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A farewell to Świniary sequence of mass-aggregated, spine-coated echinoids *Psammechinus* and their associates (Middle Miocene; Holy Cross Mountains, Central Poland)

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ABSTRACT:

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The Świniary sand-pit (Middle Miocene, Badenian; southern slopes of the Holy Cross Mountains, Central Poland), which has yielded innumerable fossils of various kinds over the last fifty years, is revisited. Most significant there were mass accumulations of a single echinoid species, *Psammechinus dubius* (L. AGASSIZ, 1840), tests of which preserved spine canopies and Aristotle's lanterns in position. Other echinoids represented were rare, e.g. *Spatangus austriacus* LAUBE, 1871, 'Giant *Psammechinus* sp.'*,* *Echinocardium peroni* COTTEAU, 1877, and *Echinocyamus pusillus* (O.F. MÜLLER, 1776). The pit has since been abandoned and recultivated entirely; in view of this an updated review of, and supplement to, previous data on the Świniary biotic assemblages, and their environmental living conditions, is here presented. The mass accumulations of *Psammechinus dubius* are interpreted to have been of storm origin, i.e. mass transportation and burial of live, or freshly dead, specimens. Hinted at is a predatory activity of the starfish *Astropecten forbesi* HELLER, 1858, upon juveniles of *Psammechinus dubius* absent from the storm-related thanatocoenoses. Associated with echinoderms are, amongst other groups, verrucid barnacles *Verruca* sp. and inarticulate brachiopods *Discinisca leopolitana* (FRIEDBERG, 1921) derived from eulittoral habitats, as well as pieces of terrestrial amber swept out of the shore. A general shallowing-up trend in the Świniary sequence is recognised, as indicated by environmental conditions changing from deeper offshore to proximal sublittoral, possibly shallow subtidal.

Key words: Echinoids, *Psammechinus*, Eco-taphonomy, Mass burial, Miocene, Poland.

INTRODUCTION

The exposure of Miocene sands at Świniary on the southern slopes of the Holy Cross Mountains, Central Poland (see Text-fig. 1) is now definitely lost. Since the early 1970s these quartz sands, the Świniary Sands, had widely become famous for their countless fossils of various kinds, in particular diverse echinoderms, the exceptional preservation of which was noted by the senior author (RADWAŃSKI 1970, 1973a). The Świniary exposure was often recommended both for scientific research, collection of fossils by amateurs, and education in palaeobiological and palaeoenvironmental studies (see RADWAŃSKI 1973b, 1974; CHRISTENSEN & *al*. 1973; PRZYBYSZEWSKI 1975; MACHALSKI 1996). Of special interest, and scientific value, were large slabs of

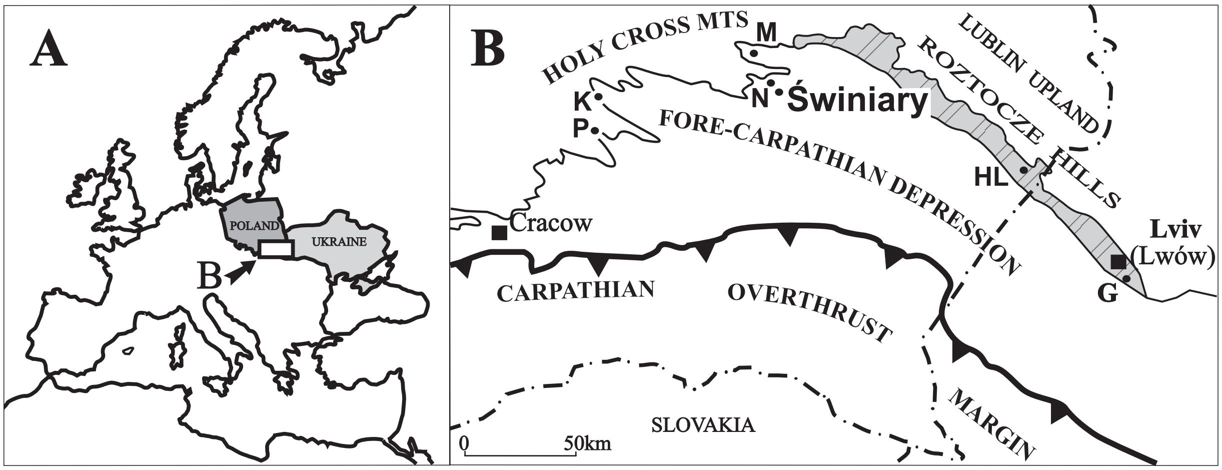

Fig. 1. Map showing location of the former Świniary outcrop, and the extent of Middle Miocene (Badenian) transgressive deposits in the Fore-Carpathian Depression, from Poland to the Ukraine. Indicated are referenced localities: **K** – Korytnica in the Korytnica Bay, **P** – Pińczów, **M** – Malice and Męczennice in the Opatów Bay, **N** – Nawodzice, **HL** – Huta Lubycka, **G** – Gleboviti (=Chlebowice)

cemented sand, replete with randomly distributed specimens of the regular echinoid *Psammechinus dubius* (L. Agassiz, 1840). Such slabs, occasionally available from the deeper parts of the section when these were dragged out from temporary rainwater pools, were often collected during excursions organised by several European universities and museums, e.g. the Institute of Geology, University of Aarhus (Denmark), the Institute of Palaeontology, University of Salzburg (Austria), and Oertijdmuseum, De Groene Poort, in Boxtel (The Netherlands). Both the unique state of preservation and mass accumulations of these echinoids have recently been noted by Nebelsick & Kroh (2002) to be significant in analyses of echinoid palaeoecology and taphonomy.

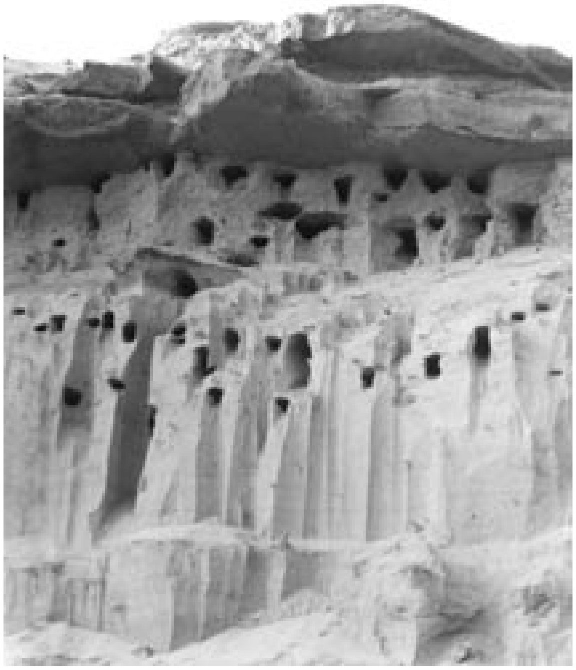

Fig. 2. Świniary sand-pit in the early 1990s: a refuge of Sand Martin colonies whose nesting tunnels sculpture the cliffs of the echinoid-bearing sands (Member C in Text-fig. 3), typically with horizontal lines of holes; overlying is Member D with cementations of the beachrock type (see Pl. 1, Fig. 1)

Unfortunately, from the early 1970s onwards, the state of the sequence exposed and thus access to its fossil contents, have changed significantly from time to time, being dependent of the demand of sand, economic reasons, and technology in the window-pane factory (now, the Pilkington Sandoglass) at Sandomierz, for which the Świniary exposure was the main source of quartz sand. In the mid-1980s, a deeper excavation exposed the lower part of the section with echinoid-bearing cemented sands *in situ*, and loose megacross-bedded sands (Members A and B in Text-fig. 3), which yielded diverse biota previously unknown from the Świniary sequence. This has allowed us to complement the section (see Text-fig. 3; compare Radwański 1970, fig. 2; and 1973a, fig. 6). In the 1990s, the exposure markedly deteriorated, and the sand-pit was abandoned (see Text-fig. 2), its site to be recultivated. Only the upper part of the section was then available for study of physical features of the sand grains in terms of their regional provenance along Miocene seashores (Kenig & Wysocka 1996, Wysocka 1999a).

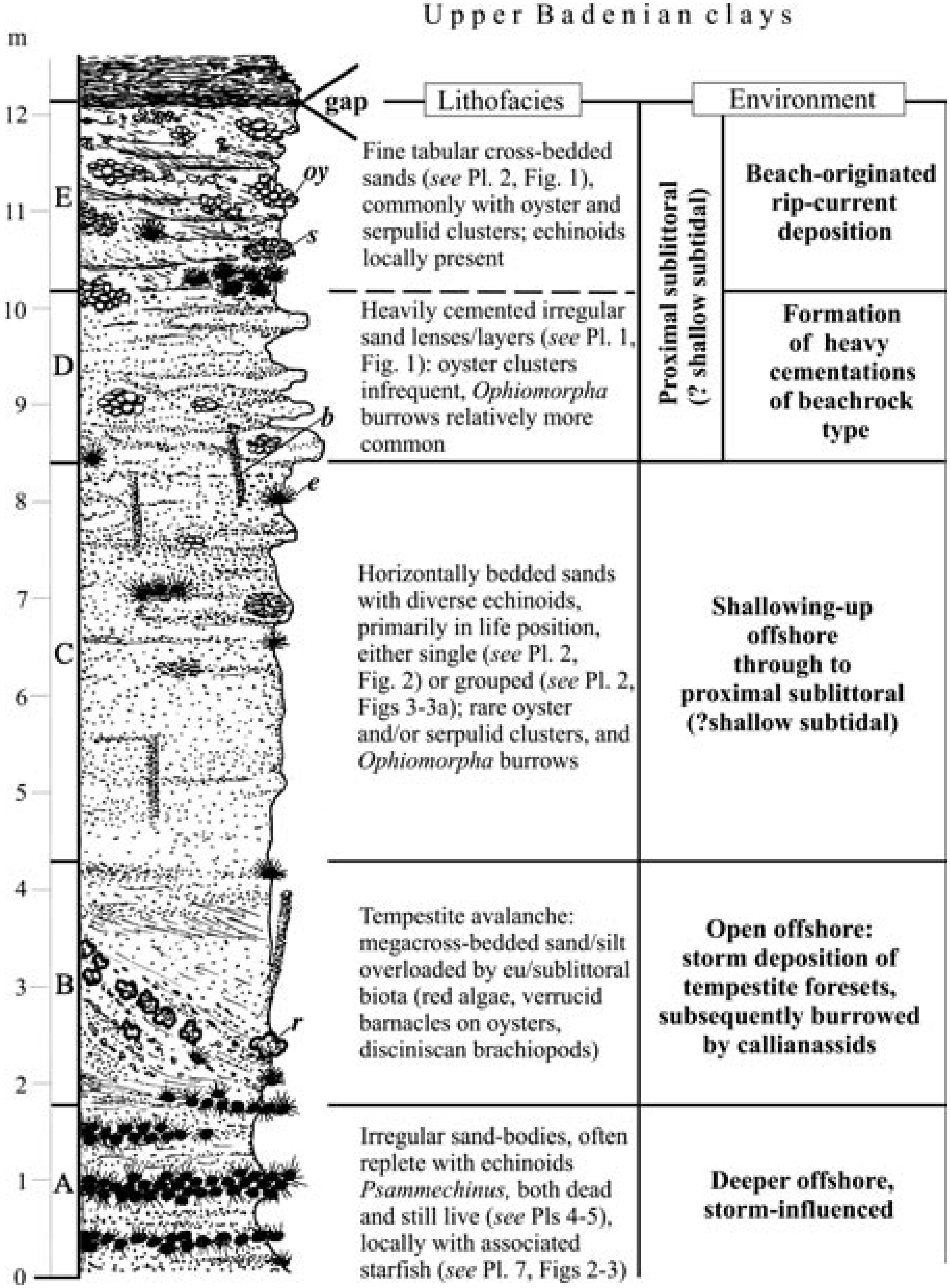

Fig. 3. The Middle Miocene (Badenian) fossiliferous sequence at Świniary and its successive depositional members (A-E). Typical fossils: **e** – echinoids of various kind, **oy** – oyster clusters, **s** – serpulid clusters, **r** – red-algal balls (rhodoliths), **b** – *Ophiomorpha* burrows

PALAEOGEOGRAPHIC SETTING

The Świniary Sands represent a lithosome typical of the southeasterly Middle Miocene (Badenian) seashores of the Holy Cross Mountains, Central Poland. Their occurrence is confined to that region where old-Palaeozoic (Lower to Middle Cambrian, locally Ordovician) fine-grained clastics and shales formed the hinterland, in contrast to the westerly shores constituted of Mesozoic carbonates featuring a Dalmatian type of shore (see RADWAŃSKI 1969, 1970, 1973a). The depositional pathway, the sands underwent from source to shore, still remains unclear and nothing can here be added to diverse interpretations offered previously in the regional literature (reviews in RADWAŃSKI 1973a, WYSOCKA 1999a).

The total thickness of the Świniary Sands, as based on borehole data, is estimated to be 20-22 metres (see PAWŁOWSKI 1965, p. 41; RADWAŃSKI 1973a, p. 394), 12 metres of which were accessible when the sand-pit was most extensively worked in the mid-1980s (see Text-fig. 3).

The history of geological-palaeontological investigations of the Świniary Sands and a description of the depositional environment of the sequence have been published earlier (RADWAŃSKI 1970, pp. 380-382; and 1973a, pp. 394-400).

At that time, the depositional environment of the Świniary Sands (Members C – E, see Text-fig. 3) was thought to be comparable to that of the Gulf of Manaar along the Sri Lankan (Ceylonese) shores at depths ranging between 10 and 18 metres (see HERDMAN 1906; ALLEE & SCHMIDT 1949, pp. 206-207; and discussion in RADWAŃSKI 1973a, p. 396). This interpretation compares well with newer data, discussed below.

STRATIGRAPHY

The Świniary Sands are of Middle Miocene (Badenian) age in the Central Paratethyan stratigraphy, which corresponds to the Upper Langhian – Lower Serravallian interval of the Mediterranean stage division. Its age is thus coeval with that of the Korytnica sequence and other open-marine facies yielding a wealth of biota indicative of the littoral/sublittoral zone. All are developed just at the base of a transgressive cycle widely distributed along the Fore-Carpathian Depression in Poland and the Ukraine (see Text-fig. 1 and RADWAŃSKI 1970, 1973a; BAŁUK & RADWAŃSKI 1977; WYSOCKA 1999a, 2002; RADWAŃSKI & WYSOCKA 2001).

In calcareous nannoplankton terms this part of the Middle Miocene (Badenian) transgressive cycle ranges from within NN5 up to the basal part of NN6 Standard Zone (see MARTINI 1977, BAŁUK & RADWAŃSKI 1977).

DEPOSITIONAL SEQUENCE

The Świniary Sands sequence, intermittently exposed at Świniary sand-pit in between the 1970s and mid-1990s, reveals five distinct members (A-E), as follows (see Text-fig. 3).

Member **A** – Irregular sand layers, poorly calcite cemented, and often replete with spine-coated tests of the echinoid *Psammechinus dubius* (L. AGASSIZ, 1840). Such monospecific mass accumulations are also irregular in distribution, either appearing in the top parts of layers (see Pl. 3, Figs 1-2), or forming their own streaks and lenses. In some thinner sandy layers, echinoid tests accumulated preferentially at the bottom and the top parts of a particular bed (see Text-fig. 5 and Pls 4-5), which is interpreted below. Associated with echinoids is the starfish *Astropecten forbesi* HELLER, 1858, whose skeletons remain not disarticulated (see Pl. 7, Figs 2-3). All cementations appear stronger near, and around, echinoderms, which suggests that these were the centres of calcium-carbonate precipitation.

Member **B** – A peculiar set of megacross-bedded sand/silt (almost 2 metres thick), overloaded with red-algal balls (rhodoliths), small clusters of oysters *Neopycnodonte leopolitana* (NIEDŹWIEDZKI, 1909), commonly overgrown by verrucid barnacles *Verruca* sp., and entrapping minute valves of inarticulate brachiopods *Discinisca leopolitana* (FRIEDBERG, 1921) which may also occur loose in the sand (see Pl. 8, Figs 1-4). Sporadically, smaller or larger pieces of amber were found dispersed throughout the sediment (see Pl. 10, Fig. 1). Rare burrows *Ophiomorpha nodosa* LUNDGREN, 1894, are present in the upper part of this unit.

