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CONODONT BIOSTRATIGRAPHY OF THE "OCKERKALK" (SILURIAN) FROM SOUTHEASTERN SARDINIA

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Key-words: Biostratigraphy, Conodonts, Ockerkalk, Silurian, Southeastern Sardinia.

Riassunto. Negli Ockerkalk affioranti nella zona di Silius (Cagliari) sono state riconosciute ventidue specie di conodonti, che hanno permesso di datare questa unità al Ludlow-Pridoli. Tre biozone a conodonti (*latialata*, *snajdri* e *crispa)* sono state individuate per la prima volta in Sardegna, come pure è nuovo per l'Europa il ritrovamento della forma "americana" *Pelekysgnathus index*.

Abstract. Twenty-two conodont species are recognized in the Ockerkalk exposed in the Silius area (Gerrei, southeastern Sardinia). The fauna, which is the first reported from this peculiar facies, indicates a Ludlow and e.-m. Pridoli age for this limestone. Three conodont biozones (*latialata*, *snajdri* and *crispa)* are reported for the first time in Sardinia and the *Pelekysgnathus index* horizon is newly recovered in Europe.

Introduction.

The Ockerkalk is a peculiar Silurian limestone known in Thuringia (Jaeger, 1976, 1977), Sardinia (Jaeger, 1976, 1977; Barca & Jaeger, 1990), and reported also in Spain, the Carnic Alps and the western Czech Republic (Jaeger, 1976, 1977; Barca & Jaeger, 1990). Owing to its poor fossil content, there is little available information on the age and nature of this limestone.

There are two main purposes to the present study. The first is to achieve a detailed conodont biostratigraphy for the Ockerkalk in the Silius area (Gerrei, southeastern Sardinia) and, thereby, provide a good tool for biostratigraphic analysis and correlation. The second is to add new information to the knowledge on the depositional history of the Silurian sequences in Sardinia.

The rich conodont collection described here provides firm evidence of a Ludlow and e.-m. Pridoli age for the Ockerkalk, from the *A. ploeckensis* Biozone to the top of the *Oz. remscheidensis eosteinhornensis* Biozone (*Oulodus elegans detortus* Subzone). The

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Pe. latialata, *Oz. snajdri* and *Oz. crispa* biozones are reported for the first time in Sardinia. A similar chronological assignment had already been inferred by Jaeger (1977) only on the basis of the relationships with the underlying and overlying graptolite bearing shales ("the correlation with Thuringia was accomplished with the precision of one zone each for both the base and the top of the Ockerkalk"; Barca & Jaeger, 1990, p. 567) and not on the fossil content of the limestone. The biosedimentologic analysis confirms the Ockerkalk as a quiet pelagic facies in the Silurian seas.

This paper is a preliminary result of the project "Silurian Ockerkalk biostratigraphy and palaeoecology" arranged between the Institute of Paleontology, University of Modena and the Department of Earth Sciences, University of Cagliari, led by E. Serpagli and S. Barca.

Geological setting.

Silurian and lower Devonian fossiliferous rocks are not particularly widespread in southeastern Sardinia, where they belong to the Sarrabus Unit and the Gerrei Unit, the highest weakly metamorphic tectonic units of the Hercynian nappe belt of Sardinia (Carmignani et al., 1982, 1992) (Fig. 1a, c).

In northern Sardinia the Carboniferous suture between the Armorican and Gondwanan plates ("Posada-Asinara Line"; Fig. 1a) separates the High Grade Metamorphic Complex from the underlying Medium to Low Grade Metamorphic Complex of the Nappe Zone. In southwestern Sardinia, the most external nappes (Arburese, Sarrabus and Gerrei Units) overthrust the External Zone of the Sulcis-Iglesiente, where slightly deformed anchimetamorphic autochthonous rocks are exposed (Carmignani et al., 1992).

Synthetically, the stratigraphic succession of the Gerrei tectonic Unit (Fig. 1b) has at its base the San Vito Sandstone, which is composed of thick siliciclastic sediments containing Cambro-Tremadoc acritarchs. An important stratigraphic unconformity ("Sarrabese Phase") separates the San Vito Sandstone from the overlying pre-Caradocian acid metavolcanites ("Porphyroids"). Caradoc-Ashgill fossiliferous sediments rest transgressively over the older metavolcanites. These deposits consist of conglomerates, arkosic sandstones and siltstones; partially or totally silicified limestones are present at the top of the sequence, as well as spilitic metabasites. The succession continues with shales and limestones of Silurian/Devonian to early Tournaisian age (see below). Finally, conglomerates and siltstones assigned to the Hercynian flysch (Spalletta & Vai, 1982; Barca & Spalletta, 1984) terminate the succession of the Gerrei tectonic Unit.

The Silurian and early Devonian is represented, at least in the Gerrei tectonic Unit, by the classical Thuringian facies triad: "Lower Graptolitic Shales" (LGS)- "Ockerkalk" (OK)- "Upper Graptolitic Shales" (UGS). Southeastern Sardinia has strong lithological and faunistic similarities with the Saxothuringian Zone of the Variscan Orogen.

