Riv. It. Paleont. Strat.	v. 98	n. 2	pp. 119-136	tav. 8-11	Settembre 1992

THE HERCYNIAN ARBURESE TECTONIC UNIT OF SW SARDINIA NEW STRATIGRAPHIC AND STRUCTURAL DATA

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Key-words: Arburese Tectonic Unit, Conodont biostratigraphy, Biosedimentology, Palaeozoic, Hercynian orogenesis, Sardinia.

Riassunto. Nuovi dati strutturali e biostratigrafici basati prevalentemente sui Conodonti hanno permesso di riconoscere tre diverse componenti entro l'unità tettonica dell'Arburese nella Sardegna sud-occidentale. Di queste sub-unità viene fornita una descrizione stratigrafica e biosedimentologica. Per la prima volta poi, alcuni piani e biozone a Conodonti relative all'intervallo Siluriano-Devoniano inferiore, sono segnalate in Sardegna.

Abstract. New structural and biostratigraphic data, mainly based on conodonts, permit the recognition of three different sub-units within the Hercynian Arburese Tectonic Unit of SW Sardinia, which are here described. Some stages and conodont biozones of Silurian-Early Devonian age are reported for the first time in Sardinia.

Introduction.

A large part of the Palaeozoic rocks widely exposed west of Campidano, known in literature as «Postgotlandiano» and regarded to be of Late Devonian and/or Early Carboniferous age (Taricco, 1922; Vardabasso, 1941; Salvadori & Zuffardi, 1955; Vai & Cocozza, 1974) are presently interpreted as belonging to a large Hercynian tectonic unit, the «Unità dell'Arburese» (Barca et al., 1982). This unit is represented by a sequence of fossiliferous sediments and volcanic low-grade metamorphic rocks ranging in age from Cambrian-Early Ordovician to Silurian-Early Devonian, thrusted over the autochthonous Palaeozoic rocks of the Iglesiente-Sulcis foreland. Strong stratigraphic and structural similarities allow correlation of this unit with the other structurally higher Hercynian tectonic units of southeastern Sardinia (Carmignani et al., 1986).

Recent investigations of the northernmost outcrops of the Arburese Unit (immediately south of Sant'Antonio di Santadi village) together with new biostratigraphic and structural evidences support the recognition of at least three minor tectonic units

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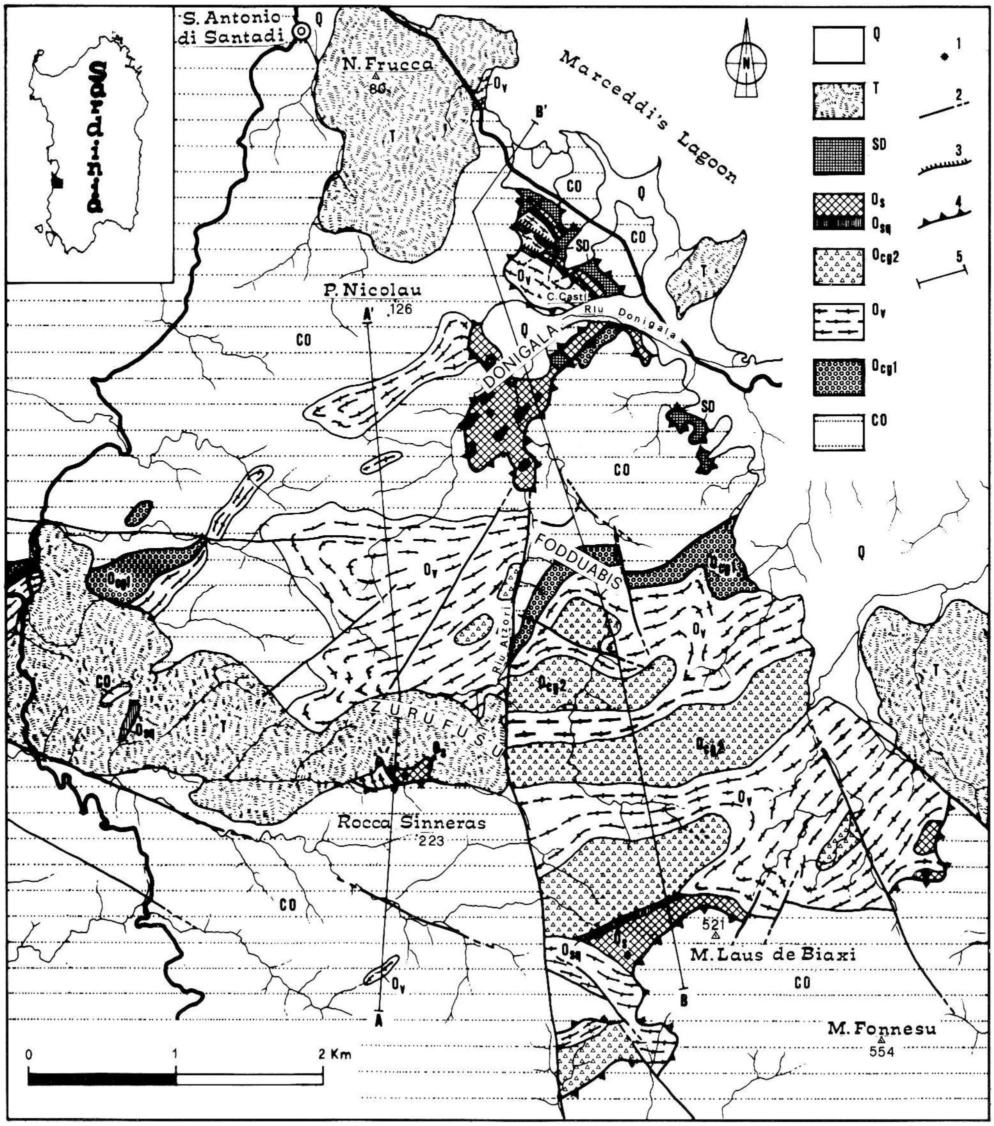

