

Paleontological content, constituent analysis and microbiofacies of Early Devonian pelagic limestones from the Fluminimaggiore area (SW Sardinia)

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ABSTRACT — Paleontological content and sedimentological features of Lower Lochkovian-Upper Pragian pelagic limestones, cropping out in two sections near the village of Fluminimaggiore (southwestern Sardinia), are studied in detail.

Among various fossils, 12 species of ostracodes, mostly belonging to Podocopida, are illustrated for the first time from Sardinia. This ostracofauna could represent a benthic assemblage of sublittoral-upper bathyal environment (« Eifeler Ökotyp » versus « Thüringer Ökotyp », Bandel & Becker, 1975).

On thin sections of 15 samples, from both sections, a modal quantitative analysis of main constituents and skeletal sand, represented by 7 different taxa, is also included. Five main microfacies are distinguished on the basis of their fabrics, and genetical interpretation within the various lithotypes.

Paleontological and sedimentological data from this study would suggest deposition in a pelagic environment linked to a regressive evolution of submarine rises (« Schwellen facies ») inside a relatively deep epeiric sea. According to this hypothesis, the presence of a wide cratonic area in the whole circum-Mediterranean area during Early Paleozoic would be further confirmed.

RIASSUNTO — [Contenuto paleontologico e microbiofacies dei calcari pelagici del Devoniano inferiore dell'area di Fluminimaggiore (Sardegna sud-occidentale)] — Vengono analizzati in dettaglio sia il contenuto paleontologico sia le caratteristiche sedimentologiche di calcari pelagici, di età compresa fra il Lockoviano inferiore ed il Pragian superiore, affioranti in due sezioni nei pressi del villaggio di Fluminimaggiore (Sardegna sud-occidentale).

Fra le varie forme fossili, vengono illustrate, per la prima volta in Sardegna, 12 specie di ostracodi per lo più appartenenti all'ordine Podocopida. Questa ostracofauna apparterebbe ad una associazione bentonica di ambiente sublittorale-suprabatiale (« Eifeler Ökotyp » versus « Thüringer Ökotyp » Bandel & Becker, 1975).

Su sezioni sottili di 15 campioni, provenienti da entrambe le sezioni, è stata eseguita l'analisi modale quantitativa dei costituenti principali e delle particelle scheletriche, rappresentate da 7 differenti taxa. Si sono inoltre riconosciute 5 principali microfacies delle quali vengono fornite le descrizioni, le caratteristiche strutturali e tessiturali, l'interpretazione genetica e la loro distribuzione nell'ambito dei vari tipi litologici.

Sulla base dei dati emersi da questo studio, è possibile ipotizzare un ambiente deposizionale pelagico legato alla probabile evoluzione regressiva di zone sopraelevate in un mare epicontinentale di media profondità. Da questo punto di vista, verrebbe fornita una ulteriore prova sulla presenza di una vasta area epicontinentale in tutta l'area circum-mediterranea durante il Paleozoico inferiore.

INTRODUCTION

The purpose of this paper is to illustrate the paleontological content and microfacies of Lower Devonian limestones, cropping out near the village of Fluminimaggiore (southwestern Sardinia). Useful data for a tentative reconstruction of the ancient depositional environment of such limestones have mainly been obtained either by studying thin sections with modal analysis of constituents, in particular of the skeletal sand fractions, or considering some of their sedimentological structures in the field.

The examined sections, named « Galemму 1st » and « Corti Baccas 3rd », are very close to each other and located about one kilometer north of the village of Fluminimaggiore (for the location of outcrops see Serpagli *et al.*, 1978 and Mastandrea, 1985b). These outcrops were chosen among others from the same area because the biostratigraphic position was known on the basis of conodonts (Gnoli, Mastandrea & Olivieri, 1981; Mastandrea, 1985a, 1985b; Olivieri, 1985; Serpagli & Mastandrea, 1980, Serpagli *et al.*, 1978), and because they are tectonically relatively undisturbed. In general the Siluro-Devonian sequence of south-

western Sardinia is strongly affected by tectonics and, according to Serpagli (1971, p. 77), « it is impossible to find continuous sequences of fossiliferous marine strata where the order of superposition can be clearly observed ». From this point of view, the sections mentioned above represent an exception.

The geological setting of the Fluminese area was described in the last years by several authors to whose papers the reader can refer to (for a selected bibliography see Carmignani, Coccozza & Pertusati, 1983; Gnoli & Serpagli, 1985a). However, soon Gnoli, Leone, Olivieri & Serpagli (paper in progress) will propose new formational names for the Silurian-Lower Devonian rocks complemented by an accurate description of the various lithostratigraphic units.

This research is part of large project carried out by members of the Institute of Paleontology, University of Modena, in collaboration with the Geological Survey of Prague, regarding the various aspects (paleontology, biostratigraphy, facies, paleoecology and paleobiogeography) of the Silurian-Devonian boundary in Sardinia.

LITHOLOGY AND AGE

Lithologically the «Galemmu 1st» and «Corti Baccas 3rd» sections, of very limited thickness (12.5 and 15.6 m respectively), consist of massive grey tentaculite nodular limestones (pl. 1, fig. 1), subordinate dark grey fine micritic cephalopod bearing, partly allodapic, limestones (*sensu* Vai, 1980) (pl. 1, figs. 3, 4) alternating with thin layered calcareous shales (= «stylonodular limestones» Flügel, 1982), and dark grey, more or less fossiliferous, silty shales. These rocks are practically the same as those well described by Bandel (1972) from the Lower Devonian of the Central Carnic Alps, where the German terminology of «Flaserkalk, plattiger Flaserkalk, Kalkknollen-Schiefer and Schiefer» was applied. Vai (1980) proposed a new environmental interpretation for the latter lithotypes after an accurate description of a pelagic Devonian «test» sequence based on an eco-

stratigraphic approach. The types of limestones and related rocks from Sardinia are also closely comparable with the nodular limestones and shales with nodules described by Tucker (1973, 1974) from the upper slope of the «Schwellen facies» in the Rhenohercynian Geosyncline and with similar Lower Devonian rocks from the eastern Montagne Noire (Tucker, 1974; Feist, 1983) and Anti-Atlas, Morocco (Wendt *et al.*, 1984).