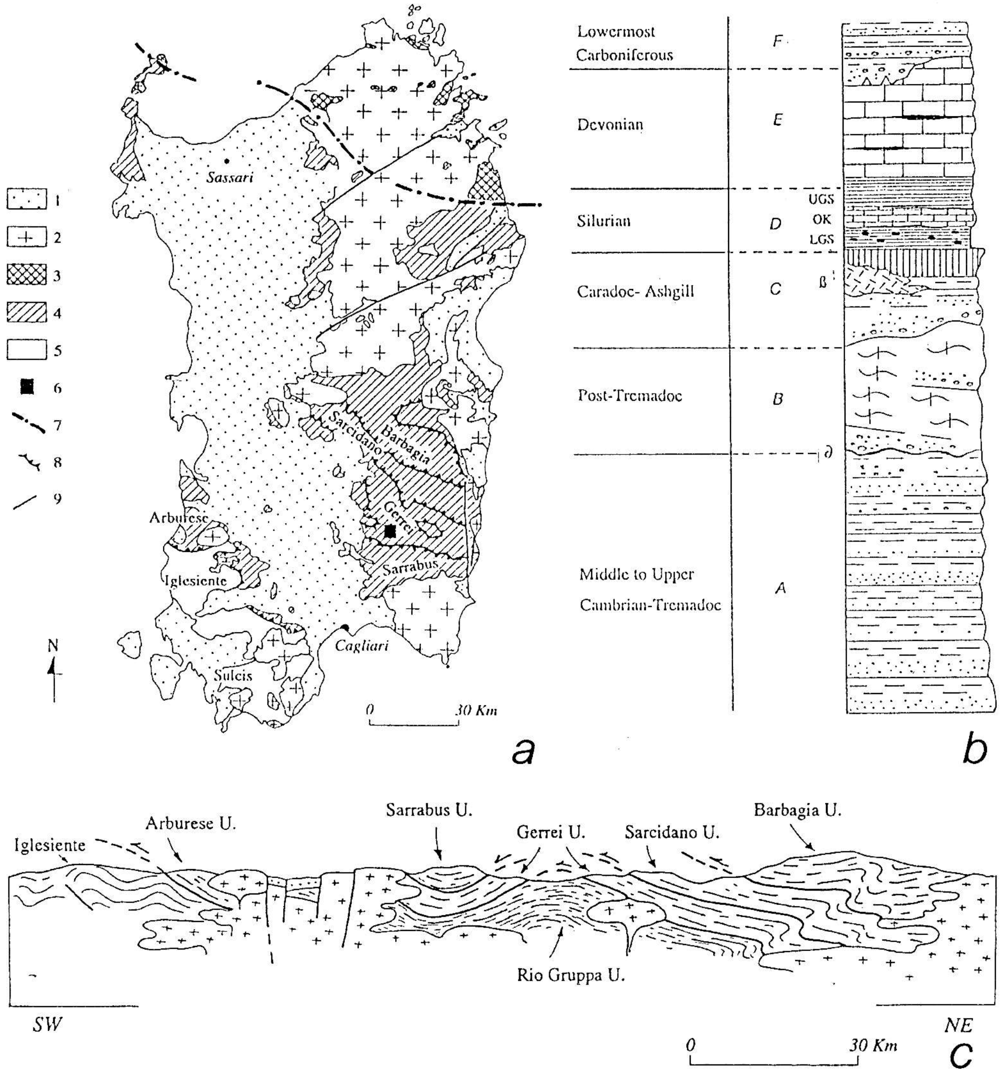

Fig. 1 - a) Synthetic structural sketch-map of the Paleozoic Sardinian Basement: 1) post-Hercynian sediments and volcanites; 2) Hercynian granitoids; 3) High Grade Metamorphic Complex; 4) Medium to Low Grade Metamorphic Complex (Internal and External Hercynian Nappe Zones); 5) Epi-Anchimetamorphic Complex (External Zone); 6) investigated Silius area; 7) Posada-Asinara Suture Line; 8) major Hercynian overthrusts; 9) Cenozoic faults.

b) Stratigraphic column (not to scale) of the Gerrei tectonic Unit: A) San Vito Sandstone; ∂) angular unconformity of the "Sarrabese Phase"; B) rhyolitic to rhyodacitic metavolcanites ("Porphyroids" Auct.) with associated conglomerates and arkosic sandstones; C) conglomerates, sandstones and siltstones with spilitic metabasites (β) and partially silicified limestones; D) "Lower" (LGS) and "Upper (UGS) Graptolitic Shales" and intercalated "Ockerkalk" (OK); E) prevailing massive limestones and interbedded shales; F) conglomerates, sandstones and siltstones (Culm-type flysch).

c) NE-SW geological cross-section through the Nappe Zones and the External Zone.

The "Lower Graptolitic Shales" are mainly composed of alum slates (i.e. silica-argillaceous shales rich in carbon and pyrite; Jaeger, 1977) with interbedded lydites (bedded cherts) in the lower part. Llandoverian graptolites of the *vesiculosus, gregarius, convolutus, turriculatus, crispus, griestoniensis* and *spiralis* biozones are documented. Nodules, lenses and layers of phosphorites are frequent in the middle-upper part, where several graptolite biozones, including the new ones recently proposed across the Wenlock-Ludlow boundary, have been recognized (Gortani, 1922; Barca & Jaeger, 1990; Jaeger, 1991). According to Barca & Jaeger (1990) the LGS extend into the early Ludlow, at least up to the *colonus/nilssoni* Biozone, whereas the succeeding *chimaera* Biozone could probably be present by analogy with Thuringia (Barca & Jaeger, 1990, p. 567). As we will see later, this graptolite biozone will probably not be recovered, as the base of the Ockerkalk already includes the coeval *A. ploeckensis* conodont Biozone.

The Ockerkalk is a calcareous "intermezzo" of a bluish-grey argillaceous limestone, weathering to shining ochre, with a typical irregular flaser texture. It is almost always characterized by a high pyrite content, evident also in the conodont heavy fraction. Apart from the occurrence of the giant pelagic crinoid *Scyphocrinites* (Helmcke, 1973; Jaeger, 1976, 1977; Barca & Jaeger, 1990), the fossil content of this limestone reported so far is very low and composed of rare ostracodes, orthoceratids, small brachiopods, solitary corals, conulariids, trilobites and trace fossils. The Ockerkalk has been considered to cover the interval from below the middle of the Ludlow to near the top of the Silurian (*M. chimaera* to *M. transgrediens* biozones; Jaeger, 1976).

The "Upper Graptolitic Shales" are composed of alum slates only; lydites and phosphorites are missing. Planktonic graptolites are the only fossils found in abundance throughout the black shales; rare *Ceriatocaris* (Jaeger, 1977) and a pterineid bivalve (Barca & Jaeger, 1990, p. 568) have been recorded. According to the composite section prepared by Barca & Jaeger (1990, fig. 9), *Scyphocrinites* occurs also in the lower part of the UGS.

It is worth to mentioning that the last Silurian graptolite biozone (*transgrediens*) known from the classical Thuringian sequence has not been found so far in southeastern Sardinia. On the contrary, the lowermost Devonian ones (*uniformis, praehercynicus, hercynicus*) occur in the Baccu Scottis section (eastern Gerrei). The absence of the *transgrediens* Biozone in southeastern Sardinia could be explained by a lack of exposure (Barca & Jaeger, 1990). However, the occurrence of *Oulodus elegans detortus* as well as the lack of *Icriodus woschmidti woschmidti* makes possible that, like in Thuringia (Jaeger, 1977), the highest part of the *transgrediens* Biozone could be discovered in the near future.

Diverse features from the Gerrei and Sarrabus sequences have been noted about 8 km westward in the San Basilio area (western Gerrei; Leone, Olivieri & Serpagli, in progress). A very rich nautiloid fauna has recently been reported from an equivalent unit of the Ockerkalk (Gnoli, 1993). Here the typical Silurian-lowermost Devonian sequence is represented by a different facies from the Gerrei one, having only in its lower part the lyditic alum slates rich in graptolites corresponding to the first element of the Thuringian triad (Gortani, 1922; Barca & Jaeger, 1990). Here grey-green shales, which were probably deposited in basinal areas deeper than the Ockerkalk, are present.

