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Cambrian microfauna and palaeoecology of the Campo Pisano Formation at Gutturu Pala (Iglesiente, SW Sardinia, Italy)

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ABSTRACT – The microfossil content of nodular limestones of the late Early to Middle Cambrian Campo Pisano Formation from the Gutturu Pala section of southwestern Sardinia is described and discussed with respect to palaeoecological conditions. Based on detailed facies investigations, the vertical succession of the sedimentary evolution and fossil distribution is interpreted as an environmental change from shallow-subtidal conditions at the beginning of the Campo Pisano Formation to at least deep-subtidal conditions at its end. Due to the faunal characteristics, an interim shallowing during that process is likely.

A dramatic facies replacement with the onset of the Campo Pisano Formation indicates a strong reorganisation of the environment, explained by tectonic instability of the platform, accompanied by moderate relative sea-level rise and palaeogeographical and maybe climate changes. During most of the time, the persistence of only one palaeoecological assemblage indicates a more or less stable, open marine, deeper subtidal environment for most of the Campo Pisano time.

Among the taxa represented in the highly fossiliferous sediments, trilobites, echinoderms, brachiopods, and poriferids predominate; further elements are cancellorids, hyolithids, pelagiellids, hyolithelminthids, and bradoriid arthropods. This occurrence in the Campo Pisano Formation is published here for the first time. The following bradoriid and trilobite species are newly introduced: *Hipponicharion ichnusum* n. sp., *Condylopyge antiqua* n. sp., and - described in open nomenclature - *Clavigellus?* n. sp.

RIASSUNTO – [Microfauna cambriana e paleoecologia della Formazione di Campo Pisano nella sezione di Gutturu Pala (Iglesiente settentrionale, Sardegna)] – I microfossili contenuti nei calcari nodulari del Cambriano inferiore sommitale e medio della Formazione di Campo Pisano della sezione di Gutturu Pala, Sardegna sud-occidentale, sono descritti e discussi in relazione alle condizioni paleoecologiche. Sulla base di dettagliate analisi di facies, dell'evoluzione sedimentaria e della distribuzione dei resti fossili, la successione verticale è stata interpretata in termini di variazioni ambientali che indicano condizioni sub-tidali poco profonde alla base della Formazione di Campo Pisano fino a condizioni sub-tidali profonde (probabilmente anche molto profonde) alla sommità della stessa formazione. Le caratteristiche delle faune suggeriscono inoltre la presenza di un episodio intermedio correlabile con un sensibile abbassamento del livello marino.

La drastica sostituzione di facies, che segna l'inizio della Formazione di Campo Pisano, indica una imponente riorganizzazione degli ambienti. Ciò è spiegabile innanzitutto con l'instabilità tettonica della piattaforma, alla quale si accompagnano un moderato innalzamento del livello marino e variazioni climatiche indotte dall'assetto paleogeografico. La persistenza, durante un ampio intervallo temporale, di una sola associazione paleoecologica, indica che la deposizione della maggior parte della Formazione di Campo Pisano sia avvenuta in un ambiente marino aperto, sub-tidale profondo, più o meno stabile.

Fra i gruppi di organismi rappresentati nei sedimenti riccamente fossiliferi predominano trilobiti, echinodermi, brachiopodi e poriferi; sono inoltre presenti componenti minori quali cancelloridi, hyolithidi, pelagiellidi, hyolithelminthidi e bradoridi. La presenza di molti di essi nella Formazione di Campo Pisano è pubblicata per la prima volta in questo articolo. Sono state inoltre istituite formalmente due nuove specie, *Hipponicharion ichnusum* n. sp. e *Condylopyge antiqua* n. sp., appartenenti rispettivamente agli ostracodi bradoridi e ai trilobiti agnostidi, mentre una nuova specie di trilobiti corynexochidi, attribuita a *Clavigellus?* n. sp., è stata lasciata in nomenclatura aperta.

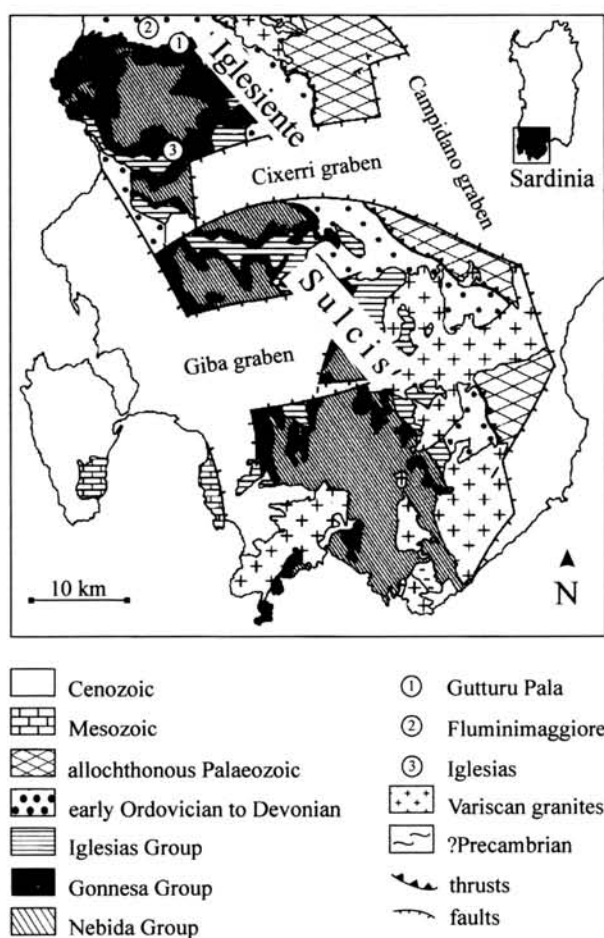
INTRODUCTION

In southwestern Sardinia (Text-fig. 1) autochthonous Cambro-Ordovician sediments crop out in the Iglesias and Sulcis area (summary monograph: Bechstädt & Boni, 1994). The Cambrian succession within this suite is under investigation since the 19th century. Whereas the early work was mainly focused on palaeontological topics (e.g. Bornemann, 1886, 1891; Meneghini, 1888), research changed later to sedimentological, facies and other interests.

The entire Cambrian succession has a thickness of about 2000 m and indicates an evolution from a clas-

tic shelf environment (Nebida Group) to an isolated carbonate platform (Gonnesa Group) followed by the drowning and cover of the platform by siliciclastic sediments (Iglesias Group; Text-fig. 2).

The Nebida Group (Early Cambrian) consists of a basal siliciclastic portion with local calcimicrobial-archaeocyathan buildups (Matoppa Formation) and an upper alternation of shallow marine siliciclastic deposits and carbonates (Punta Manna Formation). The overlying Gonnesa Group (Early Cambrian) is completely composed of carbonates: whereas the lower part (Santa Barbara Formation) is mainly represented by dolostones, the higher part consists of



Text-fig. 1 - Geological map of southwestern Sardinia (modified after Bechstädt *et al.*, 1988) with indication of the working section at Gutturu Pala locality.

limestones (San Giovanni Formation). The youngest unit of the Sardinian Cambrian is the Iglesias Group (uppermost Early Cambrian to Early Ordovician), showing a carbonate basal part (Campo Pisano Formation) and a siliciclastic upper part (Cabitza Formation) that continues into the Early Ordovician (Text-fig. 2).

During the last decades, there was an intensive sedimentological and palaeontological work focused on the Early Cambrian units, e.g. the archaeocyaths were investigated by Debrenne, Perejón, Moreno-Eiris and colleagues, the trilobites by Rasetti and Pillola, and the sedimentary facies mainly by Cocozza, Gandin, and by the working group of Bechstädt and Boni. A summary of the palaeontological, sedimentary and facies investigations on the Sardinian Cambrian, as well as an extensive list of publications was published by Pillola (1991) and Bechstädt & Boni (1994).

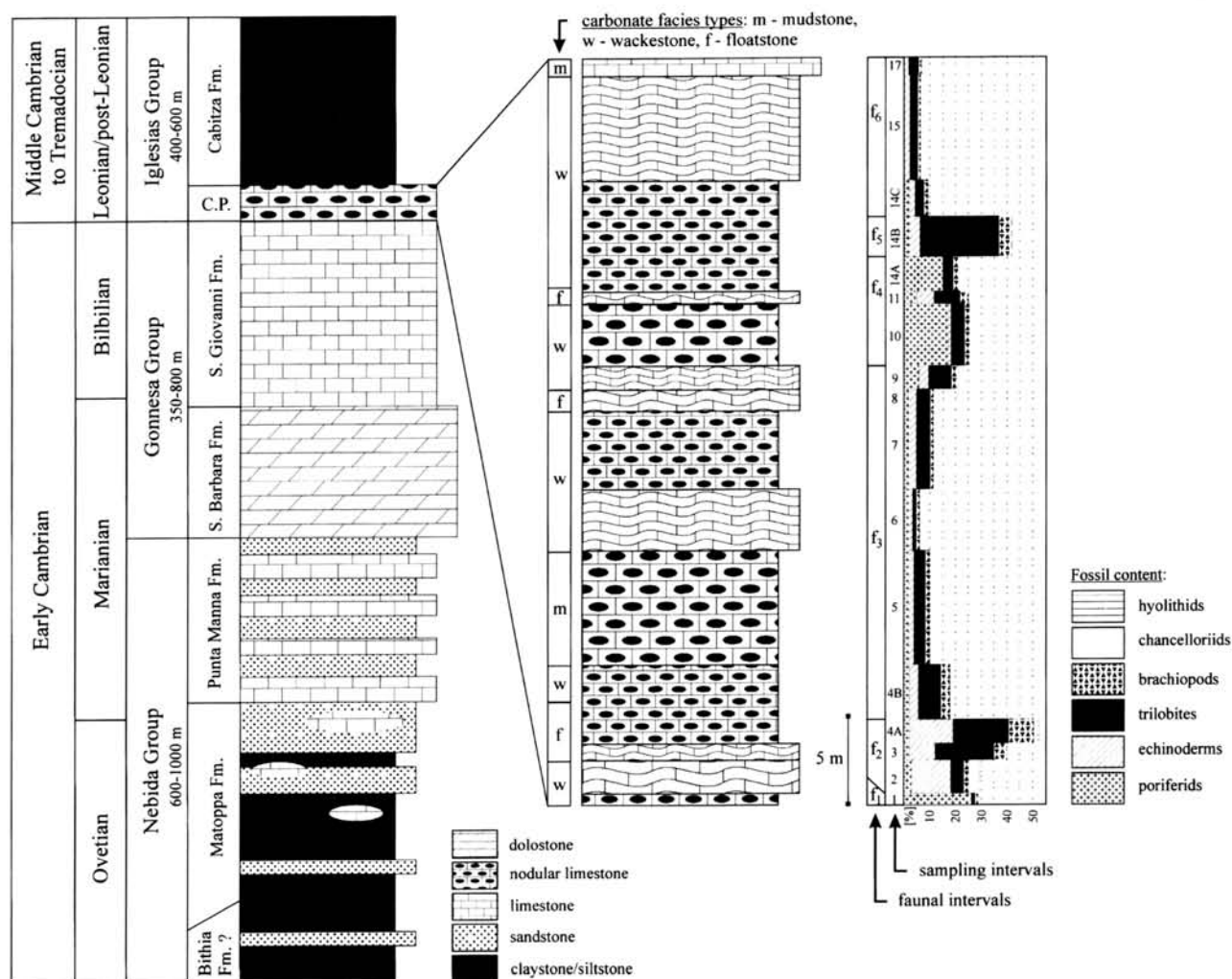
The uppermost Early Cambrian to Early Ordovician Iglesias Group has received only little

