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The Muschelkalk (Middle to Upper Triassic) of the Monte di Santa Giusta (NW Sardinia): sedimentology and biostratigraphy

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Keywords: Sardinia, Triassic, Muschelkalk, Ladinian, Carnian, sedimentology, biostratigraphy, conodonts, palynomorphs

ABSTRACT

A lithostratigraphic reference section for the Muschelkalk of NW Sardinia has been described in the locality Monte di Santa Giusta (Nurra Province). It is mostly composed of carbonates of Lower Ladinian to Lower Carnian age (Fassanian to Julian), which overlie the terrigenous interval (Lower Triassic to Anisian) of the Buntsandstein, also known as “Verrucano sardo”. Biostratigraphy of the Sardinian Muschelkalk is based on palynological data, and Tethyan conodont assemblages, which confirm Tethyan influences in the so called Germanic Triassic of Sardinia.

Palynological data have been obtained for the base and for the top of the carbonate section: the ages are Lower Fassanian, and Cordevolian to Julian. The conodont association, which occurs only in the middle part of the section, indicates an Upper Fassanian to Lower Longobardian age. We pointed out the occurrence of *Carinella japonica* in Sardinia, so far the westernmost locality for the species in all the Western Tethys.

Sedimentological data provide evidence for a shallow and quiet marine environment located on a carbonate ramp. The conodonts are allochthonous in this environment, and brought from the open sea during events of higher energy.

In terms of sequence stratigraphy, and according to biostratigraphic data, the carbonate series corresponds to a third order sequence (UAA-2.2), however younger at the Monte di Santa Giusta than in the Cycle chart.

RIASSUNTO

La sezione litostратigrafica di referenza per il Muschelkalk della Sardegna Nord-occidentale è stata descritta nella località Monte di Santa Giusta (Provincia della Nurra). Essa è essenzialmente composta da carbonati di età Ladinico inferiore (Fassaniano a Giulico), che sormontano l'intervallo terrigeno (Trias inferiore a Anisico) del Buntsandstein, classicamente conosciuto come “Verrucano sardo”. La biostratigrafia del Muschelkalk è basata sui dati palinologici e sulle associazioni a conodonti della Tetide; queste ultime confermano le influenze tetidee nel cosiddetto Trias germanico della Sardegna.

I dati palinologici sono stati ottenuti per la base ed il tetto della serie carbonatica: le età sono rispettivamente Fassaniano inferiore e Cordevolico a Giulico. L'associazione a conodonti, che è stata rinvenuta soltanto nella parte centrale della sezione, indica un'età Fassaniano superiore a Longobardico inferiore. Segnaliamo inoltre la presenza di *Carinella japonica* in Sardegna, che rappresenta la località più ad ovest di tutta la Tetide occidentale dove la specie è stata segnalata.

Lo studio sedimentologico mostra evidenze di una rampa carbonatica situata in un ambiente marino, tranquillo e poco profondo. I conodonti, alloctoni in questo tipo di ambiente desposizionale, sono trasportati durante gli eventi ad alta energia, dal mare aperto verso la costa.

In termini di stratigrafia sequenziale, ed in accordo con i dati biostratigrafici, la serie carbonatica corrisponde ad una sequenza di 3° ordine (UAA-2.2); tuttavia essa risulta più giovane al Monte di Santa Giusta che nella “Cycle chart”.

Introduction

The studied area covers the highs of the Monte di Santa Giusta, located 15 km West from Porto Torres, on the road to the village of Canaglia, Nurra Province, Northwestern Sardinia (Fig. 1). The Monte di Santa Giusta is composed of Triassic siliciclastic and carbonate deposits referred to the Germanic facies, Buntsandstein and Muschelkalk.

The Triassic deposits lie unconformably on the metamorphic complex of the Nurra, at the extreme Northwestern end of the Sardinian hercynian basement; they are usually separat-

ed from the Paleozoic basement by a thin terrigenous interval, known as “Verrucano sardo” (Lower Triassic to Anisian). This terrigenous interval crops out at the base of the carbonate succession (Fig. 2).

The first geological report of the Monte di Santa Giusta can be found in the “Voyage en Sardaigne” by Lamarmora, published in 1857. During the 19th and early 20th centuries, other Authors (Lovisato, 1884, 1903; De Stefani, 1891; Tornquist 1901, 1904) dedicated their studies to the geology and pa-

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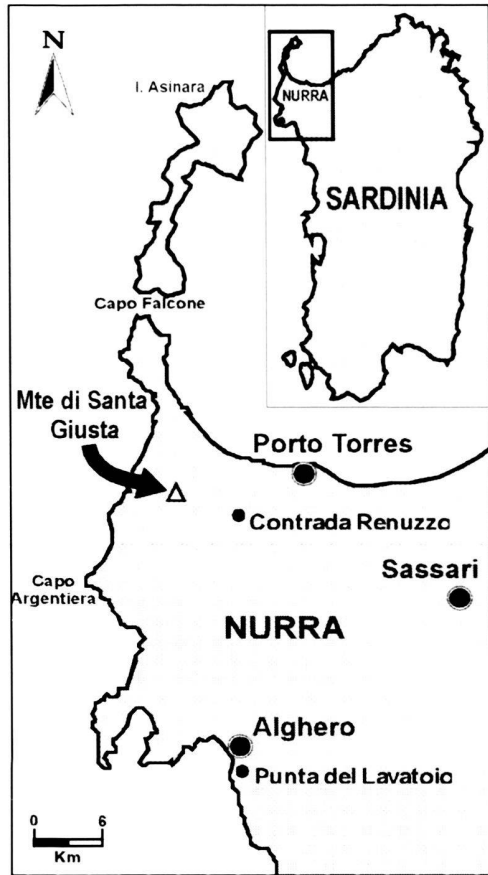


Fig. 1. Location map of the Monte di Santa Giusta (NW Sardinia).

leontology of the Permian and Triassic of Sardinia. In 1936, Oosterbaan published an extensive contribution to the geology of the Nurra Province, with special interest for Triassic deposits. The Author noticed the Germanic facies of the lithologies, and confirmed Alpine influences through some Upper Muschelkalk faunas in Sardinia; he also pointed out that the Muschelkalk of the Monte di Santa Giusta is obviously different from the Middle Triassic deposits of La Punta del Lavatoio (Southern Nurra, Fig. 1).

Investigations of the Triassic of Nurra restarted in 1977 when Gandin et al. published a description of the transition between the Permo-Triassic sandstones with porphyric and tuffaceous levels, and the calcareous and argillaceous series of the Muschelkalk with *Costatoria gr. goldfussi* Alberti and *Encrinus liliiformis* Lamarck.

In 1980, Flaviani described the complete succession of the Monte di Santa Giusta; conodonts were reported for the first time in the Upper Muschelkalk with *Encrinus liliiformis*. The author considered the sandstones, and the argillaceous, gypsiferous and dolomitic deposits as the lower part of the Middle Muschelkalk.

