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Ichnofabrics of the Upper Cretaceous marlstones in the Opole region, southern Poland

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ABSTRACT:

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Two basic types of ichnofabrics occur in the marlstone-dominated Turonian-Coniacian deposits in the Opole region, namely the *Thalassinoides* and *Chondrites* ichnofabrics. Trace fossils (*Chondrites, Ophiomorpha, Palaeophycus, Phycosiphon, Planolites, Taenidium, Teichichnus, Thalassinoides, Trichichnus*) indicate the *Cruziana* ichnofacies. In the *Thalassinoides* ichnofabric, the trace fossils occur almost entirely against a totally bioturbated background, indicating relatively well-oxygenated sediments. In the *Chondrites* ichnofabric, trace fossils are smaller and the background is almost entirely bioturbated. Only in the lower part of the Odra quarry section, primary lamination is locally preserved. Generally, the *Chondrites* ichnofabric indicates less oxygenated and possibly deeper sediments than the *Thalassinoides* ichnofabric. Occurrence of the *Chondrites* ichnofabric in the Lower Turonian and Upper Lower Coniacian can be related to widely known anoxic events.

Key words: Ichnofabrics, Trace Fossils, Palaeoenvironment Analysis Marlstones, Cretaceous, Poland.

INTRODUCTION

Transformation of primary sediment fabric by burrowing organisms is very strong in some deposits. Organisms produce determinable structures known as trace fossils and undeterminable biodeformational structures. The latter commonly have been neglected in ichnological analysis of palaeoenvironments, however, both of them are a source of important information. A more complete picture can be obtained by studies of structures and textures of sediments formed by burrowing organisms, where determinable and undeterminable structures are involved, i.e. by analysis of ichnofabrics, which have been initiated in the Eighties for the Upper Cretaceous chalk (EKDALE & BROMLEY 1983, BROMLEY & EKDALE 1986). Recently, ichnofabric analysis is a dynamically developing sub-discipline of ichnology, used for instance by oil companies for analysis of cores. Especially fine-grained sediments, which appear as homogenous, are suspected to be strongly bioturbated. They need a careful ichnofabric analysis for understanding of depositional processes and determination of other important features of their palaeoenvironment.

The above outlined problems encouraged us to study the ichnofabrics in a thick succession of the Upper Cretaceous marly deposits of the Opole region in the southern Poland (Text-figs 1, 2), which are important resources of the cement industry. Presenting the results of these studies is the main aim of this paper. Trace fossils in these deposits are known from earlier studies. Pyritized fillings of some burrows in the so-called Lower Marls in the Odra quarry have been described by KUTYBA (1977) who determined part of them as *Thalassinoides*. LIPIARSKI & TARKOWSKI (1989) recognized *Thalassinoides suevicus*

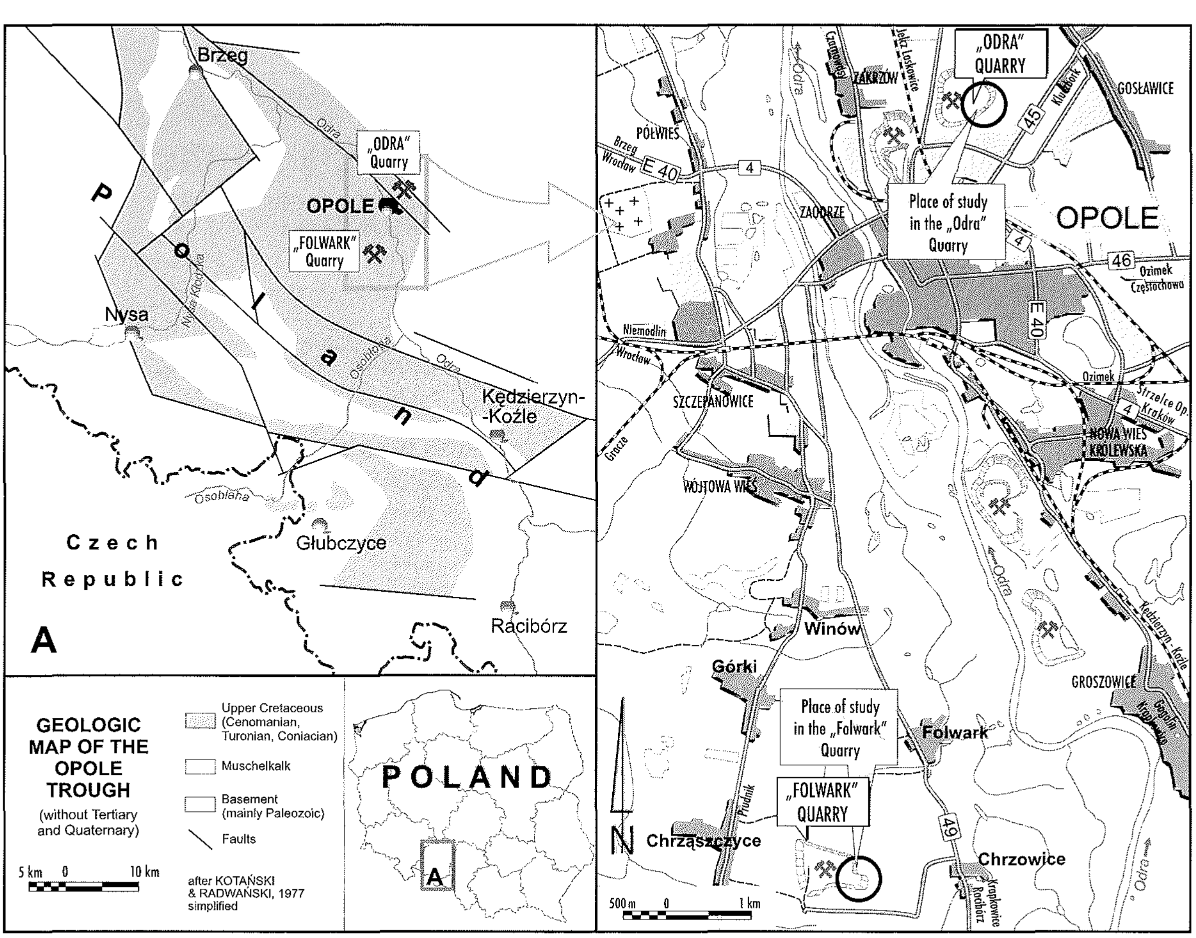


Fig. 1. Geological and locality maps of the Opole region

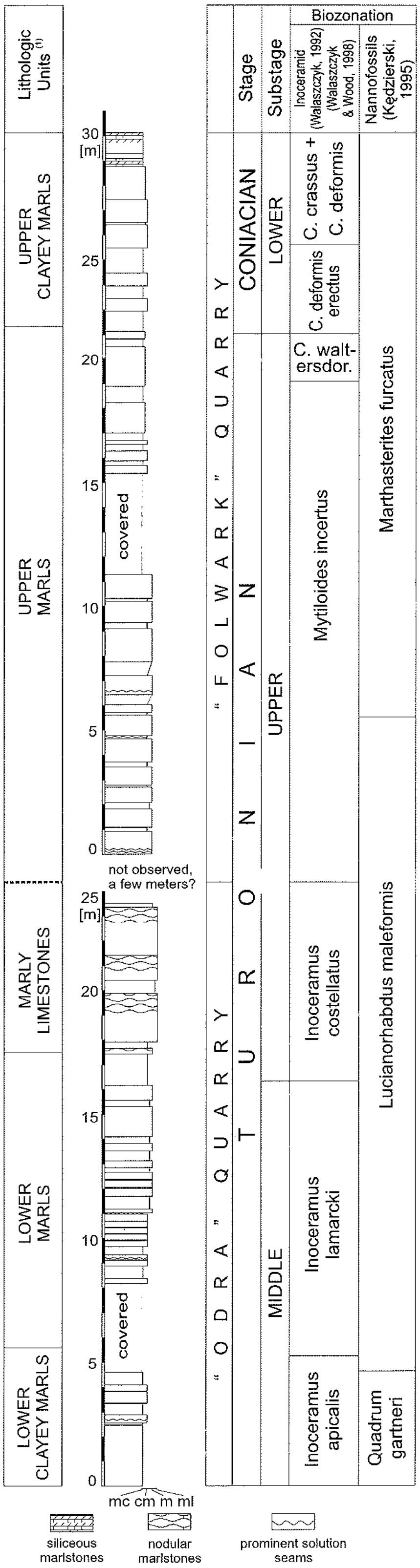
and *Chondrites* in the Odra and Bolko quarries in Opole. Nevertheless, more systematic ichnological studies have never been carried out for these deposits. Almost all illustrated specimens are housed at the Institute of Geological Sciences of the Jagiellonian University in Kraków (acronym 161P).

GEOLOGICAL SETTING

Epicontinental marls, marlstones, marly mudstones and marly limestones form the main part of the so-called Opole Cretaceous (kreda opolska). They fill up the Opole Trough (Opole Depression) (*e.g.* BIERNAT 1960, BOSSOWSKI & SAWICKI 1968) (Text-figs 1, 2, 3), in which they rest discordantly upon the Devonian, Carboniferous, Permian, and Triassic basement, and are covered discordantly by Miocene and Quaternary deposits. They form a small monocline with a gentle western dip, which is cut by a few faults oriented approximately WNW-ESE (KOTAŃSKI & RADWAŃSKI 1977).

The history of study of discussed deposits goes back to the XIX-th century. The work "Geologie von Oberschlesien" by ROEMER (1870) was the main geological study about the Opole Cretaceous for decades. After that, knowledge about stratigraphy, lithology, tectonics structure and sedimentary environments of Opole Trough has been still improved (*e.g.* LEONHARD 1898, ASSMAN 1926, BIERNAT 1960, ALEXANDROWICZ 1974, KOTAŃSKI & RADWAŃSKI 1977, KŁAPCIŃSKI & TEISSEYRE 1981, KOZDRA 1993, KĘDZIERSKI 1995). In 1973 ALEXANDROWICZ & RADWAN proposed subdivision of the Opole Cretaceous into six units on the base of the content of CaO. Lately WALASZCZYK (1988, 1992) and TARKOWSKI (1991) published a detailed inoceramid stratigraphy. According to them the Odra quarry represents the Middle to Upper Turonian, and the Folwark quarry the Upper Turonian and Lower to Middle Coniacian. To agree with the new scheme of Coniacian inoceramid stratigraphy the uppermost part of Folwark quarry belongs to upper Lower Coniacian (*e.g.* WALASZCZYK & WOOD 1998).

