, was reported by Fabricius (2007) and Hjuler and Fabricius (2009), as well as recently documented by the geochemical and stable isotopic study of Hu et al. (2012). It should also be mentioned that in newly deposited nannofossils-rich sediments, organic components are usually preserved, therefore some early diagenetic features such as the alteration of coccolith shields may be enhanced by microbial action due to removal of organic coatings on the bioclasts by bacteria (Fabricius, 2007). The microbial action, creating a local microenvironment favoring early hardening of sediments, is documented in the rock studied by the presence of aggregate grains (Fig. 3E). Aggregate grains are common in the modern environments in Bahamas. According to Winland and Matthews (1974) these grains can be created under conditions where there is a supply of firm carbonate grains, uneven water turbulence, high water circulation rates, and very low sedimentation rates.

When examined petrographically, the psammitic marls of the olistoliths are comparable with detrital reef-derived limestones, such as the talus apron surrounding a reef, termed floatstones (see Flügel, 2004). The abundance of coccolith shields that are held together in the groundmass as an amoeboidal mosaic, and non-calcareous material occurring only locally as clusters (Fig. 5F) suggest that due to sedimentary conditions the newly deposited sediments were depleted of fine-grained components such as clay minerals. It is reasonable to infer that the scarcity of clay in the carbonate sediments facilitated recrystallisation processes such as overgrowths on the coccolith shields. It is suspected that the tiny components were periodically removed from the starting sediment for the psammitic marls accumulating in the area surrounding a reefs and deposited in a quieter water environment, forming starting sediments for the aleuritic fissile marls. Therefore, originally the former were deposited in a different facies zone than the latter. The hardening of the aleuritic fissile marls-forming mud was limited due to the abundance of clay. Consequently, they were redeposited as soft sediments. This conclusion is supported by the similarity of the mineralogy of the psammitic marls in the olistoliths and the aleuritic fissile marls from the olistostrome matrix. A correlation between early hardening of chalk and chalk facies was reported also for the North Sea Chalk by Fabricus and Borre (2007) and Hjuler and Fabricius (2009). It is likely that volcanic material was the original non-calcareous component of the marls studied (see Bromowicz and Górniak, 1988) and subsequently underwent alteration to clay. Silica released due to alteration of volcanic glass to clay and that derived from dissolution of siliceous bioclasts (sponge spicules) appear to be the sources for the siliceous cement which occurs in the rocks studied. Because siliceous cement clogs mostly intrabiotic pore space (Fig. 5E), it is related to the mesogenetic stage of diagenesis and cannot be considered as a factor causing the early hardening of the starting sediments.

## CONCLUSIONS

The lithological and sedimentological features of the Lower Cieszyn Shales (Vendryně Formation) exposed in the Nowa Marglownia Quarry near Goleszów correspond to the matrix-rich MyG facies of Ghibaudo (1992). Both the olistoliths and the matrix of the olistostrome are composed of calcareous rocks differing in grain size, which on the bases of field characteristics are called marls. The olistoliths, considered to be redeposited as rigid material, are composed of two varieties of psammitic marls, which differ in parting style, with lumpy and bedded varieties. The matrix, thought to be redeposited as soft material, consists of aleuritic fissile marls.

Based on mineralogy and microscope images (optical microscopy) the psammitic marls from the olistoliths studied are clay-bearing detrital limestones with bioclasts (floatstones), sand-lean and slightly silicified. The aleuritic marls from the olistostrome matrix are petrographically marls (Fig. 6). Despite their different fabrics both the psammitic and the aleuritic marls are composed of similar constituents but the former are dominated by carbonates whilst the latter contain higher amounts of clay (Table 1).

FESEM/BS petrography shows that the groundmass of the psammitic marls is principally composed of severely diagenetically altered coccolith shields locally separated by clay minerals or held together by overgrowth cement considered to be eogenetic in origin.