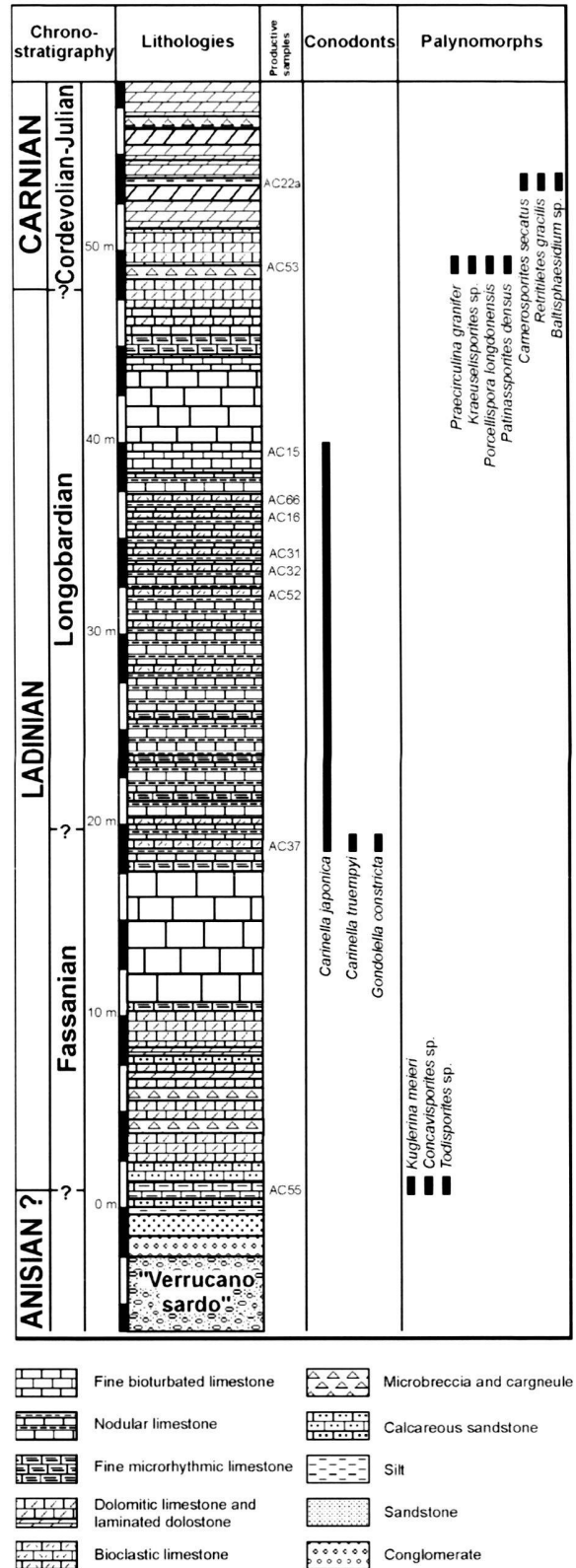


Fig. 2. Synthetic stratigraphic section of the Middle to Upper Triassic carbonate series of the Monte di Santa Giusta with diagnostic organisms.

In 1985, Bagnoli et al. evidenced a Ladinian conodont fauna from two sections in Northwestern Sardinia: Punta del Lavatoio, near Alghero, and Contrada Renuzzo, Southeast Monte di Santa Giusta. The Authors identified "*Epigondolella*" *truempii*, indicative of the upper Curionii Zone (Late Fassanian).

Cherchi & Schroeder (1985) quoted an unpublished study (Bartusch, 1985, Diploma University of Frankfurt) on the Monte di Santa Giusta, in which Triassic conodonts were also recognized from two different intervals. Bartusch identified *Metapolygnathus truempii* (Hirsch, 1971) which is known from the Upper Fassanian of Provence (France), and *Metapolygnathus hungaricus* (Kozur & Vegh, in Kozur & Mock, 1972) described from the Lower Longobardian of the Balaton Plateau (Hungary). According to Cherchi & Schroeder (1985), "*Bartusch has shown at the Monte Santa Giusta that the ranges of M. truempii and M. hungaricus overlap considerably, so that the two species do not seem to be always suitable for identifying the boundary between Fassanian and Longobardian*". In fact, in this paper it is demonstrated that the two species are to be considered as synonyms (see taxonomy).

New sedimentological and biostratigraphic data on the Triassic of the Monte di Santa Giusta have been recently presented in a Ms Degree Thesis of the University of Geneva (Carrilat, 1997); lithologies and microfacies of the Muschelkalk are here summarized. The Middle to Upper Triassic age [Lower Ladinian (Fassanian) to Lower Carnian (Julian)] of the Muschelkalk is mainly confirmed on the basis of conodonts and palynomorphs biostratigraphic analysis.

The Triassic Succession of the Monte di Santa Giusta

The Triassic synthetic succession of the Monte di Santa Giusta is composed of 60 meters of carbonate rocks overlying the terrigenous 50 meters thick "Verrucano sardo", generally considered as Lower Triassic to Anisian in age. The following carbonate lithotypes and microfacies are recognized; they occur repetitively along the succession, and may interfinger (Fig. 2).

Fine bioturbated limestone. They consist of dark limestone characterized by a clear patina, and form two massive sedimentary bodies in the field. Each body is composed of 3 to 4 beds of micritic limestone, up to 1 m thick. The surface of the beds is strongly vermiculated, and sometimes shows concentrations of recrystallised dasyclad algae (*Diplopora* sp.), often in life position, as well as load structures and microstylolite (Pl. 1, Fig. 1, 2).

The microfacies is relatively monotonous, dominated by dark mudstone. The thin bioturbation trails are characterized by a darker filling, underlined by black borders. Similar bioturbations were identified as *Spongiomorpha suevica* (Rieth) at the Punta del Lavatolo succession (Gandin, 1978). In some levels the micrite is totally recrystallised into microspar, or dis-

plays small spots of secondary dolomite. Microfossils are represented by small gastropods, filaments, thin shelled ostracods, often with connected valves, scarce echinoid fragments and benthic foraminifers, mostly Nodosariidae.

This type of bioturbated limestone has been identified in the Middle Triassic of numerous localities of the Western Tethys, often containing *Rhizocorallium*. Described in the Lower Muschelkalk of the Germanic Basin as "Wellenkalk" (Mägdefrau, 1929), a similar facies has been observed in younger strata in Minorca (Bourrouilh, 1973), Majorca (Colom, 1975), Sardinia (Gandin, 1978), in the Alps (Baud, 1987), and in the Pyrenees (Fréchengues, 1993). It represents the classic "*Calcaire vermiculé*" of the Dasycladacean carbonate platform (Zaninetti, 1976), now commonly identified as a ramp (Baud et al., 1991; Michalik et al., 1992).

The depositional environment of the algal bioturbated micritic limestone, which represents the deepest water deposit of the studied carbonate series, corresponds to the deep ramp zone (Fig. 3). Normal marine conditions are indicated by the presence of Dasyclad algae.

Fine microrhythmic and nodular limestone. The microrhythmic limestone is located at the base and at the top of the massive algal bioturbated limestone. It mainly consists of grey thin bedded (5 to 15 cm thick) micritic limestone with microrhythms. The nodular limestone is represented by a yellow mudstone, showing centimeter long bluish spots. Beds are 5 to 10 cm thick and are intercalated within marly levels. Some calcareous beds display cherts and/or strong bioturbation. In the microrhythmic, as well as in the nodular limestone, thin bioclastic intercalations occur (Pl. 1, Fig. 3, 4); they consist of calcarenites, and in the nodular limestones, they are often coarser, corresponding to calcirudites (Pl. 1, Fig. 5, 6). The calcarenites and calcirudites are described below as Bioclastic limestone.

Both lithologies of the Fine microrhythmic and nodular limestone exhibit the same microfacies; it is a mudstone (microsparite) in which some microrhythms can be observed, especially when the rock has been preserved from recrystallisation. The microrhythms contain some quartz grains, and are underlined by thin layers of organic matter. Similar structures have been described by Fréchengues (1993) in the Triassic of the Pyrenees. Diagenetic processes and compaction of the mudstone, together with secondary overgrowth of the bioclastic intercalations, are responsible for the nodular structure. In thin section, Nodosariidae represent the main microfossils; they appear usually accumulated, aligned parallel to the bedding. Filaments, and some connected valves of ostracods are associated. A few pyritized foraminifers (*Ammodiscus* sp.) were found in the conodont preparations, which were not observed in thin sections.

The depositional environment of the microrhythms and nodular limestone containing no macrofossil corresponds to a less deeper zone than where fine bioturbated limestones deposit. It was attributed to a shallow carbonate ramp; probably

in connection with the lagoon. Large quantities of mud are indicative of limited water circulation. The microrhythms as well as the calcarenitic intercalations reveal punctual presence of currents, also responsible for the displacement of the Nodosariidae, in a low energy environment.

Bioclastic limestone. This lithotype consists of bioclastic micrite (biomicrite to coarser biomicrudite) intercalated within the Fine microrhythmic and nodular limestone; the bioclastic micrite is the most productive for conodonts (Pl. 1, Fig. 3, 4). The bioclastic horizons often present yellow to orange spots linked to secondary dolomitisation, which make the levels well recognizable in the field.

The microfacies reveals wackestone to packstone, in which the dark grey micrite is locally replaced by sparite; the packstone to wackestone shows plane to low-angle laminae. No larger scale sedimentary structure were observed. Evidence for major dissolution is pointed out by omnipresent microstylolites.

