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Exceptional Preservation in the Jurassic of Osteno

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Exceptional preservation in the Jurassic of Osteno

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[Plates 1–3]

The Sinemurian deposit of Osteno, discovered in 1964, is remarkable for the exceptional preservation of its fossils. They are almost exclusively non-calcareous organisms such as fishes, crustaceans, polychaetes and nematodes. Their exceptional fossilization is due to a metasomatic process implying a molecule-for-molecule replacement of the organic material by colloidal calcium phosphate, a process that has permitted the preservation of the soft tissues of the organisms in some cases even to cellular level.

The Osteno deposit formed on a poorly oxygenated sea bottom inhabited by fauna with a low taxonomic diversity, in some cases monotypic. Infaunal organisms are not found in the deposit since the H_2S–O_2 boundary was probably situated slightly below the water–sediment interface.

1. Introduction

The deposit of Osteno, discovered in 1964 (Pinna 1967), outcrops in a series of quarries situated in Lombardy, along the shore of Lake Lugano. The deposit is not extensive and contains a rather sparse fossil assemblage, chiefly crustaceans, cephalopods, polychaetes, nematodes, ophiuroids, fishes and plants. It is, however, notable for the exceptional fossilization, including the preservation of the soft tissues of the organisms.

Although the deposit was discovered in 1964 and the first data on the fauna were published in 1967, systematic study only began in 1980, with the opening of an excavation by the Museum of Natural History of Milan. Hence the data relating to the composition of the fauna are limited, and the study of the sedimentary environment and modes of fossilization is only at the preliminary stage. For these reasons I must limit myself to a general review of the deposit and its fossils, emphasizing, however, the sedimentary and faunal characteristics hitherto noted and which seem pertinent to a reconstruction of the sedimentary environment and of the mechanisms responsible for the exceptional preservation of the organisms.

2. The fossiliferous formation

The Jurassic Osteno fossiliferous formation consists of a compact, unstratified bed of grey spongolithic micrite, 4 m thick, incorporated in the otherwise unfossiliferous Lombardische Kieselkalk Formation.

The bed is delimited at the top and bottom by non-fossiliferous layers of marl that grade into layers of saccharoidal limestone without any fossils. These, in turn, are linked to the Lombardische Kieselkalk. The fossiliferous series seems to be the result of a single sedimentary episode, limited both in time and space. This would appear to have interrupted the normal sedimentation locally and for only a short period (figure 1).

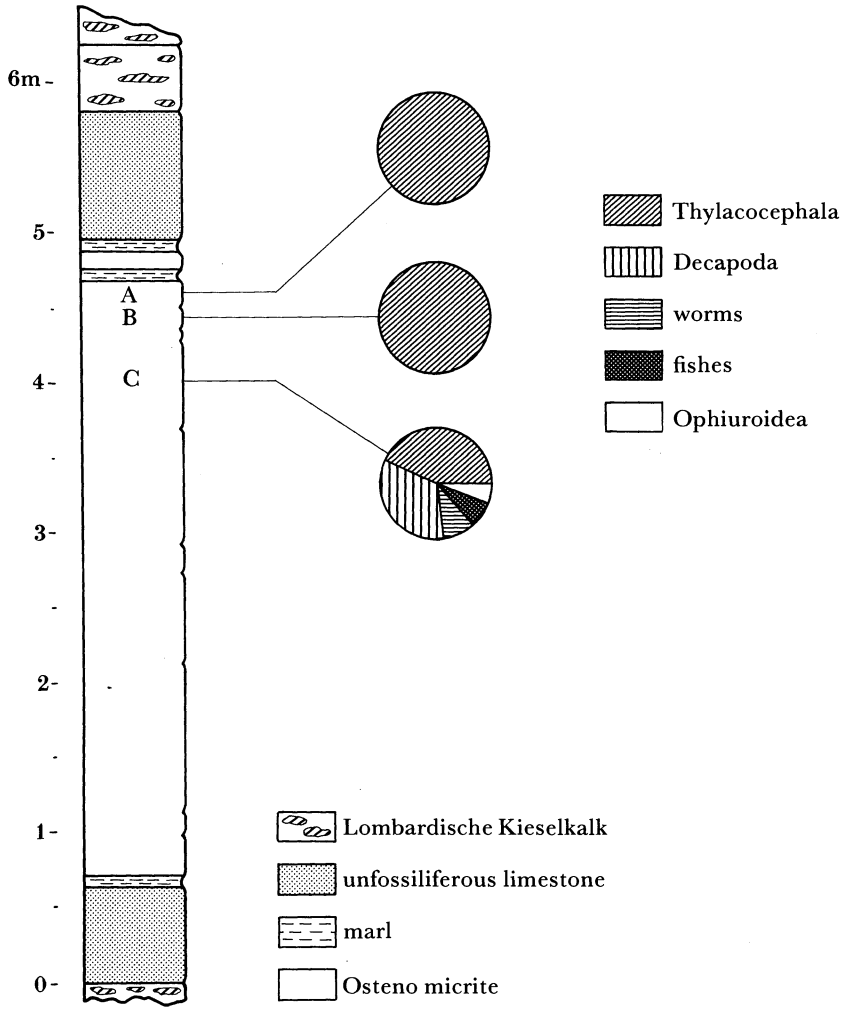

FIGURE 1. The Osteno fossiliferous series.

The fossiliferous rock consists of microcrystalline calcite containing granules of pyrite, often altered into haematite, and diffuse limonitic material. The rock abounds in monaxon spicules of sponges and radiolarians, originally siliceous but now totally or partly replaced by calcite. Locally small geodes are to be found containing volatile hydrocarbons. The rock does not contain either foraminifers (apart from one specimen of *Nodosaria*) or nanoplankton.

The fossiliferous rock is extremely homogeneous; it is not stratified but shows a false stratification due to post-sedimentary phenomena. These very fine laminations are determined by a rhythmical alternation of levels with greater and lesser concentrations of limonitic material. This lamination is very regular through the whole thickness of the fossiliferous bed. No other sedimentary structures are present: there are no traces of cross lamination, grading, current patterns or bioturbation.

3. DATING THE OSTENO FORMATION

It has been possible to date the Osteno fossiliferous series thanks to the discovery of ammonites of the genera *Sulciferites*, *Ectocentrites* and *Coroniceras*, indicating a Sinemurian age.

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In particular the finding of the species *Coroniceras bisulcatum* (see figure 7, plate 1) places the fossiliferous series in the Lower Sinemurian '*bucklandi zone*'.