The Ockerkalk of the Silius area.

Two sections, about 400 meters apart, have been investigated west of Silius village (Gerrei), about 25 km west of Baccu Scottis (eastern Gerrei) and 7 km south of Goni (Gerrei), classical graptolite sections well known in the literature. They have been named Silius I° (SIL I°) and Genna Ciuerciu (GCIU) (Fig. 2, 3; Pl. 1).

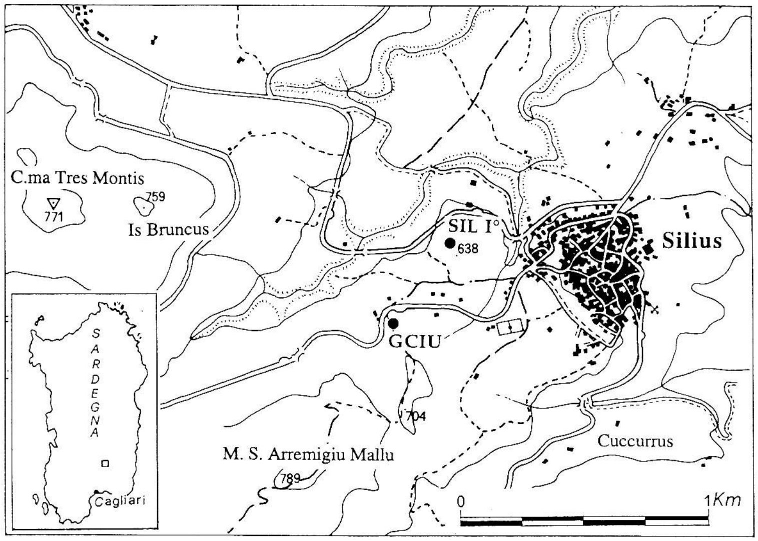

Fig. 2 - Location map of the sections studied in this paper.

Unfortunately, no graptolites have been found so far in the LGS below the Ockerkalk, at least in the SIL I° section where black shales are better exposed. The first calcareous levels of the GCIU section are badly exposed. UGS are not present at the top of either section as they are not shown or are missing due to erosion.

For this reason, our study has been mainly focused on the Ockerkalk which has a total thickness in the studied area of about 28 meters. This is, however, correct only for the SIL I° section as the upper 10 meters of the GCIU section (samples 7A- 10 X) are part of a small local tectonic overlap evidenced by this conodont study. Imbricate structures of Silurian rocks are in fact very common in southeastern Sardinia (Barca & Jaeger, 1990, p. 574).

The limestone has an irregular nodular structure (Pl. 2, fig. 2), locally covered by rock alteration and lichens. The lobolith-horizon well known along the north Gondwana margin across the S/D boundary and already recorded both in southwestern Sardinia (Gnoli et al., 1988, pl. 1, fig. 1a-c, 4, 5) and in southeastern Sardinia

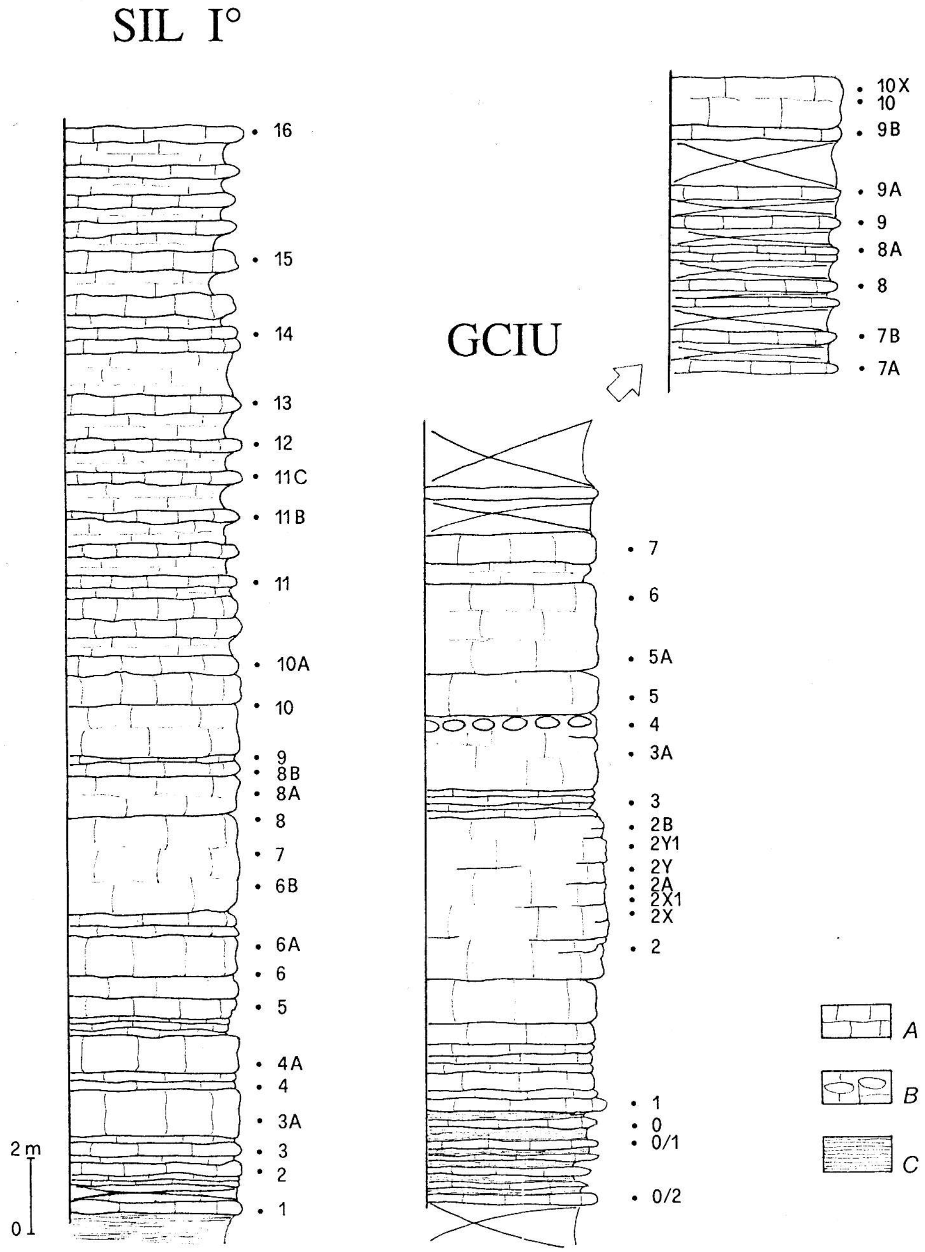

Fig. 3 - Sketch of stratigraphic columns of sections Silius I° and Genna Ciuerciu. A) Nodular and/or massive limestone; B) lobolith level; C) shales.

