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Conodont stratigraphy of a highly tectonised Silurian-Devonian section in the San Basilio area (SE Sardinia, Italy)

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*ABSTRACT – Several conodont species belonging to five late Silurian biozones (*Ancoradella ploeckensis, Polygnathoides siluricus, Ozarkodina crispa, Ozarkodina remscheidensis, Oulodus elegans detortus*) and four Early and Late Devonian biozones (*delta, pesavis, kitabicus-excavatus *and Late* rhenana*) allow a better interpretation of stratigraphy and tectonics of the San Basilio area in western Gerrei. Frasnian sediments are documented for the first time in SE Sardinia.*

RIASSUNTO – [Stratigrafia a conodonti di una sezione fortemente tettonizzata di età Siluriano-Devoniano nell'area di San Basilio (Sardegna SE)] *– Grazie alla biostratigrafia a conodonti viene interpretata la complessa tettonica di una sezione nell'area di San Basilio (Sardegna sud-orientale) e viene ricostruita la successione originaria. Sono documentate cinque biozone a conodonti del Siluriano superiore (*Ancoradella ploeckensis, Polygnathoides siluricus, Ozarkodina crispa, Ozarkodina remscheidensis, Oulodus elegans detortus*), tre del Devoniano Inferiore (*delta, pesavis *e* kitabicus-excavatus*) una del Devoniano Superiore (Late* rhenana*). Vengono inoltre documentati per la prima volta sedimenti frasniani nel Sud-Est della Sardegna.*

INTRODUCTION

In Sardinia, the Hercynian orogeny produced tectonic nappes which were thrust towards the external zone of the orogen, i.e. from north-east to south-west in present-day geographical terms (Carmignani *et al.*, 1982; 1992). These nappes partly overlap the autochthonous Palaeozoic succession of Sulcis-Iglesiente. They comprise several tectonic units made up of sedimentary rocks (mainly terrigenous) that were deposited between the Middle Cambrian (Barca *et al.*, 1981) and the Early Carboniferous (Maxia, 1984; Barca, 1991). These tectonic units show different degrees of metamorphism, from green schist to amphibolite facies (Di Simplicio *et al.*, 1974).

Silurian and Devonian fossiliferous rocks are quite widespread in south-eastern 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. The Palaeozoic sequence of the Gerrei region is built up by a thick siliciclastic formation (San Vito Sandstones) bearing Cambro-Tremadoc acritarchs unconformably overlain ("Sarrabese unconformity") by acid metavolcanites ("Porphyroids"), regarded pre-Caradoc in age. Caradoc-Ashgill fossiliferous sediments, consisting of conglomerates, arenites (mainly lithic greywackes and feldspatic greywackes) and siltstones, rest transgressively on the older metavolcanites. At the top of the sequence limestones, partially or totally silicified in the Sarrabus Unit, as well as spilitic metabasites, are also present. The succession continues first with lyditic black shales (LGS) and limestones (in "Ockerkalk" facies) of Silurian age, and again with black shales (UGS) followed by nodular argillaceous limestones with dacryoconarids (Early-Middle Devonian). The upper Devonian-lowermost Carboniferous sequence ends with pelagic limestones (*Clymeniae* Limestones *Auct.*) and the whole succession terminates with conglomerates and siltstones related to a flysch complex of the Hercynian orogeny. More data on part of this sequence have been recently reported by Barca *et al.* (1995), Ferretti & Serpagli (1996), Corradini *et al.* (1998, 2000 and in press).

To point out that, whereas some lithostratigraphic units exist inside the Sarrabus unit, no official units have been up to now proposed for the Gerrei Unit. Lower (LGS) and Upper Graptolitic Shales (UGS) and Ockerkalk are, in fact, facies-names and not official lithostratigraphic units. Furthermore, in several papers different names are used to name formations and members, belonging to sub-tectonic units, which are very often the same; this practice not only produce confusion, but also does not follow the recommendations of the International Stratigraphic Guide (Hedberg, 1976; Salvador, 1994).

PREVIOUS DATA

Published data available from the San Basilio area are mostly by Naud (1979; 1982), Gnoli (1993),

Gessa (1993) and Ferretti *et al.* (1998). Further data were added by Loi (1988, unpublished master thesis).