The bioclasts, of variable size and shape, consist of numerous fragments of echinoderms, bivalves, costulated or smooth brachiopods (Rhynchonellida and Terebratulida) and gastropods; costulated gastropods are generally of bigger size. Some connected smooth valves of ostracods are also present. Dasyclad algae (*Diplopora* sp.), *Spirorbis* sp., recrystallised foraminifers, such as *Aulotortus* sp. and *Lamelliconus* sp., are to be found in association with Nodosariidae; encrusting forms (*Tolypammina gregaria* Wendt?) (Pl. 2, Fig. 1) build up irregular masses around the clasts, or they fill up burrows. Some pellets, and some oncoids ranging from 0.3 to 1.5 cm are observed; fragments of bivalves, brachiopods and crinoids constitute the nuclei of the oncoids (Pl. 1, Fig. 5, 6). Some algal balls are characterized by cauliflower structure trapping thin bioclasts. Large crinoid ossicles, partially derived from *Encrinurus liliiformis* Mill., are abundant, sometimes forming a crinoidal sand (Pl. 2, Fig. 2); some are entirely preserved, others are sharply broken or rounded by transport. These features indicate various energy conditions. The crinoidal sand must be provided by a shoal located in the vicinity of the Monte di Santa Giusta environment, while encrusting foraminifers and oncoids developed in the back shoal zone.

The depositional conditions of the Bioclastic limestone are of higher energy, in contrast to those of the Fine microrhythmic limestone in which the Bioclastic limestone is intercalated. The diversity of bioclasts related to some allochthony, and their random distribution in the beds attest of their deposition during sporadic events such as tidal currents or storms, also responsible for conodont transportation. Repetitive bioclastic accumulations have been identified as tempestites from numerous localities in Muschelkalk deposits, for instance in SW Germany (Aigner, 1985; Demonfaucon, 1982), in Provence (Brocard & Philip, 1987), in Silesia (Dzulynski & Kubicz, 1975), in the Pyrenees (Fréchengues, 1993), in eastern France (Püringer, 1984), and in the Carpathians (Michalik et al., 1992).

Dolomitic limestone and laminated dolostone. This facies assemblage is characterized by thin beds (2 to 4 cm thick) of white to yellowish dolomitic limestone and dolostone. Erosion reveals thin and regular dark laminations on bed surfaces, and small concretions of calcite and/or silica identified as gypsum pseudomorphs. Numerous intercalated brown and white cherts are observed lying parallel to the stratification (Pl. 2, Fig. 3, 4).

The microfacies consists of laminated dolomicrosparite and dolopelmicrite with laminoid fenestrae. It presents some dolomitic peloids, disjointed cryptalgal mats ("leopard facies"), and rare well preserved Nodosariidae arranged parallel to laminations. Gypsum pseudomorphs exhibiting geopetal structures are common within the laminations, as well as sandy aggregates. Bioclastic levels, similar to those previously described as tempestites in the Bioclastic limestone, but which do not contain conodonts, are intercalated within the laminated dolostones.

Palynological analysis of the dolomitic facies reveals that more than 50% of the palynofacies is made out of small chains of cyanobacteria, which were also identified by scanning electron microscopy. Similar microbial filaments have been described by Gall (1990) from a Lower Triassic laminated limestone of the Buntsandstein (Vosges, France).

Late diagenetic recrystallisation may obliterate thin structures and laminations, producing a homogenous dolomicrosparite. A few desiccation cracks are observed only in this facies. The "leopard facies" probably derives from *in situ* mechanical and/or biological deformation of the cryptalgal laminae.

The dolomitic limestone and laminated dolostone were deposited close to the shore, in the back bank environment, in an evaporitic context. Even though evaporites were not directly observed in the field, silicification, algal mats, pseudomorphs, collapsed breccias and cargneules give evidence for primary evaporites and dolomite. Different levels of gypsum and dolomite attest of a period of instability before the main marine transgression.

Coastal plain deposits. They are intercalated in the Dolomitic limestone and laminated dolostone. Characterized by various facies, they are normally rich in quartz, forming calcareous sandstones (Pl. 2, Fig. 5); they can also be marly or altered in *cargneule*. Some thin levels of silts and clays and a few polygenic microbreccias containing mud pebbles are associated to these deposits.

The microfacies of the calcareous sandstones consists of 40 to 60% of sharp and not well-sorted quartz grains. Less than half of the particles is smaller than 250 μm ; bigger elements (up to 1 mm) are scarce and randomly distributed. A few levels present an upward fining, and well-preserved climbing ripples. The carbonate cement is made out of sparite or dolosparite. Oxides (hematite) and silicates (zircon) are present in this facies. In coarser sandy levels rounded quartz pebbles occur measuring up to 6 mm.

The microbreccias contain dolomitised and/or very thin sandy lithoclasts; coarser quartz grains are also present as well as centimetric argillaceous mud pebbles. The matrix consists of recrystallised micrite into microsparite to sparite.

The environment of deposition corresponds to the coastal plain zone. Calcareous sandstones interfingering with laminated and dolomitic limestones indicate a trend of progressive incursions of the sea. The heterogeneous detrital levels (microbreccias) reveal continental influences in the transgressive Muschelkalk deposits of NW Sardinia.

Flood plain deposits. They are located at the base of the carbonate succession and represent a 50 meters thick terrigenous interval (Buntsandstein). The lower part of this interval is characterized by whitish to yellow conglomerates. This passes upward to alternations of red silts, yellowish to grey sandstones, and white arkosic sandstones (Pl. 2, Fig. 6). The proportion of silt rises towards the top of the terrigenous interval, while the presence of arkosic sandstone diminishes.

The depositional environment of these silts, sandstones and conglomerates corresponds to the lowest part of a flood plain. A removal from the detrital source is evidenced upward, before the carbonate sedimentation starts.

Depositional Model

A 3D depositional model for the Triassic carbonate succession of the Monte di Santa Giusta is presented in Fig. 3. It is mostly based on the detailed study of the facies and microfacies and their relationship as well.

The sediments were deposited on a carbonate ramp, in a restricted shallow marine environment. The carbonate ramp (Ahr, 1973) differs from a carbonate platform by the lack of any protective barrier (reef) towards the open sea. This absence makes the carbonate ramp sensitive to swells, waves and storms (Aigner, 1985), responsible, at the Monte di Santa Giusta, for bioclastic (biomicrite to biomicrudite) intercalations within bioturbated or microrhythmic mudstones. Similar bioclastic deposits, such as tempestites, have also been observed in the Middle Triassic Punta del Lavatoio section, of the Southern Nurra Province (Gandin, 1978).

Concerning the Monte di Santa Giusta carbonate ramp, facies distribution from the deepest to the most shallow water environment is as follows:

- The **Fine bioturbated limestone** corresponds to the deepest zone of the carbonate ramp, attesting of a calm and soft sea bottom. Dasyclad algae (*Diplopora annulata*) and some foraminifers (*Pilamina* sp.) characterize the bioturbated facies (*Calcaire vermiculé*), which is well developed all around the Middle Triassic Western Tethys.
- Closer to the coast, the bioturbated limestone is gradually replaced by the **Fine microrhythmic and nodular limestone**, which contains bioclastic intercalations (Bioclastic limestone).

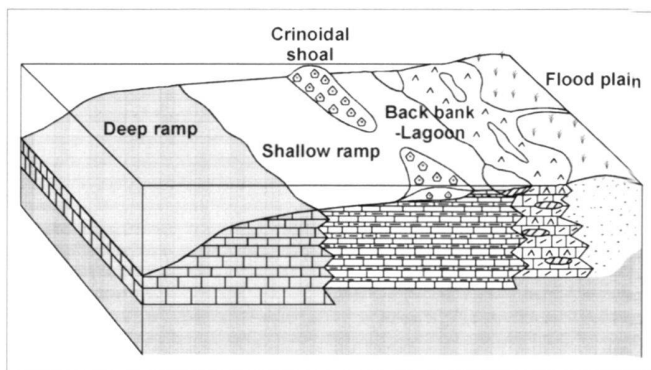


Fig. 3. Schematic depositional model and facies evolution of the Monte di Santa Giusta Middle to Upper Triassic carbonate series.