(Helmcke, 1973; Jaeger, 1976, 1977; Barca & Jaeger, 1990) has been discovered in the GCIU section. The apparent absence in the SIL I° section may be the result of rock alteration.

Loboliths from GCIU are clearly visible in the outcrop (Pl. 2, fig. 1), with well-preserved local geopetal structures. The diameter of their bulbous holdfasts may be as much as 20 cm, in full agreement with previous records. Unluckily, owing to matrix lithification, they cannot be isolated like those found in the Fluminimaggiore area (Iglesiente, southwestern Sardinia) in a slightly younger horizon.

The lobolith bearing horizon is assigned to the *Oz. r. eosteinhornensis* Biozone, in perfect agreement with former findings from SE Sardinia (see Barca & Jaeger, 1990, right column of fig. 9) and with the uppermost Silurian lobolith-horizon known in Europe and in North Africa (Haude, 1972, 1992).

Loboliths and crinoid stems, all parallel to the bedding, are the only macrofossils clearly visible in outcrop. Small thin-shelled bivalves, ostracodes, brachiopods, gastropods, trilobite fragments, crinoids, rare small cephalopods and sponge spiculae were revealed by thin section analysis (Pl. 3). A rich conodont fauna is also present (Fig. 4, 5). All these organisms are scattered in a micritic mudstone, only locally concentrated in thin wackestone-bands of disarticulated debris. A crinoidal content enrichment is visible in the GCIU section across the samples GCIU 3A and GCIU 4 (Pl. 3, fig. 3, 4), belonging to the same bank which culminates in the lobolith-level at the top. Geopetal structures and bioturbation fabric are present. Red veins, mainly composed of secondary calcite crystals with abundant iron oxide borders (Pl. 3, fig. 7, 8), extend along the limestone nodules. Pyrite crystals are locally present in the matrix or sometimes at the vein borders. Lamination is visible in the matrix of some samples.

A quiet pelagic environment below normal wave-base of fine-grained sediment and with bioclastic input variable in time and probably in space, especially in the crinoidal fraction which is higher in the GCIU section, may be supposed.

The Silurian to lower Devonian sequences of southeastern Sardinia differ significantly from those of southwestern Sardinia, mainly in the cardiolidid nautiloid-bearing levels of southwestern Sardinia, which are in age partly equivalent to the Ockerkalk but deposited in a shallower environment (Gnoli et al., 1980; Ferretti, 1989). If the study now in progress of the San Basilio area confirms the first impressions, the three major upper Silurian facies reported in Thuringia (*Orthoceras* limestone, Ockerkalk limestone and deeper shales) would be present also in Sardinia, as already suggested by Barca & Jaeger (1990).

Previous biostratigraphical research.

No direct biostratigraphic data were available so far from the Ockerkalk and the stratigraphical assignment of this peculiar level had been deduced only on the basis of the graptolites occurring in the lower and upper black shales in which the Ockerkalk is intercalated (Gortani, 1922; Jaeger, 1976, 1977; Barca & Jaeger, 1990). We report for

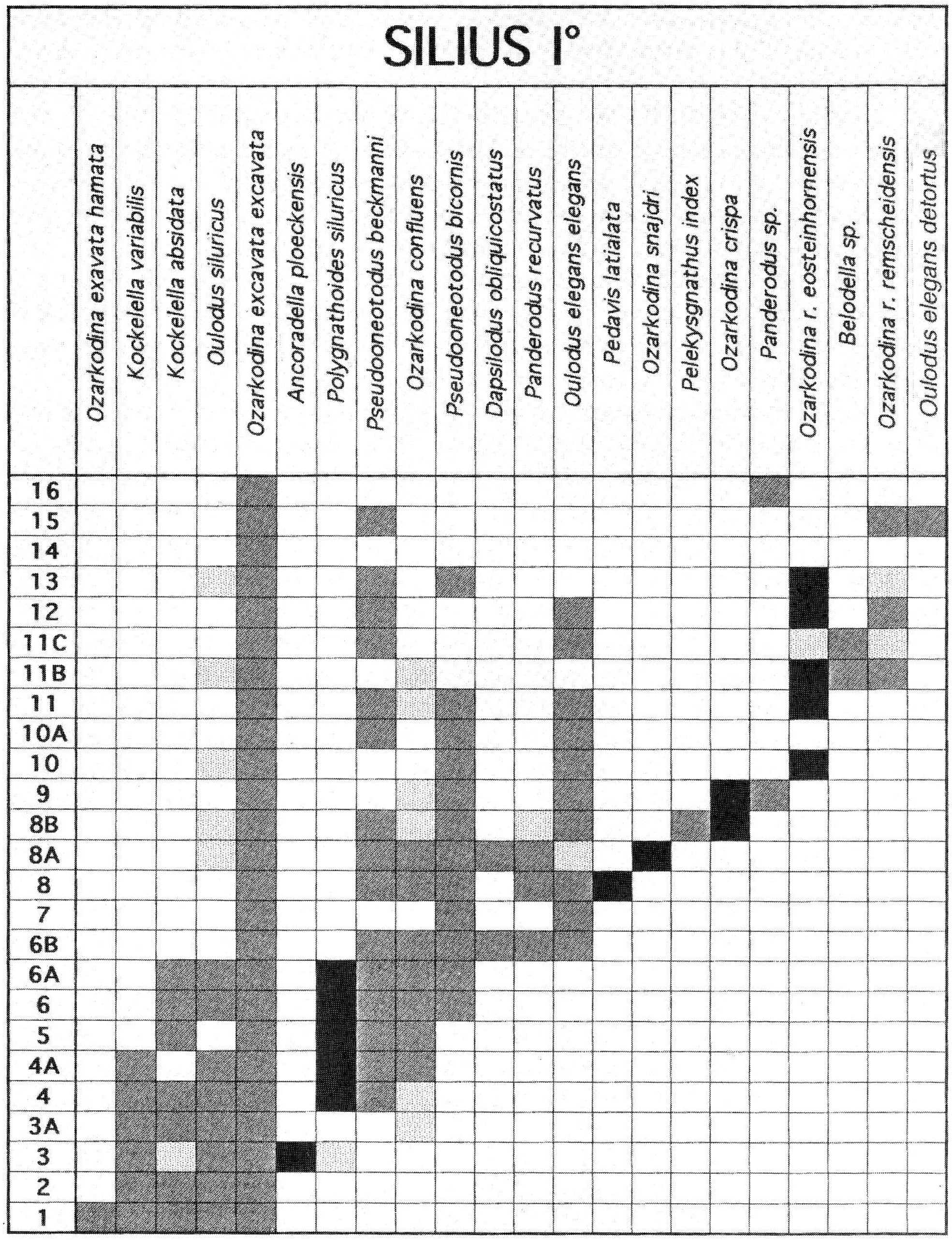

Fig. 4 - Distribution of conodont species in the SIL I° section. Index species are in black. Light grey pattern indicates uncertain occurrences based on rare, fragmentary specimens or on minor elements of the apparatus.

