Mem. Soc. Geol. It.,
20 (1979), 405-423, 9 ff., 4 tabb.

PALEOECOLOGICAL REMARKS ON THE "ORTHOCERAS LIMESTONE" OF SOUTHWESTERN SARDINIA (MIDDLE-UPPER SILURIAN) (*)

Memoria di MAURIZIO GNOLI (**), GIAN CLEMENTE PAREA (***),
FRANCO RUSSO (**) & ENRICO SERPAGLI (**)

(presentata a Siena, nella Seduta tematica del 18-19 maggio 1979)

CONTENT

KEY WORDS: *Shelf environment, death assemblage, sedimentary structures, depth indicators, Silurian.*

RIASSUNTO

Dallo studio della fauna e delle caratteristiche sedimentologiche dei calcari a « *Orthoceras* » di Fluminimaggiore risulta che questi sedimenti si depositarono in un mare normalmente ossigenato ricco di fauna esclusivamente pelagica nelle parti superiori e decisamente tossico verso il fondo.

Analisi statistiche ed esperimenti di laboratorio hanno portato gli scriventi a considerare il particolare tipo di orientamento presentato dai fossili come un effetto del moto ondoso. I gusci ed i loro frammenti, sparsi su un fondo di fango fine, verrebbero disposti dalle onde a bande successive che rappresenterebbero l'equivalente meccanico delle increspature di fondo tipiche dei fondi sabbiosi.

Potrebbe trattarsi di un mare epicontinentale di profondità limitata tale da permettere al moto ondoso di agire sul fondo.

ABSTRACT

A study of the fauna and of the sedimentological characteristics of the "*Orthoceras* limestone" has shown that these sediments were deposited in a normally oxygenated sea rich in an exclusively pelagic fauna in the upper parts but definitely toxic towards the bottom.

Statistical analyses along with laboratory experiments have led the writers to consider that the particular type of orientation found in the fossils is the result of ware motion. The shells and their fragments, distributed on the fine mud of the bottom, must have been positioned by the waves in successive belts which represent the mechanical equivalent of ripple marks, typical of sandy bottoms. Possibly this was an epicontinental sea of limited depth so that the ware motion could affect the sea bottom.

INTRODUCTION

The objective of this study was to try to define the environmental conditions that controlled the deposition of the "*Orthoceras* limestone" in Southwestern Sardinia.

(*) Work supported by the Consiglio Naz. delle Ricerche, grants: 78.01881.66, IGCP Project n. 53: Ecostratigraphy and 78.00308.05.

(**) Istituto di Paleontologia dell'Università di Modena, Italy.
(***) Istituto di Geologia dell'Università di Modena, Italy.

Both the fauna content and the lithological and sedimentological characteristics of these limestone are taken into consideration in this report. From the paleontological point of view we have tried to determine the environmental significance of the individual taxa as well as that of the entire association. The sedimentological aspects of the study were directed towards evaluating the energetic characteristics of the environment by means of the sedimentary structures. In particular we based our conclusions on the distribution and orientation of the orthoconical shells of nautiloids.

Further information was obtained from the lithological characteristics of the rocks.

GEOLOGICAL REMARKS

A brief summary of the Silurian rocks is given here in order to place in perspective the "*Orthoceras* limestone" dealt with in this paper.

Silurian marine sediments, which are exposed in two main areas (Iglesiente at SW and Gerrei at SE), are represented chiefly by black shales rich in graptolites. Well bedded black limestone with cephalopods ("*Orthoceras*"), *Cardiola*, graptolites, gastropods, brachiopods, ostracods and conodonts occurs in the upper part of the sequence. On the basis of conodonts, the "*Orthoceras* limestone" was dated by SERPAGLI (1967, 1971) as Uppermost Wenlockian-Ludlovian in age.

A complete Silurian stratigraphic record is unknown in Sardinia since it is impossible to find continuous sequences of fossiliferous marine strata. Furthermore, it is virtually impossibile to trace individual beds over long distances. Lateral facies changes and intrusions of magmatic rocks, to which mineralized veins are connected, greatly complicate the geological mapping of this region.

Because of the intense tectonic activity and poor outcrops, it is impossible to measure the thickness of the "*Orthoceras* limestone" with any precision; however, the overall thickness should be of the order of 30 meters.

The "*Orthoceras* limestones" in the Fluminimaggiore area are found as more or less flattened prismatic blocks surrounded by non calcareous pelites. These limestone blocks are generally not longer than a meter and their edges are slightly rounded. The pelites clearly have flown around the hard blocks which are often folded in various ways, sometimes very tightly.

On the basis of what can be observed in the field, the breaking up of the calcareous layers and the incorporation of the fragments in the silt-clay matrix have been caused by intense tectonic activity. No signs of deformation of the blocks in the plastic state were observed not even at the edges.

The occasionally observable rounding of the edges of the limestone blocks, which is not pronounced however, was caused solely by dissolution and disintegration associated with surface weathering.

The "*Orthoceras* limestones" in the studied region are made-up of sparite or microsparite having widely variable crystal sizes, even within the same thin section, (general between 30 and 300 microns). These sparites must be derived from the recrystallization of a very fine calcareous mud in which fragments and shells of orthoceratids were scattered with a few bivalves and some gastropods as described in the paragraph regarding the fauna.

The orthoceratid shells have varying sizes from a few millimeters to around 30 centimeters in length for whole specimens. Some fragments of living chambers reach a diameter of about 20 centimeters, hence, considering an angle of expansion of approximately 2°, these chambers must have been part of a 2 meter long shell.

In the microspar surrounding the nautiloids, shell fragments of all dimensions down to a few microns are present. The overall aspect is that of a completely random association of shells and shell fragments. Concentration of small shells in the "shadows" of those having greater dimensions were never observed.

Some chemical analyses gave values of $CaCO_3$ close to 96-98%, which can certainly be considered a little in excess given the impossibility of eliminating with certainty every spot or veinlet of sparry calcite. X-ray diffraction analyses of the small amount of insoluble residue, after removal of the organic fraction, showed the presence of quartz, mica, chlorite and/or montmorillonite and feldspar (1).

Often the calcareous mud partially penetrated the shells, occupying only the lower part and decreasing in thickness towards the apical portion (fig. 1). The remaining upper parts of the shells are filled by blocky calcite cement.

SEDIMENTOLOGICAL REMARKS

GEOMETRY OF THE "ORTHOCERAS LENSES"

The term "*Orthoceras* lens", used by the first authors that delt with them (TARICCO, 1921-1922, p. 13; GORTANI, 1922, p. 365; NOVARESE & TARICCO, 1922, p. 318-319) and recently adopted also by SERPAGLI (1970) and SERPAGLI & GNOLI (1977), is purposely not used in this article since the lenticular form in any sedimentary body implies the existence of different environmental conditions between the thicker center and the ends. The difference in environmental conditions, for example, could be a different distribution of the action of the current between the bottom and the sides of a channel of which the lens represents the filling. It is important to note here that if the so called "*Orthoceras* lenses" represent orthogonal sections of sedimentary bodies formed by filling of channels, they should be elongated in a particular direction in the form of ribbon shaped bodies and not be essentially equidimensional as they actually are.

Another situation able to produce lenticular sedimentary bodies could be the accumulation of particular organisms, or sediments derived from them, on certain areas of the bottom particularly favorable to the organisms concerned. In a situation of this type, there should exist a transition belt in which the favorable conditions progressively disappear outwards until they no longer exist. In this way lenticular accumulation would be produced whose dimensions are greater by one or more orders of magnitude to those of the constituent elements. Various other ways of accumulation of lenticular deposits can be hypothesized, all of which, however, imply the existence of sedimentary structures or characteristics which change from the center to the margins because of the variation in genetic conditions.

On the contrary, the most evident aspect in all of the blocks of "*Orthoceras* limestone" examined is the uniformity of the characteristics over the entire external surface and in the observable sections. In addition, the observable blocks have sizes of the same order of magnitude of the shells they contain and in certain cases the dimensions of the blocks are less than those of the enclosed shells.

From these considerations it follows that the Orthoceras formations must have originally consisted of an alternation of calcareous layers with pelitic layers that were poor or completely lacking in carbonates.

Within the calcareous layers the fossils are not uniformly distributed in either the horizontal or vertical direction.

More evident is that the larger shells are more densely packed in certain levels, separated by variable thicknesses of micrites that are lacking or poor in fossils. A closer examination shows that the predominantly micritic rock contains thin laminae very

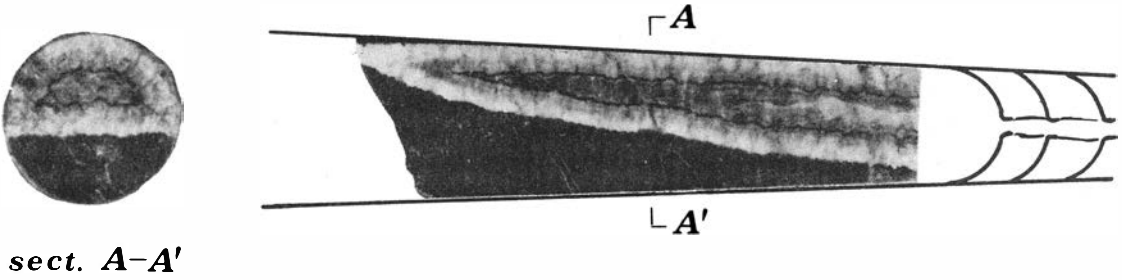

Fig. 1 - Axial and cross section of a living chamber of *Kopaninoceras* ? *thyrsus* (BARRANDE) showing the progressive wedging out towards the apex of the muddy infilling, x 1.