This age is confirmed by similarities existing between part of the Osteno fossil fauna and that of the Sinemurian of Lyme Regis, Dorset, England. Some organisms found at Osteno, in particular the crustacean decapods and the genus *Squaloraja*, are directly comparable to those found in the Dorset deposit.

4. Composition of the fossil association

Fossil remains are present throughout the whole thickness of the fossiliferous series: 1308 specimens have been found to date (see table 1). The majority of these have been found between 1964 and 1979, without any precise indication of their position within the stratigraphic sequence. Hence they do not offer any insight into the statistical distribution of taxa within the sequence.

Table 1. Composition of the fossil association

taxon	number of specimens
Brachiopoda	2
Pelecypoda	2
Cephalopoda Ammonoidea	23
Cephalopoda Coleoidea	3
Crustacea Decapoda	
Penaeidea	186
Astacidea Erymidae	51
Palinura Glypheoidea	233
Eryonoidea	76
undetermined decapods	74
Crustacea Hoplocarida	2
Crustacea Thylacocephala	398
Annelida Polychaeta Errantida	13
Nematoda	6
Ophiuroidea	33
Enteropneusta	1
fishes	159
Equisetopsida	3
Cycadeoideopsida	4
Caytoniales	7
Coniferopsida	22
undetermined plants	12

The taxa represented in the Osteno deposit are listed in table 1. The fossil association of Osteno (figure 2) has the following composition (in terms of numbers of individual specimens): 50.39% crustacean decapods; 28.90% crustacean Thylacocephala; 11.55% fishes; 3.49% land plants; 2.40% Ophiuroidea; 1.89% cephalopods; 0.94% polychaetes; 0.44% nematodes. These percentages refer to the entire fossiliferous association regardless of the localization of the fossils in the different stratigraphic levels. Hence they do not reflect the effective distribution of the taxa in the various fossiliferous levels.

Only part of the fossil association has been studied: Crustacea Erionoidea (Pinna 1968, 1969); Cephalopoda Coleoidea (Pinna 1972); Thylacocephala (Arduini *et al.* 1980, 1984; Pinna *et al.* 1982, 1984); Enteropneusta (Arduini *et al.* 1981); Polychaeta (Arduini *et al.* 1982*a*);

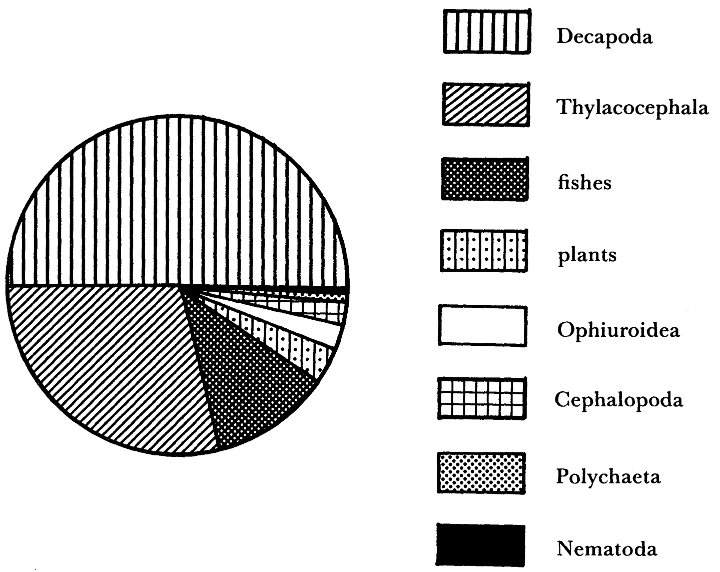


FIGURE 2. Percentage distribution of taxa in the Osteno deposit.

Nematoda (Arduini *et al.* 1983) and land plants (Bonci & Vannucci 1985). The fishes are being studied by Dr Colin Patterson of the British Museum (Natural History).

(*a*) *Cephalopoda*

The cephalopods are represented by ammonites of the genera *Coroniceras*, *Ectocentrites* and *Sulciferites* and by the remains of Coleoidea, mostly hooks either isolated, or contained in the regurgitations and in the gastric remains of the Thylacocephala.

Only three specimens of partly complete Coleoidea have been found. However, one of these is relatively complete with arms, hooks *in situ*, traces of the muscles and the jaw apparatus. It has not been possible to observe the ink sac in any of these specimens.

(*b*) *Crustacea Decapoda*

The crustacean decapods include the suborder Peneidea with numerous specimens of the genus *Aeger*, the suborder Astacidea with the genera *Eryma* and *Phlyctisoma* and the suborder Palinura with the genera *Glyphea*, *Mecochirus*, *Pseudoglyphea* and *Coleia*.

(*c*) *Crustacea Hoplocarida*

The two specimens found are not well preserved: they can be attributed to the order Stomatopoda, of which they are the oldest known representatives.

(*d*) *Crustacea Thylacocephala*

The class Thylacocephala was established in 1982 on the basis of specimens found in the Osteno formation (Pinna *et al.* 1982). The class is represented by about 400 specimens, the majority of which are attributed to the species *Ostenocaris cypriformis* (Arduini *et al.* 1982*a*, *b*, 1984). However, the possibility cannot be excluded that other species may be present in the deposit.

The Thylacocephala have been interpreted as benthonic necrophagous organisms lacking developed sense organs, without eyes, and having a cephalon modified into a large cephalic sac that acted as an attachment device on soft marine bottoms.

The specimens are exceptionally preserved. In many of them, besides the chitinous carapace, the cephalic sac, the three pairs of cephalic appendages, the segmented thorax with short thoracopods and the recessed abdomen have also been preserved. In some specimens the branchiae, the muscles and the stomach with its gastric contents are preserved too (figures 12, 13, plate 2; figures 15–18, plate 3).

(*e*) *Annelida Polychaeta*

Thirteen specimens of polychaetes of the order Errantida have been attributed to the new taxon *Melanoraphia maculata* (Arduini *et al.* 1982*a*, *b*) analogous to the living genus *Lumbrinereis*. The specimens are about 15 cm long. Their jaw apparatus, originally chitinous, has been preserved together with the aciculae bordering the body on both sides and the imprint of the body in which the stomach is visible. Along the body itself some marks are visible, they are interpreted as traces of the original colour (figure 8, plate 1).

(*f*) *Nematoda*

The phylum is represented by six specimens placed within the new taxon *Eophasma jurasicum* (Arduini *et al.* 1983). In these specimens the musculature of the pharynx and the oesophagus can be distinguished (figure 6).

(*g*) *Ophiuroidea*

The group is represented by 33 small specimens (average diameter 8 mm) which will be referred to the genus *Palaeocoma*.