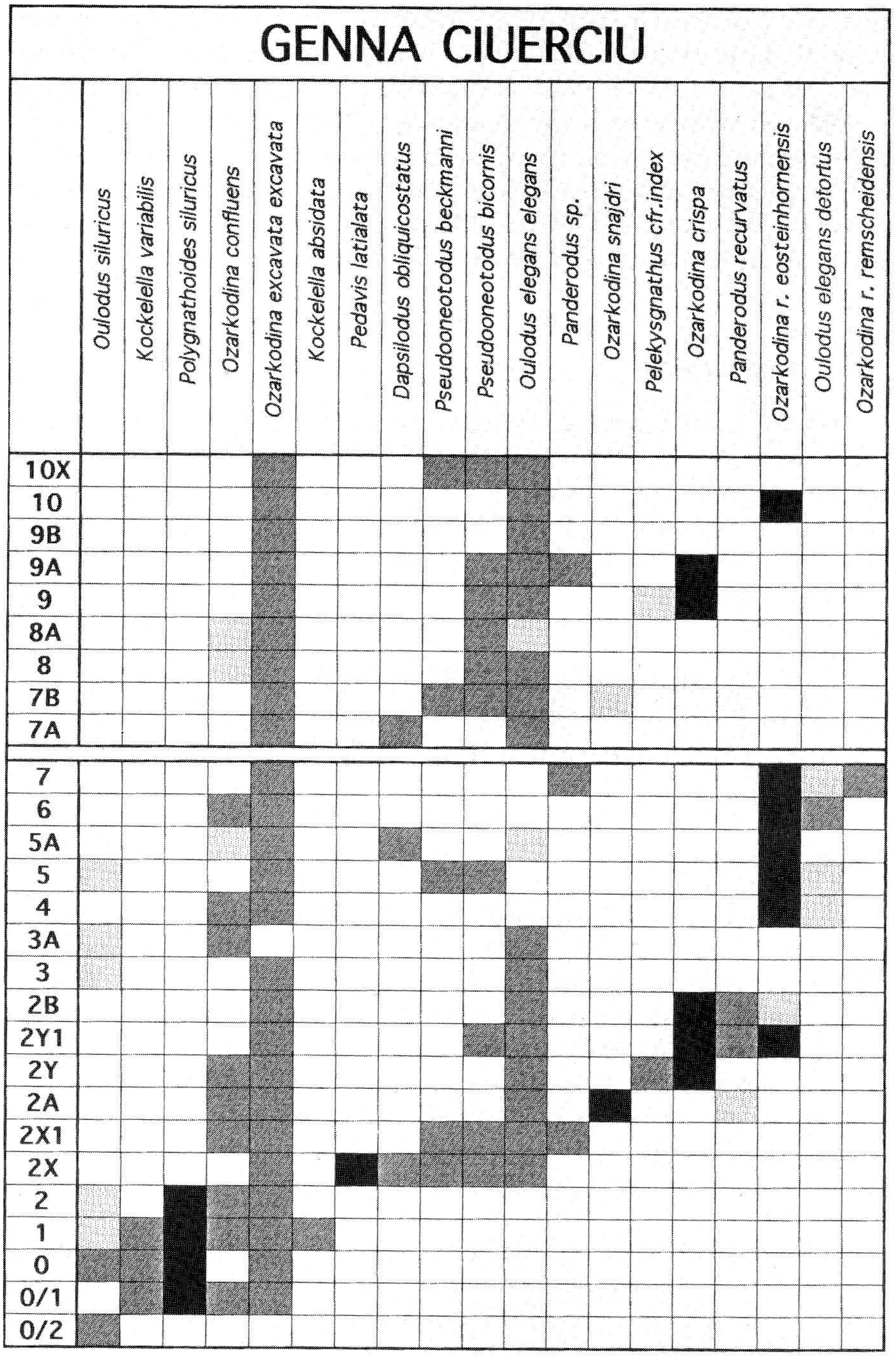

Fig. 5 - Distribution of conodont species in the GCIU section. Index species are in black. Light grey pattern indicates uncertain occurrences based on rare, fragmentary specimens or on minor elements of the apparatus.

the first time conodonts from Silurian rocks of the Gerrei tectonic Unit. A few lower Devonian (Emsian) species had been found in one sample by Bagnoli (1980) and a rich conodont fauna from the very high horizons of the same tectonic unit (Frasnian-earliest Tournaisian) has been known for many years (Olivieri, 1970).

On the other hand, some upper Silurian conodonts have been reported in southeastern Sardinia but only from sediments belonging to the Sarrabus tectonic Unit (Barca et al., 1986; Barca & Olivieri, 1992) whereas a richer fauna has been recently discovered in the San Basilio area (western Gerrei; Leone, Olivieri & Serpagli, in progress).

Conodont fauna remarks.

Fifty-two samples, ranging in weight from 2.6 to 9.1 kg, have been processed for a total of about 270 kg. Almost 9,000 conodont elements, belonging to twenty-two species, are reported (Fig. 4, 5; Pl. 4). *Ozarkodina excavata excavata* is the dominant species, being almost 60% of the whole fauna. The two sections yielded an extremely variable number of conodonts per kg. We have in fact a maximum rate of 120-170 elements per kg against a minimum of 4-5 elements. Distribution rates are, however, not strictly comparable between the two sections. This seems very strange as the sections are very close.

The Conodont Alteration Index (CAI) of the studied samples is 4.5-5 which indicates heating in excess of 250-300 C°, probably related to the close intrusive Hercynian mass of Mt. Settefratelli cropping out in the extreme southeastern part of the island.

Conodont biostratigraphy.

Conodont range data from the SIL I° section (Fig. 4) have been integrated with range data from the GCIU section (Fig. 5), in order to obtain a composite section which covers the Ockerkalk thickness (28 meters) in the studied area. This compilation was possible because of the closeness of the two sections (Fig. 2). On the basis of the resulting data, it is possible to remark that:

1) The index species *Polygnathoides siluricus*, *Pedavis latialata*, *Ozarkodina snajdri* and *Ozarkodina crispa* appear in the sequence without any apparent co-occurrence.

