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The (late-) Post-Variscan continental succession of Sardinia

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INTRODUCTION

The purpose of this chapter is to illustrate the characteristics of the main continental, sedimentary and volcanic Permian (and Upper Carboniferous) basins in Sardinia. In order to understand their history better, in some places (*e.g.* in the Gerrei and Nurra regions) this framework has also involved the overlying terrestrial deposits, up to the Middle Triassic marine ingression represented by the Muschelkalk.

The older Stephano-Autunian floral sediments have long since attracted attention because of the presence of anthracite layers and the abundance of vegetal remains. However, during the last three decades, further research has also addressed numerous and varied geological topics, with interregional correlation. These new investigations have generally been carried out by the Cagliari, Genova, Modena, Pavia, Pisa, Roma and Siena Universities, the Italian Geological Survey, and some Sardinian working groups, as well as by several foreign researchers.

As shown by the reference lists, most of the opinions expressed and conclusions reached in this recent period have been published or are in print.

THE UPPER CARBONIFEROUS TO MIDDLE TRIASSIC MAGMATIC AND SILICICLASTIC DEPOSITS OF SARDINIA - AN OVERVIEW

Following the Variscan orogeny, a large-scale calcalkaline magmatism took place on the island. The intrusive sequence gave rise to hundreds of plutons over a period of more than 25 Ma, from at least 310 Ma to about 280 Ma. According to Ghezzo & Orsini (1982) and Carmignani *et al*. (1989), this plutonic complex forms the southern part (about 6000 Km^2) of the Sardinian-Corsican batholith, which, in Sardinia, after initial syntectonic activity with peraluminous granites, granodiorites and tonalites, largely (ca. 74%) includes late tectonic intrusions generally composed of older (307 ± 6 Ma) tonalites to tonalitic granodiorites and younger (302 ± 5 Ma) monzogranitic granodiorites to monzogranites. Post-tectonic intrusions (ca. 25% of the batholith), which occurred under a tensional regime after rapid regional uplift, contain leucogranites (289 ± 1 Ma) in the "Axial Zone "(Northern Nurra and NE Sardinia) and the "External Zone" (SW sector). The Early Permian magmatism was also emphasised on the island by consistently calc-alkaline intermediate to acidic volcanic activity.

At the same time, a few small, fault-bounded and subsiding intracontinental, alluvial-to-lacustrine basins were formed (Fig. 1). Thus these trough fills, which rest unconformably on the Variscan basement, generally include both the deposits derived from the external and internal igneous eruptions, and the clastic sediments eroded from the surrounding structural highs. Carbonate–siliceous sediments, formed *in situ*, also occur. As a consequence, these basins show marked facies and thickness changes, so that suitable correlation is often hampered.