---

(1) The authors thank Dr. G. GARUTI, Ist. Mineralogia and Petrologia, Modena University, for having done the X-ray diffraction analyses.

rich in small shells or fragments of shells. Such laminae are of relatively reduced lateral extension, at the most of the order of 10 cm or slightly more (fig. 2).

The laminae or layers made-up of medium sized or large shells are much more extensive laterally but it was not possibile to determine their actual sizes because of the scarcity of observable blocks. The laminae formed by the thin concentrations of small fossil remains can not be the result of simple sedimentation since their lateral extension is too limited but rather must have been caused by the reworking *in situ* of the upper part of the sediment itself immediately after its deposition.

In fact, the laminae (or better, layers) caused by general variations in the conditions of sedimentation have a considerable continuity and extension. One can quote as an example the varves or laminae present in some calcareous layers of the Swabic Jurassic which are continuous, with negligible variations in thickness, for various kilometers. (Personal communication from Prof. A. SEILACHER).

The concentrations of fossils described here recall to mind the concentrations of pebbles or various shells due to the action of waves on heterogeneous mud bottom. Considering the limited lateral continuity of the laminae, the general aspect and the absolute absence of cross laminations even on a small scale that could indicate the presence of currents, the agent that most probably concentrated the fossil remains must have been waves.

The shells and shell fragments, as already said, are in part filled with micrite, that constitutes the mass of the rock, and in part with sparry calcite.

The filling of the shells by the original calcareous mud, more or less rich in fragments, is in general quite extensive; it sometimes reached the innermost parts of the sifuncle.

Sometimes it can also happen that whole large shells and small ones are telescoped together (fig. 3). It quite frequently occurs that even the more fragil parts of the shells, such as the living chamber and apical extremity, are well preserved. The living chambers of the larger shells are typically fractured by the compaction causing a reduction of as much as 30% of the original thickness. On the basis of their particle

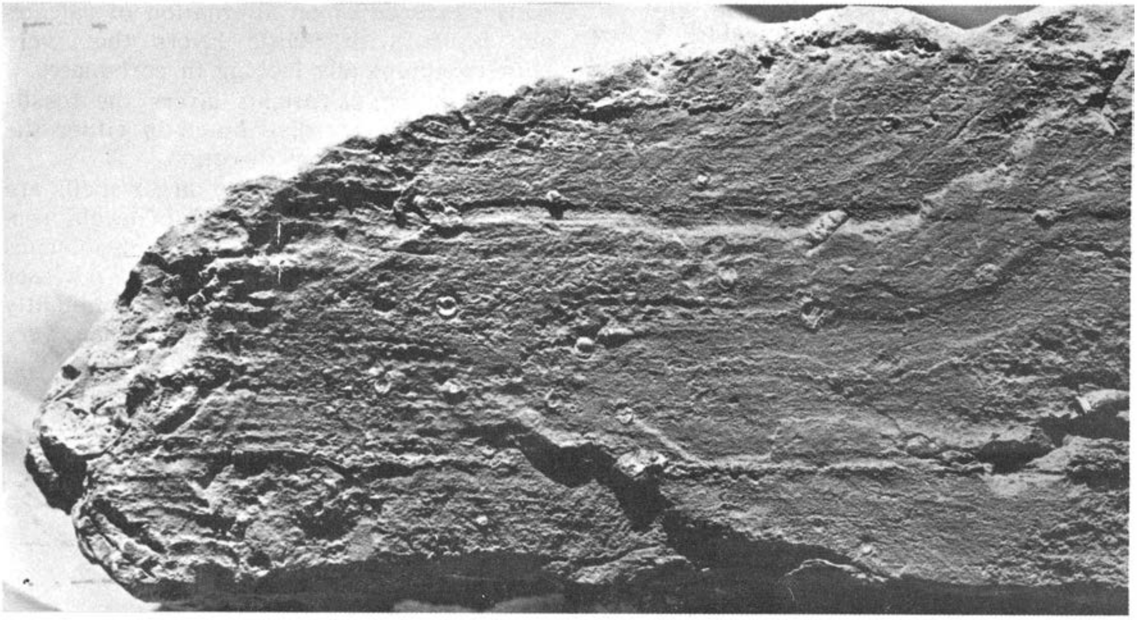

Fig. 2 - Weathered cross section of a slab of "*Orthoceras*" *limestone*. The plane-parallel arrangement of the laterally vanishing laminae of shell debris is clearly independent from the lenticular outer shape of the edge of the slab, x 1.

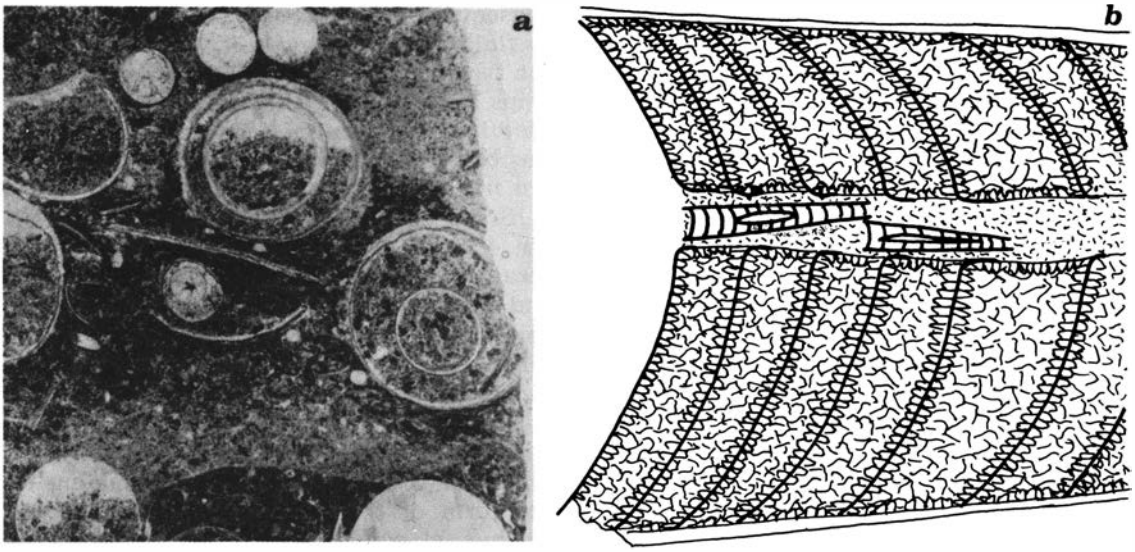

Fig. 3 - Orthoconic shells telescoped together with the guest shell occupying the living chamber (*a*) (cross section, x 5) or the siphuncle of the host (*b*) drawing after a photograph, x 1).

size, these sediments can be classified as medium-fine silts. Visible traces of burrowing animals were not found in any of the samples examined. This maight be the result of two opposite situations: either burrowing animals were really absent in the sedimentary environment or they were present in such large quantities, with respect to the rate of sedimentation, that there was time for them to homogenize completely the sediment. Of these two hypotheses, however, only the first is valid because of the presence of the laminae previously discussed as well as of a certain orientation of the shells which will be described later.

The black colour of the rock which tends to be altered in grey, (more or less light), by oxidation must be due to organic matter in the absence of iron monosulfides. Organic matter (both carbonaceous and bituminous) was found in the insoluble residue.

In effect, many of the *Orthoceras* blocks have rusty spots evidently caused by oxidation of iron sulfides. Closer observation showed that the sulfides were concentrated in the living chambers near the openings of some shells where in fact, the rock has actually a brown-yellowish color. This fact, which can be explained by the permanence of soft parts of the mollusk in many living chambers at least until the time of the first burial, proves the existence of reducing conditions above the bottom other than in the mud itself. The Eh = O level, must therefore have been located within the water of the sedimentary environment (above the bottom).

As already said, the shells of orthoceratids are concentrated in preferred levels, where the shells are definitely ordered in a horizontal or very nearly horizontal position.

Examination of an horizontal section of the orthoceratid plates and blocks shows that the shells are not uniformly distributed in the horizontal plane. In some plates they are apparently randomly distributed, while in others they show a certain orientation is developed.

In sufficiently extensive plates, belts one found in which the shells are iso-oriented in alternation with other belts in which the shells are less clearly iso-oriented and often trending perpendicularly to those of the surrounding area. Considering the relationship between the sizes of the shells and the consistency of their orientation, the shells that more often have a more preferred orientation are those that are more elongated. As a first approximation, this is equivalent to say those having an average length of 2-5 cm.

Another observable characteristic in the samples was that the orientation of the large shells and shell fragments (those having a diameter greater than 2-3 cm) determined that of the smaller shells around them.

Altogether, the observations of sufficiently extensive plates suggests of a periodic alternation of belts in which the fossils were oriented first in a particular direction and than in a direction either perpendicular to the first or more or less random. The existence of such a periodic pattern leads one to think of the effect of an oscillatory motion such as wave motion. In that case, the repetition of the belts with the fossils oriented longitudinally alternating with those oriented transversally, would be analogous to the crests and the trough of ripple marks. It is evident that ripples of this type would be formed on an incoherent sandy bottom and not on a bottom consisting of fine mud; however, *a priori*, it is plausible that rigid bodies with a specific weight only sligthly greater than that of water could be oriented by wave motion in such a way as to develop a structure analogous to ripple marks on the bottom. Also, the width of the belts observed in the orthoceratid plates (about 10 cm each, thus ~ 20 cm from crest to crest of the hypothesized analogues to ripple marks) is of the same order of magnitude as the ripple marks reported in the literature and observed by one of the authors along various tracts of the Italian coast at a depth of several meters. Also, the non negligible prevailing sense of orientation of cones may be considered analogous to the sligth asymmetry which often characterizes the ripple made by the waves. To check the plausibility of the interpretation proposed here, the orientation of the shells was studied with statistical methods in order to test the existence of prevailing orientations as well as the objectivity of the subdivision into distinct belts.