Palaeonvironment of the Opole Cretaceous was considered as a shallow, rather calm sea below storm wave



(1) Alexandrowicz & Radwan, 1973

Fig. 2. Stratigraphic column of the studied sections

base (*e.g.* Biernat, 1960). Walaszczyk (1992) ascribed the discussed deposits to the bedded marly chalk facies. Kozdra (1993) placed the sedimentation at outer shelf depths on the base of foraminifers. Deposits of the Opole Trough represent a single transgressive – regressive cycle, which began in the Cenomanian, with maximum flooding during the Late Turonian, and regression since the Coniacian (*e.g.* Tarkowski 1991).

More informations about the geological setting and history of study have been given by Walaszczyk (1988, 1992) and Tarkowski (1991).

STUDIED SECTIONS

The Odra and Folwark quarries, which together represent the most complete surface section of the Opole Cretaceous, have been chosen for study of ichnofabrics. The Odra Quarry is situated close to the centre of Opole, along the Luboszycka street, in the northern part of the "Chabry" housing estate (Text-fig. 1). The section (Text-figs 2, 4) represents 25 m-thick Middle – Upper Turonian deposits (*Inoceramus apicalis, I. lamarcki and I. costellatus* Inoceramid Zones; Walaszczyk 1992). According to Alexandrowicz & Radwan (1973) this section contains the Lower Clayey Marls, Lower Marls, and the Marly Limestones Units (Text-fig. 2). Generally, marly claystones, clayey marls and marls dominate in the lower and middle part, and marly nodular limestones in the upper part of the section. They display rhythmic bedding (Text-fig. 3). Typically, marlstone – claystone rhythms are 1-3 m thick. Generally, total content of calcium carbonate increases upwards. The sediments in the lower part (Lower Clayey Marls unit) are dark grey in colour at the base and become gradually light grey at the top, reflecting an increase in carbonate content. Macrofossils, such as inoceramids, echinoids, brachiopods or sponges are very common. Locally, they are concentrated in distinct horizons (*see* Walaszczyk 1988, 1992; Tarkowski 1991). In thin-sections, foraminifers are very abundant.

The Folwark Quarry is located close to the country road No. 49, about 5 km south of Opole, between the villages of Chrzowice, Chrząszczyce and Folwark (Text-fig. 1). The Upper Marls and Upper Clayey Marls Units (Alexandrowicz & Radwan 1973) crop out here in a 30 m-thick section (Text-figs 3, 4). They belong to the Upper Turonian – Lower Coniacian substages (*Mytiloides incertus, Cremnoceramus waltersdorfensis, C. deformis erectus* and *C. crassus + C. deformis* Inoceramid Zones; Walaszczyk 1992, Walaszczyk & Wood 1998) (Text-fig. 2). Strongly bioturbated dark grey clayey marlstones dominate. They are rhythmically interbedded with marly claystones forming 1-4 m thick packages (Text-fig. 3). The uppermost part of the section consists of 3 m thick, slightly siliceous marlstones interbedded with 0.7 m thick, soft marly claystones. Macrofossil are dominated by inocermids. Brachiopods, echinoids, ammonites and sponges are also common. Foraminifers are the most common microfossils. The siliceous marls contain abundant radiolaria (KOZDRA 1993). Generally, the carbonate contents decreases upwards.

ICHNOFABRIC ANALYSIS

Material and methods

Ichnofabrics have been analysed in polished slabs prepared from systematically collected samples through the investigated sections. Some trace fossils have been observed on parting surfaces in the field and in laboratory. For improvement of colour contrast, the polished surfaces have been oiled (Buschinsky oil technique, BROMLEY 1981). Several additional sections through the specimens were made to enable three-dimensional observations of the ichnofabriscs.

TRACE FOSSILS

Chondrites ispp. (Pl. 1, Figs 1-2, 5, 7; Pl. 2, Fig 4; Pl. 3, Figs 1-6; Pl. 4, Figs 1-2, 4-5; Pl. 5, Figs 2, 6) is a system of tree-like sharp-angle branching, downward penetrating, flattened tunnels, 0.3-1.5 mm in diameter. In cross-section, they appear as patches of circular or elliptical small spots and short bars. Fill of the trace fossil is darker or lighter than the host rock. Specimens observed on sub horizontal parting surfaces in the upper part of the Folwark section and in the lower part of the Odra section display straight tunnels, less than 1 mm wide, and sharp-angle branching typical of *Chondrites intricatus* (BRONGNIART). Probably, most specimens observed in cross-section belong to this ichnospecies. In the Folwark quarry, some *Chondrites* display winding tunnels, which are about 1.5 mm wide. They belong to *Chondrites targionii* (BRONGNIART). Some fillings of *Chondrites* display coarser grains and faint menisci (Pl. 5, Fig. 6). For more information about *Chondrites* see FU (1991) and UCHMAN (1999).

Ophiomorpha isp. (Pl. 1, Fig. 3) occurs as oblique, tubular walled trace fossils, 12-15 mm in diameter, covered with indistinct knobs, filled with darker material than the host rock. The knobby wall is the diagnostic feature of *Ophiomorpha* (*e.g.* FREY & *al.* 1978).

