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Early Permian continental biota from Southeastern Sardinia (Ogliastra and Gerrei)

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Introduction

For more than a century the latest Carboniferous?- Early Permian basins of Sardinia have yielded a lot of palaeontological data, mainly macroflora (see the reviews of Comaschi Caria, 1959; Filigheddu, 1985; and Cassinis & Ronchi, 2002).

In the '90s, the most significant Lower Permian troughs (Perdasdefogu, Escalaplano, Seui, Lu Caparoni) were intensively reinvestigated and highlighted a rich fossil record (Broutin *et al.*, 1996; Ronchi, 1997; Ronchi *et al.*, 1998; Broutin *et al.*, 2000).

The first two aforementioned basins are located in central and southeastern Sardinia (Ogliastra and Gerrei), and the corresponding literature is generally old and scarse (Maxia, 1938; Pecorini, 1974; Sarria, 1987). Both basins were bordered by main faults and show a complex and significantly differing sedimentary and volcanic evolution. In particular, the Perdasdefogu Basin displayed perennial alluvial-to-lacustrine environments with blackish fine and coarse deposits passing to freshwater limestones. In turn, an alluvial-to-palustrine setting characterises the Escalaplano Basin, of which the sedimentary deposits are also associated with volcanic products.

On the whole, the discovered palaeontological contents (amphibians, algae, stromatolites, permineralised macrofloras, ostracods, lamellibrancs, gastropods, fish teeth and remains) are typically "Autunian" (Ronchi *et al.*, 1998; Broutin *et al.*, 1999), and allow to ascribe the deposition in such basins to the Lower Permian.

Some of the most representative fossil biota groups will be briefly described (for the macro- microfloral content, see the introduction of this Guide).

Permian Algae and Stromatolites

Permian algae and stromatolites were recently discovered in the Lower Permian deposits of Sardinia (Freytet, 1997; Freytet *et al.*, 1999).

The Perdasdefogu basin fill contains a carbonate unit (upper member of the Rio su Luda Fm.; Ronchi, in press) with laminated stromatolites (Fig. 1; Pl. 1). The first occurrence of these structures was observed in the dolostones of a wall near anthracite exploitations (Nuraghe San Pietro). The stromatolites show two main shapes of buildups: large domes

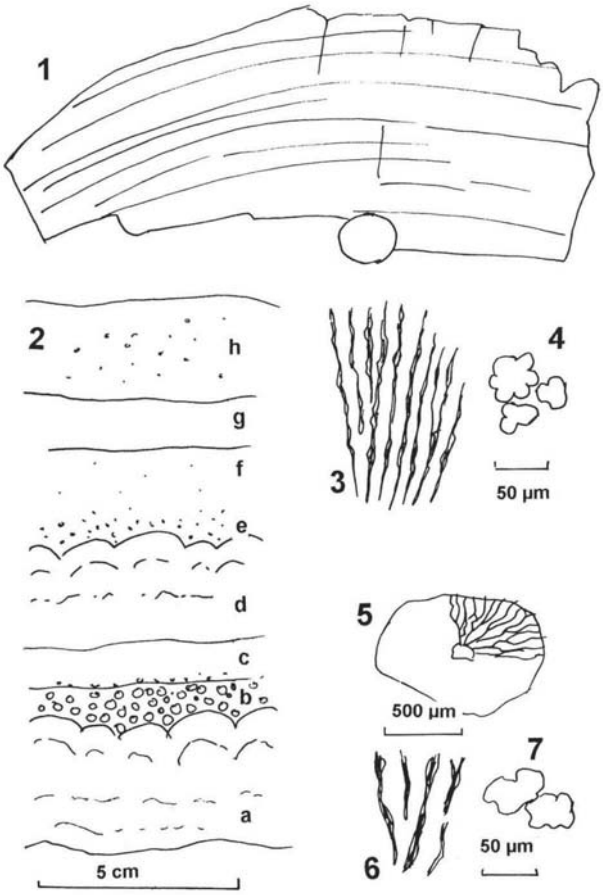

Fig. 1 - 1: domal stromatolite, Perdasdefogu Basin: stone in a wall (after photo). Circle is a large coin.
2: section of an alternation of stromatolites (*Collenia*-like) (a, d), oolithic layers (b, c, e, h) and dolomicritic layers (f, g). Perdasdefogu Basin. Detail of a stone in a wall (after photo).
3-4: *Toutinella sardiniana* Freytet 1997, Escalaplano Basin. 3: longitudinal section; the filaments are white, irregulatly jointing; 4: transverse section, showing the lobate habitus of the filaments.
5-7: *Toutinella radiata* Freytet, 1997, Escalaplano Basin. 5: section of a colony; the filaments are white; 6, detail of filaments (in white) in longitudinal section; 7: transverse section (lobate).