(*h*) *Enteropneusta*

A very rare fossil enteropneust, entirely soft-bodied, has been found in the Osteno deposit. The specimen has been named *Megaderaion sinemuriense* (Arduini *et al.* 1981). It is a small specimen, about 20.5 mm long. The body is divided into three distinct parts: an ogival portion interpreted as a proboscis, an intermediate rectangular part interpreted as a collar and a terminal vermiform portion stretched out and folded back, interpreted as the branchiogenital region and as the tail. In the branchiogenital region the external gonads are visible. *Megaderaion sinemuriense* (figure 10) is analogous to the living genus *Stereobalanus*.

(*i*) *Fishes*

According to the data supplied by Patterson a new genus of eel-shaped neoselachian shark predominates among the Osteno fishes. Representatives of the genera *Pholidolepis* and *Pholidophorus* and isolated scales of coelacanths analogous to the genus *Holophagus* are quite frequent. Representatives of the genera *Cosmolepis*, *Furo* and *Dapedium* and the hybodont sharks are rare.

The species *Squaloraja polyspondyla* and the genera *Placopleurus* and *Pteroniscus* together with the holocephalan group Myriacanthidae are each represented by one specimen.

(*j*) *Plants*

In the deposit there are no remains of recognizable marine plants whereas land plants are relatively abundant. The Equisetopsida are represented by the genus *Equisetites*, the Caytoniales by the genus *Pachypteris*, the Cycadeoideopsida by the genera *Zamites* and *Otozamites*, and the Coniferales by the genera *Brachyphyllum* and *Pagiophyllum*.

(*k*) *Trace fossils*

Coprolites are very frequent in the deposit. To a lesser extent gastric remains have been found, containing onychites and vertebrae of small selachians. These have been interpreted as gastric remains of crustacean Thylacocephala. In fact the same association of onychites-vertebrae of selachians has been observed in the stomach of some large specimens of Thylacocephala (figures 15, 18).

The systematic research started in 1980 has explored the first three upper levels of the series (levels A, B, C). Only large specimens of crustacea Thylacocephala were found in the levels A and B; level C contains large and medium-sized Thylacocephala, crustacean decapods belonging to different taxa, errant polychaetes, ophiuroids and various fishes in the percentages noted in figure 11.

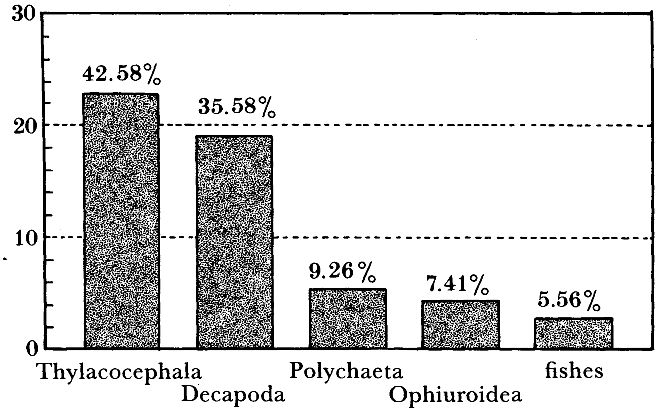


FIGURE 11. Percentage distribution of taxa in level C, Osteno deposit.

5. PRESERVATION OF THE FOSSILS

The organisms preserved in the Osteno deposit are almost exclusively non-calcareous organisms such as crustaceans, polychaetes, nematodes, fishes and plants. Among the calcareous organisms present are those with entirely calcitic skeletons, such as ophiuroids and brachiopods, but these none the less are very rare. Organisms with aragonitic shells and structures are not preserved. Only moulds, imprints and the phosphatic, corneous or chitinous parts of aragonitic organisms have been preserved. One of the two pelecypods found in the deposit is fossilized as an internal cast, whereas the second has been preserved as a shell imprint. The calcareous

DESCRIPTION OF PLATE 1

FIGURE 3. Es. i 6362, ammonite with fractured and dislocated siphuncle (magn. ×4.3).

FIGURE 4. Es. i 6360a, *Sulciferites* sp. with periostracum (magn. ×2).

FIGURE 5. Es. i 6361, ammonite with *Anaptychus* (magn. ×3.2).

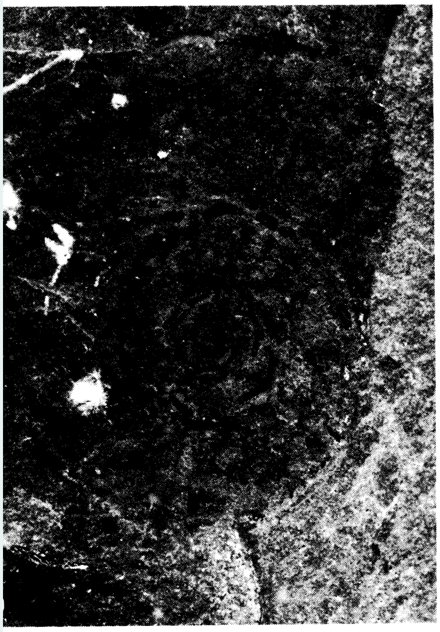
FIGURE 6. Es. i 784, *Eophasma jurasicum* (magn. ×2.2).

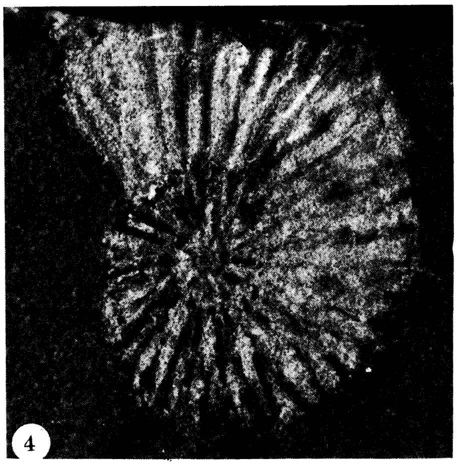
FIGURE 7. Es. i 6359, *Coroniceras bisulcatum* (magn. ×1).

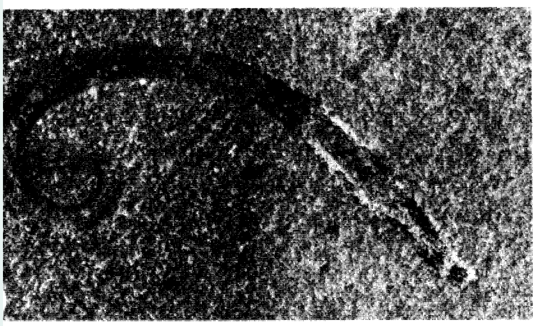
FIGURE 8. Es. i 1366, *Melanoraphia maculata* (magn. ×1.2).