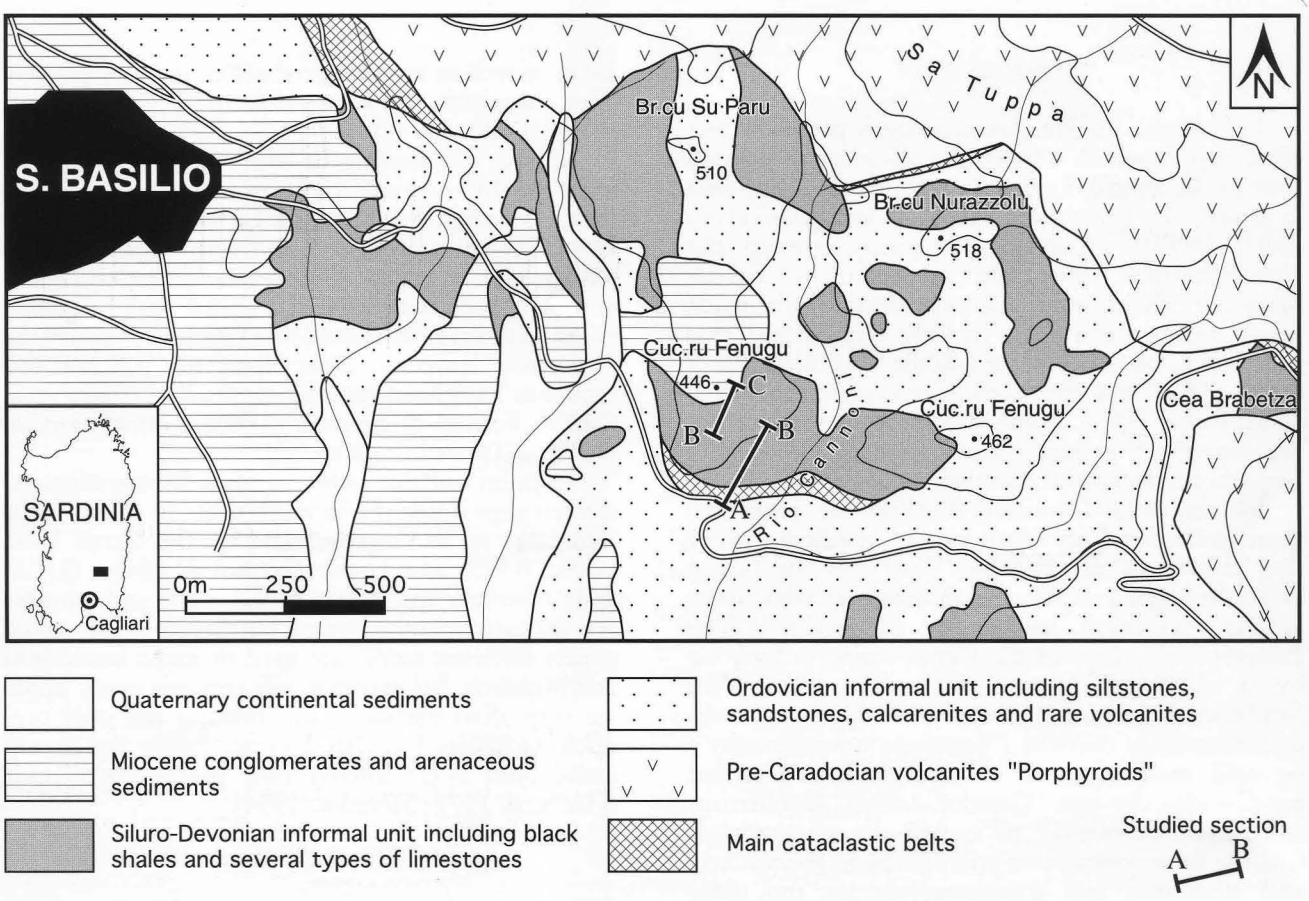
In the first, mostly lithostratigraphic paper, Naud (1979) proposed an upper Ordovician "fossiliferous" guide-horizon (no formal lithostratigraphical units - Rio Canoni shales). The only fossils he listed from that level are two genera (*Strophomena, Rostricellula*?) and two families (Rafinesquinae and Trigonirhynchiidae) of brachiopods, few fragmentary and indeterminate conodonts and an isolated coral whereas the brachiopod ?*Platystrophia*, cystoids (*Heliocrinites* aff. *rouvillei*, *Oocystis* sp. and ?*Corylocrinus* sp., ?*Caryocystites* sp.) have been reported from a different area by Helmcke (1972) and Helmcke & Koch (1974), respectively.

From the Rio Canoni shales cropping out in the Rio Canoni area, Loi (1988) discovered brachiopods (*Nicolella actoniae, Svobodaina ellipsoides, Svobodaina* sp., *Longvillia mediterranea, Onniella* sp., *Howellites* sp., *Leptaena* sp.), gastropods and an unassigned trilobite pygidium. The Rio Canoni shales are, therefore, manifestly fossiliferous but the poor preservation has discouraged any detailed palaeontological study.

In a second paper, Naud (1982) proposed six local tectonic units, stressed their structural complexity and described three sections (numbered 3, 4 and 5) one of which (4) corresponds, more or less, to the area investigated in detail in the present research. A late Silurian age was claimed by the author for some levels on the basis of the conodont species *Kockelella variabilis* and of an indefinite "*Orthoceras*" fauna.

More recent, mostly paleontological data are due to Gnoli (1993), Gessa (1993) and Ferretti *et al.* (1998). The first author recorded six nautiloid Silurian species, one of which (*Oonoceras potens*) had never been recorded in the rich, well known coeval cephalopod fauna of western Sardinia. Gessa (1993) recorded five species of dacryoconarids from different levels within argillaceous limestones; one of that, left in open nomenclature (*Nowakia* sp. A), has some analogies with two Emsian species. A conodont fauna, newly discovered from the late Ordovician section Cea Brabetza (Ferretti *et al.*, 1998), is the latest biostratigraphic contribution to San Basilio area.