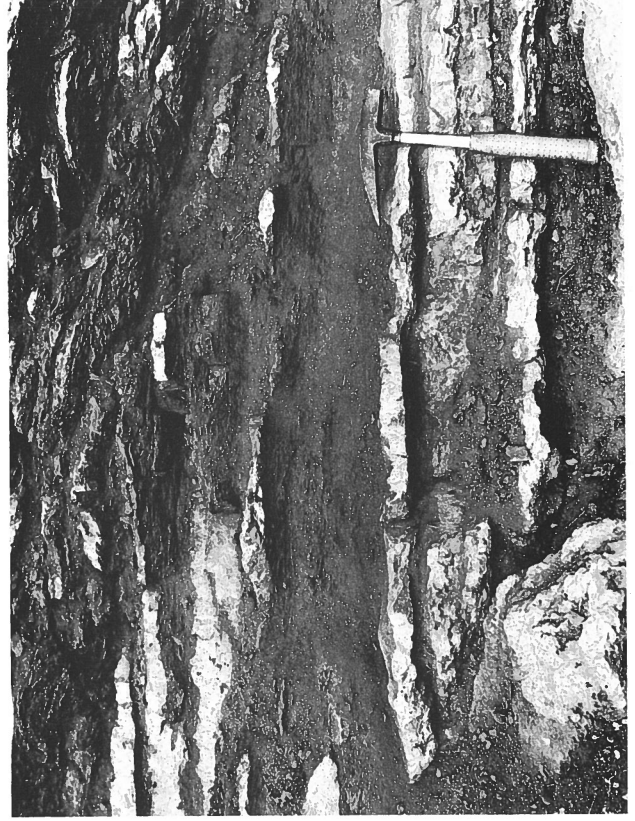
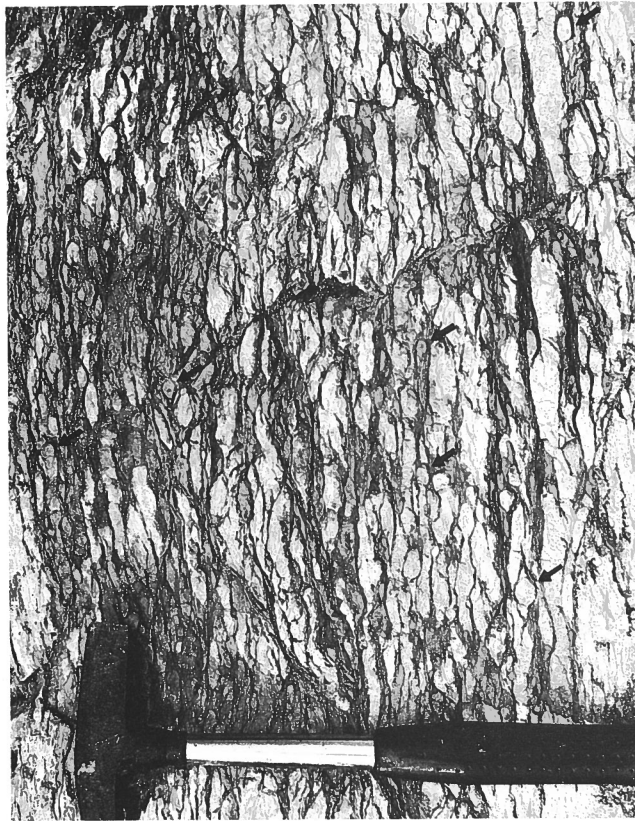
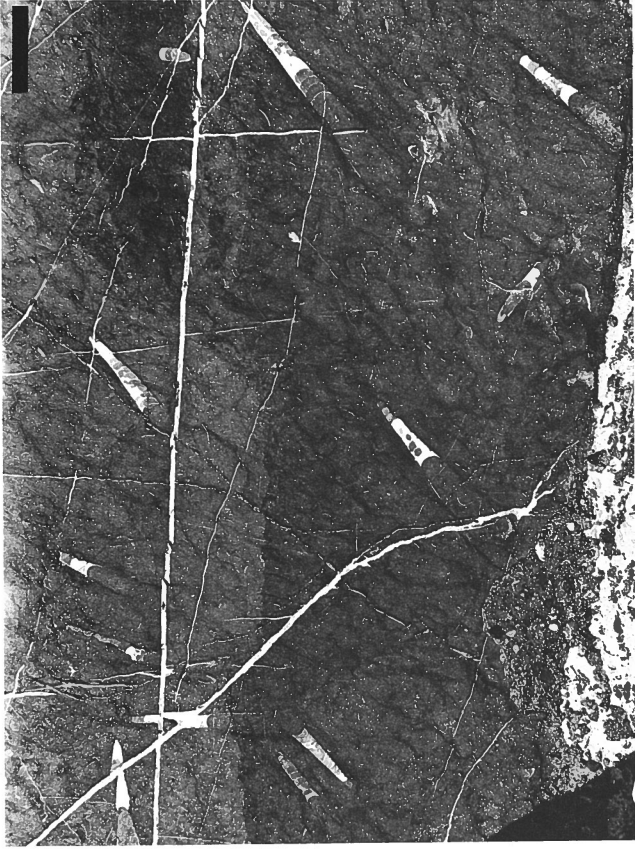
The various lithologies, observed in «Galemmu 1st» and «Corti Baccas 3rd» sections, are schematically shown in the stratigraphic logs reported in text-figs. 1 and 2. Because of their gradual vertical and lateral change, the different lithotypes are difficult to distinguish in the field. The main lithological changes are related to the different amount of fine terrigenous supply associated to the autochthonous lime mud, which influenced the rate of sedimentation. Nevertheless, by a comparison with other coeval sections outcropping in the Sulcis area (i.e. the «Mt. Padenteddu» section, Gnoli *et al.*, 1981; Olivieri, Mastandrea & Serpagli, 1981), the «Galemmu 1st» and «Corti Baccas 3rd» sections must be interpreted as a condensed sequences.

Stratigraphically the «Galemmu 1st» section belongs entirely to the uppermost Lower Gedinnian (Lochovian) (Serpagli *et al.*, 1978). According with the zonal scheme of Klapper and Johnson (1980), the conodont fauna with the diagnostic species *Ancyrodelloides kutscheri* and *A. trigonicus* Bischoff & Sanemann indicates the presence of the *delta* Zone.

The biostratigraphy of the «Corti Baccas 3rd» section, based on conodonts, was recently studied by Mastandrea (1985b) who recognized the typical assemblages of the *kindlei* Zone (samples B to D) and *pirenae* Zone (samples D1, E, E1, F,) of the Middle and Middle-Upper Pragian respectively. A precise stratigraphical assignment of the lowermost part of the section (sample A) was prevented because there were recovered conodonts belonging only to the apparatus of *Ozarkodina remscheidensis remscheidensis*, which ranges from the Upper Pridolian to the lowermost

EXPLANATION OF PLATE 1

- Fig. 1 - Nodular limestones, one metre below level A2 of the «Corti Baccas 3rd» section. Arrows indicate cross-sections of scattered orthocone cephalopods, mostly parallel to the bedding plane.
- Fig. 2 - Bed surface of cephalopod bearing nodular limestone showing a preferential orientation of fossils by paleocurrent activity. Displaced block from uppermost part of «Corti Baccas 3rd» section. Scale = 10 cm.
- Fig. 3 - Allodapic beds and interbedded dark shales at the base of the «Corti Baccas 3rd» section. The lowermost bed represents level A. The head of the hammer indicates the allodapic bed shown in detail in fig. 4.
- Fig. 4 - Polished vertical section of an allodapic bed fragment. An encrinitic packstone (microfacies 4) is shown at the base and burrowed mudstone (microfacies 1) with large orthocone fragments toward the top. Note the reverse grading of bioclasts and their setting «at the shadow» of a large nautiloid (lower left).



Upper Lochkovian (Klapper & Ziegler, 1979; Klapper & Johnson, 1980). However, on the basis of lithostratigraphic comparisons with other sections outcropping in the same area and of the whole paleontological content (see below) the first levels of this section may be dated as latest Early Lochkovian and, in terms of conodont biostratigraphy, should correspond to the *eurekaensis* Zone. Except for these lowermost beds, mainly represented by cephalopod micritic limestones alternating with shales, the overlying layers, four metres thick, of the « Corti Baccas 3rd » section could represent the lateral equivalent of the whole « Galemму 1st » section.

Conodont assemblages attributable to the *pesavis* and *sulcatus* biozones were not recorded at this level of the Fluminense Lower Devonian sequence. As pointed out by Gnoli & Serpagli (1985), it is difficult to state if their absence is due to lack of fossils, to tectonized horizons or to a real hiatus.

MACROFOSSILS AND FAUNAL CONTENT OF INSOLUBLE RESIDUES

Only rare orthocone cephalopods, mostly michelinoceratids, scattered pelmatozoan ossicles and crinoidal stem fragments were recognized on the weathered surfaces of « Galemму 1st » limestone beds.

Except for the conodonts (for the list of these fossils see Serpagli *et al.*, 1978), few silicified badly preserved ostracodes, and secondarily phosphatized phyllocarid mandibles (Gnoli & Serpagli, 1984), insoluble residues of samples from « Galemму 1st » section did not yield any other diagnostic fossils.

On the contrary, calcareous and some silty beds of the « Corti Baccas 3rd » are very fossiliferous. Beside various crinoidal fragments (mostly stems), abundant in most samples, more than two hundred specimens of orthocone cephalopods were collected mainly in the lower eight micritic beds of the section (level A up to 80 cm). Both whole juvenile shells and large fragments of mature specimens are represented in this fauna; they were studied by Gnoli (1983) who recognized twenty different species pertaining to thirteen genera. The most common forms are *Kopaninoceras floweri* Gnoli (30% of the whole fauna), *Murchisonoceras? subnotatum* (Barrande) (12%), *Arkono-ceras? cf. adjectum* Zhuravleva (11%), *Mimogeisonoceras cf. liberum* (Barrande) (10%), *Hemicosmorthoceras semimbricatum* Gnoli (8%) and *Sphaerorthoceras* sp. A *sensu* Gnoli, 1983 (6%). The occurrence of the important index species *Jovellania buchi* (De Verneuil) in level C is consistent with the age inferred from the conodonts (*kindlei* Zone) for this part of the section. To date, this cephalopod fauna represent the only one described from the Lower Devonian of the Mediterranean area. Scattered orthocones, slightly deformed by compaction and oriented by current activity, are present in several nodular limestone beds (pl. 1, fig. 2).