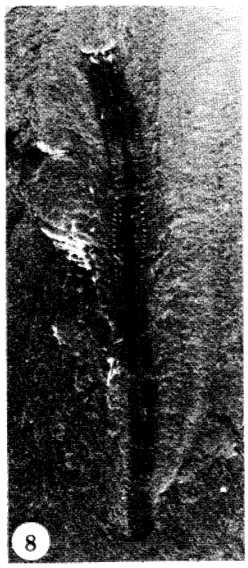
FIGURE 9. Es. i 6264, section of bundle of the stomach muscle of *Ostenocaris cypriformis*, in which the fibres are preserved (magn. ×1720).

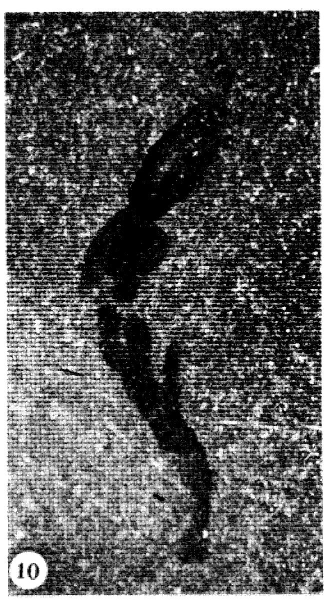
FIGURE 10. Es. i 751, *Megaderaion sinemuriense* (magn. ×4.5).











FIGURES 3–10. For description see opposite.

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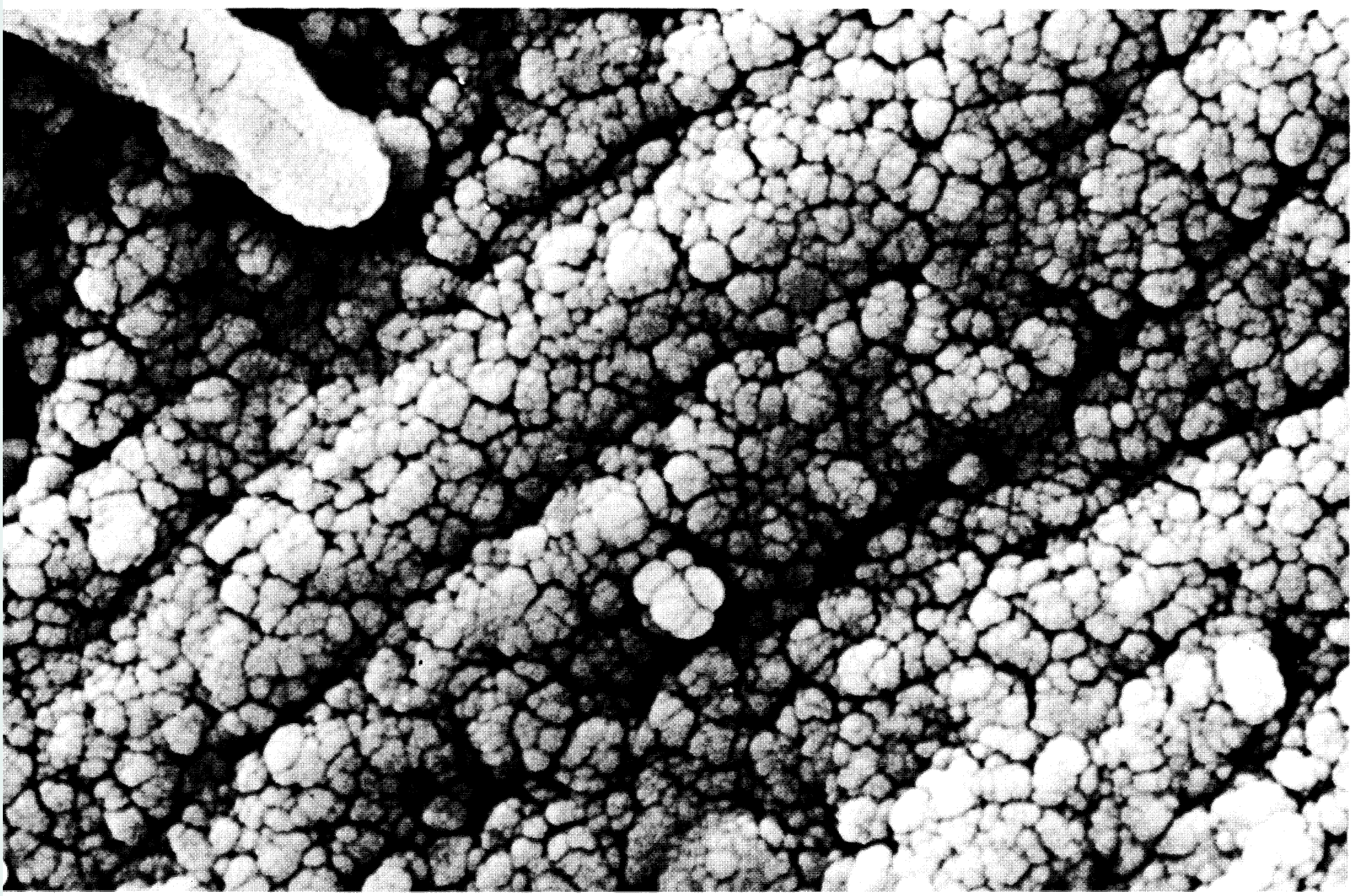

FIGURES 12 AND 13. Es. i 6263, retractor muscle of *Ostenocaris cypriformis* substituted by calcium phosphate (magn. ×2500 and 11000).

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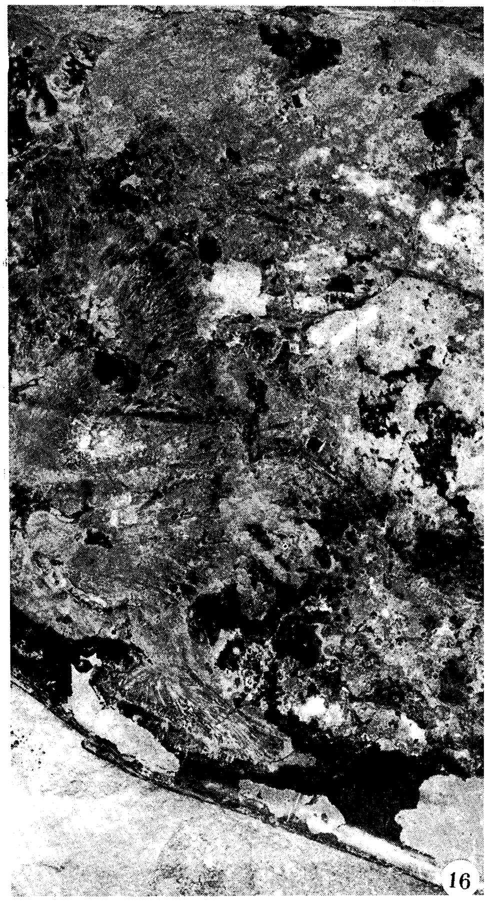

FIGURES 15–18. For description see opposite.