detailed study. Investigations on this unit were focused in rather subordinate aspects of work on the whole Cambrian succession or on special palaeontological remains. Following that work, the lower unit (Campo Pisano Formation) represents a condensed carbonate succession consisting of more or less nodular silty limestones (Loi *et al.*, 1995). The origin of the nodularity was interpreted by Gandin (1979) and Cocozza & Gandin (1990) as due to compaction and early dissolution processes on a tectonic instable and morphological differentiated shelf. These authors compare this nodular facies to the Jurassic "Ammonitico Rosso". In contrast, Elicki (2001) presented arguments for a deposition in a morphologically rather low diversified subtidal shelf environment. After that author, the nodular texture of the Campo Pisano Formation is a result of complex late diagenetic processes. Palaeontologically, the Campo Pisano Formation was never subjected to intensive investigation until recent years. Sporadic works came from Cherchi & Schroeder (1984, foraminifera and problematica), from Mostler (1985, poriferids) and from Pillola (1991, trilobites). Since the middle of the 90's, the microfauna of the Campo Pisano Formation is under investigation by the Freiberg University working group. Hitherto, some work on the so-called "small shelly fossils" is already published by Elicki (2002), Elicki *et al.* (2003) and Elicki & Wotte (2003). A number of further publications from there are in progress.

Regarding the higher part of the Iglesias Group (Cabitza Formation), some newer work is on the biostratigraphy and sedimentology of this siliciclastic unit. Loi *et al.* (1995) were able to subdivide this portion by trilobites and graptolites into six different biostratigraphic levels reaching from the early Mid-Cambrian to the Early Ordovician (Caesaraugustian to Tremadocian). The depositional environment following the Campo Pisano carbonates is interpreted by different authors as a deeper basin setting based on sedimentological and taphonomic characters (Gandin *et al.*, 1987; Cocozza & Gandin, 1990; Loi *et al.*, 1995). For the late Mid-Cambrian to the Tremadocian higher Cabitza Formation, in contrast, a relatively shallow environment was interpreted by Loi *et al.* (1995) because of typical sedimentary features.

The aim of this paper is to present for the first time the microfauna of an entire section of the Campo Pisano Formation, which was attained by chemical preparation and by thin sections, and to discuss their palaeoecological relevance.

The palaeontological specimens described and figured herein are housed at the Geological Institute of Freiberg University (archive number 536), despite the trilobite material, which is at Dipartimento di Scienze della Terra (Cagliari University; acronym DSTCP 23).



Text-fig. 2 - Geological column of the Cambrian succession of southwestern Sardinia and of the Campo Pisano Formation at Gutturu Pala. On the right: fossil content, sampling horizons and faunal ranges are shown for each level.

THE SEDIMENTARY SUCCESSION OF THE CAMPO PISANO FORMATION AT GUTTURU PALA

The Gutturu Pala locality, where the here reported fauna comes from, is an abandoned sulphide-ore mine situated in the northern Iglesiente area about 4 km southeast of Fluminimaggiore (compare Text-fig. 1). The late-diagenetic to epigenetic pre-Variscan mineralization (Boni & Balassone, 1994) has taken place within the massive carbonates of the San Giovanni Formation (Gonnesa Group), the overlying Campo Pisano Formation, interesting here, is effected only locally at its base. The whole sedimentary succession at Guturru Pala (thickness is about 46 m) is tectonically tilted, so that the stratification is more or less vertical today. On the top of the Campo Pisano Formation, the siliciclastic sediments of the Cabitza Formation follow gradually.

The colour of the Campo Pisano limestones at Gutturu Pala is mostly red or light-red, only occasionally light-grey colours occur, while dark facies occurs at the base of the lithostratigraphic unit. Near the transition to the overlying Cabitza Formation, light-greenish/yellowish colours were observed. The colours are bound to clay minerals, but show no distinct distribution pattern over the profile. After testifying 13 samples (GP 1 to GP 14) for the clay/quartz content, there is no very strong correlation between colour and clay amount or between occurrence of biota/biofacies and clay content, but it seems to exist an indefinitely trend that the redder the rock colour the higher the clay content. So, the colour may represent a proxy of the siliciclastic input, but more extensive investigation is needed to verify this indication. Generally, the clay content of the samples is less than 10% (averaged 6%). Much fewer is the quartz

content: only in some horizons an amount of less than 1% was detected. X-ray investigations carried out in this section (Lecca *et al.*, 1983) revealed the occurrence of quartz, chlorite, illite and Fe-oxides.

Carbonate microfacies types of the Campo Pisano Formation are generally very rich in mud and include mostly wackestones, subordinately mudstones and floatstones. As the siliciclastic content, the carbonate facies types show no distinct vertical pattern of distribution.

The most conspicuous feature visible in the field is the nodular texture of large portions of the section. This diagenetic nodularity is typical for many (not for all) of the Campo Pisano sections (Pl. 1, fig. 1). The intensity of the nodular texture seems to depend on a distinct minimum content of clay. So, a distinct nodularity was observed at Gutturu Pala only in limestones showing a clay content more than about 6%; in contrast, there are also (but rare) limestones with a relatively high clay content (8.5%) which are hardly nodular (e.g. at the transition to the overlying Cabitza Formation). Most of the limestones at Gutturu Pala are more or less wavy to bulbous by origination of diagenetic nodules (by pressure solution), which are separated from each other by accumulative seams of non-soluble material. There is no detectable correlation between the degree of nodularity and the occurrence of carbonate microfacies types or the fossil content.

Sedimentary features (e.g. erosive surfaces, cross-bedding, grading, ripples, and bioturbation) were not observed. Whereas the transition from the underlying massive limestones of the San Giovanni Formation (Gonnesa Group) to the Campo Pisano Formation (Iglesias Group) is rather distinct and sharp, the transition of the Campo Pisano Formation to the overlying Cabitza Formation is gradual over a permanent increase of the clay content and a small alternation of limestone and claystone within the last few decimetres of the Campo Pisano Formation.

PALAEONTOLOGY

To obtain pristine data, for fossil biodiversity estimations solely thin-section investigations were used. Chemical extracted fossils were exclusively used for taxonomic work.

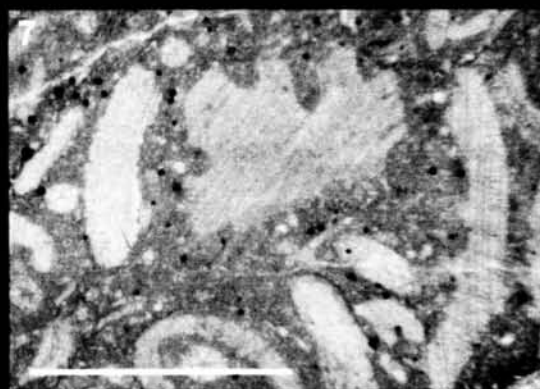
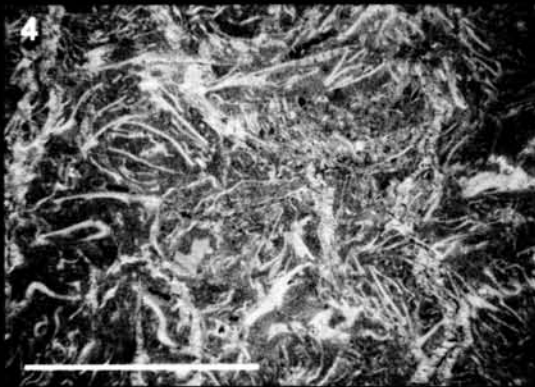
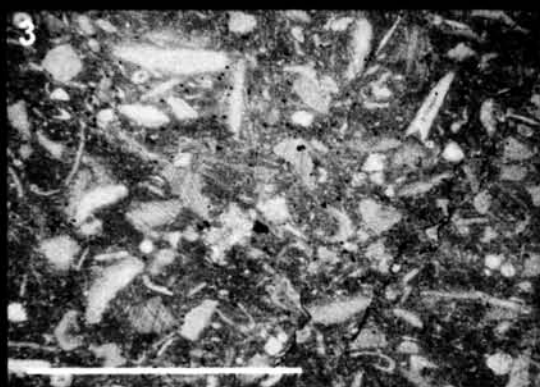
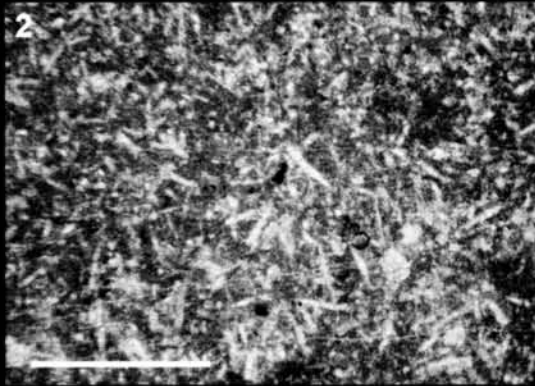
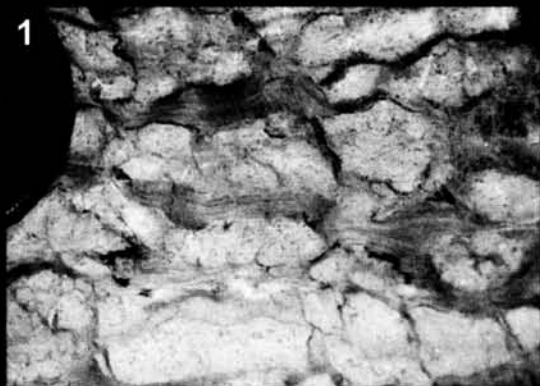
During our investigation the following groups of organisms were observed from the Gutturu Pala section:

many:	trilobites, echinoderms, brachiopods, poriferids.
moderate:	chancelloriids, hyolithids.
rare:	hyolithelminthids, bradoriids, pelagiellids.