Fig. 1 - Geological sketch-map of the S. Antonio di Santadi area. CO) Cambrian-Lower Ordovician sandstones, siltstones and mudstones. Ocg1) Ordovician (pre-Caradoc) feldspatic sandstones with siltitic intercalations and conglomerates. Ov) Ordovician (pre-Caradoc) acid volcanites and volcanoclastites. Ocg2) Ordovician (pre-Caradoc) coarse clastic sediments. Osq) Upper Ordovician (Caradoc-Ashgill) coarse and mainly quartzitic detritic sediments. Os) Upper Ordovician (Caradoc-Ashgill) fossiliferous siltstones and sandstones. SD) Silurian-Lower Devonian black fossiliferous limestones and grey nodular limestones. T) Sedimentary and volcanic Tertiary rocks. Q) Quaternary deposits. 1) Fossiliferous outcrops. 2) Faults. 3) Minor overthrusts. 4) Main overthrusts. 5) Location of sections.

within the Arburese Unit. Each sub-unit is affected by low-grade metamorphism and is separated by important overthrusting surfaces marked by cataclasites. These new sub-units are, from the base to the top of the structure, the Donigala sub-unit, the S. Antonio di Santadi sub-unit and the Monte Fonnesu sub-unit (Fig. 1, 2).

A detailed stratigraphic and biosedimentologic analysis of each of these sub-units is given. In particular, some stages and biozones of the Silurian as well as the presence of the Early Devonian is documented in this area for the first time on the basis of conodonts of the Donigala sub-unit.

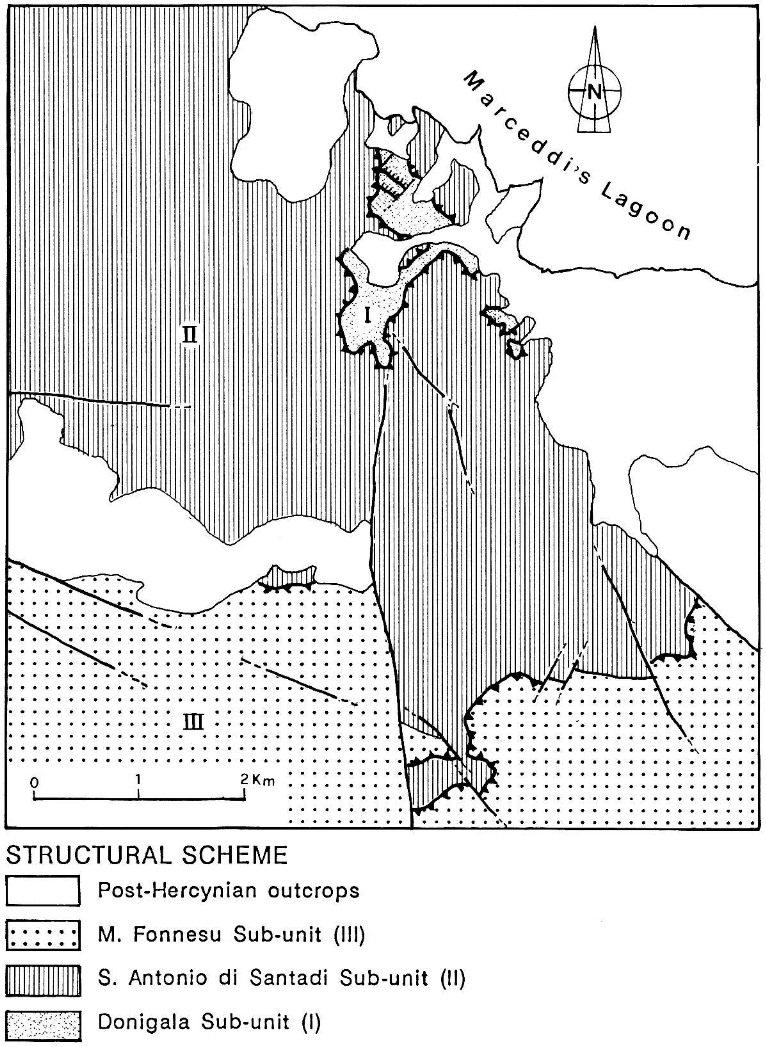

Fig. 2 - Structural scheme of the S. Antonio di Santadi area.

Stratigraphic setting.

The lithology of the different parts comprising the Arburese Tectonic Unit is here described in stratigraphic order. It will be emphasized each time which tectonic sub-unit they belong to.

Cambrian-Early Ordovician («Postgotlandiano» Auct., pars): C. O.

Rocks of Cambrian-Early Ordovician age have been recognized only in the S. Antonio di Santadi and Monte Fonnesu sub-units.

A rhythmic repetition of beds of grey-greenish micaceous sandstones and levels of grey to greenish or black siltstones and mudstones characterizes this sequence. In addition, frequent and dominant Ta-e Bouma turbiditic sequences have been recognized. Current ripples, flute casts, erosional channels and possible bioturbation (burrows and trails) are quite common at the base of the beds. The top of the sequence is always characterized by black, violet or light-green siltstones alternating with or followed by thick micaceous sandstones and quartzitic microconglomerates (such as in the Fodduabis and Bruncu is Crobus localities).

The total thickness of this sequence is difficult to establish. The base is unknown and strong Hercynian folding affected these sediments. However, we can estimate a minimum thickness of 600 metres. A submarine fan environment of deposition is inferred on the basis of the depositional features just described and the siliciclastic and mainly turbiditic nature of the unit (Vai & Cocozza, 1974; Barca & Marini, 1980; Barca et al., 1982).

Acritarchs found in the upper part of the sequence document the Tremadocian (Barca et al., 1982; Pittau, 1985), while a Cambrian age is supposed for the lower part on the basis of similarities with the San Vito Sandstones and Solanas Formation of the Sarrabus-Gerrei regions and with the shales of the Cabitza Formation in the Iglesiente area (Barca et al., 1987, 1988).

Pre-Caradocian volcanic-sedimentary complex: Ocg1, Ov, Ocg2.

This volcanic-sedimentary continental sequence is separated from the underlying sediments by a clear erosional surface.