In addition, a series of laboratory experiments on the effect of wave motion on elongated bodies slightly heavier than water were carried out.

THE PROBLEM OF NAUTILOID ORIENTATION

Symmetric and asymmetric scattered elongated bodies showing a preferred orientation are relatively common in clastic sediments. The preferred orientations are the consequence of mechanical action related to fluid motion. However, what exactly are the types of motion and the precise relationships between the direction of motion of the fluid and the preferred orientation of the bodies that have undergone the action are not at all known with precision.

Some papers (see critical review in POTTER & PETTIJOHN, 1963) report only on the measurements made on the oriented shells and do not provide any data that helps to confirm or disprove the direction and the sense of the current inferred as responsible for the particular orientation found.

Results of more thorough laboratory experiments evidence that various patterns of orientation can be produced depending on the form of the bodies as well as the experimental conditions. In their critical review POTTER & PETTIJOHN (1963, p. 37-40) point out the uncertain value of the relationships that can be established between shell orientation and the current that has caused the orientation.

More recently, KELLING & WILLIAMS (1967) found that on a silty bottom, depending on the flow conditions of the current, shells of *Mytilus* may be distributed in varying ways.

BRENCHLEY & NEWALL (1970) affirmed on the basis of laboratory experiments that, with the present state of knowledge, it is still too soon to arrive at a general valid conclusion regarding the orientation that can be expected for an association of fossils or shells.

Among the researchers who are involved in studies of orthoconical shell orientation, KRINSLEY (1960), REYMENT (1971) and LAUBERE (1977) consider only the currents capable of orienting the shells on the bottom. LAUFELD (1974) explicitely considers wave motion as a source of perturbation of the orientation caused by currents. Also KEY (1954) probably refers to wave motion when comparing the orientations of the Ordovician orthoceratids of St. Joseph's Island to that of water-soaked or semi-floating pieces of wood that are distributed respectively parallel and perpendicular to the coast in lakes.

In 1953 PETRANEK and KOMARKOVA held that perpendicular wave motions, other than perpendicular currents, could be the cause of two perpendicular directions of Palaeozoic orthoceratid shells of the Bohemian Basin. BALASHOV (1965) considered both wave motion and currents as being responsible for an orientation along a single direction.

Hence, from this examination of the literature it results that (i) a considerable uncertainty persists regarding the exact relationship between orientation of shells and the motion of the water that acts on them and (ii) the fundamental cause of the orientation of shells is considered more or less to be the action of currents and only in exceptional cases that of wave motion.

It also seems that up to now the cases considered are always those in which the shells have more or less the same type of orientation in all the surfaces examined. However, the orthoconids of Fluminimaggiore are sparsely distributed in a discontinuous way, specifically in parallel belts in which the elements tend to be alternatively distributed according to two orientations which are discernably perpendicular to each other.

LABORATORY EXPERIMENTS

In order to experimentally study the effect of wave motion on elongated bodies lying on the bottom, a simple system was built to produce waves with controlled characteristics in a small basin.

A tank of galvanized sheet iron was built with dimensions 200 × 25 cm and a depth of 15 cm. The experiments were carried out with 6.5 cm of water in the basin. Waves were produced by moving a vertical plate back and forth in the tank. The plate was 10 cm high and 24.5 cm wide and immerged in the water until a few mm of the bottom. To obtain the required motion, an electric engine was used to drive the vertical plate by means of a suitable handle and reducing gear. A meter to count the rotations was inserted between the reducing gear and the plate so that the number of waves used for each experiment could be calculated.

Grains of barley, 8 mm long and 3 mm in diameter, were used as the elongated bodies. These were found to be suitable as regards both shape and specific weight. For the experiments with conical bodies, some specimens of *Turritella* collected from the Adriatic Sea and some *Ceritium* were used. Their dimensions were about 30 mm in length with a maximum diameter of 8 mm.

In the course of the experiments it was necessary to eliminate interference produced by waves reflected from the two extreme walls of the basin both at the back of the generating plate and in front of it. The waves generated at the back of the plate were sufficiently neutralized with a very permeabile and irregular bar made-up of a small accumulation of very angular rock fragments.

The disturbances by the waves reflected from the end wall of the thank were neutralized by shifting a movable wall to make the lenght of the experimental tank multiple of the wave-lenght used. Thus, the experiments could be carried out with standing waves. The lenght of the waves used was 22 cm and the period 0.75 seconds.

Also, some experiments were carried out with progressive waves. Even though it was not possible to completely eliminate disturbances caused by reflected waves, the results obtained were very similar (fig. 4*d*).

As can be seen from figures 4*b* and 4*c*, the waves perceptibly oriented the barley and turritellids parallel to the axes of the ripples in correspondence to their crests as well as in a preferred direction perpendicular to the crests in the troughs between them.

Some differences can be seen when the distributions of the grains of barley and the shells of *Turritella* are compared with that of the « *Orthoceras* » shells (for example, fig. 7). In the studied rocks the belts made-up of the shells perpendicular to the belt itself are more evident. Probably, this orientation corresponds to the furrows located between the crests of the ripples. This difference is probably caused by the different characteristics of the substrate on which the shells were found in nature (fine soft mud) and that used for the shells of *Turritella* and the grains of barley (smooth sheet iron). It is also worthwhile to keep in mind that given their different size, the "*Orthoceras*" shells should have a much greater mutual interaction in the belts where they accumulated parallel to the structure

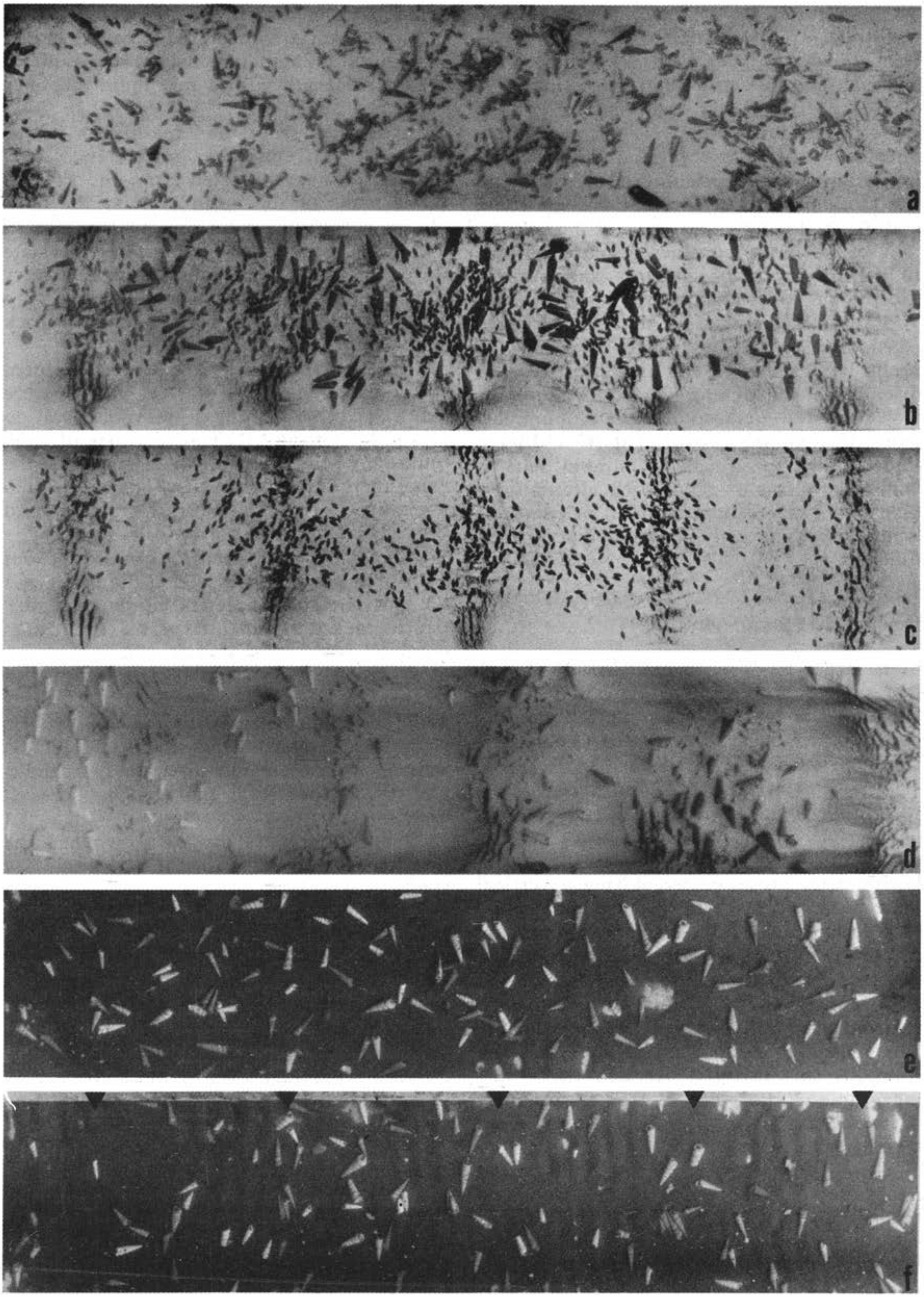
a
b
c
d
e
f

Fig. 4 - Laboratory experiments in a tank. *a*) Barley seeds and turritellids randomly scattered on the smooth bottom of the tank. *b*) The same as above after the action of 100 waves. Rhythmic concentrations of fine debris washed out from seeds and shells mark the crests of the standing waves (lenght 22 cm). *c*) The same as above with barley seeds only. *d*) Experiment with progressive waves (approximatively the same waves lenght). *e*) Turritellids randomly scattered on sandy bottom (medium grained sand). *f*) The same as above after the action of 100 waves. The position of the crests of the standing waves is shown by markers. Note that after wave action turritellids and seeds tend to be more densely packed beneath each crest of the waves where they are parallel to the crest itself. In the area between the crests, shells and seeds appear unoriented or at right angle with the waves.

