Late Ordovician conodont faunas from southern Sardinia, Italy:
biostatigraphic and paleogeographic implications

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KEY WORDS – Conodonts, Late Ordovician, Ashgill, Sardinia, Italy, North Gondwana.

ABSTRACT – Conodont faunas recovered from several localities in southwestern and southeastern Sardinia are assigned to the Late Ordovician on the basis of the recovery of Amorphognathus ordovicianus Brenner & Mei, 1933 and A. lindstroemi (Serpagli, 1967). A peculiar Amorphognathus species that has been found in slightly older sediments is described. 28 species belonging to 18 genera constitute the conodont collection; elements of Hammersdornia europaea (Serpagli, 1967) and Scabbdaldea alipea (Henningsen, 1948), together with those of Amorphognathus, numerically dominate the fauna. The same dominance was already reported in the “Tonfaiszark” of the Carnic Alps (Serpagli, 1967). Tasia of the genera Phuctodina, Dichodella, Sagittodontina, Istonium and Icriodina are described and discussed for the first time for Sardinia. The conodont fauna, composed of about 13000 elements obtained by the processing of about 550 kg of limestone, includes species typical of the Mediterranean Province. Nevertheless, the extreme paucity of its markers Sagittodontina robusta Knüpfel, 1967 and Istonium erectus Knüpfel, 1967, which together represent less than one per cent. of the fauna, and the presence of other typical indicators of lower latitude affinity like Phuctodina and Dichodella reveal the mixed character of Sardinian fauna. Together with the Carnic Alps, Sardinia probably occupied an outer position of lower latitudes (compared to the typical north-Gondwanan regions of the circumpolar belt) where faunistic interchange with both the British and Baltic provinces was possible.


INTRODUCTION

Ordovician sediments deposited in Southern Europe are mostly constituted by clastic sequences interrupted at the end of the Period by a significant carbonate episode with variable thickness in different areas. The conodont fauna that has been reported from this horizon represents the cold-water “Mediterranean” fauna of high latitude (Sweet & Bergström, 1984) corresponding to the Mediterranean Province already documented on the basis of other fossil groups (Spjeldaes, 1961, 1967). This calcareous event is developed also in southern Sardinia (Italy).

Helmecke and Kok (1974), in the attempt to date the porphyroids from the Sarrabus-Gerrei area of southeastern Sardinia, listed (pp. 93-94) a few Ordovician conodonts ("Amorphognathus aff. ordovicianus, A. cf. tvaerenis, Drepanodus altipes, Drepanodus sp. and Proniodus sp.") of which no descriptions or illustrations were provided. Ferretti and Serpagli (1991) and Ferretti (1992) reported Late Ordovician conodonts from a single locality of the Iglesiente in the southwestern part of the island.

Intensive investigation carried out in the last ten years on all the Ordovician exposed in southern Sardinia has resulted in a considerable amount of new information on the occurrence and distribution of conodonts in the region (Ferretti & Serpagli, 1998). New outcrops were discovered and sampled. Only five of the fourteen areas tested all over southern Sardinia yielded conodont faunas. Some of these results have been preliminary reported in the ECOS VII Sardinia Guide-book (Ferretti et al., 1998a, b, c). In this contribution we present a global consideration of the fauna as a whole.
THE ORDOVICIAN OF SARDINIA

Southwestern and southeastern Sardinia are separated today by the Pliocene to mid-Pleistocene tectonic depression of the Campidano (Text-fig. 1) which replicates the older structure of the Sardinian Graben (=Sardinian rift) of Late Aquitanian to Early Burdigalian Age (Cherchi & Montadert, 1982; Hammann & Leone, 1997). Palaeontological and sedimentological studies have mostly dealt with these two areas individually.

Ordovician rocks are abundant in Sardinia and belong either to autochthonous or to allochthonous and/or paraautochthonous structural units.

The most important post-Sardic Ordovician autochthonous sequence (1000 m thick) of south-
western Sardinia is the Iglesiente-Sulcis sequence represented by terrigenous deposits and typical marine sediments in the upper part. Five formations (M. Argentu Fm., M. Orri Fm., Portixeddu Fm., Domusnovas Fm. and Río S. Marco Fm.), some of which subdivided in members, were introduced by Leone et al. (1991). The Late Ordovician has been known for a long time as a rich source of well preserved fossils mostly from the dark-grey very fine sandstones, siltstones and shales, having pyritic and phosphatic nodules towards the top, of the Portixeddu Formation and from the initially arenaceous and subsequently shale-marl Domusnovas Formation. Brachiopods, bryozoans and echinoderms are dominant, associated with trilobites, ostracodes, gastropods, bivalves, cephalopods, corinulits, conularids, corals, hyolithids, sponges, chitinozoans, acritarchs and graptolites.

The post-Sarrabese succession of southeastern Sardinia is represented by a lower volcanic and volcanoclastic complex overlain by an Upper Ordovician mainly terrigenous sequence with extremely subordinate limestones (Leone, 1998). Formal lithostratigraphic units were introduced by Barca and Di Gregorio (1980), Loi (1993) and Loi and Dabad (1997) in the Sarrabus area, whereas no formal subdivision of the Ordovician was ever proposed for the Gerrei, owing to the strong variability of subunits and the local facies variations attributed to an extremely variable morphology of the bottom of the basin. Late Ordovician faunas of brachiopods, trilobites, bryozoans, crinoids, cystoids, gastropods, and rare orthocone cephalopods were recovered from the Punta Serpeddi and Tuviso formations in the Sarrabus and from the informal "Rio Canoni shales" (Naud, 1979) in the Gerrei.

The Ordovician succession of the Iglesiente-Sulcis differs from that of southeastern Sardinia mostly in its lack of Middle Ordovician volcanics and in having a thick glacimarine Hirnantian succession (Leone et al., 1991; Hammann & Leone, 1997). Together with a clearly differing zircon typology and geochemistry (Loi & Dabad, 1997) this would indicate the existence of different sedimentary basins. On the other hand the strong similarities in the tectono-sedimentary development of southwestern and southeastern Sardinia undoubtedly suggest a close original palaeogeographic relationship. Furthermore, the existence in both basins of a complete Cambrian to Lower Ordovician succession and of a Middle Ordovician stratigraphic gap ("Sardin unconformity" of southwestern Sardinia and "Sarrabese unconformity" of southeastern Sardinia) reinforces the similarity with other regions of the North Gondwana "unstable shelf region" (Hammann, 1992; Hammann & Leone, 1997).

