

# REEFAL ENVIRONMENTS AND SEDIMENTARY PROCESSES OF THE ANISIAN KARCHOWICE BEDS IN UPPER SILESIA, SOUTHERN POLAND

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**Abstract:** The Anisian shallow-marine Karchowice Beds of the Upper Silesia represent reefal habitats and circum-reefal environments, where biological-mechanical interactions determine sedimentary processes and facies pattern. The purpose of this study was recognition of the interaction between biological and mechanical controls of carbonate deposition. Such interdependence resulted in considerable lateral variability of thickness and lithological features, observed at a distance of 25 km. The western part of the basin is dominated by proximal facies (reefal facies), whereas the eastern one represents distal facies (fore-reef). Sedimentary succession in the western area is twice as thick than the eastern one. It resulted from different rate of subsidence owing to block tectonics, controlled by reactivated ancestral Silesian-Moravian Fault. Small-scale synsedimentary faults confirm syndepositional tectonic activity in the region.

Palaeogeographical position caused that the Upper Silesia was strongly affected by monsoon climate, generating storms. These storms contributed to episodic deposition, prevailing during the sedimentation of Karchowice Beds. However, most of time was represented by prolonged non-deposition periods, recorded as interstratal hiatuses, but also by forming of firmgrounds, micritization and coating of bioclasts or substrate recolonisation by organisms.

**Key words:** Middle Triassic, palaeoenvironments, sponge-coral reefs, Upper Silesia.

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## INTRODUCTION

The Muschelkalk of Upper Silesia is a 150-m-thick carbonate succession formed in relatively shallow sea. One of the Muschelkalk lithostratigraphic unit, called the Karchowice Beds, comprises first, precisely dated, Mesozoic reefs built by sponges and the oldest *in situ*-preserved scleractinian corals.

These sponge-coral buildups provide excellent opportunity to investigate qualitative aspects of unique early Mesozoic reef builders and dwellers. Moreover, very interesting from sedimentological point of view is the study of interplay between the biotic and mechanical processes of carbonate deposition within the reef and the adjoining area.

This paper focuses on introduction of general succession and lateral facies variability of the Karchowice Beds, on reconstruction of their sedimentary environment and on defining relationship between grain size, amount of calcareous sediment input and sponge buildups shape.

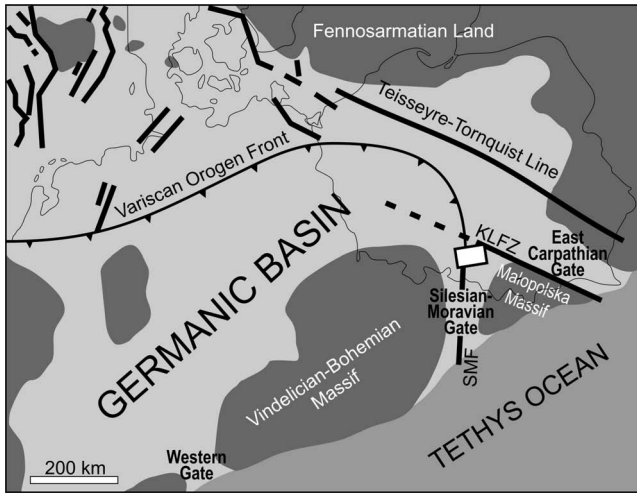
## GEOLOGICAL SETTING

### PALAEOGEOGRAPHY

In Middle Triassic times, the semi-closed Germanic Basin, as the northern periphery of the Tethys Ocean, was situated at subtropical latitudes. Communication with the Tethys was provided by fault-controlled seaways: the East Carpathian, Silesian-Moravian and Western Gates (Fig. 1). Due to their diachronic opening and closing, the Silesian-Moravian Gate was principal communication way between the Tethys and the Germanic Basin during Anisian times (Senkowiczowa, 1962; Szulc, 2000). This resulted in uninterrupted sedimentation and complete succession of the Muschelkalk in the Upper Silesia.

### STRATIGRAPHIC POSITION

Precisely established stratigraphic position of the Karchowice Beds as the uppermost unit of the Lower Muschelkalk is based on many different correlation tools (Fig. 2). The most important amongst them are conodonts, which al-

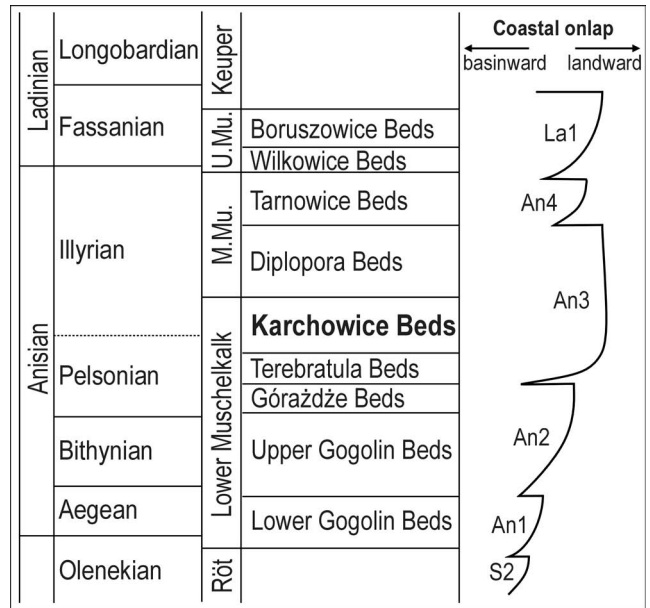


**Fig. 1.** Palaeogeographical position of the studied area (white rectangle). KLFZ – Kraków-Lubliniec Fault Zone, SMF – Silesian-Moravian Fault (partly modified after Narkiewicz & Szulc, 2004)

lowed to state that the boundary between the Pelsonian and Illyrian lies within the unit. This boundary was defined by disappearance of *Neospathodus kockeli* and first appearance datum of *Gondolella excelsa* assemblage zone (Zawidzka, 1975). The former index fossil probably represents *Neogondolella praeszabói bystrickyi* (Narkiewicz & Szulc, 2004).

Investigations of echinoids and crinoids brought another useful biostratigraphic tool for age determination. The Karchowice Beds belong to *dubius-silesiacus* crinoid zones, which correspond to the upper part of the Pelsonian and the lower part of the Illyrian (Hagdorn & Głuchowski, 1993).

Magnetostratigraphic scale (Nawrocki & Szulc, 2000) and sequence stratigraphy scheme (Szulc, 2000), obtained

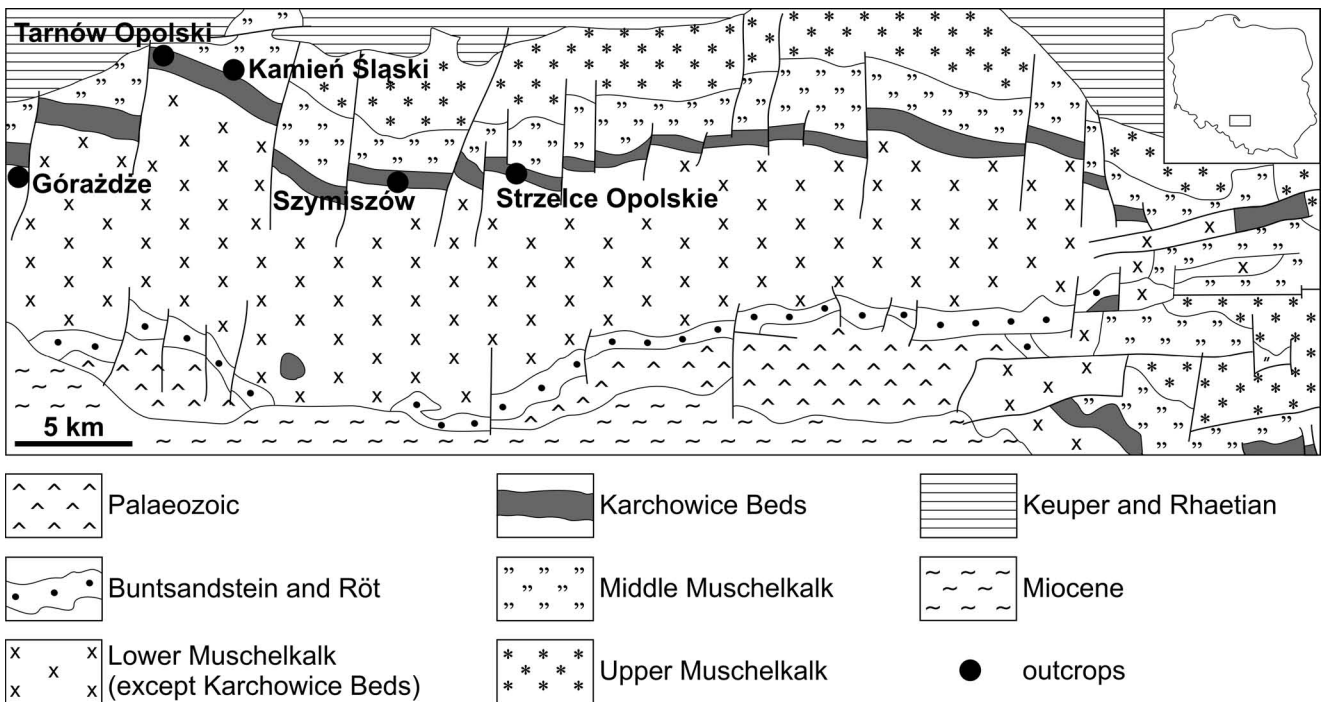


**Fig. 2.** Stratigraphic position of the Karchowice Beds and simplified sequence stratigraphy framework of the Silesian Muschelkalk (compiled from Zawidzka, 1975; Nawrocki & Szulc, 2000; Szulc, 2000; Narkiewicz & Szulc, 2004)

for the Triassic of the Germanic Basin and correlated with the Tethys domain, confirmed Pelsonian–Illyrian age of the Karchowice Beds.

**BIOTA ASSEMBLAGE**

The Karchowice Beds contain the richest fauna assemblage of the entire Muschelkalk succession, which is repre-



**Fig. 3.** Geological map of studied area (simplified after Bodzioch, 1997)

sented by Tethyan, Germanic and endemic Silesian forms. Such diversity reflects two factors: 1) ameliorated life conditions during the highstand system tracts (HST), for example oxygenation, salinity, temperature, water energy, depth (Szulc, 2000), and 2) occurrence of reef habitats, created by hexactinellid sponges together with the oldest *Scleractinia* corals, giving shelter for many groups of organisms.

According to Assmann (1944), bivalve fauna is the most numerous. It comprises 44 species, among which 15 are exclusively Upper Silesian taxa, 12 are characteristic for entire Germanic Basin, 4 are found also in the Tethyan province, and 13 occur both in the Germanic and Alpine domains. Among 33 gastropods two thirds are endemic Silesian forms, five are Tethyan and two are Germanic. Other groups of organisms are not so abundant: brachiopods comprise ten species, cephalopods – five species, vermes and fish – both for a four species, crustacean – three species and amphibians. The faunal list was extended by investigations of Bodzioch (1997).

Since Assmann's (1944) publication, only few macrofauna groups have been individually elaborated: sponges (Pisera & Bodzioch, 1991; Bodzioch, 1993), corals (Morycowa, 1988; Morycowa & Szulc, 2006), and echinoderms (Hagdorn & Głuchowski, 1993).

#### SEQUENCE STRATIGRAPHY AND PALAEOENVIRONMENTAL CONTEXT

The Lower Muschelkalk was divided into three third-order depositional sequences. The Karchowice Beds, together with the *Terebratula* and *Diplopora* beds, form the 3<sup>rd</sup> Anisian sequence (An3), passing to the Middle Muschelkalk (Fig. 2; Szulc, 2000).

Rapid transgression coming from the Tethys at the beginning of An3 sequence is represented by the transgressive system tracts (TST) of the *Terebratula* Beds – dark grey marly wavy/nodular limestones with bioclastic intercalations. Brachiopod *Coenothyris vulgaris* appears explosively as a reaction to deteriorated oxic conditions, elevated salinity and reduced temperature. After sea-level stabilization (from the maximum flooding surface onward) the basin was being aggradationally filled with calcareous sediments and the oxygenation was improving gradually. It is expressed by sediment colour change and onset of the richest benthic communities of the entire Muschelkalk (the Karchowice Beds). The sponge-coral reefs indicate the optimal open-marine stage in the Muschelkalk sea history. The final HST of An3 sequence is represented by oolitic bars, dasyclad shoals, oncolites and evaporites of the *Diplopora* Beds (Szulc, 2000).

#### METHODS

The Karchowice Beds have been studied in several outcrops over the entire Upper Silesia. Some of them are too small or poorly exposed to observe lateral facies changes. For this reason the author decided to study the horizontal and vertical variability of deposits at five sites, stretched at a distance of ca. 25 km (Fig. 3):

- Strzelce Opolskie – active quarry,
- Szymiszów – inactive quarry to the south of the road E-40 (4),
- Kamień Śląski – active quarry to the north-east of railway station “Kamień Śląski”,
- Tarnów Opolski – active quarry,
- Góraźdże – borehole.

The field sedimentary studies were completed by analyses of thin sections and polished slabs. A petrographic microscope was used for microfacies description. For each of the section a detailed lithofacies log has been prepared. The lithostratigraphic logs were correlated over the basin by using of some correlation horizons. To illustrate the main stages of basin evolution during the discussed time span, four simplified 3D sedimentary models were constructed.