---

much more than would be the case for the grains of barley.

It is necessary at this point to emphasize that these experimental studies were carried out with very simple equipment and that the objective was not to obtain quantitative data regarding either the depth to which a wave of a particular length can act or the relationship between wave length and size of the ripples and oriented bodies. The only correctly utilizable information from these experiments is that wave motion is actually capable of orientating elongated cyndrical or conical bodies according to a periodic pattern of alternating belts, within which the elongated bodies are distributed in a characteristic way. Such a distribution of conical bodies is schematically represented in fig. 5. With conical bodies of the same size and shape, uniformly scattered on the bottom surface, a rose diagram related to a limited portion of the total field may assume the shape of one of the diagrams represented in fig. 5. The shape of an analogous rose diagram will be a little more irregular and asymmetric when the conical bodies are different in size, not exactly at right angle each other, not uniformly scattered on the bottom surface and possibly with a slightly prevailing sense due to any perturbance whatever. The arms of the cross or the modal classes of the rose diagrams must be in any case either parallel or perpendicular to the belts if they do exist.

ORIENTATION ANALYSIS OF THE ORTHOCONIC NAUTILOIDS

Statistical analyses were employed in order to verify the existence and width of the belts cointaining fossils seen to be alternately oriented in the two preferred directions. In these analyses only the reciprocal orientations of the orthoconic shells within each single sample were considered. The reason for this was that the intense tectonic dislocations which completely broke-up the original calcareous strata made it impossible to reconstruct the true geographic orientation of the samples.

In each sample the azimuth of the growth axis of the orthocones was measured with respect to an arbitrary selected direction of reference. These data were taken from the smooth surfaces of 3 plates coming from the localities Perd'e Fogu, Galemmu and Corti Baccas respectively, all in the Fluminimaggiore area. The surfaces examined were cut parallel to the strata and had

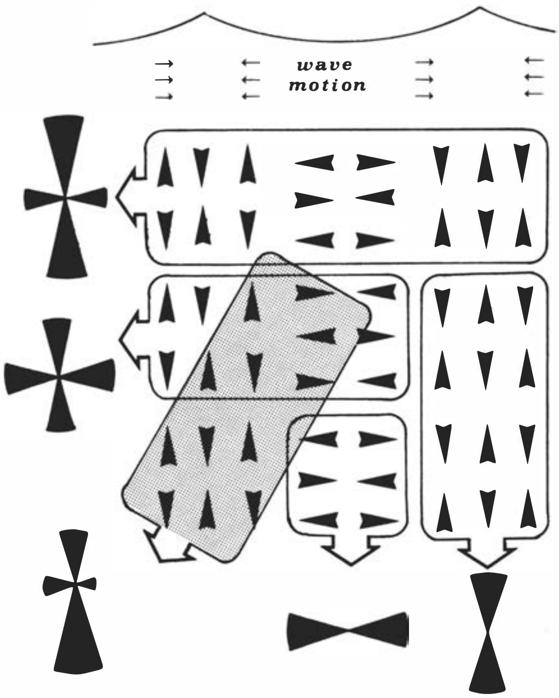

Fig. 5 - Schematical pattern of distribution of conical bodies oriented by wave action. This figure shows how the shape of each rose diagram is controlled by the size and orientation of the sampled area.

dimensions of some decimeters squared. The fossil remains, of sizes over a centimeter, had a density of about 10 specimens per 100 cm^2.

Using the method of REYMENT (1971) for quantitative analysis, the growth axis of each orthocone was considered as a unit vector whose origin was the apical part of the orthocone. The following expression gives the components of the mean vector in a series of observations:

$$x = \frac{1}{N} \sum_{i=1}^{N} \cos \alpha_i \; ; \; y = \frac{1}{N} \sum_{i=1}^{N} \sin \alpha_i$$

where N = the number of fossils per sample and α_i ($i = 1, \ldots N$) are the angles between a reference direction and that of the growth axis of the orthocones.

In polar coordinates, the mean vector is as follows:

$$r = \sqrt{x^2 + y^2} \quad ; \quad \tan \theta = \frac{y}{x}$$

The dispersion of a series of angular measurements can be expressed by mean of the mean angular deviation, *s* (analogous to the standard deviation) which is related to the value of *r* by the following equation:

$$s = \sqrt{2(1 - r)}$$

The values of s, r and θ mean for the three samples examined are given in table 1. In order to verify that the environmental characteristics did not change with time, measurements on samples 2 and 3 were made on two different levels of stratification about 2 centimeters apart (2', 2'', 3', 3''). To further verify the influence of the fossil size on orientation, specimens in sample 1 were analysed separately according to length (class 1a, ≦ 20 mm; class 1b > 20 mm).

The circular distribution diagrams for the shells in the plane examined are given for each sample in fig. 6.

The following considerations are suggested by the data of Table 1: *a*) With time, the orientation of the fossils varied little (26°) or remained practically constant, at least for the 4 periods represented by the two faces of the available plates; *b*) The orientation of the fossils was not influenced in any determined way by their size or their length.

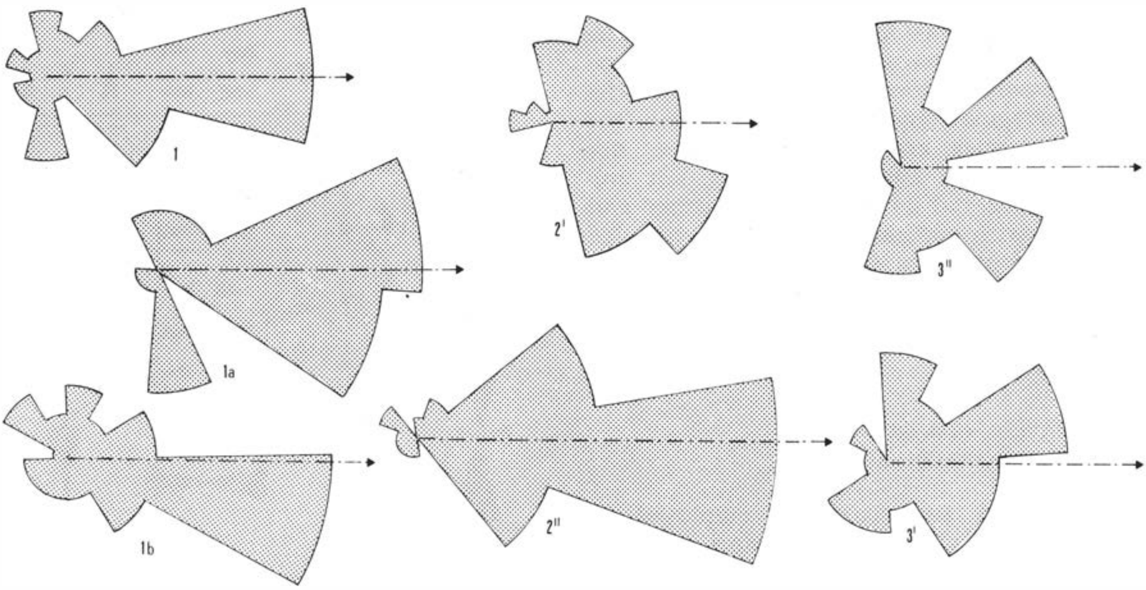

Fig. 6 - Rose diagrams of fossil nautiloid orientations. 1, sample n. 1 from Perd'e Fogu; 1*a* the same sample but taking in account only specimens ≤ 20 mm in length 2'-2'' upper and lower surfaces of sample n. 2 from Galemmu; 3'-3'' upper and lower surfaces of sample n. 3 from Corti Baccas.

TABLE 1

Mean angle and angular deviation; N = number of specimens in each sample; s° = mean angular deviation; r = mean angular vector; θ° = mean angle. (See text on page 414).

Sample	N	s°	r	θ°
1	101	60°	0.45	314°
1a	59	65°	0.34	328°
1b	42	50°	0.61	304°
2'	61	57°	0.50	256°
2"	43	46	0.68	259°
3'	38	65°	0.35	294°
3"	40	63°	0.38	320°

From an examination of the polar diagrams of figure 6 one sees that almost all the specimens are distributed in a semiplane. The existence of a preferred direction, with a relatively limited dispersion, is particularly evident in the graphs relative to samples 1, 1a, 1b and 2'.

A statistical verification of the non randomness of the distribution is supplied by Rayleigh's test if the hypothesis of a polymodal distribution is excluded. When applied to our data, this test, amply illustrated by REYMENT (1971), gave the results reported in table 2 and confirms a non random distribution in all the samples.

In order to give more statistical significance to a distribution of this type, the χ^2 test was applied. As seen from the values given in table 3, the hypothesis of a uniform distribution is significantly discarded. The level of significance falls to 5 to 10% only for sample 3. The comparative analysis of this slightly anomalous data, along with the unclear unimodality seen in figure 6 for semples 3', 3" and 2', led us to verify the possibility of a distribution in homogeneous zones having differing average directions and density. For this purpose, the following empirical procedure was used: The surfaces of the samples considered (1 and 3") were divided into parallel strips, 5 cm wide, perpendicular to the main modal direction pointed out by the rose diagrams of fig. 6. The width of the strips was chosen as to contain a sufficient number of specimens. In this analysis only specimens with length more of 20 mm were used.