with decimetrical diameter (Fig. 1.1) and layers of adjacent small columns, separated by laminae of deformed millimetrical oolites (Figs 1, 2). The oolitic structures are concentric and their external shape is rounded, sometimes polygonal (Pl. 1); some of them are replaced by ferroan dolomite. In thin sections, no filaments are evident due to an intense recrystallisation (dolomitisation), which has destroyed most of the structures. Black and white submillimetrical laminations also show, in the light laminae, small rounded bodies like planctonic algae of *Bothryococcales*? type.

In the Escalaplano Basin, the San Salvatore section exhibits two horizons with algal "nodules". The first one occurs about 25 m above the Variscan basement, in the form of thin layers, half meter in thickness, and it is made up of abundant *Toutinella radiata* (Fig. 1, 5-7). The second algal horizon is just below the thick andesite lava flow which tops the Lower Permian succession. It occurs in the form of centimetre-to-decimetre calcitic masses, scattered in a reddish pelitic mudstone, which are represented by the algae *Toutinella sardiniana* (Fig. 1, 3-4).

The genus *Toutinella* is characterised by radiating branched filaments, filled by sparite and showing a lobate transverse section. Two species come from the San Salvatore section (locus typicus), while two other species from the Permian of Morocco (*T. marocana*) and the Miocene of Spain (*T. hispanica*). The plurilobate transverse section of the filaments is unknown in marine or non-marine, modern as well as fossil algae. A bacterial origin

can possibly be compared to epiphytic disc on living large *Nostoc parmelioides*, but in this case the "filaments" are only 1 μm in diameter (Freytet & Verrecchia, 1993). See discussion in Freytet (1997).

Permineralised Macrofloras

Permineralised plants (Pl. 2) from the silicified horizons of the "unità calcareo-selciosa" (Rio su Luda Fm.) have been described for the first time from Galtier *et al.* (1998), and later from Ronchi *et al.* (1998) and Broutin *et al.* (2000). Fossiliferous localities are Funtana Nuragi and Is Alinus, north of Perdasdefogu village. They occur generally as numerous small plant fragments preserved in angular cherts and suggestive of plant accumulation in coal balls; occasionally a specimen contains a single large fragment of cordaitean or calamitean stem.

The plant assemblage consists of the genera *Sphenophyllum*, *Arthropitys*, *Astromyelon*, *Calamostachys*, *Pecopteris*, *Scolecopteris*, *Stipitopteris*, *Psaronius*, *Ankyropteris*, *Anachoropteris*, *Cordaites* leaves and wood and probable medullosan wood and ovules.