## RESULTS

### GENERAL COMPOSITION

According to lithofacies succession, the Karchowice Beds may be divided into five units, called respectively: Transitional Complex, Lower Bioclastic Complex, Lower Sponge Complex, Upper Bioclastic Complex, and Upper Sponge Complex (Figs 4–6; Matysik, 2007).

Each unit displays distinctive lateral variety of thickness and basic sedimentary features (Fig. 4). After this lateral variety, the study area was divided into the western part (Góraźdże, Tarnów Opolski, Kamień Śląski), representing proximal facies assemblage (reefal facies) and the eastern one (Szymiszów, Strzelce Opolskie), dominated by distal facies (fore-reef belt; Fig. 5).

### DESCRIPTION OF THE UNITS

#### *The boundary between the Terebratula and Karchowice Beds*

In the whole area this boundary is defined by firmground horizon (Fig. 7A) with *Thalassinoides* and *Balanoglossites* trace fossils. Primary pelitic deposit contains numerous thin-shelled bivalves and foraminifers (Fig. 7C). The burrows are filled by a brighter colour crinoid-shelly deposit. Dark halo-structures, enriched in pyrite, developed around burrows (Fig. 7D). Filled older burrows may be cut by younger ones (Fig. 7E). In Tarnów Opolski, firmground evolved into hardground with *Trypanites* borings (Fig. 7B, C).

#### *The Transitional Complex*

The bipartite Transitional Complex is twice thicker in the eastern region (1.2 m) than in the western area. Its lower part consists of pale grey and beige crinoid-shelly packstones (calcirudites and calcarenites) with common intraclasts, derived from the underlying firmground (Fig. 7A). The sediments may display normal grading.

The upper part (resembling the *Terebratula* Beds) is composed of thin-bedded, dark-grey marly wackestones with brachiopods and oysters, grading up into highly bioturbated limestones (Góraźdże site) or wavy/nodular limestones (Strzelce Opolskie site).



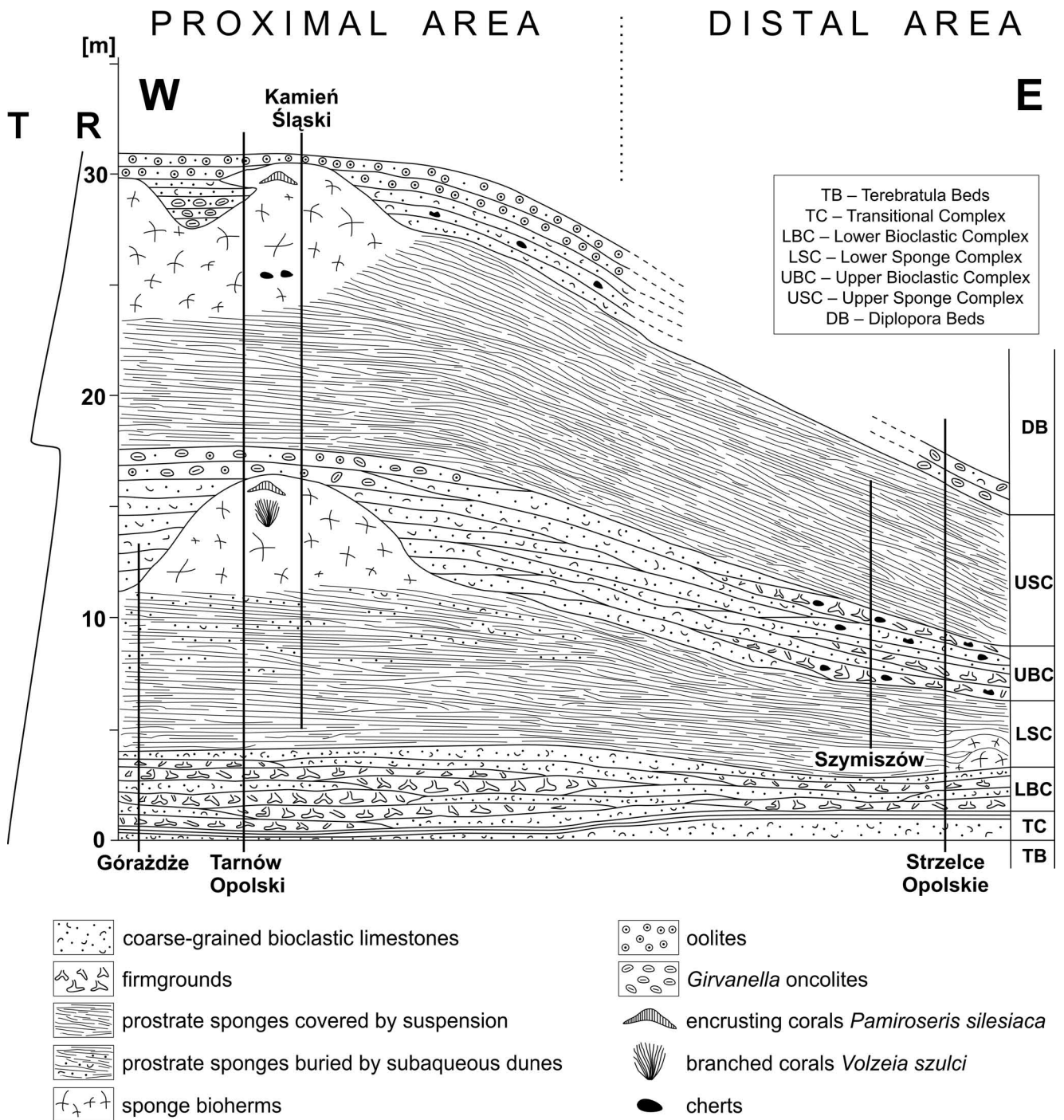


Fig. 5. Lithofacies scheme of the Karchowice Beds. Vertical lines denote stratigraphic range of each outcrop. Transgressive-regressive (T-R) trend is marked on the left

Despite significant lateral variability over the basin, the Transitional Complex shows generally deepening-upward trend exemplified by: thinning layers, fining grain size, increasing micrite/bioclasts ratio and return to fauna assemblage typical of deeper-water Terebratula Beds (Fig. 7F).

#### The Lower Bioclastic Complex

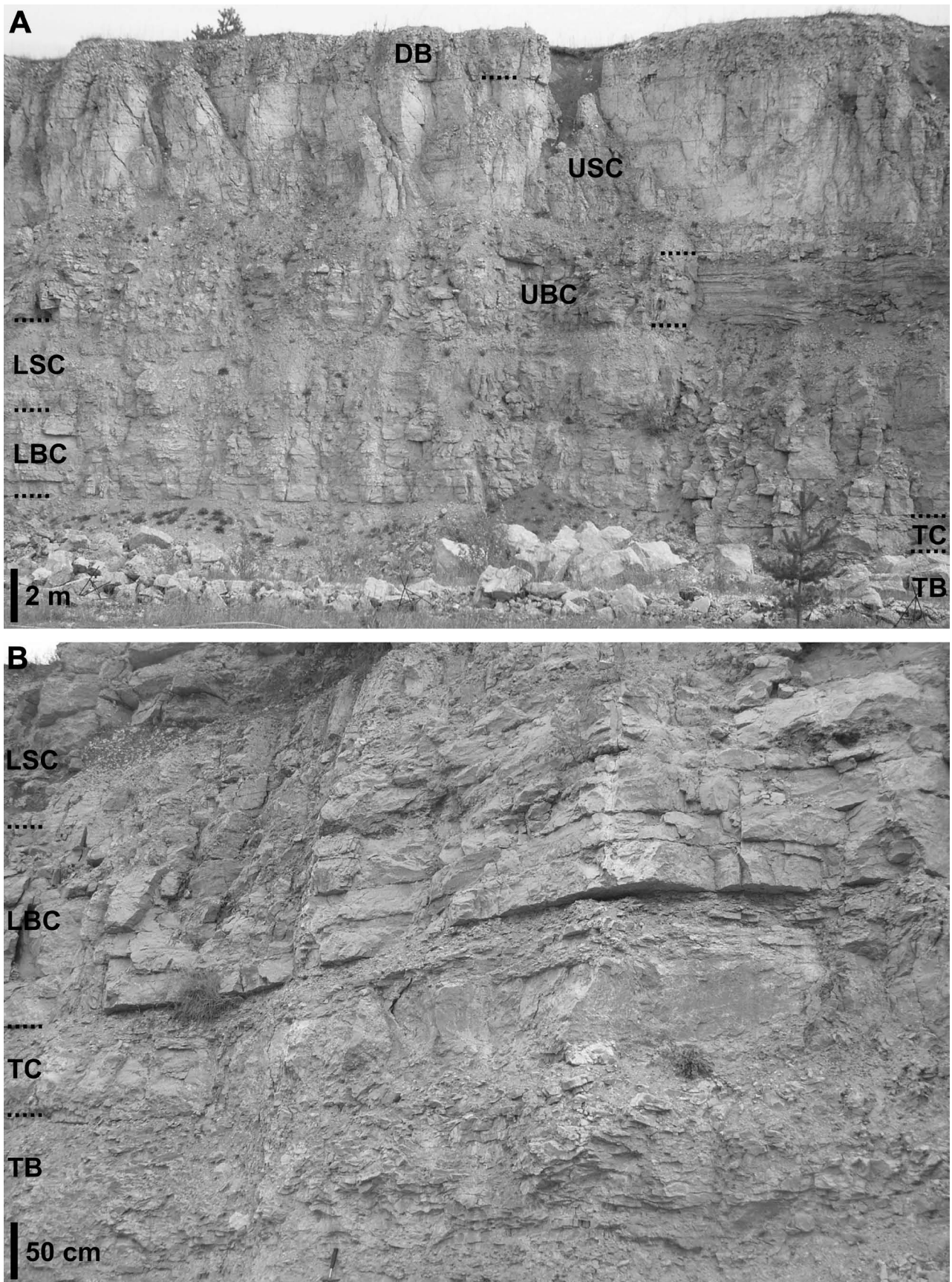
The Lower Bioclastic Complex of both regions reaches similar thickness (2–3 m) and displays alternation of two lithological types of limestones: fine-grained bioturbated

and coarse-grained bioclastic (Figs 8E, 9A). Horizontal and vertical composition of such alternations shows intense variability at a distance of even 50 m. Proportion of coarse-grained bioclastic limestones to fine-grained bioturbated ones is higher in the western area (Fig. 4).

#### Fine-grained bioturbated limestones

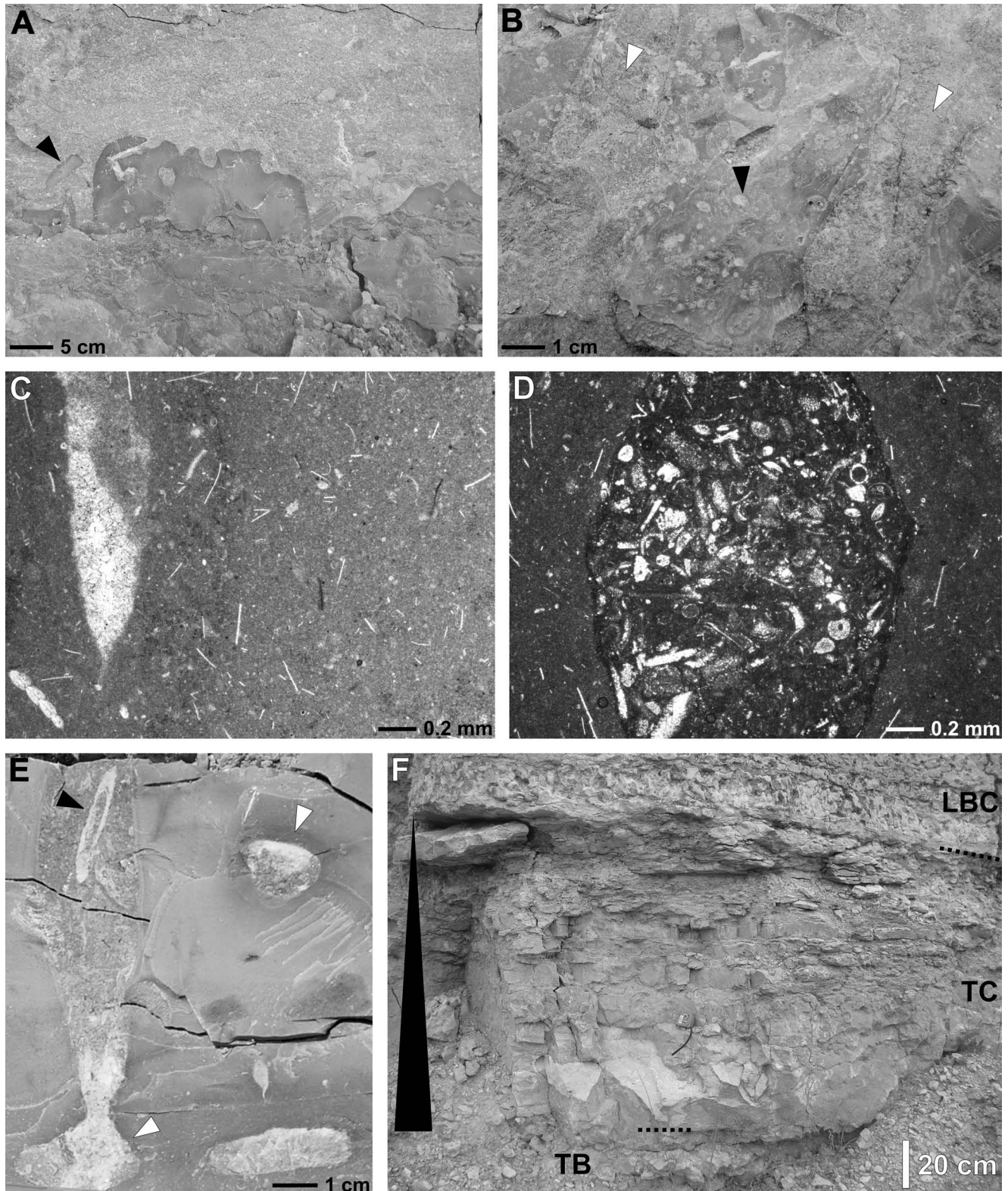
The fine-grained bioturbated type is built by grey calcilutites and calcisiltites, bearing *Thalassinoides/Balanoglossites* isp. These firmgrounds display rarely preserved pri-