Member **C** – Horizontally bedded sands with thin, irregular or discontinuous clay/silt interbeddings (see Pl. 2, Fig. 2 and Pl. 9, Fig. 1). Echinoids, primarily *Psammechinus dubius*, occur either singly, usually in life position, with spine canopy and Aristotle's lantern preserved (see Pl. 2, Fig. 2), or forming larger groups of so-preserved specimens (see Pl. 2, Figs 3-3a). Other echinoids (*Schizaster*, *Scutella*) are very rare, represented by fragmentary tests. All echinoid tests in this unit are diagenetically altered, and most of them would pulverise partly (see Pl. 2, Fig. 2), or completely at the weakest blow.

Of other fossils, typical are small clusters of oysters *Neopycnodonte leopolitana*, and of tubular polychaetes *Serpula subpacta* ROVERETO, 1903. Burrows *Ophiomorpha nodosa* are rare, but well developed (almost 1 metre in length/depth), and preserved in the lower part of the unit (see Pl. 9, Fig. 1), whereas in the upper part they become commoner, but usually are fragmentary with their higher/upper portion truncated.

Member **D** – Heavily cemented, irregular sand lenses or layers, intercalated with loose sand (see Pl. 1, Fig. 1) containing infrequent clusters of *Neopycnodonte leopolitana* and rare echinoids, mostly *Psammechinus dubius*, and single specimens of *Echinocardium peroni* COTTEAU, 1877 (see Text-fig. 4), *Spatangus austriacus* LAUBE, 1871 (see Pl. 6, Figs 1a-1b), 'Giant *Psammechinus* sp.' (see Pl. 6, Figs 2a-2b) and *Echinocyamus pusillus* (O.F. MÜLLER, 1776). Burrows *Ophiomorpha nodosa* are relatively commoner than in the preceding unit, but all specimens are fragmentary, more or less deeply truncated by synsedimentary erosion. Some of the cemented sand bodies are sculptured at their top by symmetric oscillation ripples of low amplitude, but of reasonable wave-length (15-20 cm, see RADWAŃSKI 1973a, pl. 3, fig. 2).

All cementations in this unit are calcitic, and disintegrate completely when treated with acid. In the residue, apart from quartz, small aggregates of barite appear. Micro-aggregates of barite are also revealed by SEM analysis (see below and Text-fig. 6.3 and 6.3a). Moreover, in some cavities and/or diagenetic cracks of cemented sand bodies, aggregations of native sulphur may also be found (RADWAŃSKI 1973a, p. 394). In microscopic view, visible in a sparry calcite cement is abundant hash of molluscan shells, echinoderm debris, bryozoan colonies, polychaete tubes, foraminiferal tests, and coralline algae, which all indicate the original composition of a more or less bioclastic sand. This, combined with the presence of ripples over the top surface of some cementations, indicates the synsedimentary origin of the sand bodies discussed. All these cementations are suggested to be comparable to those forming beachrocks of present-day carbonate seashores.

Member **E** – Finely tabular cross-bedded sands (see Pl. 2, Fig. 1) with abundant clusters of oysters *Neopycnodonte leopolitana* (the largest clusters reach half a metre across), as well as of indeterminate bryozoans, and of polychaetes *Serpula subpacta*. Of echinoids, only small-sized *Parasalenia* sp. occur entrapped in some oyster clusters. Small-sized invertebrates are also represented by numerous scallops, bryozoans, foraminifers, and rare uncemented polychaetes *Ditrupa*. On the other hand, teeth of large-sized sharks – Mako (*Isurus hastalis* – see Pl. 8, Fig. 5) and Sand Shark (*Odontaspis*), represent the vertebrates. Diagenetically formed 'barite roses' are common (see Pl. 10, Fig. 2), to accumulate locally in the scree.

Overlying the studied sequence of Members A – E is, with a stratigraphical gap, an Upper Badenian clay sequence (see Pl. 1, Fig. 2) that belongs to a separate sedimentary cycle, not discussed in the present paper.

ECHINODERMS OF THE ŚWINIARY SANDS

Echinoderm assemblages in the Świniary Sands are dominated by one echinoid species, *Psammechinus dubius* (L. AGASSIZ, 1840), and contain minor amounts of other echinoids (both regular and irregular), starfish and ophiuroids. All are preserved as complete skeletons, making them into the most spectacular fossils of the former exposure (see Pls 2-7). Such a state of preservation in echinoids has recently been widely discussed (SMITH 1984, pp. 15-21; RADWAŃSKA 1999, pp. 299 and 352-355; RADWAŃSKI & WYSOCKA 2001, pp. 301-302; SCHMID & *al*. 2001; NEBELSICK & KROH 2002), but it is rarely mentioned for starfish (BAŁUK & RADWAŃSKI 1968, pp. 455 and 468; RADWAŃSKI 1970, p. 378; MEYER 1984; BLAKE & ZINSMEISTER 1988; NOSOWSKA 1997, p. 227) and ophiuroids (MEYER 1984; ISHIDA & FUJITA 2001; RADWAŃSKI 2002, p. 400: earlier references therein). From these data, it appears that there is a general consensus that this is due to very rapid burial of either live or freshly dead specimens captured by a rather bulky sediment.

Diagenetic processes of pressure-solution have involved a heavy armouring of all echinoderm skeletons with sand grains. Such armouring is largely advanced in echinoid tests and their spines (see Pl. 3, Figs 1-2), to cause damage to their skeletons. This armouring damage is comparable to that of other invertebrates destroyed by so-called pitting processes (see RADWAŃSKI 1965a, pp. 187 and 205). Identical armour has also been noted in the majority of tests and spine canopies in the echinoid *Echinocardium* from Chlebowice in the Ukraine (RADWAŃSKI & WYSOCKA 2001, p. 302).

Echinoids

Dominant in the Świniary Sands is the species *Psammechinus dubius* (L. AGASSIZ, 1840), commonly mass-accumulated in Member A, and less frequent in Member C in which they occur either singly, or in groups locally (see Pl. 2, Figs 2-3, and Pls 3-5). Other species/genera are rare (see Pl. 6), to appear in Member A, or C and D. All were first recorded by RADWAŃSKI (1970, 1973a) and PRZYBYSZEWSKI (1975), and were subsequently described by MĄCZYŃSKA (1988). Further revisions (PHILIPPE 1998, p. 231; RADWAŃSKI & WYSOCKA 2001, pp. 306-307) and new finds are here briefly commented upon.

Psammechinus dubius (L. AGASSIZ, 1840)

This species, common in the Miocene of Tethys/Paratethys settings (see LAMBERT 1910, p. 35; VADÁSZ 1915, p. 32), was first identified at Świniary by PRZYBYSZEWSKI (1975, pp. 63-66), who also noted its frequency to be between 2 to 3,000 specimens in some layers exposed at that time (PRZYBYSZEWSKI 1975, p. 63 and pl. 4, fig. 4). In earlier reports (RADWAŃSKI 1970, 1973a,b), the species was referred to as *Psammechinus* sp.

Spine canopies, not yet reported for *Psammechinus dubius* (L. AGASSIZ, 1840), are typified by relatively long spines (see Pl. 2, Fig. 3a and Pl. 3, Figs 1-2) different from those of other species in the genus (see e.g. STRENGER 1963, KIER 1972).

In addition to Świniary (see also MĄCZYŃSKA 1988, 1991), the species was also reported by MĄCZYŃSKA (1979), albeit rarely (3 specimens), from Nawodzice and (3 other specimens) from Huta Różaniecka, 20 km west of Huta Lubycka (locality HL in Text-fig. 1) in the most easterly part of Middle Miocene (Badenian) sandy facies in Poland, as well as by SZÖRÉNYI (1953) from coeval deposits in the Ukraine. Referred to this species were also several dwarfish (? juvenile) specimens from Korytnica (MĄCZYŃSKA 1987) and Pińczów (MĄCZYŃSKA 1993).

Spatangus austriacus LAUBE, 1871

This species, established by LAUBE (1871) for rare (three) specimens from the Miocene of the Vienna Basin, is relatively common in Member A, where it occurs singly, usually outside accumulations of the preceding species. Most specimens have a very fragile test that easily crushes when picked up, to expose an calcite-cemented internal cast. The best preserved specimens have partial spine canopies, usually at their oral side (see Pl. 6, Figs 1a-1b).

The specimens collected are of the same size (80-85 mm in length) as those reported by LAUBE (1871) from the Vienna Basin, and these by MĄCZYŃSKA (1979) from Huta Lubycka (locality HL in Text-fig. 1).

Similar, if not identical, specimens from the Pannonian Basin were referred to by VADÁSZ (1915) as "*Prospatangus hungaricus* VADÁSZ, 1915", the separate status of which was also accepted for some specimens from the Ukraine (SZÖRÉNYI 1953), and from Huta Lubycka in Poland (MĄCZYŃSKA 1979, 1991).

In the Świniary Sands, the species was first reported by PRZYBYSZEWSKI (1975, pp. 68-69), and subsequently by MĄCZYŃSKA (1988).

'Giant *Psammechinus* sp.'

This category is used for two specimens collected from the Świniary Sands, the first of which was referred to as "*Schizechinus chateleti* LAMBERT, 1910" by MĄCZYŃSKA (1988; accepted by PHILIPPE 1998, p. 60), a name adopted subsequently for another specimen, by MACHALSKI (1996, a photo on p. 23). The latter specimen has kindly been received on loan from Dr. M. MACHALSKI (private collection) to be re-illustrated herein (Pl. 6, Figs 2a-2b) and compared with the holotype of the species established by LAMBERT (1910, pp. 43-44, pl. 3, figs 1-3) upon a single Miocene specimen from the Rhone Basin. The provenance and age of that specimen are unclear (see LAMBERT 1910, p. 44; PHILIPPE 1998, p. 61). On the other way, the distinction of this species from morphologically almost identical *Schizechinus dux* (LAUBE, 1871) and *S. hungaricus* (LAUBE, 1871), from the Vienna and Pannonian Basin, is very arbitrary, as judged from the literature data (see LAUBE 1871; LAMBERT 1910, p. 44; VADÁSZ 1915, pp. 32-34; SZÖRÉNYI 1953, pp. 59-60; MĄCZYŃSKA 1979, 1988; SCHMID & *al.* 2001). Whatever the outcome, the two specimens from Świniary cannot be accommodated in any species of *Schizechinus*, and their taxonomic assignment remains controversial. Their morphology is close to that of *Psammechinus*, except for size (attaining 78 mm in ambital diameter) almost twice exceeding that of any *Psammechinus* species known to date (see LAMBERT 1910, pp. 33-41; PHILIPPE 1998, pp. 64-77). Tentatively, the two discussed specimens from the Świniary Sands are herein classified, in inverted commas, as 'Giant *Psammechinus* sp.', to suggest their possible being of a new species, even of another genus.

Echinocardium peroni COTTEAU, 1877

This species, established by COTTEAU (1877; see also 1873, p. 242) for Miocene material from Corsica seems to have been distributed in the Miocene of Europe much more widely than previously thought. As revised by PHILIPPE (1998, pp. 230-231) and RADWAŃSKI & WYSOCKA (2001, pp. 306-307), to this species belong both a test reported by MĄCZYŃSKA (1988, pl. 5, figs 1a-1e; and 1991, pl. 1, figs 9a-9d) from Świniary, as well as two specimens reported by her earlier (MĄCZYŃSKA 1979, pl. 9, figs 2 and 4) from Huta Lubycka and Monastyrz nearby.

The best preserved specimen from Member D is illustrated herein (Text-fig. 4), to compare with the holotype of the species (see COTTEAU 1877, pp. 323-325, pl. 14, figs 5-9).

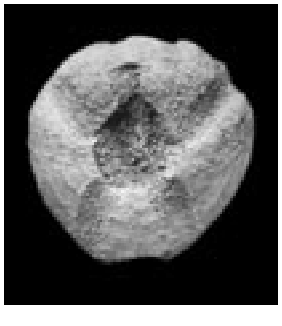

Fig. 4. *Echinocardium peroni* COTTEAU, 1877, from Member D of the Świniary Sands; nat. size

Other taxa

Fragmentary and poorly preserved specimens of *Schizaster* and *Scutella* are known from Member C, and a few specimens of *Echinocyamus pusillus* (O.F. MÜLLER, 1776) were collected from Member D (compare RADWAŃSKI 1973a, p. 395; PRZYBYSZEWSKI 1975, pp. 60-61).

Ophiuroids

A unique specimen, reported on by PRZYBYSZEWSKI (1975, pl. 10, fig. 4; re-illustrated herein as Pl. 7, Fig. 1), is an almost complete skeleton adhering to a *Spatangus* test from Member D. Its assignment, with a question mark, to the genus *Amphiophiura* MATSUMOTO, 1915 (see SPENCER & WRIGHT 1966, p. *U*95), as favoured by PRZYBYSZEWSKI (1975, pp. 61-62), is herein accepted. Although indeterminate taxonomically, this specimen is the first ophiuroid to be recorded from Miocene sequences of Poland. Previous reports concerned isolated vertebrae from the clay sequence at Wieliczka (SZAJNOCHA 1900) and from the Korytnica Clays (BAŁUK & RADWAŃSKI 1977, p. 99). In other Paratethys regions, where isolated vertebrae are locally common, complete skeletons are always rare finds, e.g. in the Vienna Basin (see KÜPPER 1954, BINDER & STEININGER 1967, MEYER 2002).

Starfish

Starfish are represented by near-complete skeletons (see Pl. 7, Figs 2-3), associated with echinoid aggregations in Member A. The structure of the skeletons and their size (12-14 cm with arms extended) allow these to be assigned to *Astropecten forbesi* HELLER, 1858, the species also known from the Miocene sequences in the Vienna Basin (HELLER 1858, pl. 1, figs 1-3) and in the Ukraine (KUDRIN 1957, pl. 3, figs 1-2).

The species recognised is the second astropectinid recorded from the sandy facies of the Holy Cross shores. The smaller-sized *Astropecten navodicensis* NOSOWSKA, 1997, occurs as complete skeletons, frequently with arms appressed tightly in a tulip-flower form at Nawodzice (locality N in Text-fig.1; see BAŁUK & RADWAŃSKI 1968, fig. 3.10-3.10a; RADWAŃSKI 1970, p. 383, fig. 3j; NOSOWSKA 1997), to make its common fame (see BLAKE & ZINSMEISTER 1988, p. 492; JAGT 1991, p. 39). At Świniary, one of the astropectinid specimens reported by PRZYBYSZEWSKI (1975, pl. 10, figs 2a-2b) belongs to this taxon. Recently, fragmentary skeletons of this species have also been recognised at Gleboviti (=Chlebowice, locality G in Text-fig. 1) in the Ukraine (RADWAŃSKI & WYSOCKA 2001, pp. 301 and 312).

Eco-taphonomy

The mode of life of modern relatives of the echinoderms recognised varies from intertidal, usually cryptic, to offshore habitats of some tens of metres (see NICHOLS 1959, STRENGER 1963, KIER 1972, ERNST & *al*. 1973).

The commonest species, *Psammechinus dubius* (L. AGASSIZ, 1840), which significantly dominates over other echinoids at Świniary, formed dense populations of thousands of specimens, not yet recorded for fossil representatives of the genus *Psammechinus* L. AGASSIZ & DESOR, 1846. Similarly dense fossil populations have hitherto been reported for the genus *Echinocardium* GRAY, 1825, solely (see KIER 1972, KOTCHETOFF & *al*. 1975, RADWAŃSKI & WYSOCKA 2001).

As far as the mode of life of fossil representatives of the genus *Psammechinus* is concerned, the only attempt was offered by KIER (1972), who interpreted a short-spined *Psammechinus* species from the Miocene Yorktown Formation of the United States to have lived either cryptically in the shorezone, or freely on a sandy bottom where they covered with sand. Such coverage, to form a kind of debris thatch, is typical of some extant genera (see SMITH 1984, p. 96), and it has recently been suggested by RADWAŃSKA (1999, p. 346) for Late Jurassic genera, such as *Trochotiara* and *Phymosoma*.