In conclusion, very few sound biostratigraphic data were up to now available from the Palaeozoic sediments of the San Basilio area and, therefore, one of the purposes of the present paper is to combine all



Text-fig. 1 - Geological sketch map west of the village of San Basilio, around the Cuccuru Fenugu 446 and Cuccuru Fenugu 462 hills, based on unpublished data of Loi (1988). The studied section is indicated by letters A-B and B-C.

new and unpublished information in order to improve the geological knowledge of the area.

THE SAN BASILIO FENUGU SECTION

The studied section is exposed on the southern slope of the 444 m high hill named Cuccuru Fenugu (as it appears on Carta Tecnica della Sardegna, at the 1:10,000 scale) almost 1600 m east-south-east of the San Basilio village (Text-fig. 1).

The sequence of the rock types, starting from the base of the hill, is listed below (Text-fig. 2):

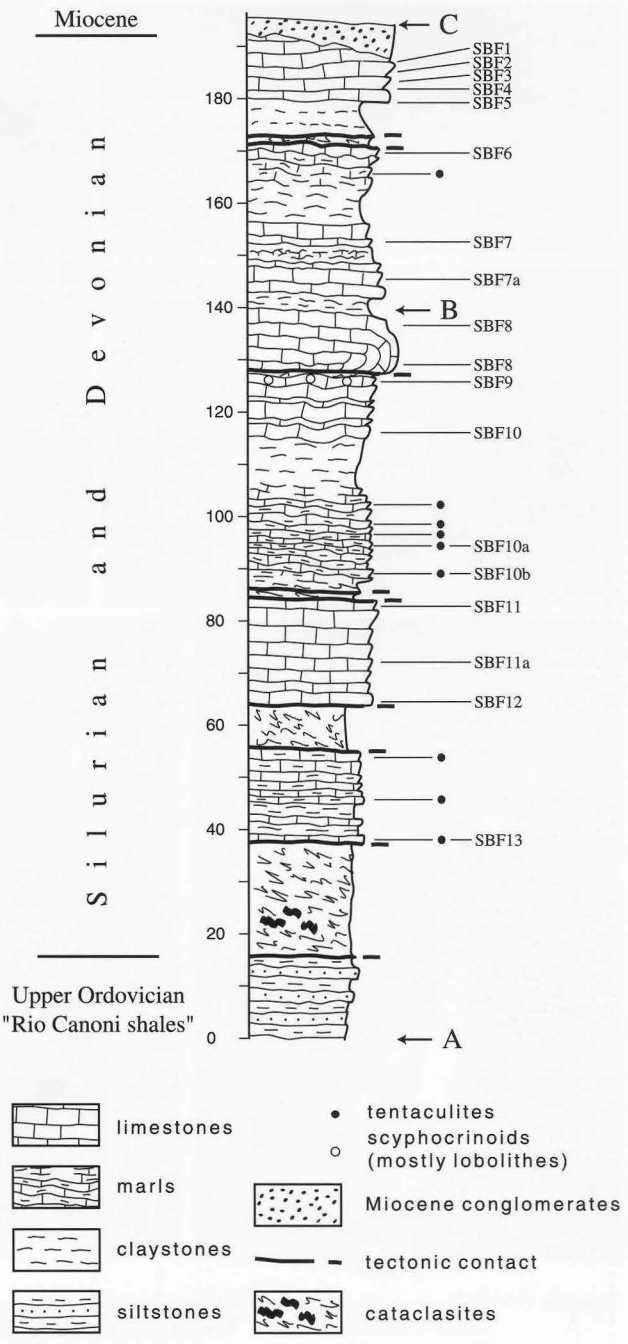
- upper Ordovician fossiliferous green-grey siltstones (Rio Canoni shales) (Text-fig. 3a,b);
- highly tectonised (cataclasites) black shales with lydites (early Silurian?) (about 22 m);
- about 20 m of marly claystones and subordinated bioclastic marly limestones and grey-bluish limestones with dacryoconarids (sample SBF13, Frasnian; Text-fig. 3e).
- highly tectonized (cataclasites) green-grey shales (about 10 m);
- "Ockerkalk"-type facies limestones (samples SBF 12, SBF 11a and SBF 11) (22 m); most of the nautiloids reported by Gnoli (1993) were collected from this interval;
- narrow cataclastic belt;
- thick sequence (20 m) of calcareous levels (samples SBF 10b and SBF 10a) with grey-green claystones interbedded bearing dacryoconarids, crinoid stems and lobolithes, and rare phacopid trilobites (Text-fig. 3d, 3f);
- grey-green claystones (8 m.);
- about 13 m of "Ockerkalk"-type facies limestones (samples SBF 10 and SBF 9);
- tectonic contact (overthrust?) followed by an overturned anticline (Text-fig. 3c), made up of limestones in "Ockerkalk"-type facies (samples SBF 7, SBF 7a and SBF 8); the limestones are followed by grey-green claystones grading to marls toward the top, marly limestones and nodular limestones (sample SBF 6). The whole thickness of this part of the sequence is about 45 m;
- narrow cataclastic belt;
- grey-green claystones (9 m.);
- bluish-grey argillaceous limestone in "Ockerkalk"-type facies (about 6 m) (five samples, from SBF1 to SBF5).

The Palaeozoic sequence ends toward the top of the hill and is transgressively covered by coarse clastic Miocene sediments.