For each strip the mean value of the cosines of the angles α_i between the direction of each specimen and the main modal direction was calculated, obtaining a certain value cos α_i. This value was used to draw the diagram of figure 7, for sample 1. This diagram results a discontinuous line with peaks and lows situated at quite regular distances, corresponding to the belts formed by groups of strips in which the mean values of $\overline{\cos}\ \alpha$ either greater than or less

TABLE 2

Randomness tests or "Rayleigh tests". (See text on this page).

Sample	N	Z	Random orientation hypothesis supported ?	
1	101	18.4	no	1%
1a	59	7.3	no	1%
1b	42	15.9	no	1%
2'	61	15.1	no	1%
2"	43	20.1	no	1%
3'	38	4.8	no	1%
3"	40	5.8	no	1%

TABLE 3

Tests for uniform distributions or "χ-square tests" (see text on this page).

Sample	N	Degrees of freedom	χ^2	Hypothesis of uniform distribution rejected ?	
1	101	11	90.2	yes	1%
1a	59	5	26.1	yes	1%
1b	42	5	28.6	yes	1%
2'	61	11	39.1	yes	1%
2"	43	11	87.3	yes	1%
3'	38	11	17.6	yes	5-10%
3"	40	11	26.0	yes	1%

than 0.71 = cos 45°, which represents the mean theoretical value of all the cos α_i values. In fact, fossils which are orientated at 45° are in an intermediate position between parallelism and perpendicularity to the main modal direction. In the belts caracterized by mean values of $\overline{\cos}\ \alpha$ greater than cos 45°, the fossils are predominantly oriented along the main modal direction. Whereas, in the belts characterized by a mean value of $\overline{\cos}\ \alpha$ less than cos 45°, the fossils are predominantly orientated in a direction perpendicular to the main modal direction. As seen from fig. 7, this analysis

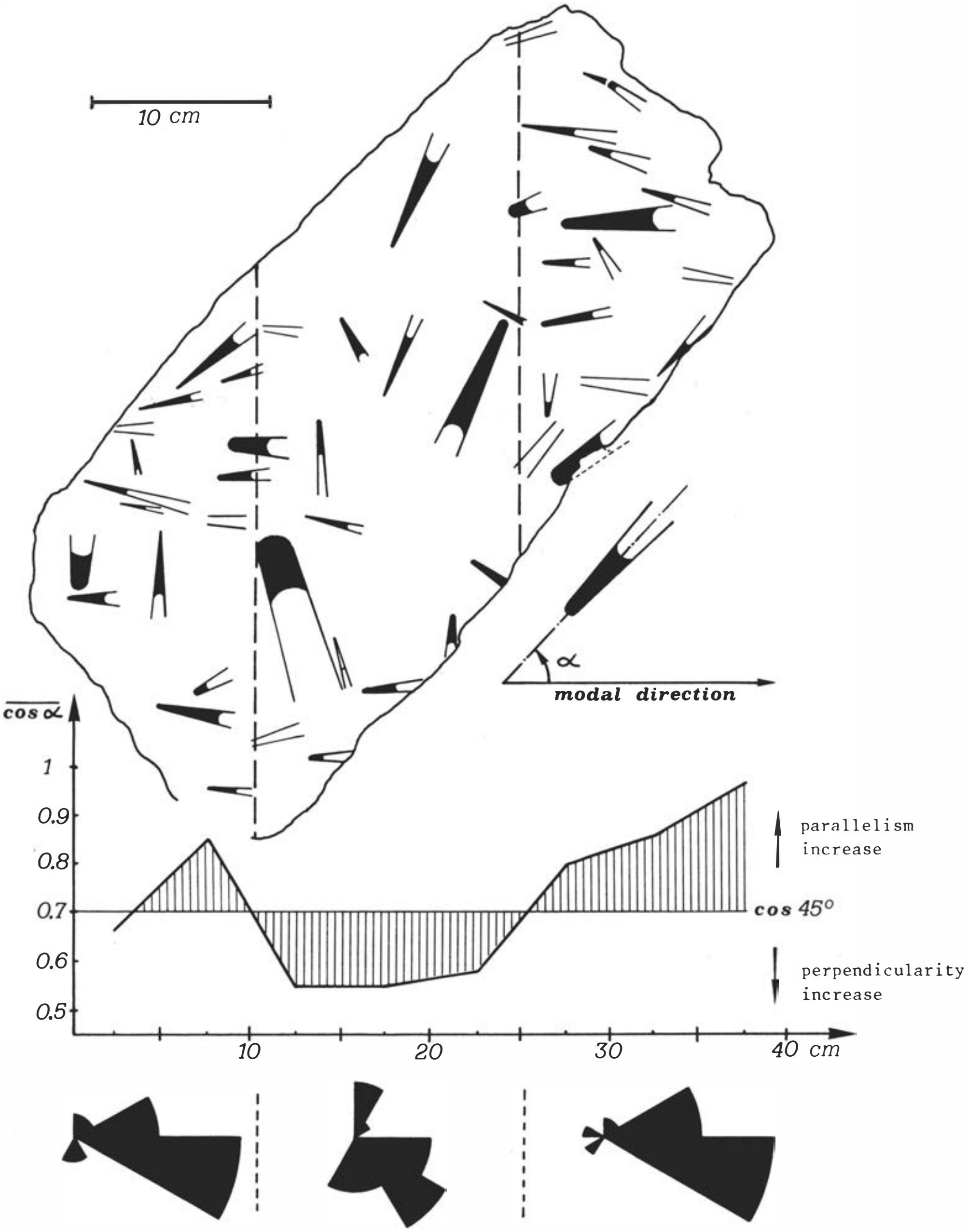

Fig. 7 - Fossil distribution in the sample 1. Diagram helps to emphasize belts where fossils tend to be alternately parallel and perpendicular to main modal direction, (see text on page 415). Rose diagrams are related to fossils distribution in each corresponding belt.

demonstrates the existence of 10-15 cm wide belts in which fossils are alternately oriented in directions parallel or perpendicular to the belt itself. Although the size of sample 3 is relatively small, the data obtained are in complete agreement with that of sample 1. Sample 2 was not used for this type of analysis since its small surface area was not sufficient to guarantee significant results. In the lower part of fig. 7, the rose diagrams relative to the orientation of the fossils in each single belt are given. In the belts where fossils tend to be parallel to the main modal direction, a certain polarity is present.

GENERAL FEATURES OF THE FAUNA

The only fossils until now recorded in the Silurian black shale sequence of southwestern Sardinia come from black limestones interbedded with shales. A few graptolites were also recorded from the underlying shales (Taricco, 1920-1921) but never illustrated.

A total of about 100 taxa were distinguished at varying taxonomic levels. A ranked list of the most abundant taxa in the "*Orthoceras* limestone" is presented in table 4.

Cephalopods followed by graptolites dominate the fauna in terms of abundance. Cephalopods are also dominant in terms of taxonomic diversity, being represented by 38 taxa compared to only 3 for gastropods. To evaluate the meaning of this statement it must be, however, kept in mind that cephalopods, conodonts and ostracods are the only well studied groups of the assemblage while no taxonomic treatment exists for graptolites, bivalves, gastropods and brachiopods.

Toghether with graptolites, which were a major group of zooplankton in Silurian seas, organisms of nektic habit as well as others possibly attached to floating plants occur in the assemblage.

NEKTIC ORGANISMS ASSOCIATED WITH THE GRAPTOLITES

Cephalopods. — They are apparently the more common fossils of all the assemblage (38 taxa - Serpagli & Gnoli, 1977) and are mostly represented by orthoconic species with no ornamentation other than growth lines. Transversally (*Hemicosmorthoceras, Plagiostomoceras*) or longitudinally (*Kionoceras*) ornamented forms are also present as well as rare cyrthoceraconic species. Such animals may have been /nektic or nektobenthic in their mode of/ life, inhabiting surface waters. According to Watkins & Berry (1977) Silurian cephalopods respond to the same hydrographic controls affecting graptolites because, for instance, in the Ludlow series of Wales and the Welsh Borderland their large scale density trends directly parallel those of graptolites.

Aptycopsis. — These problematic fossils of Silurian age belonging to the genus *Aptycopsis* Barrande, 1872, have been considered from time to time to be carapaces of phyllopods, carapaces of phyllocarids or more recently, opercula of nautiloids (Turek, 1978). In any case a nektic or planktic mode of life can be supported.

Phylloceratids species in association with graptolites already have been supported by Jones & Woodward (1888-1889) and Watkins & Berry (1977).

Conodonts. — They are not very good tools to reconstruct ancient eenvironments because there still exists disagreement concerning the original mode of life of the conodont animal. In fact, two different ecologic models have been proposed to explain the distribution patterns of conodonts, the pelagic depth stratification model and the nektobenthic model. According to Klapper & Berrick (1978), who have recently debated the problem, it is unlikely that conodonts were infaunal or sessile epifaunal benthos because there is not much congruence between lithofacies and conodont biofacies. Also Aldrige (1976, p. 102) recently noted that there is no evidence that conodonts fitted into the structure of true communities. So the probable alternatives are that they were nektobenthic or neritic pelagic animals (either planktic or nektic).

ORGANISMS POSSIBLY ATTACHED TO FLOATING PLANTS

The vast majority of bivalves, gastropods and brachiopods occur as molds or casts

Graptolites

"*Monograptus priodon*"

Brachiopods

Merista passa
* ?"*Orthis*" sp.
* ?"*Pentamerus*" sp.
* ?"*Atrypa*" sp.