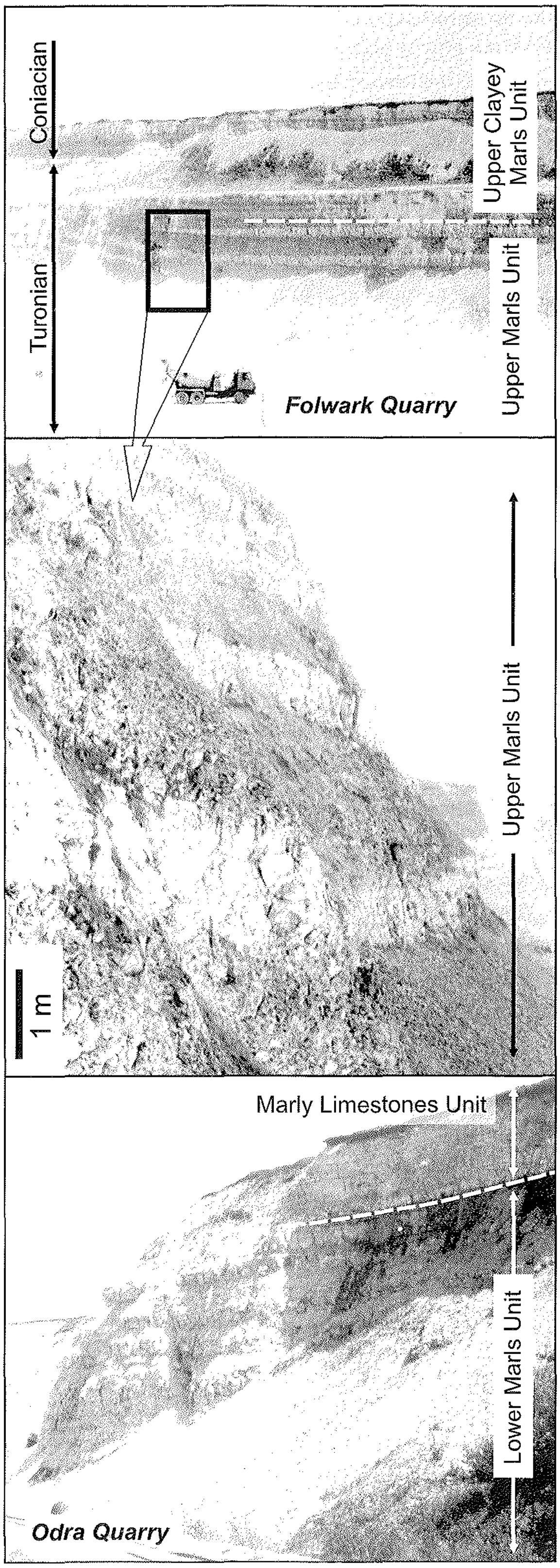


Fig. 3. General views of the Odra and Folwark quarries

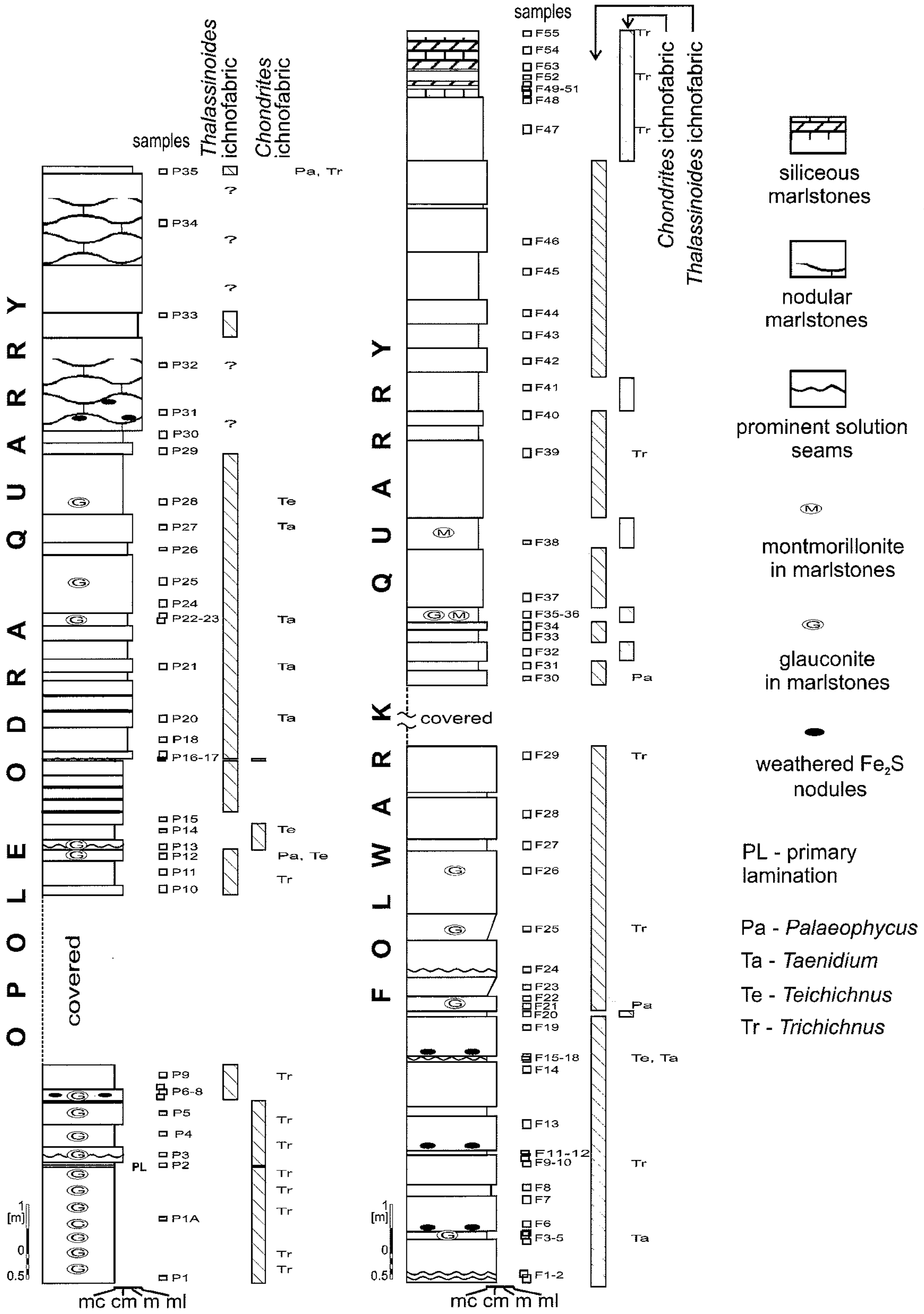


Fig. 4. Lithological columns of the studied sections and distribution of ichnofabrics and trace fossils

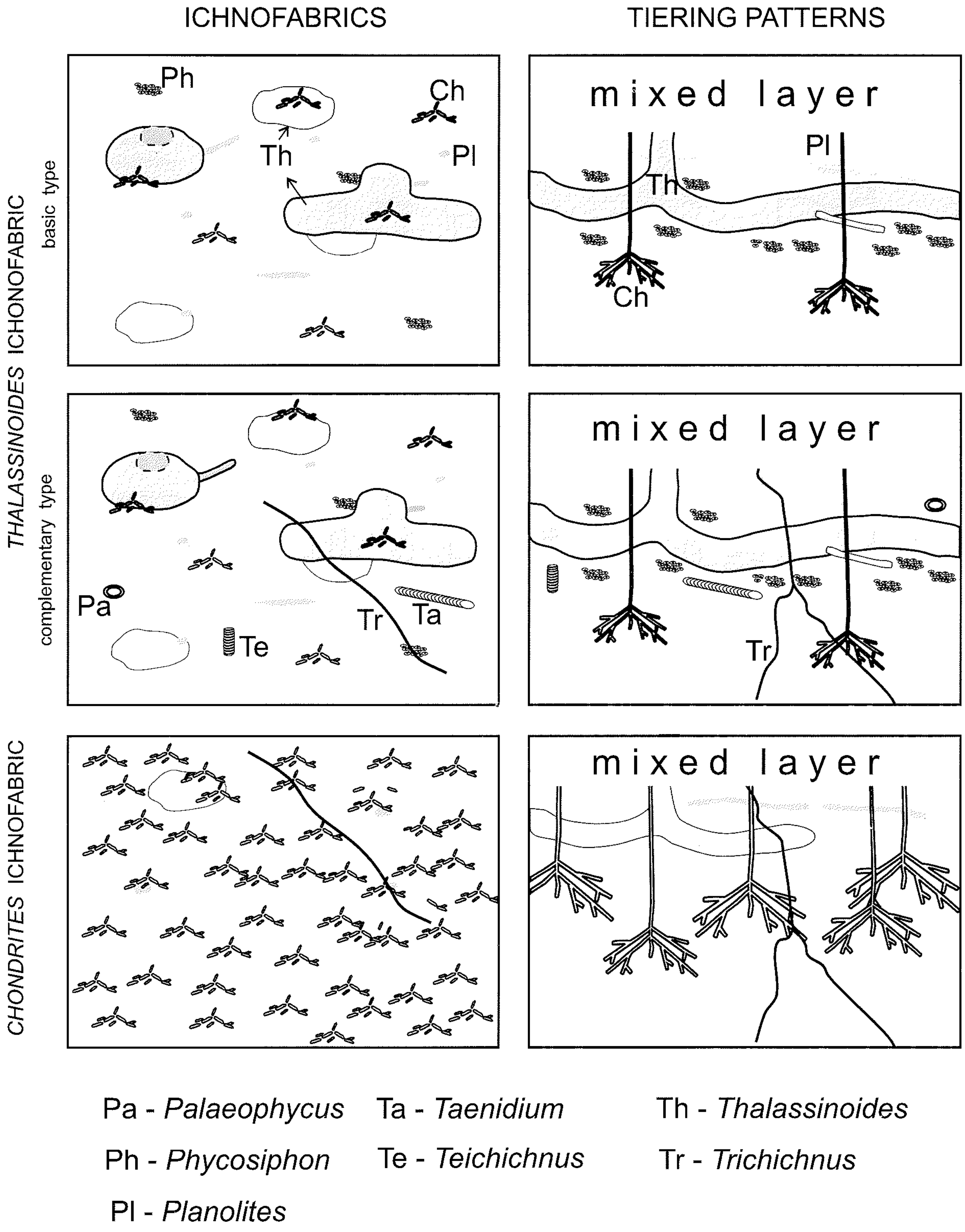


Fig. 5. Main types of ichnofabrics and reconstruction of tiering pattern

Phycosiphon isp. (Pl. 1, Fig. 4; Pl. 4, Fig. 6) is observed in vertical cross-sections as patches of dark, elongated spots, about 1 mm in diameter, surrounded by a light mantle. Appearance of this form conforms to *Anconichnus horizontalis* KERN (GOLDRING & *al.* 1991), which has been included in *Phycosiphon incertum* FISCHER-OOSTER (WETZEL & BROMLEY 1994).

Palaeophycus isp. (Pl. 1, Figs 5, 7) occurs as horizontal to subhorizontal tubes with a distinct wall, 4 mm in diameter.

Planolites isp. (Pl. 1, Figs 1-2, 5-6; Pl. 3, Figs 1, 4, 6; Pl. 4, Figs 1-4; Pl. 5, Figs 1-5) is a horizontal to subhorizontal, stright to slightly winding, unlined cylindrical trace fossil, 2-6 mm wide, filled with darker or rarely lighter sediment than the host rock. In some horizons, the filling is pyritized (*see* KUTYBA 1977). For discussion of *Planolites* see PEMBERTON & FREY (1982) and KEIGHLEY & PICKERILL (1995).

Taenidium isp. (*see* Pl. 1, Fig. 9; Pl. 3, Fig. 5) is an oblique, unwalled, simple, tubular, meniscate trace fossil filled with darker sediment than the host rock. It is 1-2 mm in diameter. *Taenidium* was discussed by D'ALESSANDRO & BROMLEY (1987) and KEIGHLEY & PICKERILL (1994), who regarded it as the product of vagile, deposit-feeding organisms, but LOCKLAIR & SAVRDA (1998) suggested that at least some *Taenidium* were produced by a sessile worm maintaining a connection to the sediment surface or shallow subsurface and keeping pace with sediment accumulation.

Teichichnus isp. (Pl. 1, Fig. 8; Pl. 4, Fig. 5) appears as vertically or obliquely stacked spreite laminae in a zone, which is 4 mm wide, 16 high, and at least 50 mm long. *Teichichnus*, discussed for instance by FILLION & PICKERILL (1990), is traditionally regarded as fodinichnion (*e.g.* HÄNTZSCHEL 1975), but LOCKLAIR & SAVRDA (1998) suggested that it can be produced by a surface detritus feeder transporting waste down the burrow.

Thalassinoides isp. (Pl. 1, Figs 1, 9; Pl. 2, Figs 1-4; Pl. 3, Figs 1, 3-4; Pl. 4, Figs 1-6) is a walled or unwalled trace fossil composed of cylindrical, mostly horizontal, branched tunnels, which are 12-25 mm wide in most specimens. Filling of the tunnels is darker than the host rock. Rarely, some tunnels contain plant detritus (Pl. 2, Fig. 2). In some horizons, they are pyritized (KUTYBA 1977) (Pl. 2, Fig. 3). Specimens observed on horizontal surfaces display characteristic Y-shaped branchings, which are typical of *Thalassinoides suevicus* (RIETH). Exceptionally, a very large specimen of this ichnospecies has been found in the Odra quarry (Pl. 2, Fig. 1). Its tunnels are about 100 mm wide. It is highly probable, that most forms observed in cross-section belong also to *T. suevicus*. Locally, vertical shafts associated with the horizontal systems occur (Pl. 4, Fig. 3). Probably, they have joined the burrow system to the sea-floor. For discussion of *Thalassinoides* see FREY & *al.* (1984).

Trichichnus lineraris FREY (Pl. 2, Fig. 5; Pl. 3, Fig. 6) is a vertical to oblique, rarely horizontal, straight to curved, simple or rarely branched, very thin, cylindrical trace fossil, which is 0.2-0.8 mm in diameter. It is filled with weathered pyritic material. For discussion of *Trichichnus* see FILLION & PICKERILL (1990) and UCHMAN (1995, 1999).