Generally, the preservation of microfossils at Gutturu Pala is not uniform. Numerous specimens were silicified during diagenesis (e.g. the trilobites and many of the brachiopods). Other taxa are preserved by original phosphate mineralogy (e.g. hyolithelminthids, bradoriids, some brachiopods). Most of the fossils are disarticulated, but they do not show signs of significant intensive or long-time transport processes (no abrasion, solution, borings). So, broken individuals are not common until the end of the Campo Pisano Formation. At the beginning of the Campo Pisano Formation, the fauna is clearly dominated by sponge spicules (= fauna 1, level GP1; Pl. 1, fig. 2). Only very seldom, some single echinoderm plates, trilobite remains or small brachiopods, bradoriids or hyolithelminthids occur. This basal part of the Campo Pisano Formation is overlain by an assemblage with a distinct higher amount on echinoderm and trilobite remains (= fauna 2, level GP2-GP4A; Pl. 1, fig. 3). Also brachiopods, chancelloriids and hyolithids occur. Fauna 3 (level GP4B-GP9) succeeds, consisting qualitatively of the same content, but showing different quantitative proportions: echinoderms and trilobites decrease significantly. The following fauna 4 (level GP10-GP14A) is characterised by a distinct increase of sponge remains. So,

EXPLANATION OF PLATE 1

- Fig. 1 - Typical nodular texture of the Campo Pisano Formation. Camera lid for scale.
 Fig. 2 - Spiculite facies in thin section at the base of the Campo Pisano Formation. Level GP1. Scale bar = 1 mm.
 Fig. 3 - Echinoderm facies in thin section. Level GP3. Scale bar = 1 mm.
 Fig. 4 - Very fossiliferous trilobite facies in thin section. Level GP14B. Scale bar = 1 mm.
 Fig. 5 - Four-rayed (4+0, only three preserved) chancelloriid sclerite in thin section. Dark internal sediment is typical for the preservation of these remains. Level GP3. Scale bar = 1 mm.
 Fig. 6 - Chancelloriid rosette in thin section showing horizontal and vertical rays (8+1) and trilobite remain. Level GP2. Scale bar = 1 mm.
 Fig. 7 - Disarticulated echinoderm elements in thin section. Middle of photograph: polygonal thecal plate with typical marginal inlets (epispines). Level GP2. Scale bar = 1 mm.
 Fig. 8 - Disarticulated echinoderm element. Same sample as for Pl. 1, fig. 7. Note the preservation of the net-like stereom. Level GP2. Scale bar = 1 mm.



this fauna is quite similar to fauna 1 with the difference that the trilobite content is higher in fauna 4. The overlying fauna 5 (level GP14B) shows a distinct decrease of poriferids and an increase of trilobites (Pl. 1, fig. 4). So, the fauna 5 is similar to fauna 2, but shows fewer echinoderms and no cancelloriids and hyolithids. The youngest faunal association of the Campo Pisano Formation at Gutturu Pala (= fauna 6, level GP14C-GP17) shows a distinct decrease of all faunal element and resembles fauna 3 in its quantitative proportions.

Summarizing, the biofacies succession within the Campo Pisano Formation at Gutturu Pala can be interpreted as two similar patterns (portions) from fauna 1 via fauna 2 to fauna 3 and, respectively, from fauna 4 via fauna 5 to fauna 6. If these successions indicate a trophic or a palaeoecological change or a changing of habitats and environments will be discussed below.

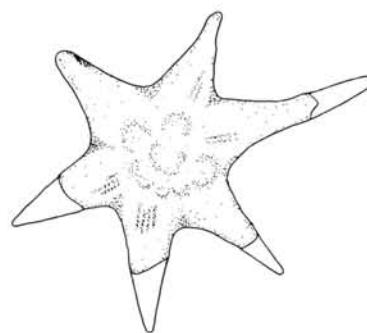
In many cases, systematic palaeontological investigation on the material attained by chemical preparation or observed in thin sections is not possible. So, the very rare hyolithids (Pl. 2, figs 3-4) are only fragmentary preserved because of the preparation procedures. The same is for the echinoderms: as well in thin sections (Pl. 1, figs 5, 7-8) as in result of the chemical preparation (Pl. 2, fig. 11), the echinoderm (eocrinoid) remains are represented by disarticulated (but not abraded) plates and so, useless for systematics. Also, the only remain of a stone-core of a pelagiellid mollusc is relictic. Nevertheless, from other sections of the Campo Pisano Formation pelagiellids have recently been described (Elicki, 2002) – all observed specimens came from the same level near the base of the Campo Pisano Formation and belong to only one species: *Pelagiella subangulata* (Tate, 1892). The problematic pelagiellid remain from Gutturu Pala comes from a stratigraphic comparable interval (GP2-level).

A special point represents the brachiopods. Many specimens were attained by chemical preparation. After first observation it seems that only very few lingulid and acrotretid species (Pl. 2, figs 5-10) represent the rather monotonous brachiopod fauna (friendly personal communication by Michal Mergl, Plzeň/Czechia).

The main microfossil content and those which allowed a systematic approach are briefly described here.

PORIFERIDS

The occurrence of sponge spicules at Gutturu Pala is very patchy (Pl. 1, fig. 2; Pl. 2, figs 13-22). Those remains predominate clearly at the lowermost part of the Campo Pisano Formation (25%, level GP1), but they decrease dramatically after some decimetres (to 1-2%). A second maximum of the spicule content occurs at level GP10/GP14A interval (about 15%).



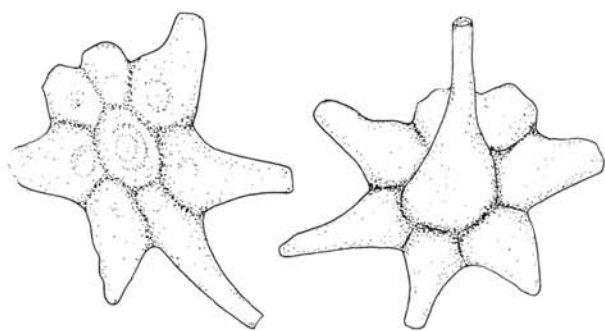
Text-fig. 3 - Completed redraw of *Eiffelia araniformis* (Missarzhevski, 1981), compare Pl. 2, fig. 14. Level GP2; max. diameter: 0.8 mm.

The remains are badly preserved and mostly represent siliceous hexactinellids and secondary phosphatised heteractinids. In some cases, it is not sure to decide if the remain represents a single needle or a broken part from a more complex spicule (Pl. 2, fig. 15). This is especially the case for some "monaxons" and cruciform "tetractins" (?stauractins of lyssakid porifera), which occur upwards in the section (level GP15). It cannot be excluded that some remains represent broken parts of phobetractine elements as described from the Campo Pisano Formation by Mostler (1985). Within the first 5 m of the profile (including the first poriferid maximum level), only simple monaxons, cruciform tetractins and pentactins were found (GP1-GP4). From the same interval the heteractinid *Eiffelia araniformis* (Missarzhevski, 1981) has been identified (Text-fig. 3; Pl. 2, figs 13-14). From the second poriferid maximum level, no specimens were attained by chemical preparation. After thin-section investigation, the spicules here seem to be the same than those at the base of the formation. Further chemical prepared specimens come from the GP15-level (following the second poriferid maximum). Here, monaxons and cruciform tetractins (= ?relics of phobetractins or ?stauractins of lyssakid porifera) occur.

Unfortunately, the poriferid taxa from the Cambrian of Sardinia published by Mostler (1985) are not indicated to distinct localities or sampling levels. Only for his newly introduced species *Sardospongia* (= *Dodecaactinella*) *triradiata*, the locality Gutturu Pala and a sampling horizon named "layer 150" is mentioned, but lacking any explanation or graphic for the position of that layer. During the present investigation, no specimens of this affinity were observed from this section.

CHANCELLORIIDS

Chancelloriids represent a problematic group of Cambrian spiny skeletal elements. They were regarded as poriferids (Walcott, 1920; Butterfield &



Text-fig. 4 - Redraw of *Chancelloria sardinica* Mostler, 1985, compare Pl. 2, fig. 23. Level GP5; max. diameter: 1.3 mm.

Nicholas, 1996) or – together with halkieriids, wiwaxiids, sachtids and siphonogonuchitids – as an own class or order named Coeloscleritophora (Bengtson & Missarzhevski, 1981). Following Mehl-Janusen (1999), the latter is polyphyletic and the chancelloriids may represent a non-poriferan group of hitherto uncertain affinity.