Cephalopods

Hemicosmorthoceras laterculum
Hemicosmorthoceras semiannulatum
Hemicosmorthoceras sp.
Kopaninoceras jucundum
Kopaninoceras ? thyrsus
Michelinoceras currens
Michelinoceras grande
Michelinoceras sp.1
Michelinoceras sp.2
Michelinoceras sp.3
Plagiostomoceras gruenewaldti
Plagiostomoceras cf. *pleurotomum*
"*Parasphaerorthoceras*" sp.B *s.* Ristedt
"*Parasphaerorthoceras*" sp.H *s.* Ristedt
"*Parasphaerorthoceras*" sp.J *s.* Ristedt
"*Parasphaerorthoceras*" sp.K *s.* Ristedt
Protobactrites ? sp.
"*Sphaerorthoceras*" *beatum*
"*Sphaerorthoceras*" *curvum*
"*Sphaerorthoceras*" *teicherti*
"*Sphaerorthoceras*" sp.
Akrosphaerorthoceras gregale
Anaspyroceras pseudocalamiteum
Orthocycloceras ? fluminese
Orthocycloceras ? cf.*lynx*
Merocycloceras declive
Kionoceras doricum
Parakionoceras originale
Arionoceras affine
Arionoceras submoniliforme
Columenoceras sp. cf. *C. columen*
Harrisoceras vibrayei
Metarmenoceras ? meneghinii
"*Orthoceras*" cf. *richteri*
Oocerina abdita
Oonoceras plebeium
Galtoceras ? sardoum
Michelinoceras subconoideum
"*Parasphaerorthoceras*" ? *subcyprium*
* "*Orthoceras*" *bronni*
* "*Orthoceras*" *dulce*
* "*Orthoceras*" *transiens*
* "*Orthoceras*" *potens*
"*Parasphaerorthoceras*" sp.F *s.*Ristedt
Hemicosmorthoceras sp. *s.* Ristedt
* *Ophidioceras* sp.

Incertae sedis (probably cephalopods)

Aptychopsis sp.

Bivalves

* *Cardium subarcuatum*
* *Cardium* sp. ind.
* *Avicula* cf.*semiauriculata*
* *Avicula* sp. ind.
Cardiola bohemica
Cardiola gibbosa
Cardiola interrupta
Maminka sp.
* *Lunulicardium* sp.
Slava sp.
Dualina sp.
Spanila sp.

Gastropods

Platyceras sp.
Platyostoma sp.
Spirina sp.
* ?"*Pleurotomaria*" sp.

Ostracodes

Beyrichia reticulata
Aparchites pygmaeus
Aparchites grecoi
Richteria lamarmorai
Entomozoe meneghinii
Entomozoe ichnusae
Entomozoe zoppii
Entomozoe subreniformis
Entomozoe (?)*amygdaloides*
Entomozoe (?)*parvula*
Entomozoe sp. ind.
Pseudoentomozoe pteroides
Kloedemia lovisatoi
Kloedemia sp. ind.
* *Cypridina tirrenica*
Balbozoe (?)*bohemica*
Balbozoe (?)*italica*
Balbozoe (?)*capellini*
Balbozoe (?)*lanceolata*

Conodonts

Acontiodus obliquicostatus
Hindeodella equidentata
Spathognathodus incl.inclinatus
Ozarkodina media
Trichonodella excavata
Plectospathodus extensus
Neoprioniodus excavatus
Kockelella variabilis
Ozarkodina ziegl. ziegleri
Trichonodella inconstans
Lonchodina greilingi
Lingonodina salopia
Lingonodina silurica
Neoprioniodus multiformis
Spathognathodus sagitta
Ozarkodina edithae
Ozarkodina fundamentata
Spathognathodus primus
Ligonodina sp.

TABLE 4

List of species recorded from Middle-Upper Silurian "*Orthoceras*" limestone. Data from MENEGHINI (1857, 1880), CANAVARI (1899), TEICHMÜLLER (1931), GORTANI (1922), COMASCHI-CARIA (1949), SERPAGLI (1967, 1971), RISTEDT (1968), GNOLI & SERPAGLI (1977), SERPAGLI & GNOLI (1977). Specimens preceeded by (*) are of uncertain determination.

and in nearly all cases, features of the shell exterior have been impressed into the internal mold, and muscle scars and hinge structures have been obliterated. This is possible only in the case of relatively thin shells; this characteristic acquires a particular importance for its paleoecological significance.

Bivalves. — Eight to ten species of praecardiacean bivalves, among which members of the genera *Cardiola*, *Slava* and *Dualina* have been recorded in consistent association with cephalopods and graptolites. Although never abundant, these species occur in all sections of the studied area and seem to be characteristic throughout Silurian deposits of the British Isles, continental Europe and North Africa. This distribution pattern supports evidence for a pelagic mode of life among praecardiaceans. According to WATKINS (1978, p. 47) who carefully studied bivalve ecology in the Silurian of the Welsh Borderland, this type of association occupied a quiet-water, deep shelf position where the oxygen conditions were apparently low.

Also BABIN & ROMBARDET (1974, p. 41) agree with an epiplanktic mode of life followed by a simple embedding into the muddy bottom of a low turbulence environment for a bivalve assemblage in a similar limestone (« Ampelites » with graptolites, ostracodes, cephalopods, etc.) from Upper Silurian of Normandy. In that assemblage, besides praecardiaceans, ambonychiaceans, pteriaceans and modiomorfoceans also are present. Finally, it is interesting to note that several specimens of *Cardiola* have been recorded and illustrated by BARRANDE (1868, 1870) fixed to the shells of nautiloids (pl. 372, fig. 1; pl. 396, fig. 16; pl. 313, fig. 3; pl. 343, fig. 17).

Gastropods. — Although no identifiable algal remains were found, it is highly probable that the few small gastropods of the assemblage were attached to floating plants, where these herbivores would also be able to find their food supply. Members of the genus *Platiceras* have been already reported as epibionts; BROOKES, KNIGHT *et al.* (1960, p. 240) found them attached to crinoid calyces.

Brachiopods. — A few articulate brachiopods belonging to the genera *Merista*, *Orthis*, "*Pentamerus*" and "*Atrypa*" sometimes occur in the assemblage. An epiplanktic mode of life for small brachiopods has been suggested several times either for Mesozoic forms (AGER, 1962) or for Palaeozoic ones (ZIEGLER *et al.*, 1968; THAYER, 1974). Further reports of brachiopods which may have lived attached to seaweed, are due, among others, to RUEDEMANN (1934), SPJELDNAES (1967) and HAVLICEK (1967).

Ostracodes. — Twenty species of ostracodes have been reported by CANAVARI (1899) from about 2,100 kilograms of rocks. The fauna, which needs a revision, is formed by members of the genera *Aparchites*, *Richteria*, *Entomozoe*, *Pseudoentomozoe*, *Balbozoe*, *Kloedenia* and "*Cypridina*". Marine ostracodes were mostly crawlers, burrowers and near-bottom swimmers but it is very likely that some forms may have had an epiplanktic mode of life. In fact (*fide* BENSON, 1961, p. 58) members of the genus "*Cypridina*", as well as a few other fossil forms, were predominantly pelagic. Also ELOFSON (1941), studying Holocene marine ostracodes from Sweden, recovered some pelagic forms.

As seen from the paleoecological significance of the fauna examined here and as already outlined by SERPAGLI & GNOLI (1977, p. 157), typically benthic fauna is completely lacking in the assemblage; all the mentioned fossils can be interpreted as pelagic organisms.

Good preservation of fossils belonging to a broad spectrum of forms further suggests lack of scavenging animals and boring sponges and algae, or strong aerobic bacterial decay of the organisms lying dead on the sea floor represents an additional evidence of toxic conditions above the bottom.

To conclude, we can assume that the Upper Silurian shelly fossils lived as epibionts to other pelagic animals or as epiplankton on seaweed which subsequently settled to the ocean floor. Although no identifiable vegetable matter was found, it seems to be very likely, that the high concentration of organic matter found in the limestone is at least partly related to floating plants. The habits of this epiplanktic assemblage are tentatively reconstructed in figure 8.

ENVIRONMENTAL CONCLUSIONS

An important conclusion that can be drawn from the observations and discussion presented in this paper is that the shells from the Fluminimaggiore "*Orthoceras* limestone" are incorporated in evenly bedded and not lenticular shaped limestone bodies. Sedimentary bodies attributable to accumulation by current action. Equally indicative of the lack of currents are the sedimentary structures observable on a small scale and the lithological characteristics; also rule out current, the fine particle size, the large quantity of organic matter (both carbonaceous and bituminous) along with the absence of any type of current bedding are all characteristics of a tranquil environment.

The discontinuous laminae, sometimes present in the limestone, made-up only of shell fragments of various sizes concentrated along distinctly plane-parallel preferred surfaces can be interpreted as clastic enrichments related to the wave action on a muddy bottom rich in fossil remains.

Also, wave motion is the only agent capable of moving the sediments on the bottom without causing an overall remixing of the water of the basin and hence without causing an enrichment of oxygen in the lower strata, thereby maintaining euxinic conditions near the bottom.

An oscillatory wave motion also is the only agent capable of causing the small shells to deeply penetrate the larger ones and of settling the shells and shell fragments in a tight packing without causing any sorting.

In addition, the orientation of the orthocones and their fragments in the limestone is very similar to that produced by waves in an experimental tank and the distribution of the graptolites recalls that observed in segments of reeds oriented by wave motion near the beach of a lake (fig. 9).