2) *Pelekysgnathus index*, newly recorded in Europe, occurs in the lower part of the *Oz. crispa* Biozone, before its North American range (Klapper & Murphy, 1975; Kleffner, 1989).

3) *Kockelella variabilis* and *Kockelella absidata* have not been recovered in the upper part of the *P. siluricus* Biozone, unlike the situation of the Cellon Profile (Walliser, 1964) where both species range throughout the whole *P. siluricus* Biozone.

4) *Pseudooneotodus bicornis* is widely distributed from the upper part of the *P. siluricus* (SIL I°) to most of the *Oz. r. eosteinhornensis* biozones and has therefore in Sardinia a longer range than elsewhere (Kleffner, 1989).

5) *Ozarkodina remscheidensis eosteinhornensis* is already present in the *Oz. crispa* Biozone, at least in the GCIU section, as recently reported by Walliser & Wang (1989).

6) *Oulodus elegans elegans* seems to start its occurrence just above the *P. siluricus* Biozone, i.e. slightly before its previously reported range (Kleffner, 1989).

7) *Ozarkodina crispa* alpha and beta morphotypes are present.

The studied fauna allows to subdivide the sections into the following biozones (from the base to the top): *A. ploeckensis* - *P. siluricus* - *Pe. latialata* - *Oz. snajdri* - *Oz. crispa* - *Oz. r. eosteinhornensis*. A *Pel. index* horizon can be also recognized in the lower part of the *Oz. crispa* Biozone and, in the uppermost part of the section, the *Oul. el. detortus* Subzone is present.

Therefore, biostratigraphical results from the SIL I° and the GCIU sections report continuously all Silurian conodont biozones from the *A. ploeckensis* to the *Oz. r. eosteinhornensis*, including the *Oul. el. detortus* Subzone (Ludlow-Pridoli).

Comparing with previous researches in Sardinia, the more interesting datum is the first record of the *Pe. latialata*, *Oz. snajdri* and *Oz. crispa* biozones which had not been even recovered in the southwestern part of the island. Gnoli et al. (1990) explained this absence with a coeval black shale deposition as other rich Silurian conodont fauna had been reported in the same area (Serpagli, 1967, 1971; Serpagli & Mastandrea, 1980; Olivieri & Serpagli, 1990; Barca et al., 1992).

The *Pel. index* occurrence in the lower part of the *Oz. crispa* Biozone allows one to suppose that the species appeared first in Europe and only in the lower Pridoli migrated to North America.

Conclusions.

Precise evidence of Ludlow and e.-m. Pridoli age for the Ockerkalk of southeastern Sardinia has been obtained from conodont occurrences. Important information on range and distribution of significant conodont species and on some Ockerkalk features have been collected.

We hope that our data may be useful to reach a further step on the path to the development of an upper Silurian reference conodont biozonation.

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PLATE 1

Fig. 1 - View of middle part of the SIL I° section.
Fig. 2 - Panoramic view of the GCIU section (levels from sample 1 to sample 7, top of the hill).

PLATE 2

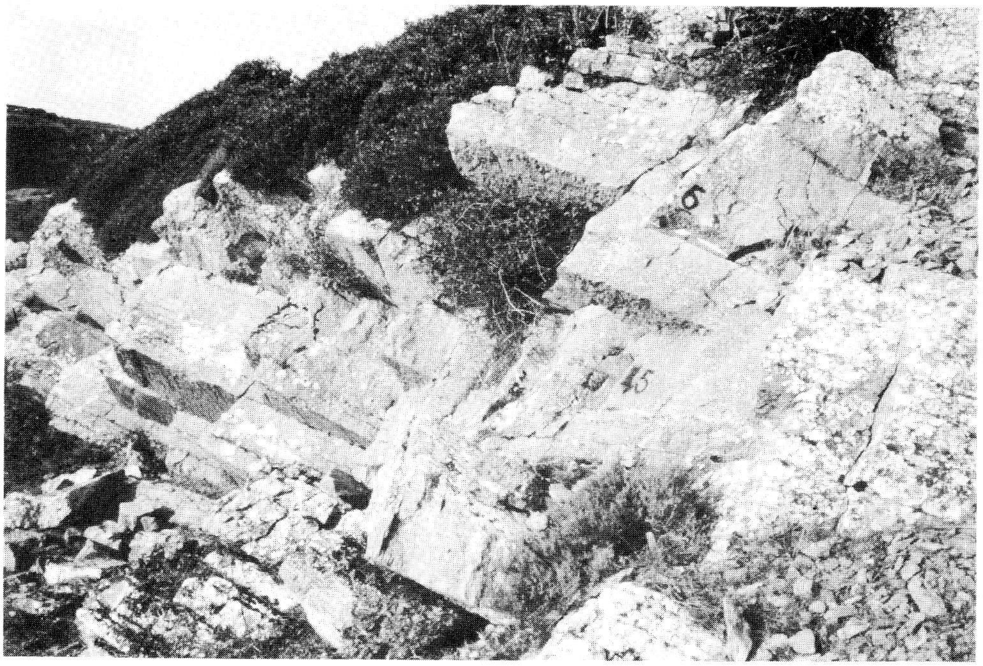
Fig. 1 - Lobolith in the GCIU section (sample 4).
Fig. 2 - Irregular nodular structure of the Ockerkalk (SIL I° section; nearby sample 7).

PLATE 3

Fig. 1 - Microbioclastic mudstone with calcified ostracodes. Sample SIL I° 4A; 16 x.
Fig. 2 - Skeletal mudstone with a cephalopod shell and calcified bioclasts. Sample SIL I° 3; 8 x.
Fig. 3 - Bioclastic wackestone with a cephalopod shell and sparse crinoid fragments. Sample GCIU 3A; 8 x.
Fig. 4 - Photomicrograph of crinoidal wackestone. Sample GCIU 4; 16 x.
Fig. 5 - Crinoid fragments. Sample SIL I° 11C; 16 x.
Fig. 6 - Skeletal mudstone with a trilobite. Sample GCIU 2Y; 16 x.
Fig. 7, 8 - Secondary calcite crystals and iron oxides distributed in veins across the limestone nodules. Sample SIL I° 4A; 50 x.