Two distinct parts have been recognized inside this complex. The lower part (Ocg1) occurs only in the S. Antonio di Santadi tectonic sub-unit (Fodduabis locality, south of Punta Trisiois) and consists of feldspatic sandstones with silty intercalations, more or less conglomeratic arkoses and polygenic conglomerates. Thick lenticular bodies of poorly sorted macroconglomerates, bearing rounded quartz and micaceous sandstone pebbles (probably derived from the underlying Cambro-Ordovician sediments) are sometimes present at the base. Toward the top of the sequence the matrix becomes more cloritic and sericitic, and more enriched in clasts of acidic volcanites.

The whole thickness of this interval is variable, up to one hundred metres. It was probably deposited in an alluvial-fan/floodplain system crossed by river channels, where the coarser material was concentrated. These unfossiliferous coarse clastic sediments are probably the equivalent of the "Puddinga" sequence of Iglesiente-Sulcis (SW Sardinia) (Leone et al., 1991; Martini et al., 1991) and of the "Rio Ceraxa Conglomerate" (Barca & Di Gregorio, 1980) of Sarrabus (SE Sardinia), both marking an important unconformity between the Cambrian/Lower Ordovician and the Middle (?)/Upper Ordovician formations ["discordanza sarda" (Stille, 1939) and "discordanza sarrabese" (Calvino, 1961) respectively).

The upper part of both the S. Antonio di Santadi and the Donigala tectonic sub-units mainly consists of volcanoclastic deposits and rhyolitic-rhyodacitic volcanites (Ov), associated with coarse clastic sediments (Ocg2) rich in volcanic clasts. This part of the sequence, with an estimated total thickness of some hundred metres, is characterized by frequent vertical and lateral variations of the above mentioned lithotypes.

This sequence starts, in fact, with thin beds of typically light-green cineritic tuffites, locally pisolitic, bearing a variable amount of clorite. This lithology is covered by lavas and ignimbrites with intercalations of sediments derived from the subaerial erosion of the same volcanites. Lavic lithotypes, generally with a massive appearance, crop out in very limited areas. A typical porphyritic or microphyritic structure with abundant glassy or hypocristalline matrix is visible in thin sections. Ignimbritic lithotypes are massive and usually dark-green in colour. Lithic fragments are frequently included. Reworked products are quite common even if hardly recognizable in the field from the primary pyroclastites. They usually consist of poorly sorted light-green feldspatic sandstones rich in clorite and sericite, more or less conglomeratic. Coarse conglomerates with rounded pebbles of acidic volcanites are also present. Overlying rocks are represented by poorly bedded brown-greenish arkosic sandstones and macroconglomerates with rhyolitic pebbles (Ocg2) (i.e. Serra Fromigas, Gennas is Tellas localities) again suggesting an alluvial fan environment.

This sequence reveals close lithostratigraphic similarities with the pre-Caradocian volcanoclastic or volcanic complexes («Porfiroidi» *Auctorum*) of sub-alkaline to calc-alkaline affinity, extensively exposed in eastern Sardinia (Di Simplicio et al., 1974; Memmi et al., 1982; Carmignani et al., 1991).

Late Ordovician (Caradoc-Ashgill): Os.

Upper Ordovician sediments are well documented in the tectonic Donigala and S. Antonio di Santadi sub-units. They occur as a transgressive fossiliferous sequence on the volcanic-sedimentary complex just described.

The basal part of the sequence is formed by thin beds (few dms) of coarse detritic sediments with well rounded clasts and scarce siliceous matrix, light to dark-grey in colour. Quartzitic or quartzitic-feldspatic sandstones and quartzitic micro-conglomerates are the main lithologies. Ripple-marks, cross lamination and normal grading are sometimes visible. The total thickness is of a few tens metres.

The lower coarse sediments grade upwards first into dark-grey fine, massive sandstones and then into ash-grey siltstones with high and sometimes transverse schistosity.

A surprisingly quite rich fossil community of brachiopods, bryozoans, crinoids, cystoids, trilobites, corals and cornulites occurs inside the siltstones (Nicosia & Del Bono, 1956; Barca & Salvadori, 1974; Giovannoni & Zanfrà, 1979). A revision of some of these fossils is currently in progress. Most of the already known fossiliferous outcrops are parts of the Donigala sub-unit whereas the new Zurufusu locality belongs to the S. Antonio di Santadi sub-unit. Several small lenses of light-brown marly limestone, interbedded with fossiliferous siltstones, have been unsuccessfully tested for conodonts in this last area.

These sediments are regarded as typical of the inner shelf, not far below normal wave base, being more littoral in the arenaceous basal part and more offshore in the uppermost siltitic part.

The original thickness of the whole sequence is hard to evaluate because of the strong thinning related to the tangential stresses of the Hercynian orogenesis. A total thickness of about 100-150 m can be in any case inferred.

Silurian-Early Devonian: SD.

Silurian-Lower Devonian sediments, only a few metres thick, are exclusively represented in the Donigala tectonic sub-unit (Donigala and S'Ardaresusu localities) because of strong tectonic laminations. The contact with the Upper Ordovician sediments is not always exposed due to tectonic disturbances or to the presence of surface detritus. Nevertheless, a rapid passage between the two sequences can be inferred.

SAMPLES	SAD-BK												SAD		
CONODONT TAXA	01	03	1	2	3	3A	3B	4	6	7	7A	7B	19	20	21
Aulacognathus cf. *kuheni*					□										
Carniodus carnulus					□										
Dapsilodus obliquicostatus				□					□						
Kockelella absidata				□		□			□						
Kockelella variabilis		□		□							□				□
Oulodus elegans ssp. ind.													□		
Oulodus siluricus								□							
Ozarkodina bohemica bohemica				□											
Ozarkodina excavata excavata	□	□	□	□		□	□	□	□	□	□	□	□	□	□
Ozarkodina confluens			□				□	□	□						
Ozarkodina remsch. remscheidensis			□										□		
Polygnathoides siluricus							□	□	□						
Pseudoneotodus bicornis					□										
Pterospathodus amorphognathoides					□										

Tab. 1 - Distribution of conodonts in the samples of the Donigala sub-unit (SAD).

This thin deposit consists, in the lower part, of black argillaceous shales with local lenses of highly fossiliferous black limestones, marly limestones and micritic limestones. Nautiloids, bivalves (mainly cardiolids), graptolites and ostracods are by far the most common and abundant organisms in the fauna, while gastropods and brachiopods are extremely rare.