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parts of the ammonites, such as the shell and the septa, are not preserved. In some specimens only the periostractum is present, other specimens consist only of the imprint of the shell (figures 4, 7). The non-calcareous siphuncle and the chitinous anaptychus are often fossilized (figures 3, 5).

The preservation of the non-calcareous organisms on the other hand is exceptional. Besides the more resistant parts of the organisms, such as the hooks of the Coleoidea, the scolecodonts, the scales of the fishes and the exoskeleton of the arthropods, many much more perishable structures are preserved. These include the muscles and branchiae of the Thylacocephala, the arms of the Coleoidea, traces of the digestive tract of both polychaetes and nematodes and the outlines of the entire body of some fishes (for example, *Squaloraja*), the enteropneust *Megaderaion*, of polychaetes and nematodes (see figures 3–10).

All these organisms are very compressed, the more delicate ones (for example, polychaetes and nematodes) are at times reduced to a thin film.

Spectrophotometric analysis has revealed that the non-calcareous fossils are essentially composed of calcium phosphate while the scanning microscope shows that the organic material has been substituted by spherulites of colloidal material with diameters ranging from 0.6 to 0.9 μm.

Hence the Osteno fossils are of metasomatic origin: molecule by molecule the organic material has been replaced by colloidal calcium phosphate. This metasomatic process is the underlying reason for the remarkable preservation of the organic structures. The muscular bundles of *Ostenocaris* (see figures 12 and 13) observed under the scanning microscope reveal that the substitution of organic material by amorphous calcium phosphate has preserved the structures of the fibre, in some cases even to cellular level (figure 9). Land plants have undergone a process of carbonization.

The organic remains found in the deposit do not appear to have suffered any decomposition, yet they are not always complete. C. Patterson (personal communication) has noted that many of the fish specimens are coiled and folded, they look as if they have been mouthed, swallowed and even partly digested and then regurgitated. This has not been observed among the crustacean decapods. Some small Thylacocephala bear signs of damage, perhaps due to the action of predatory decapods.

6. Sedimentary environment: deductions from sediment and organisms

The nature of the fossiliferous rock, the composition of the fossil biota and the characteristics of fossilization permit some deductions about the environment in which the Osteno fossil deposit was formed. The spongolithic micrite forming the deposit most likely represents a single sedimentary cycle, marked off at its top and bottom by marl levels. The ungraded, unstratified fossiliferous rock, devoid of cross-lamination, was formed on the bottom of a marine basin by uninterrupted deposition of limestone.

Description of plate 3

Figure 15. Es. i 6262, gastric contents of *Ostenocaris cypriformis* (magn. ×7.6).

Figure 16. Es. i 4558, musculature of the cephalic sac and adductor muscle of *Ostenocaris cypriformis* (magn. ×1.2).

Figure 17. Es. i 1454, *Ostenocaris cypriformis* with well-preserved branchiae (magn. ×2.8).

Figure 18. Es. i 6263, gastric contents of *Ostenocaris cypriformis* (magn. ×5.6).

Reducing conditions characterized the bottom of the sedimentary basin as evidenced by the presence in the rock of pyrite, limonitic material and hydrocarbons. The water circulation was restricted, there were no currents, and benthic conditions prohibited life, as is demonstrated by the absence of any traces of currents, by the undisturbed lamination and by the absence of bioturbation, infauna and all organisms that cannot tolerate a low level of oxygenation.

In this sedimentary environment, lacking in oxygen and with an abundance of hydrogen sulphide, dissolution of the organic aragonite took place. This is indicated both by the absence of benthic organisms with aragonitic shells and skeletons, and by the phenomena of dissolution observed in the nektonic aragonitic organisms that fell to the sea bottom, descending from the normally oxygenated upper strata of the water column.

An ammonite specimen, showing a fractured siphuncle with the various sections slightly dislocated, is a significant indication of the dissolution of the calcareous septa after deposition on the sea bottom (figure 3).

Low oxygen levels seem to be consistent both with the dissolution of the aragonite produced by the lowering of pH in the presence of hydrogen sulphide, and also with the metasomatic transformation of the organisms into calcium phosphate, a mineral found in reasonable quantities in reducing environments.

The reducing conditions existing at the bottom permitted the perfect preservation of the organisms which show no *post mortem* decay. The plants, on the other hand, were subjected to the attack of anaerobic bacteria with consequent carbonization.

Deductions based on an analysis of the composition of the fossil association lead also to the same conclusions. The fauna found in the deposit comprises two distinct fractions: nektonic elements and benthic or epibenthic elements.

The nektonic organisms make up 14.50 % of the entire fauna (figure 14): they are represented by ammonoid and coleoid cephalopods and by fishes (with the exception of some epibenthonic forms). These organisms lived near the surface, in normally oxygenated water, and descended to the bottom after death. Hence their presence in the deposit is due to vertical descent. They may be considered allochthonous elements when compared with the benthic biocoenosis of the bottom.

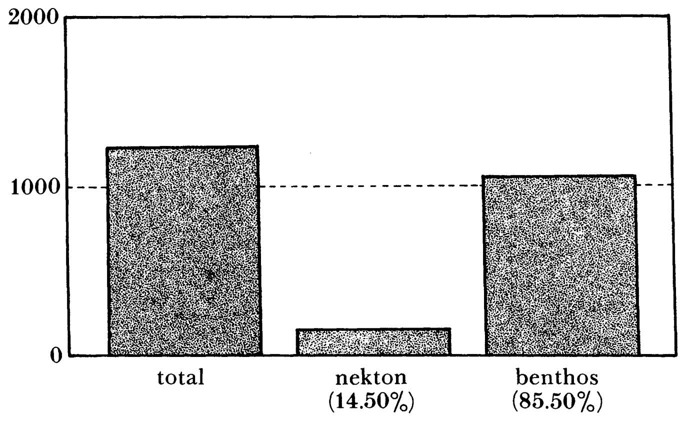

FIGURE 14. Percentage of nekton and benthos in the Osteno deposit.