LOCATION OF THE INVESTIGATED SECTIONS

The present study focuses on Upper Ordovician rocks exposed at five different localities in western (Cannamenda and Monte Cortoglia Bocciu) and eastern (Brecca, Cea Brabetza and Umbrarutta) Sardinia (Text-figs. 1-2); more specific information on some outcrops may be deduced in Ferretti et al. (1998a, b, c). Most localities represent spot limestone occurrences in each outcrop as a result of the strong tectonic activity which affected the island during the Hercynian orogenesis; in addition many units have been biostratigraphically dated for the first time. This study involved repetitive sampling and a huge laboratory background in an often exhaustive attempt to recognize the fossiliferous levels. Only about one-third of the localities tested for conodonts provided elements, and for those, about half of the collected samples proved to be barren.

Sampling in southwestern Sardinia concentrated on the upper part of the Portixeddu Formation (locality Cannamenda) and mostly on the Punta S'Argiola Member at the top of the Domusnovas Formation (localities Cannamenda and Monte Cortoglia Bocciu, both close to the Bocciu Abis village). Levels of a dark-grey limestone (bryozoan wackestone to packstone), associated with echinoderm debris and rare brachiopods, are interbedded in siltstones for about 2.5 m at the top of the Portixeddu Formation immediately below the enrichment in phosphatic nodules. A scarce conodont fauna, nevertheless bearing a peculiar Amorphognathus species (Pl. 4, figs. 1-4), was there recovered. Bryozoans, brachiopods and chitinozoans were observed in the heavy fractions; rare ostracodes were picked in the light fraction. Brachiopod evidences suggest locating the Caradoc/Ashgill boundary within this part of the unit or immediately below (Leone et al., 1991). A thin barren level of green claystones is followed by red claystones intercalated by green to pink-red calcareous horizons, locally enriched by crinoid fragments. A 4-4.5 cm level of fine-grained pink limestone, exposed in the field in the form of scattered blocks, represents the only conodont productive part of the Punta S'Argiola Member at Cannamenda. A preliminary study on facies control over conodont distribution from this section (only about one-third of the samples were productive) was attempted by Ferretti et al. (1998b). The productive limestone is constituted by a wackestone to packstone bearing echinoderm fragments associated with trilobites, bryozoans, sponges and sponge spicules, brachiopods, gastropods, and very rare small cephalopods. Ostracodes are locally accumulated. Bryozoan-packstones and encrinitic-packstones, as well as mixed bryozoan-echinoderm packstones, were
Text-fig. 2 - Detailed location of conodont localities. CDA) Cannamenda; MCB) Monte Cortoghiana Becciu; LM) Umbrarutta; SBB) Cea Brabetta; BRECCA) Brecca.

completely barren for conodonts (Ferretti et al., 1998b).

Two brachiopod levels and one trilobite horizon were reported by Leone et al. (1991) in the Domusnovas Formation, a lower one at the base related to the Nicolella fauna (similar to the association of the Portixeddu Formation) and an upper one, with brachiopods and trilobites (attributed to the Foliomena fauna) and a cyclopygid trilobite association of deeper water. The Ashgill age of the latter level was proposed on the basis of the trilobite fauna, dominated by Cyclapige marginata (Hawle & Corda, 1847) and reinforced by brachiopods of the Foliomena fauna and members of the Proboscisambon Community.

The exposure of Monte Cortoghiana Becciu, about 1.5 km SE of Cannamenda, represents probably the lateral equivalent of the upper Cannamenda horizon. Only the lower part of a 70 cm calcareous sequence produced a poorly-preserved fauna from a wackestone to packstone almost entirely represented by crinoid debris and rare trilobite fragments, associated with brachiopods and sponges.
Three localities from southeastern Sardinia (Gerrei) produced Ordovician conodont faunas. As previously remarked, no detailed lithostratigraphic classification or formal units have been proposed for the Gerrei and the informal subdivisions of Naud (1979) are here used. Within the fossiliferous upper part of the Ordovician sequence of southeastern Sardinia ("Río Canoní shales") Naud distinguished two main facies, a typical shaley facies and a sandy calcareous shaley one, apparently associated with red to white cystoid limestones for a total maximum thickness of ten meters (Leone, 1998). Metabasites indicating submarine volcanic activity are locally interbedded (e.g. at San Basilio and Breccia; Leone, 1998).

The area of Breccia, located 4 km N of the S. Vito village, is the original site from which Helmcke and Kock (1974) reported a few conodont elements. The limestone that lies immediately above the porphyroblasts has been strongly silicified and the search for productive samples has been extremely time consuming. Nevertheless, rare thin layers of grey pure limestone, represented by a packstone of mostly crinoid fragments associated with bryozoans, brachiopods and oysters, yielded moderately well preserved conodont faunas. Inarticulate brachiopods were recovered in the heavy fraction. Helmcke and Kock (1974) reported also cystoids and solitary corals.

At the Umbrarutta locality in the Lago Mulargia area, about 3 km from the Sistrus Donigala village, dark grey limestones, mostly composed by echinoderm debris, are locally interbedded with greenish or reddish silty or sandy carbonatic shales sometimes with a typical vacuolar aspect due to the dissolution of fossils. The shales contain benthic fauna with bryozoans (which closely recall the bryozoan fauna of the Portixeddu Formation of southwestern Sardinia; Conti, 1990), crinoids and brachiopods. The limestones have been intensively tested for conodonts, but with no success. A thin dark-red silicite horizon covers the bryozoan shales and it is overlain by the conodont productive limestone, a light-grey, rarely pinkish or reddish at the base, high-calcium limestone rich in echinoderm debris and weathering to yellowish-grey. The limestone is mostly a micrite mudstone (only rarely wackestone or packstone) with fragmentary echinoderm or bryozoans and rare trilobite fragments.