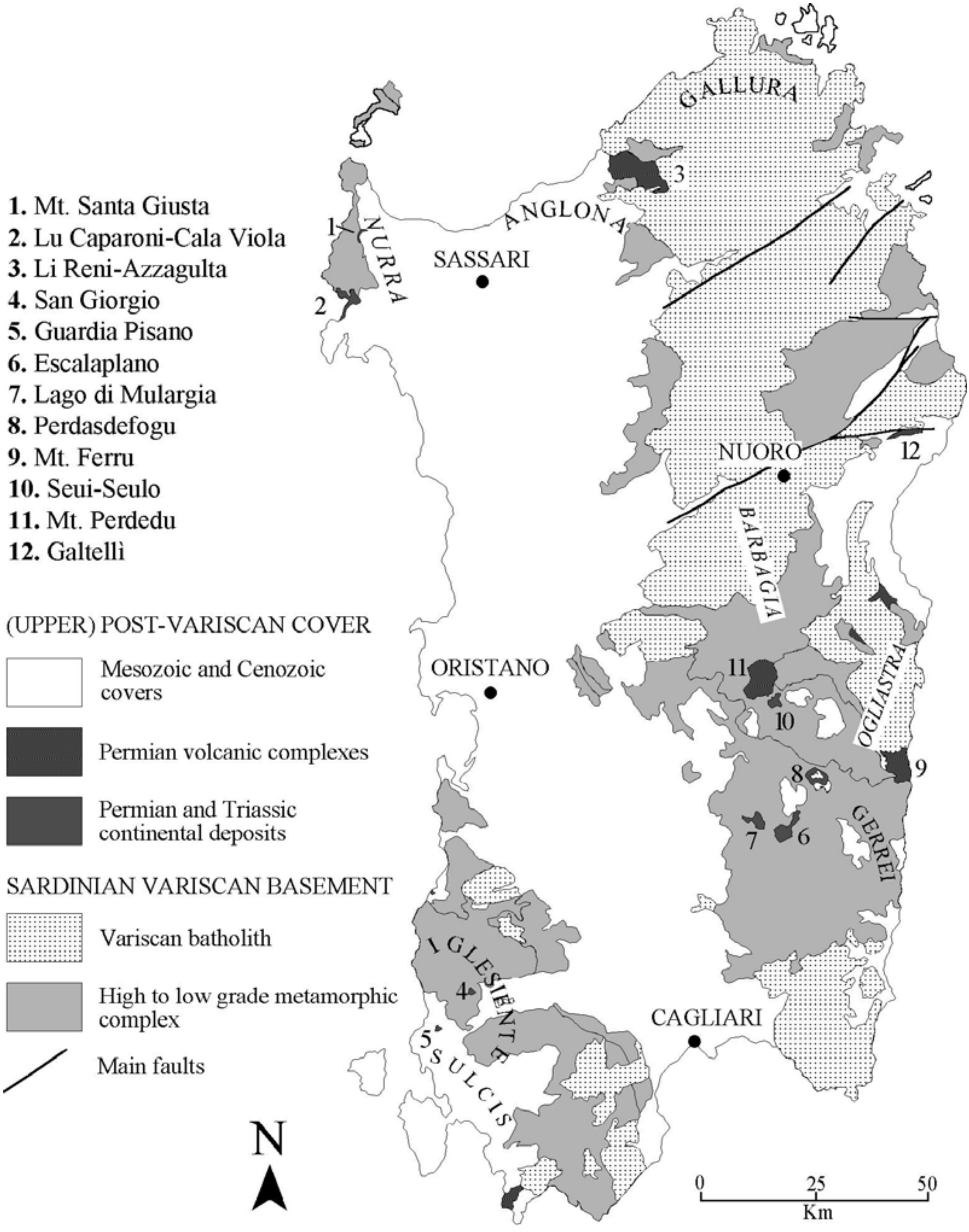

Fig. 1 - Location of the main Late Palaeozoic basins and volcanic complexes in Sardinia.

Basin inception can be attributed to crustal attenuation and tearing which affected vast parts of Hercynian Europe and nearby regions, giving rise to a large transcurrent megashear zone throughout Late Carboniferous-Early Permian times (Arthaud & Matte, 1975). The basin geometry and the structural, stratigraphical and sedimentological evolution represent typical elements of strike-slip or pull-apart basins.

In Sardinia, the best known and studied basins crop out to the north in Nurra, approximately between Cala Viola and Mt. Santa Giusta, and in the central and southern sectors of the island, such as in Barbagia (Seui), Ogliastra (Perdasdefogu), Gerrei (Escalaplano), Sarcidano (Mulargia), Sulcis (Guardia Pisano) and Iglesiente (S. Giorgio) (Figs 1, 2). Some papers published by Vardabasso (1950, 1966), Cocozza (1967), Gasperi & Gelmini (1980), Fontana *et al.* (1982, 2001), Barca *et al.* (1995), Cassinis *et al.* (1996, 1998, 2000a, and in press a,b), Cortesogno *et al.* (1998), Neri *et al.* (2000a,b), and Ronchi (2001a,b) are useful for a general review of at least some of these troughs. However, lithological, sedimentological, stratigraphical, palaeontological, petrographical and structural data will be synthetically described later in this chapter, specific to the above basins, and in particular to the Nurra area which will be the topic of a field excursion.