However, it can be demonstrated that the remains of the fishes and cephalopods deposited on the sea bed constituted an important part of the food chain in the Osteno basin. These carcasses formed the staple diet of numerous necrophagous Thylacocephala (and probably that of some of the decapods too), and this is reflected in the gastric contents found in many Thylacocephala. This view is also borne out by the particular state of preservation of many fishes that appear to have been partly digested and then regurgitated, and by the presence of isolated gastric remains always containing fragments of fishes and coleoids. From this point of view these nektonic elements of the fauna cannot be considered completely allochthonous, because they contributed to the benthic ecology.

The fauna is composed of 85.50% of benthic or epibenthic organisms (figure 14). These include crustacean decapods, stomatopods, Thylacocephala, Ophiuroidea, worms and enteropneusts, all organisms in one way or another connected with the sea bottom.

The high percentage of benthic organisms together with the other characteristics of the fauna render it difficult to consider the faunal association of Osteno as allochthonous, in other words as having accumulated on the poorly oxygenated sea bottom by transport from different normally oxygenated environments.

The other characteristics of the fauna that contrast with the conception of this fossil association as being totally allochthonous are as follows.

(i) The evidence of ecological relationships between some of the organisms living in the basin. In particular, the prey–predator relationships between Thylacocephala and fishes and Coleoidea discussed above. Since the remains of the fishes and those of the Coleoidea presumably arrived on the sea bottom after a vertical descent from a higher layer of water, and since there is evidence that these remains were the prey of the epibenthic, necrophagous Thylacocephala, I think that at least the Thylacocephala ought to be considered autochthonous, since they scavenged on the sea bottom.

Furthermore, I consider it unlikely, in the case of an association formed through transport of different elements, that the relationships existing in the living community could be casually reproduced in an allochthonous thanatocoenosis.

(ii) The absence of bottom currents renders improbable the transport and accumulation of rather bulky organisms.

(iii) The absence of any selection of the fossils according to size and the absence of any preferential orientation.

(iv) The structure of the fossil assemblage, characterized by a low taxonomic diversity (monotypic), by the predominance of necrophagous organisms and those tolerating a low oxygen level, and by the rarity of organisms requiring well oxygenated water.

7. Hypotheses for the reconstruction of the environment

The environmental reconstruction of the Osteno deposit presents many difficulties, chiefly because it has not yet been possible to define the extent of the area and the lateral correlation of the fossiliferous unit. Consequently it is not yet possible to have an idea as to what caused the isolation of the sedimentary basin.

The characteristics of the sediment and the particular preservation of the organisms certainly point to a reducing environment, a poorly oxygenated sea bottom where metazoan life was difficult at the sediment surface and impossible below the water–sediment interface.

The exceptional preservation of the organisms indicates furthermore that biological and physical destructive agents were lacking on the sea bottom, while there is evidence for the presence of benthic necrophagous organisms.

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The composition of the fauna (85.50% benthic elements), the absence of any *post mortem* transport of the benthic organisms and the persistence of traces of ecological relationships between organisms (that is, the co-occurrence of necrophagous organisms and their products), seem to exclude the notion that the fossil assemblage of Osteno may be considered as totally allocthonous.

Hence it is likely that the Osteno sea bottom was not completely anoxic but populated, though by no means densely, by an epifauna with a low taxonomic diversity (in some cases even monotypic), consisting of organisms tolerating low oxygen levels, such as necrophagous crustaceans, polychaetes, nematodes and ophiuroids.

The restricted oxygenation at the bottom was probably caused by the accumulation of organic material deriving from the decomposition of an abundant flora of algae, and by the isolation of the basin.

This accumulation had the effect of placing the limit of the H_2S–O_2 boundary almost in correspondence with the water–sediment interface, thus rendering it impossible for an infauna to exist.

I thank Maurizio Pianca and Natalino Del Fanti of the Company Montefluos (Montedison Group) for the analysis carried out on the Osteno fossils and rock.

The scanning microscope analyses were carried out in the C.N.R. Laboratory 'Alpi Centrali', Milan.