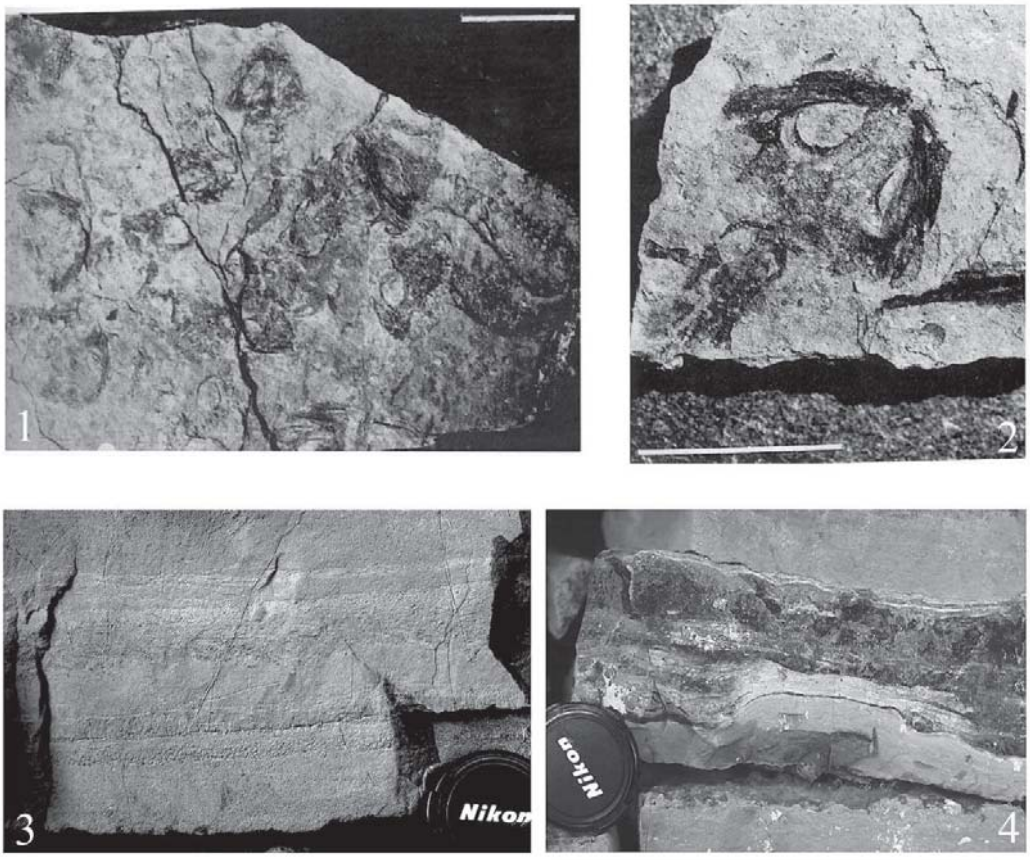

Plate 1

Figs 1-2 - Amphibians from Perdasdefogu. *Branchiosaurus* cf. "*B.*" *petrolei*. Scale-bar 10 mm. 1. Skull and pectoral girdle of a specimen; 2. Slab showing mass-mortality events on four subsequent laminae.
Fig. 3 - Oolites from the "cherty-carbonate" member (Nuraghe San Pietro).
Fig. 4 - Dome-shaped stromatolites from the "cherty-carbonate" member (Rio su Luda).

The arborescent marratialean ferns are the dominant element with the vegetative and fertile leaves *Pecopteris* and *Scolecopteris*, the most common elements. The calamitean sphenopsids are the second in abundance.

The preservation and accumulation of the plants are closely comparable to the silicified plant assemblages described from the Lower Permian of Autun and the Stephanian of Grand-Croix in Massif Central, France (Doubinger *et al.*, 1995; Galtier & Phillips, 1985). Well preserved silicified plant remains were recently found also in Germany (Dohlen Basin; Barthel *et al.*, 1995). It is certainly significant that the assemblage from the Perdasdefogu Basin is dominated by tree ferns and calamites like the nearly contemporaneous silicified vegetation from Autun.

AMPHIBIANS

Recently, a rich amphibian fauna has been recorded for the first time in Italy, within the Perdasdefogu Basin (Ronchi & Tintori, 1997); fossiliferous layers have yielded several *Branchiosaurus* cf. *"B." petrolei* (Gaudry, 1875) specimens, often in repeated mass mortality assemblages (Pl. 1). Up to now in Sardinia, only the ichnogenus *Salichnium (Saurichnites) heringi* (Geinitz, 1885), referable to amphibian lepospondyles, was found by Fondi (1979) in the Upper Carboniferous (Westphalian D?) sediments of San Giorgio Basin (Iglesiente, SW Sardinia).

Find of *Branchiosaurus* cf. *"B." petrolei*, which is a common species in the central European basins (such as Autun and Montceau-le-mines in France and Saar-Nahe, Saale and Dohlen in Germany), confirms that Sardinia was part of the same hydrographic basin of the continental Europe, with no marine sound or wide physical filter, such as a mountain range. It also widens significantly the amphibian migration routes in paleo-Europe described in Werneburg (1988).