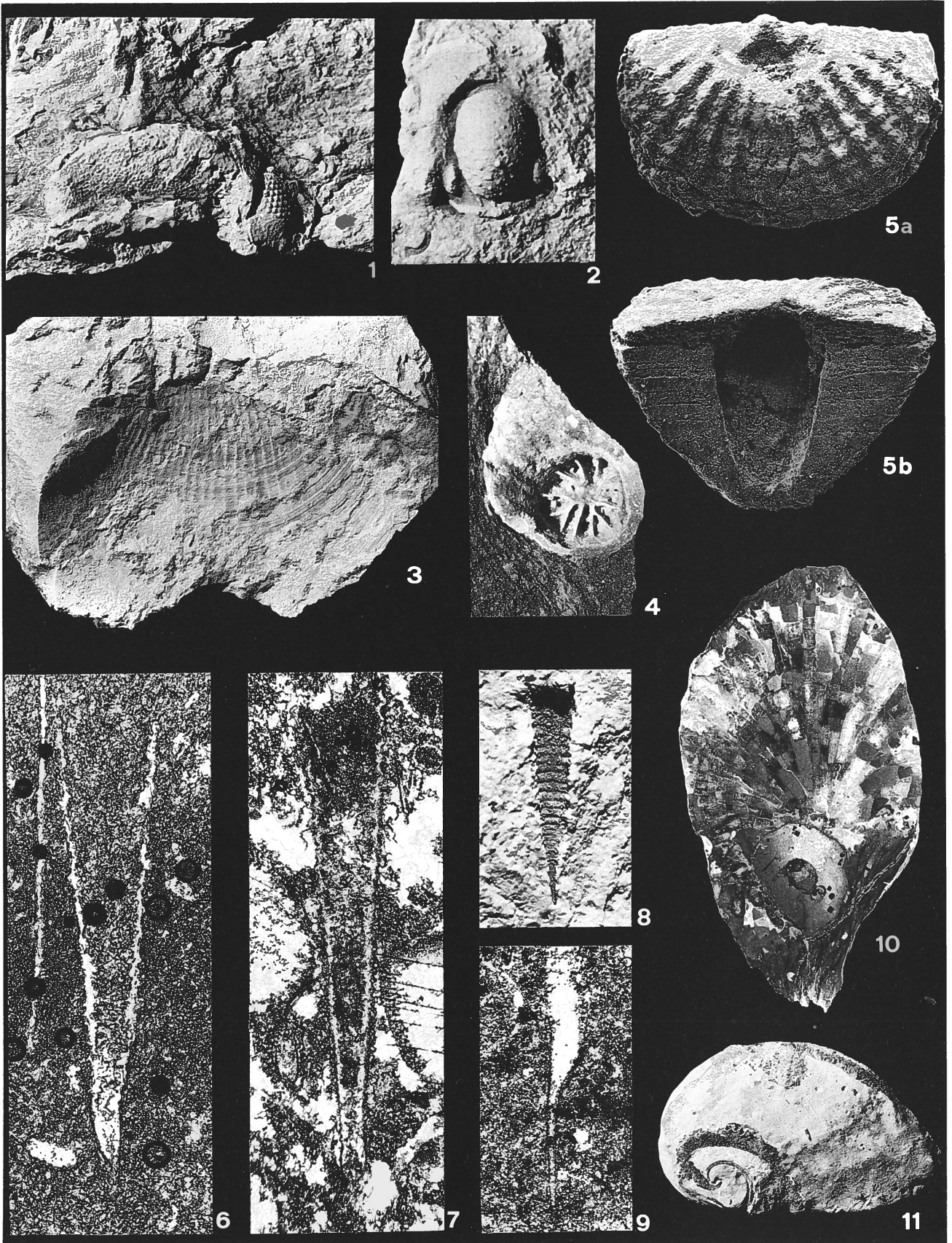
In level A some large bivalves probably belonging to *Panenka* (pl. 2, fig. 3) and few brachiopods among which *Skenidioides cf. suburbanus* (Havlicek) (pl. 2, figs. 5a, b) were also recognized.

Several specimens of brachiopods, mostly orthids, were collected in the silty shales yielding *Nowakia acuaria* between levels D1 and E. These megafossils,

EXPLANATION OF PLATE 2

If not specified, all specimens are from the « Corti Baccas 3rd » section.

- Fig. 1 - *Phacops?* sp., fragment of cephalon found in level B1 (n. 20630) x 2.
 Fig. 2 - *Otarion?* sp., glabella and part of cranidium, level A1 (n. 20631) x 10.
 Fig. 3 - External impression of a large bivalve probably belonging to *Panenka*, level A (n. 20632) x 1.5.
 Fig. 4 - Early stage of isolated rugose coral from silty shales between levels D1 and E (n. 20633) x 10.
 Fig. 5 - *Skenidioides cf. suburbanus* (Havlicek);
 5a, upper view of the brachial valve; 5b, posterior view, level A (n. 20634), both x 30.
 Figs. 6, 9 - *Paranowakia cf. bohémica* (Bouček);
 6, thin section of a mature specimen, level 2 of the « Galemму 1st » (n. 20635) x 85; 9, thin section of an apical portion, level T of the « Galemму 2nd » section (n. 20636) x 85. Note that the asymmetry of the long, open, apical spine is not due to a plastic deformation of the specimen but represents an usual feature of this form, occurring in most examined specimens.
 Figs. 7, 8 - *Nowakia acuaria* (Reinh. Richter);
 7, thin-section of a mature specimen, level D (n. 20637) x 40. The angle of expansion is lower than the real one because the unoriented section. 8, external impression of another specimen from silty shales between levels D1 and E (n. 20638) x 10.
 Fig. 10 - Polished cross-section of a small favositid colony found in silty shales between levels D1 and E (n. 20639) x 1.5.
 Fig. 11 - A platycerid gastropod from level E (n. 20640) x 1.5.



dissolved by weathering, are however preserved as neat external impressions and internal moulds and are at present under study by V. Havlíček (Geological Survey of Prague). In the same level some rounded calcareous pebbles made by fragments of favositid colonies may be present (pl. 2, fig. 10).

Other macrofossils recovered in the « Corti Baccas 3rd » section consist of scattered trilobite remains, some of which probably are belonging to the genera *Phacops*? (level B1, pl. 2, fig. 1) and *Otarion*? (pl. 2, fig. 2), rare platicerid gastropods (pl. 2, fig. 11), and small isolated rugose corals (pl. 2, fig. 4).

Among the insoluble residues of 11 samples from the « Corti Baccas 3rd » only that of the sample A yielded a large number of microfossils beside conodonts (see list in Mastandrea, 1985b). More than 50 specimens of agglutinated foraminifera were recovered from this sample by Gnoli and Serpagli (1985b) who recognized *Psammosphaera cava* Moreman, ?*Webbinoidea* sp., *Tolypammmina bransoni* Conkin, Conkin & Canis, *Tolypammmina devoniana* (Crespin) and *Hyperammmina* sp. among others. Attached forms reveal the shape of the substratum, probably represented by cephalopod fragments and crinoidal plates. The main part of the isolated fauna in sample A is however represented by silicified ostracodes with several hundred of specimens. At least 12 different taxa could be identified as follow:

Palaeocopida

Semibolbina sp. (pl. 3, figs. 1-3)

Metacopida

Gen. 3 Sp. A *sensu* Becker & Sanchez De Posada, 1977 (pl. 3, figs. 11-12)

Podocopida

Tricornina jahnkei Feist & Gross-Uffendorde, 1979 (pl. 3, figs. 4, 5)

Tricornina (Bohemina) sp. (Blumenstengel, 1969) ssp. A? *sensu* Bandel & Becker, 1975 (pl. 3, figs. 6-8)

Berounella cf. *spinosa* (Blumenstengel, 1962), (pl. 3, figs. 9, 10)

Orthocypris? sp. A *sensu* Becker & Sanchez De Posada, 1977, (pl. 3, figs. 13, 14)

Praepilatina praepilata sibirica Polenova, 1970, (pl. 3, figs. 18, 19)

Praepilatina sp. (pl. 3, fig. 20)

Baschirina germanica I. Zagora, 1967, (pl. 3, fig. 15)

Acravicula? cf. *moniellana* Becker & Sanchez De Posada, 1977 (pl. 3, figs. 16, 17)