The Cea Brabetza section is located 3 km from the San Basilio village. A lower coarse-grained arenaceous part (10 m thick) is covered by a 36 m thick succession of fine and coarse-grained calcarenites rich in echinoderm debris interbedded with marly-argillaceous levels. Sampling was mostly restricted to the lower eight meters where the section appeared not tectonically disturbed or decalcified. Limestones are mostly constituted by packstones to wackestones, strongly recrystallized and disturbed. Echinoderm debris is ubiquitous, rare bryozoan fragments are also visible in thin-section.

THE ORDOVICIAN CONODONT FAUNAS FROM SARDINIA

Conodonts have been obtained from 52 of 115 samples collected in the five localities. About 550 kg of limestones were processed for conodont recovery with acetic or formic acid. Extremely abundant residues were concentrated with sodium-polytungstate resulting in scarce (e.g. Cannamenda) or large heavy fractions (e.g. Cea Brabetza). A total of about 13000 elements have been recovered and their numerical representation in each sample is summarized in Tab. 1. Preservation is variable in the different sections, but the specimens are mostly fragmentary and encrusted. The material from Cea Brabetza (eastern Sardinia) is undoubtedly the worst in terms of preservation, whereas the best preserved specimens are from Umbrarutta and some levels of Breccia. The colour alteration index (CAI of Epstein et al., 1977) ranges from 4 to 6, suggesting thermal maturation in the 190-550° C range.

A total of 28 species belonging to 18 genera have been identified. Two of them are reported as morphospecies. This apparently high number of species does not reflect real high diversity of the fauna. In some sections (e.g. Cea Brabetza) the preservation of the material has resulted in an almost ubiquitous open nomenclature as specimens were either too fragmentary or too sparse to allow specific identification. Many genera (e.g. Istorinus) are present with only a few elements. Conodont productivity strongly differs in the various areas, as expressed in Tab. 1.

The A. ordovicicus Zone of Late Ordovician age has been documented in four localities both in southwestern and southeastern Sardinia. The fauna from these areas is essentially homogeneous throughout the sections, and is numerically dominated by Hamarodus europaenus, Amorphognathus (A. ordovicicus and/or A. lindstroemi) and Scabberdella altipes (Text-fig. 3). Elements of these taxa constitute together about two-thirds (74 per cent) of the whole assemblage reported in this study. Relatively abundant species are Panderodus gracilis (3 per cent) and Dapsilodus mutilatus (2 per cent). Other species, e.g. Cornodus bergstroemi and Plectodina cf. alpina, are extremely rare. Species of Plectodina, Dictyodina, Cornodus, Pseudocornodus, Sagittarionina and Istorinus are described and discussed for the first time for Sardinia. These conodont assemblages belong to the HDS (Hamarodus europaenus-Dapsilodus mutilatus-Scabberdella altipes) Biofacies of Sweet and Bergström (1984).

The conodont fauna recovered from the Cea Brabetza section differs from the Ordovician associations reported elsewhere in the island. Few elements of Drepaooidodus cf. suberectus (Branson & Mehl, 1933), Icriodina sp. s.f. and Oistodus venustus s.f.
Text-fig. 3 - Numbers of individual species recovered from the Sardinian conodont localities here investigated.
Stauffer, 1935 occur only here. Dapsilodus mutatus is slightly more abundant (about 5 per cent compared to an average value of 2 per cent in the other outcrops) and is associated with representatives of Amorpho-guathus sp. and Panderodus sp. Furthermore, Icriodella sp. and Icriodina sp. s.f. represent here about 5 per cent. of the fauna. Hamarodus europaeus is apparently missing and Scabbarrella is only questionably present. Owing to the peculiarity of such assemblage, no biofacies definition in the scheme of Sweet and Bergström (1984) is attempted; nevertheless remarkable similarities (mostly the presence of Icriodina and the absence of Hamarodus) occur with the Ashgill conodont fauna described by Paris et al. (1982) in the Calcaire de Rosan of northwest France, even if species are present with diverse frequencies.

COMPARISON BETWEEN SOUTHWESTERN AND SOUTHEASTERN SARDINIA

No significant differences in composition appear to exist between conodont faunas of the A. ordovicicus Zone recovered from southwestern and southeastern Sardinia. Some species have, in fact, been recovered only from one sector (e.g. Cornodus bergstromi) but with such sparse elements that it is not possible to establish if there exists true absence or simply lack of recovery. The faunas from the two sectors of the island only differ in productivity, the conodont assemblage from southwestern Sardinia being much more abundant (two-thirds of the whole Sardinian fauna here reported has been obtained from the material of southwestern Sardinia, which represents in weight only one-third of the whole productive limestone), and in a slightly different order of abundance of the three main species (Hamarodus europaeus, Scabbarrella alitipes and Amorphoguathus sp.) in the different sampled localities, which nevertheless always maintain a dominant role. In particular, the conodont assemblage from Umbrarutta is dominated by Scabbarrella alitipes (32 per cent) and shows a minor presence of Hamarodus europaeus (10 per cent), species which is on the contrary abundant in other areas of southeastern Sardinia (39 per cent at Brecca). Furthermore, the Umbrarutta assemblage is composed of slightly smaller-sized elements and has the highest CAl value in southern Sardinia.

The peculiar features of the Cea Brabetza fauna have been discussed above.

PALEOGEOGRAPHIC REMARKS

"North Africa and South Europe are assigned as a rule to the Mediterranean zoogeographic province which on the whole is a cold-water province of the circum-polar zone; marginal parts of this province may reach the temperate zone" (Havlíček, 1989, p. 79). The benthic fauna is far from uniform, reflecting "latitudinal-climatic control, geographic distribution, and various modes and rates of migrations of individual animal groups" (Havlíček, 1989, p. 80).