A few beds of grey nodular limestones alternate with compact dark siltstones and shales in the upper part of the sequence, bearing rare nautiloids and fragments of crinoidal stems. «Tentaculitids» are quite frequent in some samples. Gastropods, thin-shelled bivalves and trilobite fragments are also present.

Several small sections as well as single tectonically dislocated blocks (BK) have been sampled and tested for biostratigraphic and biosedimentologic analysis from the S. Antonio-Donigala (SAD) area. Conodonts revealed to be the most powerful tools for biostratigraphy. About 100 kgs of limestones were processed with normal acid techniques; the results are plotted in Tab. 1. The following forms have been recognized:

Aulacognathus cf. *kuheni* Mostler, 1967
Carniodus carnulus Walliser, 1964
Dapsilodus obliquicostatus (Branson & Mehl, 1933)
Kockelella absidata Walliser, 1964
Kockelella variabilis Barrick & Klapper, 1976
Oulodus elegans ssp. ind.
Oulodus siluricus (Branson & Mehl, 1933)
Ozarkodina bohemica bohemica (Walliser, 1964)
Ozarkodina excavata excavata (Branson & Mehl, 1933)
Ozarkodina confluens (Branson & Mehl, 1933)
Ozarkodina remsch. remscheidensis (Ziegler, 1960)
Polygnathoides siluricus Branson & Mehl, 1933
Pseudooneotodus bicornis Drygant, 1974
Pterospathodus amorphognathoides Walliser, 1964

The black limestones of the lower part were the more productive samples, yielding a fauna ranging from the *amorphognathoides* to the *siluricus* conodont zones (Latest Llandovery to Middle Ludlow). However, only three biozones (*amorphognathoides, bohemica bohemica* and *siluricus*) are clearly represented in these samples. This is probably due to the strong tectonic activity that affected the area and eliminated some parts of the Silurian sequence, probably in connection with the black shale horizons. Typical species of the *amorphognathoides* zone (Latest Llandovery) like *Pterospathodus amorphognathoides* (Pl. 10, fig. 7-10), *Carniodus carnulus* (Pl. 10, fig. 11, 12) and *Aulacognathus* cf. *kuheni* (Pl. 10, fig. 6) as well as the index-species *Polygnathoides siluricus* (Pl. 11, fig. 10-12) and *Ozarkodina bohemica bohemica* (Pl. 11, fig. 2-4) are reported for the first time in Sardinia.

The Middle Ludlovian age of one sample (SAD-BK 7) has also been confirmed by a preliminary study of the whole fossil community that bears, together with conodonts, *Entomis migrans, Cardiola docens, Slava* sp., *Mila* sp., *Arionoceras affine* and *Michelinoceras michelini.*

All these black Middle-Silurian limestones show close similarities with the coeval «*Orthoceras* limestone» of the Fluminimaggiore Fm. in SW Sardinia (Gnoli et al., 1990). They are dominated by current-oriented orthocones, with common fitting of the shells into each other (Pl. 8). Unfortunately, because of the tectonically dislocated nature of the samples, it was impossible to establish if this current was constant in time and direction. Geopetal fabrics show a common orientation (Pl. 8) and suggest no post-depositional movement of the shells before lithification took place.

Ostracodes are quite common in the matrix, together with micritized bioclasts (Pl. 9, fig. 1). Graptolites are often concentrated and packed in some samples. This faunal composition shows an obvious predominance of nektonic and planktonic organisms. Benthonic forms occur as well, but are very scarce. Recrystallization can obliterate the original composition of the matrix in some samples. The microfacies recognized in these blocks correspond exactly in time and aspect to those already described in the "*Orthoceras* limestones" of SW Sardinia (Ferretti, 1989) and therefore suggest a similar depositional environment.

Several samples of the upper nodular limestones produced no conodonts (SAD-BK 02; 8B; 20). Some others yielded only poor unrecognizable fragments or very few conodont elements mainly referable to the long ranging species *Ozarkodina excavata excavata*. Small bivalves, orthocones, crinoidal fragments, rare gastropods and trilobite fragments are scattered in these mudstones, indicating a very quiet deposition below wave-base. A mottled appearance of some limestones indicates bioturbation, but it's not frequent. "Tentaculitids" (Pl. 9, fig. 2) are well preserved in some samples.

Although conodonts are missing or not stratigraphically significant, we interpret these limestones of Early Devonian age because of their intimate lithologic and biosedimentologic similarities with the already described limestones of the Fluminimaggiore area in SW Sardinia (Gnoli, 1985).

Structural setting.

Pre-Hercynian, Hercynian and Alpidic tectonic events are documented in the whole studied area.

The stratigraphic unconformity between the Cambrian-Lower Ordovician sediments and the overlying continental volcanic-sedimentary complex can be related to an important pre-Hercynian tectonic phase, usually regarded, even if improperly, as a preliminary stage of the Caledonian orogenesis. This one is equivalent to the coeval «fase sarda» (Stille, 1939) and «fase sarrabese» (Calvino, 1961) well documented in Southern Sardinia. As in other Sardinian areas, no significant metamorphic and deformational effects referable to this phase are clearly visible in the Arburese region. According to recent hypothesis, the «fase sarda» originated from extensional movements of the continental crust of southern Europe occurring close to the Cambrian/Ordovician boundary (Marini, 1988; Delaperrière & Lancelot, 1989). Other authors, however, are inclined to regard the «fase sarda» of SW Sardinia as related to compressive tectonic events acting on a back-arc basin of a geodinamically active Gondwanian continental margin (Carmignani et al., 1991).

The Hercynian orogenesis is, in any case, responsible of the general structural setting of the Palaeozoic rocks cropping out in the Arburese region, as already evidenced by the whole Palaeozoic basement of Sardinia (Barca et al., 1982; Carmignani et al., 1986). This is documented by several folding phases and by strong tectonic transport from NNE toward SSW. A system of very large isoclinal folds, hectometric to kilometric in size, is referable to a first and strong folding phase that produced a penetrative schistosity well preserved mainly in the siltitic and argillitic lithotypes (slaty cleavage). The axial direction of these folds swings from N50 to N90 with a northward dip of 25° to 40°. The overturning direction of the first-phase folding is always toward the southern regions.