At Gutturu Pala, chancelloriids were found only in the lower third of the succession. The sclerites are generally very rare (less than 1%), only in level GP2 they are a little enriched (up to 5%). The stone-core-preserved, phosphatised chancelloriid rays are often disarticulated by chemical preparation procedures, but sometimes chancelloriid rosettes can be observed (Pl. 1, figs 5-6; Pl. 2, fig. 23).

Besides the usually disarticulated single rays, two more complex preserved taxa were observed: *Chancelloria sardinica* Mostler, 1985 (Text-fig. 4; Pl. 2, fig. 23) and *Allonia* Doré & Reid, 1965 (*Allonia* sp.). A more detailed determination of the chancelloriid remains from Gutturu Pala is not reasonable because of the morphological variability of those remains associated with the rareness of the findings. Mostler (1985) described his new erected species *Chancelloria sardinica* from "layer 146" (but, again, gives no explanation for the position of that layer). For the further chancelloriids mentioned by that author, no locality is indicated.

HYOLITHELMINTHIDS

Hyolithelminthids are widely accepted as polychaete-worm tubes. Typically, they are small conical phosphatic tubes with a more or less irregular curved apical area. Toward the aperture, they are elongated and more straighten. The cross section may be circular (hyolithellids) or elliptical (torellidids).

At Gutturu Pala, rare and bad preserved specimens of this fossil group were found exclusively at the base (GP1-level). The specimens were identified as *Hyolithellus* cf. *filiformis* Bengtson, 1990. The longest

fragment (Text-fig. 5; Pl. 2, figs 24-25) is nearly 3 mm long and has a circular cross-section of about 0.3 mm. The outer surface is covered by more or less regular ring-like annulations in a distance of about 50-90 μ m. The relative taxonomic uncertainty results from the bigger diameter compared to the holotype (latter: 150 μ m). All other characteristics fit well with the original description.



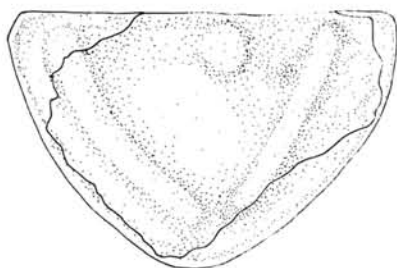
Text-fig. 5 - Redraw of *Hyolithellus* cf. *filiformis* Bengtson, 1990; compare Pl. 2, figs 24-25. Level GP1; max. length of tube: 2.6 mm.

PROBLEMATICA

A problematic remain, represented by a more or less irregular sphere is assigned to ?*Aetholicopalla adnata* Conway Morris, 1990 (Pl. 2, fig. 12). The only specimen has a diameter of 0.5 mm, numerous round openings (about 30 μ m) and is slightly flattened at the "base". The sphere is hollow and siliceous in composition (secondary diagenetic effect as in many associated brachiopods and trilobites). The general shape, size and diameters of the openings point to an affiliation to the taxon mentioned above. Because of the bad preservation, the original mineralogy and the internal structures are not preserved. So, this siliceous "envelope" may represent only the replaced outer wall of *Aetholicopalla adnata*. The fact that (in contrast to the specimens described by Conway Morris, 1990 and by Elicki, 1998) the present specimen is hollow can be interpreted in that way that the primary mineralogy was rather calcareous and diagenetically dissolved than phosphatic – a question which, hitherto, could not be surely inferred. A decision of the present specimen to the similar problematic structure *Archaeooides* is unlikely because of the lack of the flattened "base" and of differing surface structures in the latter. The biological affinity of *Aetholicopalla* is still unclear. Surely, they do not represent free-living metazoans, but maybe resting bodies for storage of propagules (Conway Morris, 1990).

ARTHROPODS

Ostracods from the Sardinian Cambrian were reported up to now only by Mostler (1985) due to observations in thin sections of Early Cambrian archaeocyathid limestones. He described ostracods as "occasional occurring, strongly recrystallized, not nearer definable, small shells". Also in the Campo Pisano Formation ostracods seem to be rather rare: only in the lowest level (GP1) only few specimens of



Text-fig. 6 - *Hipponicharion ichnusum* n. sp., completed redraw of the holotype, compare Pl. 2, figs 1 & 2. Level GP1; max. diameter: 2.9 mm.

this fossil group could be proved (Text-fig. 6; Pl. 2, figs 1-2). Because of the very characteristic and strongly significant morphological features, it is justifiable and needed to establish a new taxon on species level (see below).

Trilobites from the Campo Pisano Formation have received little attention until now. Despite their abundance as tests detectable both in the field and in thin sections (since Bornemann, 1886), systematically useful remains are difficult to collect and to prepare. Rasetti (1972) described few taxa from the localities 12r and 13r at Corovau (northern slope of Marganai mountain range, Domusnovas). According to that author, the fauna originates from the upper Campo Pisano Formation (considered at that time as uppermost Gonnese Formation) and includes *Agraulos* sp., *Corynexochus latus* Rasetti, 1972, *C. sardous* Rasetti, 1972 (both junior synonyms of *C. delagei*), *Pardailhanian hispidus* (Thoral, 1935), *Peronopsis* sp. and *Ptychagnostus* sp. Later on, sparse information was given by Pillola, accompanied by illustrations of the best preserved and biostratigraphically significant taxa from the so called CP1 and CP2 faunas, without systematic descriptions (Pillola, 1991; 1994; Loi *et al.*, 1995; Pillola *et al.*, 2002 and cited references).

Trilobites of the CP1 fauna, recognized in few

localities of SW Sardinia, include *Protolenus* (*Protolenus*) *pisidianus* Dean (in Dean & Özgül, 1994). The vertical range of this latter partially overlaps the succeeding *Acadoparadoxides mureroensis* Zone of the basal CP2 trilobite assemblage. The specimens tentatively assigned in this paper to *Clavigellus* belong to the CP1 fauna (see discussion below). The CP2 fauna clearly shows a more diversified trilobite assemblage, including the above mentioned *Acadoparadoxides mureroensis* and *Protolenus* (*Protolenus*) *pisidianus* at the base, while oryctocephalids have been found exclusively in the middle part of this formation, associated with *Acadoparadoxides mureroensis*, *Calodiscus foveolatus* Howell, 1935, and dorypygiids. In the upper part agnostids (*Peronopsis*, *Ptychagnostus*, *Diplagnostus*) are associated with *Paradoxides* sp., *Pardailhanian hispidus* (Thoral 1935), *Corynexochus delagei* (Miquel 1905), *Agraulos* sp., *Dorypyge* sp., *Ctenocephalus* (*Ctenocephalus*) sp., and *Dawsonia*.

The specimens obtained by chemical preparation are usually tiny and more adapted to the study of small trilobites as agnostids and eodiscids or immature developmental stages of larger individuals. Consequently, the informations about larger trilobite remains from the Campo Pisano Formation at Gutturu Pala are missing. In this paper the occurrence of *Condylopyge antiqua* n. sp., *Skryjagnostus* aff. *pompeckji* and representatives of Acontheinae is reported for the first time from the Sardinian Middle Cambrian; in addition, the Gutturu Pala fauna allows to identify *Dawsonia* as *D. bohemicus* (Šnajdr, 1950).

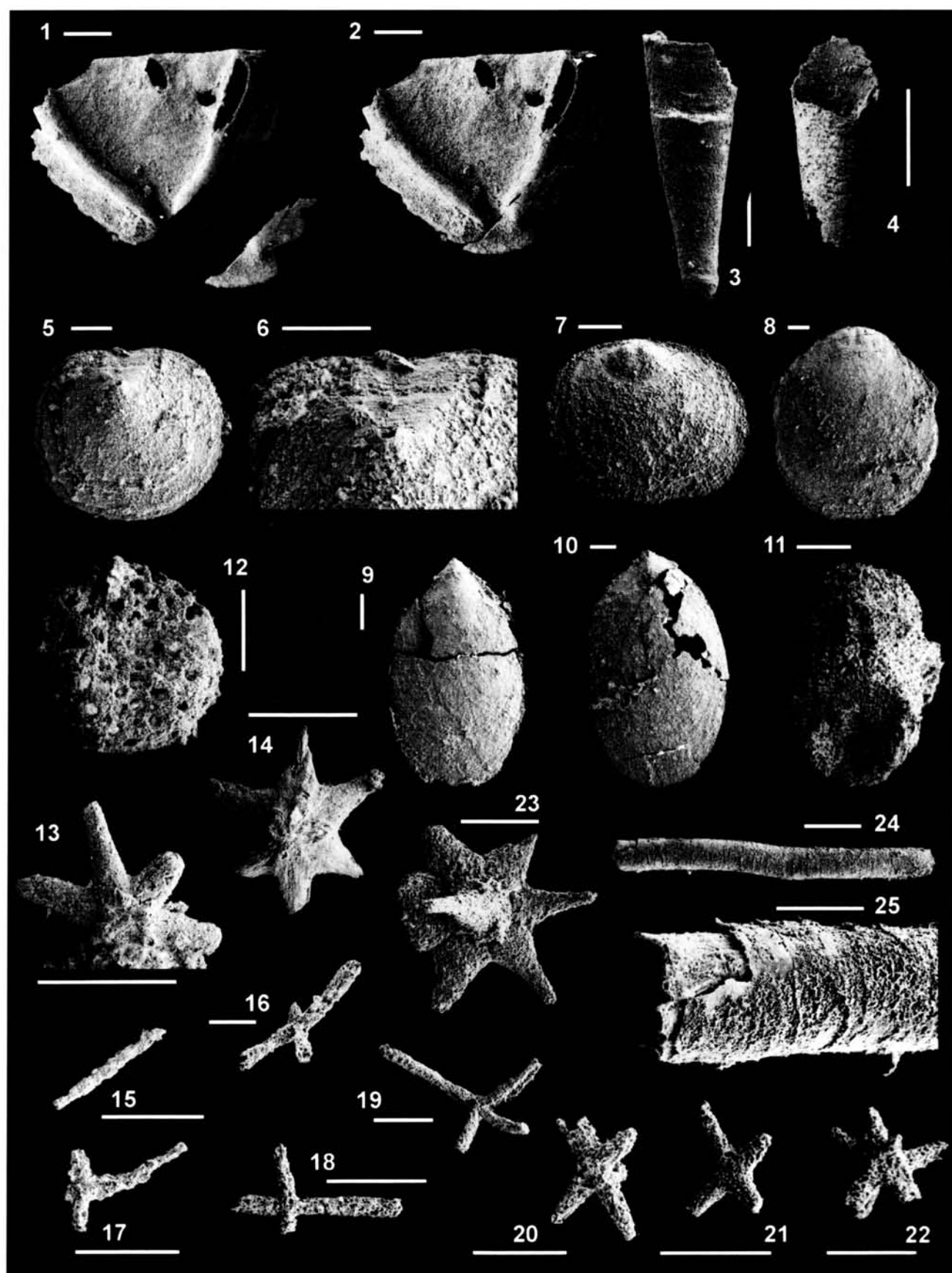
Due to the paucity and preservation of the arthropod taxa, description is restricted to the best represented and preserved species.