As regards conodonts, Late Ordovician provincialism has been thoroughly discussed by Sweet and Bergström (1984) and updated in terms of multielement taxonomy by Bergström (1990b). Three different provinces, Baltic, British and Mediterranean, were recognized by Bergström (1990b) inside the Atlantic Faunal Region, which is characterized by high latitude cool- to cold-water faunas. Whereas the Baltic and British provinces show many similarities, the Mediterranean is a distinctive high-latitude fauna having its markers in Sagittodonta, Iotorinus and Nondius (Bergström, 1990b; Nowlan et al., 1997). Paleogeographic reconstruction and biostratigraphic relations inside the Mediterranean Province are complicated and continental Europe is often conveniently referred to as a whole unit of high latitude located at the southern hemisphere extremity. Paris (1990b). Paris and Robardet (1990) and Robardet et al. (1990), mainly using respectively chitinozoans or the evolution of climatic features, attempted a reconstruction of relative positions of many European localities, postulating the existence in North Gondwan of a South Armorican Ocean, as a branch of the Rhaetic Ocean. Its northern margin was represented by the mid-North Armorican and Central Iberian domains (as an extension of the Moroccan and Saharan platform), the southern one by the Ebro-Aquitanian Domain, by southernmost Europe and Bohemia.

Hammann (1992) reinterpreted the distribution of many early Paleozoic areas of North Gondwana in a shelf to basin transect, recognizing a main stable shelf (including North Africa and the terranes of the Central Iberian Zone and Armorica) and an unstable shelf region (including Pyrenees, Catalonia, Montagne Noire, Sardinia, the Alps, parts of the Carpathians and large parts of Turkey) locating southwestern Sardinia in an outer shelf-to-slope transitional zone. According to the author, the South Armorican Ocean would not have existed, but was simply part of the southern Mid-European Rhaetic Ocean.

Havlíček et al. (1994, p. 24) recently reinterpreted the Mediterranean Province as a "mosaic of various terranes often largely differing from each other". They established Perunica, including the major part of the Bohemian Massif, as a separate microcontinent in the Ordovician, located between the Gondwanan and North European (Baltic) cratons, and occasionally in communication with Armorica (which, at that time, according to the authors, included Spain, France, Carnic Alps and Sardinia).

The global composition of the conodont fauna recovered in Sardinia is apparently closely similar to
that reported from other areas of the cold-water Mediterranean Province in the Late Ordovician. Nevertheless, the Sardinian fauna differs strikingly from the others in the relative proportion of the species. Sagittodonta robusta and Isterinus erectus are present in greater abundance from areas interpreted as parts of the Northern Gondwana margin. These two species are widely distributed in Spain and France (e.g. Fuganti & Serpagli, 1968; Hartvelt, 1970; Lindström & Pelhate, 1971; Cars, 1975; Weyant et al., 1977; Hafrenrichter, 1979; Paris et al., 1982; Sarmiento, 1990; Ferretti, 1992; Sarmiento & García López, 1993), and are dominant in Thuringia (32 per cent and 19 per cent respectively; Ferretti & Barnes, 1997) and Libya (45 per cent and 6 per cent respectively; Bergström & Massa, 1992). A recent conodont fauna from Bohemia (Ferretti, 1998) is too scarce to allow conclusions, nevertheless, elements of S. cf. robusta appear to also be well represented there in the Pernick Bed conodont collection (22 per cent). S. robusta and I. erectus are on the contrary almost undetectable in Sardinia (less than 1 per cent.), the former being represented mostly by very rare rainiform elements and the latter by a few specimens. In addition, these two genera have been recently reported with rare representatives also from south Wales (Barnes et al., 1998). Furthermore, typical low-latitude genera that occur fairly widely in the British Province and in the Carnic Alps, like Plectodina and Dichiodella, are also reported in Sardinia, stressing once more the links between these two European areas and their difference with other areas of North Gondwana.

The uniqueness of the Carnic Alps conodont fauna described by Serpagli (1967) was already emphasised by Sweet and Bergström (1984). The great abundance there of Hamarodus europaeus (25 per cent) and the presence of typical species like Plectodina alpina, Anella pseudorobusta, Dichiodella exilis and "Strachanognathus parvus", not reported elsewhere in continental Europe, led Sweet and Bergström (1984) to include the Carnic Alps, the Baltic Province, part of the British Province and south-central China (Pagoda Limestone) in the HDS (H. europaeus-D. miatus-S. alpina) Biofacies. Other areas of southern Europe and North Africa (Libya, Thuringia, Spain, NW France) were instead attributed to the S. robusta-S. alpina Biofacies. Ferretti and Barnes (1997) reinforced this assumption observing that the Carnic Alps have the most diversified fauna in southern Europe and that they had closer relations to more temperate faunas. On the basis of lithological and faunal data, Schönlaub (1992, 1998) inferred for the Southern Alps a paleolatitudinal position at approximately 50°S in the Late Ordovician.

The Sardinian conodont assemblage here described has indeed much in common with the Carnic Alps, having in H. europaeus (26 per cent), Amorphognathus sp. (including elements of A. ordoensis and A. linstroemii) and S. alpina its dominant components (74 per cent of the fauna). Similarly, also rare elements of Plectodina cf. alpina and Anella cf. pseudorobusta are present. The diversity of our fauna is certainly much lower than that of the Carnic collection, and many species are represented by sparse elements and incomplete apparatuses. Furthermore, another typical indicator of that fauna, Nordiodus indicus, abundant in the Carnic material (Serpagli, 1967; Bagnoli et al., 1998) and reported also from Sierra Morena in Central Spain (Fuganti & Serpagli, 1968; Ferretti, 1992) has so far not been found in Sardinia. Up to now, the presence of Nordiodus, together with the absence of Rhodosagnostus, would represent the only common features between the Carnic Alps and the Mediterranean Province. Our data would therefore suggest, even for Sardinia, a more external position of lower latitudes inside the Mediterranean Province compared to the other north-Gondwanian regions of the circumpolar belt.

Any faunistic comparison between separate geographic areas within a 4-8 million years interval (estimated duration of the Ashgill Series; Barnes, 1992) gains significance whenever this analysis involves the shortest possible time interval. The recovery of A. linstroemii (Text-fig. 4) in Sardinia and the Carnic Alps (and possibly Bohemia) allows a more precise age definition and reinforces the observations proposed above. This species has so far not been reported in the typical Sagittodonta-Scabbarrella conodont faunas from Gondwana (Thuringia, Libya, Spain, France) where the corresponding calcareous episode might be slightly older, as already suggested by Sweet and Bergström (1984).