Initial basin deposition was generally marked by the formation of a "basal conglomerate", originally named by Vardabasso (1950, 1959) as "Verrucano", and later (1966) as "Verrucano sardo". This deposit, which lies unconformably on the Variscan basement and ranges from zero to some tens of metres in thickness, is generally made up of metamorphic and subordinate volcanic clasts eroded from the local substrate.

Recent studies have concentrated on a large number of fossil vegetal remains from the lower stratigraphical sections of the basins, because they are mainly typical of Autunian flora and generally indicate the onset and development of the basins at the beginning of the Early Permian (Broutin *et al.*, 1996; Ronchi *et al.*, 1998) (Fig. 2). In fact, we presently lack evidence of a clear Carboniferous age. Only the small S. Giorgio Basin in SW Sardinia (Iglesiente) highlighted some palaeontological elements (vertebrate footprints and macro-microflora) which on the whole have been interpreted as pertaining to a pre-Permian (?Westphalian–Stephanian) time interval (Cocozza, 1967; Del Rio, 1973; Fondi, 1979; Del Rio & Pittau, 2000) (Fig. 2).

From the above, except for the S. Giorgio Basin, the fluvio-lacustrine and locally, also the fluvio- palustrine siliciclastic sedimentation during the preliminary evolution of the Sardinian basins was coeval with abundant, extrusive and subvolcanic magmatic activity (*e.g.* Vardabasso, 1959; Lombardi *et al.*, 1974; Traversa & Vaccaro, 1992; Cassinis, 1996; Cortesogno *et al.*, 1998), which shows a common calc-alkaline signature but different geochemical trends (Fig. 2). Generally, this volcanic activity began with acidic explosives and major volumes of andesitic lavas and breccias. Throughout the Early Permian, dacitic dykes and lavas (Perdasdefogu Basin), and abundant rhyolitic products such as lavas and widespread ignimbrites were emplaced.

In the Seui Basin (Fig. 2), during the deposition of these ignimbrites, dacitic and subordinate rhyolitic cryptodomes formed along the basin marginal faults, which were approximately N–S and E–W trending (relative to their present orientation), and subdivided the basin into smaller portions. The growth of the cryptodomes triggered the gravitational collapse of basement and cover slices. The relationship between the disjunctive tectonics, probably linked to a transtensional/transpressional regime, and the volcanics make the Seui Basin a relevant and attractive example (Cassinis *et al.*, in press a).

However, in other parts of Sardinia (*e.g.* in Gallura and Nurra) the volcanic succession seems to have been affected by abrupt changes. The Lower Permian rocks are essentially characterised by calc-alkaline acidic tuffs and ignimbrites (*e.g.* Cassinis *et al.,* 1996 *cum* bibl.; Cortesogno *et al.*, 1998) (Fig. 2).

In Nurra, the "Autunian" fluviolacustrine and volcanic deposits of the Punta Lu Caparoni Fm. (Cassinis *et al.*, 1996 and in press b) are unconformably overlain by a light coarse-grained detrital unit (Pedru Siligu fm.), which in its turn is followed, as in other parts of Sardinia, such as in Mulargia and Guardia Pisano, by Permian red clastics (Porto Ferro and Cala del Vino Fms), indicating prevalent braided and meandering alluvial environments (Fig. 2). In Nurra, rhyolitic tuffs and ignimbrites of presumed alkaline affinity also occur (Cassinis *et al.*, 1996, in press b, and in this Guide). In particular, this alkaline nature shows evidence to the NE, around Mt. Santa Giusta, at about 40m below the Lower-Middle Triassic Buntsandstein deposits. (Fig. 2). Owing to their stratigraphic position and their compositional affinity with the "Saxonian-Thuringian" volcanic rocks present in nearby Corsica and in Provence (to which Sardinia was attached during the Palaeozoic and Triassic), the debated volcanics of Nurra must be interpreted as the result of younger magmatic events than those of calc-alkaline affinity during the basal Early Permian.