PLATE 4

Fig. 1 - *Polygnathoides siluricus* Branson & Mehl. Upper view of Pa element. Sample GCIU 0/1; 45 x.
Fig. 2 - *Ozarkodina remscheidensis eosteinhornensis* (Walliser). Lateral view of Pa element. Sample GCIU 5A; 90 x.
Fig. 3 - *Ozarkodina remscheidensis remscheidensis* (Ziegler). Lateral view of Pa element. Sample SIL I° 11B; 90 x.
Fig. 4, 5 - *Pelekysgnathus index* Klapper & Murphy. Lateral view of two Pa elements. Sample SIL I° 8B; 85 x.
Fig. 6 - *Ozarkodina crispa* (Walliser). Lateral-upper view of Pa element-alpha morphotype. Sample GCIU 2Y; 70 x.
Fig. 7 - *Ozarkodina snajdri* (Walliser). Upper view of Pa element. Sample GCIU 2A; 80 x.
Fig. 8 - *Ozarkodina crispa* (Walliser). Lateral view of Pa element-beta morphotype. Sample SIL I° 8B; 60 x.
Fig. 9 - *Ozarkodina crispa* (Walliser). Upper view of Pa element-beta morphotype. Sample GCIU 2Y; 45 x.
Fig. 10 - *Pedavis latialata* (Walliser). Upper view of Pa element. Sample GCIU 2X; 60 x.
Fig. 11 - *Kockelella absidata* Barrick & Klapper. Lateral view of Pa element. Sample SIL I° 4; 70 x.
Fig. 12 - *Ozarkodina excavata hamata* (Walliser). Upper view of Pa element. Sample SIL I° 1; 90 x.
Fig. 13 - *Ancoradella ploeckensis* Walliser. Upper view of Pa element. Sample SIL I° 3; 70 x.
Fig. 14 - *Pseudooneotodus bicornis* Drygant. Lateral view of Pa element. Sample GCIU 2X1;110 x.
Fig. 15 - *Kockelella variabilis* Walliser. Upper view of Pa element. Sample GCIU 1; 60 x.



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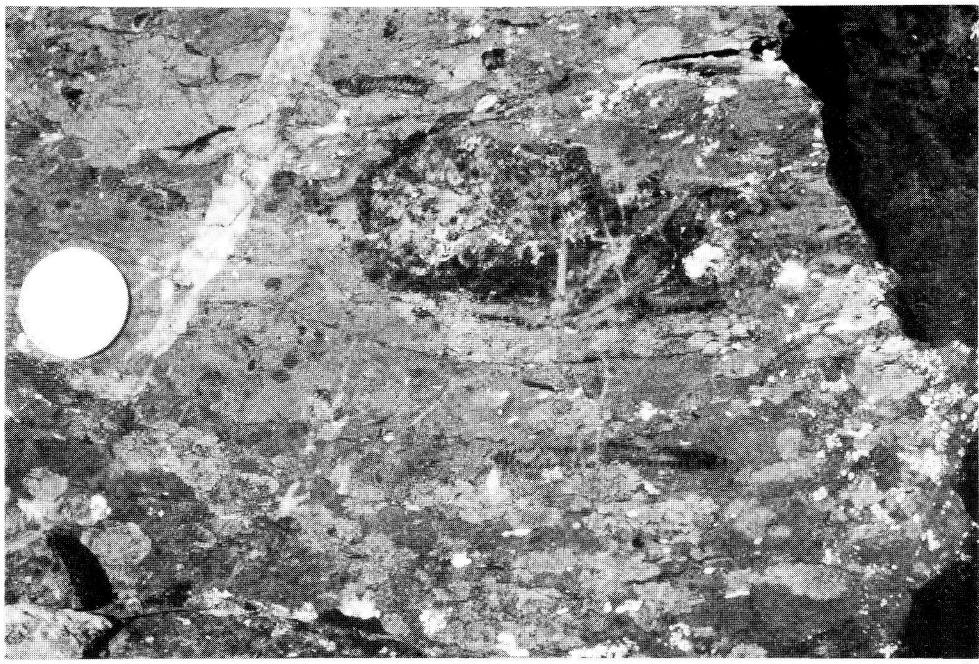

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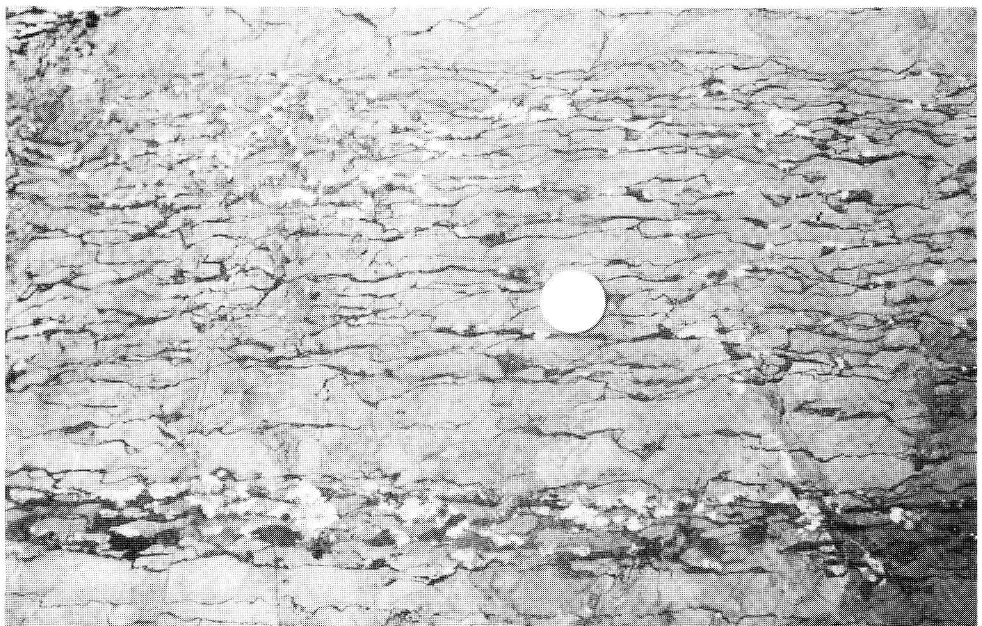