A temperate-boreal water mass was recently suggested by Stouge and Rasmussen (1996) for the faunistic assemblage of the HDS Biofacies, which is known from a variety of lithologies and appears to be indifferent to the bottom conditions, occupying a deep shelf to marginal settings.

Text-fig. 4- Possible relationship between Late Ordovician (Ashgill) conodont provinces and biofacies (venus Sweet & Bergström, 1984; Bergström, 1990b) during the A. ordoensis Zone (including also Sardinian data). Circles indicate conodont reports with, whenever possible, relative frequencies of significant conodont taxa. Sites: IR: Ireland; SU: Sweden; IN: Italy; IT: Italy; EN: England; DE: Germany; N: North; S: South; E: East; W: West; M: Mediterranean; Gn: Gondwana; Sw: Sweden; Est: Estonia; PL: Poland; BO: Bohemia (numerical data calculated after Ferretti, 1998); CA: Carnic Alps (numerical data computed after Serpagli, 1967); SA: Sardinia (this paper); F: NW France; E: Spain (sm: Sierra Morena, ic: Iberian Chains); LF: Libya (numerical data deducted after Bergström & Missa, 1993); TH: Thuringia (numerical data calculated after Ferretti & Barnes, 1997). Conodont biofacies - LF: (R): Amorphognathus-Plectodina (Rhodosagnostus); HDS: Hamarodus europaeus-Dipoliodus miatus-Scabbarrella alpina; SS: Sagittodonta robusta-Scabbarrella alpina.
BRITISH PROVINCE

AP (R) Biofacies

EN*

IR*

W*

Plectodina

HDS Biofacies

CA*

SS Biofacies

SA*

26 0.4

21 0.02

Nordradina

ichiodina

F

E

ic

TH

Ly

0 45

23 6

He Sg

Sc Is

He: Hamarodus europaeus
Sg: Sagittodontina robusta
Sc: Scabbidella allipes
Is: Istoricus erectus
■ A. lindstroemi
* True Hirnantia fauna
In the subsequent Hirnantian stage, the temperate location of both Sardinia and Carnic Alps appears to have persisted, as suggested by the distribution of the well-known latest Ordovician Hirnantia fauna. Haviček (1990) recognized inside this brachiopod fauna two climatic belts, a belt with Plectothyrella libyca Haviček, 1973 and P. chantweli Haviček, 1971 (corresponding to the Bani Province of Rong & Harper, 1988) located in the circumpolar sphere, and a belt with Plectothyrella crassicostis (Dalman, 1828) and Kinnella kielanae (Temple, 1965) (corresponding to the Kosovo Province of Rong & Harper, 1988). The latter represents the "typical Hirnantia fauna" and reached the temperate or even the subtropical zone (Rong & Harper, 1988). P. crassicosta and K. kielanae were reported by Leone et al. (1991) in the Rio San Marco Formation of southwestern Sardinia, as well as K. kielanae was reported in the Pläcken Formation of the Austrian Carnic Alps (Jaeger et al., 1975; Schönbaur, 1980; Schönbaur et al., 1994). The existence in Bohemia, Sardinia and the Carnic Alps of a true Hirnantia fauna was preliminarily underlined by Ferretti and Barnes (1997) who attributed this occurrence to a different latitudinal/ecological response.

All data discussed above are tentatively plotted in Text-fig. 4 (the true Hirnantia Fauna being indicated by an asterisk), representing the distribution of the main conodont provinces and biofacies in the A. ordовичicus Zone inside part of the Atlantic Faunal Region. Differently from the Sagittodonta robusta-Scabbardella altipes Biofacies and from the Amorphognathus-Plectodina Biofacies, which would have characterized respectively the Mediterranean and the British Province, the Hormadus europaeus-Dapsilodus mutatus-Scabbardella altipes Biofacies appears at that time to be widespread in all three provinces (British, Baltic and Mediterranean). The British Province was also characterized by the Amorphognathus-Plectodina Biofacies (Sweet & Bergström, 1984), as also recently revealed by the preliminary study of Late Ordovician conodonts from South Wales (Barnes et al., 1998) constituted for about two-thirds by elements of Amorphognathus, Plectodina-Aphelognathus and Eucarniodus. Links between the Carnic Alps and the British Province are expressed, among other factors, by the abundance of Plectodina inside the faunas (especially the material from the Valberta Section, Bagnoli et al., 1998). The Carnic Alps are also characterized by a significant development of the genus Walliserodus. Relations between Carnic Alps and Central Spain are expressed by the common occurrence of the genus Nordiodus. Part of Sardinia (Cea Braberza) and NW France, furthermore, are linked by the recovery of Icriodina (and by the absence of Hormadus). Libya and NW France are, finally, the only two areas inside the Mediterranean Province where the A. ordовичicus fauna does not include so far elements of Hormadus.

EXPLANATION OF PLATE 1

Figs. 1-11. - Amorphognathus sp. (ordовичicus-nisistrumy Group).  
1) lateral view of Pa element; IMPU 25755, sample CDA-CA 5, x 75;  
2-3) upper views of Pa elements; IMPU 27498 and IMPU 27499, sample LM 1, x 65 and x 85 respectively;  
4) upper view of Pa element; IMPU 25790, sample LM 3, x 95;  
5-6) antero-lateral views of Pb elements; IMPU 25801 and IMPU 25758, samples LM 3 and CDA-RO (97), x 90 and x 75 respectively;  
7-8) lateral views of Sa elements; IMPU 25804 and IMPU 27500, samples LM 20 and LM 1, x 140 and x 100 respectively;  
9) antero-lateral view of Sc element; IMPU 25761, sample CDA-CA 5, x 120;  
10-11) lateral views of Sd elements; IMPU 25762 and IMPU 25807, samples CDA-GR (97) and LM 1, x 100 and x 160 respectively.

12-13) posterolateral views of M elements; IMPU 25763 and IMPU 25764, sample CDA-GR (97), x 100 both;  
14) antero-lateral view of M element; IMPU 25765, sample CDA-CA 5, x 110.

Fig. 15. - Amorphognathus lindstromi (Serpagli, 1967).

Figs. 16-17. - Cernuodus bergstroemi Serpagli, 1967. Lateral views, IMPU 25701 and IMPU 25788; samples CDA-CA 4 and CDA-CA 5, x 100 and x 140 respectively.