The noted feature of relatively long spines in *Psammechinus dubius* studied (see Pl. 2, Figs 3-3a; Pl. 3, Figs 1-2) is interpreted as of defensive nature, to deter possible predators (see SMITH 1984, p. 97). In these echinoids, such strategy has certainly evolved instead of coverage which requires (see SMITH 1984, p. 96) short spines to camouflage. Moreover, their herd mode of life (see SMITH 1984, p. 97) could effectively ensure against possible predators. The dense populations of *Psammechinus dubius* studied spread widely over the sea floor, and their members had a vagile mode of life, possibly amidst algal fronds or in seagrass, as is typical (see STRENGER 1963) for the present-day *Psammechinus microtuberculatus* (BLAINVILLE), which is common along the Adriatic shores.

Burrowing, more or less deeply, were *Spatangus austriacus* LAUBE, 1871, and *Echinocardium peroni* COTTEAU, 1877, which may be inferred from data on their congeners, both modern and fossil (see NICHOLS 1959, KIER 1972, ERNST & *al.* 1973, SMITH 1984, RADWAŃSKI & WYSOCKA 2001).

Present-day species of the starfish genus *Astropecten*, as concisely reviewed by CHRISTENSEN (1970, p. 3), lie buried in the sediment when resting, and come out onto the bottom surface when searching for prey.

Although the echinoderms of the Świniary Sands studied represent the remains of original communities that survived taphonomic loss, some biological relationships between echinoderms themselves may be postulated.

The starfish *Astropecten forbesi* HELLER, 1858, preserved in *Psammechinus*-bearing beds, was probably a predatory species in the living echinoid community. Its function is inferred to have been identical with that of modern astropectinids whose diet consists, to some extent, of small-sized echinoids (see CHRISTENSEN 1970, pp. 10-34). Similarly, such predatory activity of starfish upon ophiuroids is also evident (see CHRISTENSEN 1970, pp. 26-27; ARONSON & BLAKE 2001, p. 34; fig. 3D). These data allow the assumption that the association of astropectinids and ophiuroids with echinoids in the Świniary Sands (Member A and D) resulted from their co-occurrence in some communities, subsequently destructed and rapidly buried in a sand mass. Furthermore, the general lack of juvenile *Psammechinus* in the assemblages studied (excepted are some from Member D: see Pl. 6, Figs 2a-2b) may supposedly be explained by the presence of astropectinids preying upon them (!).

The echinoderm communities, densely populated by the echinoid species *Psammechinus dubius* (L. AGASSIZ,

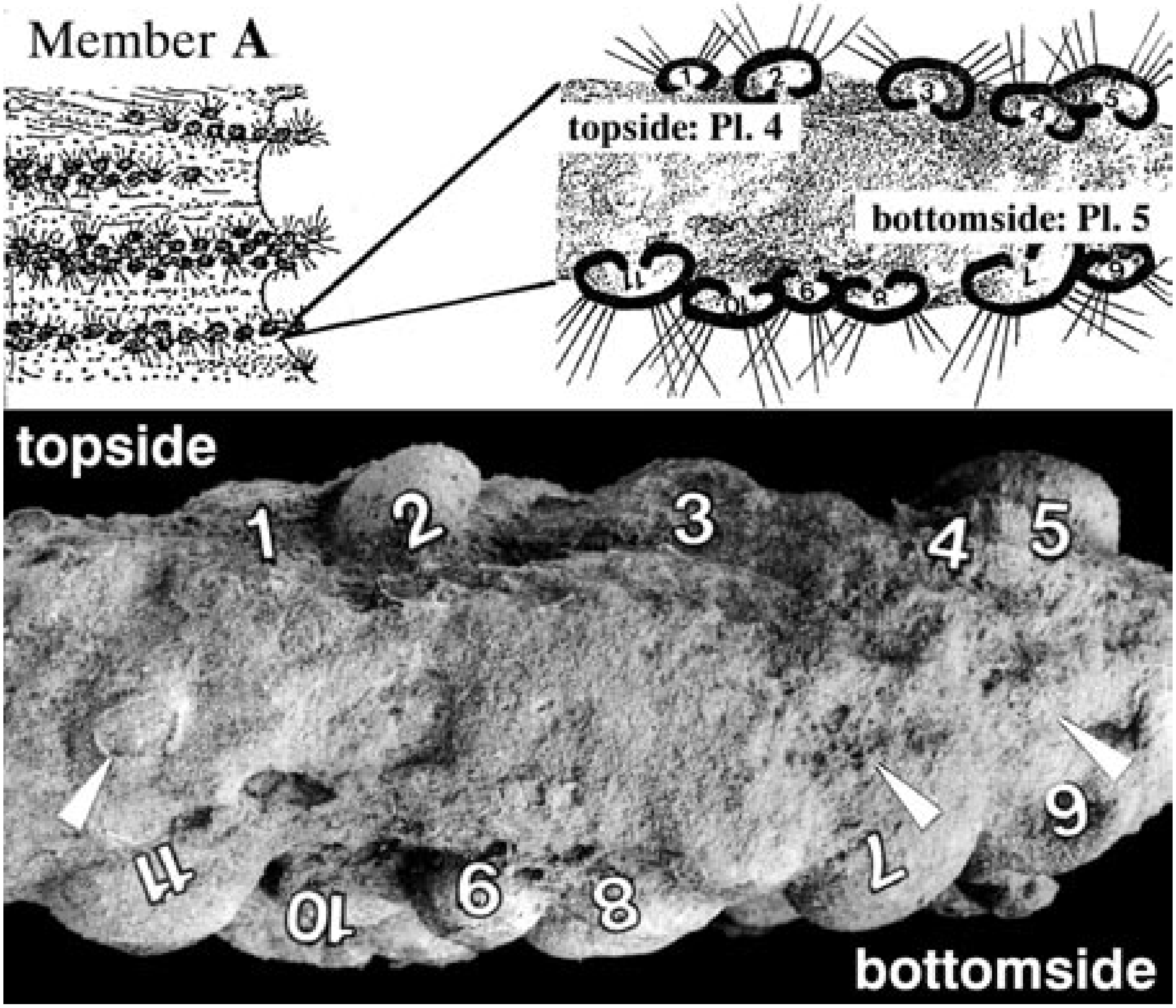

Fig. 5. Lateral view (photo in actual size; and a sketch, above) of the *Psammechinus*-bearing slab of cemented sand from Member *A*, to show the position of echinoids at its topside (see Pl. 4) and bottomside (see Pl. 5)

Interpretation: The echinoids *Psammechinus dubius* (L. AGASSIZ, 1840) caught up violently by storms from their habitat(s), and stirred up with a bulk of sand, were deposited within a sand body. The echinoids which survived the stress (specimens numbered *1* to *5*), were able to escape from the sandy mass, to relocate onto the topside of sand (see Pl. 4). The torpid and/or lifeless ones (specimens numbered *6* to *11*) were overturned and accumulated under a sandy mass, now exposed in upside-down position over the bottomside of the sand body (see Pl. 5); moreover, some overturned specimens are also entombed in the sand interior (arrowed)

1840) in a herd-like fashion (cf. NÉRAUDEAU 1991), became an easy "tidbit" when stormy stirring-up acted to catch and transport them violently out of their habitats. Mass occurrence of the echinoids thus led to mass transport and, finely, to mass burial, regardless of their being alive, or freshly dead from eventful stress. In some cases, as interpreted herein (Text-fig. 5), some of the specimens could survive that stress, others not. The mass-mortality beds ("Fossillagerstätten") of the Świniary Sands are considered consequently to be typical thanatocoenoses, in which a lack of juveniles was of primary origin, resulting from predation by associated starfish.

Storm agitation leading to mass burial of fossil echinoderms is commonly postulated (see reviews by ASLIN 1968, KIER 1972, SMITH 1984, MEYER 1984, RADWAŃSKA 1999, RADWAŃSKI & WYSOCKA 2001, NEUMANN 2001, NEBELSICK & KROH 2002, RADWAŃSKI 2002) and regarded to correspond with present-day mass mortality cases (see e.g. SMITH 1984, LAWRENCE 1996, NEUMANN 2001, NEBELSICK & KROH 2002). Physical events other than storms, to have caused mass accumulation, are rarely demonstrated in present-day communities (see HIGGINS 1974, pp. 469-470; SMITH 1984), or interpreted for fossil assemblages (SCHMID & *al*. 2001).

Within the sandy facies of the Middle Miocene (Badenian) shores in the Ukraine and Poland (see Text-fig. 1), this is the second case of mass echinoid accumulation. Yet, it is the first of regular echinoids; the other instance involving *Echinocardium leopolitanum* described in the former report (RADWAŃSKI & WYSOCKA 2001). It should be noted that apart from the two locations of mass-accumulated *Psammechinus dubius* (L. AGASSIZ, 1840) and *Echinocardium leopolitanum* RADWAŃSKI & WYSOCKA, 2001, neither of these species nor their congeners are common in other locations, being represented there at most by single specimens (see SZÖRÉNYI 1953; MĄCZYŃSKA 1979, 1987, 1988, 1991, 1993; RADWAŃSKI & WYSOCKA 2001).

ASSOCIATED BIOTA

Associated to those echinoid accumulations in the Świniary Sands are diverse biota, either scattered singly throughout the sequence, or forming various monospecific clusters. In both cases, they often tend to be confined within the limits of some members of the sequence (see Text-fig. 3). The systematic groups recognised are here briefly reviewed, to record the presence of newly collected forms, and to supplement previous data formerly summarised (RADWAŃSKI 1973a, pp. 394-395). All of the body fossils reviewed have calcitic or organophosphatic skeletal remains, whereas aragonitic forms were completely lost during diagenetic processes. Moreover, some trace fossils, both borings and burrows, are reported herein.

Red algae

The red alga *Lithothamnion* sp., whose colonies form more or less spherical balls (rhodoliths) of various size (up to 6-7 cm across, see Pl. 8, Fig. 4), are common or even mass-accumulated along the scrolls of megacross-bedded sands in Member B. Their occurrence mode is thus similar to that in cross-bedded sands at Garbów Nowy in the Opatów Bay (see RADWAŃSKI 1973a, fig. 4) or at Chlebowice in the Ukraine (see RADWAŃSKI & WYSOCKA 2001, p. 298 and fig. 5b).

Green algae

The occurrence of the green alga *Neomeris courtyi* MORELLET, 1913, of the order Dasycladales PASCHER, 1931, was reported from the Świniary sequence (probably, from Member *E*, then exposed) by MAŁECKI (1970, p. 171; see also GÉNOT 1987, p. 2/23), who interpreted it, however, to be indicative of oligohaline waters of shore embayments or lagoons (MAŁECKI 1970, pp. 168 and 173).

Tube-dwelling polychaetes

Tube-dwelling polychaetes are common components of Member C through E, in which they form monospecific clusters of the species *Serpula subpacta* ROVERETO, 1903. Such clusters of various size (attaining over 10 cm across, see RADWAŃSKI 1973a, pl. 8, figs 1-2) are particularly significant in Member E, where they are allochthonous, having been deposited in cross-bedded sands (see Pl. 2, Fig. 1). In former reports, this serpulid was referred to as "*Serpula gregalis* EICHWALD", a species which has different tube morphology and taxonomic assignment (see SCHMIDT 1955, pp. 47 and 64; RADWAŃSKI 1973a, p. 395). Rare in Member E is *Ditrupa cornea* (LINNAEUS, 1767), a free-living species, in uncemented tubes, very common at other localities along the Holy Cross shores (e.g. Korytnica, Pińczów; see RADWAŃSKA 1994, p. 63). The taxonomy of the species has recently been discussed (see RADWAŃSKA 1994, p. 62) since this Linnean species was suggested by TEN HOVE & SMITH (1990, p. 101) to be identical to the extant species *Ditrupa arietina* (O.F. MÜLLER, 1776).

Bryozoans

Indeterminate bryozoans, of a very fragile, bushy morphology of small colonies, forming irregular clusters, are common locally in cross-bedded sands of Member E (see

Pl. 2, Fig. 1). An armour of colonies by sand grains greatly hides their morphology and prevents any taxonomic assignment.

Disciniscan brachiopods

Brachiopods collected from the Świniary sequence are only the inarticulates with an organophosphatic shell. They are represented by the species *Discinisca leopolitana* (FRIEDBERG, 1921), dorsal valves of which are common in megacross-bedded sands of Member B. These minute valves, usually 4-5 mm, the largest attaining 8 mm anterio-posteriorly, are often entrapped in oyster shells, or their fragmentary clusters (see Pl. 8, Fig. 3), but some may occur loose in the sand as well. In oyster clusters, they also appear in Member E.

The species, first noted by ŁOMNICKI in 1897, and formally established by FRIEDBERG (1921) upon specimens from the Lwów area (=Lviv, see Text-fig. 1), has long been regarded as endemic to this region, and confined to shallow-marine sand facies (see FRIEDBERG 1921, pp. 6-7; RADWAŃSKA & RADWAŃSKI 1984, p. 260). Recently, it has also been reported from the St. Margarethen marls (Badenian) of the Eisenstadt-Sopron Basin in Austria, by SCHMID & *al*. (2001, pp. 16-17).

Verrucid barnacles

Verrucid barnacles occur exclusively as epibionts of oyster shells dispersed singly, or as fragmentary clusters, in megacross-bedded sands of Member B. The state of preservation of complete shells (all valves of the crown, and opercular plates in position, see Pl. 8, Figs 1-2) and of the etchings they produce, are identical to those from the littoral rubble facies of the Korytnica Bay (see BAŁUK & RADWAŃSKI 1977; RADWAŃSKI 1977, pl. 8c) and sublittoral sands at Nawodzice (see BAŁUK & RADWAŃSKI 1968; RADWAŃSKI 1977, pl. 8a-b; localities K and N in Text-fig. 1). As with the Świniary material, it should be classed as a separate species, close/ancestral to the extant *Verruca stroemia* (O.F. MÜLLER, 1776).

As far as the authors know, such preservation state of verrucid barnacles is exceptional in the Neogene of the Tethys/Paratethys areas. Apart from Poland, it has only been reported from the Pliocene of Sicily by SEGUENZA (1874, pl. 4, figs 1-2 and pl. 5, fig. 1).

Callianassid decapods

Assigned to the activity of callianassid decapods are burrows *Ophiomorpha nodosa* LUNDGREN, 1894, occurring throughout the Świniary sequence from Member *B* to the lower part of Member D. In the latter, they are more frequent than in the preceding members, but are usually truncated more or less deeply by synsedimentary erosion. The largest burrows, attaining over one metre in length/depth, appear in the lower part of Member C, where they often sculpted out of the sand cliffs by wind (see Pl. 9, Fig. 1).

Significant is the recovery of a well-preserved callianassid chela, entrapped in an oyster cluster from Member D. This skeletal fragment (see Pl. 9, Fig. 2) is assigned to the species *Callianassa pseudorakosensis* LÖRENTHEY & BEURLEN, 1929, one of the common callianassids reported from Miocene sequences of the Pannonian Basin in Hungary (see LÖRENTHEY & BEURLEN 1929, pp. 67-69 and pl. 2, figs 16-18; MÜLLER 1984, p. 52).

From the stated co-occurrence of callianassid skeletal remains and burrows, the latter are consequently thought to have been produced by this callianassid species to which the skeletal parts belong, that is *Callianassa pseudorakosensis* LÖRENTHEY & BEURLEN, 1929.

Non-ostreid bivalves

Briefly discussed here are small, thin-shelled, non-ostreid bivalves; the number of taxa is circa twenty as listed in previous reports (referenced in: RADWAŃSKI 1973a, p. 395). These are represented largely by multiribbed scallops of a very confused taxonomy (see KRACH 1967, PRZYBYSZEWSKI 1975). Isolated scallop valves are especially common in some layers of cross-bedded sands in Member *E*. None of the non-ostreid bivalves recognised supply detailed environmental data.

Oysters

Oysters are common components in almost the whole section, from Member B up to Member E, to form exclusively monospecific clusters of the species *Neopycnodonte leopolitana* (NIEDŹWIEDZKI, 1909). In former reports, this oyster was referred to as “*Ostrea cochlear* POLI 1795”, an extant species evidently congeneric, but distinct specifically (see NIEDŹWIEDZKI 1909; RADWAŃSKI 1973a, p. 394; PRZYBYSZEWSKI 1975; FRENEIX 1975).