Early cementation due to recrystallization of coccoliths shields (overgrowth cement) appears to be the main factor affecting redeposition of the chalk-type sediments as consolidated material i.e. as olistoliths. The psammitic marls from the olistoliths are clay-lean in composition. The sedimentary environment in which they were originally deposited was favourable for clay particle removal from newly-deposited sediments that facilitated early hardening of sediments by overgrowth cementation.

The psammitic marls from the olistoliths exhibit depositional textures of floatstones, i.e. those limestones that are deposited in the outer shelf zone. Therefore, these marls appear to be composed of calcareous material that originated principally from reefs destroyed by wave action and storms. The resultant material (talus apron) accumulated in front of or around the reefs, which are considered to be an area favourable for early cementation.

The progress of early cementation in the rocks studied appears to be related to the litofacies. Sediments that accumulated close to reefs, consolidated early owing to the abundance of nannofossils and environment-mediated scarcity of fine-grained non-calcareous material, were redeposited as olistoliths. The higher content of non-carbonate components in the fine-grained material removed from reefs zone, and originally deposited in a quieter water environment, apparently hindered cementation, and so these sediments were redeposited as muds.

The Lower Cieszyn Shales (Vendryně Formation) petrographically correspond to a dirty chalk facies from the North Sea area that have been deposited by gravity flow or slumping.

This paper argues that early carbonate cementation due to the development of coccolith overgrowths influences the mode of intrabasinal catastrophic redeposition of sediments. A more general conclusion seems justified also: the mode of sediment redeposition reflects the facies variability in the primary sedimentary environment.

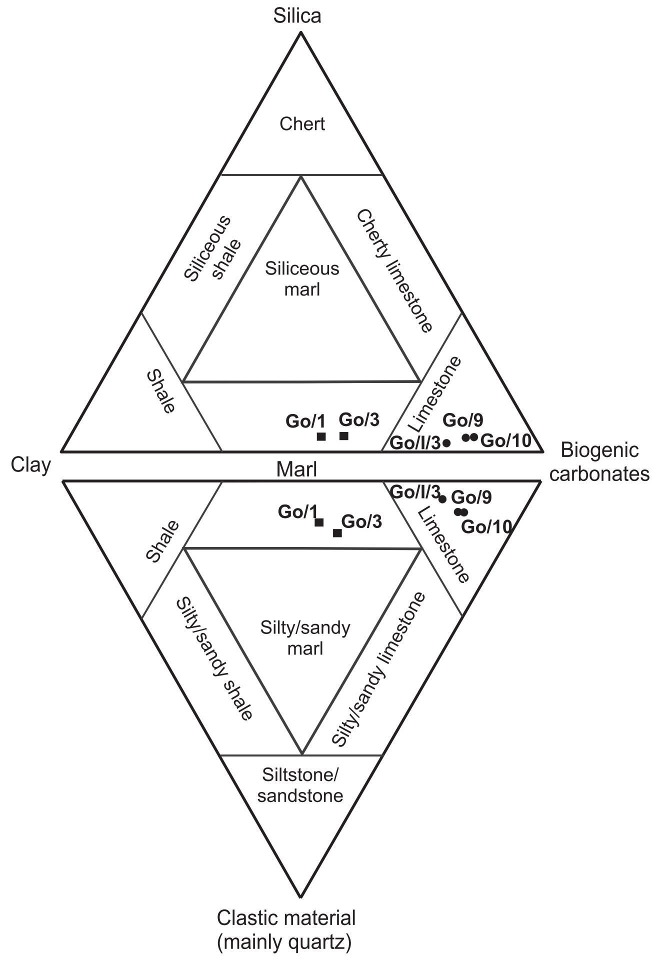


**Fig. 6. Petrographic classification of psammitic marls (circles) from olistoliths and aleuritic shaly marls (squares) from the olistostrome matrix**

Ternary diagrams by Shipboard Scientific Party (1984)

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