Figs. 18-20. - Anella cf. pseudorebusa (Serpagli, 1967).  
18-19) lateral views of M elements; IMPU 25775 and IMPU 25702, samples CDA-CA 4 and BRECCA H 4, x 105 and x 135 respectively;  
20a-b) lower-lateral and lateral views of Sa element; IMPU 25774, sample CDA-CA 5, x 115 and x 105 respectively.

Figs. 21-22. - Icriodina cf. superba Rhodes, 1953.  
21) lateral view of Pb element; IMPU 25795, sample CDA-CA 4, x 115;  
22) posterolateral view of Sa element; IMPU 25811, sample LM 18A, x 90.

Fig. 23. - Icriodina sp. Upper view of Pb element; IMPU 25705, sample CDA-97 (4), x 75.
SYSTEMATIC PALEONTOLOGY

Orders and families are mostly from Sweet (1988). All figured specimens are deposited in the paleontological collections of the Dipartimento di Scienze della Terra of the University of Modena and Reggio Emilia. Repository numbers from IPUM 25754 to IPUM 26048 denote specimens already illustrated in Ferretti et al. (1998a, b, c); numbers from IPUM 27498 to IPUM 27530 are reserved for newly figured material. The conodont fauna from southern Sardinia is composed of the species listed below:

Amorphognathus ordovicicus Branson & Mehl, 1933
A. lindstroemi (Serpagli, 1967)
A. sp. A
Anella cf. pseudorobusta (Serpagli, 1967)
Carnoecus bergrotenoi Serpagli, 1967
Dipsiplodon mutatus (Branson & Mehl, 1933)
Dioshida cf. exilis Serpagli, 1967
Dioshida? sp.
Drepanoistodus cf. subrectus (Branson & Mehl, 1933)
Hamadodus europaeus (Serpagli, 1967)
Hamadodus sp.
Icriodella cf. superba Rhodes, 1953
Icriodella sp.
Icriodina sp. s.f.
Istusinus erectus Knüpfen, 1967
Oistodus venustus s.f. Stauffer, 1935
Panderodus gracilis (Branson & Mehl, 1933)
Panderodus sp.
Plectodina cf. alpina (Serpagli, 1967)
Plectodina sp.
Pleurostodus? sp.
Pseudonoecodontus sp.
Sagittodontina robusta Knüpfen, 1967
Sagittodontina cf. robusta Knüpfen, 1967
Scabbdellida altipes (Henningsmoen, 1948)
Scabbdella? sp.
Walliserodus sp.
Walliserodus? sp.
"carriiform" element sensu Ferretti & Barnes, 1997
Indet. fragments

Systematic descriptions have been made only for poorly known taxa that are sufficiently well represented and for taxa to which significant taxonomic contributions can be presented. Illustrations are provided for all taxa; whenever possible, the same element of the apparatus has been figured from material of both southwestern and southeastern Sardinia. Synonymy is limited to references to the first description of morphospecies, first apparatus reconstruction and most recent papers, with special regards to reports from the Atlantic Faunal Region.

Order BELODELLIDIDA Sweet, 1988
Family ANSELLIDAE Fähræus & Hunter, 1985?

Genus HAMARODUS Viira, 1974

Type species – Distomodus europaeus Serpagli, 1967.

HAMARODUS EUROPAEUS (Serpagli, 1967)
Pl. 2, figs. 1-14

1955 Microcoleodus? sp. RHODES, p. 133, pl. 15, figs. 15, 19, 22.
1955 Corydolodus elongatus Rhodes - Rhodes, p. 135, pl. 7, figs. 5-6.
1959 Corydolodus n. sp. LINDBRÖM, p. 438, pl. 3, figs. 34-36.
1959 Oistodus n. sp. LINDBRÖM, p. 440, pl. 3, fig. 13.
1964 ?Neoprimoinius brevissimus n. sp. WALLISER, p. 47, pl. 4, fig. 5; pl. 29, figs. 5-10.

EXPLANATION OF PLATE 2

Figs. 1-14 – HAMARODUS EUROPAEUS (Serpagli, 1967).
1-2) lateral views of Pa elements, IPUM 25820 and IPUM 25784, samples LM 3 and CDA-CA 5, x 80 and x 70 respectively;
3-4) lateral views of Pb elements, IPUM 25821 and IPUM 25777, sample LM 3 and CDA-CA 5, x 95 and x 70 respectively;
5-6) lateral views of M elements, IPUM 25779 and IPUM 25782, sample CDA-CA 5, x 70 and x 50 respectively;
7-8) lateral views of Sa elements, IPUM 25785 and IPUM 25794, samples CDA-CA 5 and CDA-TR 3 (98), x 100 and x 115 respectively;
9-10) lateral views of Sb elements, IPUM 25786 and IPUM 25817, sample CDA-CA 4 and sample LM 20, x 95 and x 105 respectively;
11-12) lateral views of Sc elements, IPUM 25823 and IPUM 25780, samples LM 1 and CDA-CA 4, x 170 and x 95 respectively;
13-14) lateral views of Sd elements, IPUM 25824 and IPUM 25825, samples LM 1 and LM 3, x 155 and x 135 respectively.

Figs. 15-16 – HAMARODUS sp.
15) lateral view of Pa element, IPUM 25826, sample LM 1, x 60;
16) lateral view of Pb element, IPUM 25827, sample LM 1, x 75.

Figs. 17-23 – Soebbdellida altipes (Henningsmoen, 1948).
17-19) lateral views, IPUM 25705, IPUM 25706 and IPUM 25796, samples LM 1, CDA-CA 4 and CDA-CA 5, x 70, x 55 and x 50 respectively;
20-21) lateral views, IPUM 25707 and IPUM 25797, samples LM 3 and CDA-CA 5, x 60 both;
22-23) lateral views, IPUM 25798 and IPUM 25798, samples CDA-CA 5 and LM 1, x 65 and x 60 respectively.
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Remarks -- According to Orchard (1980), several elements of Rhodes' material (1955) from the Keisley Limestone belong to the apparatus of this taxon.