Beecherella carinata Ulrich, 1981

Eridostraca

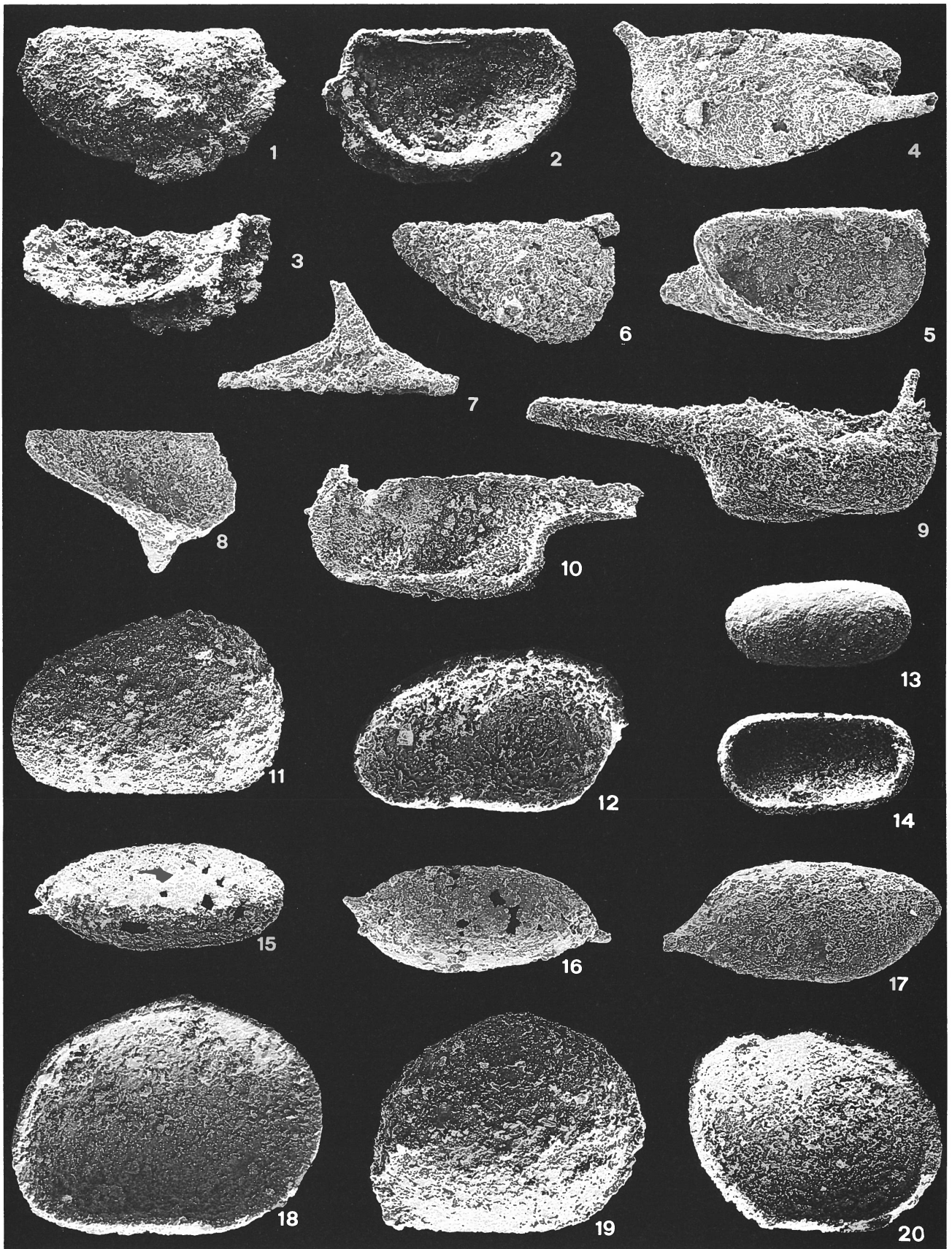
Cryptophyllus sp.

At present, we can only state that Podocopida seem to dominate the ostracofauna, which shows close relationships with those described from the Lower Devonian of Montagne Noire (Feist & Gross-Uffendorde, 1979), Asturias in northern Spain (Becker & Sanchez De Posada, 1977), and from the Carnic Alps (Bandel & Becker, 1975). In agreement with latter authors, the « Corti Baccas » ostracofauna belongs to the benthic assemblage of sublittoral environments (« Eifeler Ökotyp » *versus* « Thuringer Ökotyp » Bandel & Becker, 1975). Usually valves are not displaced

EXPLANATION OF PLATE 3

All specimens were found from the light fraction of insoluble residue of sample A of the « Corti Baccas 3rd » section. All. x 60.

- Figs. 1-3 - *Semibolbina* sp.
1, lateral view of a right valve (n. 20641); 2, internal view of a right valve (n. 20642); 3, ventro-internal view of a left valve (n. 20643).
- Figs. 4, 5 - *Tricornina jahnkei* Feist & Gross-Uffendorde;
4, lateral view of a left valve (n. 20644); 5, internal view of a left valve (n. 20645).
- Figs. 6-8 - *Tricornina (Bohemina)* sp. (Blumenstengel) ssp. A? *sensu* Bandel & Becker, 1975;
6, lateral view of a right valve (n. 20646); 7, ventral view of a right valve (n. 20647); 8, ventro-internal view of a left valve (n. 20648).
- Figs. 9, 10 - *Berounella* cf. *spinosa* (Blumenstengel);
9, lateral view of a right valve (n. 20650); 10, internal view of a right valve (n. 20649).
- Figs. 11,12 - Gen 3 sp. A *sensu* Becker & Sanchez De Posada, 1977.
11, lateral view of a right valve (n. 20651); 12, internal view of a left valve (n. 20652).
- Figs. 13-14 - *Orthocypris*? sp. A *sensu* Becker & Sanchez De Posada, 1977;
13, lateral view of a left valve (n. 20653); 14, internal view of a right valve (n. 20654).
- Fig. 15 - *Baschirina germanica* I. Zagora; right lateral view of the carapace (n. 20655).
- Figs. 16,17 - *Acravicula*? cf. *moniellana* Becker & Sanchez De Posada;
16, left lateral view of the carapace (n. 20656); 17, lateral view of a right valve (n. 20657).
- Figs. 18,19 - *Praepilatina praepilata sibirica* Polenova;
18, internal view of a left valve (n. 20658); 19, lateral view of a right valve (n. 20659).
- Fig. 20 - *Praepilatina* sp.; internal view of a right valve (n. 20660).



and each form is represented by several specimens at different growth stages, suggesting that the ostracode assemblage may be considered autochthonous. Up to now Lower Devonian ostracodes were never recovered from Sardinia and a more exhaustive taxonomical description will be matter of further contributions.

In addition to what mentioned above, few more fossils were recovered in other residues: some ostracodes in samples B, D, and E and rare small inarticulated brachiopods in sample A, B, and B1.

Finally, with the help of a 10x lens, an incredible number of dacryoconarid tentaculites were easily recognized in the field on the weathered surfaces of several calcareous beds in both sections. No detailed study was made on these fossils, however, the most common forms seem to belong to *Paranowakia* cf. *bohemica* (pl. 2, figs. 6, 9) in samples 1-6 of the « Galemme 1st », *Nowakia acuaria* (pl. 2, figs. 1, 8) in samples D-F of the « Corti Baccas 3rd », and styliolinids in several samples of the upper part of the latter section.

Further informations on the faunal content are based on thin sections analysis of the skeletal sand.

CONSTITUENT ANALYSIS

METHODOLOGICAL REMARKS

Modal analysis of the constituents and of the skeletal sand fraction (= ostracomass of Jaanusson, 1972) was obtained by quantitative method by point-counting on standard thin sections (2.5 x 3 cm) using an optical microscope (usually at 60 x magnification) and a point-counting device. About 3000 determinations were made on each thin section, which were cut perpendicularly to the bedding plane and in portions of rock possibly free of megafossils and large veins. Skeletal grains of various taxa were recognized either by their optical characteristics or by their shape and, following Jaanusson's suggestions (1972, p. 221), were considered as « grain-solid » (Dunham, 1962). Practically, voids inside skeletal grains were not counted

as constituents of the particles but separately regarded as matrix or cement; thus the percentage value of the skeletal sand is related to weight and not to volume. Following this method, the value of the ostracomass is affected by sorting and type of particles (that is, a well sorted tentaculite packstone could give an ostracomass value close to a poorly sorted crinoidal wackestone).

The dimensional boundary between the sand fraction and matrix is fixed at the value of 0.10 mm (for a broader discussion of this parameter see Jaanusson, 1972).

Sometimes, also polished slabs were utilized for some sedimentological remarks.