As clearly expressed in Fig. 1-4, the first-phase folding structures are always cut by important overthrusting surfaces, marked by wide outcrops of cataclasites (Carosi et al., 1990). They formed mainly in connection with the weaker horizons of the Upper Ordovician-Silurian-Lower Devonian sequence which appears, as noted above, greatly thinned or even completely destroyed. The main overthrusts produced common sequence repetitions, sometimes very thick, allowing a subdivision of the large nappe of the Arburese into the already named sub-units (Fig. 4): Donigala, S. Antonio di Santadi and M. Fonnesu.

As already expressed in the nappe zone of eastern Sardinia (Carmignani et al., 1986, 1991), the large Arburese Hercynian nappe is also affected by an imbricate fan-type structure, evidenced by a series of thrust-faults marked by cataclasites separating each sub-unit or thrust sheets.

In this structural setting, the lower Donigala sub-unit is exposed by erosional effects in a wide tectonic window (Fig. 1, 2, 3) which shows the Late Ordovician-Devonian fossiliferous sequences of the Arburese Unit. The overlying S. Antonio di Santadi sub-unit and M. Fonnesu sub-unit are made of the older Cambro-Ordovician sequences. In particular, the former is more complete and thicker than the latter, owing to the strongest erosion which affected the structurally higher M. Fonnesu sub-unit, build up almost exclusively by the oldest Cambro-Ordovician sediments (Fig. 4).

The metamorphism affecting the entire Arburese sequence is restricted to the clorite zone of the «green-schists» typical of the very high structural levels. No significant variation of metamorphic intensity has been observed in the three tectonic sub-units.

Late folding with scattered axial directions, mostly from NW-SE to NE-SW, produced wide antiforms and sinforms which generated a new folding on the first-phase structures and overthrust surfaces. However, important metamorphic deformation has not been observed. On the contrary, a fracture or crenulation cleavage is present.

The Alpidic tectonics is, finally, responsible of the three main faulting systems mapped in the area. A first one occurred with N-S direction parallel to the Oligo-Mio-

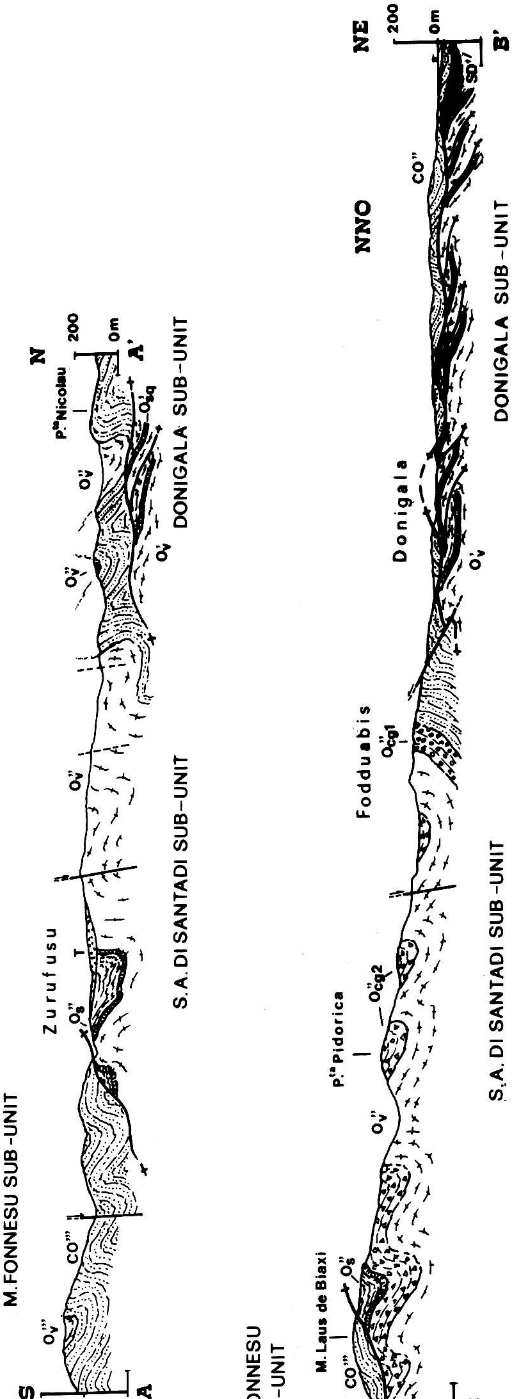

Fig. 3 - Geological sections of the S. Antonio di Santadi area.

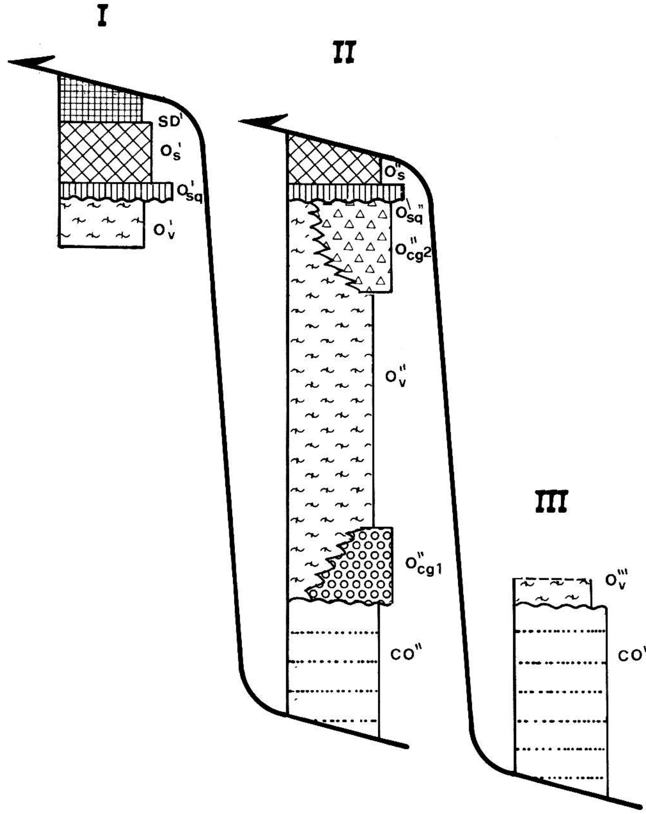

Fig. 4 - Stratigraphic columns and tectonic relation of the three tectonic sub-units within the Hercynian Arburese Tectonic Unit. I) Donigala sub-unit, II) S. Antonio di Santadi sub-unit and III) M. Fonnesu sub-unit.

cenic rift, the second with E-W direction parallel to some Oligo-Miocenic grabens normal to the main rift, and the third one with NNW-SSE direction parallel to the Plio-Pleistocenic graben of the Campidano (Cherchi & Montadert, 1984).