Dzik (1994) has renamed this species after the ramiform elements found by Walliser (1964) in the 'Berech I' of the Cellon Section from the Carnic Alps. It is highly probable that the Austrian fauna records the presence of this species so its name should be accordingly changed. However, because Nowlan (1983) and Stouge and Rasmussen (1996) inferred the existence of more than one species of Hamarodus during the A. ordovicianus Zone and keeping in mind that our material from Umbrarutta reveals unusual distacodiform elements classified as Hamarodus sp. (while no significant differences were noticed within the set of ramiform elements), we believe a different nomenclature without new complete collections available from the Cellon level to be premature.

Occurrence -- Upper Middle and Late Ordovician of Europe, China and eastern Canada.

Hamarodus sp.
Pl. 2, figs. 15-16

1998a Hamarodus sp. -- Ferretti et al., pl. 4.1.2, figs. 10-11.

Two distacodiform denticulated elements in our fauna apparently differing from the classical Pa and Pb elements of Hamarodus europaicus are briefly described.

EXPLANATION OF PLATE 3

Figs. 1-7 - Sagittodonta robusta Knüüper, 1967.
1-2) lateral views of Pa elements. IPUM 25770 and IPUM 25709, samples CDA-RO (97) and LM 1, x 75 and x 110 respectively;
3-4) antero-lateral views of Pb elements. IPUM 25831 and IPUM 25772, samples LM 20 and CDA-CA 20, x 85 and x 75 respectively;
5) lateral view of Sb element. IPUM 25771, sample CDA-CA 20, x 100;
6-7) lateral views of S4 elements. IPUM 25773 and IPUM 25833, samples CDA-RO (97) and LM 3, x 95 and x 125 respectively.

Figs. 8-9 - Plectodontina cf. alpina Serpagli, 1967.
8) lateral view of Sc element. IPUM 27510, sample CDA-TR (207), x 90;
9) lateral view of M element. IPUM 25791, sample CDA-CA 1-2, x 115.

Figs. 10 - Plectodus sp. Posterior view of Sa element. IPUM 25036, sample SBB 0, x 75.

Figs. 11, 13-14 - Dictododontia cf. ulsis Serpagli, 1967.
11) lateral view of Pa element. IPUM 27511, sample CDA-CA 5, x 75;
13) postero-lower view of Sa element. IPUM 25789, sample CDA-GR (97), x 145;
14) lateral view of Sb element. IPUM 25790, sample CDA-CA 5, x 100.

Figs. 12 - Dictododontia sp. Lateral view of Pa element. IPUM 25712, sample CMA 2, x 140.

Figs. 15-17 - Pandocius gracilis (Branson and Mehl, 1933). Lateral views. IPUM 27567, IPUM 25712 and IPUM 27513, samples CDA-CA 5, LM 1 and BRECCA H3, x 75, x 90 and x 100 respectively.

Figs. 18-19 - Isterius erectus Knüüper, 1967.
18a-b) lateral and close lower views. IPUM 27514, sample LM 1, x 130 and x 280 respectively; note the integral profile of the basal cavity of fig. 18b;
19) lateral view. IPUM 25769, sample CDA-CA 1-2, x 115.

Figs. 20-23 - Dapalodontus muticus (Branson & Mehl, 1933).
20-22) lateral views. IPUM 27515, IPUM 25809 and IPUM 25793, samples CDA-CA 20, LM 20 and CDA-CA 5, x 125, x 175 and x 125 respectively;
23a) lateral view. IPUM 27516, sample CDA-TR 2 (97), x 160;
23b) detail of the former figure, x 750.
Description – The Pa element is characterized by the strongly twisted antero-basal part and by a pronounced anterior keel running almost to the top of the cusp. Basal profile extremely sinuous. The Pb element is characterized by a well developed anteriorly directed anticusp, whose anterior margin forms an angle of about 130° with the posterior one. Basal profile quite regular, less flared in its median part than that of the equivalent Pb elements of H. europaeus.

Occurrence – Late Ordovician of southern Sardinia (Italy).

Family DAPSILODONTIDAE Sweet, 1988
Genus DAPSILODUS Cooper, 1976

Type species – Distacodus obliquicostatus Branson & Mehl, 1933.

**DAPSILODUS MUTATUS** (Branson & Mehl, 1933)
Pl. 3, figs. 20-23

1933 *Belodoides mutatus* n. sp. Branson & Mehl, p. 126, pl. 10, fig. 17.
1959 *Acodus inornatus* n. sp. Ethington, p. 268, pl. 39, fig. 11.
1959 *Distacodus procerus* n. sp. Ethington, p. 275, pl. 39, fig. 8.
1967 *Acutidus curvatus* Branson & Branson - SERPAGLI, p. 41, pl. 6, fig. 3a-c.
1967 *Acutidus mutatus* (Branson & Mehl) - SERPAGLI, p. 41, pl. 6, figs. 1a-b, 6 a-b.
1987 *Acutidus procerus* (Ethington) - SERPAGLI, p. 46, pl. 9, figs. 6-11.
1980 *Dapsilodus mutatus* (Branson & Mehl) – ORCHARD, p. 20, pl. 5, figs. 6, 15-16, 21.
1990a *Dapsilodus mutatus* (Branson & Mehl) - BERGSTROM, pl. 2, figs. 1-2; pl. 3, fig. 14; pl. 4, fig. 8.
1994 *Dapsilodus mutatus* (Branson & Mehl) - DEIK, p. 64, pl. 11, figs. 24-26, 31-35, pl. 14, figs. 8-9, text-fig. 6d.
1998 *Dapsilodus mutatus* (Branson & Mehl) – FERRETTI, p. 130, pl. 2, fig. 15.
1998a *Dapsilodus mutatus* (Branson & Mehl) – FERRETTI et al., pl. 4,1, figs. 10-11.
1998b *Dapsilodus mutatus* (Branson & Mehl) – FERRETTI et al., pl. 3,1, figs. 16-17.
1998c *Dapsilodus mutatus* (Branson & Mehl) – FERRETTI et al., pl. 1,1, figs. 19-21.
1998 *Dapsilodus mutatus* (Branson & Mehl) – BAGNOLI et al., pl. 1,2, figs. 10-11.