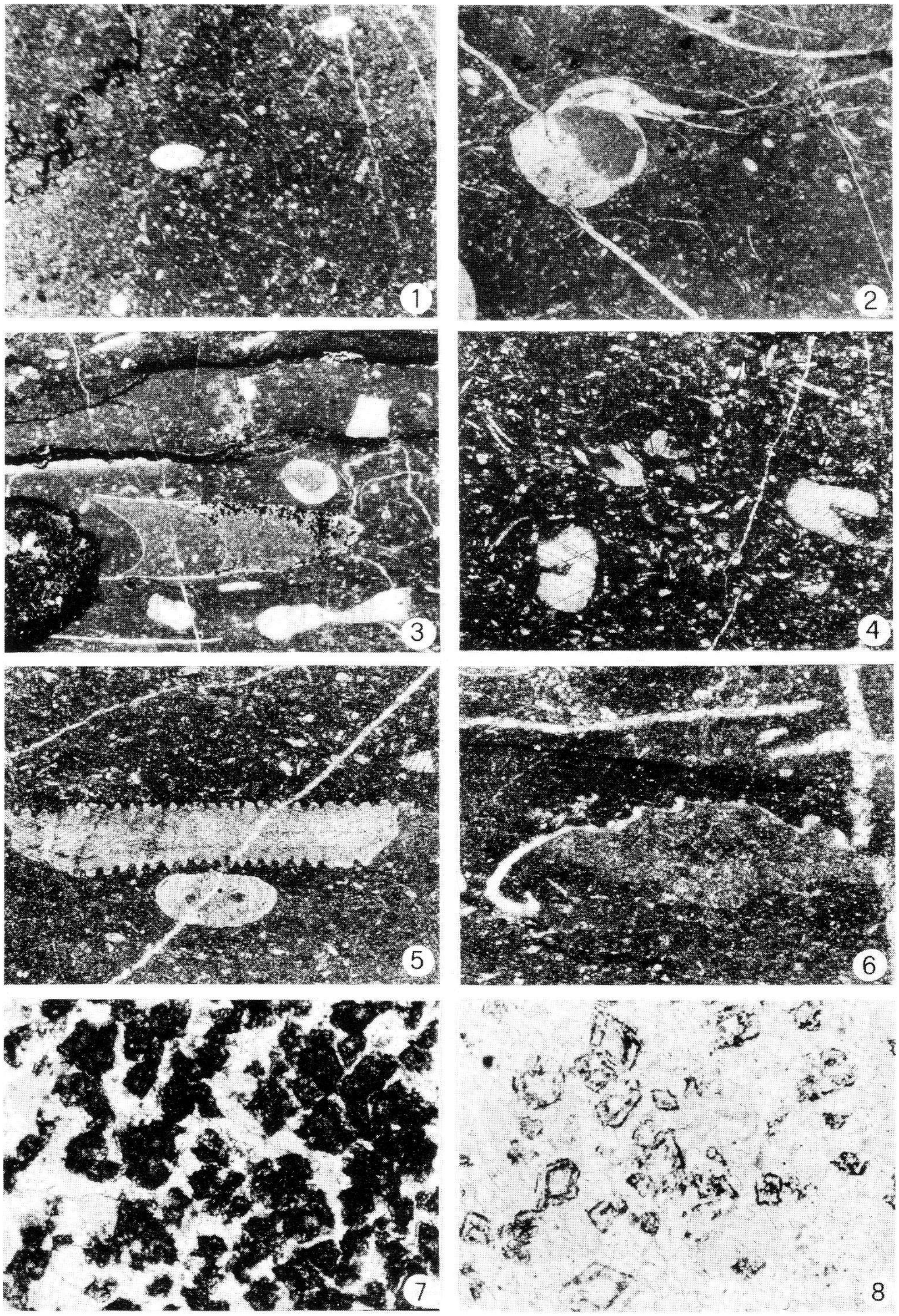
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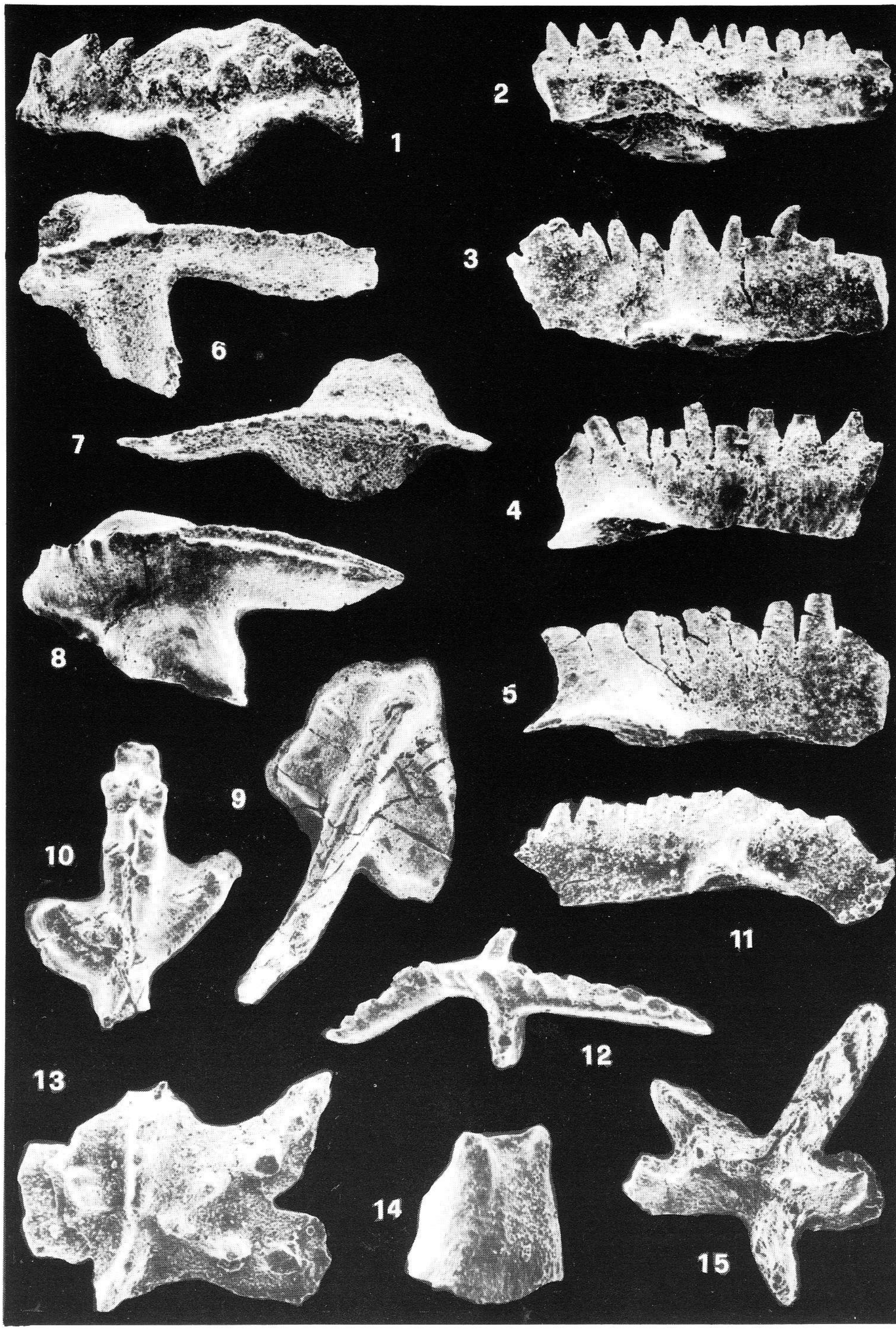
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