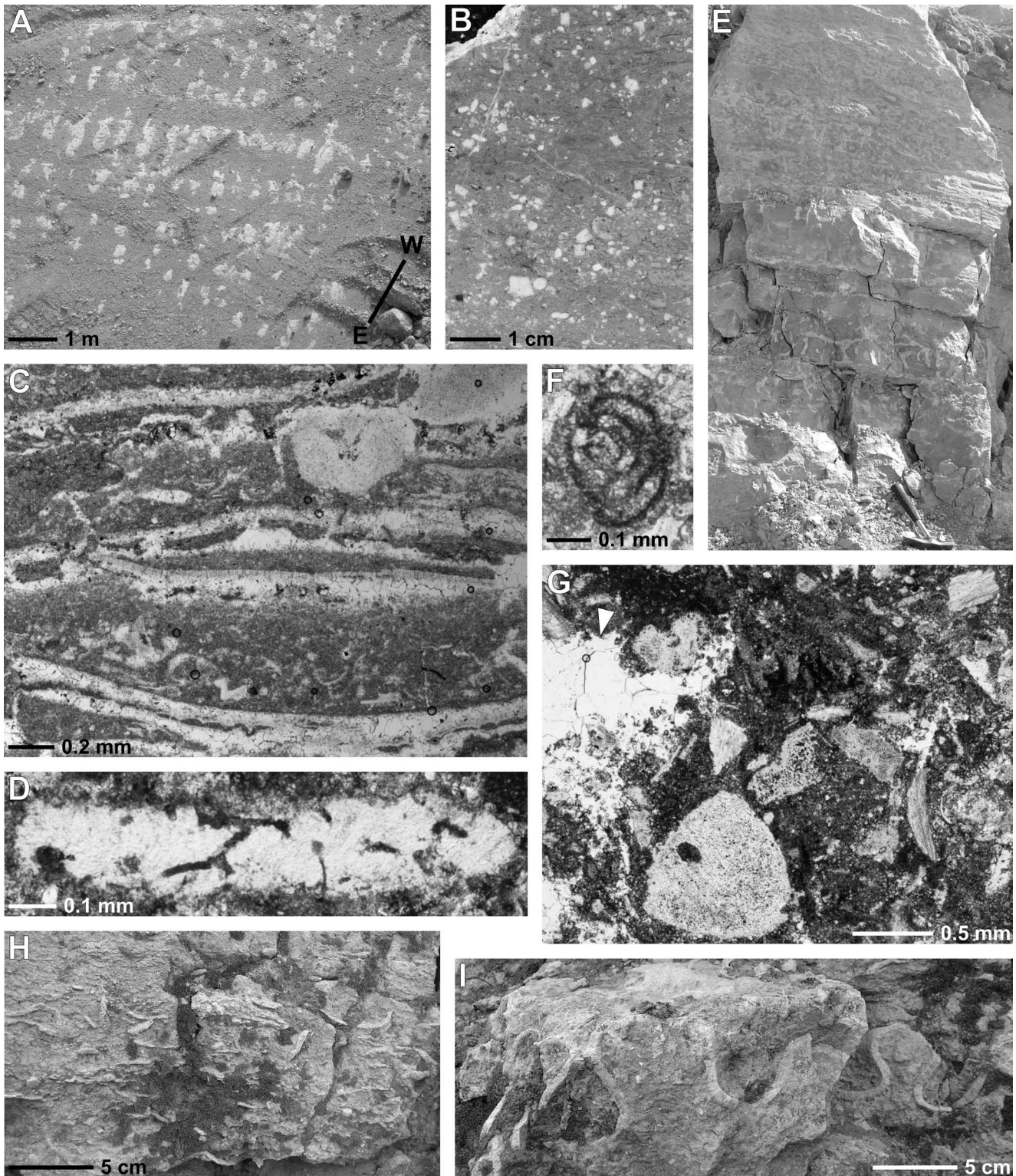
**Fig. 6.** General view of the Karchowice Beds in the Strzelce Opolskie quarry. TB – Terebratula Beds, TC – Transitional Complex, LBC – Lower Bioclastic Complex, LSC – Lower Sponge Complex, UBC – Upper Bioclastic Complex, USC – Upper Sponge Complex, DB – Diplopora Beds. **A.** Complete succession of divided units; **B.** Transition between deeper-marine nodular Terebratula Beds and relatively shallow Karchowice Beds





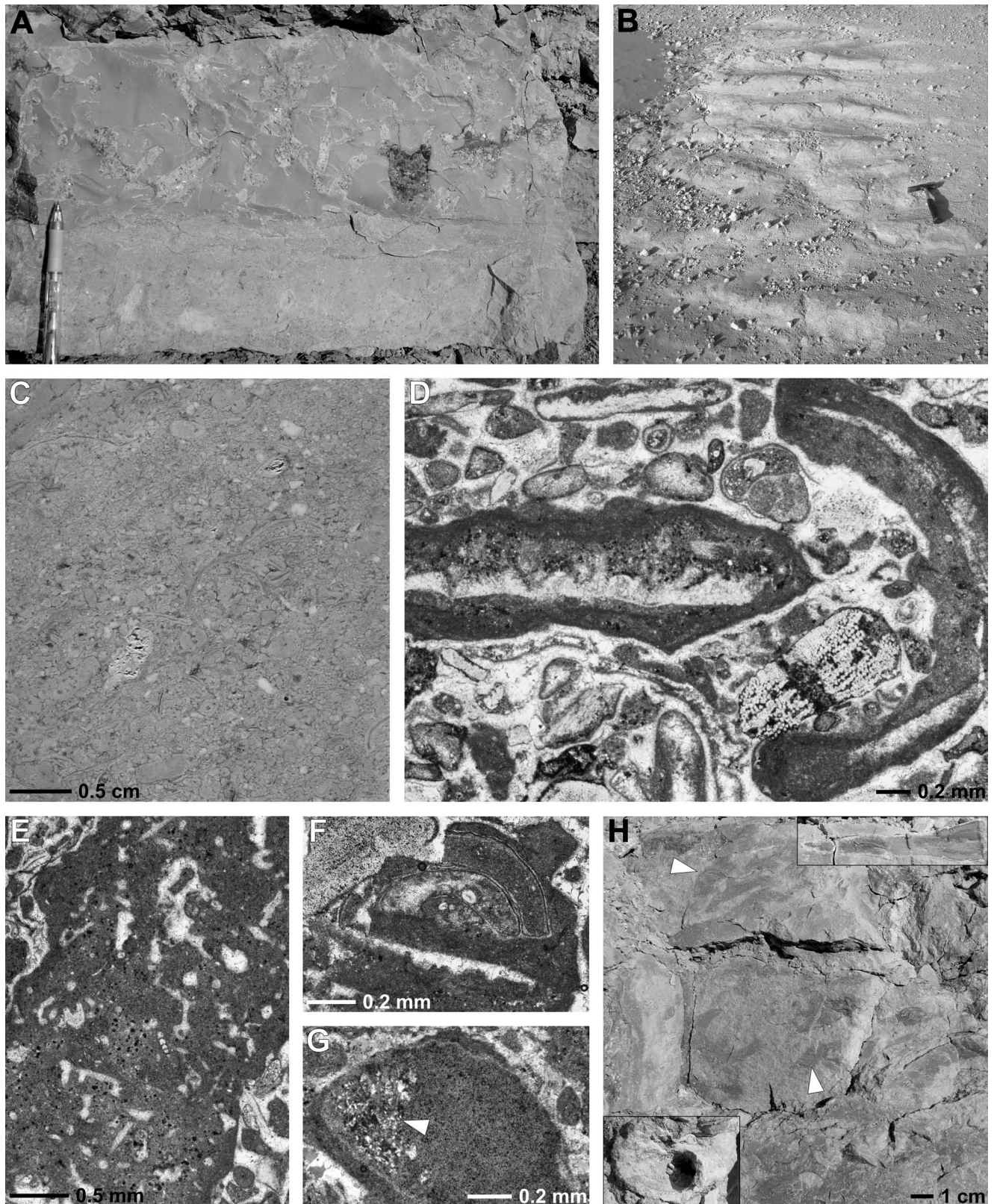
**Fig. 7.** The Transitional Complex in both parts of the basin. **A.** Firmground determining boundary between *Terebratula* and Karchowice Beds. Black arrow points to intraclast derived from firmground. Strzelce Opolskie; **B.** Hardground with *Trypanites* borings (black arrow). White arrows point to burrows infilled by coarser sediment. Tarnów Opolski; **C.** Detail of B. Bored micritic limestones containing thin-shelled bivalves and forams. Thin section; **D.** Detail of B. Burrow filled with bioclastic deposit. Thin section; **E.** Halo-effect structure around burrows (white arrows). Black arrow shows possible escape structure. Tarnów Opolski; **F.** Deepening-upward succession of the Transitional Complex (black triangle). TB – *Terebratula* Beds, TC – Transitional Complex, LBC – Lower Bioclastic Complex. Strzelce Opolskie





**Fig. 8.** The Lower Bioclastic Complex from distal facies (Strzelce Opolskie). **A.** Oscillatory ripples. Ripple crests are running from E to W; **B, C.** Poorly rewashed sediments. Thin section; **D.** Bioclast bored by fungi. Thin section; **E.** Several firmground horizons with rare intercalations of coarse-grained bioclastic deposits; **F.** Foraminifer as a common component of fine-grained bioturbated limestones. Thin section; **G.** Burrow infilled with trochites and shell debris. White arrow points to blocky calcite crystallized in open voids. Thin section; **H, I.** The uppermost correlation horizon of the Lower Bioclastic Complex. Sponge debris (H) followed by undulate-shaped sponges (I)





**Fig. 9.** The Lower Bioclastic Complex in Tarnów Opolski, representing proximal area. **A.** Coarse-grained bioclastic deposits capped by firmground; **B.** Oscillatory ripples. Ripple crests are running from E to W; **C.** Grain-supported packstone; **D.** Thin section of loosely packed cortoid grainstone with abundant gastropods; **E.** Reworked clump of sponge automicrite with stucked foraminifer. Thin section; **F.** Serpulid encrusting bioclast. Thin section; **G.** Silification of trochite (white arrow). Thin section; **H.** The uppermost correlation horizon of the Lower Bioclastic Complex with fragments of calcified sponge mummies (white arrows and lower insert) and cherts (upper insert). Scale is the same



mary parallel lamination. Micritic deposit contains bivalves; their aragonitic shells are dissolved and replaced with blocky or palisade calcite. Gastropods, crinoids, foraminifers, echinoid spines and brachiopods occur occasionally (Fig. 8F). Micrite envelopes developed around some bioclasts. Quite often silica substitutes carbonates in shells, especially of oysters. Some bioclasts are bored by fungi (Fig. 8D).

The burrows are filled by yellowish calcareous material, mainly composed of bivalves and crinoids. Blocky calcite crystallized in remnant open voids (Fig. 8G).

#### Coarse-grained bioclastic limestones

The coarse-grained bioclastic type in both regions is built by beige, creamy and light grey crinoid-shelly calcirudites and calcarenites, which sometimes display normal grading. Top of some beds is shaped as wave ripples with straight or slightly sinusoidal crests, running parallel from E to W in Tarnów Opolski (Fig. 9B) and from NEE to SWW in Strzelce Opolskie (Fig. 8A). Ripple lengths amount to 30–40 cm.

Poorly reworked packstones and wackestones, dominating in the eastern outcrops, indicate relatively low energy of sedimentary environment (Fig. 8B, C). The bioclasts are encrusted sometimes by serpulid tubes.

Grain-supported packstones and grainstones of the western part denote deposition in agitated waters (Fig. 9C, D). Many bioclasts exhibit micritic rims, what allows to classify them as cortoids and oncoids (Fig. 9D). Some cortoid nuclei (mostly shells and crinoids) underwent micritization due to microborers activity. The bioclasts may be encrusted by serpulids (Fig. 9F). The matrix is composed of peloids. An important role among allochems, as environmental indicators, play gastropods and reworked clumps of sponge automicrite (Fig. 9E). Silification of bioclasts is common phenomenon (Fig. 9G). All grains are loosely packed and cemented mainly by spar. In both regions rare penetrations may occur in coarse-grained bioclastic limestones.

The uppermost correlatable horizon of the Lower Bioclastic Complex, in both regions, contains cherts and bodies of siliceous sponges. In the bottom part of this horizon the sponges are broken (Figs 8H, 9H), but just above they create undulate-shaped rigid construction with significant lateral continuity (Fig. 8I). This was the first time, when sponges settled and stabilized the substrate successfully.

#### *The Lower Sponge Complex*

The Lower Sponge Complex in the eastern area reaches a thickness of about 3.5 m and is composed of pinkish cavernous micritic limestones. Micritic limestones display feature of microbially-controlled decay of the sponge bodies (automicrite). The layers, ranging in thickness between 3 and 7 cm, are interpreted as prostrate sponge colonies and the caverns as growth voids enclosed among sponge bodies. In the plane view of bed sponge paragasters are well visible. Between biostromes may occur few-mm-thick layers of fine-grained calcareous sediment with rare trochites and disarticulated shells. The bioclasts might also stuck within automicrite biostromes during decaying organic sheaths.