- In the carbonate ramp model of Aigner (1985), a crinoid bank occurs landward creating a back-bank area. Despite the fact that no barrier was observed at the Monte di Santa Giusta, the extensive presence of crinoidal sand in the **Bioclastic limestone** is the witness of a large crinoidal shoal delimiting a lagoonal depositional environment. From time to time, bioclasts coming from the shoal and from open sea were brought by storms into the lagoonal micritic sediments. These bioclasts were quickly colonized by encrusting foraminifers (*Tolypamina gregaria?*) and cyanobacterias forming oncoids. According to Wilson (1975), oncoids are typical of shallow and calm back-bank environments, developing on the edge of lagoons or channels. The complete succession of a bioclastic intercalation presents a sharp erosive base underlying a not well sorted bioclastic packstone, grading up to parallel and low-angle laminated facies. The bioclastic intercalation gives evidence for the distal part of tempestites.
- The back bank, mud rich, lagoonal environment passes laterally and gradually landward to the **Dolomitic limestone and laminated dolostone**, where dolomite and gypsum develop (Chamley, 1988). Desiccation cracks, fenestrae and laminae originating from algal mats become common and characterize this environment. On shore, gypsum beds develop in calcareous sandstones and clays related to the flood plain, where silts, sandstones and conglomerates attest of the detrital source.

Biostratigraphy

Biostratigraphically significant microfossils (conodonts and palynomorphs) occur all along the Middle to Upper Triassic section of the Monte di Santa Giusta (Fig. 2). Palynological slides were prepared from samples collected in a marly level of the supratidal deposits (AC55), at the base of the calcareous interval, and in the Dolomitic limestone and laminated dolostone (AC22a, AC53), at the top of the series. Samples for conodont

extractions (AC: 15, 16, 31/32, 37, 52, 66) were all collected in the Bioclastic intercalations of the Fine microrhythmic and nodular limestone in the middle of the section.

Conodonts

The bioclastic intercalations (Bioclastic limestone) of the Fine microrhythmic and nodular limestone are the most productive for conodonts. Preparations were realized with formic acid attacks on small rock samples (less than 1 kg). The conodont fauna is not abundant, but well preserved. The identified species at the Monte di Santa Giusta are *Gondolella constricta* Mosher & Clark, 1965, described from the Humboldt Range (Nevada), *Carinella truempyi* (Hirsch, 1971) originally recorded from the Muschelkalk of Provence (France), and *Carinella japonica* (Hayashi, 1968) first described from the Adayama Formation (Japan). *Gondolella constricta* has also been recorded from the European Alps, the Carpatho-Balkan Range, the Hellenids, the Kocaeli Peninsula (Turkey), and from Japan. *Carinella truempyi* is known from the Southern France type locality, and from the Balaton Plateau (Hungary). At the Monte di Santa Giusta, 3 specimens of *Gondolella constricta* and 3 specimens of *Carinella truempyi* have been identified in sample AC37.

Carinella japonica is known from Japan, and in Europe from the Hellenids and the Carpatho-Balkan Range; this is the first occurrence of the species in Sardinia, which is so far the westernmost locality for *Carinella japonica* in all the Western Tethys. At the Monte di Santa Giusta, 35 specimens have been identified from samples AC: 15, 16, 31/32, 37, 52, 66.

According to Kovacs & Kozur (1980), *Carinella truempyi* is considered as an index fossil for the Truempyi-range-Zone, which corresponds to the Upper Curionii-Zone of the Upper Fassinian; *Gondolella constricta* has a longer range, from Illyrian to Fassinian (Vrielynck, 1987). Consequently, the joint occurrence of *Carinella truempyi* and *Gondolella constricta* indicates an Upper Fassinian age for the lower to middle part of the carbonate series of the Monte di Santa Giusta (Fig. 2). The stratigraphic range of *Carinella japonica*, which is well represented throughout the middle part of the studied section, extends from the top of the Gredleri-Zone to the base of the Archelaus-Zone (Krystyn, 1983), that is during a short interval within the Lower Longobardian. This allows concluding that the conodont bearing part of the section of the Monte di Santa Giusta is of Upper Fassinian to Lower Longobardian age.

Taxonomy

CONODONTOPHORIDA Eichenberg 1930

GONDOLELLA Stauffer and Plummer, 1932

Type-species: *Gondolella elegantula* Stauffer and Plummer, 1932

Gondolella constricta Mosher and Clark, 1965

Pl. 3, Fig. 1-3

- 1965 *Gondolella constricta* n. sp. Mosher & Clark, p. 560, pl. 65, figs. 11, 14, 15, 19, 21, 25.
- 1965 *Gondolella mombergensis* Tatge – Mosher & Clark, p. 560, pl. 65, figs. 20, 23, 27, 28.
- 1965 *Gondolella mombergensis* – Budurov & Stefanov, pl. 1, fig. 2.
- 1966 *Gondolella constricta* – Clark & Mosher, p. 390, pl. 47, figs. 1, 2, 5.
- 1966 *Gondolella mombergensis* – Catalov & Stefanov, pl. 1, figs. 9, 17.
- 1968 *Gondolella constricta* – Mosher, p. 937, pl. 116, figs. 3, 4, 7, 11.
- 1968 *Gondolella constricta* – Mosher, pl. 119, figs. 1, 2, 3.
- 1968 *Gondolella constricta* – Hayashi, p. 70, pl. 1, fig. 1.
- 1968 *Gondolella navicula* Huckriede – Budurov & Zagortschev, pl. 1, figs. 22, 23.
- 1971 *Neogondolella constricta* (Mosher & Clark) – Sweet et al., pl. 1, figs. 4, 5.
- 1971 *Neogondolella mombergensis* (Tatge) – Sweet et al., pl. 1, fig. 24.
- 1971 *Gondolella mombergensis* – Mock, pl. 4, fig. 7.
- 1971 *Gondolella constricta* – Hayashi, pl. 2, fig. 7.
- 1972 *Neogondolella constricta* – Budurov & Stefanov, p. 838, pl. 4, figs. 29–31.
- 1973 *Neogondolella constricta* – Mosher, pp. 165–166, pl. 19, figs. 30, 31.
- 1973 *Neogondolella constricta* – Sweet in Ziegler ed., pp. 131–132, pl. "Neogondo. I", fig. 4.
- 1974 *Neogondolella constricta* – Budurov & Stefanov, pp. 299–300, pl. 1, figs. 7, 8, 15–18.
- 1975 *Neogondolella constricta* – Budurov & Stefanov, pp. 15–16, pl. 3, figs. 1, 2.
- 1975 *Neogondolella constricta* – Catalov & Stefanov, p. 1264, pl. 1, figs. 1–5.
- 1975 *Gondolella constricta* – Trammer, pl. 24, figs. 2, 3.
- 1975 *Gondolella constricta* – Zawidzka, pl. 42, fig. 1.
- 1975 *Neogondolella mombergensis* – Gedik, pp. 131–132, pl. 1, figs. 1, 2, 3.
- 1975 *Gondolella constricta* – Zawidzka, pl. 42, figs. 1, 3.
- 1976 *Neogondolella constricta* – Patruilus et al., pl. 3, fig. 2.
- 1976 *Neogondolella mombergensis* – Kemper et al., p. 106, pl. 6, fig. 5.
- 1977 *Neogondolella constricta* – Sudar, pp. 285–286, pl. 6, figs. 9–11.
- 1977 *Gondolella constricta* – Misik et al., pl. 6, fig. 3.
- 1978 *Neogondolella constricta* – Catalov & Budurov, p. 89, pl. 1, figs. 9–12.
- 1979 *Neogondolella mombergensis* – Mietto & Petroni, p. 9, pl. 1, fig. 1.
- 1980 *Gondolella constricta* – Kovacs & Kozur, pl. 3, figs. 4a–d.
- 1983 *Neogondolella constricta* – Kolar-Jurkovsek, p. 339, pl. 9, figs. 1–2.
- 1984 *Gondolella constricta* – Pevny, p. 168, pl. 79, figs. 5–6, 12.
- 1984 *Gondolella constricta* – Nicora & Kovacs, p. 144, pl. 7, figs. 1, 4, 8, 9, 10, 11, 12, 14, pl. 8, figs. 3–5.
- 1986 *Neogondolella constricta* – Sudar, pl. 6, figs. 10–16, pl. 7, figs. 9–11.
- 1987 *Gondolella constricta* – Vrielynck, p. 134, pl. 3, figs. 1–3.
- 1997 *Gondolella constricta* – Pevny & Salaj, pl. 9, figs. 14–15; pl. 10, figs. 1–2; pl. 11, figs. 2–3.