In this context, the aforementioned "post-Autunian" igneous activity mirrors the second alkaline magmatic cycle of French authors (as in Vellutini, 1977; Bonin, 1988; Broutin *et al.*, 1994, and references therein), which contrasts decidedly with that of the previous calc-alkaline Permo-Carboniferous cycle. In northern and eastern Sardinia, some studies have also ascribed a number of alkalibasaltic dykes, commonly intruding the post-Variscan igneous complex, to the above second magmatic cycle (Vaccaro *et al.*, 1991, *cum* bibl.). On the basis of stratigraphic evidence and radiometric dating (Cozzupoli *et al.*, 1971, 1984; Lombardi *et al.*, 1974; Atzori & Traversa, 1986; Vaccaro *et al.*, 1991; Traversa & Vaccaro, 1992), the emplacement of these alkaline products occurred between the "Autunian" and "Buntsandstein" deposits, *i.e.* probably from late Early Permian up to the beginning of Early Triassic times. Such volcanics, as well as some lamprophyres of Sardinia, provide evidence of a Permian and Triassic extensional regime (Baldelli *et al.*, 1985).

Only in some parts of Sardinia do fluvial Buntsandstein-like reddish deposits occur on the top (Fig. 2). In Nurra, this late siliciclastic sequence starts with a thin light quartz-conglomerate horizon (Conglomerato del Porticciolo) about 5 m thick, which unconformably covers the preceding rocks. Above follows the Arenarie di Cala Viola red formation, generally assigned to Olenekian and Anisian times, and probably persisting up to the Ladinian marine Muschelkalk. In the Gerrei region, near Escalaplano, some conglomerate-sandstone layers, which lie directly on the Variscan metamorphic substrate, grade upwards to finegrained and marly red-beds alternating with thin gypsum lenses (Fig. 2). These upper outcrops, which could be generally related to particular Buntsandstein conditions, due to the presence of a significant palynological assemblage have recently been ascribed to late Anisian times (Pittau *et al.*, 2000b; Costamagna *et al.*, 2000).

Furthermore, in order to decipher better some stratigraphical nomenclature of the island, we would like to point out that the above Permian and Triassic siliciclastic succession – specifically the prevalent red sequences II and III ranging from the Lower Permian continental deposits ("Autunian") to the Middle Triassic marine carbonates ("Muschelkalk") – was mostly defined by more recent authors, such as Gasperi & Gelmini