Trichichnus isp. (Pl. 2, Figs 6-7) is a vertical to horizontal, straight to curved, simple or rarely branched, thin cylindrical trace fossil, which is 1.2-2.2 mm in diameter. It is filled with weathered pyritic material. So far known ichnospecies of *Trichichnus* are less than 1 mm in diameter (see diagnosis of this ichnogenus by FILLION & PICKERILL, 1990). The described form displays all features of *Trichichnus* except for the size, but we are of the opinion that the size limit should be enlarged. This problem needs further study.

Ichnofabrics

Two main types of ichnofabrics are distinguished, namely the *Thalassinoides* and *Chondrites* ichnofabrics (Text-fig. 5).

The *Thalassinoides* ichnofabric (Pl. 4, Figs 1-4) is characterised by a totally bioturbated background, walled or unwalled *Thalassinoides, Planolites*, light or dark *Chondrites, Trichichnus* and *Phycosiphon*. *Chondrites* cross cuts *Thalassinoides* and *Planolites*. *Planolites* is cross cut by *Thalassinoides*, but reverse situations also occur. *Phycosiphon* cross cuts *Planolites* and *Thalassinoides*, but in some cases patches of *Phycosiphon* are cross cut by *Thalassinoides* (Pl. 4, Fig. 6). *Trichichnus* cross cuts all other trace fossils. Other trace fossils (*Taenidium, Teichichnus, Ophiomorpha, Palaeophycus*) are very rare. *Palaeophycus* is cross cut by *Chondrites*. In several cases, different generations of *Thalassinoides* cross cut each other (*e.g.* Pl. 4, Fig. 3), forms with better outlined margin cross cutting commonly forms with less outlined margin. *Phycosiphon* occurs commonly in small patches. The bioturbated background is characterised by diffuse mottling. The *Thalassinoides* ichnofabric occurs in marly limestones, marlstones, and in marly mudstones. It dominates in the middle part of the Odra quarry section and in the lower and middle part of the Folwark quarry section.

A peculiar kind of the *Thalassinoides* ichnofabric occurs in the nodular marlstones of the upper part of the Odra quarry section, and locally from the Folwark section, where it is strongly transformed by diagenesis. Trace fossils display here much lower colour contrast. They are commonly deformed by growing nodules and are cut by solution seams (Pl. 4, Fig. 2).

The *Chondrites* ichnofabric is characterised by a totally bioturbated background, dominance of elite *Chondrites*, which cross cuts rarely occurring *Planolites* and small *Thalassinoides* (Pl. 3, Figs 1-6). Locally, *Trichichnus* occurs, altogether more frequently than in the *Thalassinoides* ichnofabric. It cross cuts the remaining trace fossils. This ichnofabric occurs mainly in marly mudstones (Lower Clayey Marls) in the lower part of the Odra quarry section and in siliceous marlstones (Upper Clayey Marls) of the upper part of the Folwark quarry section.

Locally, thin (1-2 mm), dark non-bioturbated laminae occur (Pl. 2, Fig. 8; Pl. 3, Fig. 3) within the *Thalassinoides* ichnofabric. In a few cases two converging laminae have been observed. The laminae seem to cut the ichnofabric. Their origin is not clear. There is no evidence that they belong to poorly preserved *Zoophycos* or any other primary structure. In horizontal section the laminae are structurless. Locally, solution seams are observed along them. In some places they enveloped, nodule-like small portions of gray marlstone. This suggests a diagenetic rather than primary origin.

DISCUSSION

The trace fossil assemblage of the *Thalassinoides* ichnofabrics is typical of the *Cruziana* ichnofacies, which is most characteristic of poorly sorted unconsolidated substrates of subtidal zones between fair-weather wave base and storm wave base (FREY & SEILACHER 1980; FREY & PEMBERTON 1985). However, FREY & *al.* (1990) and PEMBERTON & *al.* (1992b) noted that the *Cruziana* ichnofacies can also occur in tidal-flat, lagoonal, or estuarine environments, but a presence of stenohaline organisms, eg. echinoids, suggests normal salinity marine conditions. The examined assemblage contains the typical trace fossils of the *Cruziana* ichnofacies, such as *Teichichnus* (SEILACHER 1967; PEMBERTON & *al.* 1992a, b) or variable oriented *Thalassinoides* and *Ophiomorpha* (FREY & SEILACHER 1980). The trace fossils were produced by deposit feeders (*e.g. Thalassinoides, Teichichnus*) and by suspension feeders (*Ophiomorpha* (?). Presence of these two trophic groups characterises the *Cruziana* ichnofacies (FREY & SEILACHER 1980). *Chondrites* and *Trichichnus* are rather typical of deeper, fine-grained low energetic, less oxygenated, fully marine environments. The *Chondrites* ichnofabric dominated by *Chondrites* represents probably deeper parts of the *Cruziana* ichnofacies. *Chondrites* is abundant in the upper offshore siliciclastic facies of the North American Seaway, and it became rare in the middle shoreface, where the distal *Cruziana* ichnofacies occurs (MACEACHERN & PEMBERTON 1992).

The *Thalassinoides* ichnofabric is very similar to the ichnofabrics of the *Thalassinoides*-dominated shallower-shelf chalk, in contrast to the *Zoophycos*-dominated deep-water settings of epicratonic and deep-sea chalk (EKDALE & BROMLEY 1984). The ichnofabric of the nodular marlstones is similar to some extent to the ichnofabric from nodular chalk from England (KENNEDY & GARRISON 1975), but it is very poorly developed.

The *Chondrites* ichnofabric indicates less oxygenated deposits than the *Thalassinoides* ichnofabric. *Chondrites* is common in poorly oxygenated deposits (BROMLEY & EKDALE 1984). Trace fossil diversity is lower in the former, and size of trace fossils is smaller. This is the typical phenomenon related to oxygen restricted environments (*e.g.* SAVRDA 1992, 1995, 1998, and references therein). Nevertheless, evidence of longer anoxia allowing for formation of laminated layers, is almost absent. Only in a few centimetres thick layer from the lower part of the Odra quarry section, poorly preserved primary lamination occurs (Pl. 2, Fig. 9). Very short anoxic events were, however, possible, but hypothetical thin layers related to these events were completely destroyed by subsequent bioturbation. It is not excluded that the very dark filling of some trace fossils derives from such layers.

There is a basic problem concerning the origin of the colour contrast between background and filling of the trace fossils. Some deeper open burrows, especially when abandoned, may have been depleted of oxygen. Formation of pyrite, especially along burrow walls that were lined with mucus, can take place very easy. Small pyrite particles can be responsible for the dark colour of some fillings. This diagenetic origin of the colour contrast may be true of some *Thalassinoides* and *Planolites* from the lower part of the Odra quarry section (Pl. 2, Fig. 3; Pl. 5, Figs 3-4) and should be treated rather as an exception. More likely, however, the colour contrast results from primary heterogeneity of sediments. Centimetre or decimetre thick layers of darker sediments enriched in organic matter and clay minerals can be deposited alternately with lighter layers of sediments enriched in carbonates and depleted of organic matter. Such a layering is common in fine-grained hemipelagic and pelagic environments and is related to Milankovitch cyclicity (FISCHER 1986, DE BOER & SMITH 1994). Burrows produced in lighter layer can be filled with sediments from the darker layer and vice versa. They form the so-called piping zone. Such a rhythmic layering with distinct piping zones has been recognized in the Upper Cretaceous Demopolis Chalk in Alabama, USA (LOCKLAIR & SAVRDA 1998).

Primary layering at a decimetre scale is only locally and then poorly preserved in the lower part of the Odra quarry section (Lower Clayey Marls), at the transition from the darker deposits with the *Chondrites* ichnofabric to the lighter deposits with the *Thalassinoides* ichnofabric (Pl. 2, Fig. 10). Dark filled trace fossils occur in a few light marlstone beds and form a piping zone. In the remaining part of the studied section only locally very indistinct colour changes reveal the primary layering. Nevertheless, traces of primary layering are evidence of rhythmic sedimentation of the studied deposits, which can be related to a cyclicity. Scour cycles, manifested mainly by omission surfaces can be excluded because the latter were not found. The nodular marlstones from the upper part of the Odra quarry display dissolution surfaces, but it is not clear whether they can be related to some dissolution cycles or only to nodule formation. For the remaining part of the sections, by the elimination, only productivity and dilution cycles remain to account for the primary layering.

Apart of the problematic decimetre scale rhythms, there are a few metres thick rhythms expressed by variations in the content of calcium carbonate. They lasted about 100 Ky, as can be calculated from the inoceramid stratigraphy by WALASZCZYK (1992). This corresponds to Milankovitch' eccentricity cycles. In consequence, the decimetre scale rhythms may be related to obliquity or precession cycles. However, these problems need further studies.

Primary differences in sediment characters are also indicated by diffrent grain size in the burrow fillings and background sediment. Especially some *Thalassinoides* (Pl. 3, Fig. 4) and *Planolites* (Pl. 5, Figs 1-2) from the *Thalassinoides* ichnofabric contain coarser, calcarenitic sediment, while the background is composed of calcilutitic sediment. Probably, the calcarenitic sediment was transported into deeper environments by storms. Nevertheless, thin tempestite beds are not preserved owing to intensive bioturbation. Similar processes have been described from the Caribbean region (WANLESS & *al.* 1988, TEDESCO & WANLESS 1991), where some recent storm-derived sediments are preserved only in *Callianassa* burrows and form so-called tubular tempestites. The absence of tempestites preserved in beds in the investigate sections suggests indirectly a deeper and calmer environment beyond the range of thick tempestites, which would have resisted destruction by bioturbation.