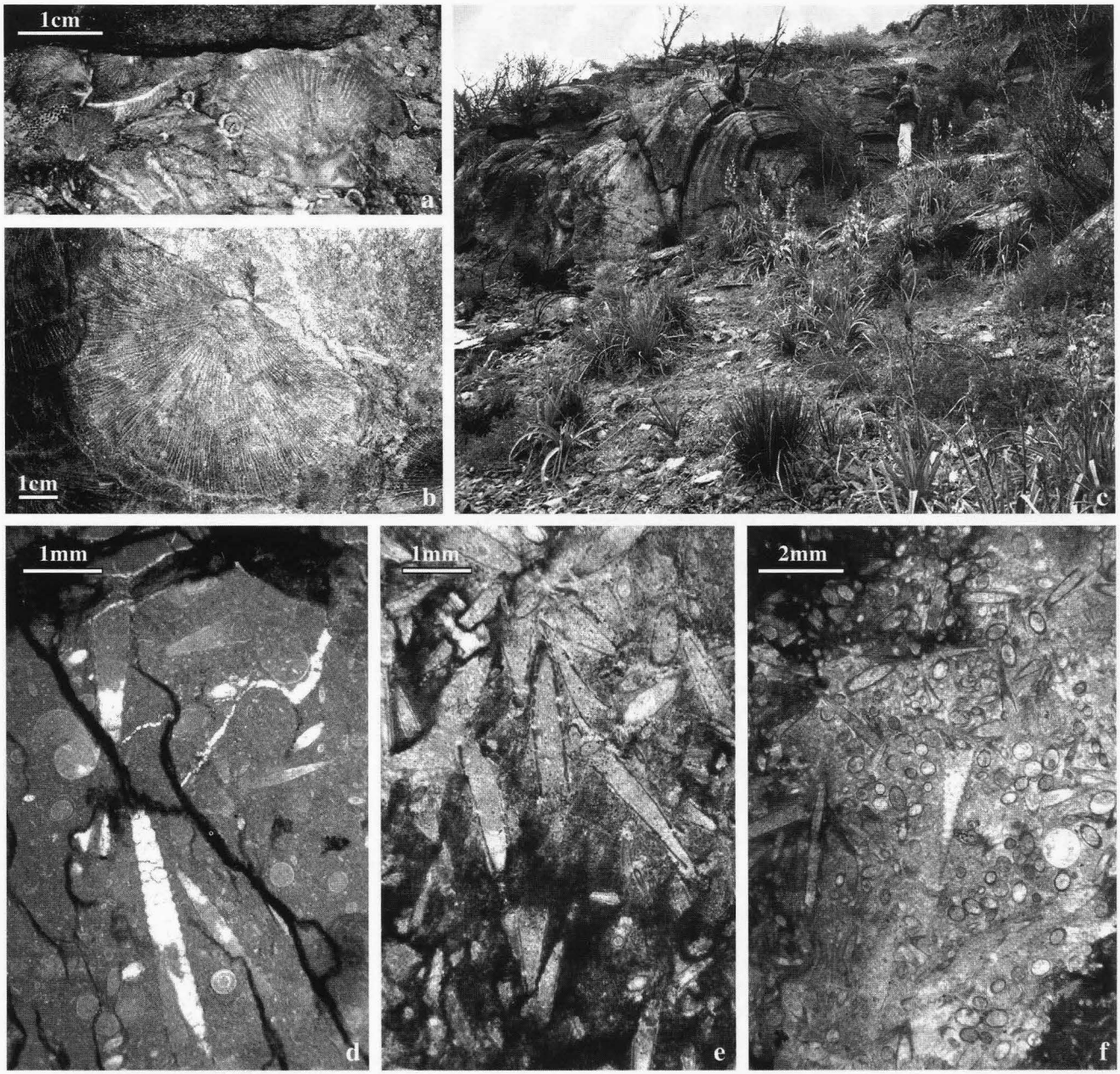
CONODONT DATA

Detailed biostratigraphic data are all based on conodonts recovered from 18 calcareous productive samples collected from several levels. Two more samples collected from more shaly intervals were barren. The frequency of the specimens resulted very variable throughout the section. Owing to the structural complexity only 5 samples, collected from the "Ockerkalk"-type limestones may be regarded as belonging to a regular sequence. All samples, ranging in weight from 2.5 to 6.3 kg, for a total amount of about 88 kg, were processed in diluted formic acid.

Most of the specimens are poorly preserved being often squeezed and distorted, owing probably to diagenesis, tectonic stresses and low-grade metamorphism.



Text-fig. 2 - Lithological column of the SBF Section.



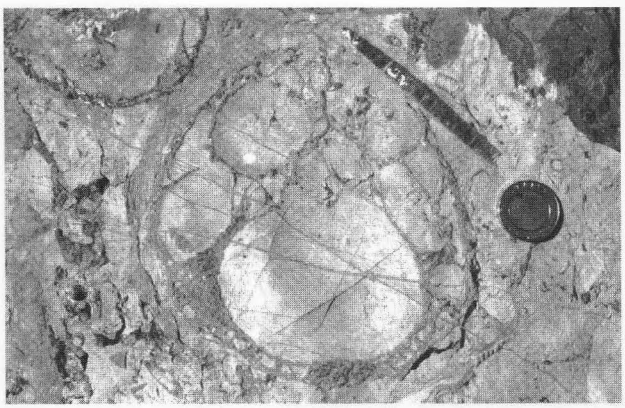
Text-fig. 3 - a) Typical assemblage occurring in the Late Ordovician siltstones of Rio Canoni shales; b) Specimen of *Longvillia mediterranea* Havlicek from the Rio Canoni shales; c) Overturned anticline in the mid-part of the section (sample SBF 8); d) Dacryoconarids and gastropods microfacies, sample SBF 10b, Lochkovian; e) Dacryoconarids microfacies, sample SBF 13, Frasnian; f) Dacryoconarids microfacies, sample SBF 10a, Emsian.