The mass-mortality events could be related to a sudden environment change in the waters of the Perdasdefogu palaeolake: freato-magmatic eruptions or subaqueous fumaroles could have poisoned the waters, thus causing frequent extinctions of the living communities. Periodical shortages of oxygen, up to total depletion (due to high temperatures and salinities - summer overheating of the basin?- or to heavy decay of organic matter), could also have produced mass-mortality of gill-breathing animals. Preservation of fully articulated skeletons and, in a few specimens, of very fine structures such as external gills are in contrast with drying hypothesis. Microbial films could have played an important rule in preserving small organisms, sealing the bottom just after the mass mortality event.

Based on new samples, Werneburg & Ronchi (in prep.) are able to investigate about 100 amphibian skeletons. Preliminarily, the following taxa could be determined: *Melanerpeton eisfeldi* Werneburg, 1988, *Apateon kontheri* Werneburg, 1988, *Apateon flagrifera* (Whitthard, 1930).

Interestingly, the same association of species is known from the famous amphibian locality "Gottlob", Upper Goldlauter Fm. of the Thuringian Mountains (East Germany). This association is very characteristic for the *Melanerpeton eisfeldi*–zone in the amphibian-zonation of Werneburg (1996, 1999). Compared to the biostratigraphic reference section for the Upper Carboniferous/Lower Permian of Central Europe, the amphibian containing level of the Rio su Luda Fm. could be correlated with the interval between the Lower Goldlauter Fm. up to the Lower Oberhof Fm., that means topmost Ghzelian to lower Asselian of the global scale (for up to date correlation charts see Schneider, J.W. & Roscher, M. in /www.geo.tu-freiberg.de/palaeo).

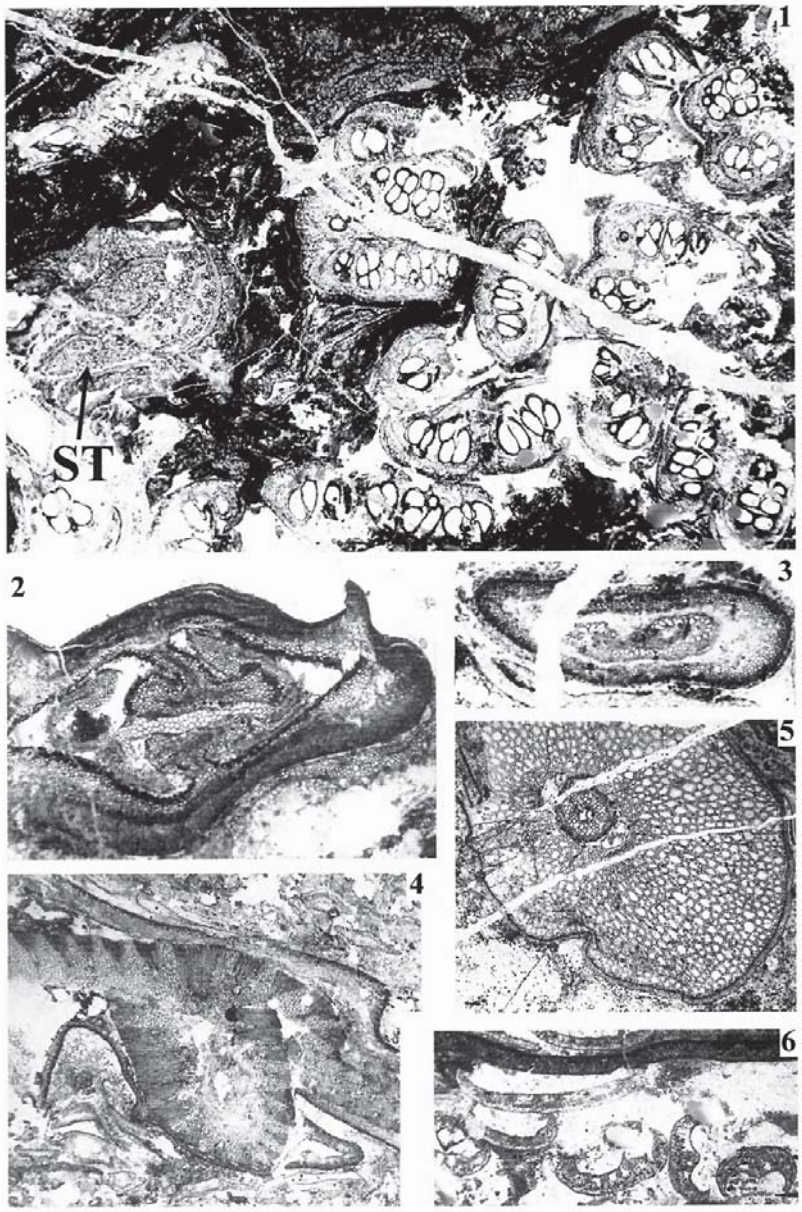

Plate 2
Silicified macrofloras from the Perdasdefogu Basin (photographs and identification by Jean Galtier; plate by Jean Broutin) (After Broutin *et al.*, 2000, p. 81).