The sea in which the studied rocks were

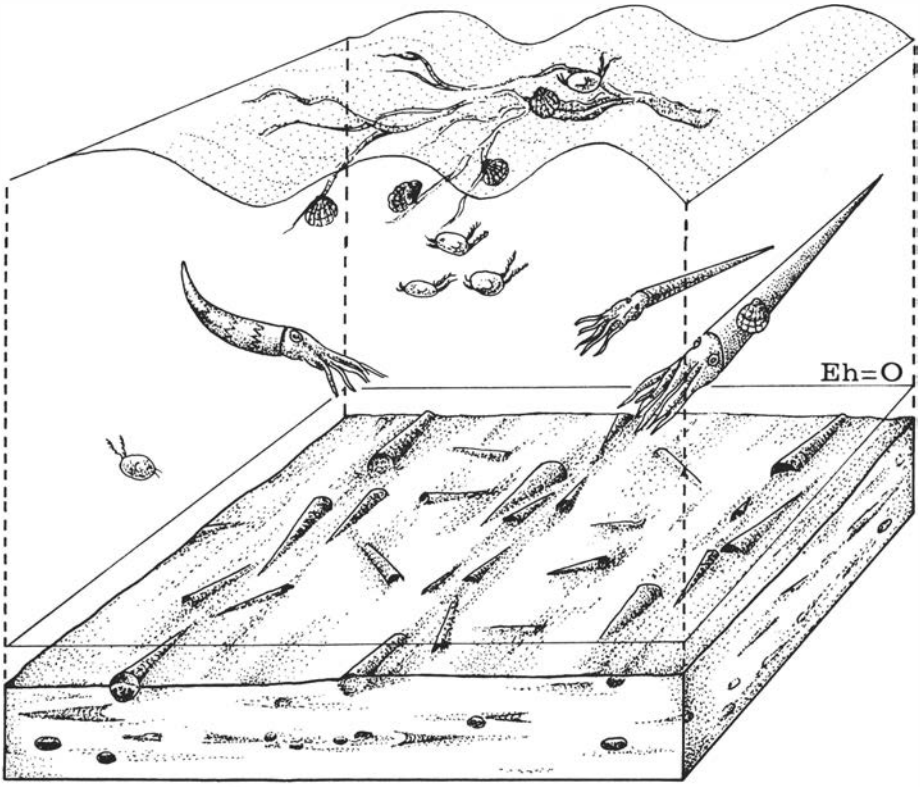

Fig. 8 - Hypothetical reconstruction, not to scale, of the "*Orthoceras*" limestone environment with schematical representation of the orientation of the shells on the bottom.

deposited must have been practically devoid of terrigenous supply with the exception of slight amounts of fine silt and clay as evidenced by the almost pure limestone whose impurities are essentially represented by carbonaceous and bituminous organic matter. The high content of organic material and the complete absence of bioturbation indicates that the depositional environment must have been anoxic.

The presence of iron sulfides near the openings of various shells is a further indication that the alteration of the soft parts must have occurred in strictly euxinic conditions.

As previously stated, the fauna of the "*Orthoceras* limestone" also contains representatives of various other types of organisms and is very rich in specimens. Since specimens of every size are present, indicating that death occured at all stages of development, it is reasonable to assume that the taphacoenosis almost entirely represents the biocoenosis without successive enrichments or impoverishments of some species on the basis of their size or shape.

All the organisms represented by the fossil remains had without doubt a pelagic mode of life or at least can very reasonably be considered as such. Completely lacking are remains of exclusively benthic organisms, both epibionts and endobionts.

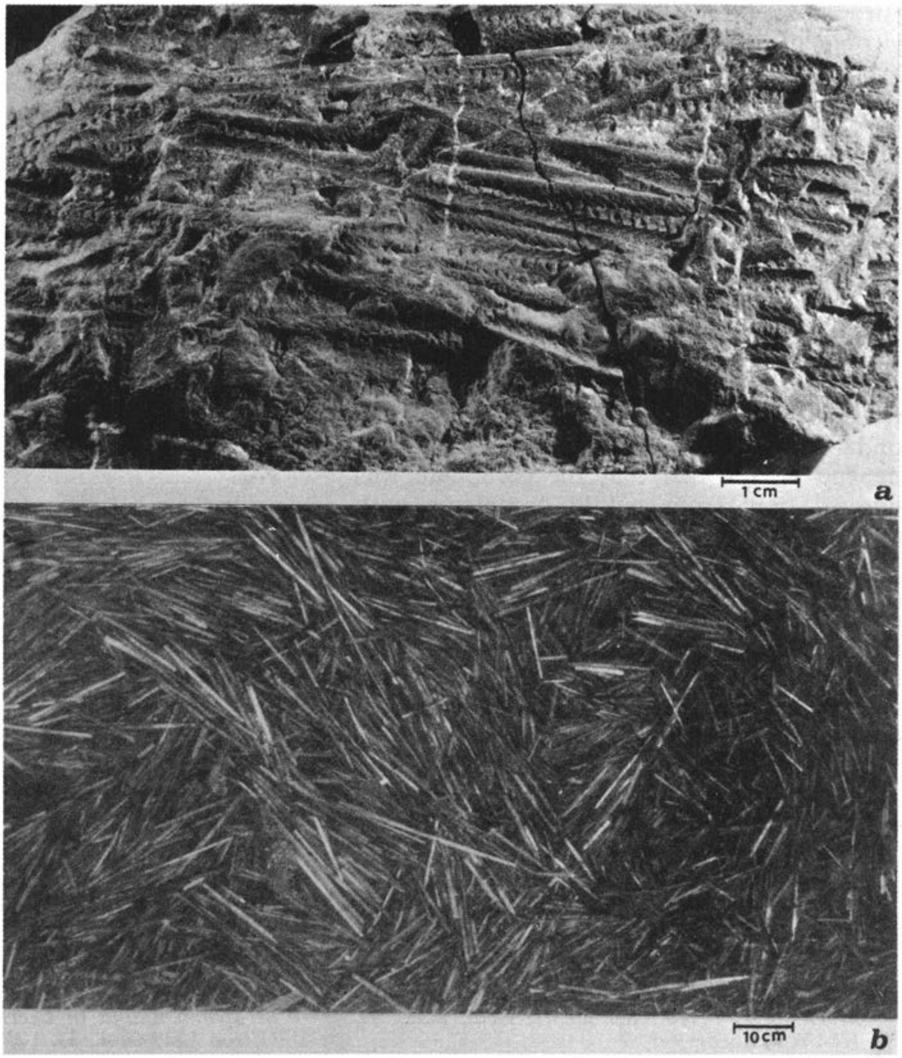

Fig. 9 - Rhabdosomes of *Monograptus* from the "*Orthoceras*" limestone of Fluminimaggiore (a) showing a pattern close to that of an accumulation of segments of reeds in shallow water near the beach of Vico lake (Central Italy) (b).

Finally, all evidence leads to the conclusion that the organisms from the "*Orthoceras* limestones" of Fluminimaggiore lived in a normally oxygenated sea rich in pelagic fauna in its upper parts and fell after death in the euxinic environment near the bottom where their remains accumulated and from time to time were weakly agitated by wave motion.

One can immagine such a sea to be analogous, for example, to the present Black Sea. It is not possible to make a quantitative evaluation of the real depth of such a sea since the depth at which wave action can have an effect depends on the wave size and this, in turn, depends on the fetch of the winds which generate them, and fair versus storm conditions, and both of these parameters are unknown. However the environment in which the orthoceratids had been living can be immagined as an epicontinental sea of limited depth.

Considering a thickness of the order of twenty to thirty meters for the calcareous sequence and its uppermost Wenlokian-Ludlovian age (time lapse corresponding to around 15 million years), the velocity of sedimentation must have been of the order of 1 Boubnoff (1 μ/year). This velocity (**Fisher**, 1969) is at the lower known limit for calcareous sediments in shallow water.

Aside from the imprecision in the evaluation of the total thickness, which could be underestimated, this very low rate really depend on the fact that the carbonate was derived only from nektic organisms with contributions from benthic fauna and flora lacking completely.

Finally, it must be pointed out that the present contribution support the hypothesis, already supposed by **Berry** & **Boucot** (1967), **Holland** (1971), **Vai** (1972, 1979), of a shelf sea upon a stable structural platform al least during the second half of the Silurian.

Manoscritto consegnato il 18 maggio 1979.
Ultime bozze restituite il 6 giugno 1980.

REFERENCES

Ager D. V. (1962) - *The occurrence of pedunculata brachiopods in soft sediments.* Geol. Mag., **99,** 184-186, Oxford.

Aldridge R. J. (1976) - *Comparison of macrofossil communities and conodont distribution in the British Silurian.* Geol. Assoc. of Canada, Special Paper **15,** 91-104, 3 text-figs, Toronto.

Babin C. & **Rombardet** M. (1974) - *Mollusques Bivalves du Silurien supérieur et de l'extrême base du Dévonien en Normandie.* Annales de la Soc. Geol. du Nord, **94,** 19-45, pls. 1-6, Lille.

Balashov S. G. (1968) - *Ordovician endoceratoids of URSS.* Leningrad University Press, 1-276, pls. 1-51, 23 text-figs (in Russian), Leningrad.

Bandel K. (1972) - *Palokologie und Palaegeographie im Devon und Unter-Karbon der zentralen Karnischen Alpen.* Palaeontographica Abt. A, **141,** 1-117, pls. 1-10, Stuttgart.

Bandel K. (1974) - *Deep-water limestones from the Devonian-Carboniferous of the Carnic Alps, Austria.* Spec. Publs. Int. Ass. Sediment. **1,** 93-115.