THE MAIN CONSTITUENTS OF THE LIMESTONE AND COMPOSITION OF THE SKELETAL SAND

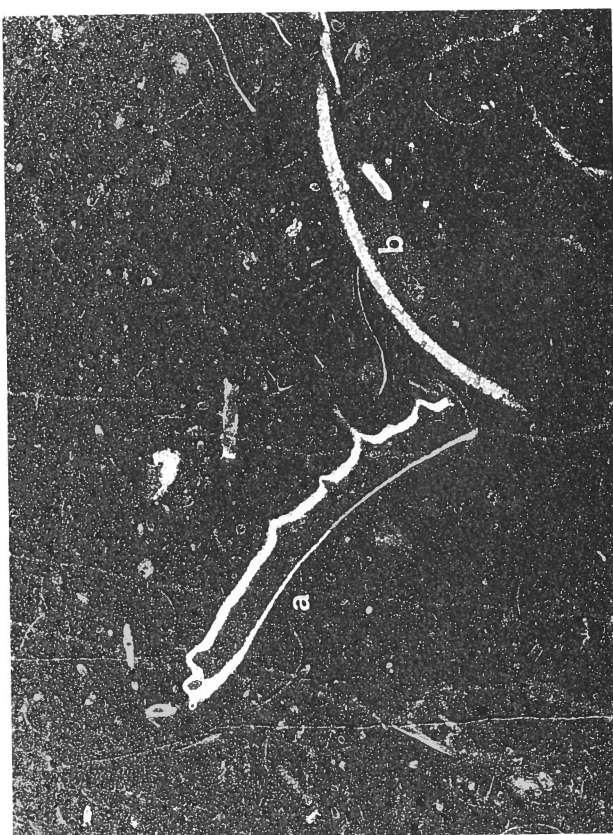
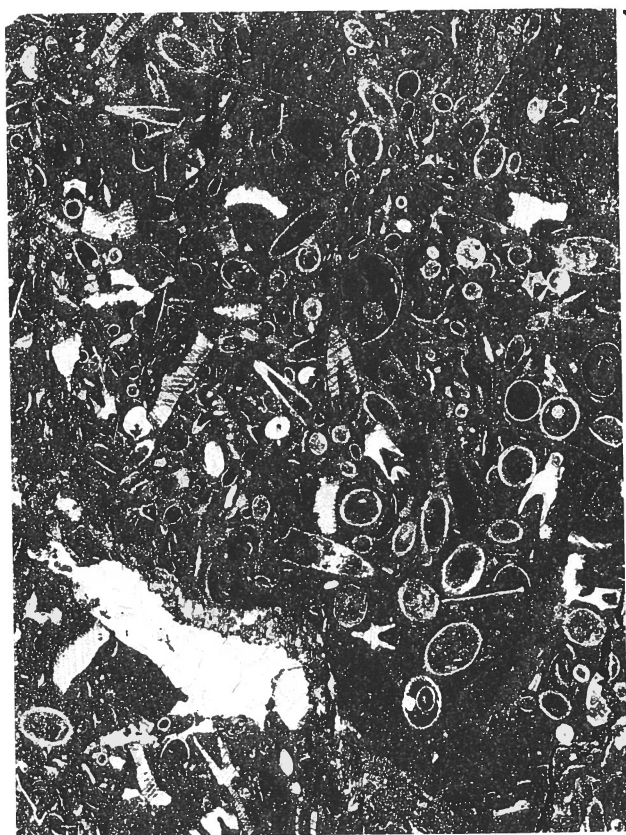
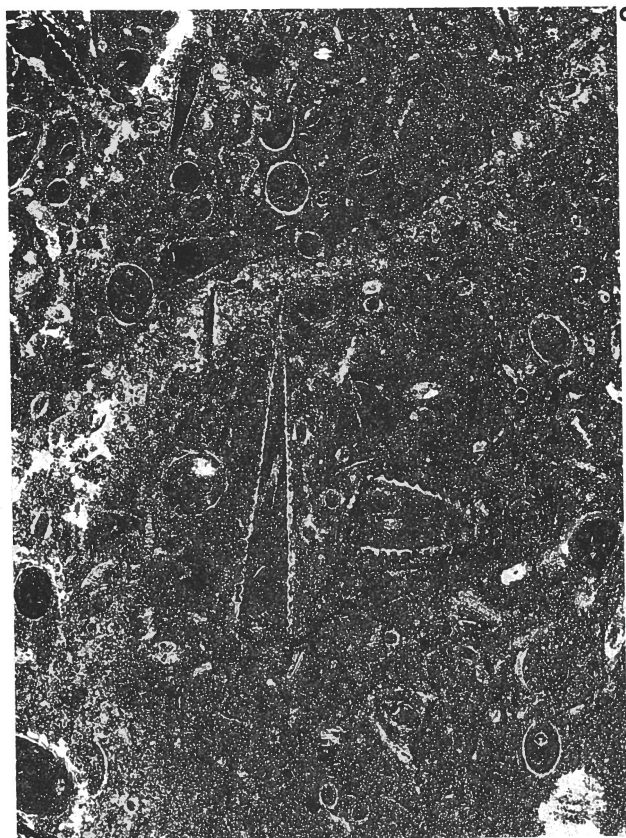
1) In addition to the matrix, cement and bioclasts, also quartz grains, opaque minerals, and terrigenous material (inside stylolites only) were considered in the point-counting of the main constituents. The percentage values of each sample are reported in the upper part of text-figs. 1 and 2. The total amount of fine terrigenous material, not recognizable in thin section, is equated to the amount of insoluble residue.

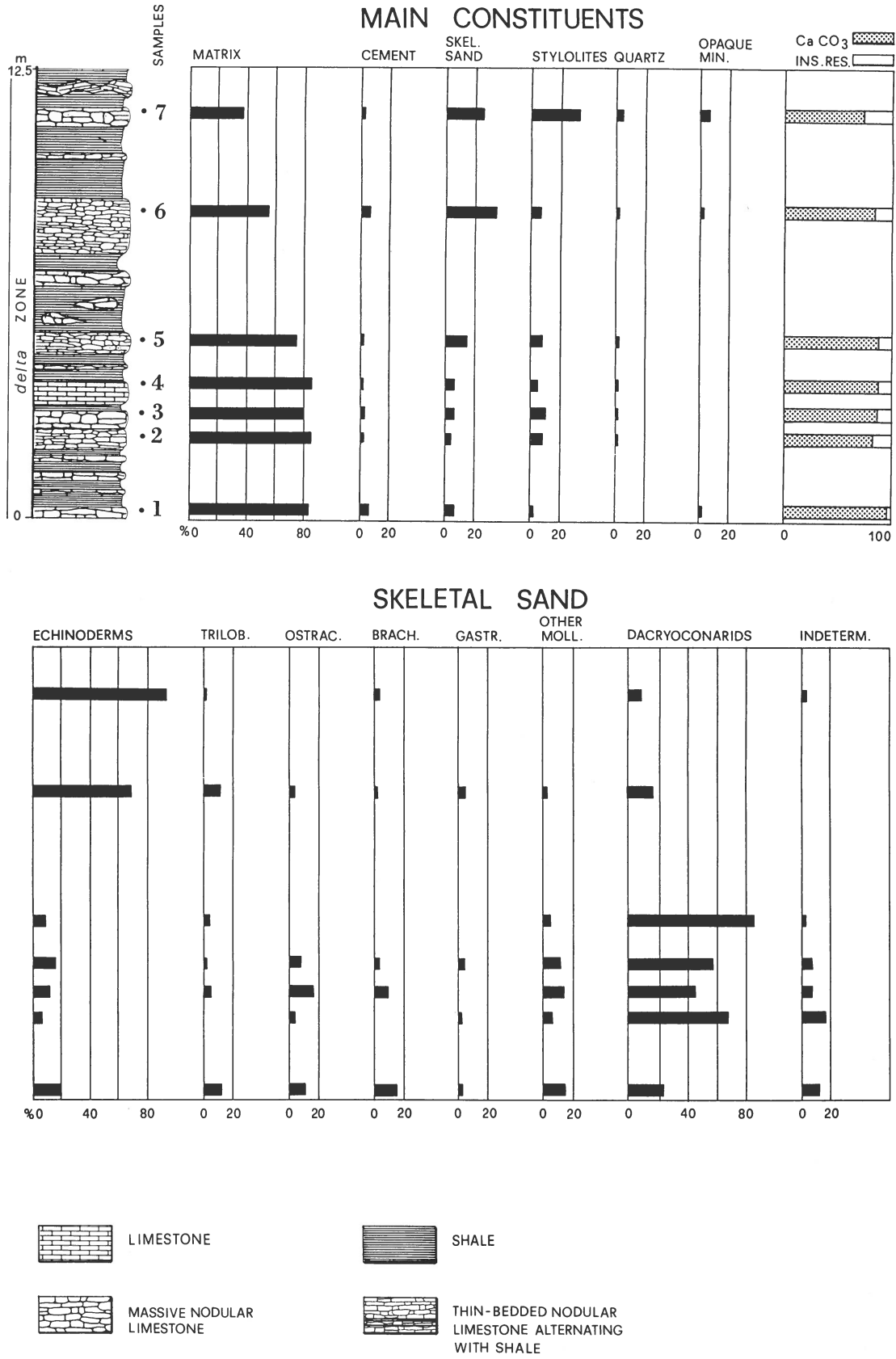
Matrix, that represent the bulk of the sediment, mostly consists of a mixture of more or less recrystallized micrite (microsparite), subordinate fine (less than 0.1 mm) skeletal debris and a varying amount of terrigenous material (see values of insoluble residues). In all samples the matrix maintains an average value of 80%, except in sample 6 and 7 of Galemme section where it drops at 40-50% balanced by an increase of skeletal sand and non-calcareous fraction, respectively. The maximum value (93%), in sample A2, is depending by a certain amount of terrigenous material.