Except biostromes, few knobby buildups up to 1.5 m in height have been found in the Strzelce Opolskie quarry (Fig. 10A–C). The upper boundary of the Lower Sponge Complex is sharp (erosional) (Fig. 10D)

The Lower Sponge Complex in the western region is bipartite: lower eight metres of biostromal buildups is followed by high-relief bioherms (Fig. 11A, D, E). Each of these two parts shows internal complex structure, reflecting basin evolution and changes of water energy and input of calcareous detritus.

The bottom part of biostromal buildups is built, similarly like in the eastern area, by 3–7-cm-thick biostromes with growth voids, alternated sometimes by thin layers of detrital calcareous material. Upsection, thin intercalations of sediment are replaced by cross-stratified sand bodies up to 30 cm of thickness (Fig. 11B, C).

The biostromal part is covered by bioherms up to 6 m high and 20 m wide. They create distinct, isolated steep-sloped bodies, scattered at a distance of up to a few hundred metres. Main constructors, that is hexactinellid sponges (*Tremadictyon*, *Silesiaspongia*, *Hexactinoderma* and *Calycomorpha* sp.), may be accompanied by scleractinian corals. Up to now, over 20 coral species have been determined, including *Eckastraea prisca*, *Volzeia szulci*, *Pamiroseris silesiaca* and solitary corals, named as “*Montlivaltia*”. For more details about biolithite builders see Morycowa (1988), Pisera and Bodzioch (1991), Bodzioch (1993), Morycowa and Sulc (2006).

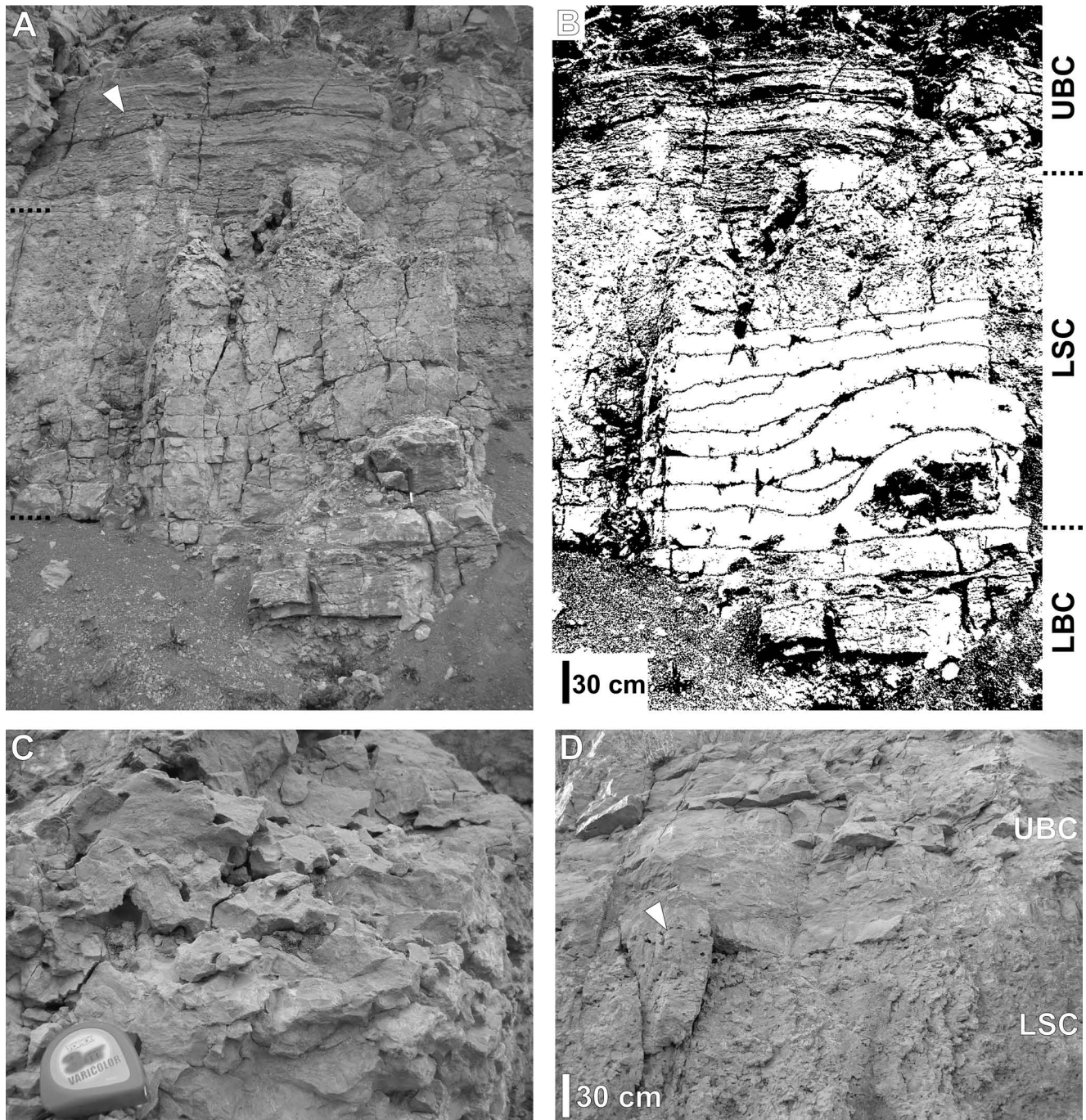
Some bioherms display a characteristic succession, described by Sulc (2000). In the lower part, together with hexactinellid sponges occur delicate-branched corals *Volzeia szulci*, which settled low-energy niches. Both of them are capped by lamellar colonies of *Pamiroseris silesiaca* of the shallowest high-energy growth phase.

Internal structure of the bioherms is composed of several tens of beds. Regarding the bed shape, two kinds of bioherms may be distinguished. In first type all beds follow the general semicircular form of buildup. A new bed, coating an older one, expanded mainly vertically and in lesser extent horizontally (aggradational growth). These constructions contain no *Volzeia szulci* corals. The second type, comprising branched *Volzeia szulci*, is composed of lenticle-shaped beds. On the bioherm flanks were deposited sands of the Upper Bioclastic Complex, which simultaneously covered the biostromal sponges (Figs 5, 10D).

#### *The Upper Bioclastic Complex*

The Upper Bioclastic Complex demonstrates different lithofacies evolution in the western and eastern regions (Figs 4, 5). In the eastern part, its thickness oscillates between 1.7 m (in Szymiszów) and 2.8 m (in Strzelce Opolskie). Like the Lower Bioclastic Complex it consists of random alternations of two limestone types: fine-grained bioturbated and coarse-grained bioclastic ones (Figs 4, 12A). Lithological features of each type demonstrates many similarities to those from the Lower Bioclastic Complex. Therefore only new attributes are described in this chapter. Several chert horizons occur in both lithological types. In firmgrounds, beside *Thalassinoides/Balanoglossites* trace fossils, *Teichichnus* isp. was recognized (Fig. 12E). Micritic

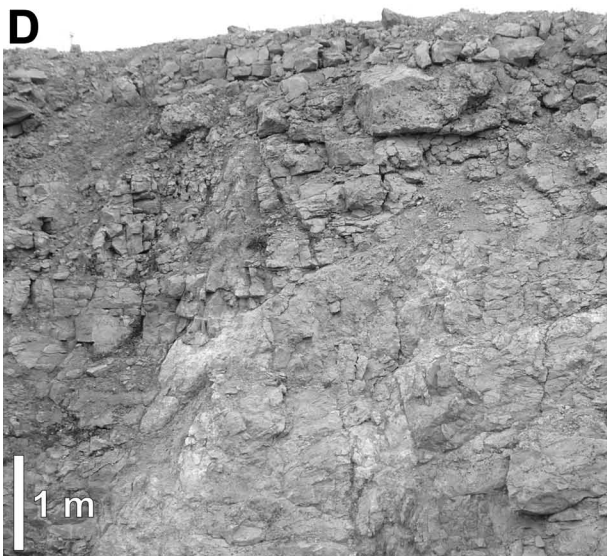
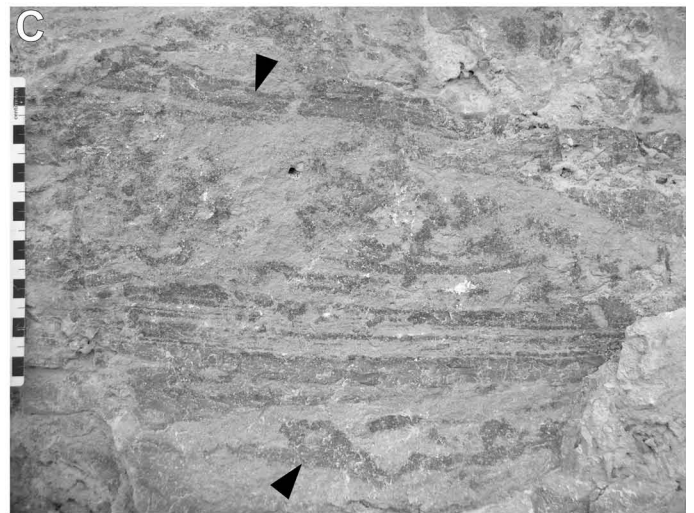
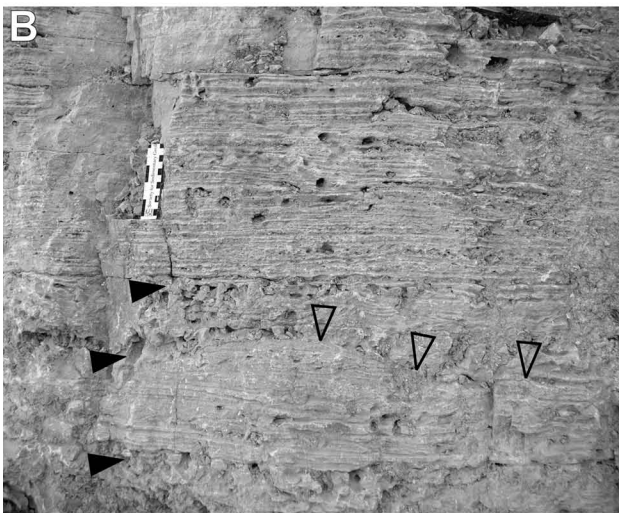




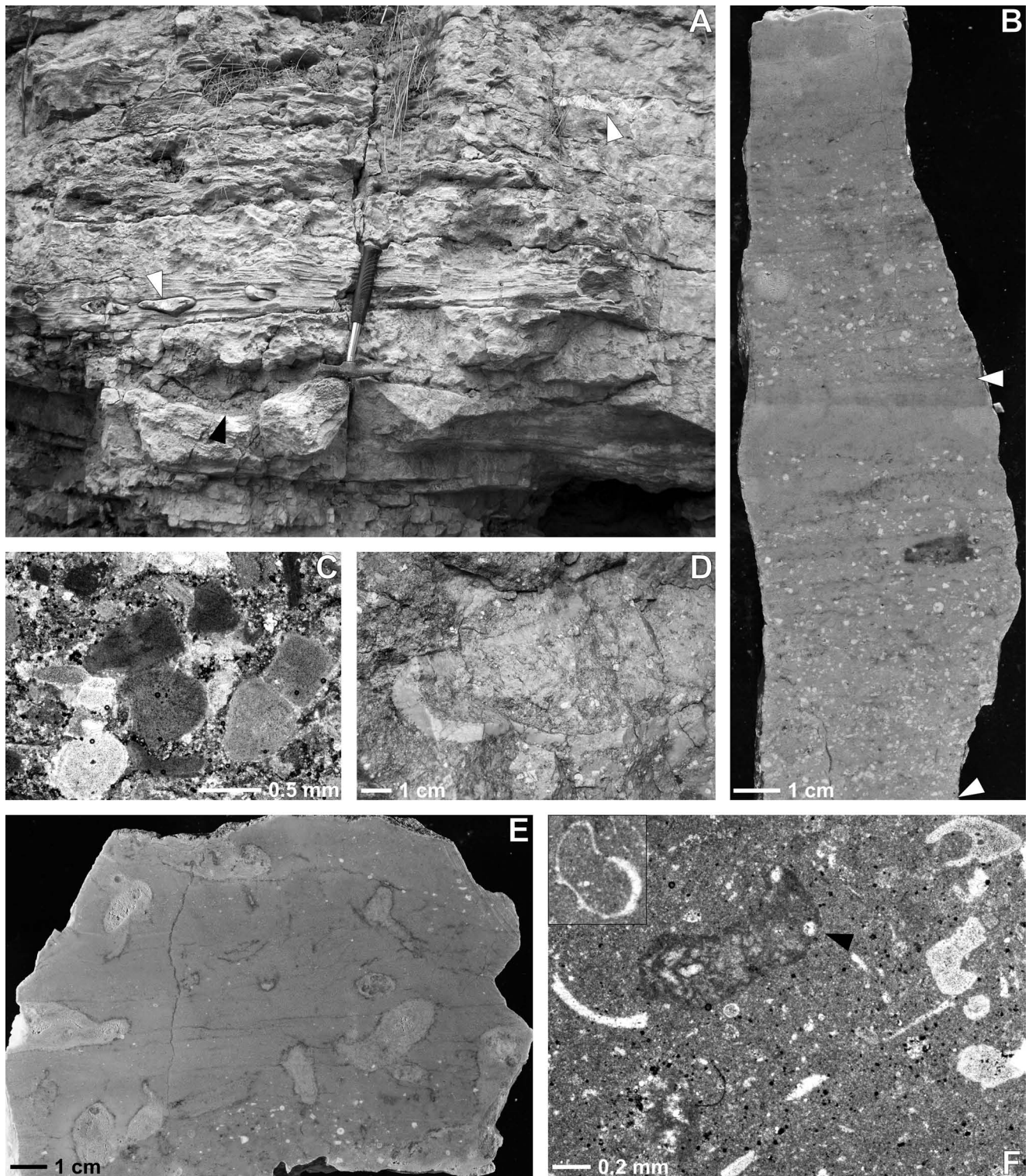
**Fig. 10.** The Lower Sponge Complex in Strzelce Opolskie (distal facies). LBC – Lower Bioclastic Complex, LSC – Lower Sponge Complex, UBC – Upper Bioclastic Complex. **A, B.** Small cavernous sponge buildup. White arrow points to cherts of the Upper Bioclastic Complex; **C.** Detail of A. Cavernous micritic limestones interpreted as sponge colony; **D.** Sharp boundary between prostrate sponges (LSC) and firmgrounds of UBC (white arrow)