In addition to the main bordering faults limiting eastward the Palaeozoic mountains of Arburese from the Plio-Pleistocenic graben of Campidano, of relevance also is the presence in the mapped area of a N-S fault, coincident with the Rio Atzoris Valley (Fig. 1), which produced a shortening of the western block of at least 200 metres.

Acknowledgements.

We wish to express our gratitude to Prof. M. Gnoli and P. Rompianesi for their continuous and always fruitful assistance in the field work. Claudio Gentilini and Piero Vezzani helped us in the photographic work and Giancarlo Leonardi in the graphic work. They are deeply thanked. Field, laboratory and printing expenses were supported by grants of MURST (resp. Prof. S. Barca and Prof. E. Serpagli) and by the EEC in the context of the project «Silurian ecostratigraphy in Ireland and Sardinia».

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PLATE 8

Highly fossiliferous black limestones showing cross-sections of current iso-oriented orthocones and geopetal fabrics. Note the frequent telescoping of the shells (SAD-BK 7A; 3 x). Middle Silurian (Wenlock-Ludlow).

PLATE 9

Fig. 1 - Ostracodes and micritized bioclasts packed inside a nautiloid shell. Black cephalopod-limestones (SAD-BK 3A; 15 x). Middle Silurian (Wenlock-Ludlow).

Fig. 2 - "Tentaculitid"-wackestone; nodular limestone belonging to the Donigala sub-unit (SAD 20; 15 x). Early Devonian.

PLATE 10

Fig. 1, 2 - *Kockelella variabilis* Barrick & Klapper, 1976.
1) Upper view of Pa element. SAD-BK 2; 100 x.
2) Lateral view of M element. SAD-BK 7A; 85 x.

Fig. 3-5 - *Ozarkodina excavata excavata* (Branson & Mehl, 1933).
3,4) Lateral views of Pa elements. SAD-BK 03 and BK 6; 120 x and 60 x.
5) Lateral view of M element. SAD-BK 7A; 85 x.

Fig. 6 - *Aulacognathus* cf. *kuheni* Mostler, 1967.
Lateral view. SAD-BK 3; 60 x.

Fig. 7-10 - *Pterospathodus amorphognathoides* Walliser, 1964.
7) Upper view of Pa element. SAD-BK 3; 80 x.
8) Lateral view of M element. SAD-BK 3; 110 x.
9,10) Lateral views of Pb elements. SAD-BK 3; 85 x.

Fig. 11, 12 - *Carniodus carnulus* Walliser, 1964.
11) Lateral view of Pb element. SAD-BK 3; 110 x.
12) Lateral view of Sb element. SAD-BK 3; 110 x.

PLATE 11

Fig. 1 - *Ozarkodina confluens* (Branson & Mehl, 1933).
Lateral view of Sc element. SAD-BK 6; 120 x.

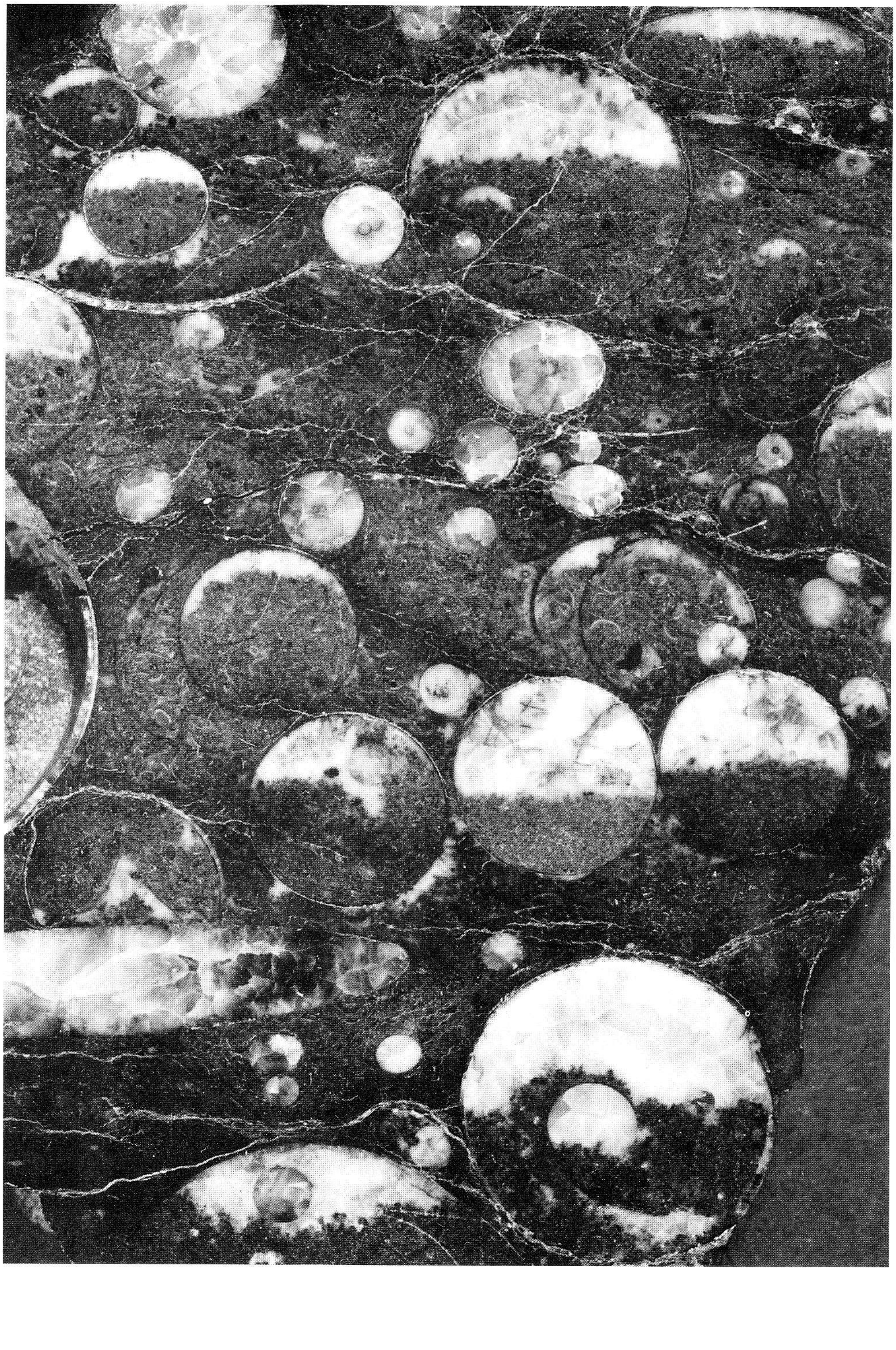
Fig. 2-4 - *Ozarkodina bohemica bohemica* (Walliser, 1964).
2) Lateral view of Pb element. SAD-BK 2; 120 x.
3, 4) Lateral views of Pa elements. SAD-BK 2; 120 x.