It was considered that the discussed deposits represent a single transgressive – regressive cycle with a Late Turonian maximum of transgression (ALEKSANDROWICZ 1974, TARKOWSKI 1991). The cited authors regarded the clayey units, especially the Lower Clayey Marls and the Upper Clayey Marls, to have been supplied with clay minerals from the land. The most calcareous Marly Limestone Unit in their opinion was deposited in a wide basin, far away from the land, in a deeper setting, with minimum influence of terrigenous material. In our opinion the opposite explanation is possible, which corresponds well to the sea level curve of HAQ & *al.* (1987). The Marly Limestone Unit represents much shallower palaeoenvironments than underlying and overlying more clayey units. The background supply of clay was constant, but production of carbonate fluctuated and derived mainly from coccolithophorids (KĘDZIERSKI, 1995).

The *Chondrites* ichnofabric can be related to Oceanic Anoxic Events (OAE). In the lower part of the Odra quarry (Lower Clayey Marls) it corresponds to the OAE at the Cenomanian/Turonian boundary and Early Turonian (*e.g.* ARTHUR & SCHLANGER 1979; JENKYNS, 1980). The *Chondrites* ichnofabric in the upper part of the Folwark quarry (Upper Clayey Marls) can be connected to the Middle Coniacian OAE (*e.g.* ARTHUR & SCHLANGER 1979; JENKYNS 1980). In the siliceous marls rich in radiolaria (Upper Clayey Marl), the *Chondrites* ichnofabric may also reflect a deeper palaeoenvironment.

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PLATE 1

Trace fossils from the Opole marls

1 – *Chondrites* isp. (Ch) and *Planolites* isp. (Pl). Weathered horizontal parting surface. Siliceous marlstone (Upper Clayey Marls), Folwark quarry, 161P8.

2 – *Chondrites* isp. (Ch), *Planolites* isp. (Pl) and *Thalassinoides* isp. (Th). Polished and oiled slab, vertical section. Marlstone (Upper Marls), Folwark quarry, 161P9 (F15).

3 – *Ophiomorpha* isp. Horizontal parting surface. Marlstone (Upper Marls), Folwark quarry, 161P10(F30).

4 – *Phycosiphon* isp. (Ph). Polished and oiled slab, vertical section. Marlstone (Upper Marls), Folwark quarry, F4.

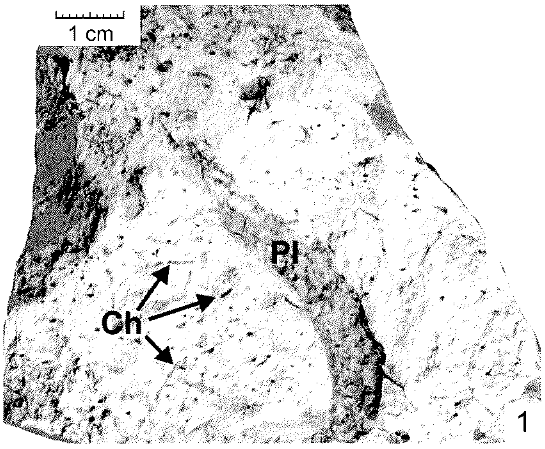
5 – *Palaeophycus* isp. (Pa), *Chondrites* isp. (Ch) and *Planolites* isp. (Pl). Polished and oiled slab, vertical section. Marlstone (Lower Marls), vertical cross section. Odra quarry, 161P11(P12).

6 – *Planolites* isp. Horizontal parting surface. Marlstone (Upper Marls), Folwark quarry, 161P12(F29).

7 – *Palaeophycus* isp. (Pa) and *Chondrites* isp. (Ch). Polished and oiled slab, vertical section in marlstone (Lower Marls). Odra quarry, P15.

8 – *Teichichnus* isp. Polished and oiled slab, oblique section in marlstone. Folwark quarry (Upper Marls), 161P13(F15).

9 – *Taenidium* isp. (Ta) and *Thalassinoides* isp. (Th). Polished and oiled slab, oblique section in marlstone (Upper Marls). Folwark quarry, 161P14(F17).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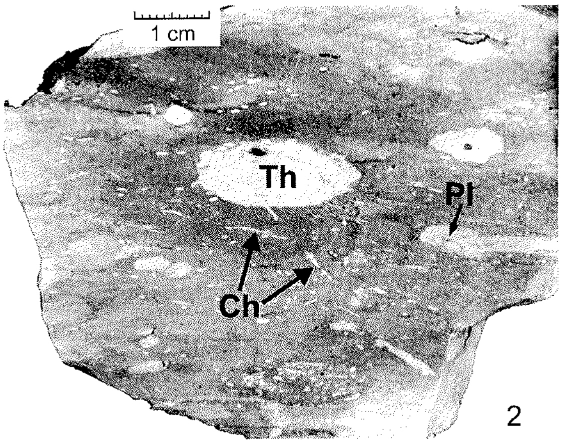
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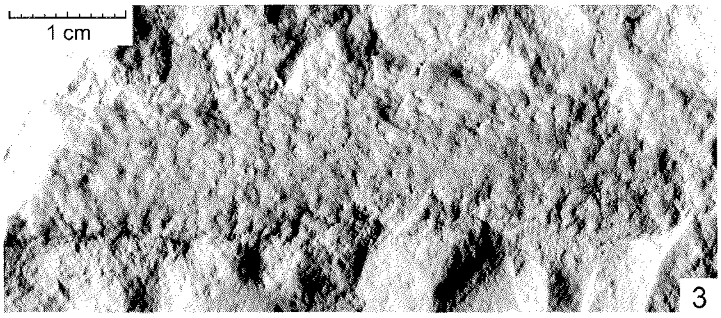
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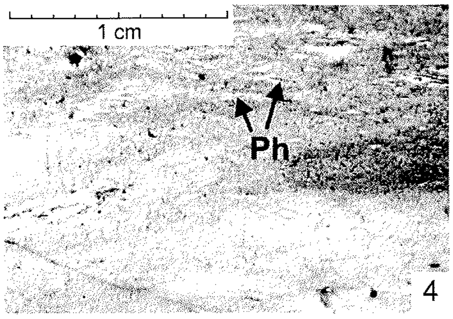
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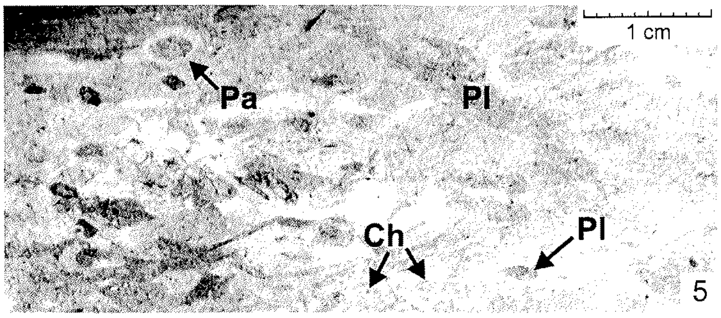
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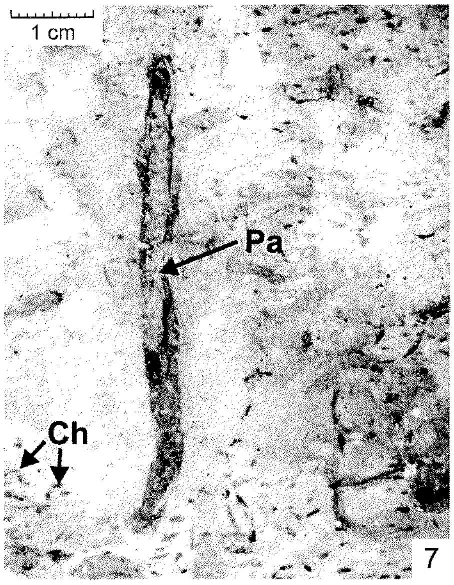
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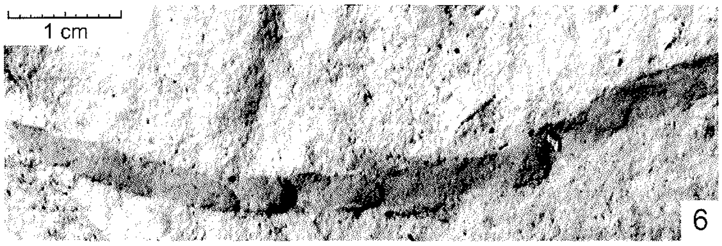
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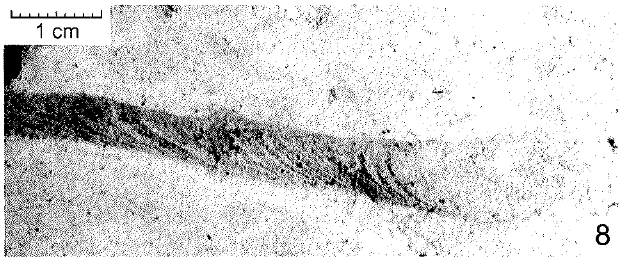
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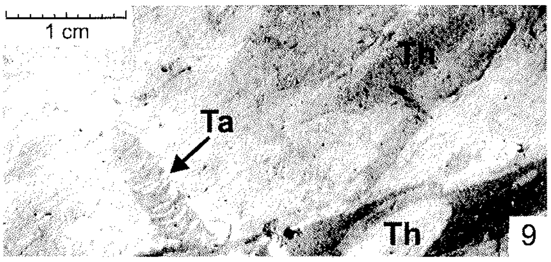
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9

PLATE 2

Trace fossils and ichnofabrics from the Opole marls

1 – Large *Thalassinoides* isp. Horizontal parting surface. Marlstone (?Lower Marls), Odra quarry. Field photography. Courtsey by J. SZULC.

2 – *Thalassinoides* isp. filled with carbonized plant detritus. Marlstone (Lower Marls), Odra quarry. Field photography.

3 – Pyritized *Thalassinoides* isp. Horizontal parting surface. Marlstone (Lower Clayey Marls), Odra quarry. 161P1.

4 – *Thalassinoides* isp. (Th), *Chondrites* isp. (Ch) and *Planolites* isp. (Pl). Polished and oiled slab, vertical section. Marlstone (Upper Marls), Folwark quarry, 161P2(F10).