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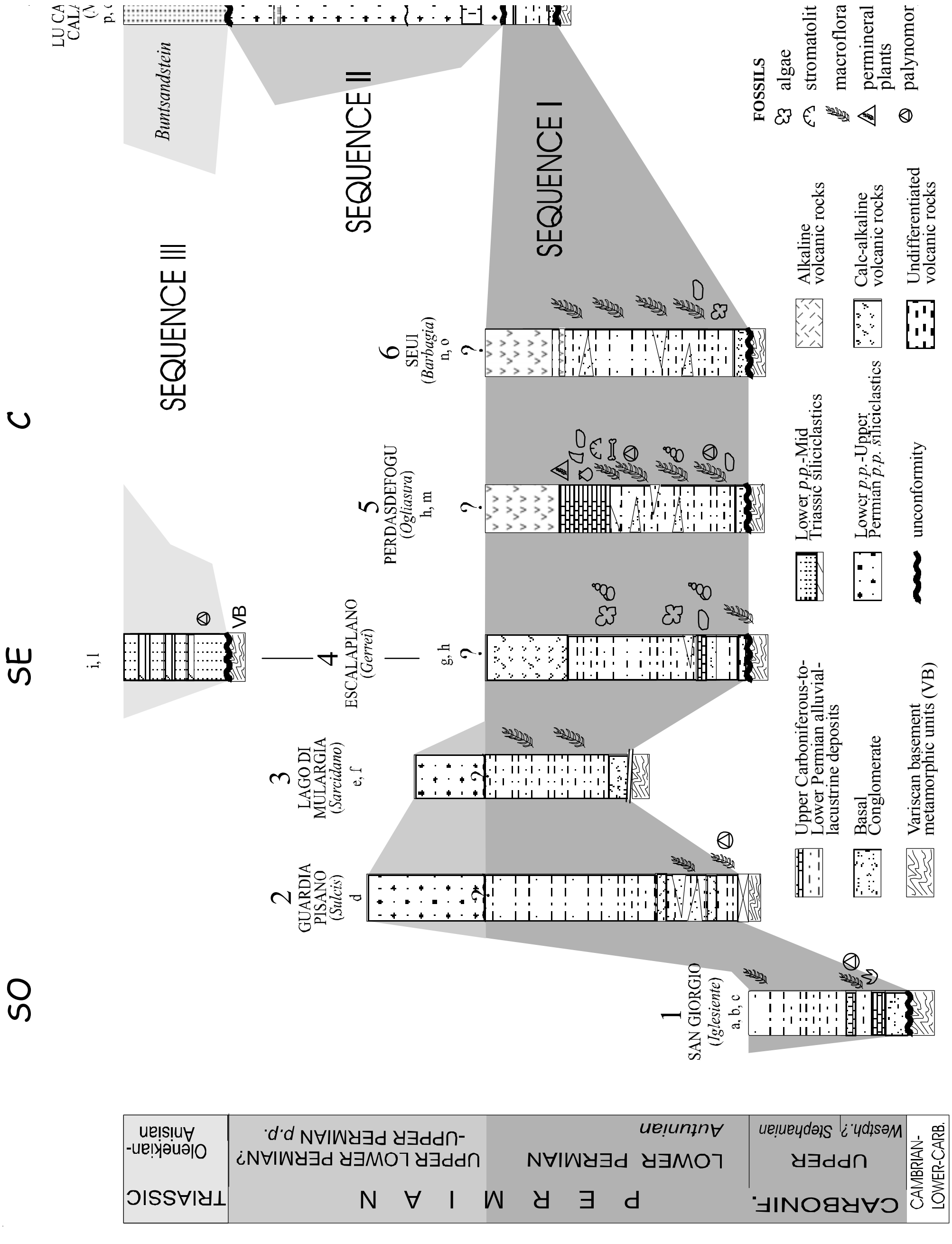
Fig. 2 - Schematic Upper Carboniferous to Triassic stratigraphic sections, along with fossils and their position indicated beside the columns, from the main continental basins of Sardinia. (Location in the inset map; data from the references cited above the columns: a. Cocozza, 1967; b. Del Rio, 1973; c. Del Rio & Pittau, 2000; d. Pittau *et al.*, 2000a; e. Francavilla *et al.*, 1977; f. Barca *et al.*, 1995; g. Pecorini, 1974; h. Ronchi, 1997; i. Costamagna *et al.*, 2000; l. Pittau *et al.*, 2000b; m. Sarria, 1987; n. Lauro *et al.*, 1963; o. Sarria & Serri, 1986; p. Gasperi & Gelmini, 1980; q. Cassinis *et al.*, 1996; r. Fontana *et al.*, 2001; s. Cassinis *et al.*, 2001 and in press b; vertical distances are not time- or thickness-related). Three sequences or major cycles, separated by distinct unconformities, can be highlighted throughout the basin evolution (after Ronchi, 2001b, redrawn and modified).