All conodont specimens are black indicating a Colour Alteration Index (CAI) of the studied samples between 4.5-5.5, corresponding to a heating in excess of about 350 °C probably related to regional metamorphism. This is also proved by the fact that several elements of the apparatuses are "texturally altered", showing the features of the group of "regionally metamorphosed conodonts" as described by Rejebian *et al.* (1987, fig. 1).

Preliminary reports on the occurrence of *Coryssognathus dubius* (Rhodes, 1953) in some samples, and its stratigraphic range have been already discussed (Serpagli *et al.*, 1997).

BIOSTRATIGRAPHY

The age of the fauna spans from late Silurian to Frasnian, but most intervals of this time have not



Text fig. 4 - Detail of a slab bearing several crinoid remains, among which well preserved cirrus lobolithes and fragments of stems. Late Silurian, Pridoli, *detortus* Zone.

been documented in the San Basilio Fenugu Section. The Silurian Sardinian Conodont Zonation (Corradini & Serpagli, 1999) has been followed for the Silurian, the "Column B3030di96 – Conodonten-Zonen" (Carls & Weddige, 1996) and the Late Devonian Standard Conodont Zonation (Ziegler & Sandberg, 1990) for the Devonian.

The following biozones and/or biointervals have been recognised:

The *Ancoradella ploeckensis* Zone (Ludlow, Late Silurian)

The *A. ploeckensis* Zone have been recognised in sample SBF 5 by the occurrence of the marker *Ancoradella ploeckensis* Walliser, 1964. The fauna includes also *Ozarkodina exc. excavata* (Branson & Mehl, 1934), *Kockelella v. variabilis* Walliser, 1957 and *Oulodus siluricus* (Branson & Mehl, 1934).

The *Polygnathoides siluricus* Zone (Ludlow, Late Silurian)

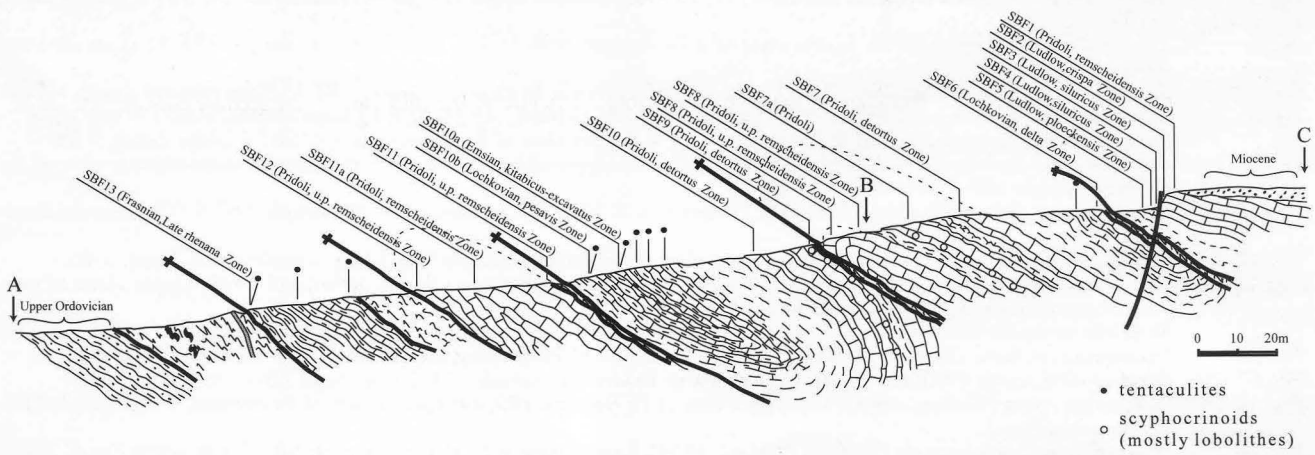
The *Pol. siluricus* Zone occur in samples SBF 3 and SBF 4. Beside the marker, *Polygnathoides siluricus* Branson & Mehl, 1934, the fauna includes *Oz. exc. excavata* (Branson & Mehl, 1934), *Oz. confluens* (Branson & Mehl, 1934) and *Coryssognathus dubius* (Rhodes, 1953).

The *Ozarkodina crispa* Zone (Ludlow, Late Silurian)

The *Oz. crispa* Zone is reported from sample SBF 2. The association is quite rich and includes *Ozarkodina crispa* (Walliser, 1964), *Oz. rem. eosteinhornensis* s.l., *Oz. snajdri* (Walliser, 1964), *Oz. exc. excavata* (Branson & Mehl, 1934), *Oulodus el. elegans* (Walliser, 1964), *Pelekysgnathus* cf. *index* (Klapper & Murphy, 1975), *Pseudooneotodus beckmanni* (Bischoff & Sannemann, 1957), *Ps. bicornis* Drygant, 1984, *Belodella resima* Philip, 1965 and *Panderodus recurvatus* (s.l.).