5 – *Trichichnus linearis* FREY. Vertical parting surface. Marlstone (Lower Clayey Marls), Odra quarry, 161P3.

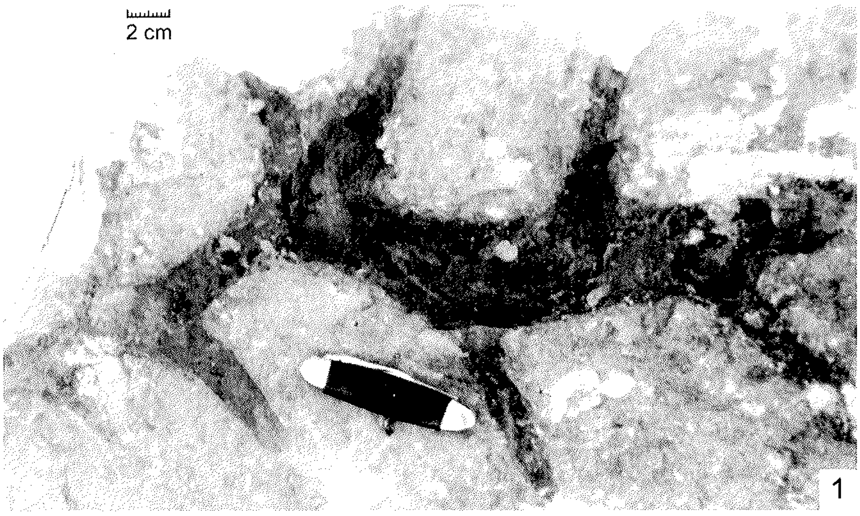
6 – *Trichichnus* isp. Vertical parting surface. Marlstone (Lower Clayey Marls), Odra quarry. 161P4.

7 – *Trichichnus* isp., horizontal parting surface; marlstone (Upper Clayey Marls), Folwark quarry, 161P5(F55).

8 – Black lamina in vertical cross-section, polished and oiled surface, vertical section; marlstone (Upper Marls), Folwark quarry, 161P6(F2).

9 – Partially bioturbated muddy marlstone, primary lamination in the upper part; Lower Clayey Marls, Odra quarry, 161P7.

10 – Small scale-rhythmicity in the Lower Clayey Marls, Odra quarry; light bioturbated marlstone layer interbedded with darker, partially bioturbated muddy marlstones; field photography.



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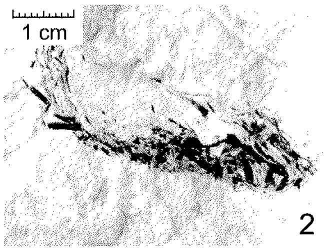

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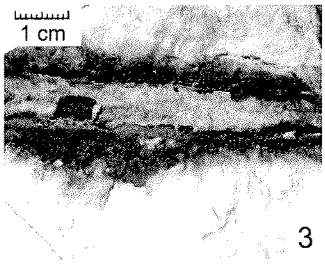

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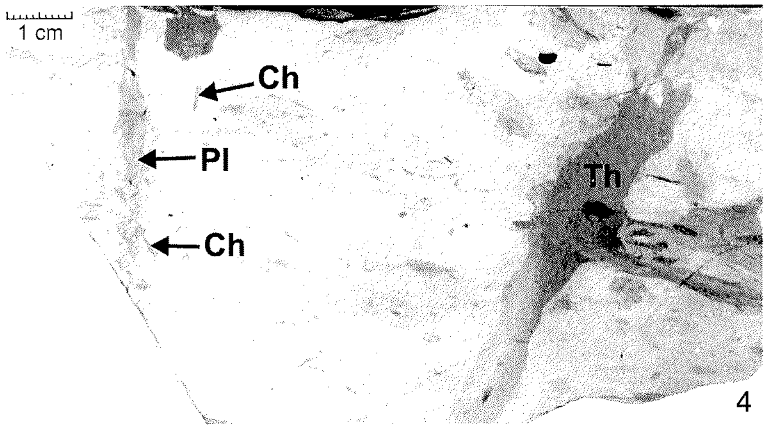

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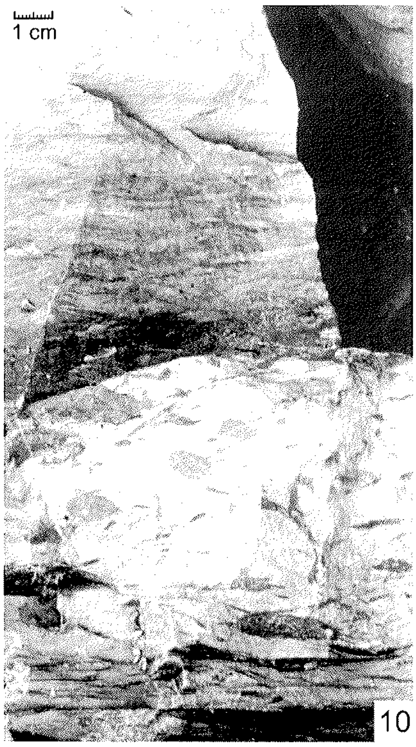

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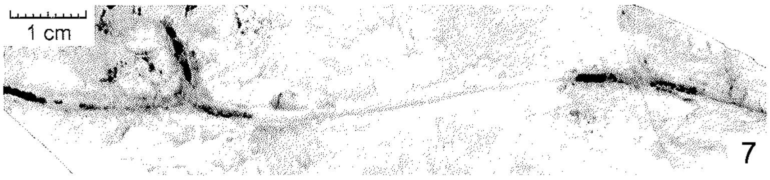

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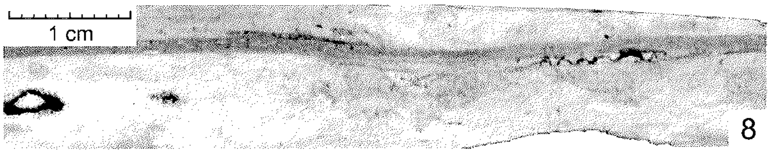

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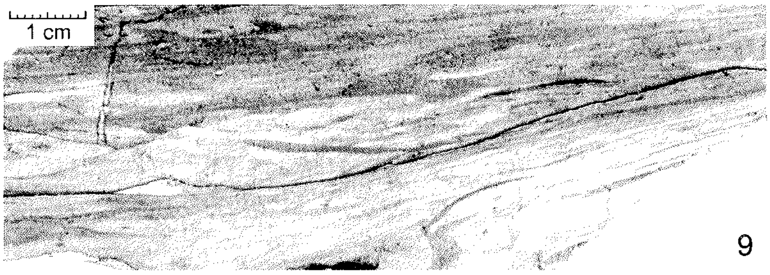

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PLATE 3

Chondrites ichnofabrics from the Opole marls in polished and oiled slabs

1 – *Chondrites* isp. (Ch), *Planolites* isp. (Pl), and *Thalassinoides* isp. (Th); marls (Lower Clayey Marls), Odra quarry, P7.

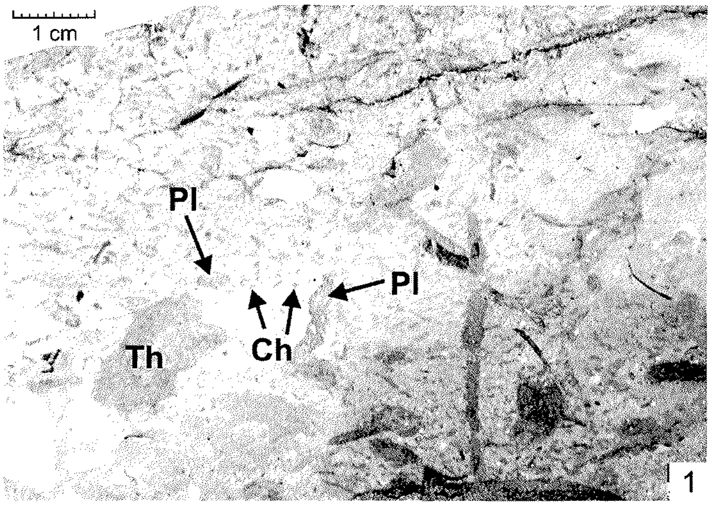
2 – *Chondrites* (light fine spots); glauconitic marly mudstone, Lower Clayey Marls, Odra quarry, P4.

3 – Black laminae, *Chondrites* isp. (Ch) and *Thalassinoides* isp. (Th); vertical cross section; marly mudstone (Lower Clayey Marls), Odra quarry, 161P15(P3).

4 – Calcarenite mixed with calcilutite by bioturbation, *Chondrites* isp. (Ch), *Planolites* isp. (Pl), and *Thalassinoides* isp. (Th); vertical cross section; marlstone (Lower Clayey Marls), Odra quarry, 161P16(P5).

5 – *Taenidium* isp. (Ta) and *Chondrites* isp. (Ch). Marls (Lower Marls), horizontal section; Odra quarry, 161P17(P21).