In Member B, oyster clusters are fragmentary, representing pieces of larger ones. In Members C-D, they occur sporadically, to attain the largest size and diversity in Member E where they become abundant. Some of these bear shells oriented radially, having grown freely (unattached) when overturned and rolled by wave action (see Pl. 8, Fig. 6; and RADWAŃSKI 1973a, pl. 5, fig. 2). Others were growing upwards (see RADWAŃSKI 1973a, pl. 5, fig. 1), having been either preserved in life position, with shells oriented upwards, or overturned. Those preserved in their original position attain the largest size of a half-metre across (see description of Member E).

The species *Neopycnodonte leopolitana*, established by NIEDŹWIEDZKI (1909) for specimens from the Lwów area (=Lviv, see Text-fig. 1), is typical of the sandy facies extending along the Miocene shore from Lwów in the Ukraine, through the Roztocze Hills, as far as the Świniary Sands in the west (see Text-fig. 1).

Rock-borers

The rock-boring activity of invertebrates is recognised solely in oyster shells, particularly those from Member *E*. Borings of the sponge, *Cliona celata* GRANT, 1826, and of the polychaete, *Polydora ciliata* (JOHNSTON, 1838), are here confined to some oyster clusters, but are absent from others. The borings are identical to those reported from the rocky coast, as well as from diverse molluscan shells of all circumlittoral facies along the Holy Cross shores (see RADWAŃSKI 1969, 1970, 1977; BAŁUK & RADWAŃSKI 1977).

Sharks

Sharks are represented by isolated teeth which occur rarely in cross-bedded sands of Member E. Most of the specimens are preserved as crowns devoid of roots, and only some are complete. These belong to large-sized forms – the Mako (see Pl. 8, Fig. 5), *Isurus hastalis* (L. AGASSIZ, 1843), and the Sand, *Odontaspis acutissima* L. AGASSIZ, 1843, both known from the *Leithakalk*-type of facies (the Pińczów Limestone) in the western part of the Holy Cross shores. At Pińczów (locality P in Text-fig. 1), these co-occur with other large-sized sharks (*Notidanus*, *Galeocerdo*, *Hemipristis*, *Carcharodon*), skates, and teleost fish (RADWAŃSKI 1965b, 1974), as well as with the aberrant crocodile *Tomistoma*, and mammals (sirenian *Thalattosiren*, delphinids and phocoenids, and baleen whales; see CZYŻEWSKA & RADWAŃSKI 1991).

EXOTIC COMPONENTS

Terrestrial amber

During sieving sands of Member B, some pieces of amber have occasionally appeared. These pieces, several centimetres across, more or less rounded (see Pl. 10, Fig. 1), display a structure and colour which are well comparable to that of some varieties of the world-famous Baltic Amber of Eocene age. Conchoidal surfaces of some pieces have supposedly resulted from cracking and fracturing of originally larger specimens, as deduced from information supplied by sand-pit workers who in the 1980s found an amber lump the size of a human's head.

The presence of fairly common pieces of amber in a coeval sequence has previously been noted by SAMSONOWICZ (1934, p. 54) at Malice, near Męczennice (locality M in Text-fig. 1), north of Świniary, within the frames of the Opatów Bay (see RADWAŃSKI 1970, fig. 2) typified by widespread coastal swamps developed along the Middle Miocene (Badenian) shores (see RADWAŃSKI 1967, 1970, 1973a). A share of resin-producing trees in the coastal flora of the mainland is thus inferred, either for a nearby region, or eastwards, as far as the Ukraine from where the potentially resiniferous conifers were reported (see RADWAŃSKI & WYSOCKA 2001, p. 310).

Barite and 'barite roses'

In many samples of sands from Member E there occur reasonable amounts of barite, attaining a few percent per weight of washing residue. Barite appears usually as tiny, single tabular crystals, more or less bevelled at the edges to form almost rounded flakes, a few millimetres across. Larger crystals (over 3-4 mm in diameter) either tend to form, or just compose, the so-called 'barite roses' of isometric shape, attaining 10-15 millimetres in diameter, and larger, irregular aggregates even more (up to 20-25 mm).

The 'barite roses' are composed of several larger "crested" crystals interwoven with quartz grains, and impure with calcite inclusions (see Text-fig. 6); this, combined with their greyish colour, gives a granular earthy appearance to the roses (see Pl. 10, Fig. 2). Due to high specific gravity of barite (G = 4.468), they accumulate locally along the sand scree, after heavy rainfall in particular.

In cementations of Member D, barite forms micro-aggregates of various sizes and shapes, all densely interwoven with sand grains (see Text-fig. 6/*3-3a*).

The presence of barite has not hitherto been reported from any Middle Miocene (Badenian) sedimentary sequence other than the Gypsum Member of the Fore-Carpathian Depression. However, it is common in sulphur-bearing gypsum deposits of the region nearby (Piaseczno-Tarnobrzeg; see PARAFINIUK 1987, 1989). In the sequence of Świniary Sands studied, in which the sulphur- and barium-yielding Gypsum Member is absent (stratigraphical gap above the Sands; see Text-fig. 3), the provenance of barite is thought to be diagenetic through the regional percolation of vadose waters, late in the Neogene and/or in the Quaternary up to the present, as revealed by geochemical data (see PARAFINIUK 1987, and 1989, p. 54).

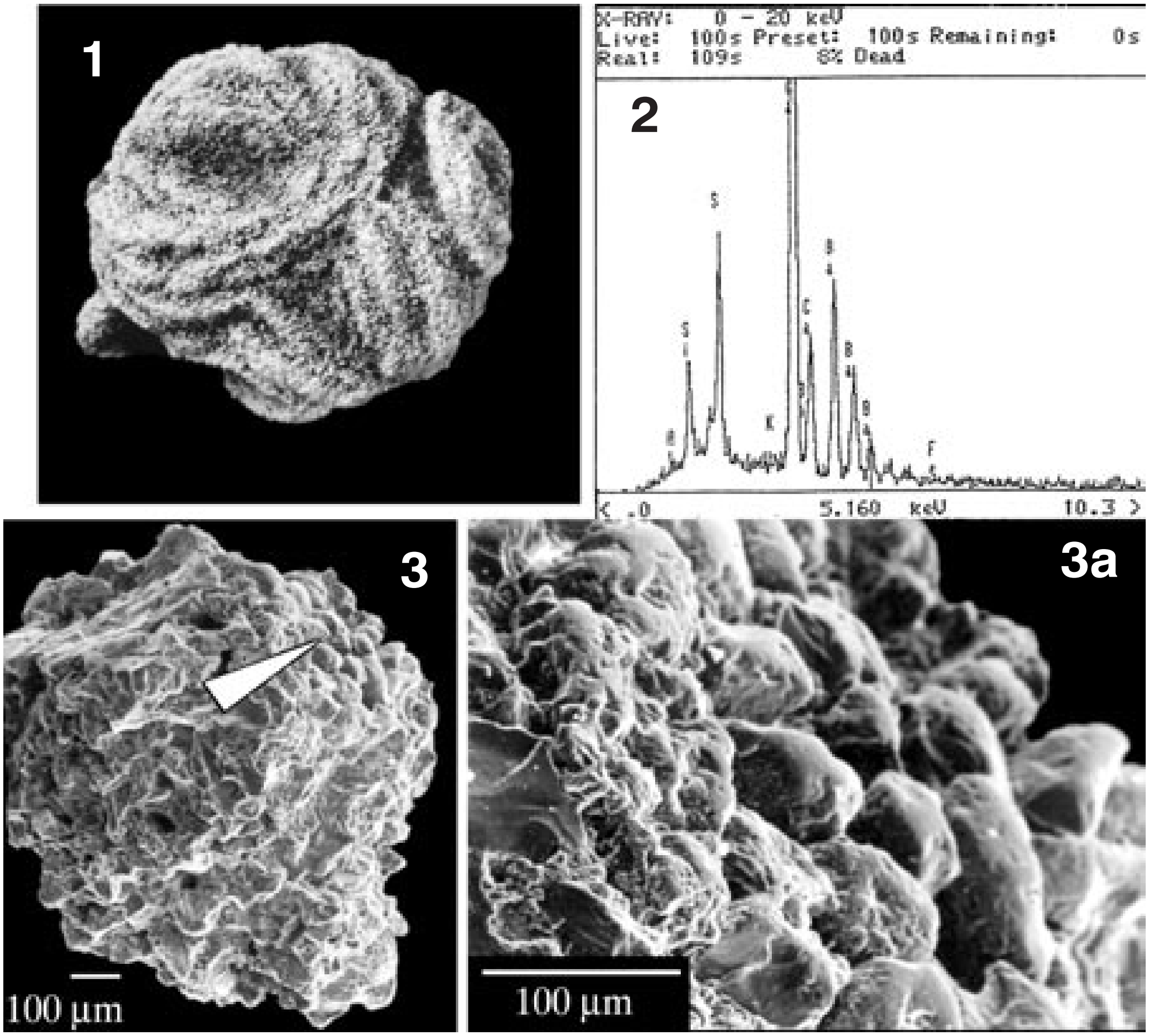

Fig. 6. Barite from Świniary Sands. **1 – '**Barite rose' from Member E (see Pl. 10, Fig. 2), taken × 4; **2** – Energy-dispersive spectrum of a 'barite rose' from Member E; **3–3a –** Barite micro-aggregate from Member D: **3** – General view, **3a** – Close-up (arrowed in 3), to show quartz grains sticking out of the aggregate

PHYSICAL PARAMETRES AND *SEM* IMAGES OF SAND

An attempt to recognise the depositional pathway of sand grains, from their mother rock to the burial site, was undertaken in the 1990s through sedimentological analysis, including SEM treatment (KENIG & WYSOCKA 1996, WYSOCKA 1999a). Quartz sands of Member *C*, the lowest part of the sequence then exposed (1993–1994), had a uniform granulometric composition and lack of distinct changes in grain-size parameters, the mean grain size (Mz), and the sorting coefficient (σ) including. The mean grain size varies from 2.25 to 2.5 ϕ, which qualifies the sands as fine-grained; the sorting coefficient varies from 0.3 to 0.68, i.e. within the range typical of well- to very-well-sorted deposits. The mineral content of sands is uniform, with only small amounts of heavy minerals, muscovite, and feldspar. The fraction below 0.25 mm reaches less than 10% of content, and is composed of organic detritus, quartz grains, as well as calcite and barite aggregates.

In SEM analysis, quartz sands of Member C are typified by their surface characters pointing to a short transport from the source area. They are associated with grains pointing to a shore environment, and bearing few features of chemical origin. The sample yields an abundance of polished grains and those with V-shaped subaqueous pits (Text-fig. 7.1-7.1a), typical of a high-energy shore environment (see KRINSLEY & DOORNKAMP 1973).

The Member *E* reveals a smaller amount of rounded grains, those with a polished surface, and arch-shaped subaqueous pits (Text-fig. 7.2-7.2a). Instead, partially rounded grains prevail and fractured ones are also present. Both types of grains are characterised by a frosted surface. On sharply edged grains, originating from conchoidal fractures, traces of surface dissolution and precipitation start to appear. Even very smooth conchoidal fractures are covered with a silica precipitation dust. Etching forms are either concordant with crystallographic directions, or irregular. The increase of frosted grains in samples from the topmost part of Member E points to an advance of chemical corrosion (see KRINSLEY & DOORNKAMP 1973).

Cementation bodies of very fine-grained quartz sands in Member D contain 7 to 50% of calcite. Angular or poorly rounded quartz grains are characterised primarily by features pointing to the etching processes of their surfaces. Mechanic fractures, rarely present, are indicative of the shorezone (see KRINSLEY & DOORNKAMP 1973). Thin-section analysis reveals a lack of contacts, or single quartz grain contacts in calcite matrix in which there also occur barite micro-aggregates (Fig. 6.3-6.3a). The low content of magnesium (0.05 to 0.30%), and particularly of strontium (25 to 61 ppm), in the calcite matrix unequivocally points to fresh or mixed pore waters saturating the sediment during subsequent diagenesis (see KENIG & WYSOCKA 1996). The diagenetic processes connected with the evolution of calcite cement and the dissolution of quartz grains took place with variable intensity. Some parts of the cemented bodies are poorly lithified ($\rho < 1.8$ g/cm^3), but the majority are strongly lithified, with bulk density ranging from 2.06 to 2.46 g/cm^3 (RUTKOWSKI 1976).

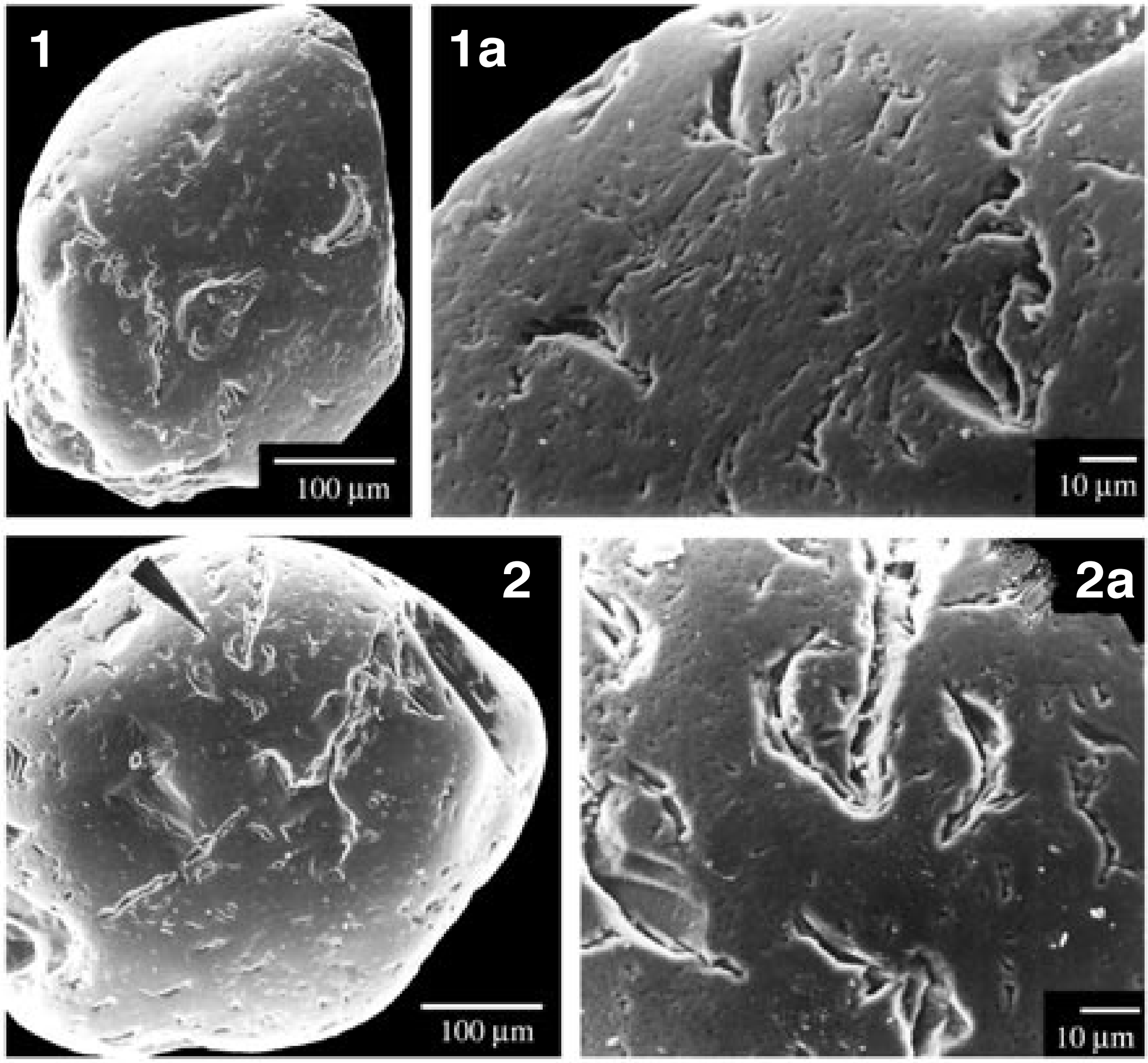

Fig. 7. Microtextures of quartz grains. **1–1a –** Fractured rounded grain, polished; Member C: **1** – General view, **1a** – Close-up of another side, to show large *V*-shaped pits and arch-shaped incisions, **2–2a –** Rounded grain, polished; Member E: **2** – General view, **2a** – Close-up (arrowed in 2), to show arch-shaped incisions, densely distributed on the grain surface

In conclusion, the physical features of quartz grains in the Świniary Sands were apparently produced by hydrodynamic agents prevailing under moderately to extremely shallow marine conditions, and no share of continental (fluvial, and/or aeolian) processes may be detected. It is thus apparent that neither river load (deltaic including), nor coastal dunes may be indicated as a direct source of sand.