The *Ozarkodina remscheidensis* interval Zone (Pridoli, Late Silurian)

This biozone is the most widespread in the section, since it has been recognised in samples SBF 1, 7A, 8, 9, 11, 11A, and 12. Furthermore, it is possible to state that samples SBF 8, 11 and 12 belong to the upper part of the zone, on the basis of the occurrence of *Oz. rem. remscheidensis* (Ziegler, 1960). The fauna includes also *Oz. rem. eosteinhornensis* (Walliser, 1964), both α and β morphotypes, *Oz. exc. excavata* (Branson & Mehl, 1934), *Oz. confluens* (Branson & Mehl, 1934), *Coryssognathus dubius* (Rhodes, 1953), *Oul. el. elegans* (Walliser, 1964), *Oul. siluricus* (Branson & Mehl, 1934), *Pseudooneotodus beckmanni* (Bischoff & Sannemann, 1957) and *Ps. bicornis* Drygant, 1984.



Text-fig. 5 - Cross section of the Cuccuru Fenugu hill showing the complex tectonics. For lithology refer to Text-fig. 2.

The *Oulodus elegans detortus* Zone (Pridoli, Late Silurian)

The latest Silurian biozone occurs in samples SBF 7, SBF 9 and SBF 10, as testifies the recovery of the *Oul. el. detortus* (Walliser, 1964). Beside the marker, the fauna includes also *Oz. rem. remscheidensis* (Ziegler, 1960), *Oz. rem. eosteinhornensis* (Walliser, 1964), both α and β morphotypes, *Oz. exc. excavata* (Branson & Mehl, 1934), *Oz. confluens* (Branson & Mehl, 1934), *Coryssognathus dubius* (Rhodes, 1953), *Ps. bicornis* Drygant, 1984 and *Belodella resima* (Philip, 1965).

The *delta* Zone (Lochkovian, Early Devonian)

The *delta* Zone is reported from sample SBF 6. The fauna includes *Ancyrodelloides limbacarinatus* Murphy & Matti, 1982, *A. transitans* (Bischoff & Sannemann, 1957), *A. trigonicus* Bischoff & Sannemann, 1958, *Icriodus angustoides alcolae* Carls, 1969 and *Ps. beckmanni* (Bischoff & Sannemann, 1958).

The *pesavis* Zone (Lochkovian, Early Devonian)

Sample SBF 10b yielded a very scarce fauna; however the occurrence of *Oz. pandora* (Murphy & Matti, 1982) ε morph. suggests to date it to the *pesavis* Zone. *Belodella* sp. is also present.

The *kitabicus-excavatus* interval (Emsian, Early Devonian)

Sample 10a yielded a very poor, badly preserved fauna, too. The recovery of a couple of fragments of *Polygnathus* cf. *dehiscens* and a few specimens of *Pandorinellina steinhornensis* ssp. suggests to refer the sample to a *kitabicus-excavatus* interval.

The Late *rhenana* Zone (Frasnian, Late Devonian)

The Late *rhenana* Zone is identified from the sample SBF 13, on the basis of the joint occurrence of *Icriodus alternatus alternatus* Branson & Mehl, 1934 and *Ancyrodella ioides* Ziegler, 1958. The association includes also *Ancyrodella* cf. *buckeyensis* Stauffer 1938, *Ancyrognathus triangularis* Youngquist, 1945, *Palmatolepis hassi* Müller & Müller, 1957 and *Polygnathus procerus*, Sannemann, 1955.

TECTONICS

Usually the Silurian and Devonian sequences of the Gerrei Tectonic Unit are discussed together by most authors and grouped under the simplified, general name of "Silurian-Devonian". Besides the scantiness of biostratigraphic data up to a few years ago, this practice was also conditioned by the tectonic complexity of the region, which characterises the rocks of this stratigraphic interval; however, it can be