Cement, averaging less than 10%, is quantitatively unimportant in the Galemme and Corti Baccas limestones. It mainly consists of drusy calcite inside veins, geopetal fabrics, and intergranular voidfilling either

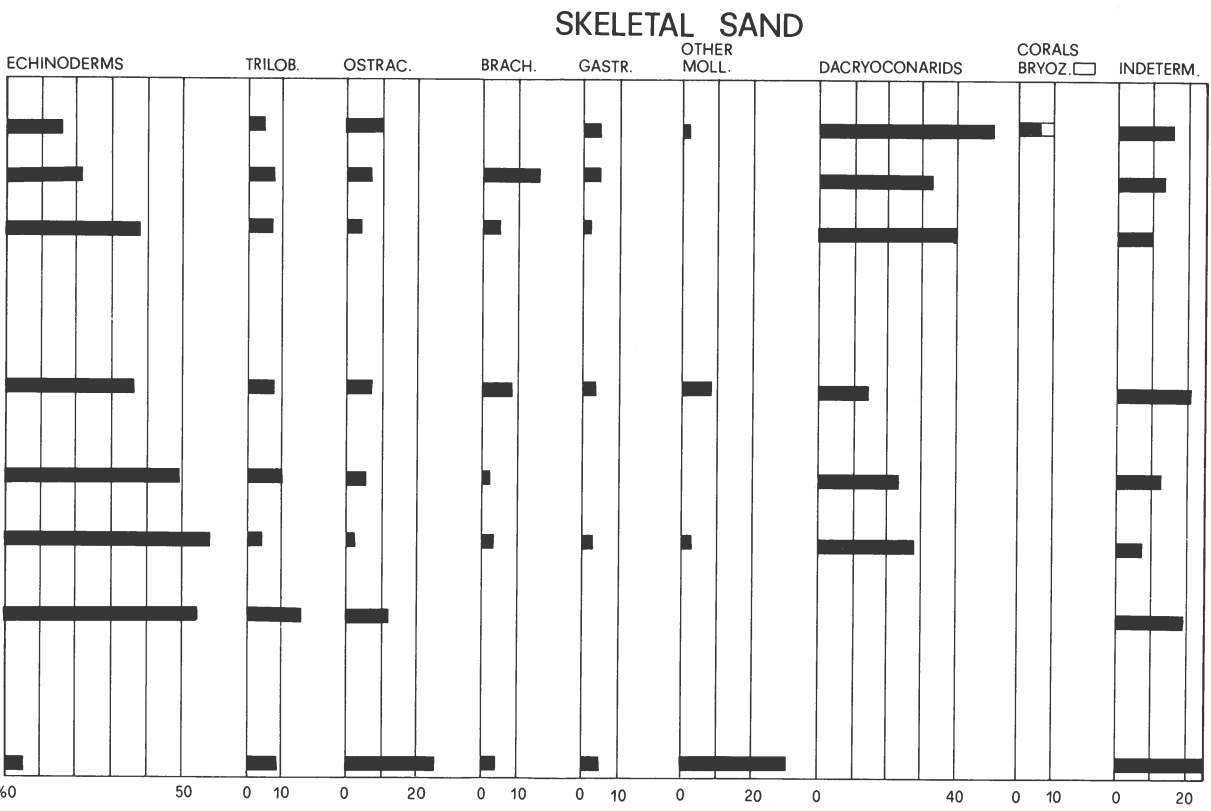
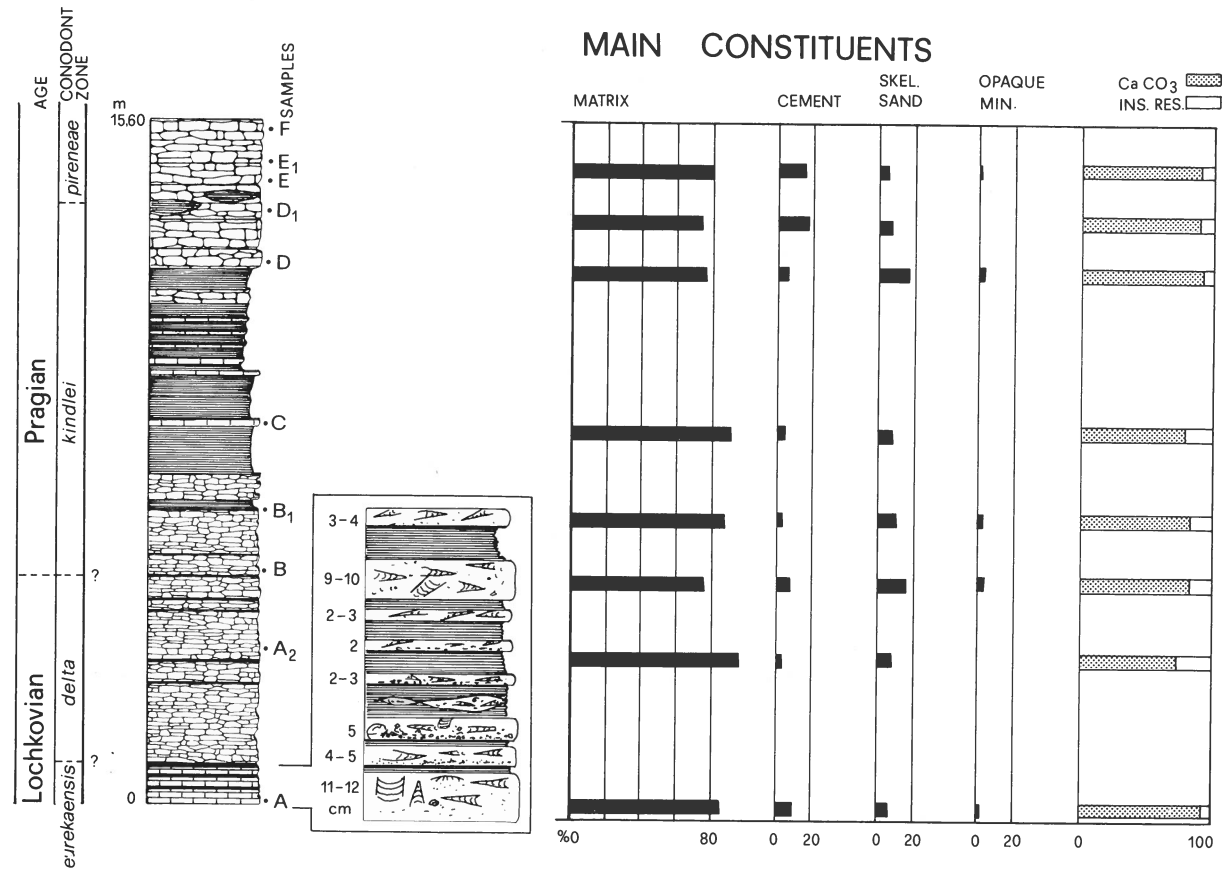
EXPLANATION OF PLATE 4

- Figs. 1-2 - Microfacies 1 - Bioturbated tentaculite wackestone-packstone;
1, the bulk of bioclasts is here represented by styliolinid and crinoidal plates (level B of the « Corti Baccas 3rd » section) x 15; 2, the dominant biosomata consists of nowakiids (*N. acuaria*), (level D of the « Corti Baccas 3rd » section) x 15; in both thin sections the sediment is completely homogenized by an intensive bioturbation.
- Figs. 3,4 - Microfacies 2 - Pelagic mudstone;
3, large bioclast are (a) trilobite and (b) cephalopod fragments, respectively. Thin curved filaments mostly represent displaced valves of ostracodes. (Micritic beds, 55 cm above level A of the « Corti Baccas 3rd » section), x 15; 4 the thin section shows a burrow infilled by radiaxial calcite at the top and collapsed fecal pellets at the bottom (level A), crossed nicols, x 15.





Text-fig. 1 - Constituent analysis of « Galemму 1st » limestones.



Text-fig. 2 - Constituent analysis of « Corti Baccas 3rd » limestones.

between densely packed bioclasts (pl. 4, fig. 4) or formed by the « umbrella effect ». Syntaxial overgrowth of pelmatozoan plates is common. In samples E-F of the Corti Baccas section drusy calcite partially infills stromatactis-type structures; their shape and genetical interpretation are described in Microfacies 3. In sample A (Corti Baccas section) a small amount of radiaxial cement is present in cavities, originally burrows, with collapsed fecal pellets at their bottom (pl. 4, fig. 4).

The amount of *skeletal sand* is variable with mean values lower than 10% in most samples. It reaches values of 18%, 24% and 37% in samples B, D (Corti Baccas), 7, and 6 (Galemmu), respectively, where portions of the sediment are « grain-supported » (see also next paragraph).

The term « stylolites » is used here for identifying the fine, non-calcareous material concentrated in sheets and lenses of stylolaminites between small lenses and nodules of limestone, either generated by pressure solution during late diagenesis, or primary deposition due to an increase of terrigenous supply. In normal practice these types of structures are ignored in the point-counting of main constituents; however, in some beds of « stylonodular limestone » (*sensu* Flügel, 1982, p. 92), as in sample 7 of Galemmu section, they characterize the 30% of the sediment. In thin-sections it is, however, very difficult to distinguish the matrix inside the stylolaminites which percentages may be overestimated (sample 7, Galemmu section) or underestimated (sample A2, Corti Baccas section) in respect of the amount of insoluble residue.