Class OSTRACODA Latreille, 1806
Order BRADORIIDA Raymond, 1935
Family HIPPONICHARIONIDAE Sylvester-Bradley, 1961
Genus HIPPONICHARION Matthew, 1886

Type species – *Hipponicharion eos* Matthew, 1886.

EXPLANATION OF PLATE 2

- Figs 1, 2 - *Hipponicharion ichnusum* n. sp.; same specimen in both pictures, stereo-photograph with weak reconstruction of broken part of margin, holotype. Level GP1. Scale bars = 0.5 mm.
Figs 3, 4 - Unassigned hyolith remains. Levels GP8 (fig. 3) and GP2 (fig. 4). Scale bars = 0.5 mm.
Figs 5-8 - Unassigned acrotretid brachiopods. Fig. 6 is detail of (5). Level GP15 (figs 5-6, 8), GP9 (fig. 7). Scale bars = 0.2 mm.
Fig. 9, 10 - Unassigned lingulellid brachiopods in phosphatic preservation. Level GP1. Scale bars = 0.2 mm.
Fig. 11 - Disarticulated echinoderm remain. Level GP2. Scale bar = 0.2 mm.
Fig. 12 - ?*Aetholicopalla adnata* Conway Morris, 1990. Level GP2. Scale bar = 0.2 mm.
Fig. 13 - Small specimen of *Eiffelia araniiformis* (Missarzhevski, 1981). Level GP2. Scale bar = 0.2 mm.
Fig. 14 - Bad preserved ?*Eiffelia araniiformis* (Missarzhevski, 1981). Level GP4. Scale bar = 0.5 mm.
Figs 15-22 - Unassigned sponge spicules. Level GP15 (figs 15-19), level GP1 (figs 20-22). Scale bars = 0.2 mm (figs 16, 19-22), 0.5 mm (figs 15, 17, 18).
Fig. 23 - *Chancelloria sardinica* Mostler, 1985. Level GP5. Scale bar = 0.5 mm.
Figs 24-25 - *Hyolithellus* cf. *filiformis* Bengtson, 1990. (25) is detail of (24). Note the ring-like ornamentation of the tube. Level GP1. Scale bars = 0.5 mm (fig. 24), 0.2 mm (fig. 25).



HIPPONICHARION ICHNUSUM n. sp.

Pl. 2, figs 1-2; Text-fig. 6

2003 *Hipponicharion* sp. – ELICKI *et al.*, p. 33, pl. 5, fig. 2.*Holotype* – Right valve; FG 536/1 (Pl. 2, fig. 1).*Repository* – Geological Institute, Freiberg University, archive number 536.*Derivation of name* – After its occurrence in Sardinia (historical name: Ichnusa).*Type horizon and locality* – Basal Campo Pisano Formation (first 0.5 m; level GP1), Gutturu Pala mine, about 4 km SE of Fluminimaggiore (SW Sardinia).*Material* – Three specimens.*Occurrence* – Late Early Cambrian (latest Toyonian = latest Bilbilian), Campo Pisano Formation.*Diagnosis* – Carapace large (maximum length: 2.8 mm; maximum height: 2.1 mm) and sub-triangular in lateral view. Dorsal margin straight. Ventral, anterior and posterior margins only fragmentary preserved, but – if visible – without ornamentation. Lateral surface smooth. Very long anterior and posterior crest-like lobes parallel to sub-parallel to the margin and reaching near to the dorsal margin. Ventrally, the lobes approach each other very, but they do not come in touch. Anterior lobe nearly straight, posterior lobe slightly curved. Mid-dorsally a circular node is prominently developed.*Discussion* – The new species differs from the other known hipponicharionids as follows: from *H. eos* Matthew, 1886, *H. taidaltensis* Gozalo & Hinz-Schallreuter, 2002, *H. geyeri* Hinz-Schallreuter, 1993 and *H. elickii* Gozalo & Hinz-Schallreuter, 2002 it differs clearly by the more sub-triangular shape of the carapace, by the size and shape of the lobes, and by the occurrence of a prominent mid-dorsal node. A further difference to *H. geyeri* Hinz-Schallreuter, 1993 is the lack of pits. From *H. hispanicum* Gozalo & Hinz-Schallreuter, 2002 the new species mainly differs in the shape of the carapace and in the presence of a prominent mid-dorsal node.The biostratigraphic level of the finding horizon of *Hipponicharion ichnusum* results from the position 0-0.5 m above the San Giovanni Formation (Gonnesa Group). The top of the latter was biostratigraphically defined by Perejón *et al.* (2000) on the basis of archaeocyaths as Toyonian 2-3 (respectively mid to late Bilbilian, latest Early Cambrian). On the other hand, after Loi *et al.* (1995), based on trilobites,the Early–Mid Cambrian boundary in Sardinia is situated several metres above the base of the Campo Pisano Formation, that means that *H. ichnusum* is late Toyonian (= late Bilbilian) in age.The palaeobiogeographic distribution of the genus *Hipponicharion* Matthew, 1886 was discussed by Gozalo & Hinz-Schallreuter (2002), coming to the result that the genus is restricted to western Gondwana, Avalonia, and Baltica and so, typical for the Acadobaltic Province *sensu* Szdzy (1972).

Class TRILOBITA Walch, 1771

Order AGNOSTIDA Kobayashi, 1935

Suborder AGNOSTINA Salter, 1864

Superfamily CONDYLOPYGOIDEA Raymond, 1913

Family CONDYLOPYGIDAE Raymond, 1913

Genus CONDYLOPYGE Hawle & Corda, 1847

Type species – *Battus rex* Barrande, 1846
(by monotypy), Bohemia.

CONDYLOPYGE ANTIQUA n. sp.

Pl. 3, figs 1-12

2003 *Condylopyge* sp. – ELICKI *et al.*, p. 29, pl. 3, figs 3-7.*Holotype* – Cephalon, DSTCP 23155, Pl. 3, fig. 5.*Repository* – Dipartimento di Scienze della Terra, Cagliari University, acronym DSTCP 23.*Derivation of name* – From the Latin “ancient”.*Type horizon and locality* – Campo Pisano Formation, level GP9, 24.7 m above the base; Gutturu Pala section, Fluminimaggiore, SW Sardinia.*Material* – Level GP9: one poorly preserved enrolled specimen, 11 cephalon and 4 pygidia, DSTCP 23001-07, 23016-17, 23029-31 and 23155; level GP14: 4 cephalon and 2 pygidia, DSTCP 23065-69 and 23154. Additional specimens from loose block GPLB: 19 cephalon and 11 pygidia, DSTCP 23082-100, 23118-121, 23135-137, 23141-144.*Occurrence* – Early Middle Cambrian, Campo Pisano Formation.*Diagnosis* – A *Condylopyge* species crescentiform shaped, relatively small anterior lobe, strong spines on the occipital ring and at the posterolateral edges, long preglabellar field and well-developed borders, in both cephalon and pygidium. Pygidial axis slightly tapering backwards, bearing the trace of tree faint furrows and a poorly marked keel, occasionally risen into a faint node; obsolete or faint impressed medial furrow posterior to the pygidial axis.

Description – Cephalon with parallel to gently rounded sides, anterior margin well rounded. Narrow border and border furrow, both broadening and shallowing in correspondence of anterolateral regions (Pl. 3, fig. 6); short and strong paired lateral spines, extending backwards from genal region. Preglabellar field long (sag.), about 1/2 of the anterior lobe, separated from a raised anterior border by a well-impressed border furrow. Axial furrows deep and sharp. Glabella convex, fungiform in shape, as long (sag.) as 70-80% of the cranidial length, consisting of two lobes separated by deep, gently anteriorly arcuate transverse furrow. Anterior lobe crescentiform, sagittal length about half the width, extended posterolaterally, occupying 28-30% of the cranidial length (little less in immature stages). Prominent posterior glabellar lobe, sub-elliptical to rounded sub-quadrate in outline, slightly longer (sag.) than wide (tr.) with obsolete median ridge toward posterior, and very faint median tubercle at posterior end; narrow and low occipital lobe of about equal width (tr.) as the anterior glabellar lobe, composed of a pair of swollen basal lobes and a middle portion mostly represented by the base of a well developed posterior occipital spine. Genal region narrow around the anterior lobe, broadens adjacent to posterior lobe.

Unreleased thoracic segment (Pl. 3, fig. 7) shows a well-developed median node on the axial ring. Pygidium sub-ovate in outline, with well-developed posterolateral border. Axis convex, gently tapering backwards, occupying (sag.) 65 to 75% of whole pygidial sagittal length and transversally, about 1/2 of the maximum width of the pygidial shield, showing more or less marked trace of tree pairs, shallowing backwards furrows, impressed only at adaxial ends (Pl. 3, fig. 8) and a poorly marked keel, occasionally risen into a faint node. Faint shallow median furrow on posterior margin. Border wide, particularly developed and shallower in correspondence of the posterolateral regions; gutter-like border furrow, shallower and wider at posterolateral portions. Measurements of holotype: sagittal cranidial length about 2 mm.