Fig. 1 - Fertile pinnules of *Scolecopteris* and its probable parent frond rachis *Stipitopteris* ("ST"), X7;
Fig. 2 - *Ankyropteris* rachis, X15;
Fig. 3 - *Anachoropteris* rachis, X18;
Fig. 4 - *Arthropitys* sp. (Stem of *Calamites*), X7;
Fig. 5 - Root of *Psaronius* (seed-fern), X5;
Fig. 6 - Leaves of *Cordaites* (upper part) and *Pecopteris* (lower part), X10.

Fish teeth and remains

Isolated vertebrate remains (ichthyolites) from the Perdasdefogu Basin

First fish remains where discovered by Ronchi & Tintori (1997 and personal communication 1999) in the limestones of the Ortu Manu section, cherty-carbonate unit of the Rio su Luda Fm. Their study is in progress. The acid dissolution of about 1 kg limestones, sampled by J. Schneider during the Brescia congress fieldtrip 1999, has delivered the following diverse fauna of aquatic vertebrates:

- *Xenacanthus* sp., rare
- *Bohemiacanthus* type Om to Ogo, very common
- *Acanthodes* sp.
- longitudinal striated teeth of an palaeoniscoid fish
- two types of palaeoniscoid scales – very common smooth, very rare sculptured scales
- amphibian remains as jaws, limb bones and isolated teeth of small and large forms as well

Besides that, silicified ostracods are very common.

Isolated fish remains from Guardia Pisano

Lacustrine limestones from Guardia Pisano close to Gonnesa, sampled by J. Schneider during the Brescia Symposium field trip in 1999, have delivered first isolated fish remains. Interestingly, the diversity is very low and absolutely dominated by very tiny teeth (about 0.5 mm), dermal denticles and spine fragments of the hybodont shark *Lissodus*. These tiny isolated remains of *Lissodus* point on a small sized fish of about 20-30 cm in length. Furthermore, some scales and spine fragments of *Acanthodes* have been found. The blunt teeth of *Lissodus* are adapted to durophageous feeding, whereas *Acanthodes* is an plancton feeder. This fauna appears to be in strong contrast to the very diverse fauna from Ortu Manu in the Perdasdefogu Basin (see below).

First *Lissodus* teeth of the European Upper Carboniferous and Lower Permian have been reported by Gebhardt (1986) and Hampe (1996). Unfortunately, up to now the stratigraphic range of *Lissodus* teeth is not well enough documented for biostratigraphic conclusions.

Palaeobiogeography and biostratigrapy

Unexpectedly, based on the xenacanth teeth-zonation of Schneider (*e.g.* 1996) the *Bohemiacanthus* teeth give nearly the same age as the amphibians – Upper Manebach to Upper Goldlauter Fm. of the Thuringian Mountain reference section, about topmost Ghzelian to lower Asselian of the global scale. Unexpected, because the distribution/ migration of aquatic vertebrates is strongly linked to river systems. Sardinia is situated at the southern border of the Variscan Orogen, which certainly should have formed a watershed. Possibly, the migration of semi-terrestrial amphibians is not so strong linked to river connections, but the xenacanths as every fishes need rivers for their distribution. Based on areal dynamics of populations and species, we had expected different species in Central Europe and Sardinia because of physiogeographical barriers and resulting restricted genetic exchange. But the amphibians and xenacanths investigated here indicate the same time level in their separate phylomorphogenetic development. So we have to look for migration routes – one possibility could be any connection between the Thuringian Mountain basin, the basins in the French Massiv Central, Southern French basins and Sardinia (Werneburg 1989a, b, 1999; Schneider & Zajic 1994, Schneider *et al.*, 2000).

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