The recognised succession of quartz-grain surface features testifies to an evolution in a sedimentary environment, from a high-energy one, with a distinct influence of the shorezone characterised by stable physicochemical conditions and little aggressiveness to quartz grains, to an environment more aggressive chemically to quartz grains. An interpretation of this succession is given under the following heading.

DEPOSITIONAL ENVIRONMENT

The sands in the lower part of the Świniary sequence accessible at deeper excavations to expose Member A, are typified by a mass occurrence of the echinoid *Psammechinus dubius* (L. AGASSIZ, 1840), accumulated throughout irregular layers. Those echinoid-bearing are, as a rule, weakly cemented, which is obvious from their destruction at occasional gusts of wind. All echinoids are jumbled together in haphazard positions (see Pl. 3, Figs 1-2). In some thinner layers, positions of echinoids on the top surface, and inverted on the sole (see Text-fig. 5 and Pls 4-5), show that some were dead, but others still alive, when the layer was deposited. Such taphonomic premises indicate that the echinoids, and associated starfish, were caught from their habitats and transported in a huge mass of sand, from which the live specimens could only occasionally escape. Storm-induced transportation and widespread deposition over the offshore bottom are thus postulated for successive layers/sand bodies of Member A.

In Member B, the occurrence of some biota unknown from other members is significant. These are red-algal balls (rhodoliths), disciniscan brachiopods, and verrucid barnacles. Of these, the rhodoliths have evidently been formed in the photic zone, most probably in shallow embayments along the shore, as in the western part of the Holy Cross Mountains (see RADWAŃSKI 1969). The verrucid barnacles were as yet known from extremely shallow depths decreasing to almost nil (see BAŁUK & RADWAŃSKI 1968, 1977). Similar bathymetric conditions are inferred for the disciniscan brachiopods, especially those recognised in the Oligocene and Miocene sequences of Europe (see RADWAŃSKA & RADWAŃSKI 1984, 1989, 2003). Taking a uniformitarian approach into account, there is the case of present-day intertidal populations of *Discinisca strigata* (BRODERIP, 1834) which show a preference for protected (cryptic) habitats (see PAINE 1962; RADWAŃSKA & RADWAŃSKI 1989, p. 76). For *Discinisca leopolitana*, clusters of empty oyster shells were such refuges which they successfully sheltered in. All the biota discussed are thought to have been derived from eulittoral, or extremely shallow subtidal, habitats to which terrestrial amber was sometimes also supplied. The megacross-bedded unit, they are embedded in, is consequently interpreted as reflecting violent storm input, which has supposedly formed a tempestite avalanche prograding towards the open offshore. Because of temporary access to these deposits, the spatial extent of the stormy input could not be recognised. After storm waning, the freshly settled sand layers were dwelt by callianassid decapods, to produce burrows *Ophiomorpha nodosa* LUNDGREN, 1894.

The frequency of *Ophiomorpha nodosa,* from the first specimens in Member B, increases upwards the sequence, having been controlled by shallowing in the water column. Bathymetric conditions at shallow depths are the same as discussed earlier (RADWAŃSKI 1970, pp. 384-386), following a classic report by WEIMER & HOYT (1964).

Horizontally bedded sands of Member C are indicative of deposition under low-energy conditions, fairly distant from stormy stirring-up. Suggested is that the distal tempestites, thus vertical settling from the water column, were responsible for burial of echinoids in life position, to create an unforgettable scenery of former days (see Pl. 2, Figs 2-3).

A notable feature of Member D is the presence of calcareous cementations which contain diverse shell debris absent from the loose sands. The cross-bedding of loose sands is not engulfed by cementations, which remains intact by currents. On the other hand, some cementations are sculptured by well-developed symmetric oscillation ripples, preserved on their top surfaces. All these data clearly indicate a synsedimentary origin for the cementations, and not epigenetic, as suggested earlier (see CZAPOWSKI 1976, KENIG & WYSOCKA 1996, WYSOCKA 1999a). The cementation process occurred during very early diagenesis, to follow formation of megaripples, and it was simultaneous with sedimentation around. An analogy to present-day beachrocks is thus impressive, although these have long been reported as intertidal, and confined to carbonate beaches of low latitudes (see GINSBURG 1953, GISCHLER & LOMANDO 1997, GISCHLER 2003). The rapidity of intertidal lithification to form beachrocks, and their synsedimentary fracturing in the surf zone have not escaped from earlier observation (see GINSBURG 1953, p. 85).

In the above context, it is important to stress that HERDMAN (1906) had even earlier observed in the Gulf of Manaar in Ceylon, identical cementations formed in the intertidal zone (locally) to offshore depths of 6-9 fathoms (11 to 16 metres). At these depths, cementations (called *paars*) are intermittently either covered, or swept out of the sand, to be rapidly overgrown by pearl oysters (see HERDMAN 1906, pp. 110-111). The cementations in Member D of the Świniary Sands are thought to have been formed under sublittoral bathymetric conditions, not having been exposed to disruption in the surf zone. Nevertheless, their composition and structure are almost identical to those of the present-day beachrocks.

Finely tabular, unimodal cross-bedded sands of Member E are typified by the presence of diverse fossils, particularly clustered oysters *Neopycnodonte leopolitana* (NIEDŹWIEDZKI, 1909), polychaetes *Serpula subpacta* ROVERETO, 1903, and indeterminate bryozoans (see Pl. 2, Fig. 1). Most of such clusters are fragmentary, having been torn out of larger ones by high-energy agents, and only the largest oyster clusters are *in situ*. Notable is the occurrence of isolated teeth of large-sized sharks, *Isurus* and *Odontaspis*, probably derived from turbulent shallows where their skeletons disarticulated. The green alga *Neomeris* and numerous scallop valves could have been derived from such nearshore depths. Shallow depths are also inferred from the fine unimodal cross-bedding which may be ascribed to the action of rip currents (see GRUSZCZYŃSKI & *al*. 1993, pp. 222-223, fig. 5) originated at the beach zone. The permanent presence of such cross-bedding, the damage of skeletons and clusters, and their redeposition, indicate the highest energy, thus the shallowest, environment of all members in the Świniary sequence.

To summarise, the section formerly exposed at Świniary sand-pit (Members A – E, see Text-fig. 3) represents a shallowing-up sequence, with sediments ranging from deeper offshore to proximal sublittoral, possibly shallow subtidal settings. The source of sand is suggested to have been established along the shore of a rather flat topography, where quartz freed from weathering products of fine old-Palaeozoic clastics. The weathering of the Palaeozoic basement has progressed through the earlier Tertiary (after Laramide uplift by the Cretaceous decline; see RADWAŃSKI 1969, 1973a) until the Middle Miocene (Badenian) sea transgression.

The sequence studied makes up the upper part of the Świniary Sands, the total lithosome being about twice as thick (see PAWŁOWSKI 1965, WYSOCKA 1999a) as revealed by borehole data. The original depth of the basin, when the basement was tectonically stabile, may be estimated for the basal part of the lithosome (never exposed) in the order of 30-40 metres, well comparable to that of the Korytnica Bay in the western part of the Holy Cross shore (see BAŁUK & RADWAŃSKI 1977, p. 89).

The shallowing-up trend of the basin, leading to the emersion in the Korytnica Bay situated just at the shore, and to a stratigraphical gap in the Świniary sequence deposited off the shore, has been ascribed (RADWAŃSKI 1973a, b) to geotectonic uplift of the Holy Cross Mountains, then embraced into the Carpathian fore-bulge arch, i.e. the northerly frame of the Fore-Carpathian Depression (=Carpathian foredeep). The syndepositional tectonics (block-faulting, throwing down southwards) then advanced has recently been documented by borehole data (WYSOCKA 1999a, p. 385 and fig. 5).

FINAL DIAGENESIS AND EPIGENESIS

Diagenetic processes in the Świniary Sands are manifested by: (i) Complete removal of aragonitic skeletons ('taphonomic filter' of NEBELSICK 1995), except those contained in cementations of sands in Member D; (ii) Pressure-solution (=pitting) processes that caused a heavy sand armour to many fossils, echinoderms in particular; (iii) Fracturing of some synsedimentary (early diagenesis) cementations of sands in Member D.

Fig. 8. A final farewell to the Świniary Sands: the present-day (June 16, 2003) status of Świniary sand-pit, now a local football field

Late epigenetic processes, acting possibly through to the Holocene, introduced native sulphur and barite to the Świniary Sands. Their concentrations are confined to Member D and E, thus to the topmost part of the sequence exposed to weathering and percolation of vadose waters. Chemical corrosion of quartz grains, revealed in SEM analysis, may be ascribed to the aggression of such waters. Where native sulphur concentrates usually along fractures of cementations, aggregates of barite are locally borne in the cementations themselves. Local concentrations of limonite, either within the loose sands, or along the cracks in cementations, should be attributed to late epigenetic to present-day processes.

A FAREWELL

The present-day state of the sand-pit (see Text-fig. 8) does not allow for any further access to the Świniary Sands. All that is left of this spectacular section is the material contained in the various museum and university collections. Let us treasure these. It is thus a time to say: A farewell to the section and its ubiquitous fossils, the echinoderms in particular!

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Dr. Marcin MACHALSKI (Institute of Palaeobiology, Polish Academy of Sciences, Warsaw) is thanked for making available a showy specimen of 'Giant *Psammechinus* sp.' sticking out of the cemented sand (see Pl. 6, Figs 2a-2b).

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REFERENCES

ALLEE, W.C. & SCHMIDT, K.P. 1949. Ecological Animal Geography; An authorized, rewritten edition based on *Tiergeographie auf oekologischer Grundlage* by Richard HESSE; pp. 1-715. *John Wiley and Sons*; New York.

ARONSON, R.B. & BLAKE, D.B. 2001. Global climate change and the origin of modern benthic communities in Antarctica. *American Zoologist*, **41** (1), 27-39.

ASLIN, C.J. 1968. Echinoid preservation in the Upper Estuarine Limestone of Blisworth, Northamptonshire. *Geological Magazine*, **105** (6), 506-518.

BAŁUK, W. & RADWAŃSKI, A. 1968. Lower Tortonian sands at Nawodzice, southern slopes of the Holy Cross Mts, their fauna and facies development. *Acta Geologica Polonica*, **18** (2), 447-471.

— & — 1977. Organic communities and facies development of the Korytnica Basin (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **27** (2), 85-123.

BINDER, H. & STEININGER, F. 1967. Drei fossile Ophiuren (*Amphiura* [*?*] *kühni* n.sp.) aus dem Jungtertiär von Österreich. *Annalen des Naturhistorischen Museums in Wien*, **71**, 19-26.

BLAKE, D.B. & ZINSMEISTER, W.J. 1988. Eocene asteroids (Echinodermata) from Seymour Island, Antarctic Peninsula. *Geological Society of America, Memoir*, **169**, 489-498.

CHRISTENSEN, A.M. 1970. Feeding biology of the sea-star *Astropecten irregularis* PENNANT. *Ophelia*, **8**, 1-134.

CHRISTENSEN, J., GEYTI, A. & PRIISHOLM, S. 1973. Świniary. *In*: Polen Ekskursionen, Vol. **2** (Rejse-rapport), pp. 88-90. *Geologisk Institut, Aarhus Universitet*; Aarhus. [*In Danish*]

COTTEAU, G. 1873. *In*: A. LOCARD, Sur la faune des terrains tertiaires moyens de la Corse. *Bulletin de la Société Géologique de France, Série 3*, **1**, pp. 236-242.

— 1877. Echinides. *In*: A. LOCARD, Description des échinides des terrains tertiaires moyens de la Corse. *Annales de la Société d'Agriculture, d'Histoire Naturelle et des Arts Utiles de Lyon, Série 4*, **9** (*for 1876*), pp. 233-341.

CZAPOWSKI, G. 1976. Several kinds of carbonate cementation in Miocene sediments in the vicinity of Sandomierz (Holy Cross Mts., Central Poland). *Bulletin de l'Académie Polonaise des Sciences, Série des Sciences de la Terre*, **24** (2), 83-92.

CZYŻEWSKA, T. & RADWAŃSKI, A. 1991. Middle Miocene (Badenian) delphinid and phocoenid remains from the Fore-Carpathian Depression in southern Poland. *Acta Geologica Polonica*, **41** (3-4), 183-191.

ERNST, G., HÄHNEL, W. & SEIBERTZ, E. 1973. Aktuopaläontologie und Merkmalsvariabilität bei mediterranen Echiniden und Rückschlüsse auf die Ökologie und Artumgrenzung fossiler Formen. *Paläontologische Zeitschrift*, **47**, 188-216.

FORBES, E. 1852. Echinoderms of the Crag. *Monographs of the Palaeontographical Society*, **6** (19) pp. 1-20. London.

FRENEIX, S. 1975. Au sujet du phylum *Neopycnodonte navicularis* – *Neopycnodonte cochlear*. VIth Congress of the Regional Committee on Mediterranean Neogene Stratigraphy, Bratislava 1975, pp. 443-449. Bratislava.

FRIEDBERG, W. 1921. Les Brachiopodes miocènes de la Podolie Occidentale. *Prace Naukowe Uniwersytetu Poznańskiego, Sekcja Matematyczno-Przyrodnicza* (*Travaux de l'Université de Poznań, Section des Sciences*), **2**, 1-20.

GÉNOT, P. 1987. Les Chlorophycées calcaires du Paléogène d'Europe nord-occidentale (Bassin de Paris, Bretagne, Cotentin, Bassin de Mons). Thèse de Doctorat d'Etat, Université de Nantes, **1**, pp. 1-500, and **2**, pp. 1-48. Nantes.

GINSBURG, R.N. 1953. Beachrock in South Florida. *Journal of Sedimentary Petrology*, **23** (2), 85-92.

Gischler, E. 2003. Beachrock. *In*: Middleton, G. (*Ed.*), *Encyclopedia of Sediments and Sedimentary Rocks*. Kluwer Academic Publishers.

Gischler, E. & Lomando, A.J. 1997. Holocene cemented beach deposits in Belize. *Sedimentary Geology*, **110** (3/4), 277-297.

Gruszczyński, M., Rudowski, S., Semil, J., Słomiński, J. & Zrobek, J. 1993. Rip currents as a geological tool. *Sedimentology*, **40** (2), 217-236.

Heller, C. 1858. Über neue fossile Stelleriden. *Sitzungsberichte der mathematisch-naturwissenschaftlichen Classe der kaiserlichen Akademie der Wissenschaften*, **28** (2), 155-170.

Herdman, W.A. 1906. Report to the Government of Ceylon on the pearl oyster fisheries of the Gulf of Manaar, Part **5**, pp. 1-448. *The Royal Society*; London.

Higgins, R.C. 1974. Specific status of *Echinocardium cordatum*, *E. australe* and *E. zealandicum* (Echinoidea: Spatangoida) around New Zealand, with comments on the relation of morphological variation to environment. *Journal of Zoology*, **173** (4), 451-475.

Ishida, Y. & Fujita, T. 2001. *Ophiura sarsi sarsi* (Echinodermata, Ophiuroidea) from the late Middle Miocene to Early Pliocene formations of North Hokkaido, Japan. *Journal of the Geological Society of Japan*, **107** (12), 784-793.

Jagt, J.W.M. 1991. Early Miocene luidiid asteroids (Echinodermata, Asteroidea) from Winterswijk-Miste (The Netherlands). *Contributions to Tertiary and Quaternary Geology*, **28** (1), 35-43.