**Fig. 11.** The Lower Sponge Complex in the western region (reefal facies). **A.** Spatial distribution of sponge biostromes (bs), bioherms (bh) of the Lower Sponge Complex (LSC) and the overlapping bioclastic sands of the Upper Bioclastic Complex (UBC). Kamień Śląski; **B.** Cavernous colonies of prostrate sponges (black arrows) mimicking top surface of subaqueous dune (open arrows). Scale bar is 11 cm. Tarnów Opolski; **C.** Detail of B. Black arrows mark bodies of prostrate sponges; **D.** Bioclastic sands overlapping sponge bioherm. Tarnów Opolski; **E.** Detail of D. Sponge automicrite







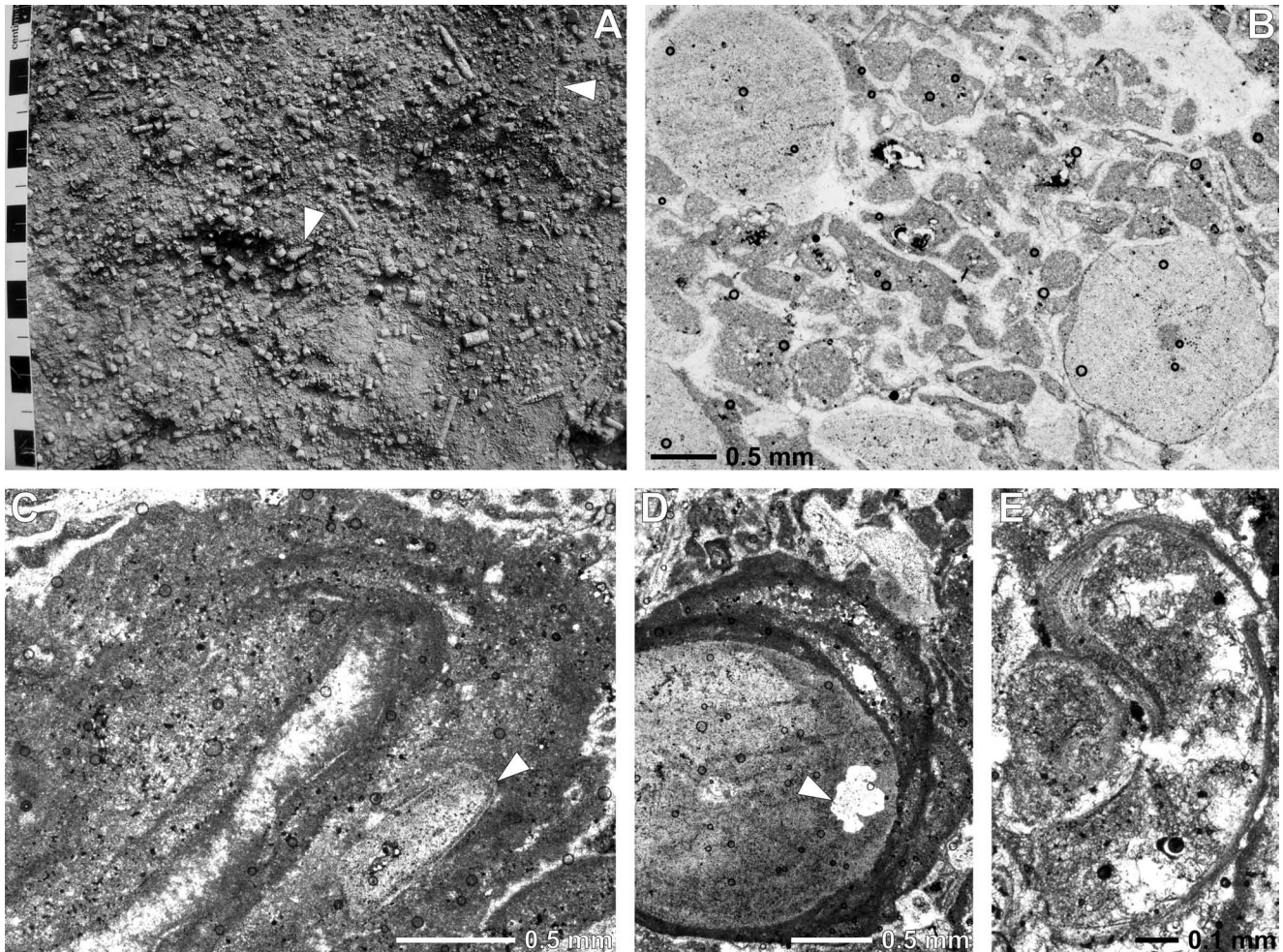


**Fig. 12.** The Upper Bioclastic Complex from the fore-reefal facies. **A.** Alternation of firmgrounds and coarse-grained bioclastic sediments. White arrows show flat-shaped cherts. Black arrow marks erosive channel; **B.** Two distal tempestites with normal grading. White arrows mark their bases; **C.** Crinoid packstone. Thin section; **D.** Overturned calcified sponge body in bioclastic deposit; **E.** Cross-section of fine-grained bioturbated limestone (firmground); **F.** Detail of E. Crinoids, bivalves, ostracods and *Tubiphytes* (black arrow) in micrite. Thin section. All pictures from Szymiszów

sediment contains rare ostracods and *Tubiphytes* sp. (Fig. 12F). The coarse-grained bioclastic limestones comprise overturned tube-shaped sponges (Fig. 12D) and broken fragments of biostromes. Calcified monaxons can be ob-

served under the microscope. Articulated crinoid columnals and sporadic complete crinoid calyxes, indicate episodes of fast burial (Fig. 12C). Deposit sometimes displays normal or reverse grading (Fig. 12B). Erosive channels were recog-





**Fig. 13.** The Upper Bioclastic Complex in the reefal zone (western area), composed of coarse-grained bioclastic limestones. **A.** Weathered surface of storm deposit, containing articulated crinoid columns. White arrows point to echinoid spines. Scale in centimetres; **B.** Detail of A. Densely-packed peloidal grainstone. Thin section; **C.** Oncoid, containing incorporated trochite (white arrow). Thin section; **D.** Oncoid with hemispheroidal laminae. Trochite is partly silified (white arrow). Thin section; **E.** Serpulid encruster. Thin section. All pictures from Tarnów Opolski

nized. These features are typical for distal tempestites. The Upper Bioclastic Complex boundary with the underlying Lower Sponge Complex is sharp (erosional; Fig. 10D).

In the western region the thickness of the Upper Bioclastic Complex amounts to 5.4–6.0 m. However, fundamental difference depends on lack of firmgrounds, being totally substituted for coarse-grained bioclastic sediments (Fig. 13A). Macroscopically, these are yellowish crinoid-shelly calcirudites and calcarenites (pakstones and wackestones), sometimes exhibiting normal or reverse grading. The cherts are lacking, although silification can be observed under the optical microscope (Fig. 13D). Beside trochites and rare bivalves, the thin sections show great number of very densely packed peloids, cemented with spar (Fig. 13B). It suggests early compaction. Articulation of crinoid columns is common phenomenon as an effect of storm-generated fast burial (Fig. 13A). Around the bioclasts thin micrite cortices are visible. Thick rims of common oncoids, containing incorporated bioclasts or serpulid encrustations, as well as hemispheroidal laminae, display multi-stage coating process (Fig. 13C–E). Some beds of these limestones pos-

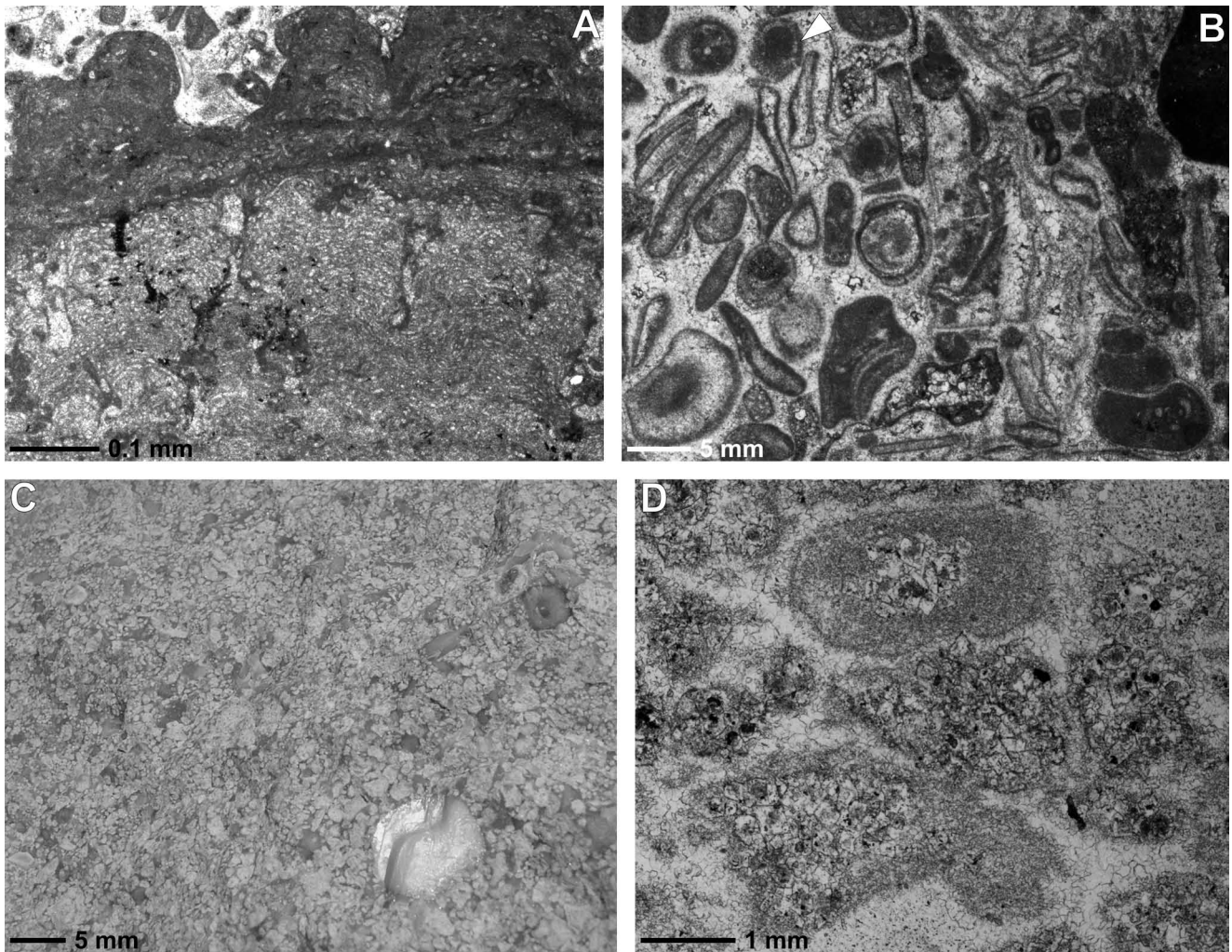
sess very irregular shape (e.g., lenticular, wedged) according to water energy modifications nearby the bioherms. The Upper Bioclastic Complex boundary with underlying Lower Sponge Complex is gradual (as mentioned above).

In the western area, the reefs of the Lower Sponge Complex are capped by extremely shallow-water deposits. These are *Girvanella* oncolites with frequent gastropods and sporadic ooids in Tarnów Opolski (Fig. 14A, B) and peloidal grainstones with rare crinoids in Kamień Śląski (Fig. 14C). Peloids (up to 2 mm in diameter) might undergo dolomitisation (Fig. 14D). Impoverishment in crinoids reflects restriction of normal marine conditions. All these features point to regression, when some of the bioherms could be emerged and undergone meteoric diagenesis (karstification, dolomitisation; Hagdorn *et al.*, 2007). To the east the shallowing trend is not so obvious.