Scattered authigenic quartz crystals and opaque minerals, mostly represented by cubical pyrite micro-

crystals, are also recognizable as accessory components.

2) Data on the composition of skeletal sand per each sample are summarized in the lower part of figs. 1 and 2 and allow us to make the following remarks.

Echinoderm remains, mainly consisting of columnar and arm plates of pelmatozoan, predominate the skeletal sand of several samples and sometimes represent the bulk of bioclasts (sample A2, 6, 7). Their abundance may be strongly overestimated in respect to the original biocenosis because the skeleton of such organisms is easily disintegrated into several component plates. Furthermore the lack of identifiable specimens of pelmatozoans prevents from discerning whether they are benthic organisms. In absence of other indications we favour this interpretation.

In the studied samples trilobites and ostracodes, distinguishable in thin section on the basis of their shape, do not seem important producers of skeletal sand. Only in samples A2, B1 (Corti Baccas), 1 and 6 (Galemmu) trilobites reach values slightly higher than 10%. Ostracodes display a significant percentage in samples A and 3 (27% and 18% respectively). In both these groups each individual produces by ecdysis several carapaces and, increasing largely, the number of potential fossils. Also the arthropod percentages may be overestimated.

With the exception of sample A (Corti Baccas section) where cephalopods represent 30% of the skeletal sand fraction, other molluscs are poorly represented. Articulate brachiopods also are quantitatively unimportant and, usually, they are preserved as whole shells very small in size. Tentaculitids (Styliolinids and Nowakiids, including *Nowakia acuaria*) are, in addition to the echinoderms, the most common preserved bio-

EXPLANATION OF PLATE 5

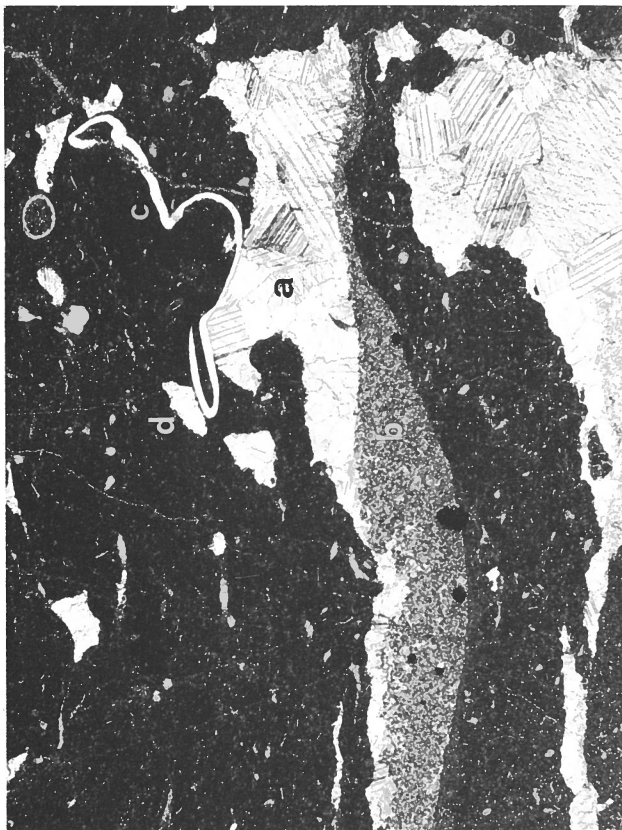
- Fig. 1 - Microfacies 3 - Stromatactis-bearing mudstone; the photomicrograph shows several open-space structures of stromatactis type of different size, sub-parallel to the bedding plane. The larger one is infilled by (a) drusy calcite at the top and (b) fine light recrystallized micrite at the bottom. The latter is interpreted as the collapsed sediment originally baffled by ?algal organism that generated the cavity (see also text). Note the trilobite fragment (c), laying at the top of the cavity, originally supported by the soft-bodied organism that is partly adapted to the shape of the bioclast. This, in turn, constitutes a hard substratum where other ?algal colonies (d) can develop. Dark spots, at the bottom of the cavity, consist of pyrite microcrystals. (Level E of the « Corti Baccas 3rd » section) x 15.
- Fig. 2 - Microfacies 5 - « Stylonodular limestone »; sheets and lenses of stylolaminites (a) alternate with lenses of crinoidal wackestone parallel to the bedding. Pressure solution affected the sediment after its consolidation. Low degree of compaction before the sediment cementation is suggested by a very rare intergranular pressure solution at grain contact. Some bioclasts show drag fabrics. Arrows indicate authigenic quartz inside echinoderm plates and sediment. (Level 7 of the « Galemmu 1st » section) x 15.
- Figs. 3,4 - Microfacies 4 - Bioclastic (encrinitic) packstone; Both photomicrographs are from the same thin section. Sparry calcite occur in geopetal fabrics, intergranular voids between densely packed unsorted bioclasts and syntaxial overgrowth of crinoidal plates. These last represent the bulk of the skeletal fraction. Other bioclasts consist of tentaculites, large trilobite fragments, ostracodes and small gastropods. (Level 6 of the « Galemmu 1st » section) x 15.



2



4



1



3

somata and represent the bulk of the pelagic components in most sample (for example samples 2-5, Galemму, D-E, Corti Baccas).

In all thin-sections there are fragments which could not be identified. They are plotted as indeterminate skeletal grains.

To sum up, the occurrence of various taxa constituting the skeletal sand generally is consistent with the occurrence of macrofossils and with the fossil content of the insoluble residues. The faunas are alternatively dominated by pelagic (dacryoconarids, cephalopods), epiplanktonic (pelmatozoans) and benthic sessile assemblages (pelmatozoans, brachiopods). In the « Galemму 1st » limestones, dacryoconarids dominate in the lower half of the section, replaced in abundance by echinoderms in the upper half of it. In the « Corti Baccas 3rd », from base to top, the amount of sessile organisms gradually decrease, and, in the mean time the pelagic (planktonic) faunal components increase. Vagile epifauna, represented by trilobites and ostracodes, plays a subordinate role except in sample A of the « Corti Baccas 3rd » section where ostracodes are important as paleoenvironmental indicators.

DESCRIPTION OF MICROFACIES

On the basis of data obtained from the constituent analysis in addition to textural and structural observations, five main microfacies have been recognized among the Galemму and Corti Baccas limestones.

1 - BIOTURBATED TENTACULITE WACKESTONE-PACKSTONE (pl. 4, figs. 1, 2).

This correspond to the SMF type 9 (Flügel, 1982). It is one of the most commonly represented microfacies within our sections (i.e. samples B, D, D1, Corti Baccas, 1, 5, Galemму) and, in general, in Lower Devonian pelagic nodular limestones of southwestern Sardinia.

The matrix, grey to light grey in colour, consists of micrite and very fine detritus (calcisiltite). Usually the sediments is mud-supported, only occasionally grain-supported. In addition to tentaculites (Styliolinids and Nowakiids), other bioclasts are mostly crinoidal plates and subordinately trilobite fragments. Grains are moderately sorted and homogenized by intensive bioturbation. Tentaculites, in fact, lie at different angles to the bedding plane; a preferential orientation in thin layers and geopetal structures inside them were never observed. This strong mixing, probably due to soft-bodied organisms at the sediment-water interface (or just below), may be favoured by a slow rate of sedimentation. Compaction inside this microfacies is very rare.

2 - PELAGIC MUDSTONE (pl. 4, figs. 3, 4).

This microfacies is also very common in Sardinian limestones (samples A, Corti Baccas, 2, 3, 4, Galemму). It alternates with microfacies 1 within nodular beds and represents together with MF 1 the normal pelagic deposition. Similar microfacies is also present at the top of some « allodapic beds » (*sensu* Vai, 1980) in the lowermost part of « Corti Baccas 3rd » section (pl. 1, fig. 4).

Matrix represents the bulk of the sediment and consists of micrite, grey to dark grey in colour.

Fossil content is very poor. It includes rare to few planktonic (dacryoconarids), nektonic (cephalopods) organisms and scattered thin-shelled mollusc. Sometimes vagile benthos is represented by ostracode and trilobite fragments.

Burrows, infilled by radiaxial calcite and collapsed fecal pellets at their bottoms (pl. 4, fig. 4), occur in this microfacies at level A.

3 - STROMATACTIS-BEARING MUDSTONE (pl. 5, fig. 1).

This microfacies represents a variation of MF 2, which is described separately because of the importance of stromatactis structures during the deposition of pelagic limestones in the Upper Pragian sequence of southern Sardinia. A coeval stromatactis-bearing carbonate mound was preliminarily described by Gnoli *et al.* (1981). Formation of these structures must be due either to peculiar paleoenvironmental conditions or to decay of a certain group of algae (?Cyanophytes). Cryptalgal genesis for the Sardinian stromatactis bodies remains to demonstrate, although some features (i.e. shape, colour, sedimentary structures, different generations of cement inside the cavities, isotope analysis, etc.) would suggest this origin (Gnoli *et al.* in preparation).