Józefkowicz, P. 1976. Miocene sequence of Huta Lubycka (Roztocze Hills): its facies development and organic communities. Unpublished M.Sc. thesis; Institute of Geology, University of Warsaw. [*In Polish*]

Kenig, K. & Wysocka, A. 1996. Sands and calcite cement-bodies (the Baranów Beds) from Świniary, eastern margin of the Holy Cross Mts. *Geological Quarterly*, **40** (2), 203-230.

Kier, P.M. 1972. Upper Miocene echinoids from the Yorktown Formation of Virginia and their environmental significance. *Smithsonian Contributions to Paleobiology*, **13**, 1-41.

Kotchetoff, B., Kotchetoff, Y. & da Veiga Ferreira, O. 1975. Contribution à la connaissance des gisements fossilifères miocènes au Nord du Cap d'Espichel. *Comunicaçoes dos Serviços Geológicos de Portugal*, **59**, 59-106.

Krach, W. 1967. Matériaux pour la connaissance du Miocène de Pologne, III-ème partie. *Rocznik Polskiego Towarzystwa Geologicznego* (*Annales de la Société Géologique de Pologne*), **37** (2), 213-231.

Krinsley, D.H. & Doornkamp, J.C. 1973. Atlas of quartz sand surface textures; pp. 1-91. *Cambridge University Press*; Cambridge.

Kudrin, L.N. 1957. Palaeoecological investigations of the lowermost Tortonian deposits from the south-western part of the Russian Platform. *Geologicheskij Sbornik*, **4**, 277-294. [*In Russian*]

Küpper, K. 1954. Ophiuroidea aus dem Torton des Wiener Beckens. *Paläontologische Zeitschrift*, **28** (3/4), 159-166.

Lambert, J. 1910. Description des Echinides des terrains néogènes du Bassin du Rhône. *Mémoires de la Société Paléontologique Suisse*, **37** (1), 1-48.

Laube, G.C. 1871. Die Echinoiden der oesterreichisch-ungarischen oberen Tertiaerablagerungen. *Abhandlungen der kaiserlich-königlichen geologischen Reichsanstalt*, **5** (3), 55-74.

Lawrence, J.M. 1996. Mass mortality of echinoderms from abiotic factors. *In*: M. Jangoux & J.M. Lawrence (*Eds*). Echinoderm Studies, **5**, pp. 103-137. *Balkema*; Rotterdam/Brookfield.

Lörenthey, E. & Beurlen, K. 1929. Die fossilen Dekapoden der Länder der Ungarischen Krone. *Geologica Hungarica, Series Palaeontologica*, **3**, 1-420.

Machalski, M. 1996. Fossilien Sammeln in Polen: Vorkarpatensenke. *Fossilien*, **14** (1), 22-26.

Małecki, J. 1970. Chlorophyta from Miocene sediments of Poland. *Rocznik Polskiego Towarzystwa Geologicznego* (*Annales de la Société Géologique de Pologne)*, **40** (1), 167-175.

Martini, E. 1977. Calcareous nannoplankton from the Korytnica Basin (Middle Miocene; Holy Cross Mountains, Poland). *Acta Geologica Polonica*, **27** (2), 125-133.

Mączyńska, S. 1979. Echinoids from the Miocene deposits of the Roztocze region, south-eastern Poland. *Prace Muzeum Ziemi* (*Travaux du Musée de la Terre*), **32**, 29-36.

— 1987. A supplementary account on the echinoids from the Korytnica Basin (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **37**, 145-153.

— 1988. Echinoids from the Middle Miocene (Badenian) sands from Southern Poland. *Prace Muzeum Ziemi* (*Travaux du Musée de la Terre*), **40**, 59-64.

— 1991. The Miocene echinoids of Poland. *Bulletin of the Geological Society of Greece*, **25** (2), 549-560.

— 1993. Echinoids from the Pińczów Limestones (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **43** (1/2), 103-114.

Meyer, C.A. 1984. Palökologie und Sedimentologie der Echinodermenlagerstätte Schofgraben (mittleres Oxfordian, Weissenstein, Kt. Solothurn). *Eclogae Geologicae Helvetiae*, **77** (3), 649-673.

— 2002. Ophiuroidea aus dem Karpatium des Korneuburger Beckens (Niederösterreich; Untermiozän). *Beiträge zur Paläontologie*, **27**, 325-331.

Mihály, S. 1985. Late Badenian Echinoidea from new exposures in Budapest. Magyar Állami Földtani Intézet Évi Jelentése 1983, pp. 235-262. Budapest.

Müller, P. 1984. Decapod Crustacea of the Badenian. *Geologica Hungarica, Series Palaeontologica*, **42**, pp. 1-317.

Nebelsick, J.H. 1995. Actuopalaeontological investigations on echinoids: The potential for taphonomic interpretation. *In*: R. Emson, A. Smith & A. Campbell (*Eds*), Echinoderm Research 1995. *Proceedings of the fourth European echino-*

derms colloquium, pp. 209-214. *Balkema*; Rotterdam/Brookfield.

NEBELSICK, J.H. & KROH, A. 2002. The stormy path from life to death assemblages: The formation and preservation of mass accumulations of fossil sand dollars. *Palaios*, **17**, 378-393.

NÉRAUDEAU, D. 1991. Lateral variations of size-frequency distribution in a fossil echinoid community and their palaeoecological significance. *Lethaia*, **24** (3), 299-309.

NEUMANN, C. 2001. Massenmortalität bei rezenten und fossilen Spatangiden. *Greifswalder Geowissenschaftliche Beiträge*, **9**, 28-29.

NICHOLS, D. 1959. Changes in the Chalk heart-urchin *Micraster* interpreted in relation to living forms. *Philosophical Transactions of the Royal Society of London*, ***B*242** (693), 347-437.

NIEDŹWIEDZKI, J. 1909. Über eine neue miozäne Austernart: Ostrea Leopolitana. Bulletin International de l'Académie des Sciences de Cracovie, Classe des Sciences Mathématiques et Naturelles, Année 1908, pp. 1073-1075. Cracovie.

NOSOWSKA, E. 1997. Asteroids from the Nawodzice Sands (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **47**, 225-241.

PAINE, R.T. 1962. Filter-feeding pattern and local distribution of the brachiopod, *Discinisca strigata*. *Biological Bulletin*, **123** (3), 597-604.

PARAFINIUK, J. 1987. Strontium and barium in the sulphur-bearing Miocene deposits of the northern part of the Carpathian Foredeep (SE Poland). *Archiwum Mineralogiczne*, **43** (1), 87-143.

— 1989. Strontium and barium minerals in the sulphur deposits from Tarnobrzeg region (SE Poland). *Archiwum Mineralogiczne*, **43** (2), 41-60.

PAWŁOWSKI, S. 1965. Quartzsand-pit at Świniary. *Przewodnik 38 Zjazdu Polskiego Towarzystwa Geologicznego*, pp. 40-52. Warszawa. [*In Polish*]

PHILIPPE, M. 1998. Les échinides miocènes du Bassin du Rhône: révision systématique. *Nouvelles Archives du Muséum d'Histoire Naturelle de Lyon*, **36** (1/2), 1-441.

PRZYBYSZEWSKI, W.J. 1975. Miocene sands of Świniary: their fauna and facies development. Unpublished M.Sc. thesis; Institute of Geology, University of Warsaw. [*In Polish*]

RADWAŃSKA, U. 1994. Tube-dwelling polychaetes from the Korytnica Basin (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **44** (1/2), 35-81.

— 1999. Lower Kimmeridgian echinoids of Poland. *Acta Geologica Polonica*, **49** (4), 287-364.

RADWAŃSKA, U. & RADWAŃSKI, A. 1984. A new species of inarticulate brachiopods, *Discinisca polonica* sp.n., from the Korytnica Basin (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geologica Polonica*, **34** (3/4), 253-269.

— & — 1989. A new species of inarticulate brachiopods, *Discinisca steiningeri* sp.nov., from the Late Oligocene (Egerian) of Plesching near Linz, Austria. *Annalen des Naturhistorischen Museums in Wien*, **90A**, 67-82.

— & — 2003. BOSQUET's (1862) inarticulate brachiopods: *Discinisca elslooensis* sp.n. from the Elsloo Conglomerate. *Bulletin de l'Institut Royal des Sciences Naturelles de Belgique, Sciences de la Terre*, **73**, 185-194.

RADWAŃSKI, A. 1965a. Pitting processes in clastic and oolitic sediments. *Rocznik Polskiego Towarzystwa Geologicznego* (*Annales de la Société Géologique de Pologne*), **35** (2), 179-210.

— 1965b. A contribution to the knowledge of Miocene Elasmobranchii from Pińczów (Poland). *Acta Palaeontologica Polonica*, **10** (2), 267-276.

— 1967. Remarks on some Lower Tortonian brown-coal bearing sediments on the southern and eastern slopes of the Holy Cross Mts. *Bulletin de l'Académie Polonaise des Sciences, Série des Sciences Géologiques et Géographiques*, **15** (1), 33-39.

— 1969. Lower Tortonian transgression onto the southern slopes of the Holy Cross Mts. *Acta Geologica Polonica*, **19** (1), 1-164.

— 1970. Dependence of rock-borers and burrowers on the environmental conditions within the Tortonian littoral zone of Southern Poland. *In*: T.P. CRIMES & J.C. HARPER (*Eds*), Trace fossils. *Geological Journal, Special Issue* **3**, 371-390. Liverpool.

— 1973a. Lower Tortonian transgression onto the south-eastern and eastern slopes of the Holy Cross Mts. *Acta Geologica Polonica*, **23** (2), 375-434.

— 1973b. Fore-Carpathian Depression. In: Polen Ekskursionen, Vol. **1** (Kollokvie-rapport), pp. 94-132. *Geologisk Institut, Aarhus Universitet*; Aarhus.

— 1974. Kaleidoscope: Miocene Sea. *Polish Weekly*, No. **52** (664), pp. 10-11. Warszawa.

— 1977. Present-day types of trace in the Neogene sequence; their problems of nomenclature and preservation. *In*: T.P. CRIMES & J.C. HARPER (*Eds*), Trace fossils **2**. *Geological Journal, Special Issue* **9**, 227-264. Liverpool.

— 2002. Triassic brittlestar beds of Poland: a case of *Aspiduriella ludeni* (v.HAGENOW, 1846) and *Arenorbis squamosus* (E. PICARD, 1858). *Acta Geologica Polonica*, **52** (4), 395-410.

RADWAŃSKI, A. & WYSOCKA, A. 2001. Mass aggregation of Middle Miocene spine-coated echinoids *Echinocardium* and their integrated eco-taphonomy. *Acta Geologica Polonica*, **51** (4), 295-316. .

RUTKOWSKI, J. 1976. Detrital Sarmatian deposits on the southern margin of the Holy Cross Mountains (southern Poland). *Prace Geologiczne Polskiej Akademii Nauk*, **100**, 1-71. [*In Polish*]

SAMSONOWICZ, J. 1934. Objaśnienie arkusza Opatów (Explication de la feuille Opatów), pp. 1-117. Warszawa.

SCHMID, H.P., HARZHAUSER, M. & KROH, A. (*with contributions by* S. CORIC, F. RÖGL & O. SCHULTZ), 2001. Hypoxic events on a Middle Miocene carbonate platform of the Central Paratethys (Austria, Badenian, 14 Ma). *Annalen des Naturhistorischen Museums in Wien*, **102 A**, 1-50.

SCHMIDT, W.J. 1955. Die tertiären Würmer Österreichs. *Denkschriften der Österreichische Akademie der Wissenschaften, Mathematisch-Naturwissenschaftliche Klasse*, **109** (7), 1-121.

SEGUENZA, G. 1874 (for 1873). Ricerche paleontologiche intorno ai cirripedi terziarii della Provincia di Messina. Parte 1: Fam. Balanidi e Verrucidi. *Atti dell'Accademia Pontaniana*, **10**, pp. 265-366.

SMITH, A.B. 1984. Echinoid palaeobiology, 1-190. *George Allen & Unwin*; London.

SPENCER, W.K. & WRIGHT, C.W. 1966. Asterozoans. *In*: R.C. MOORE (*Ed.*), Treatise on Invertebrate Paleontology, part U (Echinodermata 3, Vol. **1**), pp. *U*4-*U*107. Lawrence, Kansas.

STRENGER, A. 1963. Klasse: Echinoidea (Seeigel). *In*: R. RIEDL (*Ed.*), Fauna und Flora der Adria, pp. 454-460. *Paul Parey*; Hamburg - Berlin.

SZAJNOCHA, W. 1900. Ophiuroids in Miocene clays of Wieliczka. *Kosmos*, **24** (8), 387-389. [*In Polish*]

SZÖRÉNYI, E. 1953. Miozäne Echinoiden aus den westlichen Teilen der Ukraine. *Geologica Hungarica, Series Palaeontologica*, **23**, 1-122.

TEN HOVE, H.A. & SMITH, R.S. 1990. A re-description of *Ditrupa gracillima* GRUBE, 1878 (Polychaeta, Serpulidae) from the Indo-Pacific, with a discussion of the genus. *Records of the Australian Museum*, **42** (1), 101-118.

VADÁSZ, M.E. 1915. Die mediterranen Echinodermen Ungarns. *Geologica Hungarica,* **1** (2), 1-178.

WEIMER, R.J. & HOYT, J.H. 1964. Burrows of *Callianassa major* SAY, geologic indicators of littoral and shallow neritic environments. *Journal of Paleontology*, **38** (4), 761-767.

WYSOCKA, A. 1999a. Depositional and tectonic controls on Early Badenian clastic sedimentation in the Sandomierz-Tarnobrzeg area (Baranów Beds, northern Carpathian Foredeep). *Geological Quarterly*, **43** (4), 383-394.

— 1999b. Sedymentacja klastycznych utworów badeńskich wschodniej części Roztocza, pomiędzy Zwierzyńcem a Lwowem. Unpublished Ph.D. thesis; Institute of Geology, University of Warsaw. [*In Polish*]

— 2002. Clastic Badenian deposits and sedimentary environments of the Roztocze Hills across the Polish-Ukrainian border. *Acta Geologica Polonica,* **52** (4), 535-561.