Occurrence: Triassic of Nevada, European Alps, Sardinia, Carpatho-Balkan Range, Hellenids, Kocaeli Peninsula (Turkey), Japan.

Age: Upper Anisian to Lower Ladinian (Illyrian to Fassinian). In NW Sardinia: Upper Fassinian.

Carinella truempyi (Hirsch, 1971)
Pl. 3, Fig. 4–6

- 1967 *Polygnathus mungoensis* Diebel – Pomesano Cherchi, p. 229, pl.16, figs. 5–17.
1967 *Gondolella milleri* Muller – Pomesano Cherchi, p. 230, pl.16, figs.18–20; pl. 17, figs. 1–3.
1971 *Gladigondolella truempyi* n. sp. Hirsch, pp. 66–68, pl.1, figs. 1–10.
1972 *Gladigondolella truempyi truempyi* Hirsch - Hirsch, p. 815, pl. 1, figs. 1–3.
1972 *Gladigondolella truempyi denticulata* n. subsp. Hirsch – Hirsch, p. 815, pl. 1, figs. 4–6.
1972 *Metapolygnathus truempyi* (Hirsch) – Kozur, pl. 1, fig. 4.
1972 *Epigondolella truempyi* (Hirsch) – Kozur & Mostler, pl.1, figs. 2–3.
1972 *Epigondolella hungarica* n. sp. Kozur & Vegh in Kozur & Mock, p. 8, pl. 2, figs. 3–7.
1977 *Epigondolella? Hungarica* – Ziegler, pl. 3, figs. 4a–c.
1980 *Metapolygnathus truempyi* – Kovacs & Kozur, pl. 5, figs. 5.
1980 *Metapolygnathus truempyi* – Kozur, pp. 124, 144–145.
1981 *Carinella truempyi* (Hirsch) – Hirsch, p. 206.
1984 “*Epigondolella? truempyi*” – Bagnoli et al., pp. 312, 314, pl.1, figs. 1a–4b; pl. 2, figs. 1a–4b.
1985 *Metapolygnathus truempyi* – Bartusch in Cherchi & Schroeder, pp. 46–47.
1987 *Carinella truempyi* – Vrielynck, p.122.

Occurrence: Muschelkalk of Provence (France), Sardinia, Balaton Plateau (Hungary).

Age: Lower Ladinian (Fassanian, except the lowermost part). In NW Sardinia: Upper Fassanian.

Remark: *Epigondolella hungarica* Kozur & Vegh in Kozur & Mock, 1972, from the Balaton Plateau (Hungary) is here considered as a junior synonym of *Carinella truempyi* (Hirsch, 1971). Both names have been used for the Triassic of the Monte di Santa Giusta by Bartusch (1985), who adequately noticed the overlapping of the respective ranges of *hungarica* and *truempyi*.

Carinella japonica (Hayashi, 1968)
Pl. 3, Fig. 7–15

- 1968 *Polygnathus japonicus* n. sp. Hayashi, p. 73, pl. 3, figs. 1 a–c.
1972 *Metapolygnathus japonicus* (Hayashi) – Kozur, p. 3.
1977 *Epigondolella? japonica* (Hayashi) – Ziegler, pl. 3, figs. 1 a–c.
1978 *Carinella japonica* (Hayashi) – Catalov & Budurov, p. 93, pl. 2, fig. 17.
1980 *Metapolygnathus japonicus* – Kovacs & Kozur, pl. 7, figs.1–2.
1981 *Carinella hungarica* (Kozur & Vegh) – Koike, pl.1, fig. 38.
1983 “*Epigondolella? japonica*” – Krystyn, pl. 7, figs. 1–3.
1987 *Carinella japonica* – Vrielynck, pl.1, figs 7–12.

Occurrence: Japan, Sardinia, Hellenids, Carpatho-Balkan Range.

Age: Upper Ladinian (Lower Longobardian), from top of *Gredleri* to base of *Archelaus* Zones.

Remarks: In the material from the Monte di Santa Giusta, a few specimens of *Carinella japonica* display a rounded posterior end instead of a pointed one in accordance with the original diagnosis. As this particular character is not related to the size, it is not an ontogenetically changing feature. Consequently, the posterior basal plane is not pointed either, but rounded and may present a by-pass and a constriction, which is sometimes visible on the platform.

Palynomorphs

Samples of silts, marly limestones and marly dolostones occurring throughout the succession have been submitted to palynological analysis. Plate 4 illustrates some of the palynomorphs yielded by three productive samples. The lack of palynomorphs in the middle part of the section prevented establishing of a detailed palynostratigraphic zonation for the Triassic of the Monte di Santa Giusta. Nevertheless, together with the conodont zonation, palynomorphs helped to refine the stratigraphic column (Fig. 2).

Among abundant amorphous organic matter (AOM), the most characteristic Middle Triassic palynomorph of the base of the calcareous interval is *Kuglerina meieri* Scheuring, 1978 (sample AC55). This species, first recorded from the Longobardian Upper Meride limestone (Monte San Giorgio, Ct. Ticino, Switzerland), extends, according to Van der Eem (1983), from the Fassanian to the Lower Cordevolian. At the Monte di Santa Giusta, *Kuglerina meieri* is associated with the long ranging specimens *Concavisporites* sp., and *Todisporites* sp. The absence of a Carnian assemblage, and the scarcity of *Kuglerina meieri* in sample AC55 allow to conclude that the first appearance of this species in the studied area is in the Ladinian, possibly in the Lower Fassanian. This age is in agreement with the stratigraphic position of *Kuglerina meieri* 20 meters below the first occurrence of the conodont assemblage with *Carinella japonica*, *Carinella truempyi* and *Gondolella constricta* of Upper Fassanian age.

In the upper part of the section, 10 meters above the last occurrence of *Carinella japonica*, which is indicative of the Lower Longobardian, a marly dolostone level yielded *Praecirculina granifer* (Leschik in Kräusel & Leschik, 1956) Klaus, 1960, *Kraeuselisporites* sp., *Porcellispora longdonensis* (Clarke) Scheuring, 1970 (sample AC53), commonly recorded in the Middle Ladinian to Carnian (Blendinger, 1988), and *Patinasporites densus* Scheuring, 1970. This last species is considered as a Carnian element. It first occurs in the *vigens-densus* phase of Van der Eem (1983) (Lower Carnian, Cordevolian except lowermost part) and ranges up to the uppermost Carnian (Warrington, 1996).

The last significant palynomorphs observed in the uppermost part of the section, in a marly dolostone located 5 meters below the top, are *Camerosporites secatus* Leschik, 1956, associated with *Retitriletes gracilis* Schulz, 1967 and rare marine elements such as *Baltisphaeridium* sp. (sample AC22a). *Camerosporites secatus*, first recorded from the Keuper of the Basel area (Switzerland), is significant of the *Camerosporites secatus* phase, which is generally considered as an uppermost Ladinian-Carnian event (Visscher & Krystyn, 1978; Visscher & Brugman, 1981; Van der Eem, 1983). In sample AC22a, diagnostic elements to discern a Carnian age are lacking, nonetheless because a Carnian age is documented in the underlying part of the succession (AC 53), then the presence of *Camerosporites secatus* is referable to the Carnian part of this phase. *Camerosporites secatus* was notably pointed out in the