Fig. 5, 6 - *Kockelella absidata* Walliser, 1964.
5) Lateral view of Pa element. SAD-BK 6; 85 x.
6) Posterior view of M element. SAD-BK 6; 50 x.

Fig. 7 - *Oulodus elegans* ssp. ind.
Antero-lateral view of Pb element. SAD 19; 120 x.

FIg. 8, 9 - *Ozarkodina confluens* (Branson & Mehl, 1933).
8) Lateral view of Pa element. SAD-BK 1; 85 x.
9) Lateral view of Pb element. SAD-BK 4; 85 x.

Fig. 10-12 - *Polygnathoides siluricus* Branson & Mehl, 1933.
10) Lateral view of Pb element. SAD-BK 4; 65 x.
11, 12) Upper views of Pa elements. SAD-BK 3B and SAD-BK 4; 50 x and 85 x.



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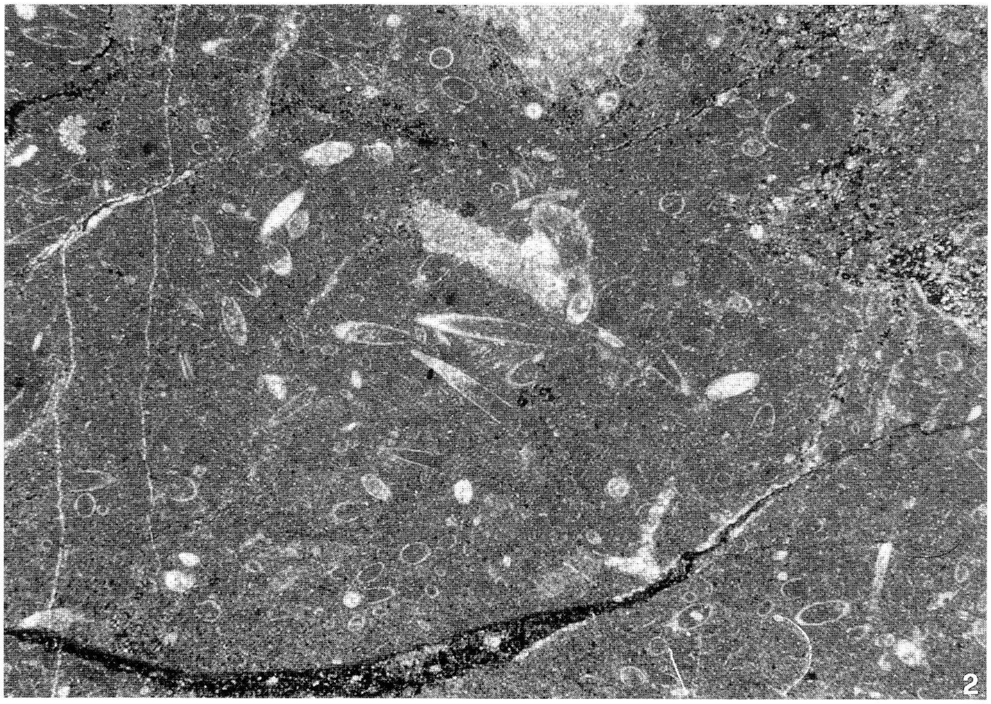