6 – *Chondrites* isp. (Ch), *Trichichnus* isp. (Tr) and *Planolites* isp. (Pl); note the diagenetic halo around *Trichichnus*; siliceous marlstone (Upper Clayey Marls), horizontal section, Folwark quarry, 161P17(F52).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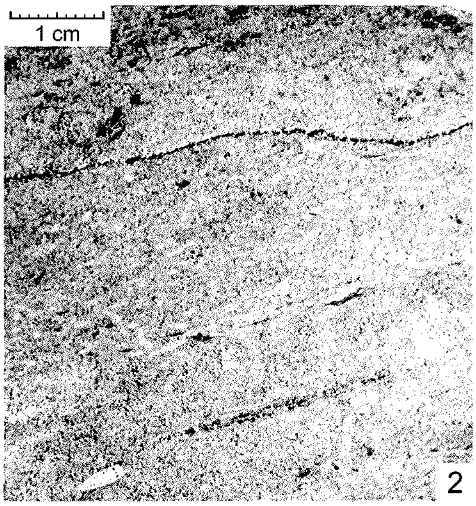
1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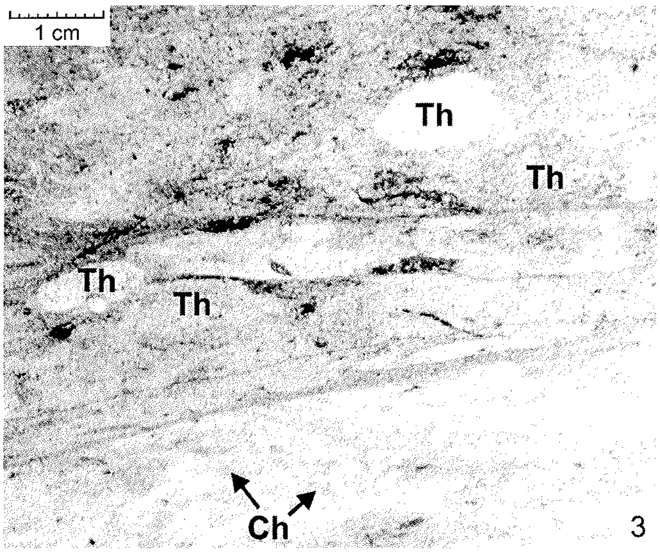
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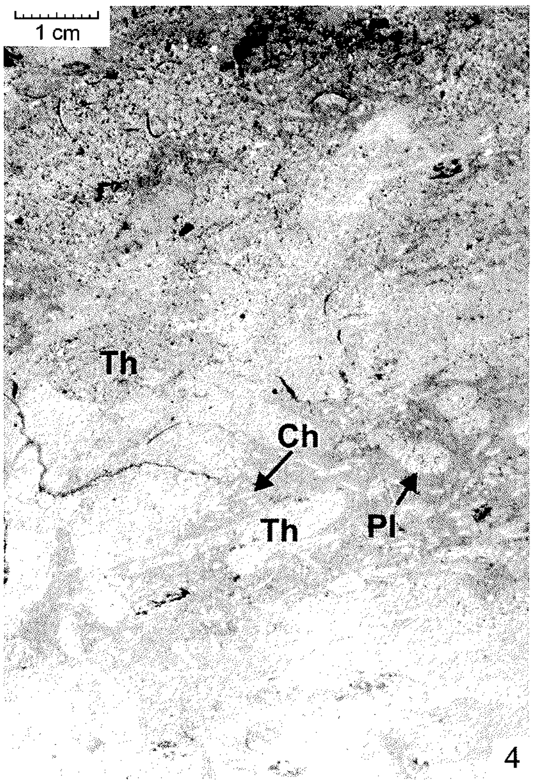
3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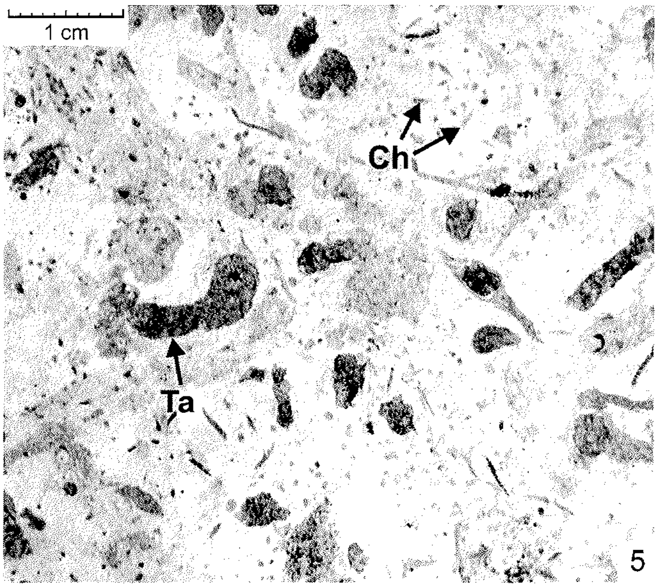
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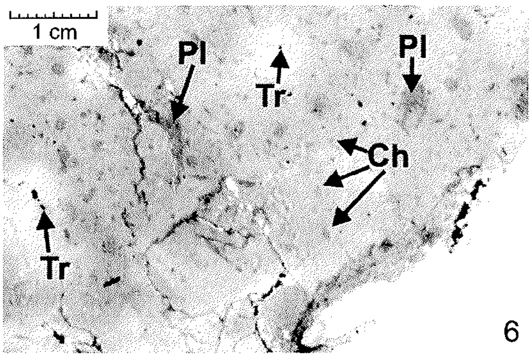
5


1 cm
Pl
Tr
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6

PLATE 4

Chondrites ichnofabrics from the Opole marls in polished and oiled slabs

1 – *Chondrites* isp. (Ch), *Planolites* isp. (Pl), and *Thalassinoides* isp. (Th); marl (Upper Marls), vertical cross-section; Folwark quarry, 161P18(F19).

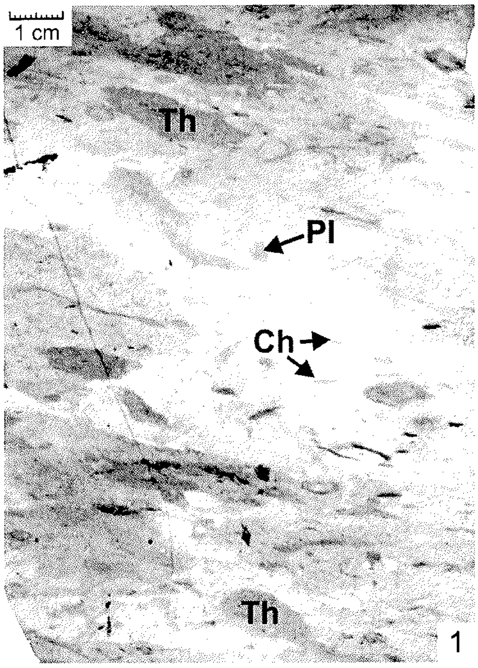
2 – *Chondrites* isp. (Ch), *Planolites* isp. (Pl), and *Thalassinoides* isp. (Th) in nodular marlstone (Upper Marls), vertical cross-section; Folwark quarry, 161P19(F16).

3 – Vertical shafts of *Thalassinoides* isp. (Thv), horizontal *Thalassinoides* isp. (Th), *Planolites* isp. (Pl); in background, several poorly preserved *Chondrites*; marlstone (Lower Clayey Marls), Odra quarry, 161P20(P7).

4 – *Planolites* (Pl) reworked by *Chondrites* isp. (Ch) and *Thalassinoides* isp. (Th); marlstone (Upper Marls), horizontal section; Folwark quarry, 161P21(F25).

5 – *Teichichnus* isp. (Te), *Chondrites* isp. (Ch), *Planolites* isp. (Pl), and *Thalassinoides* isp. (Th); marlstone (Upper Marls), vertical section; Folwark quarry, 161P22(F8).

6 – *Thalassinoides* isp. (Th) reworked by *Phycosiphon* isp. (Ph); vertical cross section; marlstone (Upper Marls), Folwark quarry, 161P22(F37).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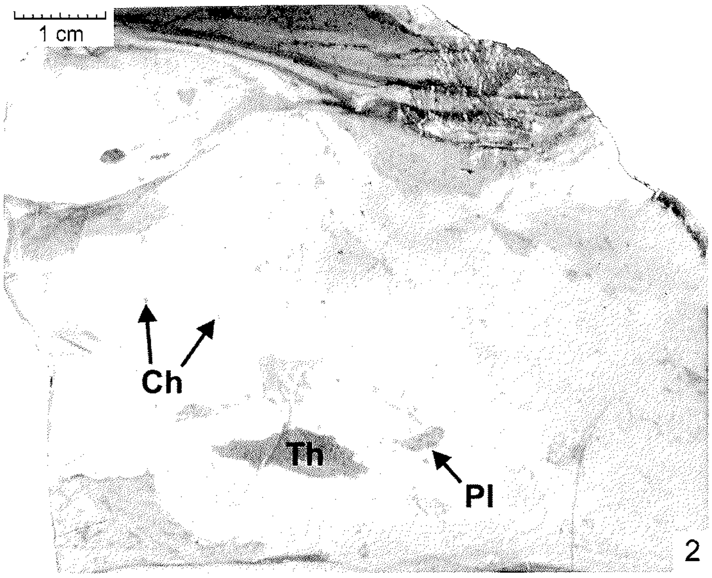
Th

1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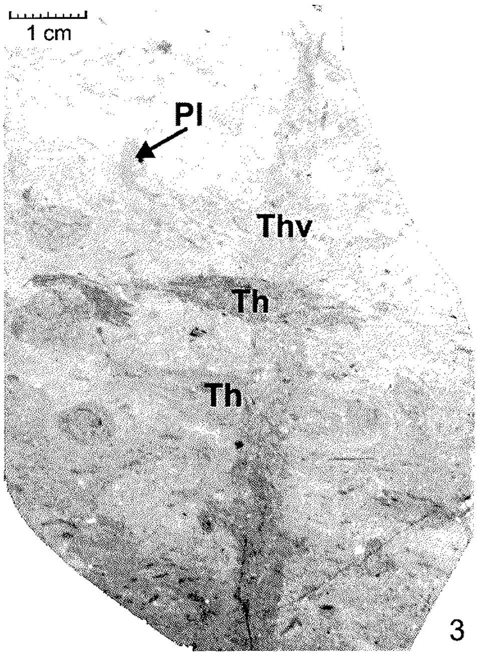
Ch
Th
Pl