#### *The Upper Sponge Complex*

In the eastern area the thickness of the Upper Sponge Complex is about 6.5 m. Just like the Lower Sponge Complex it is built by thin-bedded, pinkish micritic cavernous





**Fig. 14.** Extremely shallow-water deposits, capping reefs in the western area. **A.** Thin section of *Girvanella* oncoid. Tarnów Opolski; **B.** Skeletal grainstone with dispersed ooids (white arrow) and gastropods. Thin section. Tarnów Opolski; **C.** Peloidal grainstone with scarce crinoids. Kamień Śląski; **D.** Detail of C. Partly dolomitized peloids. Thin section

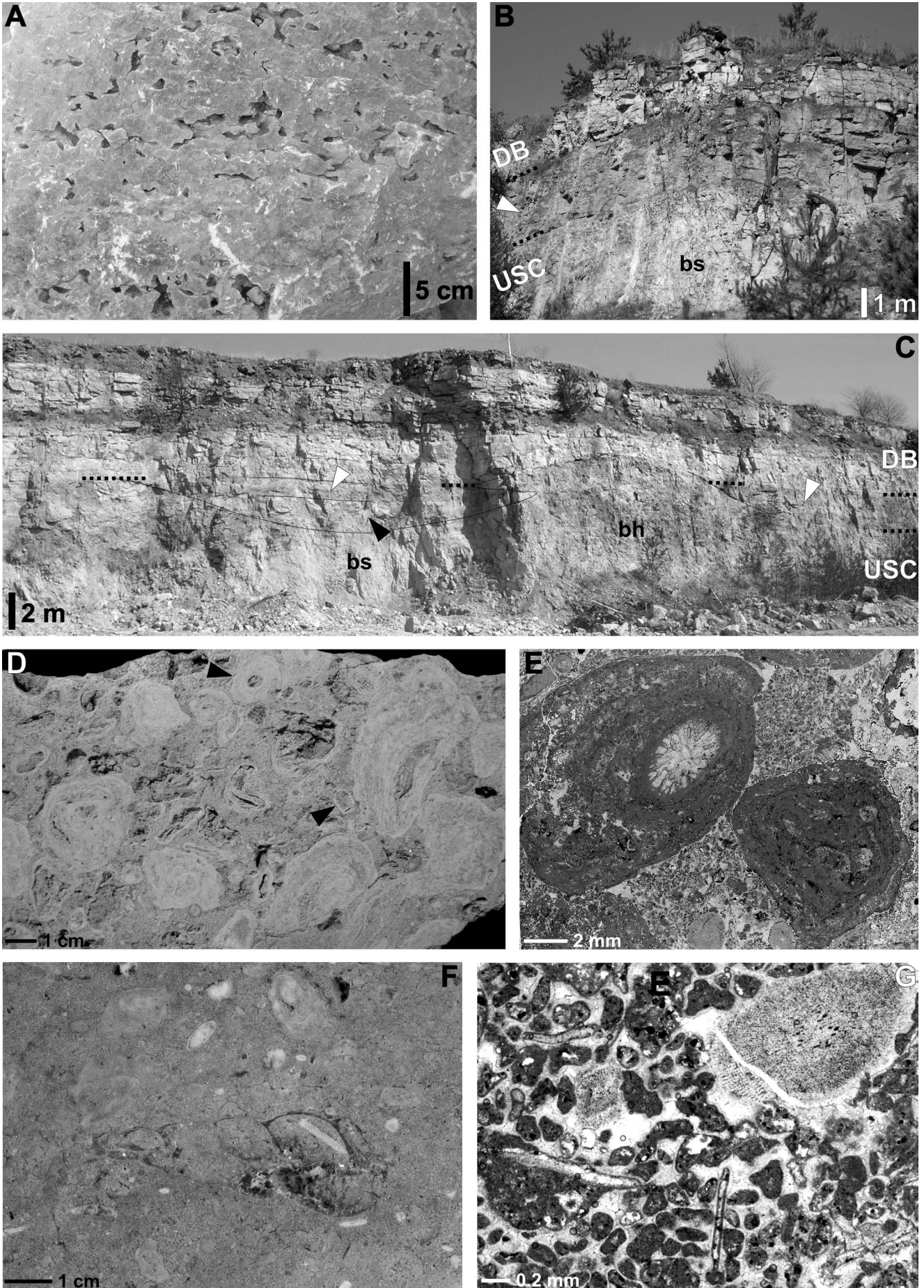
limestones, interpreted as sponge biostromes with growth voids (Fig. 15A). Prostrate sponges bound thin layers of calcareous mud. Locally remnants of burrow walls are visible on the surface of biostromes (see Fig. 17).

In the western part, the Upper Sponge Complex is clearly bipartite. The thickness of the lower biostromal part is hard to estimate (ca. 6 m). Gently-sloped sponge bioherms up to 8 m high and 30 m wide occur in the upper part (Fig. 15C). *Pamiroseris silesiaca* corals have been found at the top of bioherms (see Morycowa, 1988, fig. 2). However, characteristic succession of biolithite builders is not such well recorded as in the Lower Sponge Complex.

On the bioherm flanks, large *Girvanella* oncoids (up to 4 cm across) originated in some local shallow pans (Fig. 15D). These sediments comprise a large amount of coral fragments (mostly as oncoid nuclei; Fig. 15E). Majority of them are badly preserved, but some were determined as *Volzeia* cf. *szulci* and *?Retiophyllia* sp. In thin sections peloids and rare bioclasts may be identified as grainstones. Above the oncolites, beige and yellowish bioclastic calcarenites (3-m-thick) with flat cherts were deposited. The thin sections exhibit plenty of poorly-sorted peloids (Fig. 15G) with some crinoids, gastropods and rare brachiopods, bivalves, forams and oncoids cemented by spar. These grainstones

**Fig. 15.** The Upper Sponge Complex in both regions. **A.** Cavernous colonies of prostrate sponges. Cross-section view. Strzelce Opolskie; **B.** Sponge biostromes (bs), covered by peloidal calcarenites (white arrow) and by the Diplopore Beds (DB). USC – Upper Sponge Complex. Kamień Śląski; **C.** Spatial relationship between sponge bioherms (bh), biostromes (bs), interbioherm deposits (arrows) and the Diplopore Beds (DB). Black arrow points to *Girvanella* oncolites. White arrows mark peloidal calcarenites. Kamień Śląski; **D.** *Girvanella* oncolites, containing coral fragments as nuclei of microbial coating (black arrows); **E.** Detail of D. Thin section; **F.** Peloidal calcarenite with gastropod and oncoids; **G.** Detail of F. Peloidal grainstone. Thin section







may be called as peloidal calcarenites. Gastropods reach up to 5 cm in size (Fig. 15F). The mentioned features indicate sedimentation in shallow agitated warm waters.

#### ***The boundary with The Diplopora Beds***

In the western area, the bioherms of the Upper Sponge Complex and peloidal calcarenites are overlain by about 2.5 m thick- and medium-bedded oolites of the Diplopora Beds, which may overlap the bioherm tops (Fig. 15B, C).

In Strzelce Opolskie, the Upper Sponge Complex is capped by oncolites with coral fragments (*?Retiophyllia* sp., *?Conophyllia* sp.), which probably represent time equivalent of the western oolites, but formed in less turbulent sedimentary environment.

## **INTERPRETATION AND DISCUSSION**

The outcrops in Górazdze, Tarnów Opolski and Kamień Śląski, representing reefal proximal facies, are located more or less at the same latitude as quarries in Szymiszów and Strzelce Opolskie, which show distal fore-reefal facies assemblage. Such a facies pattern supports the statement by Szulc (2000), that the studied area was a submarine threshold block, running from NE to SW in Anisian times.

### **PALAEOENVIRONMENTAL RECONSTRUCTION**

#### ***The boundary between the Terebratula and Karchowice Beds (Fig. 16A)***

The firmground, beginning the Karchowice Beds, indicates slowdown in sedimentation rate. In some areas (e.g., Tarnów Opolski), the basin was starving and firmground evolved into hardground (Fig. 7B–D).

Darker-colour halo-structures around burrows suggest that the ichnofauna impregnated the burrow walls by organic mucus, which precluded their collapse. The substrate could be penetrated even few times, what was resulted in crosscutting traces. Some covered organisms might run away, leaving escape structures (Fig. 7E).

#### ***The Transitional Complex***

During the Transitional Complex deposition, the sedimentary setting apparently became unified, because this complex shows similar lithological features within the Silesian Basin with deepening/thinning-upward trend (Fig. 7F). Its lower part recorded few high-energy events (storms?). After that the basin returned to restricted life conditions and reduced energy level, depositing marly limestones, resembling deeper-water Terebratula Beds.

#### ***The Lower Bioclastic Complex (Fig. 16B)***

With the beginning of the Lower Bioclastic Complex, the basin topography became more differentiated. The proximal zone was situated on the west (Fig. 9) and distal area on the east (Fig. 8). This phenomenon is expressed by amount and composition of the coarse-grained bioclastic intercalations within firmgrounds. Multistage genesis of both types, representing high-energy events and quiescence

phases, is connected with various sedimentological and biological processes.

The storms destroyed biota community, redeposited older unlithified sediment and eroded sea bottom. Such mixed material was accumulated in a relatively short time. Most of it was deposited above storm-wave base. The top surface of these sediments might be remodelled into wave ripples above fair-weather wave base (Figs 8A, 9B). General NE–SW direction of ripple crests confirms that the studied area was a submarine threshold, running in the same direction as ripple tops.

These phases of agitated waters were followed by longer periods of fair-weather conditions. The skeletal fragments, such as crinoids and shells, were undergoing micritization due to exposition for microborers activity, such as fungi. They also were encrusted by serpulids. In proximal shallower areas, where access to sunlight was better, the micrite envelopes were developing around bioclasts by autotrophic microbes. Transparency of water column indicates lack of suspended material, which must be washed away to distal zone. The sea floor was also inhabited by diversified macrofauna assemblage, represented mainly by echinoderms, bivalves and brachiopods. The gastropods were living in proximal warmer waters where the bottom was being colonized by sponges too. Reworked clumps of sponge automicrite come from destruction of initial sponge constructions. Common silification of bioclasts may not necessarily confirm *in situ* source of silica. Silica could either migrate downward from overlying Lower Sponge Complex, but it surely comes from dissolution of sponge skeletons.

Finally, all the mentioned grains were deposited as coarse-grained bioclastic intercalations probably in one act of deposition. More such events were recorded in proximal areas of the basin (Fig. 4); grain-supported packstones and grainstones (Fig. 9C–G) with spar domination denote multiple reworking and micrite rewashing. The micrite could have been deposited *in situ* as horizons of firmgrounds or winnowed to distal areas of the basin. Loosely packed particles indicate quite fast deposition and cementation without advanced compaction. Therefore, this sediment was not covered by other layers over long time. Otherwise, the particles would have been densely packed. In the same time in the eastern part, representing distal facies, poorly-washed packstones and wackestones were deposited (Fig. 8B–D). Large amount of micrite indicates relatively low-energy of sedimentary environment. Rare coated grains and gastropods were probably delivered from the western proximal region. Storm events were recorded here as occasional coarse-grained bioclastic intercalations within many firmground beds (Fig. 4).

The firmgrounds exhibit the same features in the western and eastern area (Figs 8E–G, 9A), thus the mechanism of their origin was identical. The fine-grained calcareous material was accumulated under fair-weather wave base. Its parallel lamination evidences that particles were suspension-settled. After time of main deposition, sedimentation rate decreased and fair-weather period began. Firstly, the sediment became initially lithified what enabled infauna to penetrate the substrate because it prevented burrows from