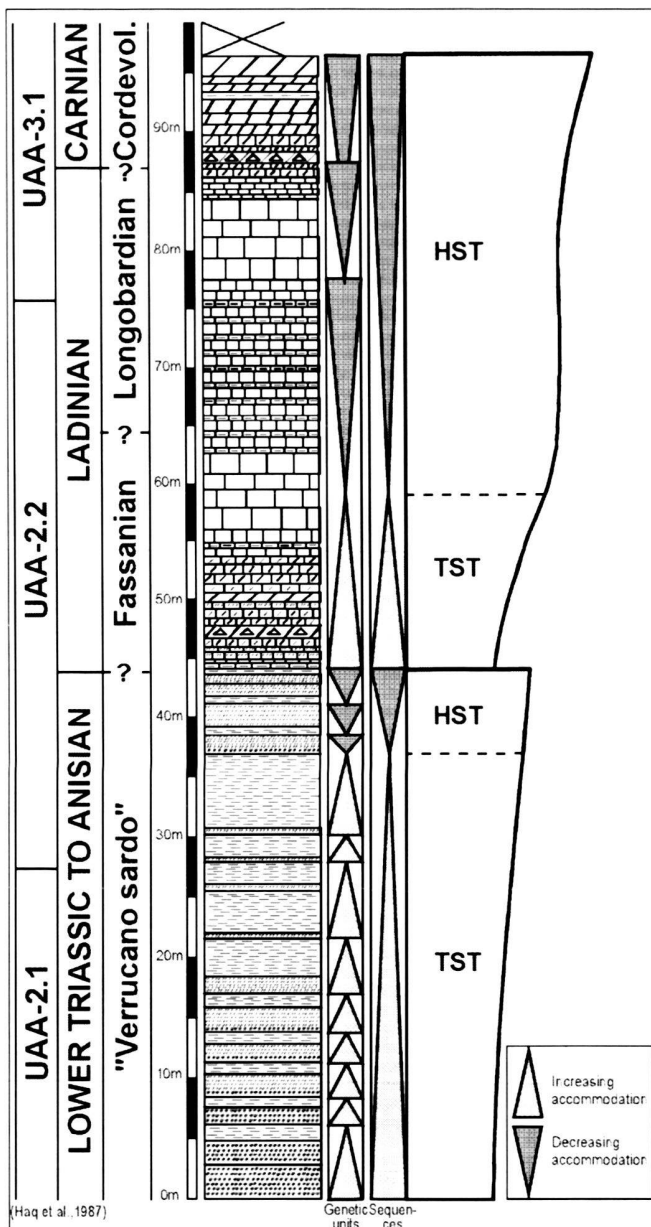


Fig. 4 Correlation between the sequence stratigraphy interpretation of the Middle (Lower Fassanian) to Upper (Cordevolian to Julian) Triassic carbonate series of the Monte di Santa Giusta and the Haq et al. (1987) Cycle chart.

Nurra Province of Sardinia (Pittau Demelia & Del Rio, 1980; Pittau Demelia & Flaviani, 1982) and attributed to the Upper Cordevolian to Julian.

In conclusion, combined palynological data and conodont biostratigraphy indicate a Lower Fassanian age for the base of the calcareous series of the Monte di Santa Giusta. The conodont bearing interval of the middle part of the section is

hence of Upper Fassanian to Lower Longobardian age; the top of the section is ascribed to the Upper Cordevolian to Julian (Fig. 2).

Sequence Stratigraphy

A correlation of the Middle to Upper Triassic of the Monte di Santa Giusta with the Cycle chart of Haq et al. (1987) is tentatively proposed on the basis of the micropaleontological data and the facies association.

The Middle Upper Triassic partition in sequences done in Haq et al. (1987) only gives an approximation, but reveals that the Monte di Santa Giusta carbonate succession corresponds to a third order sequence (UAA-2.2).

The section of the Monte di Santa Giusta is subdivided into numerous genetic units (Fig 4); each unit represents a shallowing or deepening up parasequence, respectively corresponding to decreasing or increasing accommodation. Assembling these genetic units allows to identify the genetically related transgressive and highstand deposits (Fig. 4). In the shallow environment of the Monte di Santa Giusta, lowstand systems tracts are absent, as recorded in many other shallow shelf settings (Baum & Vail, 1988). Consequently, sequence boundaries are merged with transgressive surfaces.

The sequence boundary type 1 (UAA-2.1-UAA-2.2) of the Cycle chart does not exactly match the one proposed for the Monte di Santa Giusta. Indeed, the transgressive surface is located in the Lower Fassanian, instead of the Upper Anisian, on the basis of palynological data. The first calcareous beds grading upward to massive micritic bioturbated limestone represent the transgressive system tract of the cycle. The massive limestone and the nodular limestone with conodonts of Upper Ladinian age have been deposited during the highstand system tract. The conodont bearing interval appears only in the mid highstand system tract of the Monte di Santa Giusta section: according to Brett (1995), *conditions favouring unaltered preservation are probably best developed during times of mid highstand in the deposition of marine sedimentary sequences*. A ravinement surface is located in the late highstand system tract of the Monte di Santa Giusta succession and gives evidence for a relative sea-level rise, probably linked to 4th or 5th order cycle. The calcareous and dolomitised breccias of the Lower Carnian situated at the top of the series reveal a sequence boundary before the next transgressive event. This sequence boundary is also younger than the one separating UAA-2.2 from UAA-3.1 (Haq et al. 1987) and is possibly of Lower Carnian age.

Conclusions

The lithostratigraphic reference section for the Muschelkalk of the Monte di Santa Giusta is mostly composed of carbonates of Lower Ladinian to Lower Carnian age (Fassanian to Julian). Biostratigraphy of the Muschelkalk is based on palynological data, and especially on Tethyan conodont assemblages,

which confirm Tethyan influences in the so called Germanic Triassic of Sardinia.

The association of *Carinella truempyi* and *Gondolella constricta*, occurring at the base of the conodont bearing interval, is indicative of the Upper Fassinian, and in the middle to upper part, *Carinella japonica* characterizes the Lower Longobardian (Fig. 2). This is the first occurrence of *Carinella japonica* in Sardinia, so far the westernmost locality for the species in all the Western Tethys.

Palynological data obtained for the base and for the top of the carbonate series are respectively indicative of the Lower Fassinian, and the Cordevolian to Julian.

Lithologies and microfacies analysis allowed to establish a depositional model for the Middle to Upper Triassic deposits of the Monte di Santa Giusta. Sedimentological data provide evidence for a shallow and quiet marine environment located on a carbonate ramp. The lack of any protective barrier makes the carbonate ramp sensitive to swells and waves, responsible for small bioclastic accumulations within bioturbated and/or microrhythmic mudstones. The conodonts, allochthonous in the environment and brought into the basin from the open sea, occur in the bioclastic intercalations; they are the witness of sporadic events of higher energy.

In terms of sequence stratigraphy, comparison with the Cycle chart of Haq et al. (1987) reveals that the series of the Monte di Santa Giusta corresponds to a third order sequence (UAA-2.2). On the basis of biostratigraphic data, some mismatches with the sequence boundaries are evidenced; the UAA-2.2 sequence is younger in the Monte di Santa Giusta than in the Cycle chart. This variation is related to local tectonics, which controls relative sea level.

Finally, some extended links have also been investigated, especially with the Muschelkalk of Provence, Southern France (Chabrier & Mascle, 1975; Brocard, 1991), which shows close sedimentological and biostratigraphic affinities with the Middle to Upper Triassic of NW Sardinia. These similarities confirm westward communications with the Provence and the Balearic marine domains.

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Plate 1

- Fig. 1. Vermiculated limestone
- Fig. 2. Dasycladacean mudstone
- Fig. 3. Calcarenite interlayered in microrhythmic limestone
- Fig. 4. Alternation packstone-mudstone
- Fig. 5. Nodular limestone with coarse bioclastic level (oncoids)
- Fig. 6. Oncoidal packstone

Plate 2

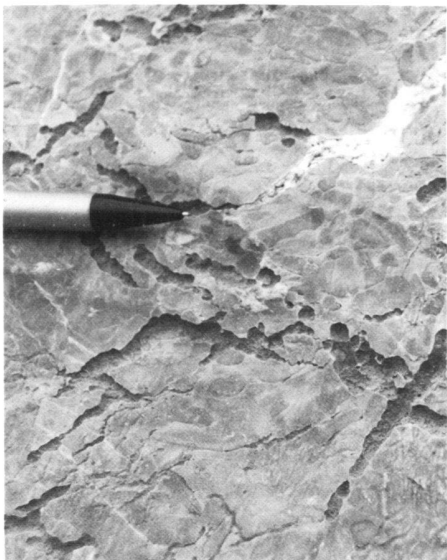
- Fig. 1. Wackestone with encrusting foraminifera
- Fig. 2. Crinoid ossicles accumulation
- Fig. 3. Dolomitic limestone and laminated dolostone
- Fig. 4. Gypsum pseudomorphs in laminated dolostone
- Fig. 5. Calcareous sandstone
- Fig. 6. White arkosic sandstones and red silts