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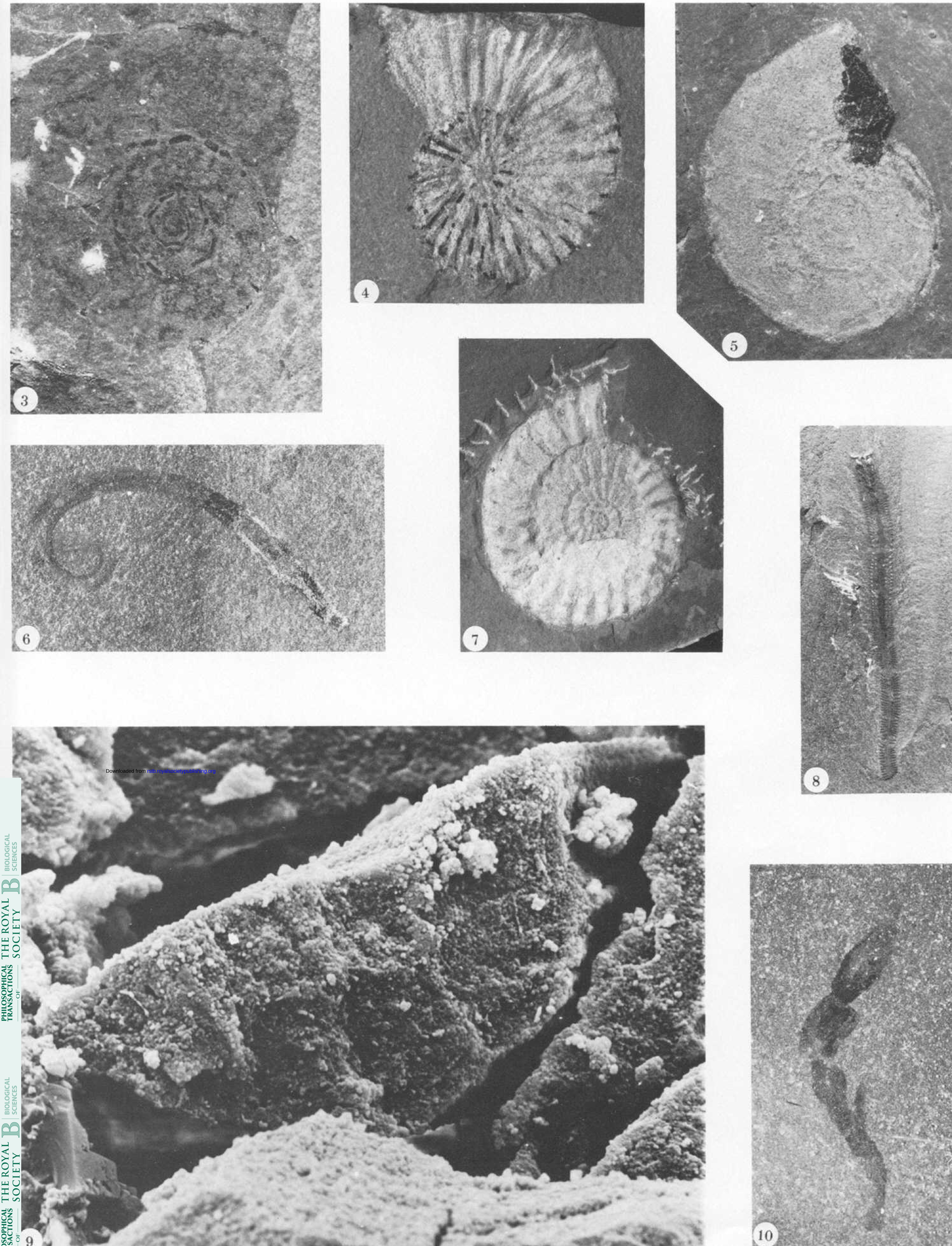
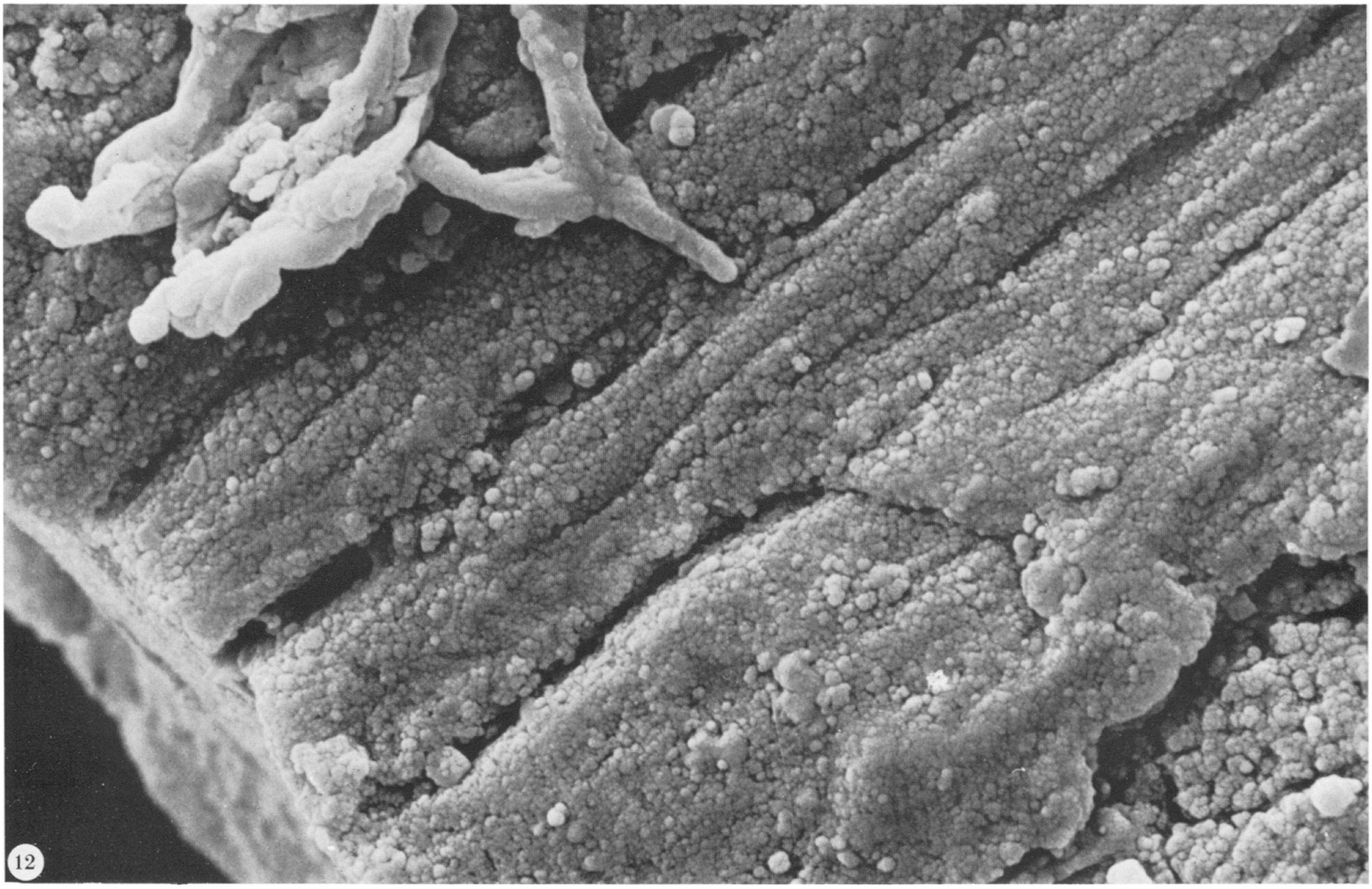
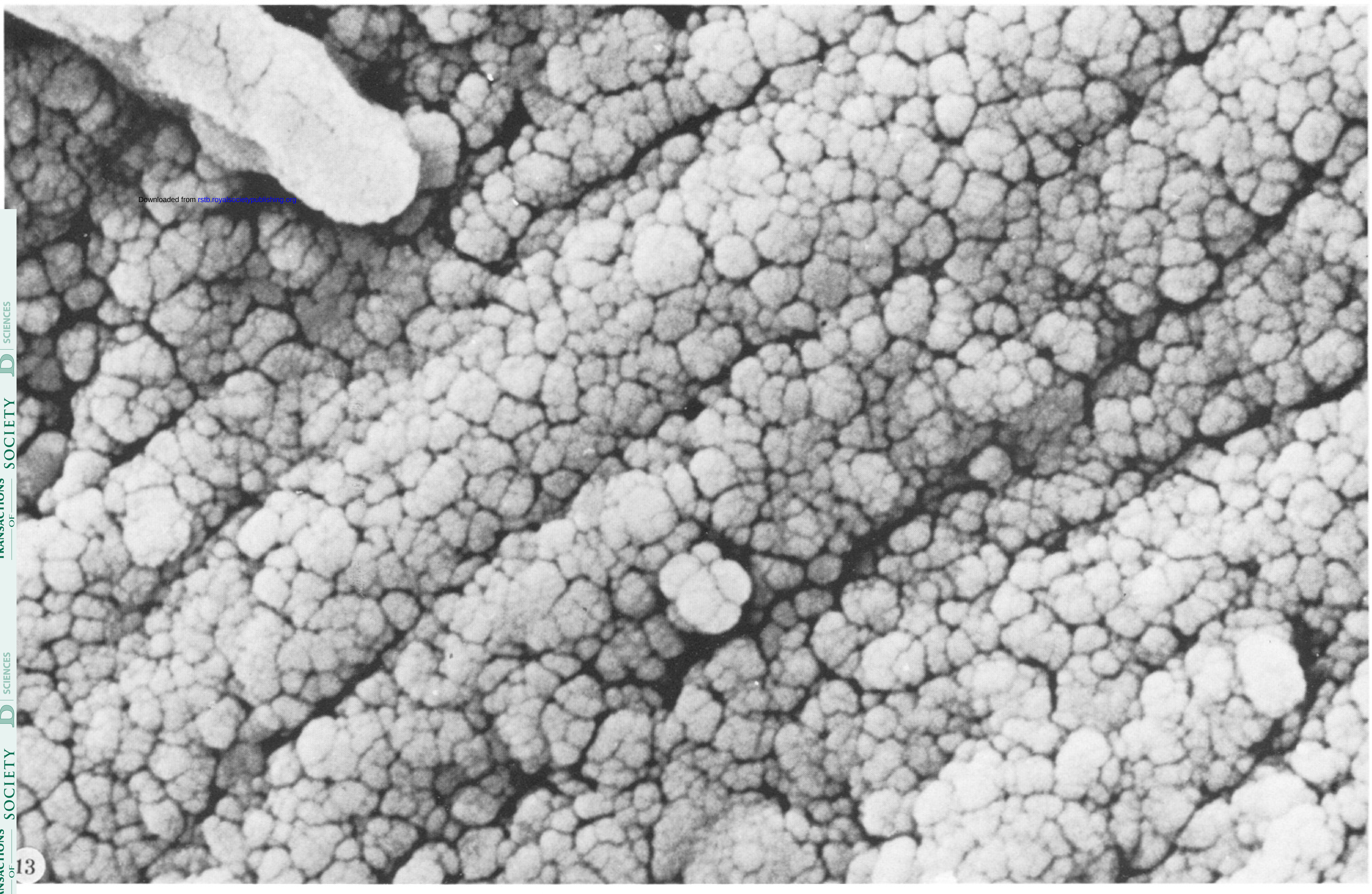
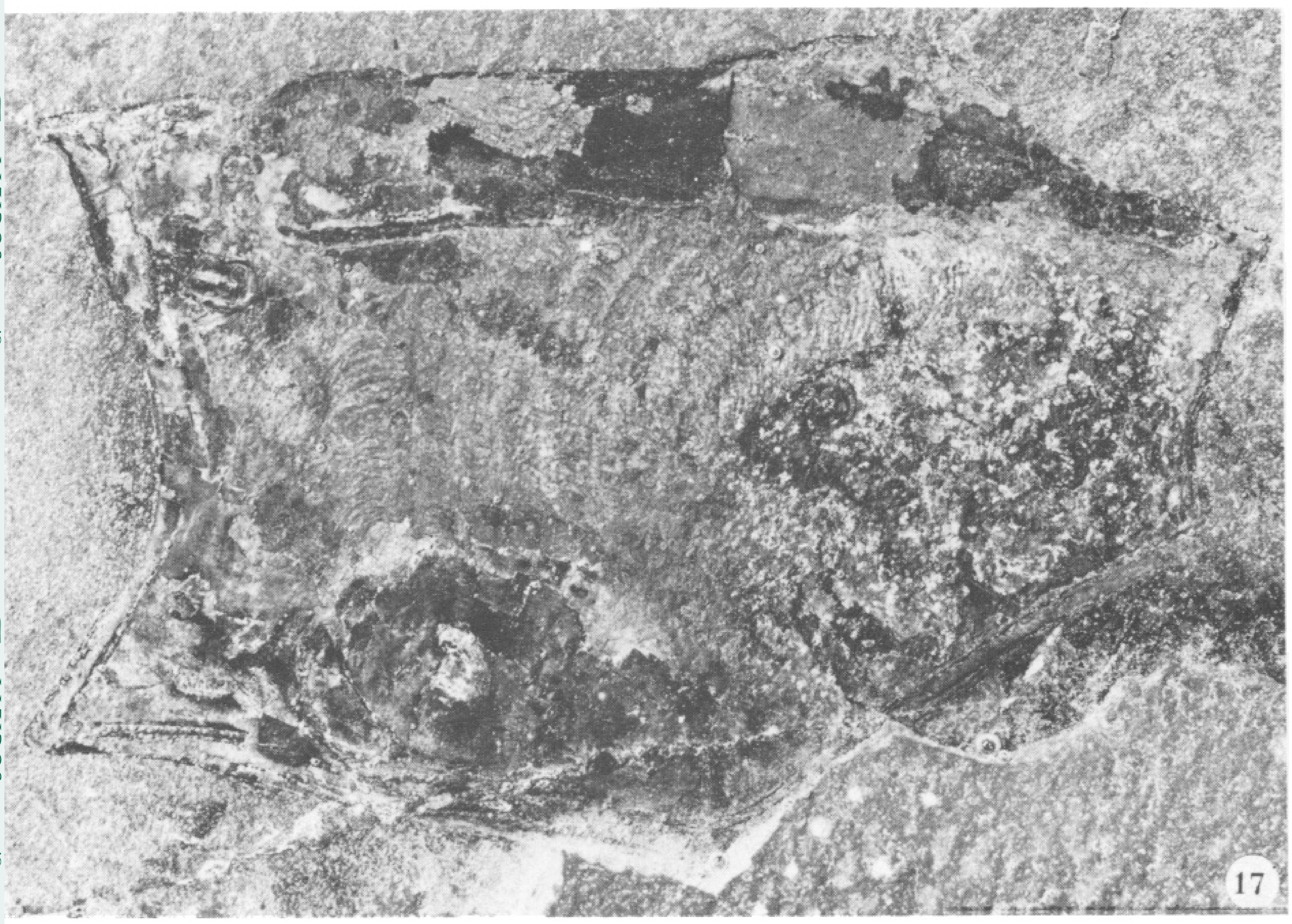


FIGURES 3–10. For description see opposite.





FIGURES 12 AND 13. Es. i 6263, retractor muscle of *Ostenocaris cypriformis* substituted by calcium phosphate (magn. ×2500 and 11000).



FIGURES 15–18. For description see opposite.