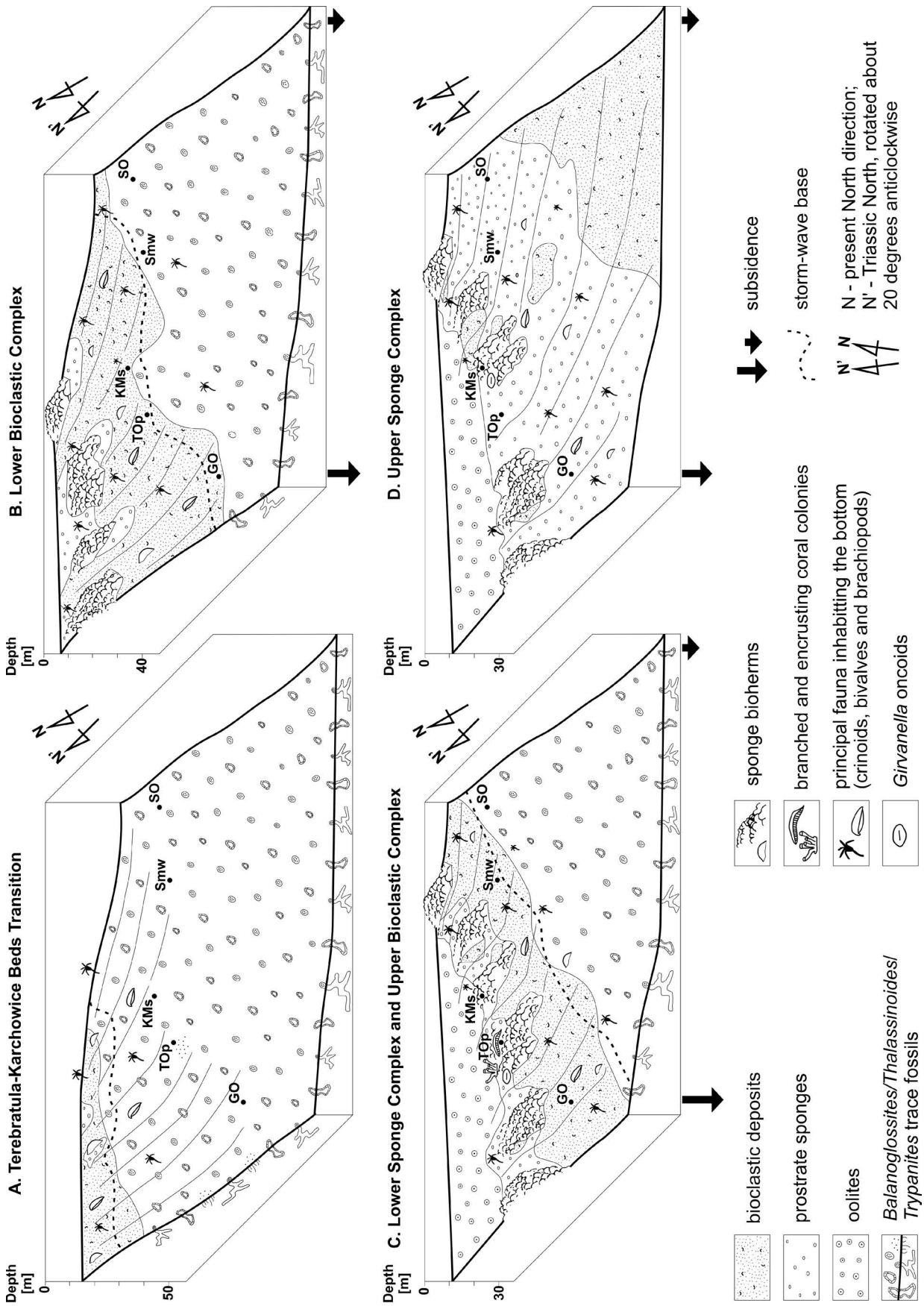
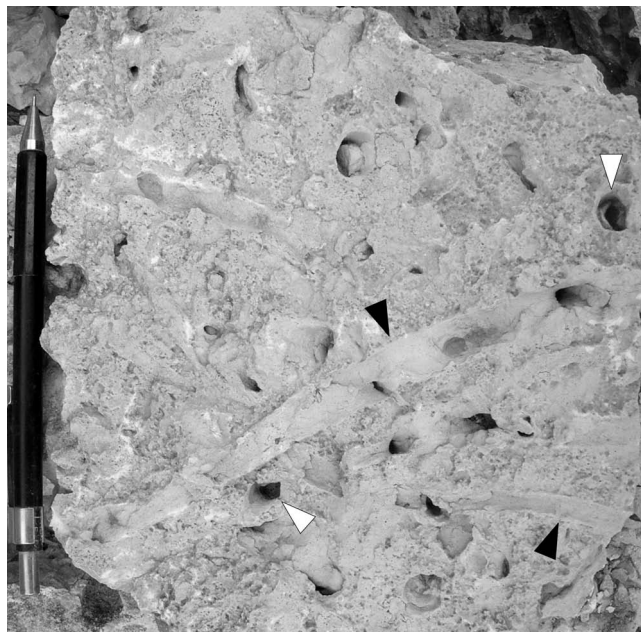


Fig. 16. Simplified 3D sedimentary models, portraying stages of basin evolution. SO – Strzelce Opolskie, Smw – Szymiszów, KMs – Kamień Śląski, Top – Tarnów Opolski, GO – Górażdże





**Fig. 17.** Surface of prostrate sponge colony. White arrows mark paragasters. Black arrows point to remnants of burrow firm walls. Strzelce Opolskie

collapsing. Grey-coloured deposit was enriched in organic matter. Depletion in oxygen was related to longer periods without water turbulence. Afterwards, firm substrate was being intensively bioturbated by ichnofauna what obliterated most of primary lamination. The *Thalassinoides* and *Balanoglossites* burrows are thought to be produced by crabs and enteropneustans (Kaźmierczak & Pszczółkowski, 1969). Many firmground beds, reaching 30 cm in thickness, show internal homogeneous structure. Therefore, the material must have been deposited as single event, probably after storm. Phases of firmground forming were interrupted by higher-energy events. Many of them were recorded only as coarser-grained infilling of burrows (Fig. 8G).

Summarizing, both firmgrounds and coarse-grained bioclastic intercalations were formed during alternating long periods of quiescence and short high-energy events. The former are represented by: 1) formation of firmgrounds (initial lithification of fine sediment and its bioturbation); 2) the micritization and coating of bioclasts; 3) the cementation without advanced compaction; 4) sea floor colonisation by fauna and flora. Deposition of fine- and coarse-grained particles supposedly followed high-energy acts (mainly storms). Waving and currents reworked skeletal sands and formed ripples.

Alternation of firmgrounds and coarse-grained bioclastic intercalations reflects changing regime of water energy. Thus, the storm-wave base must have fluctuated and the studied area was localized once above storm-wave base and once under it, depending on storm energy. Vertical and horizontal variability of such alternations reflects interplay of erosion, accumulation and diverse sea-floor morphology (Fig. 4).

The uppermost horizon of the Lower Bioclastic Complex comprises sponges debris in the bottom part, passing

upward into complete undulate-shaped sponge constructions (Figs 8H, I, 9H). This succession reflects successful colonisation of bioclastic bottom, causing stabilization of moving deposit and reduction in amount of loose particles.

#### ***The Lower Sponge Complex and the Upper Bioclastic Complex (Fig. 16C)***

After the phase of substrate stabilization (mentioned above), the volume of migrating sediment and production of new detritus became considerably reduced. However, hydrodynamic regime at the sea bottom probably remained still the same with fluctuating storm-wave base (see chapter: "Palaeoenvironmental reconstruction – the Lower Bioclastic Complex"). The prostrate sponges were covered mostly by fine-grained particles, which caused obturation of their inhalational system. Low amount of such sediment, recorded as thin intercalations sandwiching biostromes, was enough to make life-conditions unfavourable for sponges, which were forced to retreat and recolonized the substrate. The sediments, intercalating biostromes, could had being bioturbated and afterwards a storm washed the deposit away, leaving only harder burrow walls – common in the eastern distal area (Fig. 17).

Due to progressive aggradational infilling of the basin, unbalanced by sediment western (shallower) part intersected the fair-weather wave base. Permanent water turbulence caused winnowing of fine-grained sediment. The sponges became covered by migrating subaqueous dunes. Periodic breaks of sand bodies movement allowed to sponges recovery, which again bound and stabilized the upper surface of dunes (Fig. 11B, C). At the same time, the eastern (deeper) part of basin still was located near storm-wave base, where prostrate sponges were being covered by fine-grained particles.

On stabilized bottom, sponge bioherms developed. In distal region (the Strzelce Opolskie quarry), only few knobby buildups, up to 1.5 m high, appear (Fig. 10A–C). In the western area the bioherms, achieving 8 m in height and several tens of metre in width (Fig. 11A), played a role of breakwaters, which modified water energy and created new niches. These niches were settled by crinoids, gastropods, forams, brachiopods, ostracods and, most important, by coral colonies such as branched *Volzeia szulci*. Growing of bioherms stimulated rise of water energy in face side of buildups, what presumably destructed biota community and supplied new detritus to the basin. Increased sand input caused that the prostrate sponges was not capable of recovery. Finally, they were completely covered by material of the Upper Bioclastic Complex. In the reefal zone was only accumulated the coarse-grained calcareous deposit (Fig. 13). Lenticular- or wedge-shaped beds of these sediments probably reflect water energy modifications nearby the bioherms. On one hand, common articulation of crinoid columns and dense packing of grains, resulted from overloading by new sediment, indicate fast burial due to storm and waving activity. On the other hand, numerous cortoids and complex oncoids suggest longer periods without sediment redeposition. Time was also needed for substrate colonisation by fauna and flora. Fine particles were winnowed from reefal zone to distal part of basin (the eastern region)



and deposited under storm-wave base as fine-grained bioturbated limestones (Fig. 12A, E, F). Coarser material was transported to the distal area too (Fig. 12B–D). Some of these intercalations within firmground succession possess typical features for distal tempestites (articulated crinoid calyxes and columnals, normal grading, erosive channels). Overturned tube-shaped sponges, torn biostromes and calcified monaxons indicate that sponges attempted to colonize substrate, but relatively high sedimentation rate exceeded their potential for recovery.

In the final stage, the basin became filled with sediment and bioherm crest reached the sea surface. Shoals, comprising the *Girvanella* oncoids and ooids, accumulated in extremely shallow agitated waters of proximal area (Fig. 14). Dolomitisation of peloids and distinct impoverishment in stenohaline organisms, like crinoids, reflect restriction of normal-marine conditions and evaporation. The bioherms became inhabited by wave-resistant encrusting corals *Pamiroseris silesiaca*. Some buildups could be even emerged and underwent dolomitisation and karstification (Hagdorn *et al.*, 2007). In the eastern distal part of basin, shallowing-upward trend was not recorded so clearly.

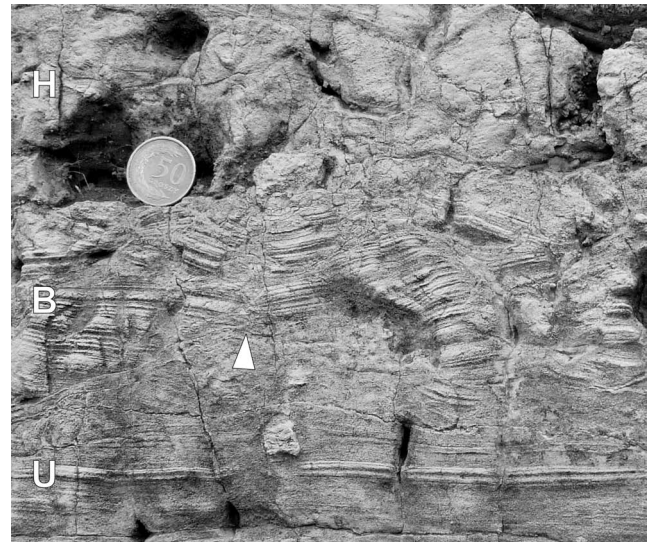
#### The Upper Sponge Complex (Fig. 16D)

After the shallowest stadium described above, the sea-level rose again. All described before stages of sponge buildups were repeated (Fig. 15). Firstly, the prostrate sponges stabilized unstable calcareous substrate in both regions. Secondly, the hexactinellid sponges colonised sea bottom, building 8-m-high bioherms in the western area. During climax conditions, the bioherms were settled by coral colonies (see Morycowa, 1988, fig. 2). Afterward, the *Girvanella* oncoids originated on the reef flanks within turbulent pans. The oncoids contain coral fragments as nuclei, surely derived from the neighbouring reefs (*?Retiophyllia* sp., *Volzeia* cf. *szulci*). Finally, peloidal calcarenites were deposited in the western area. They are capped, together with sponge bioherms, by oolites of the Diplopora Beds, indicating the shallowest stage of the HST of An3 sequence.

### SYNSEDIMENTARY TECTONICS

In general, the penecontemporaneous deformation structures are usually best preserved in fine-grained carbonates. The Karchowice Beds mostly consist of the coarse-grained limestones or biolithites, in which preservation possibility of such structures is minimal. In turn, the fine-grained deposits of the Karchowice Beds are considerably bioturbated, what could obliterate the tectonic deformations. Nevertheless, horizons displaying characteristic features for quake-triggered deformations (fading-up syndimentary faults, brittle deformations grading up into homogenized sediment) were found in Szymiszów (Fig. 18; Hagdorn *et al.*, 2009).

Variable thickness of the Karchowice Beds, reaching 30 m in the western region and 16 m in the eastern one, indicates that basin was divided into small fault-bounded blocks, controlled by different subsidence. On one hand, subsiding blocks (or maybe uplifting too) created different accommodation space, which was being filled by various



**Fig. 18.** Seismically-induced deformation structures. Upper Bioclastic Complex in Szymiszów. U – undisturbed laminated part, B – brittle deformations of lithified part, H – homogenization of unlithified part. White arrow marks the most visible dislocation of laminae. Note that faults fade up into homogenized part. Coin for scale is 2 cm in diameter

sediment volume. On the other hand, sediment-overloaded blocks were yielding greater subsidence and were creating new accommodation space in higher rate. It is noteworthy that the Lower Bioclastic Complex (when bioherms did not exist yet) reaches similar thickness (2–3 m) over the entire Silesian basin. Only since the Lower Sponge Complex, the deposit thickness is approximately twice greater in the proximal western area. Surely, this phenomenon was triggered by appearance of sponge buildups. Growing of bioherms burdened the bottom, but it also stimulated higher rate of forming of calcareous particles and higher rate of sediment accumulation in the proximal western part. Such overloaded western block (?blocks) was undergoing faster subsidence. Creating accommodation space was continually filled with carbonate sands. This was specific self-propelling system.

Reconfiguration of tectonic blocks also modified palaeorelief of the sea bottom what could influence on spatial relations between erosion and deposition. This phenomenon is probably expressed by intense horizontal and vertical variability within both bioclastic complexes, in which alternations of firmgrounds and coarse-grained bioclastic intercalations show random arrangement (Fig. 4).

All those facts imply that during time under discussion, the study area was undergoing tectonic rebuilding, resulted from activity of the Variscan Silesian-Moravian fault, reactivated during the Triassic (Szulc, 1989).

### CYCLICITY OF SEDIMENTATION

The Karchowice Beds belong to the 3<sup>rd</sup>-order sequence of the Anisian, which represents shallowing-upward trend from the Terebratula Beds to the Diplopora Beds (Szulc, 2000).



However, the present study allows to state that bipartite succession of the Karchowice Beds is cyclic. Each part is consisting of bioclastic lower member, followed by sponge complex. Repeating character of sediments resulted rather from eustatic transgression than tectonic subsidence. These sea-level fluctuations represent the 4<sup>th</sup>-order cycles.

Interpretation of higher-frequency depositional cycles and their stacking patterns in bioclastic members (Transitional Complex, Lower Bioclastic Complex and Upper Bioclastic Complex) was not the aim of this paper.