Barrande J. (1865-1877) - *Systeme Silurien du centre de la Bohême:* I. Reach. Pal., v. 2, Classe de Mollusques, Ordre des Céphalopodes; 1° ser., pls., 1-107 (1865); 2° ser., pls. 108-244 (1866); 3° ser., pls. 245-350 (1868); 4° ser., pls. 351-460 (1870); suppl. et sér. tard., pls. 461-544, Texte III (1870); Texte IV (1877); Texte V (1877); 4° ser., Distribution des Cephalopodes (1870), Prague.

Benson R. H. (1961) - *Ecology of Ostracode Assemblages.* Treatise on Invertebrate Paleontology, 56-63, Geol. Soc. of America and Univ. of Kansas Press.

Berry W. B. H. & **Boucot** A. J. (1967) - *Pelecypod-Graptolite association in the Old World Silurian.* Geol. Soc. America Bull., **78,** 1515-1522, 1 fig., Boulder.

Brenchley P. J. & **Newall** G. (1970) - *Flume experiments on the orientation and transport of models and shell valves.* Pal. Pal. Pal., **7,** 185-220, 12 figs., Amsterdam.

Canavari U. (1899) - *La fauna dei calcari nerastri con* Orthoceras *e* Cardiola *di Xea S. Antonio in Sardegna.* Paleontogr. Italica, **5,** 187-210, 2 pls., Pisa.

Comaschi Caria I. (1949) - *I fossili della Sardegna.* Istituto per gli Studi Sardi, 1-410, Cagliari.

Elofson O. (1941) - *Zur Kenntnis der mariner Ostracoden Schwedens, mit besenderer Bernckschtigung des Skagerraks.* Uppsala Univ. Zool. Bidrag., **19,** 215-534, Uppsala.

Fischer A. G. (1969) - *Geological time-distance rate; The Bubnoff Unit.* Geol. Soc. Amer. Bull., **80,** 549-552, 1 fig., Boulder.

Gnoli M. & **Serpagli** E. (1977) - *Silurian cephalopods of the Meneghini collection* (1857). Boll. Soc. *Paleont. Italiana,* **16,** (2), 137-142, 2 text-figs, 1 tab., Modena.

Gortani M. (1922) - *Osservazioni sul Paleozoico della Sardegna.* Boll. Soc. Geol. Italiana, **11,** 362-369, 1 tab., Roma.

Greenwood J. A. & **Durand** D. (1955) - *The distribution of length and components of the sum of N random vectors.* Ann. Math., Statist., **26,** 233-248, Baltimore.

Havlicek V. (1967) - *Brachiopoda of the Suborder Strophomenidina in Czechoslovakia.* Rozopravy Ustred Ust. Geol., **33,** 1-235, Prague.

Holland C. K. (1971) - *Silurian faunal provinces?* in Middlemiss F. A., Rawson P. F. & Newall G. (eds.) *Faunal provinces in space and time.* Geol. Journ. Sp. Is., **4**, 61-67.

Jones T. R. & Woodward H. (1888-1889) - *A monograph of the British Palaeozoic Phyllopoda.* Palaeontogr. Soc. Monographs, 1-208, London.

Kay M. (1945) - *Paleogeographic and palinspastic maps.* Bull. Am. Ass. Petrol. Geol., **29**, 426-450, 12 figs. Menasha.

Kelling G. & Williams P. F. (1967) - *Flume studies of the reorientation of pebbles and shells.* Journ. of Geol., **75**, 243-267, 19 figs., Chicago.

Kindle E. M. (1938) - *A pteropod record of current direction.* J. Paleont., **12**, 515-516, 1 fig., Tulsa.

Klapper G. & Barrick J. E. (1978) - *Conodont ecology: pelagic versus benthic.* Lethaia, **11**, 15-23, 3 text-figs, Oslo.

Krinsley D. (1960) - *Orientation of orthoceracone cephalopods at Lemont, Illinois.* J. Sedimentary Petrol., **30**, (2), 321-323, 1 text-fig., Tulsa.

Laufeld S. (1974) - *Preferred orientation of orthoconic nautiloids in the Ludlovian Hemse Beds of Gothland.* Geologiska Förhandlingar, **96**, 157-162, Stockholm.

Loubere P. (1977) - *Orientation of orthocones in the English Lake 'District based on field observations and experimental work in a flume.* J. Sed. Petrol., **47** (1), 419-427, figs 1-2, Tulsa.

Meneghini G. (1857) - *Paléontologie de l'Ile de Sardaigne* (in Lamarmora A., Voyage en Sardaigne). 1-584, A-H, Imprimerie Royal Turin.

Meneghini G. (1880) - *Nuovi fossili siluriani di Sardegna.* Reale Acc. Lincei, Serie 3° Mem. Classe sc. fis. mat. e naturali, **5**, 1-13, 1 tav., Roma.

Miller R. L. & Kahn J. S. (1962) - *Statistical analysis in the geological sciences.* pp. 1-483, J. Wiley & Sons Inc., New York, London.

Nagle J. S. (1967) - *Wave and current orientation of shells.* J. Sed. Petrol., **37**, (4), 1124-1138, 7 figs, Tulsa.

Petranek J. & Komarkowa E. (1953) - *Orientace schrànek hlavonozcu ve vapencich Barrandienu a jeji paleogeograficky vyznam.* Sbornik. Ustredniho ustavu geologického, **20**, 129-148, pls. 1-2, Prague. English summary in Geol. Soc. America Mem. 67, v. 2, 850-851, 1957.

Potter P. E. & Pettijohn F. J. (1963) - *Paleocurrents and basin analysis.* pp. 1-296, Springer-Verlag, Berlin-Heidelberg.

Reyment R. A. (1971) - *Introduction to quantitative paleoecology.* Elsevier Publ. Company, 1-226, Amsterdam-London-New York.

Rhoads D. C. & Morse J. W. (1971) - *Evolutionary and ecologic significance of oxygen deficient marine basins.* Lethaia, 4, 413-428, 5 text-figs., Oslo.

Ristedt H. (1968) - *Zur Revision der Orthoceratidae.* Akad. Wiss. u. Literatur, Abhandl. d. Math.-Naturwiss. Klasse, **4**, 213-297, pls. 1-5, 4 text-figs., Wiesbaden.

Ruedemann R. (1934) - *Paleozoic plankton of North America.* Geol. Soc. America Mem., **2**, 1-106, Washington.

Schwarzacher W. (1963) - *Orientation of crinoids by current action.* J. Sed. Petrol., **33** (3), 580-586, figs. 1-5, Tulsa.

Serpagli E. (1967) - *Prima segnalazione di Conodonti nel Siluriano della Sardegna e relative osservazioni stratigrafiche.* Accad. Naz. Lincei, Rend. Classe Sci. fis. matem. e naturali, fasc, 6, ser. 8, v. **42**, 856-858, Roma.

Serpagli E. (1970) - *Uppermost Wenlockian-Upper Ludlovian (Silurian) Conodonts from Western Sardinia.* Boll. Soc. Paleontol. Italiana, **9** (1), 76-96 ,pls. 21-24, text-fig. 1, Modena.

Serpagli E. & Gnoli M. (1977) - *Upper Silurian Cephalopods from Southwestern Sardinia.* Boll. Soc. Paleont. Italiana, **16** (2), 153-196, pls. 1-9, text-figs 1-13, tab. 1-3, Modena.

Sheelian P. M. (1977) - *Ordovician and Silurian brachiopods from graptolitic shales and related deep-water argillaceous rocks.* Lethaia, **10**, 201-203, Oslo.

Spjeldnaes N. (1967) - *The palaeogeography of the Tethyan region during the Ordovician:* in Aspects of Tethyan Biogeography Syst. Assoc. Publ., **7**, 45-57, London.

Taricco M. (1920-1921) - *Sul Paleozoico del Fluminese (Sardegna).* Boll. R. Com. Geol. d'Italia, **48** (6), 1-21, Roma.

Teichmüller R. (1931) - *Zur Geologie des Tyrrenis Gebietes.* Abh. Gesellschaft d. Wiss. Z. Göttingen, Matem.-Phys. Klasse, III F, **3** 1-124, 3 pls., 47 text-figs, Berlin.

Thayer C. W. (1974) - *Marine paleoecology in the Upper Devonian of New York.* Lethaia, **7**, 121-155, 24 text-figs, Oslo.

Turek V. (1974) - *Poznámky k sedimentaci "ortocerových vápenců" Barrandienu.* Casopis pro mineralogii a geologii, roš. **19**, 165-169, 1 text-fig.

Turek V. (1978) - *Biological and stratigraphical significance of the Silurian nautiloid* Aptychopsis. Lethaia, **11** (2), 127-138, 15 text-figs, Oslo.

Vai G. B. (1972) - *Evidence of Silurian in the Apuane Alps, (Tuscany, Italy).* Giornale di Geologia, **38**, 349-372, 3 pls., Bologna.

Vai G. B. (1979) - *Sedimentary evironment of Devonian pelagic limestones in the Southern Alps.* Lethaia, **12**, 4, (in press).

Watkins R. (1978) - *Bivalve ecology in a Silurian shelf environment.* Lethaia, **11**, 41-56, 11 text-figs, Oslo.

Watkins R. & Berry W. B. N. (1977) - *Ecology of Late Silurian fauna of graptolites and associated organisms.* Lethaia, **10**, 267-286, 16 text-figs, Oslo.

Ziegler A. M., Cocks L. R. M. & Bambach R. K. (1968) - *The composition and structure of Lower Silurian marine communities.* Lethaia, **1**, 1-27, Oslo.

A contribution to IGCP
Project No. 53