Discussion – *Condylonyge antiqua* n. sp. differs significantly from most described species of *Condylonyge* in having a medial furrow posterior to the pygidial axis and a posteriorly tapering rachis, which allow a clear distinction against *Condylonyge rex* Barrande, 1846, *C. carinata* Westergård 1936, and similar species.

Closely related *Condylonyge* species, showing a faintly furrowed and not posteriorly expanded pygidium, include *C. cruzensis* Liñán & Gozalo, 1986 (name modified in *cucensis* by Geyer, 1998), from Spain, *C. eli* Geyer, 1998, from Morocco, *C. globosa* (Illing, 1916) and *C. amitina* Rushton, 1966, from England, *C. regia* (Sjögren, 1872), from the *Eccaparadoxides insularis* Zone of Sweden, *Condylonyge "etaerus"* Fletcher, 1972, from SW Avalon/Newfoundland, and

Condylonyge sp. Álvaro & Vizcaíno, 2000, from southern France.

The Sardinian species is very similar to *C. globosa* (Illing, 1916), which differs from *C. antiqua* in having a shorter preglabellar field and narrower border, the posterior lobe is slightly wider than long; *C. globosa* also differs in having weaker occipital and posterolateral spines.

A close species is represented by *Condylonyge amitina* Rushton, 1966, from the Purley Shales, Warwickshire, which mainly differs from *C. antiqua* by the absence of the medial furrow, by the unfurrowed and more rounded pygidial axis, and slightly by the proportions and shape of the remaining parts of the carapace. *Condylonyge "etaerus"* Fletcher, 1972, from SW Avalon/Newfoundland, shows close similarities in the pygidial features but the cephalon differs in having shorter preglabellar field and cephalic border and longer spines at the genal corners and on the occipital ring. *Condylonyge cruzensis* possess shorter pygidial axis and a more marked keel, and a pair of pleural furrows in the pygidium; in addition, the border furrow and the border margin are relatively narrow and shows rather uniform width, both in the cephalon and in the pygidium (Liñán & Gozalo, 1986: pl. 1, figs 1-8). The occurrence of a pair of lateral furrows across the pygidial pleural field allows to distinguish *C. regia* from the Sardinian taxa.

Comparisons of *C. antiqua* with the only and incomplete cranidium of *Condylonyge* sp. from southern Montagne Noire, France (Álvaro & Vizcaíno, 2000, pl. 1, fig. 1) is delicate; however, the French species shows clearly narrower cheeks close to the anterior lobe and shorter (sag.) preglabellar field, which suggest more affinities with *C. rex*. Similar distinctive features are present in the *Condylonyge* species figured by Geyer (1988) from Morocco. *Condylonyge eli* from the Moroccan Anti-Atlas shows a relatively shorter preglabellar region and faint cephalic spines, longer pygidial axis and less rounded outline of the cephalic and pygidial shields.

Family uncertain

Genus SKRYJAGNOSTUS Šnajdr, 1957

Type species – *Skryjagnostus pompeckji* Šnajdr, 1957; Bohemia.

SKRYJAGNOSTUS aff. POMPECKJI Šnajdr, 1957
Pl. 3, figs 13-20

Material – GP9, 4 cephalon and 2 pygidia, DSTCP 23010, 23018, 23035-39; GP11, 1 cephalon and 1 pygidium, DSTCP 23051-52; GPLB, 3 cephalon and 3 pygidia, DSTCP 23131-34, 23138-40; totally 8 cephalon and 6 pygidia.

Description – Semi-elliptical, strongly vaulted cranidium, slightly wider (tr.) than long (sag.), very

faintly defined or completely effaced tapering forwards glabella. Posterior end of the glabella inclined, with occasional occurrence of a extremely narrow (sag.) and long (tr.) occipital ring (Pl. 3, fig. 16). Presence of a narrow doublure.

Pygidial shape nearly identical to the cephalon, little more vaulted in all directions, with defined rachis, especially close to the tiny articulated half ring. Rachis, occupying about 85-90% of the pygidial length (sag.), usually not clearly defined at the posterior end and expanded and slightly more elevated at middle length. Traces of a faint narrow border and doublure can be observed (Pl. 3, figs 13, 17). Cephalon larger: about 1 mm long (sag.).

Discussion – For many of the remains, the assignment is particularly difficult due to the absence of distinctive features and to the type of preservation – not only to the taxon but also for a certain distinction between cephalon and pygidia! Due to the peculiar morphology of this taxon, only few details can be added to the original diagnosis and description (Šnajdr, 1957, p. 243, in English) and on additional illustrations given by the same author (Šnajdr, 1958: pl. 6, figs 4-5, 10, 12-20). The Sardinian *Skryjagnostus* shows a clearly smaller articulated pygidial half-ring (transversally less than one third of the pygidium at the same level) and poorly defined anterior border. In contrast, the pygidial rachis is usually better defined. In addition, both, cephalon and pygidium are more

elliptical than sub-circular in shape.

The genus *Skryjagnostus* is known from the Middle Cambrian *Paradoxides pusillus* Zone of Czech Republic and *Pedinocephalus* or *Toxotis* Zone from northwestern Siberia.

Suborder EODISCINA Kobayashi, 1935

Family EODISCIDAE Raymond, 1913

Genus DAWSONIA Hartt in Dawson, 1868

Type species – *Microdiscus dawsoni* Hartt in Dawson, 1868.

DAWSONIA BOHEMICA (Šnajdr, 1950)

Pl. 3, figs 21-26

- 1950 *Aculeodiscus bohemicus bohemicus* nov. gen. nov. subsp. ŠNAJDR, p. 201, pl. 1, fig. 1; pl. 2, figs 1-6, pl. 3, figs 1-2.
 1953 *Aculeodiscus bohemicus* Šnajdr – SINCLAIR, p. 490-491.
 1957 *Aculeodiscus bohemicus* Šnajdr – ŠNAJDR, p. 240.
 1958 *Aculeodiscus bohemicus* Šnajdr – ŠNAJDR, p. 46, pl. 1, figs 1-22.
 1970 *Aculeodiscus bohemicus* Šnajdr – HORNÝ & BASTL, p. 81, pl. 1, fig. 10.
 1990 *Dawsonia bohemia* (Šnajdr) – ŠNAJDR, p. 86, text-fig. 87.
 1992 *Dawsonia bohemia* (Šnajdr) – FATKA & KORDULE, p. 49, fig. 2.
 v1995 cf. *Dawsonia* – Loi *et al.* 68, pl. 4, fig. 9.
 1996 *Dawsonia bohemia* (Šnajdr) – KORDULE, p. 43, fig. 2.
 2000 *Dawsonia bohemia* (Šnajdr) – ÁLVARO & VIZCAÍNO, p. 279, pl. 1, figs 2-6.
 2003 *Dawsonia bohemia* (Šnajdr) – ELICKI *et al.*, p. 29, pl. 3, figs 1-2.

EXPLANATION OF PLATE 3

All illustrated specimens (excepted fig. 38) are housed in the Dipartimento di Scienze della Terra, Cagliari University, Pillola Collection (DSTCP), followed by the specimen number and the acronym GP (for Gutturu Pala) flanked by the bed number. The abbreviation LB is assigned to the material originated from a loose block. Magnification x 15.8 (see scale bar).

- Figs 1-12 – *Condylopyge antiqua* n. sp. 1) Immature cephalon, dorsal view DSTCP. 23089, GPLB; 2) Incomplete cephalon DSTCP. 23003, GP9; 3) Incomplete cephalon DSTCP. 23085, GPLB; 4) Transversally compressed incomplete cephalon, DSTCP. 23083, GPLB; 5) Incomplete cephalon, holotype, DSTCP. 23155, GP9; 6) Large incomplete cephalon, DSTCP. 23090, GPLB; 7) Immature pygidium with unreleased thoracic segment DSTCP. 23154, GP14; 8) Incomplete pygidium, DSTCP. 23069, GP14; 9) Incomplete pygidium DSTCP. 23094, GPLB; 10) Pygidium DSTCP. 23157, GP14; 11) Incomplete pygidium DSTCP. 23097, GPLB; 12) Large fragmentary cephalon, anterolateral oblique view; DSTCP. 23001, GP9.
 Figs 13-20 – *Skryjagnostus* aff. *pompeckji* Šnajdr 1957. 13) Pygidium, ventral view, DSTCP. 23132, GPLB; 14) Cephalon dorsal view, DSTCP. 23035, GP9; 15) Tiny cephalon, dorsal view, DSTCP. 23036, GP9; 16) Small pygidium, antero-lateral view, DSTCP. 23037, GP9; 17) Pygidium, ventral view, DSTCP. 23134, GPLB; 18) Cephalon, DSTCP. 23138, GPLB; 19) Damaged cephalon, DSTCP. 23038, GP9; 20) Tiny pygidium, DSTCP. 23140, GPLB.
 Figs 21-26 – *Dawsonia bohemia* (Šnajdr, 1950). 21) Incomplete cephalon DSTCP. 23101, GPLB; 22) Incomplete cephalon, juvenile developmental stage, dorsal view; DSTCP. 23107, GPLB; 23) Incomplete cephalon, early developmental stage, dorsal view, DSTCP. 23106, GPLB; 24) Pygidium, DSTCP. 23108, GPLB; 25) Distorted pygidium, DSTCP. 23057, GP11; 26) Damaged pygidium, DSTCP. 23023, GP9.
 Figs 27-34 – *Corynexochus delagei* Miquel, 1905. 27) Cephalon, larval stage DSTCP. 23043, GP9; 28) Cephalon, larval stage DSTCP. 23130, GPLB; 29) Immature cranidium, DSTCP. 23025, GP9; 30) Immature cranidium, DSTCP. 23026, GP9; 31) Damaged immature cranidium, DSTCP. 23027, GP9; 32) Cranidium, DSTCP. 23060, GP11; 33) Large fragmentary cranidium, DSTCP. 23059, GP11; 34) Transitory pygidium, DSTCP. 23114, GPLB.
 Figs 35-37 – *Clavigellus?* n. sp. 35) Cranidium, larval stage, DSTCP. 23152, GP2; 36) Cranidium, larval stage, DSTCP. 23153, GP2; 37) Incomplete immature cranidium, DSTCP. 23045, GP2.
 Fig. 38 – Unassigned corynexochiid, DSTCP. 23063, GP11 (not described in the text).
 Fig. 39 – Dorypygid, DSTCP. 23042, GP9 (not described in the text).
 Fig. 40 – ?Agrauiid, DSTCP. 23116, GPLB (not described in the text).
 Fig. 41 – Ellipsocephalid gen. et sp. indet., DSTCP. 23122, GPLB (not described in the text).
 Fig. 42 – Ellipsocephalid gen. et sp. indet., DSTCP. 23050, GP4 (not described in the text).