### BIOLOGICAL-MECHANICAL SYSTEM OF INTERACTION

Analyzing evolutionary phases of sponge buildups and the ambient sediments from the Karchowice Beds one may conclude which physical environmental factors influenced sponges reactions and how the sponges themselves were able to modify their habitat.

Generally, the appearance of sponge-coral reefs is determined by many factors, that is oxygenation, access to sunlight, salinity, temperature, nutrients. As previous workers noticed (Szulc, 2000), these factors were rather constant during discussed time interval. Therefore, the author makes an assumption that other factors controlled sponge reactions.

The sponges responded to any changes by adaption of shape of their constructions to ambient conditions. It seems that only two factors controlled the shape of sponge buildups: input volume and fraction of calcareous detritus.

#### *Input of loose calcareous particles*

The author uses the term "accumulation rate" as averaged effect of erosion, redeposition and deposition in a given time interval. Regarding the dominant incidental nature of these processes in the Muschelkalk basin, much time of "accumulation rate" encompasses non-deposition phases. For our consideration a more essential factor is the amount of available detritus which possesses potential to be transported and to cover sponge bodies. For example, under low accumulation rates, volume of moving detritus may be appreciable and sufficient to bury the sponges during even one depositional event. Hence, the author introduced the term "input of loose calcareous particles".

Storms, currents and waving caused instability of bioclastic deposit as well as involved suspension in water column. Both factors hindered unconstrained colonisation by suspension-feeding sponges. Influx of loose calcareous particles obturated their pores, precluded correct feeding and forced recolonization. On one hand, the sponge larvae needed substrate stability to fasten onto. On the other hand, ontogenetic growth of sponges required protracted time intervals without detritus input. Such longer periods of non-deposition were common phenomena as inferred above, basing on micritization of bioclasts, micrite envelopes forming and firmground creation (see chapter: "Palaeoenvironmental reconstruction – the Lower Bioclastic Complex"). Surely, it is hard to imagine years-long intervals free of sedimentation especially in storm-dominated environments. Not considering time scale it is more appropriate to state

that input of loose detritus during recolonization did not exceed sponges potential for recovery.

In general, the amount of transported detritus may be diminished in different ways: 1) by stabilization of substrate (early lithification, binders activity); 2) by redeposition of unlithified material to the other parts of basin; 3) by covering with less moveable layer of sediment; 4) by reduction in grain-supplying sources. In case of the Karchowice Beds, prevailing role in drop of detritus volume played prostrate sponges. By binding the substrate they also stabilized moving subaqueous dunes.

#### *Grain size*

Energy of sedimentary environment influenced on size of accumulated grains and transparency of water column (suspension presence). Higher water turbulence rewashed deposits, leaving only coarser grains on the sea-bottom and winnowed fine-grained particles to quiescent part of basin.

Fine material felt out of suspension slowly but unceasingly and obturated sponge inhalational system. Coarse-grained deposit was transported episodically. It obturated sponge ostiae in a small extent, because dimensions of many grains exceeded pores size. Many of sponges deceased not before they became entirely buried by sands.

#### *Interplay of detritus input and grain size*

Apparently, the suspension in water column hindered high-relief bioherms forming. Even thin layers of accumulated suspension forced sponges to form only prostrate colonies (Fig. 19C, E). Since the western proximal part intersected the fair-weather wave base, volume of suspension became considerably diminished due to winnowing to quiescent basin areas. However, another problem revealed: instability of substrate. Henceforth, the subaqueous dunes were migrating across the floor and buried the sponges (Fig. 19D). After many episodes bury-recolonisation, prostrate sponges stabilized the substrate and reduced amount of loose coarse grains. Only in such conditions bioherm growth was possible (Fig. 19F).

Under high values of detritus input (independently on grain size), permanently covered sponges did not keep pace with deposition (Fig. 19A, B). As an example, elevated energy level in face side of bioherms caused that prostrate sponges, inhabiting fore-reef area in optimal conditions so far, became buried under remarkable amount of supplied detritus and did not manage to recolonize the substrate (input of loose calcareous deposit surpassed sponge recovery potential).

### IMPLICATIONS FOR STRATIGRAPHY

Some general conceptions presented in this paper stay in contradiction with the results of earlier workers. I will try to explain the reason of such inconsistency.

The Karchowice Beds name and definition was given by Assmann (1913). It is noteworthy that Assmann (1913, 1944) studied different quarries than me. Many of them were relatively small in size, for instance near Kamień Śląski (Kalkwerk Johannesthal, Kalkwerk von Grafen



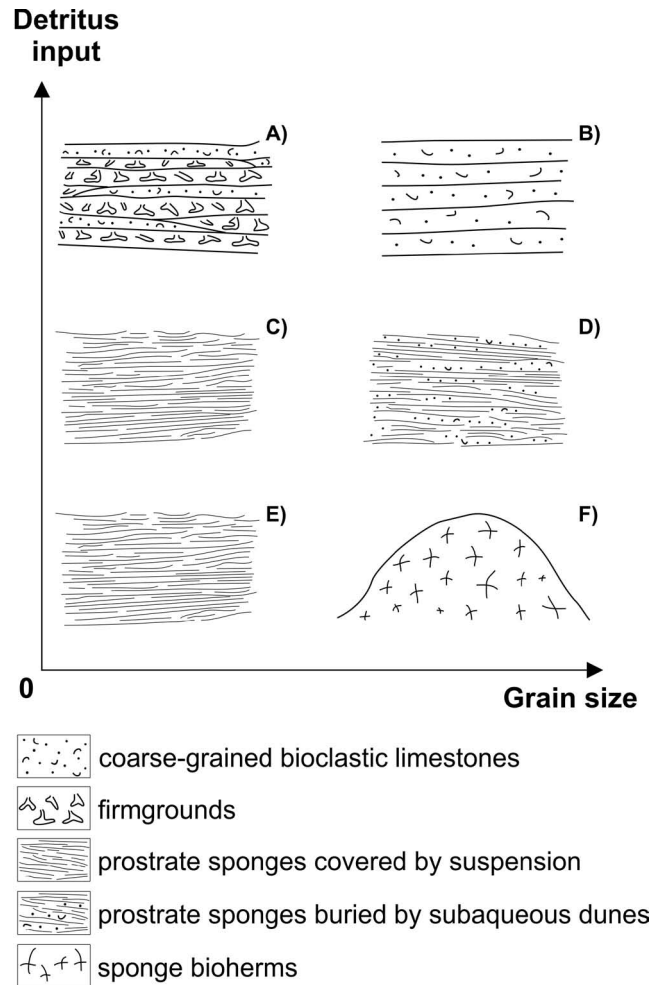
Strachwitz, Kalkwerk von Gebrüder Edlinger). Hence, vertical and horizontal facies changes could not have been properly exposed. For years, the majority of these quarries became abandoned and reclaimed. Moreover, present outcrops of the Karchowice Beds did not exist yet during Assmann's investigations, that is Szymiszów and Strzelce Opolskie. In turn, in Tarnów Opolski were localized only two small quarries (Kalkwerk von Salzbrunn, Kalkwerk der Schlesischen Kalk-Industrie), but they were too shallow to exhibit the Karchowice Beds. Nowadays, both are included into large active quarry.

According to Assmann (1913), the succession of the Karchowice Beds is tripartite with lower and upper cavernous part separated by the so-called *Cidaris transversa* horizon. Generally, it fits quite well to lithostratigraphic scheme presented here, where both Assmann's cavernous units correspond to the Lower and Upper Sponge Complexes separated by the Upper Bioclastic Complex. It is enigmatic, why Assmann did not distinguish "Lower Bioclastic Complex" as the individual subunit, because it possesses distinct lithological features. He might included it into his lower cavernous part or maybe even into the underlying Terebratula Beds.

Assmann (1944) mentioned that the thickness of the Karchowice Beds amounts to 14 m in Strzelce Opolskie site and 14 m in Kamiień Śląski. The latter value is twice lower than given in this paper (about 30 m). Three possibilities of such discrepancy exist: 1) Assmann (1944) made a mistake with correlations among particular small quarries of Kamiień Śląski; 2) the lower part of the Karchowice Beds was not exposed in Kamiień Śląski; 3) he classified upper section of the Karchowice Beds as a part of overlying Diplopore Beds. The first two cases do not require any explanation, so I will focus on the third one. Assmann (1944) distinguished two facies of the Diplopore Beds in the studied area: 1) diplopore facies, occurring in the eastern part of the basin; and 2) crinoid facies, appearing just in Kamiień Śląski site. The crinoid facies, beside numerous crinoids, contains sponge-coral reefs and similar biota assemblage as the Karchowice Beds, except for 44 new species of gastropods. Moreover, Assmann (1944) did not mention any diplopores identified in crinoid facies, what constitutes the most important criterion to define the Diplopore Beds. My recent observations allow to conclude that the Diplopore Beds are built by about 7 m of medium- and thick-bedded oolites, oncolites and diplopore debris. They contain no reefs or bioherms, however decimetre-size coral colonies have been found. Furthermore, paucity of crinoids characterizes these deposits, thus they cannot be called "crinoid facies".

Summing up, in my opinion Assmann (1913, 1944) marked the boundary between the Karchowice and Diplopore Beds too low in the succession. He included the bioherms of the Upper Sponge Complex and peloidal calcarenites, belonging to the Karchowice Beds, into the overlying Diplopore Beds.

The results of Bodzioch (1997) bring another inconsistency with those of mine, despite investigations on the same outcrops. Bodzioch (1997) has not noticed bipartite nature of the succession, where each part consists of bioclastic complex, followed by sponge member. The thickness of



**Fig. 19.** Interdependence between sponge buildup shape, size of transported grains and amount of detritus input. **A, B.** Elevated detritus input (independently on grain size) hindered growing of any sponge buildups; **C, D.** Decreasing detritus input enabled to development of sponge biostromes. Depending on grain size, the biostromes were covered by subaqueous dunes (**D**) or suspension (**C**); **E.** Even small volume of suspension forced sponges to form prostrate colonies; **F.** The bioherms grew solely under conditions of reduced detritus input and lack of suspension. For more comment see the text

sediments was incorrectly measured (9–13 m over the entire Silesia). Available outcrops of the Karchowice Beds do support my conclusions.

## CONCLUSIONS

1. During Pelsonian–Illyrian times, the Upper Silesia was strongly controlled by direct Tethys influences, expressed by open-marine carbonates and fauna assemblage. The Upper Silesia formed a submarine threshold, separating the Tethys Ocean from the Germanic Basin *sensu stricto*.

2. The Upper Silesian basin was divided into some fault-bounded tectonic blocks of diverse subsidence, as indicated by doubled thickness of the sedimentary succession in the western region (about 30 m). Synsedimentary defor-



mation structures prove contemporaneous seismic shocks due to Silesian-Moravian Fault activity. Bathymetric differences between the western and eastern regions and differentiated palaeorelief were partly caused by reconfiguration of these tectonic blocks.

3. The general succession of the Karchowice Beds is bipartite. Each part consists of bioclastic lower member, followed by sponge buildup complex.

4. The western part of the basin (encompassing Góraźdze, Tarnów Opolski and Kamień Śląski sites) represents proximal facies (reefal facies), exemplified by: 1) presence of grain-supported packstones and grainstones with cortoids, oncoids, frequent gastropods and clumps of sponge automicrite in the Lower Bioclastic Complex; 2) more coarse-grained bioclastic intercalations in the Lower Bioclastic Complex; 3) lack of firmgrounds, being totally substituted for coarse-grained bioclastic limestones in the Upper Bioclastic Complex; 4) occurrence of high-relief sponge buildups with scleractinian colonies in the Lower and Upper Sponge Complex; 5) *Girvanella* oncoids, ooids and dolomites.

5. The eastern area (Szymiszów and Strzelce Opolskie sites) represents distal facies (fore-reef), what is expressed by: 1) presence of poorly-washed packstones and wackestones in the Lower Bioclastic Complex; 2) less coarse-grained bioclastic intercalations in the Lower Bioclastic Complex; 3) alternations of firmgrounds and coarse-grained bioclastic limestones in the Upper Bioclastic Complex; 4) lack of large bioherms in both sponge complexes.

6. The fine calcareous particles felt out of suspension and accumulated under storm-wave base mostly during one depositional event (probably after storms). During fair-weather periods, firm substrate was intensively bioturbated by ichnofauna, forming firmgrounds mainly with *Thalassinoides* and *Balanoglossites* isp.

7. Coarse-grained bioclastic limestones were formed by storm, wave and current activity. The storms, recorded in the reefal zone as proximal tempestites, pass laterally into distal tempestites, observed in fore-reefal areas of basin. The tempestites owe creamy and beige colour to good oxic conditions.

8. Layers of cavernous micritic limestones 3–7-cm-thick are interpreted as prostrate sponges. By binding loose calcareous sediment they influenced on depositional processes.

9. The sponge bioherms, up to 8 m in high, played a role of breakwaters and modified water energy. Created low-energy niches were inhabited by delicate-branched corals or dwellers such as crinoids, gastropods, foraminifers, brachiopods and ostracods.

10. Shape of sponge constructions (biostromes, bioherms) depended on: 1) input of loose calcareous particles; and 2) size of supplied grains. Even low amount of suspension forced sponges to form prostrate colonies. The bioherms developed in permanently turbulent waters (wealth of food, lack of suspension) on stabilized substrate (under reduced detritus input).

11. Silification of bioclasts and cherts occurrence is resulted from dissolution of silicious sponge skeletons under alkaline conditions. The cherts appear mainly in fine-

grained bioturbated limestones. Therefore, they are concentrated in the eastern region and form several non-correlated horizons.

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