Plate 3

- Fig. 1. *Gondolella constricta* Mosher & Clark, 1965, specimen 37AC34, Mte di Santa Giusta (Nurra, Sardinia), Upper Fassanian, under side view, 550 µm.
- Fig. 2. *Gondolella constricta* Mosher & Clark, 1965, specimen 37AC34, Mte di Santa Giusta (Nurra, Sardinia), Upper Fassanian, lateral view, 550 µm.
- Fig. 3. *Gondolella constricta* Mosher & Clark, 1965, specimen 37AC34, Mte di Santa Giusta Nurra, Sardinia), Upper Fassanian, upper side view, 550 µm.
- Fig. 4. *Carinella truempyi* (Hirsch, 1971), specimen 37AC30, Mte di Santa Giusta (Nurra, Sardinia), Upper Fassanian, under side view, 500 µm
- Fig. 5. *Carinella truempyi* (Hirsch, 1971), specimen 37AC30, Mte di Santa Giusta (Nurra, Sardinia), Upper Fassanian, lateral view, 500 µm.
- Fig. 6. *Carinella truempyi* (Hirsch, 1971), specimen 37AC30, Mte di Santa Giusta (Nurra, Sardinia), Upper Fassanian, upper side view, 500 µm.
- Fig. 7. *Carinella japonica* (Hayashi, 1968), specimen 37AC37, Mte di Santa Giusta (Nurra, Sardinia), Lower Longobardian, under side view, 560 µm.
- Fig. 8. *Carinella japonica* (Hayashi, 1968), specimen 37AC37, Mte di Santa Giusta (Nurra, Sardinia), Lower Longobardian, lateral view, 560 µm.
- Fig. 9. *Carinella japonica* (Hayashi, 1968), specimen 37AC37, Mte di Santa Giusta (Nurra, Sardinia), Lower Longobardian, upper side view, 560 µm.
- Fig. 10. *Carinella japonica* (Hayashi, 1968), specimen 52AC23, Mte di Santa Giusta (Nurra, Sardinia), Lower Longobardian, under side view, 530 µm.
- Fig. 11. *Carinella japonica* (Hayashi, 1968), specimen 52AC23, Mte di Santa Giusta (Nurra, Sardinia), Lower Longobardian, lateral view, 530 µm.
- Fig. 12. *Carinella japonica* (Hayashi, 1968), specimen 52AC23, Mte di Santa Giusta (Nurra, Sardinia), Lower Longobardian, upper side view, 530 µm.
- Fig. 13. *Carinella japonica* (Hayashi, 1968), specimen 66AC14, Mte di Santa Giusta (Nurra, Sardinia), Lower Longobardian, under side view, 400 µm.
- Fig. 14. *Carinella japonica* (Hayashi, 1968), specimen 66AC14, Mte di Santa Giusta (Nurra, Sardinia), Lower Longobardian, lateral view, 400 µm.
- Fig. 15. *Carinella japonica* (Hayashi, 1968), specimen 66AC14, Mte di Santa Giusta (Nurra, Sardinia), Lower Longobardian, upper side view, 400 µm.

Plate 4

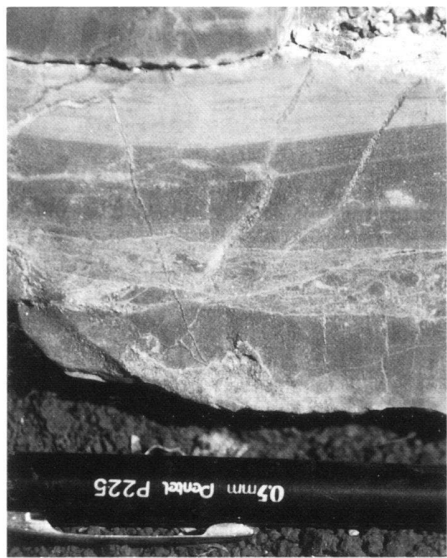
- Fig. 1. *Camerosporites secatus* Leschik, 1956, AC22A.
- Fig. 2. *Retitriteles gracilis* Schulz, 1967, AC22A.
- Fig. 3. *Porcellispora longdonensis* (Clarke) Scheuring, 1970, AC53C.
- Fig. 4. *Praecirculina granifer* (Leschik in Kräusel & Leschik, 1956) Klaus, 1960, AC53A.
- Fig. 5. *Praecirculina granifer* (Leschik in Kräusel & Leschik, 1956) Klaus, 1960, AC53A.
- Fig. 6. *Patinasporites densus* Scheuring, 1970, AC53C.
- Fig. 7. *Baltisphaeridium* sp., AC22A.



1



2



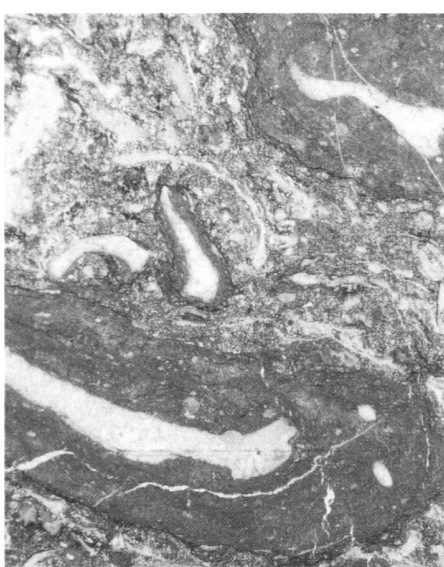
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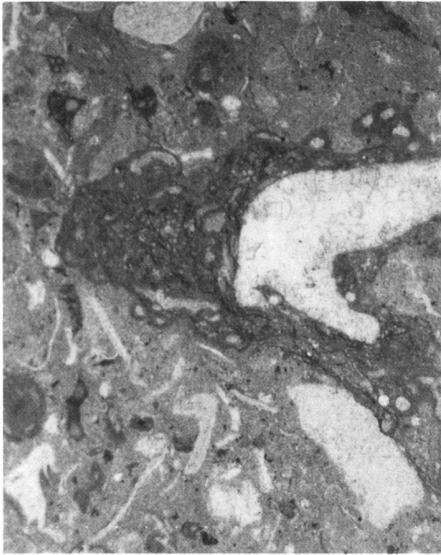
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5



6



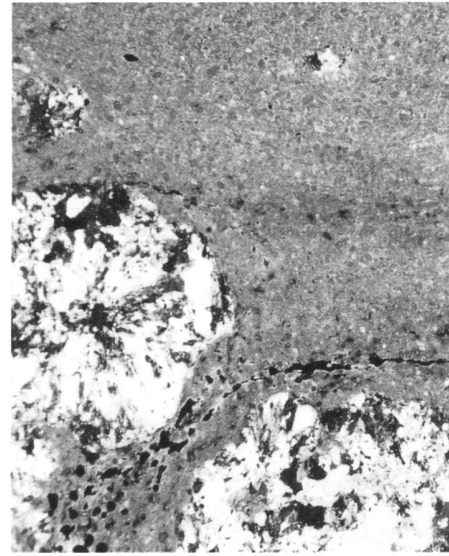
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2