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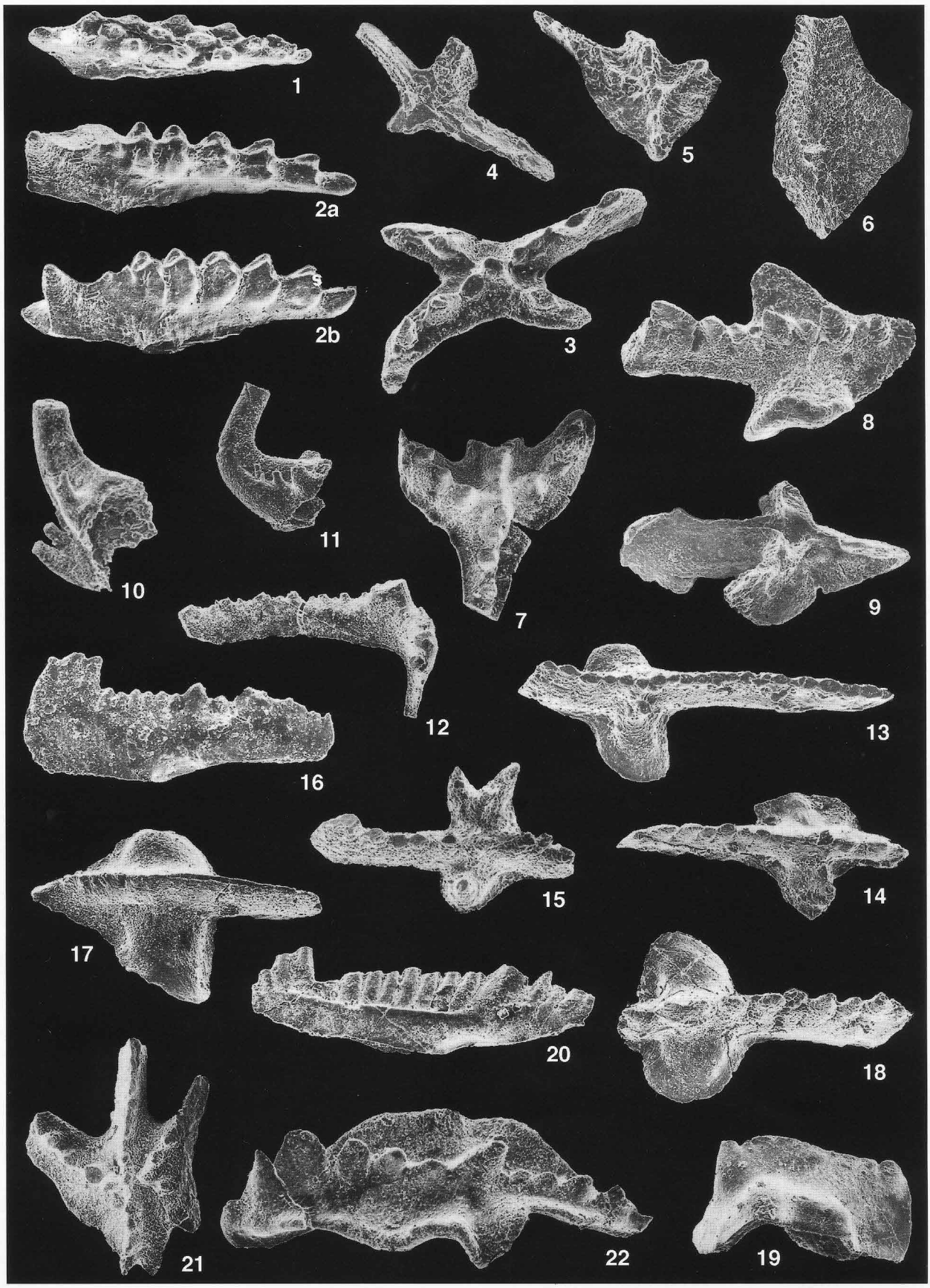
EXPLANATION OF PLATE 1

Upper Silurian (Figs 10-22), Lower (Figs 2-3, 7-9) and Upper Devonian (Figs 1, 4-6) conodonts from the San Basilio Fenugu (SBF) section (South-eastern Sardinia).