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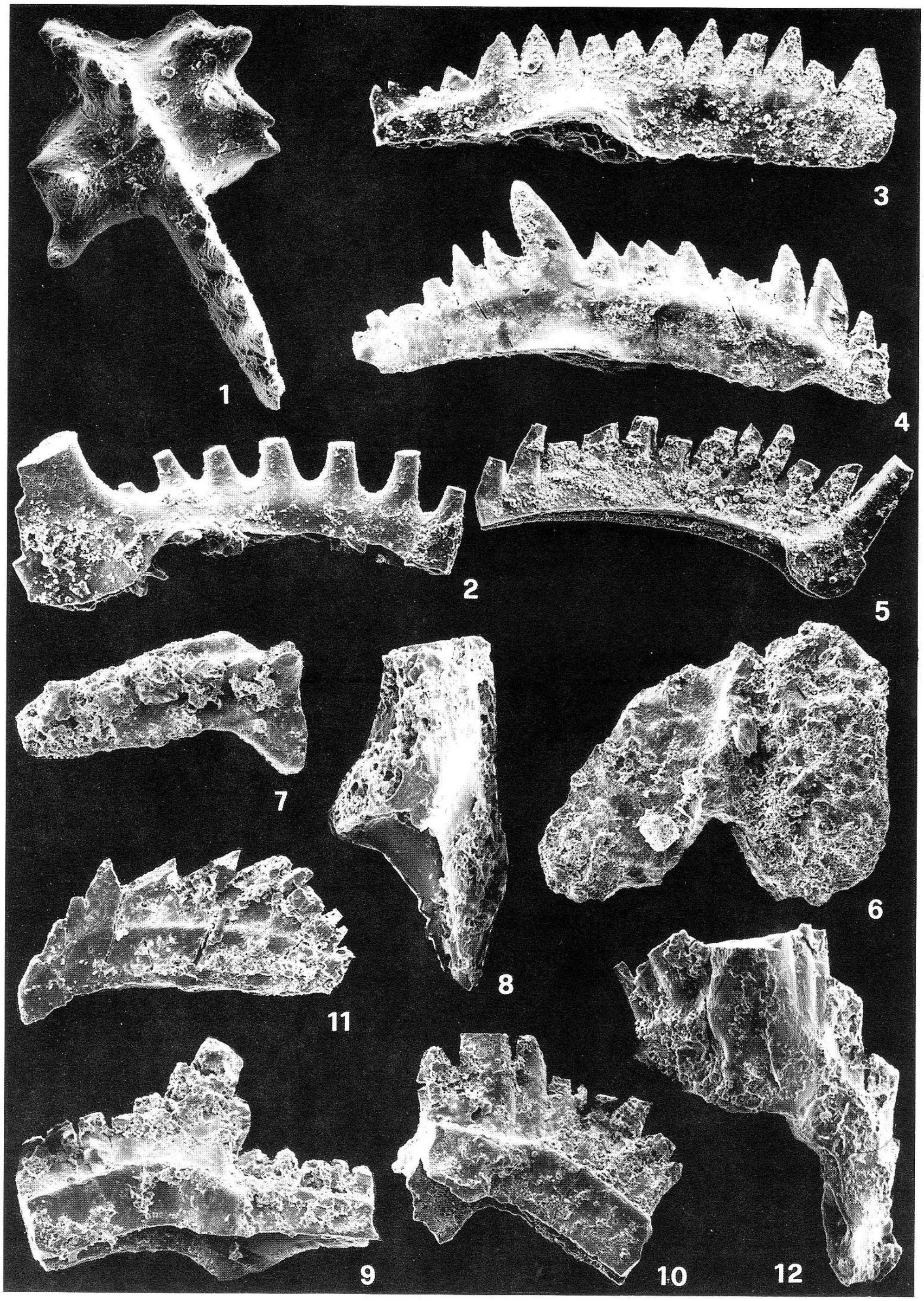
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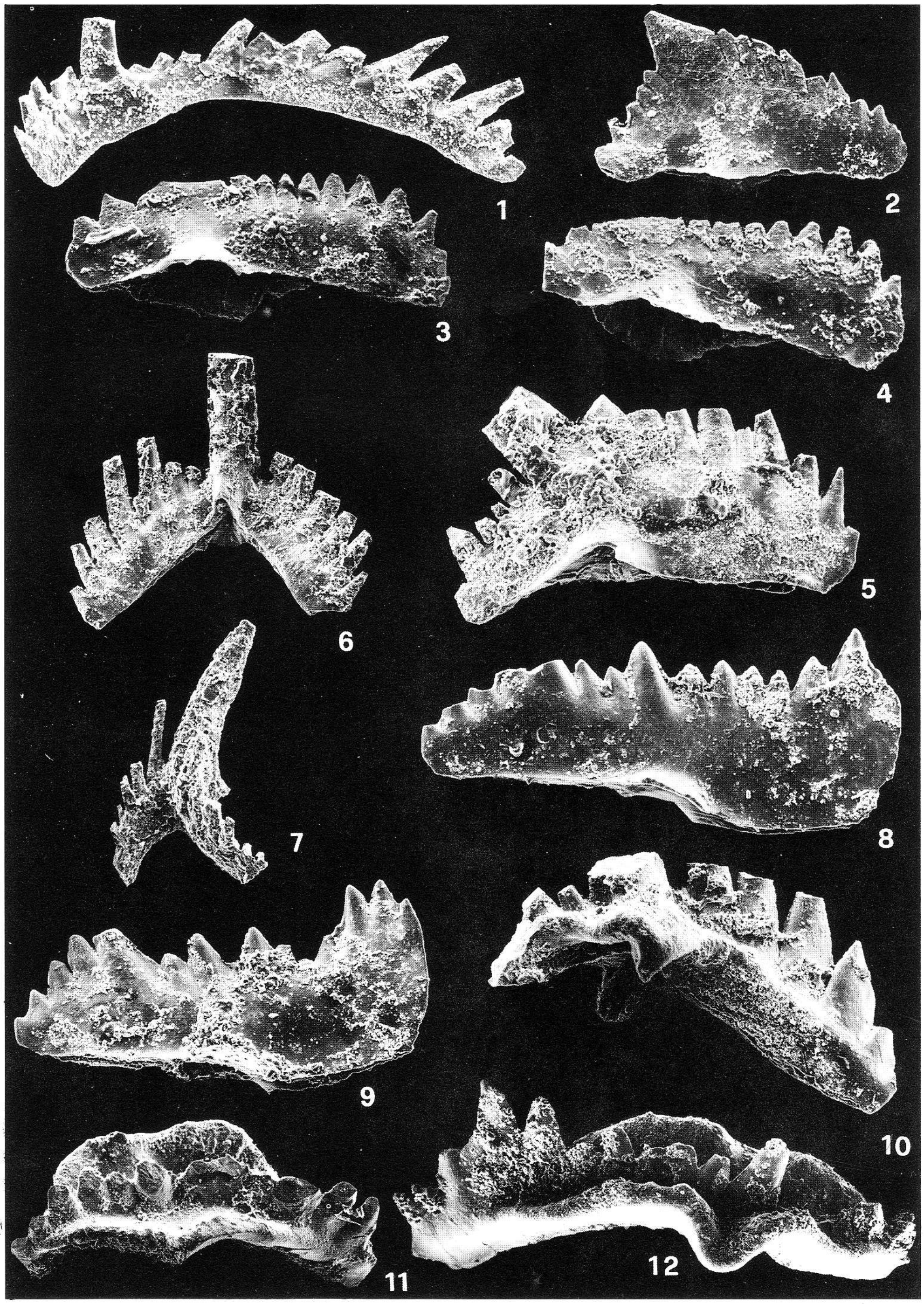

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