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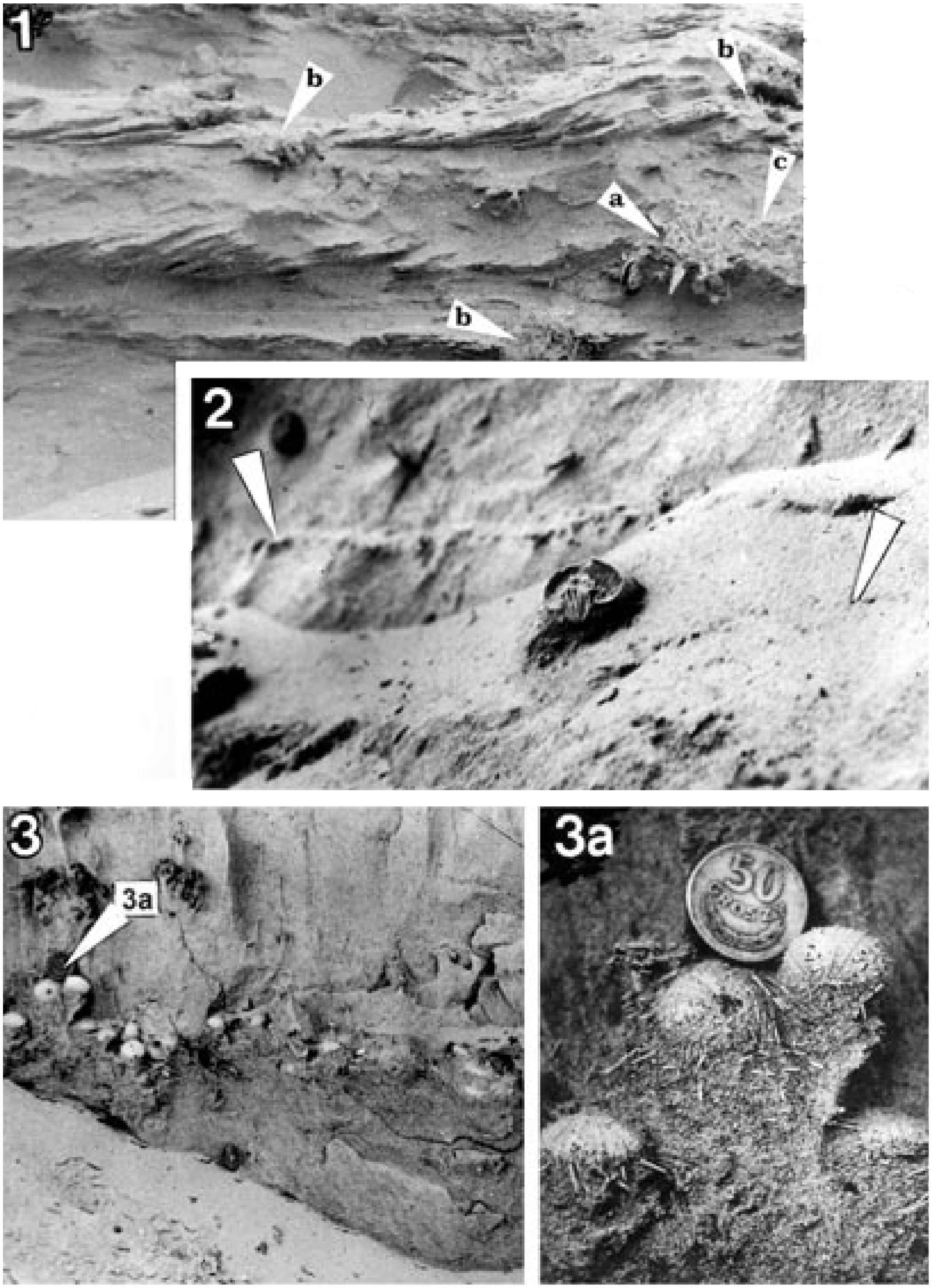
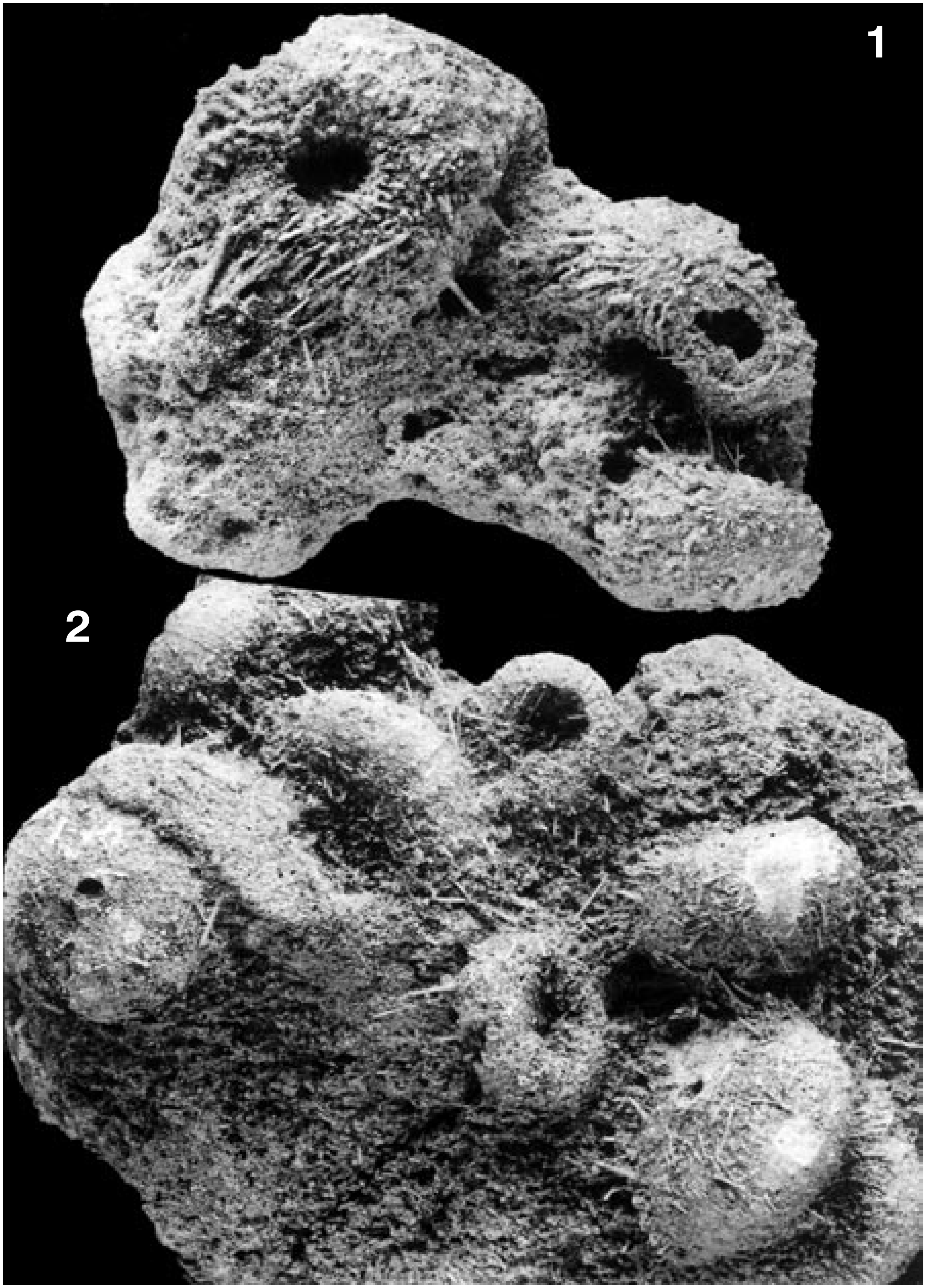
1 – Świniary sand-pit in the early 1970s: Member D is well exposed, Member C scree-covered (see Text-fig. 3, and compare RADWAŃSKI 1973a, pl. 3, fig. 1); Collage, photo by R. FRIBORG *in* CHRISTENSEN & *al*. (1973)

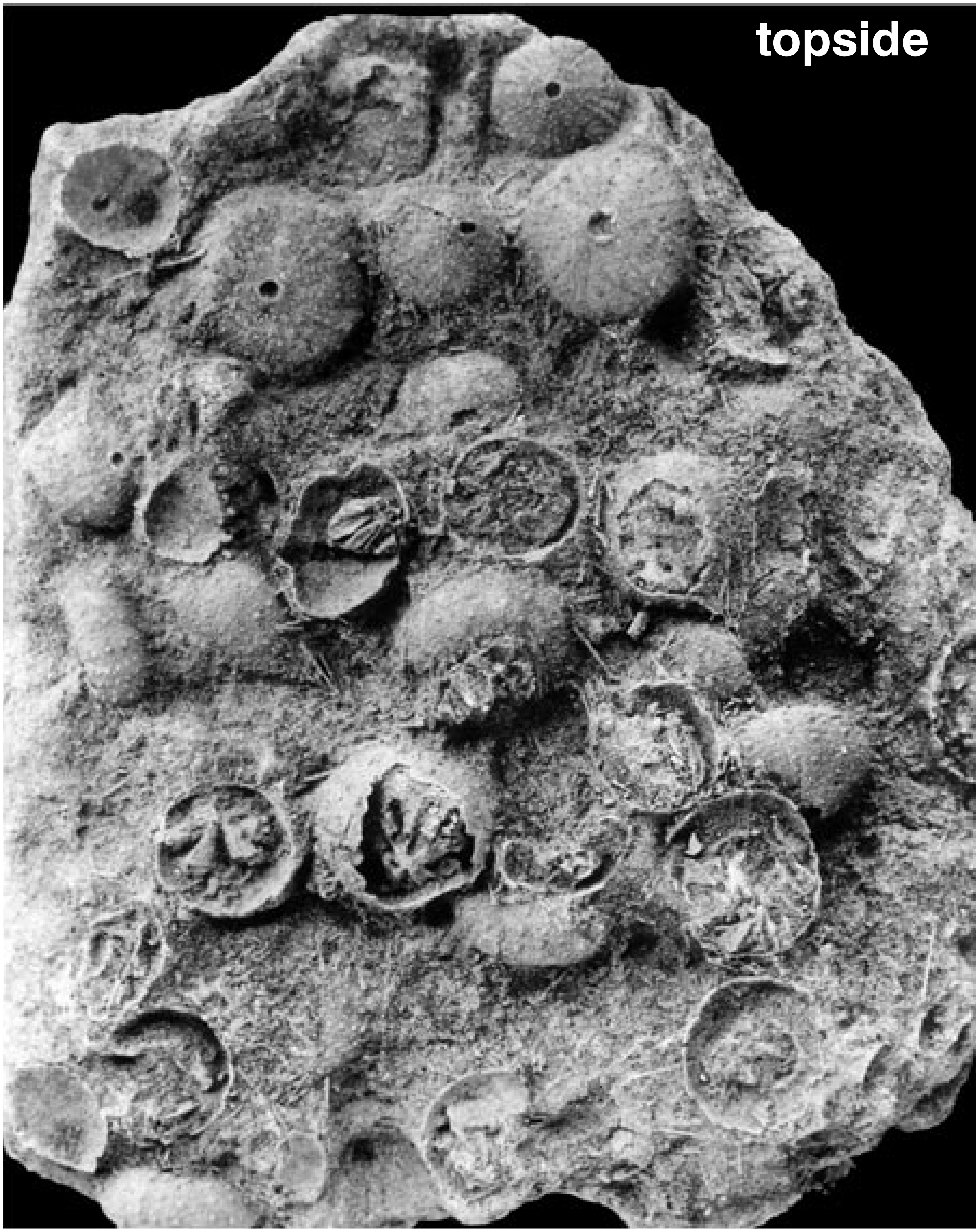
2 – Świniary sand-pit in the early 1990s: Exposed above pond level is the upper portion of Member C, Members D-E, and overlying greyish-black coloured Upper Badenian clays (see Text-fig. 3) which conflicted with sand exploitation; Photo by A. WYSOCKA, 1993



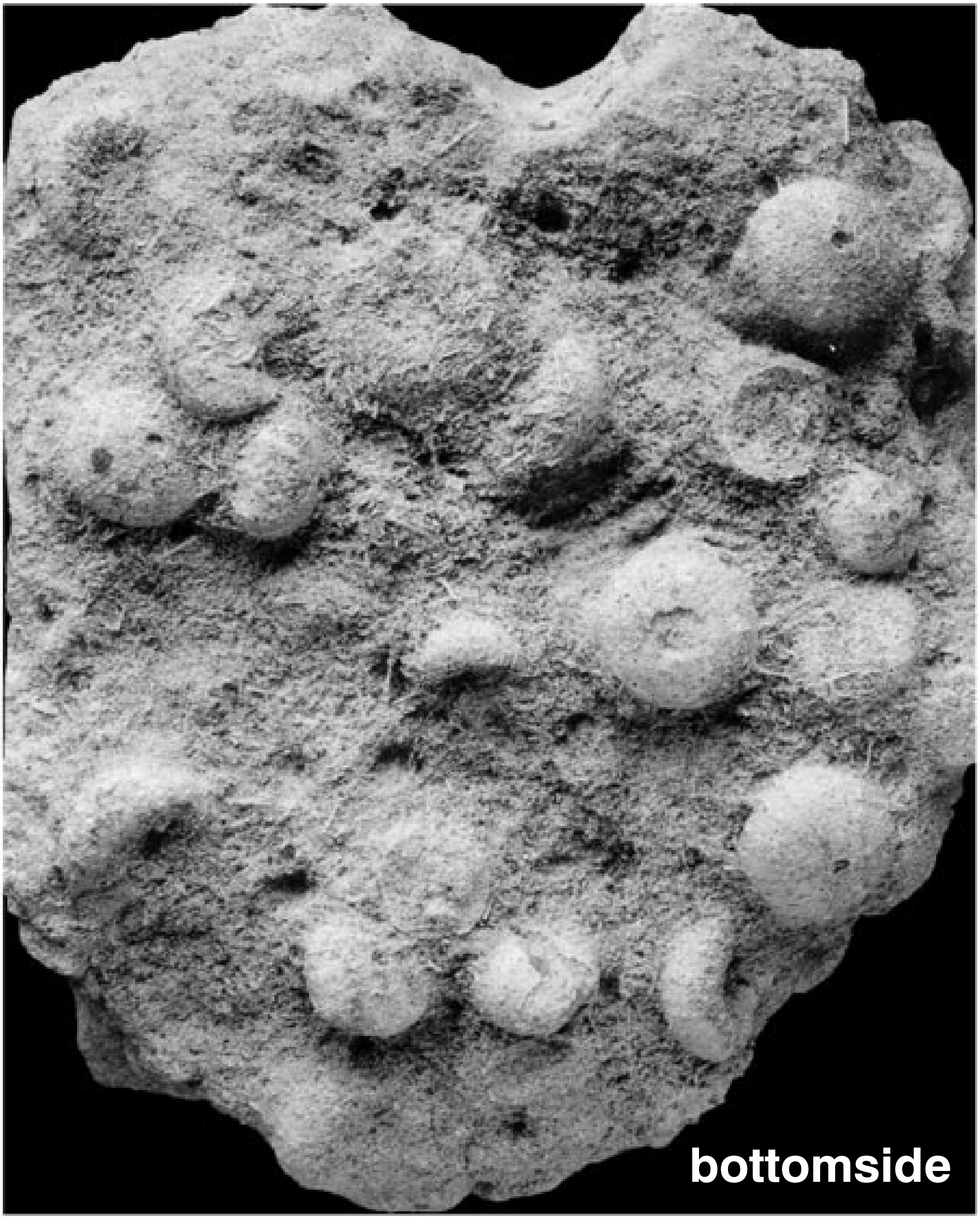
1 – Member E as exposed in the early 1970s: Fine tabular cross-bedded sand with small clusters of oysters (**a**), bryozoans (**b**), and serpulids (**c**); compare RADWAŃSKI (1973a, pl. 4, fig. 1, and 1973b, fig. 65); **2** – Member C exposed in the early 1970s: Visible are clay/silt interbeddings (arrowed) and a partly wind-exposed test of *Psammechinus dubius* (L. AGASSIZ, 1840) with part of its spine canopy and Aristotle's lantern preserved; **3** – An irregular accumulation of tests of *Psammechinus dubius* (L. AGASSIZ, 1840) in Member C, and its close-up to actual size (Fig. 3a), to show the spine canopies preserved almost completely in position (adopted from: RADWAŃSKI 1973a, pl. 6, figs 1-2)



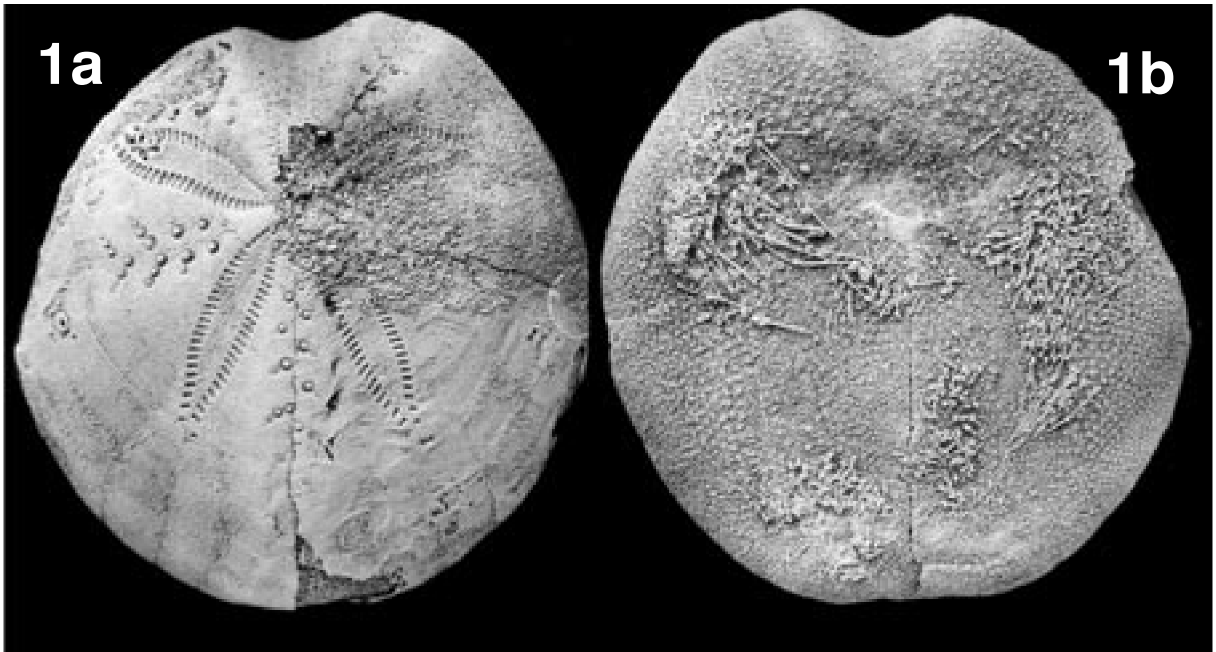
1-2 – Larger-sized specimens of *Psammechinus dubius* (L. AGASSIZ, 1840) occurring jumbled in top parts of weakly cemented sand layers of Member A (top views): Visible are spine-coated tests oriented at random, and heavily armoured with sand grains due to pressure-solution processes, × 1.5