This microfacies is present only in the uppermost levels (samples E, E1, F) of the « Corti Baccas 3rd » section, mainly belonging to the *pireneae* Zone (Upper Pragian). Matrix and fossil content are similar to those of MF2; bioturbation and burrows are completely lacking.

Stromatactis bodies, a few mm to a few cm in size, show an undulated to flat, often conformable, base and a digitated roof. Cavities are filled with sparry calcite at the top and collapsed recrystallized micrite at the bottom. Those cavities may originated from decay of soft-bodied algal-type organisms; bioclasts laying at the top of calcite infilling, now supported by the cement, may be originally supported by the soft-bodied organism (pl. 5, fig. 1). Thus, one explanation of the genesis of such stromatactis could be summarized as follow: 1) algal bodies developed on a bottom more or less consolidated by a very early

cementation during time of a relatively slow rate of sedimentation, 2) normal deposition resumed with micrite and bioclasts surrounding the algal bodies. Some bioclasts might come to rest on the algal bodies, which adapted their shape at the contact boundary; some micrite may be baffled inside algal bodies. 3) A new episode of relatively slow sedimentation provoked an early cementation of the matrix surrounding the soft organism; 4) organic matter decayed and the baffled micrite collapsed on the bottom of the so formed cavity that, 5) is infilled in its upper part by drusy calcite by late diagenesis. According to this interpretation, stromatactis of different sizes are related to the duration of the intervals characterized by low rate of sedimentation. Because of lack of bioturbation and burrowing, the rate of sedimentation of MF 3 appears higher than in microfacies 1 and 2.

4 - BIOCLASTIC (ENCRINITIC) PACKSTONE (pl. 5, figs. 3, 4).

This microfacies occurs in the lowermost part of some « allodapic beds » at the base of the « Corti Baccas 3rd » and at level 6 of the « Galemму 1st » sections.

The matrix consists of a mixture of recrystallized micrite (microsparite) and subordinate intergranular drusy calcite between densely packed bioclasts. Syntaxial overgrowth of crinoidal plates and geopetal fabrics are common.

The bulk of the sediment is mainly represented by crinoidal plates (70% of bioclasts), trilobite fragments (about 12%), a few ostracods and small gastropods. In sample 6 of the Galemму section a small amount of planktonic organisms (tentaculites) is also present. Bioclasts are usually well preserved, neither rounded nor broken (valves of ostracodes are still articulated), and very poorly sorted.

Grains support the sediment, but pressure solution structures are very rare. When present, they are stylolites sub-parallel to the bedding plane.

Two types of genesis may be hypothesized for MF 4:

- 1) Local, small scale debris flows concentrated bioclasts (mostly autochthonous or from a proximal source) along a very small channels (few cm large) during deposition of the normal pelagite, represented by microfacies 1 and 2. This process (sample 6, Galemму section) resulted in a mixture of benthic and planktonic faunal elements representative of MF that contributed along with microfacies 1 and 2 to constitute most of the nodular limestone.
- 2) Accumulation by gravity of allochthonous bioclasts within « allodapic beds ».

5 - « STYLONODULAR LIMESTONE » (pl. 5, fig. 2).

This rarely described microfacies frequently occur in our sections in calcareous shales and, in general, at the boundary between all other microfacies inside the nodular limestones.

As previously reported by Flügel (1982, p. 92) and in the description of the main constituents of the limestones (see above), MF 5 consists of very small lenses, a few mm or less thick, of fossiliferous mudstone, wackestone or packstone separated by sheets and lenses of stylolaminite parallel to the bedding plane.

The general fabric of this microfacies is due, without any doubt, to compaction and pressure solution but depending from the primary deposition of a certain amount of fine terrigenous material.

Bioclasts mainly consist of partly dissolved crinoidal plates.

Authigenic quartz microcrystals occur inside bioclasts and matrix.

The boundaries between various microfacies, which alternate each others every few mm to few cm, are usually stylolitic or discontinuous.

Evidences of an early diagenetic cementation are recorded in most of the thin sections belonging to these microfacies.

SOME SEDIMENTOLOGICAL REMARKS AND SETTING OF « ALLODAPIC BEDS »

At the base of the « Corti Baccas 3rd » section allodapic beds can be laterally seen for some metres, they alternate with apparently unfossiliferous dark shales. Their thickness ranges from about 2 cm to 10 cm.

Usually, each bed is represented by encrinitic packstone (MF 3) in its lower part and fossiliferous mudstone (MF 2) at the top, where large fragments of orthocones are so abundant that, in some cases, the rock can be classified as floatstone. As shown in fig. 4 of pl. 1, in the basal part of the bed, reverse grading of crinoidal bioclasts, which concentrate « at the shadow » of large fragment of cephalopods, may also occur. Cephalopods are not oriented and lie with the long axes at different angles to the bedding plane. They are roughly accumulated one on top of the other, sometimes telescoped together or projected above the bed surface. Despite the evidence of transport from a shallow-water environment into the basin, bioclasts are not worn.

Concerning how such beds originated, taking into account what is known to date on the depositional environment of the Upper Silurian-Lower Devonian

sequence in southwestern Sardinia, there is no evidence to interpret the « allodapic beds » as a true turbidite sequence (= allodapic limestone *sensu* Meischner, 1964) deposited in a very deep basin. Furthermore, the lack of massive thick layers with rounded and worn bioclasts and of any preferential fabric prevents us to consider these allodapic beds as originated by debris flows.

A more suitable hypothesis, able to conciliate most of the sedimentological features of these beds, seems that suggested by Vai (1980) for Lower Devonian allodapic beds from the Carnic Alps, called by this Author « Storm layers versus turbidites ». The settling of the allochthonous material might be due to turbid surficial cloud generated by storm events, which stirred the waters at the bottom of a shallow platform or of an upper slope and spread coarse to finer materials over long distances. Following this hypothesis, the burrowed mudstone of MF 2, mostly at the top of each bed, could represent the product of settling of the very fine tail of the detrital cloud.

THE DEPOSITIONAL ENVIRONMENT OF « GALEMMU » AND « CORTI BACCAS » LIMESTONES

Any reconstruction of the evolutionary history of the Lower Devonian sequence from southwestern Sardinia is biased by the lack of continuous exposures in the area. However, on the basis of the collected paleontological and sedimentological data and by comparisons with coeval sequence from Sardinia and from the circum-Mediterranean area, the depositional history of the studied sequences can be hypothesized.

It seems to me that the studied limestones and related lithotypes are characteristic of a pelagic sedimentation, which occurred on submarine rises, located upon an essentially stable structural platform. According to Berry & Boucot (1967), Holland (1971), and Vai (1972, 1980), a structural feature, resulting as a large epicontinental (shelf) area existed, between Africa and Europa from Cambrian up to Early Devonian.

The thick bedded, partly nodular, mitritic limestones associated with stromatactis (MF 3) and nodular limestone (MF 1+2) with thin interbedded shales could represent the normal pelagic deposition on the rises and upper slope. Shales with nodules (MF 5), shales, and interbedded allodapic beds (MF 2+4) were deposited, instead, at greater depths between lower slopes and basin.

According to these depositional patterns, the « Corti Baccas 3rd » section consist of from the base to the top a sequence that evolves, more or less continuously through time, from a deeper to a shallower depositional environment. A coeval section from the Sulcis area (Monte Santo section), including the M.te

Padenteddu mud mound, southern Sardinia) also shows the same trend. Thus, it seems reasonable to hypothesize that a general regressive event occurred during the Early Lochkov-Late Pragian in South Sardinia. Further investigations are needed to better illustrate this event.

As far as the depth of deposition is concerned, the benthic ostracode assemblage of level A of the « Corti Baccas 3rd » section suggests a sublittoral to upper bathyal environment (about 200 m deep). Associated encrusting foraminifera belonging to the genus *Tolypanmina*, according to Wendt (1969) and Tucker (1973), would indicate similar depths or less. Stromatactis bodies from levels E, E1, F, (« Corti Baccas 3rd » section) if related to an algal genesis, would suggest a shallow-water environment, however below the wave base.

CONCLUDING REMARKS

The present results, even if they must be verified by further detailed studies on several other sections in Sardinia, contribute to a better understanding of the faunal assemblages, depositional processes and paleoenvironment of Lower Devonian pelagic limestones in the circum-Mediterranean area. Furthermore, being Sardinia in a key paleogeographic position, the present results allow us to better evaluate the two main interpretative models of the stratigraphical-structural evolution of this area during the Early Paleozoic. From this point of view, our data emphasize the presence of an epicontinental area on an essentially stable structural platform whereas they disagree with the Jaeger's model (1976) that advocates the presence of lower bathyal to abyssal areas (more than 1000 m deep) linked to a mobile ortho-geosyncline.

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