Material – Level GP9: 5 cephalia, DSTCP 23009, 23019-21, 23040 and 5 pygidia, DSTCP 23011-12, 23022-23, 23041; level GP11: 3 cephalia and 2 pygidia, 23053-57; level GP14: one cephalon DSTCP 23070; loose block GPLB: 11 cephalia and 3 pygidia, 23101-23109, 23110, 23145, 23147-51; totally 20 cephalia and 10 pygidia.

Description – Coarsely granulose semicircular cranidium, slender elevated conical glabella, occupying 65% of the cranidial length (70% and less in early growth stages) and about 30% of maximum width of the shield at the base. Glabellar segmentation effaced, very faint trace of the occipital furrow, represented by a pair of narrow incisions, placed low on sides of the glabella, angling back beneath median strong and well developed cranial spine arising from L1 (Pl. 3, figs 21-23). Narrow to absent depressed preglabellar field, flanked by the anterior tips of the strongly convex genae. Border furrow well impressed thorough, posterior border furrow shallower. Anterior border crescentiform, wide (sag.) as 20-25% of the cranidial sagittal length, narrowing towards the genal angles, typically bearing 16-20 more or less developed radial incisions defining sub-rectangular „scrobiculae“. Posterior border widens posterolaterally.

Pygidium semicircular in shape, test clearly showing coarse granulations (Pl. 3, figs 24-26); convex conical rachis delimited by deep axial furrows, reaching the posterior border furrow, occupying about 30% (tr.) of the pygidial width. Five axial rings and terminal piece, well separated by sharp furrows. Pleural region convex, with 4-5 broad pleural ribs and 5-6 deep interpleural furrows, shallow border furrow and flat to gently convex border (Pl. 3, figs 24-26).

Discussion – The concept and the historical controversy about the genus *Dawsonia* (Hartt in Dawson, 1868) has been recently discussed by Álvaro & Vizcaíno (2000); contemporaneously, the first occurrence of *D. bohémica* outside Bohemia and comparisons with congeneric species have been made by the same authors.

In SW Sardinia, in addition to the Gutturu Pala section levels GP9, GP11 and GP14, *Dawsonia bohémica* occurs in the CP2 assemblage of the Villaggio Norma section at Monte San Giovanni (Gonnese easternmost end of the „Cabitza syncline“) and in rare pebbles originating from the Campo Pisano Formation, within the Caradocian conglomerates of the Monte Argentu Formation, north of Domusnovas. *D. bohémica* appears in Bohemia in the *Paradoxides pusillus* Zone and in southern France at the lower occurrence of *Badulesia tenera* in the Coulouma Formation, suggesting an early Caesaraugustian age.

Order CORYNEXOCHIDA Kobayashi, 1935

Family CORYNEXOCHIDAE Angelin, 1854

Subfamily CORYNEXOCHINAE Angelin, 1854

Genus CORYNEXOCHUS Angelin, 1854

Type species – *Corynexochus spinulosus* Angelin, 1854.

CORYNEXOCHUS DELAGEI Miquel, 1905

Pl. 3, figs 27-33

- 1905 *Corynexochus delagei* n. sp. MIQUEL, p. 481, pl. 15, figs 4a, b.
- 1916 *Corynexochus delagei* Miquel – WALCOTT, p. 317, pl. 55, figs 3-3a.
- 1934 *Corynexochus delagei* Miquel – LAKE, p. 181.
- 1935 *Corynexochus delagei* Miquel – THORAL, p. 46, pl. 3, figs 6-7.
- 1936 *Corynexochus delagei* Miquel – RESSER, p. 23.
- 1961 *Corynexochus* cf. *delagei* Miquel – SDZUY, 334 (616), pl. 22, fig. 6.
- 1963 *Corynexochus delagei* Miquel – WALTER, p. 369.
- ? 1968 *Corynexochus* aff. *delagei* Miquel – SDZUY, 104, pl. 5, figs 11-12.
- 1972 *Corynexochus sardous* – RASETTI, p. 63, pl. 18, figs 1-17.
- 1973 *Corynexochus delagei* Miquel – COURTESOLE, p. 136, pl. 3, figs 8-18; pl. 25, fig. 6; pl. 27, fig. 7.
- ? 1984 *Corynexochus* cf. *delagei* Miquel – SHERGOLD & SDZUY, p. 74, pl. 2, figs 9.
- ? 1984 *Corynexochus* cf. *sardous* Rasetti – SHERGOLD & SDZUY, p. 74, pl. 2, figs 10.
- v 1995 *Corynexochus sardous* Rasetti – LOI *et al.*, p. 68, pl. 4, fig. 7.
- v 1995 *Corynexochus latus* Rasetti – LOI *et al.*, p. 68, pl. 4, fig. 2.
- 2000 *Corynexochus delagei* Miquel – ÁLVARO & VIZCAÍNO, p. 280, pl. 1, figs 7-11.

Material – Level GP9, 6 cranidia and 2 pygidia, DSTCP 23013-14, 23024-27, 23043-44; level GP11, 5 cranidia and 1 pygidium, DSTCP 23058-62, 23064; level GP14, 3 cranidia, DSTCP 23072-74; level GPLB, 2 cranidia and 5 pygidia DSTCP 23111-14, 23130, 23159-60; totally 16 cranidia and 8 pygidia.

Description – Exhaustive description of this taxa has been made by several authors; more recently, Álvaro & Vizcaíno (2000) had the possibility to re-examine the Miquel and Courtesole material and add the first description of the hypostome and rostrum. The new material from Gutturu Pala is mostly represented by immature cranidia and tiny pygidia; the smallest immature cranidium (Pl. 3, figs 27-28) shows a narrow (tr.) parallel sided posterior part of the glabella, which strongly expands forwards, with deepening dorsal furrows into a pair of pits, placed just below the largest (tr.) portion of the glabella (Pl. 3, figs 27). Slightly larger cranidia clearly show the palpebral lobe and a very faint ocular ridge (Pl. 3, fig. 32, right side); at this stage the palpebral lobe is about one third of the glabellar length (exsag.), the anterior tip is close to the dorsal furrow and the posterior end far away from the glabella and from the posterior margin of the cranidium. Unfortunately, the largest cranidium is poorly preserved (Pl. 3, fig. 33) and, as for smaller specimens, nothing can be added about segmentation or peculiarities of the surface of the test

(minute quartz crystals substituted the carapace). The available pygidia also suffer of the above-cited effacement and display more or less segmented rachis, pleural field smooth or faintly furrowed and marginal furrow usually obsolete. The figured specimen (Pl. 3, fig. 34) is about 1 mm large (tr.) and represents a transitory pygidium with incipient hints of release of its anterior segments.

Discussion – The high morphological variability during morphogenetic development of *Corynexochus delagei*, the diagnostic characters considered by several authors and the type of preservation, represent the main source of uncertainty for a safe assignment of specimens to this taxa.

The shape of the glabella changes considerably from sub-parallel sided up to the middle length to more or less clavate both during growth but also with distortion/compression during diagenesis (see the imprint of deformation in terrigenous material figured by Courtessole (1972, pl. 3). In tiny specimens, such as the cranidium figured by Rasetti (1972, pl. 18, fig. 3) the glabella is more expanded anteriorly than in larger specimens and resembles closely an incomplete cranidium assigned to *C. latus* (Rasetti, 1972, pl. 18, fig. 21). In other specimens, such as the cranidia figured by Loi *et al.* (1995, pl. 4, figs 2, 7) the glabellar shape of the specimen on his fig. 2 suggests the assignment to *latus* while the obsolescence of the furrows suggest similarities with those assigned to *sardous*. The ratio between the width (tr.) of L1 and the maximum width (tr.) of the glabella has received an elevated taxonomic value in discriminating taxa of *delagei* affinities; however, as pointed out by Álvaro & Vizcaïno (2000, p. 280), this ratio ranges from 33% to 50%. The occurrence of the occipital spine and the shape of the occipital ring represented further matter of debate, but again, the variability observed on figured specimens seems mostly related to different preservation.

About pygidial features, we can notice that there are strong differences in segmentation comparing internal moulds and external surfaces (see Rasetti, 1972, pl. 18, figs 6-9, 12-14, 16) and, substantially, there are no significant differences between specimens assigned by Rasetti to *C. sardous* or *C. latus* (see Rasetti, 1972, pl. 18, figs 18-20, 25) and the specimens assigned to *C. delagei*. Similar considerations about flattening, internal/external mould morphology and paucity of the available material are valid for the Turkish material (Shergold & Sdzuy, 1984, p. 73-75, pl. 2, figs 9-11).

In agreement with Álvaro & Vizcaïno (2000), which discussed the position of the Sardinian taxa and prefer to maintain the species *C. latus*, we additionally propose to restrict the name *Corynexochus latus* to the type material and assign the remaining Sardinian material to *C. delagei*. For comparisons with other described *Corynexochus* species see Rasetti (1972), Courtessole (1973) and Shergold & Sdzuy (1984, with references).