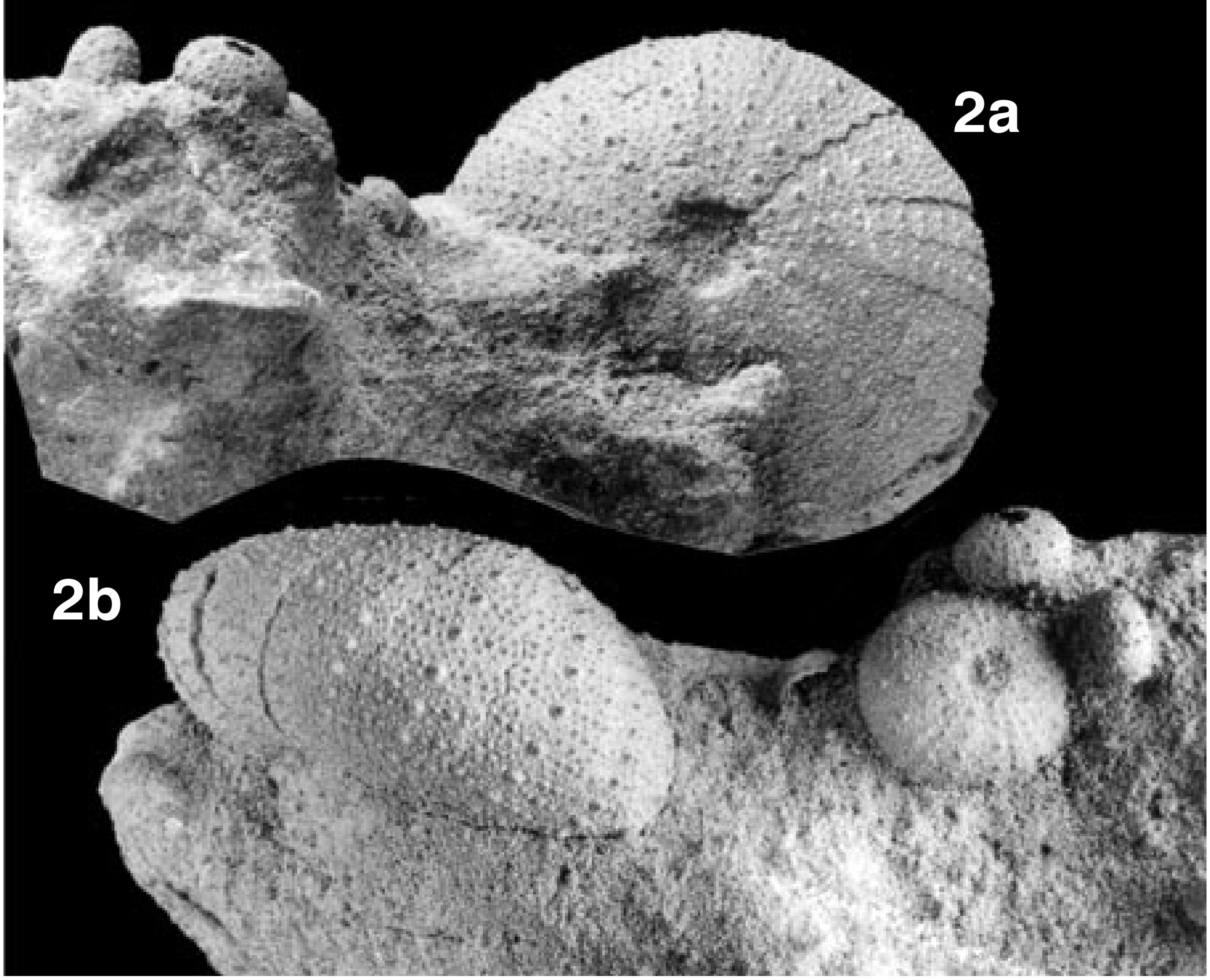


Average-sized specimens of *Psammechinus dubius* (L. AGASSIZ, 1840) at the top surface of a weakly cemented sand layer of Member A: Many specimens are in life position, contrary to those preserved at the sole of the same layer (see Pl. 5 and an interpretation: Text-fig. 5); nat. size; taken from RADWAŃSKI (1973a, pl. 7)



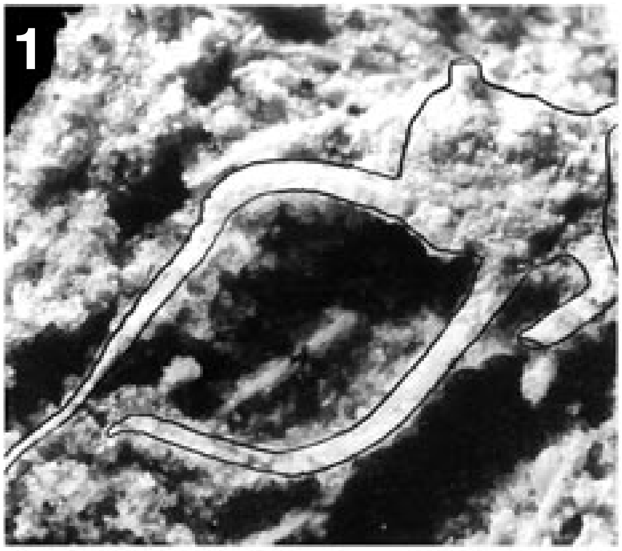
The sole of the same echinoid-bearing layer (see Pl. 4 and an interpretation: Text-fig. 5) with average-sized specimens of *Psammechinus dubius* (L. AGASSIZ, 1840): Most of the specimens are overturned to display their aboral side in a bottom view of the slab; nat. size



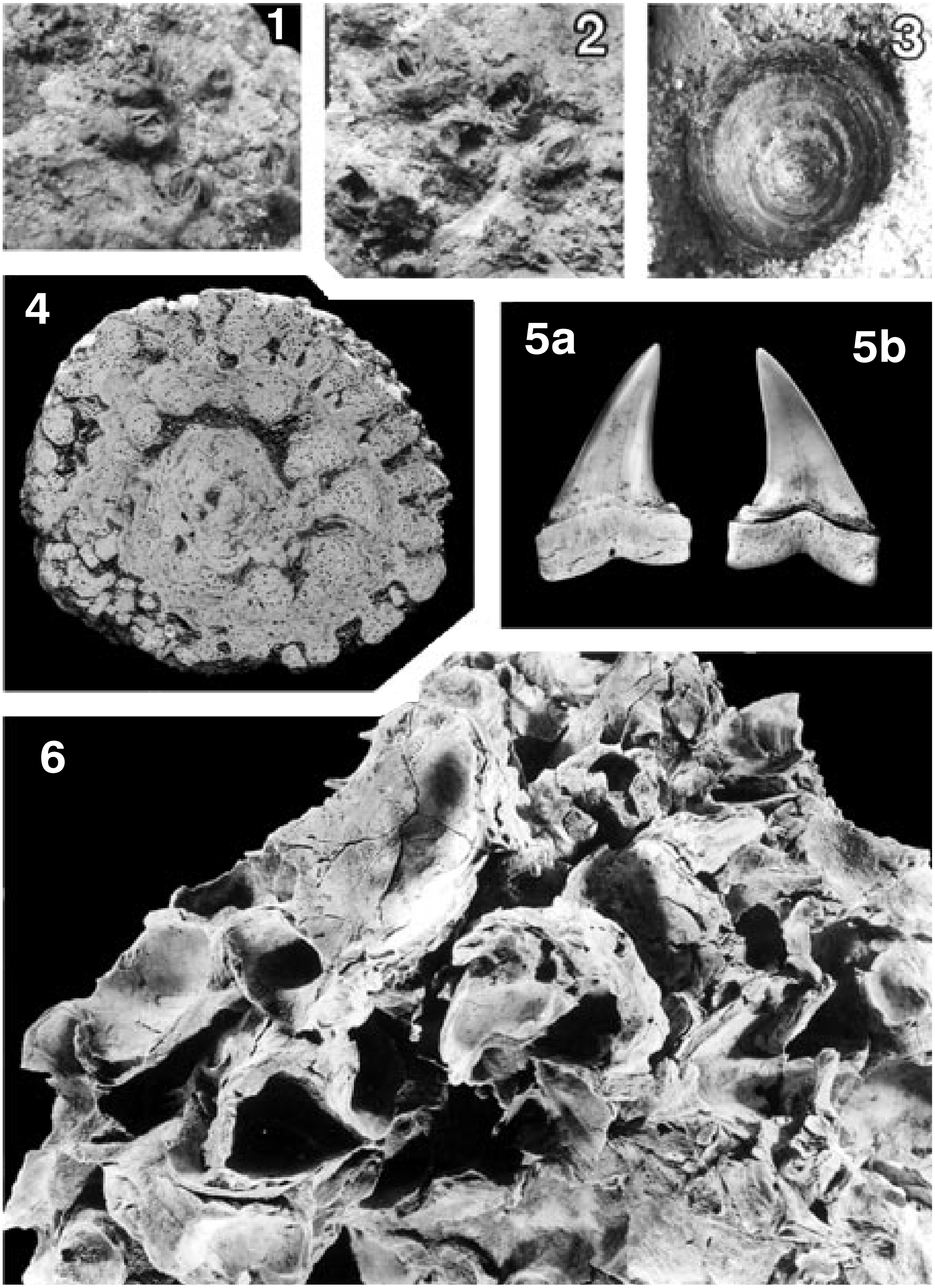


1a-1b – *Spatangus austriacus* LAUBE, 1871, from Member D: 1a – Aboral view, 1b – Oral view, to show fragmentary spine canopy; nat. size

2a-2b – Lump of heavily cemented sand body from Member D, to present a specimen of 'Giant *Psammechinus* sp.' and several specimens of *Psammechinus dubius* (L. AGASSIZ, 1840) representing various age groups. Same specimen as illustrated by MACHALSKI (1996, photo on p. 23); nat. size



1 – Ophiuroid ?*Amphiophiura* sp. cemented to aboral side of a *Spatangus* test from Member D; re-figured from PRZYBYSZEWSKI (1975, pl. 10, fig. 4); outlined with ink, × c. 6; visible is a heavy armour of sand grains, **2** – Starfish *Astropecten forbesi* HELLER, 1858, in a group of jumbled specimens of *Psammechinus dubius* (L. AGASSIZ, 1840) from Member A (see PRZYBYSZEWSKI 1975, pl. 10, fig. 3); aboral view, × 1.5; visible is a heavy armour of sand grains, **3** – Another specimen of *Astropecten forbesi* HELLER, 1858, from *Psammechinus*-bearing cemented sand of Member A (see PRZYBYSZEWSKI 1975, pl. 10, fig. 1); oral view, × 1.5

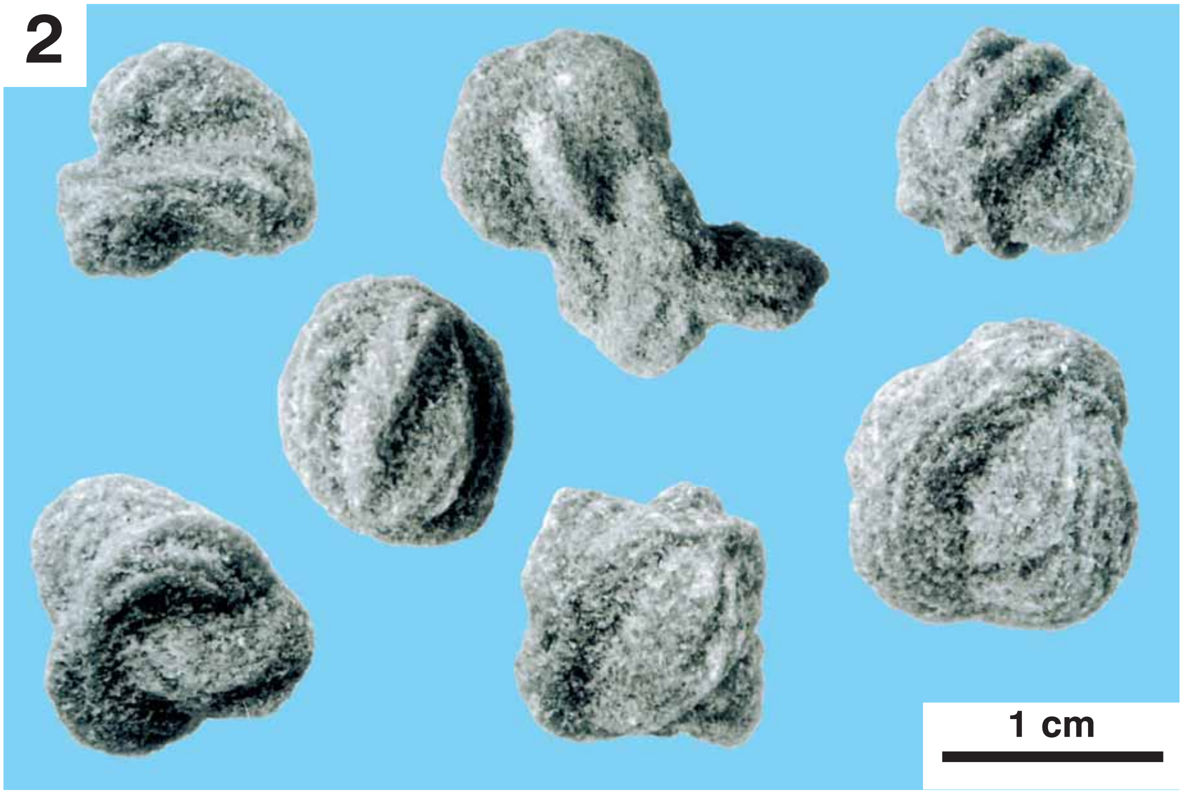


1 – Group of verrucid barnacles *Verruca* sp. encrusting an oyster shell: most of the specimens are preserved completely, with opercular plates in position, Member B, × 3, **2** – Another group of *Verruca* sp. encrusting an oyster shell: most of the verrucid crowns are devoid of opercular plates; Member B, × 3, **3** – Inarticulate brachiopod *Discinisca leopolitana* (FRIEDBERG, 1921): a dorsal valve adhering to an oyster shell; Member B, × 3, **4** – Rhodolith – an algal ball of colonies of the red alga *Lithothamnion* sp.; Member B, nat. size, **5a-5b** – Tooth of the shark *Isurus hastalis* (L. AGASSIZ, 1843): **5a** – lingual view, **5b** – labial view; Member E, nat. size, **6** – Cluster of oysters *Neopycnodonte leopolitana* (NIEDŹWIEDZKI, 1909) with shells grown in all directions; Member E, nat. size

1 – One of the largest burrows *Ophiomorpha nodosa* LUNDGREN, 1894, from the lower part of Member C (sands with clay/silt interbeddings), **2** – Right chela with the movable finger closed (outer view) of *Callianassa pseudorakosensis* LÖRENTHEY & BEURLEN, 1929; Member D, × 3

1

2



1 – Pieces of amber from Member B; note conchoidal fractures of pieces and their overall appearance comparable to that of the Baltic Amber of Eocene age, **2** – 'Barite roses' from sands of Member E; note a granular earthy appearance of rounded, 'crested' barite crystals interwoven with sand grains