2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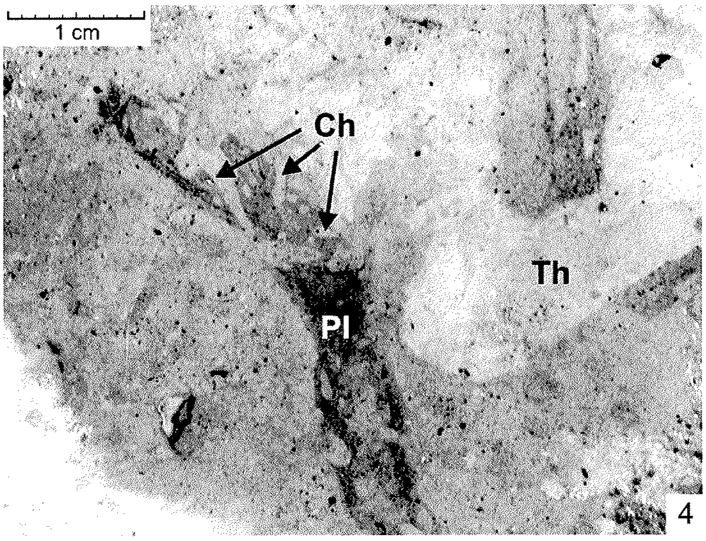
Pl
Thv
Th
Th

3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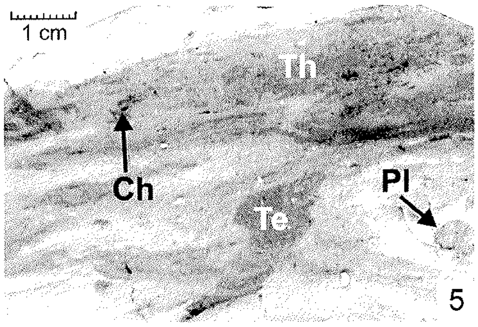
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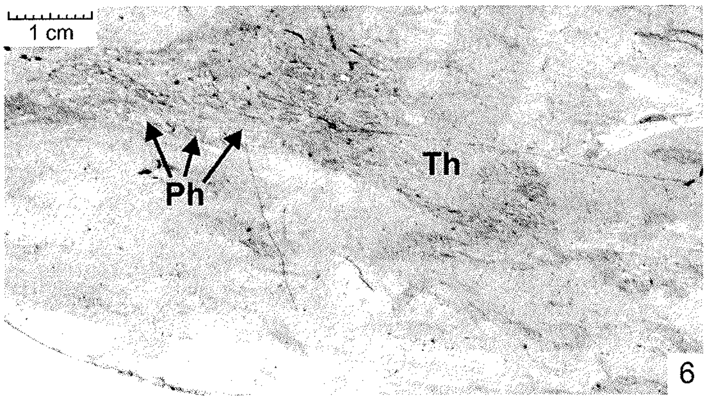
Th
Ch
Pl
Te

5


1 cm
Ph
Th

6

PLATE 5

Ichnofabrics in microfacies from the Odra quarry

1 – *Planolites* isp. burrow (Pl) in micritic marlstone filled with biosparite; Lower Clayey Marls, P7.

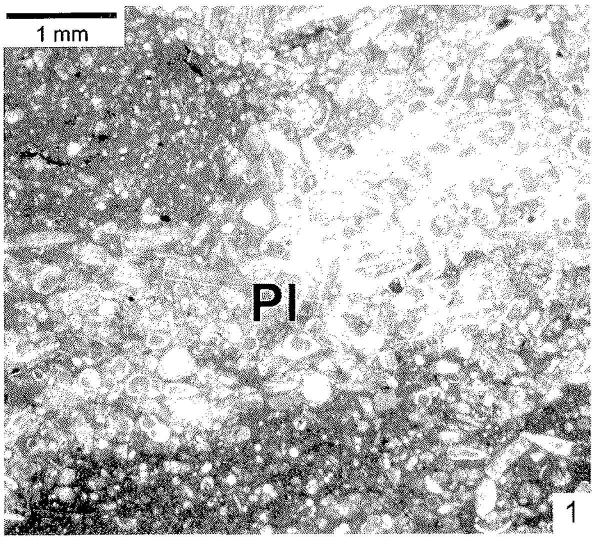
2 – *Planolites* isp. burrow (Pl) in micritic marlstone filled with biosparite, and re-burrowed by *Chondrites* isp. (Ch) filled with micritic marlstone; Lower Clayey Marls, P7.

3 – *Planolites* isp. burrow (Pl) with dispersed pyrite grains; Lower Marls, P12.

4 – *Planolites* isp. burrow (Pl) at the centre with dispersed pyrite grains; Lower Marls, P23.

5 – Microfacies contrast between *Planolites* isp. burrow (Pl) and background; Lower Marls, P24.

6 – Microfacies contrast between *Chondrites* isp. (Ch) burrow and background; Lower Marls, P23.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Pl
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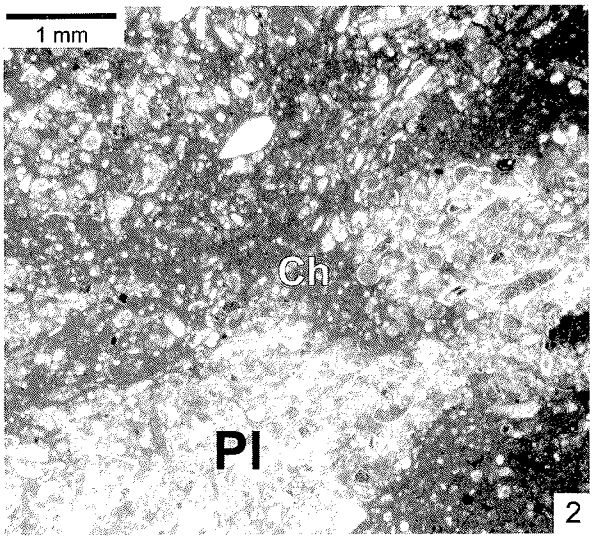
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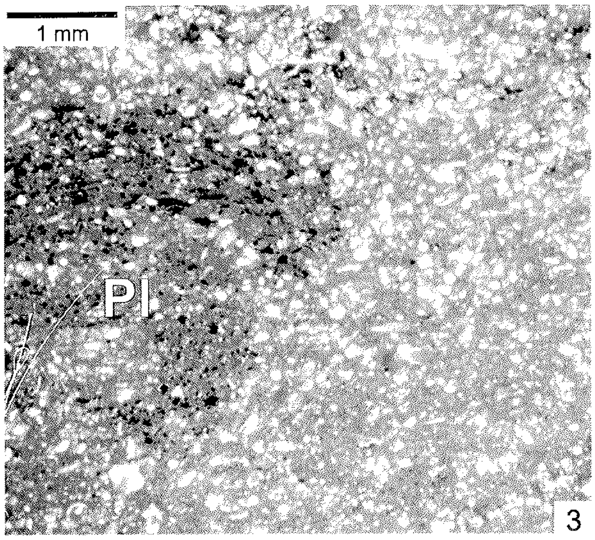
Ch
Pl
2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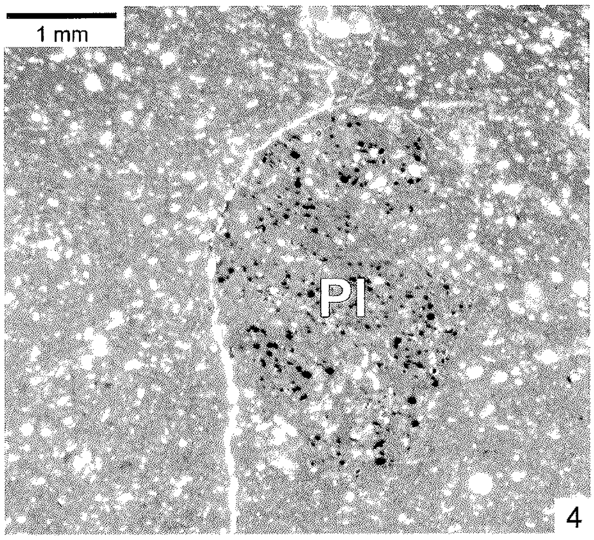
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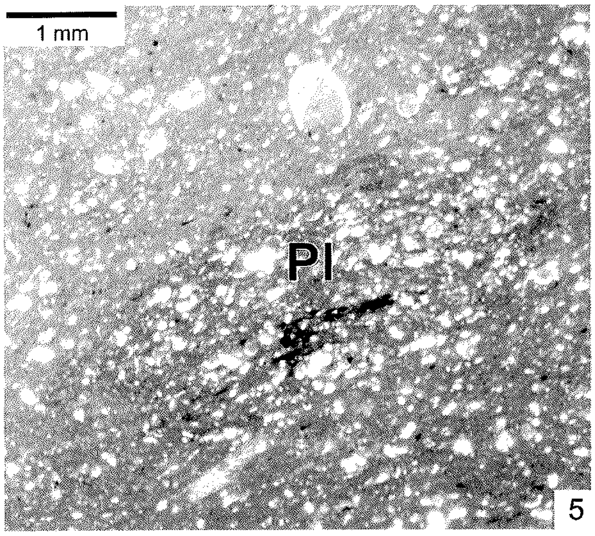
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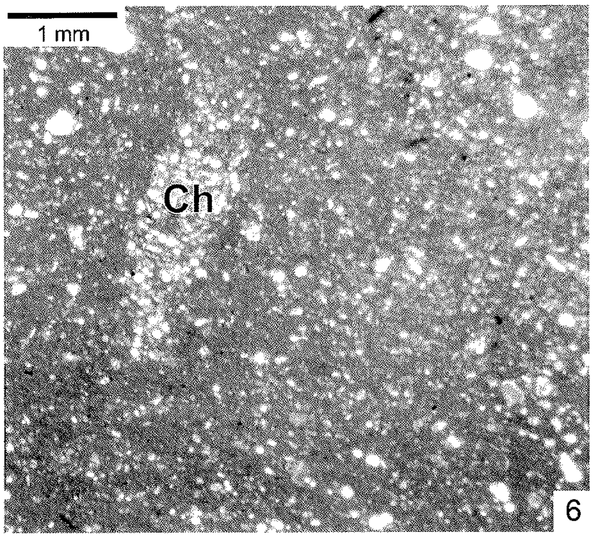
Pl
5


1 mm
Ch
6