Remarks – Only one element of our fauna revealed the antero-aboral striations described by Orchard (1980) in his collection from the Keisley Limestone. The morphospecies Oostidus venetus s.f. Stauffer, 1935, regarded as a possible M element, is scarcely present only in one locality (Cea Brabetta).

Occurrence – Middle-Late Ordovician of Europe, North America, China and Libya.

Order PRONIODONTIDA Dzik, 1976
Family BALOGNATIDAE Hass, 1959

Genus AMORPHOGNATHUS Branson & Mehl, 1933

Type species – Amorphognathus ordovica Branson & Mehl, 1933.

**AMORPHOGNATHUS** sp. A
Pl. 4, figs. 1-4

Description – Pa elements showing, in oral view, a sinuous pattern of the bar formed by the anterior and posterior processes. The M element, typical of the species, has a long anterior aboral denticle. Anterior aboral process completely contracted. Cusp not completely discrete and slightly recurved posteriorly. The outer lateral edge of cusp seems to bear, at mid-height, an incipient barb-like denticle laterally oriented.

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**EXPLANATION OF PLATE 4**

Figs. 1-4 - *Amorphognathus* sp. A.

1a-b) lateral and upper views of Pa element. IPUM 27517, sample CDA-97 (4), x 80 both;

2) upper view of Pa element, IPUM 27518, sample CDA-97 (5) SX, x 75;

3) lateral view of Pa element, IPUM 27519, sample CDA-97 (5) SX, x 95;

4a-c) posterior, antero-lateral and anterior views of M element, IPUM 27520, sample CDA-97 (4), x 150 all.

Fig. 5 - *Dapsilodus sp.* s.f. Upper view of Pa element. IPUM 26033, sample SBB 0, x 90.

Fig. 6 - *Ierodus* sp. s.f. Upper view of Pa element. IPUM 26033, sample SBB 0, x 90.

Figs. 7-10 - *Panderodus gracilis* (Branson & Mehl, 1933). Lateral views, IPUM 27521, IPUM 27522, IPUM 27523 and IPUM 27568, samples CDA-CA 5, BRECCA H4, LM 3 and CDA-CA 4, x 75, x60, x 95, and x 60 respectively.

Figs. 11-12 - *Oostidus venetus* s.f. Stauffer, 1935. Lateral views, IPUM 26046 and IPUM 26047, sample SBB 0, x 95 and x 75 respectively.

Figs. 13-14 - *Wallcicodus* sp. Lateral views, IPUM 27524 and IPUM 27525, sample BRECCA H4, x 90 and x 105 respectively.

Fig. 15 - *Prioniodus* sp. Antero-lateral view, IPUM 27526, sample BRECCA H 4, x 90.

Figs. 16-17 - *Pseudosostenus* sp. Lateral and upper views, IPUM 27527 and IPUM 27528, samples MCB (B) and BRECCA C, x 160 and x145 respectively.

Figs. 18-19 - *carinodiform* element from Ferritti & Barnes, 1997.

18) lateral view, IPUM 27529, sample CDA-GR (97), x 110;

19a-b) lower and lateral views, IPUM 27530, sample CDA-CA 5, x 125 and x 95 respectively.
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<th>Late Ordovician Conodonts of Southern Sardinia</th>
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Tab. 1 - Numerical distribution of conodonts in productive samples from southern Sardinia. Note that the symbol * denotes overestimated.
material, and the symbol * refers to material from the Portixeddu Formation of southwestern Sardinia.
Discussion – A definite denticle anterior to the cusp is preserved in the M element of the genus *Rhodesognathus* but the cusp of our element has not the reclined aspect typical of that genus and, in spite of the scarce fauna, other elements recovered in the same sample clearly belong to the genus *Amorphognathus*.

The M element outlined above clearly differs from all other *Amorphognathus* M elements so far reported and the elements here described possibly belong to a new species.

The horizon from which the Sardinian material was recovered is close to the Caradoc/Ashgill boundary according to brachiopod and trilobite evidences (Leone et al., 1991). A documented *A. ordovicius* conodont fauna is recovered from a calcareous horizon slightly above.

**Occurrence** – Late Ordovician of southern Sardinia (Italy).

**Genus Dichodella Serpagli, 1967**

**Type species** – *Dichodella exilis* Serpagli, 1967.

**Dichodella cf. exilis** Serpagli, 1967

Pl. 3, figs. 11, 13-14

cf. 1967 *Dichodella exilis* n. sp. Serpagli, p. 63, pl. 29, figs. 9-10.


**Remarks** – Bagnoli et al. (1998), studying material from a new Late Ordovician section of the Italian Carnic Alps, equivalent to the conodont association reported by Serpagli (1967), recently considered *Dichodella exilis* S.F. Serpagli, 1967 as the Pa element of the apparatus reconstructed by Orchard (1980) and named *Birkfeldia*. In addition to the elements of the apparatus proposed by Orchard, fully supported by the Carnic collection, the morphospecies *Priomodus ethingtoni* Serpagli, 1967 could be also included in the apparatus as the Pb element.

**Occurrence** – Late Ordovician of Carnic Alps and Sardinia (Italy), Sweden and Great Britain.

ACKNOWLEDGEMENTS

We are indebted to our colleagues of Cagliari and Modena Universities who have assisted us in the repetitive field-work of these last ten years. In particular, thanks are due to Sebastiano Barca for aid in the long-time search of productive levels at Umbrautra and to Francesco Leone for sharing with us the hot days and the frequent barren sampling in the Cannamenda "desert". Thanks are extended to our friend Wolfgang Hammann for long "Ordovician" talks in the field and continuous support in every stage of this work. Readers are thanked for their careful and critical reviews of an earlier version of this manuscript.

Scanning electron microscope photographs were taken by Claudio Gentilini and all figures were drafted by Giancarlo Leonardi.

This research was supported by C.N.R. and COFIN 97 grants (resp. E. Serpagli). This report is a contribution to the IGCP Project 410 "The great Ordovician biodiversification event" and was carried out within the Agreement on Scientific Cooperation between the National Research Council of Italy and the Polish Academy of Sciences.

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(Manuscript received July 14, 1999 accepted September 10, 1999)

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