Fig. 1 - *Icriodus alternatus alternatus* Branson & Mehl, 1934. Oblique-upper view of Pa element, sample SBF 13 (Late *rhenana* Zone), × 100.
Fig. 2 - *Icriodus angustoides alcolae* Carls, 1969. Oblique-upper (a) and lateral (b) views of Pa element, sample SBF 6 (*delta* Zone), × 70.
Fig. 3 - *Ancyrodelloides transitans* (Bischoff & Sannemann, 1958). Oblique-upper view of Pa element, sample SBF 6 (*delta* Zone), × 100.
Fig. 4 - *Ancyrodella ioides* Ziegler, 1958. Lower view of a Pa element with broken anterior blade, sample SBF 13 (Late *rhenana* Zone), × 100.
Fig. 5 - *Ancyrodella* cf. *bukeyensis* Stauffer, 1938. Upper view of a juvenile Pa element, sample SBF 13 (Late *rhenana* Zone), × 100.
Fig. 6 - *Palmatolepis hassi* Müller & Müller, 1957. Upper view of Pa element, sample SBF 13 (Late *rhenana* Zone), × 65.
Fig. 7 - *Ancyrodelloides trigonicus* Bischoff & Sannemann, 1958. Upper view of Pa element, sample SBF 6 (*delta* Zone), × 50.
Figs 8-9 - *Ancyrodelloides limbacarinatus* Murphy & Matti 1982. 8) Upper-oblique view of Pa element; 9) lower-oblique view of Pa element; sample SBF 6 (*delta* Zone), × 80.
Figs 10-11 - *Coryssognathus dubius* (Rhodes, 1953). 10) Pc element, × 100; 11) Sc element, × 80; sample SBF 9 (*Oz. remscheidensis* Zone).
Fig. 12 - *Oulodus elegans detortus* (Walliser, 1964). Lateral view of Sc element, sample SBF 9 (*Oz. remscheidensis* Zone). × 60.
Figs 13-14 - *Ozarkodina remscheidensis eosteinhornensis* (Walliser, 1964) β morph. *sensu* Olivieri & Serpagli 1990. Upper views of two Pa elements, sample SBF 9 (*Oz. remscheidensis* Zone), × 80.
Fig. 15 - *Kockelella variabilis variabilis* Walliser, 1957. Upper view of Pa element, sample SBF 5 (*A. ploeckensis* Zone), × 80.
Fig. 16 - *Ozarkodina confluens* (Branson & Mehl, 1934). Lateral view of Pa element, sample SBF 4 (*Po. siluricus* Zone), × 80.
Fig. 17 - *Ozarkodina* cf. *crispa* (Walliser, 1964). Upper view of Pa element, sample SBF 2 (*Oz. crispa* Zone), × 80.
Figs 18-19 - *Ozarkodina crispa* (Walliser, 1964). 18) Upper view of Pa element, x80; 19) Lateral view of Pa element, × 50. Sample SBF 2 (*Oz. crispa* Zone).
Fig. 20 - *Ozarkodina excavata excavata* (Branson & Mehl, 1934). Lateral view of Pa element, sample SBF 2 (Oz. *crispa* Zone), × 65.
Fig. 21 - *Ancoradella ploeckensis* Walliser, 1964. Upper view of Pa element, sample SBF 5 (*A. ploeckensis* Zone), × 50.
Fig. 22 - *Polygnathoides siluricus* Branson & Mehl, 1934. Oblique-upper view of Pa element, sample SBF 4 (*Po. siluricus* Zone), × 50.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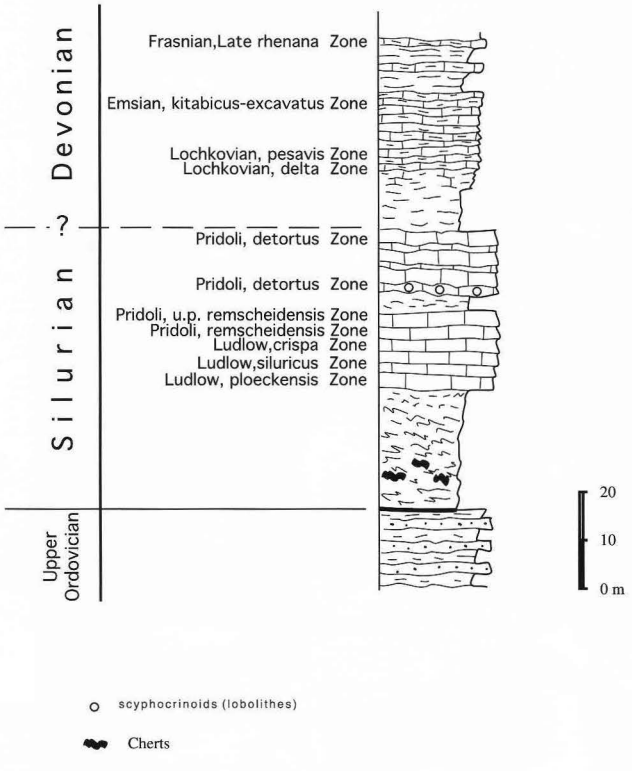
no more justified now, after the publication of many papers on Silurian and Late Devonian.

Macro- and mesoscopic field observations carried out in the San Basilio area (way-up features, partially eroded overturned folds, repetitions of portions of sequences) already emphasized this complexity (Naud, 1979; Loi, 1988), mainly consisting of NW-SE striking, SW dipping isocline folds. Such folds are characterised by an axial-plane foliation, which is evident in poorly competent rock types (shales) whereas limestone outcrops display stylolite joints with advanced dissolution processes.

The results of the sampling campaign show repetitions of reverse and normal sequences (Text-fig. 5), although attitude changes are not observed. These repetitions are caused by lamination of reverse flanks and piling up of isocline folds. Mylonite belts, varying in thickness from a few metres to dozens of metres, accompany these overlapping structures. Furthermore, two mainly clayey stratigraphic levels, favouring the sequence's décollement, were recognised. The former belongs to the Early Silurian, the latter to the basal Lochkovian.

This style of strain, occurring at different scales in different facies, according to their particular response to tectonic stresses, is found in all the region's rock types. In the lithostratigraphic units showing a certain compositional and textural homogeneity, the tectonic redoubling of the stratigraphic sequence is hardly ever observed. Once more, this fact shows that the solution of detailed statigraphic and structural problems requires a precise analysis.



Text-fig. 6 - Reconstruction of the lithostratigrafic succession cropping out in the San Basilio area; conodont biozones documented are also reported throughout the sequence. For lithology refer to Text-fig. 2.

CONCLUSIONS

The main results of the investigation on the San Basilio Fenugu Section can be summarised as follow:

Five late Silurian biozones (*A. ploeckensis*, *Pol. siluricus*, *Oz. crispa*, *Oz. remscheidensis*, *Oul. el. detortus*), three Early (*delta*, *pesavis*, *kitabicus-excavatus*) and one Late Devonian biozones (Late *rhenana*) have been documented.

Frasnian sediments have been recognised for the first time in south-eastern Sardinia on the basis of a rich conodont fauna.

The main goal of the paper, to demonstrate that the solution of detailed structural problems requires sometime a precise biostratigraphic analysis, has been fully achieved. In fact, faults, overthrusts, folds and redoublings would have been only partially recognised through the section without a conodont study.

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