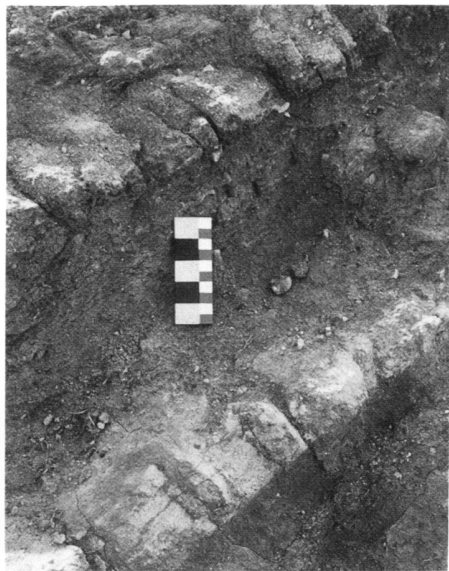
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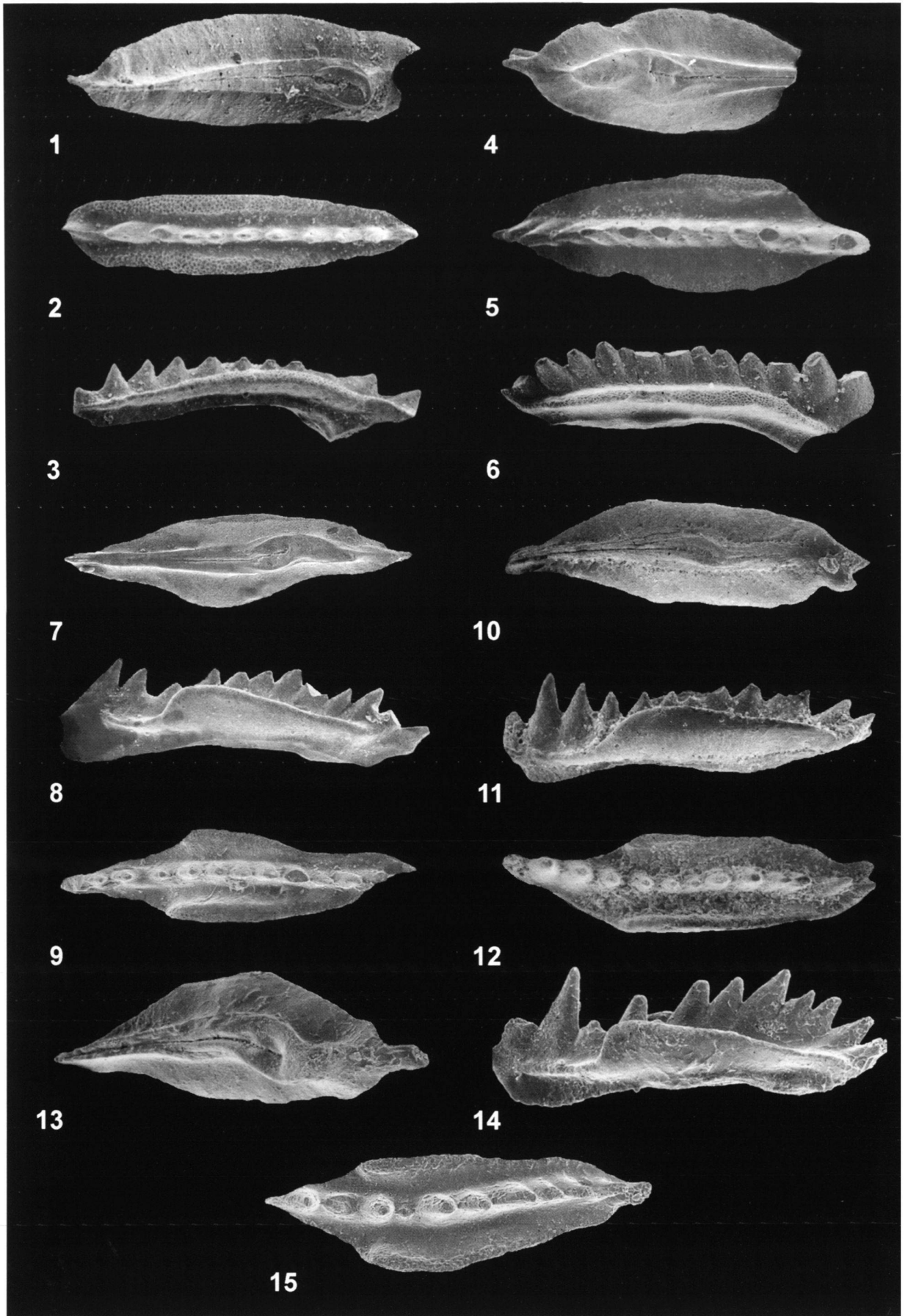
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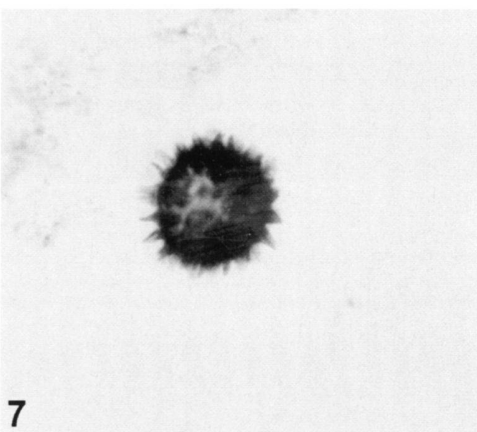
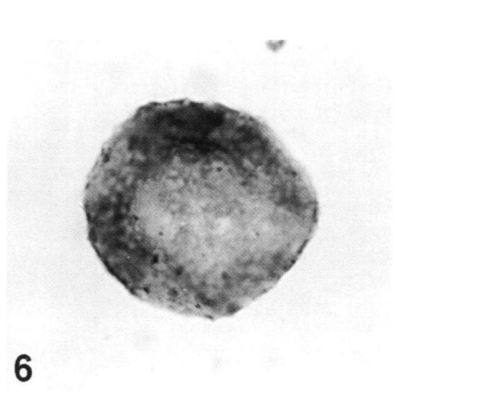
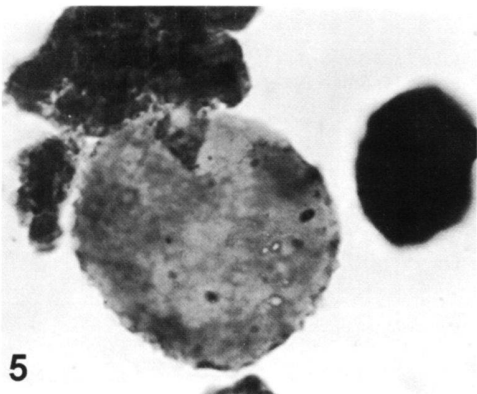
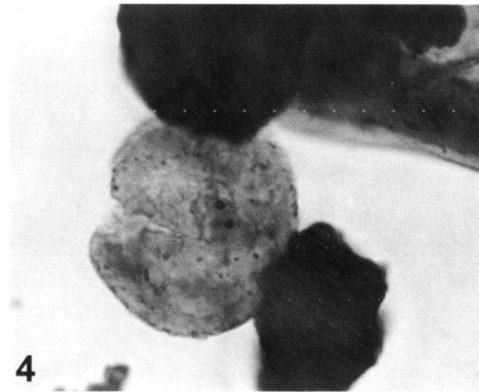
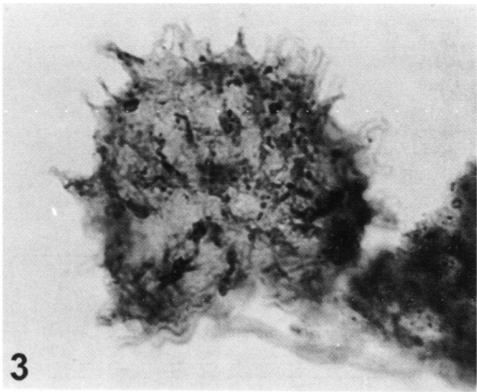
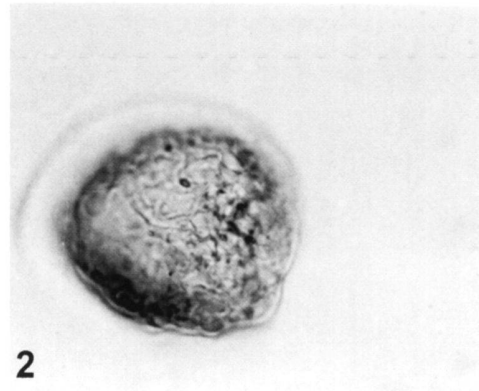
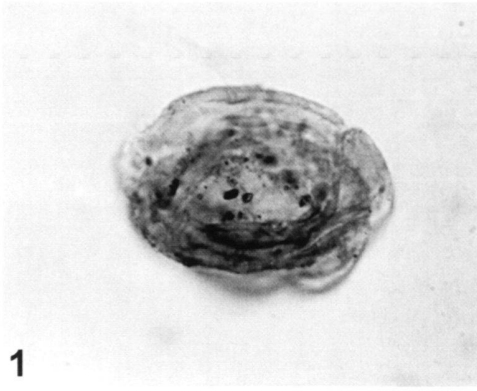


5



6





250 μm