Occurrence – *Corynexochus delagei* occurs in Montagne Noire (France) since the base of the Coulouma Formation up to the A1-A2 levels of Courtessole, in Spain (Asturias and Cantabrian Mountain Range) and Sultan Dag (Taurus Mountains, Turkey); in southwestern Sardinia, *Corynexochus delagei* ranges from the middle Campo Pisano Formation and is also known from the basal levels of the Cabitza Formation, a long range distribution which covers the upper Leonian and most of the Caesaraugustan (including the *Pardailhanian hispid* beds of the CP2 „assemblage“, the *Solenopleuropsis (Manublesia) ribeiroi* beds of the CAB1 and the *Eccaparadoxides pusillus* - *Eccaparadoxides mediterraneus* of the CAB2 levels.

Subfamily ACONTHEINAE Westergård, 1950
Genus CLAVIGELLUS Geyer, 1994

Type species – *Clavigellus annulus* Geyer, 1994.

CLAVIGELLUS? n. sp.
Pl. 3, figs 35-37

2003 *Clavigellus* sp. – ELICKI *et al.*, p. 29, pl. 3, fig. 8.

Material – 3 immature incomplete cranidia from level GP2.

Description – Club-shaped unfurrowed glabella gently expanding forward from SO and constricted at the level of L1, without preglabellar field and anterior border, elevated above fixigenae; large sub-triangular to well rounded occipital ring, slightly larger (tr.) than L1, bearing a low backward and upward directed robust occipital spine. Sub-triangular, well-rounded fixigenae, gently convex in all directions. Palpebral lobes crescentiform, abaxially inclined, occupying (exsag.) 33% to 42% of the glabellar length (excluding the occipital ring), placed about at mid-length of the glabella; faint and narrow ocular ridges, slightly obliquely directed to the largest portion of the glabella.

Anterior branches of facial suture short (exsag.) obliquely directed forwards (early meraspid) or sub-parallel for a short distance. Stout, backwards directed, genal spines, separated by a more or less impressed furrow from the posterior margin of the fixigenae. Librigenae unknown, but probably tiny and narrow.

Discussion – In agreement with Geyer, early corynexochids reveal a pronounced pedomorphic trend against dorypygids; these peculiar basal Mid-Cambrian stock is in addition is distinct by a proparian suture, short palpebral lobes and a club shaped more or less expanded glabella. The Sardinian *Clavigellus* is represented by only three meraspid cranidia, so, inappropriate to erect a new species and also to compare adequately with closer taxa. However, it differs from the Moroccan *C. annulus* in

having a less vaulted cranidium, slender glabella and more developed genal spines, and also immature specimens always have longer palpebral lobes; a meraspid of *Clavigellus annulus* (Geyer, 1994, figs 7-17) clearly shows a slender glabella, but fixigenae are much more elevated.

A closely related taxon is represented by *Corynexochella? venusta* Dean (in Dean & Özgü, 1994) from the basal Cal Tepe Formation (Taurus Mountains, Turkey), which occurs at the base of the *Acadoparadoxides mureoensis* Zone, associated with *Protolenus* (*Protolenus*) *pisidianus*. The Turkish species is clearly more similar to the Moroccan and to the Siberian taxa than the Sardinian one.

Clavigellus? n. sp. shows close similarities with the unassigned Corynexochid specimen (Pl. 3, fig. 38, from level GP11); this latter is in turn closely related to the specimen assigned to *Corynexochus* cf. *delagei* by Szdzy (1961, pl. 22, fig. 7) and, as noticed by Geyer (1994), may represent a proparian corynexochid taxon close to *Clavigellus*, bearing „strettonia-like“ palpebral lobes, present in the Iberian Chains (Spain), Montagne Noire (France) and now in Sardinia.

Occurrence – *Clavigellus?* n. sp. is restricted to the level GP2 of Gutturu Pala section, which strongly suggest correlation with the *Protolenus* (*Protolenus*) *pisidianus* beds of the CP1 assemblage (strata without *Paradoxides*) indicative of uppermost Early Cambrian age.

PALAEOECOLOGICAL DISCUSSION

As in younger systems, also for the Cambrian a complex of conditions can be assumed which significantly effected the biotic diversity of assemblages and their regional and ecological distribution. Although the preservation potential of organisms (and so the fossil record, respectively) is different depending on the occupied types of habitats, it is widely accepted that during the Cambrian benthic assemblages have dominated (Debrenne & Zhuravlev, 1997).

Generally, there are biotic and abiotic factors which influence the ecologic window. The main abiotic factors for an environment were represented by light, oxygenic level, available nutrients, temperature, chemistry of water and substrate, water energy and clastic input. Especially, the three first mentioned are strongly important and set absolute limits for the ecologic frame of an assemblage.

Except for one record of *Girvanella* published by Cherchi & Schroeder (1984), primary producers (bacteria, cyanobacteria, algae) are not known from the Campo Pisano Formation until now. This is most likely a taphonomic phenomenon, already known from many other carbonate deposits of all epochs.

At Gutturu Pala, the rather monotonous fauna 1 consists nearly exclusively of poriferid remains.

Echinoderm plates, trilobites, brachiopods, bradoriids and hyolithelminthids are extremely rare. So, filter feeders are the clearly prominent group of the depositional environment at the beginning of the Campo Pisano Formation. For these organisms a relatively shallow and most possibly muddy habitat with a moderate water agitation can be assumed (shallow subtidal, e.g. Mostler, 1985). The depth was maybe up to few tens of metres, what can be estimated due to the intertidal to very shallow subtidal conditions during deposition of the directly underlying strata and to the ecological requirements of fauna 1. There are no signs of allochthonous origin for the spiculate facies (as erosive base/planes, grading, clasts). A further argument for the autochthonism is suggested by investigations on other Campo Pisano sections, which show that this formation mostly starts with such a poriferid-rich portion. Based on these data, it can surely be assumed that fauna 1 is autochthonous. The mentioned biotic monotony may reflect a certain kind of stress, most possibly restricted water exchange and/or oligotrophic conditions.

The following fauna 2 shows a distinct increase in echinoderms and trilobite remains (mostly agnostids). Besides brachiopods, also cancelloriids and hyolithids occur. The latter are rather small and include as well specimens with circular cross-section, which are interpreted as semi-infaunal mud-stickers as those with a flattened base or with quadrangular cross-section, indicating an epibenthic mode of life (compare Elicki, 1994). Cancelloriids, typical of shallow to middle-subtidal conditions, are represented by an only low amount with a little “maximum” at the base of fauna 2. Most of the above mentioned fossil groups of fauna 2 have realised a suspension-feeding behaviour on the sediment soft- to firmground surface (brachiopods: filter-feeders, agnostids are mostly represented by benthic detritus sampling suspension- and deposit-feeders [*Condylopyge*, *Peronopsis* and most possibly also *Dawsonia*]; for discussion see Müller & Walossek, 1987; Debrenne & Zhuravlev, 1997; Whittington *et al.*, 1997; Hughes, 2001; Geyer, pers. comm.). In comparison to fauna 1, this fauna 2 indicates an increase of suspension input into the open-marine shallow to middle-subtidal conditions.

The succeeding fauna 3 contains the same fossil groups as fauna 2, but with a gradual vanishing of cancelloriids and hyolithids. The content on echinoderms and trilobites now decreases significantly. Nevertheless, these two epibenthic groups are the still dominating biota here. Whereas the deposit- and suspension-feeding trilobites represent autochthonous elements by taphonomic arguments, for the remains of the suspension-feeding echinoderms (distinctly less than in fauna 2) a movement from shallow and more agitated areas is possible (as in younger deposits, where transportation of skeletal remains of this organism group without markable agitation is possible over some distance). This fauna 3 persists over a

large portion of the section and represents a stable open-marine, probably deep subtidal environment.

The following succession of fauna 4 / fauna 5 / fauna 6 shows a quite similar pattern: first, passive filter-feeders predominate, followed by trilobite-echinoderm facies and finally a decrease of trilobites and echinoderms (dominance of most possible deposit-feeders). The fossils of the last decimetres of the Campo Pisano Formation are rather small and frequently broken.

So, it seems that the succession of habitats documented at Gutturu Pala were characterised twice by similar patterns: (1) firstly shallow subtidal, low-agitated and probably ecologically stressed (low diversity), followed by (2) a shallow to middle-subtidal, open-marine environment which changed finally (3) into the more distal and quiet deeper subtidal.

The dramatic facies replacement during the transition from the underlying San Giovanni Formation (Gonnesa Group) to the Campo Pisano Formation (Iglesias Group) indicates a reorganisation of the sedimentary and ecological environment, which may best explained by tectonic instability of the platform (subsidence impulse, tensional tectonics), most possibly accompanied by a moderate relative sea-level rise (e.g. Bechstdt & Boni, 1994; Loi *et al.*, 1995; Perejón *et al.*, 2000; Elicki, 2001). A climatic change in that time interval is under discussion. Based on sedimentological, diagenetic and isotopic investigation, Cocozza & Gandin (1990) assume a transition from arid (Santa Barbara Formation, early Gonnesa Group) to tropical-humid (San Giovanni Formation, upper Gonnesa Group) within a generally tidal-flat environment. In contrast, Perejón *et al.* (2000) agree in the arid conditions at early Gonnesa time, but they doubt (but not exclude generally) a transition to tropical-humid because of the strong diagenetic overprint of the upper Gonnesa Group. Consequently, the climatic situation during deposition of the Campo Pisano Formation may be concluded as still arid or tropical-humid. Regarding the higher terrigenous content of the Campo Pisano Formation an (1) increase of fluvial transported material and, consequently, of a wetter climate, or (2) a movement of the depositional area into other palaeoclimatic (= palaeogeographic) regions or (3) both, is most likely.

The interesting phenomenon at Gutturu Pala, that the ecological succession of faunas 1/2/3 more or less follows a second time (faunas 4/5/6) higher in the section, can be best interpreted as a moderate and temporary fall of the relative sea-level within a short time. After that sudden fall, the more or less same ecological succession of an again subsiding environment, respectively of a risen relative sea-level (from shallow subtidal to at least deeper subtidal) is well indicated by the faunal evolution.

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