SO
SE
C
1 SAN GIORGIO (Iglesiente) a, b, c
2 GUARDIA PISANO (Sulcis) d
3 LAGO DI MULARGIA (Sarcidano) e, f
4 ESCALAPLANO (Gerrei) g, h
i, l
VB
5 PERDASDEFOGU (Ogliastra) h, m
6 SEUI (Barbagia) n, o
SEQUENCE I
SEQUENCE II
SEQUENCE III
Buntsandstein
Upper Carboniferous-to-Lower Permian alluvial-lacustrine deposits
Basal Conglomerate
Variscan basement metamorphic units (VB)
Lower p.p.-Mid Triassic siliciclastics
Lower p.p.-Upper Permian p.p. siliciclastics
unconformity
Alkaline volcanic rocks
Calc-alkaline volcanic rocks
Undifferentiated volcanic rocks
FOSSILS
algae
macroflora
permineral plants
TRIASSIC
Olenekian-Anisian
P E R M I A N
UPPER LOWER PERMIAN?-UPPER PERMIAN p.p.
LOWER PERMIAN
Autunian
CARBONIF.
UPPER
Westph.? Stephanian
CAMBRIAN-LOWER-CARB.

(1980), as "Verrucano Sardo", following some conclusions reached during the Pisa international Symposium (Various Authors, 1966) about the new application of this term in the Alpine-Apennine domains.

In conclusion, the reported data allow us to subdivide the Late Carboniferous to Middle Triassic evolution of the Sardinian continental areas into at least three major tectonosedimentary cycles or sequences, separated by marked unconformities (Fig. 2). The first sequence was essentially developed from latest Carboniferous to Lower Permian, while the second sequence probably extended from part of Early Permian up to undefined Late Permian times; the third sequence began locally with a thin basal conglomerate, and was followed by typical Buntsandstein deposits, which persisted practically up to the marine ingression of the Middle Triassic Muschelkalk (Pittau Demelia & Flaviani, 1982; Pittau, 2000). The development of first calc-alkaline and than a late, Lower?-Late Permian alkaline magmatism is also recognised.

Chronostratigraphical Constraints

Paleontological Data

From Late Carboniferous ("?Westphalian-Stephanian") to Early Permian p.p.? ("Autunian") times

For more than a century the Late Palaeozoic basins of Sardinia have yielded profuse paleontological data, mostly macroflora. The problem of the age (Upper Carboniferous, Carboniferous–Permian transition or Early Permian) of the macrofloral associations, and of the sedimentary deposits in which these were collected, has been debated for a long time and it is not yet completely solved. The earlier paleontological studies of the island are briefly summarised below; taxa are cited as they were reported by the various authors.

The first record of fossil plants from Sardinia was probably made by Lamarmora (1857) who, in his *Voyage en Sardaigne*, reported some findings in the Seui, Seulo and Perdasdefogu areas. The fossils were attributed by Meneghini (1857) to the Carboniferous. Subsequently, Grand'Eury (1877), in his work on the Carboniferous flora of central France, cited these first Sardinian findings, comparing them to those found in the Saint-Etienne Basin.

More and less detailed descriptions of late Palaeozoic plant finds in the southwestern part of the island (Iglesiente) can be found in Lambert (1896), Gambera (1897), Fraas (1902), Sterzel (1902), Sartori (1904, 1909), and Pampaloni (1900). In particular, this last author recognised in the Seui Basin the following taxa: *Sphaenopteris, Calamites, Annularia, Cordaites* and *Walchia piniformis*.

The most detailed and numerous fossil flora finds from Seui-Seulo (Barbagia) can be found in the broad monograph by Arcangeli (1901); he recognised 8 exclusively Permian species, 38 late Carboniferous–Permian species and only one typically Carboniferous form.

Other sparse findings are reported in Fiorentini (1923) and Novarese (1917); in particular, this last author described macroflora found by Sartori near Pranu San Giorgio (Iglesiente) as *Walchia piniformis, Walchia filiciformis, Annularia stellata* and *Cordaites* cf. *principalis*.

In 1938, Principi determined as Carboniferous seeds (*Samaropsis fluitans*) some fossils found by Lotti (1931) in a drill core through the Permo-Triassic continental deposits near Porto Conte (Nurra). In the same period, Maxia (1938) reported the presence of *Callipteridium crassinervium* and *Alethopteris serlii* in the shales of Perdasdefogu (Rio su Luda).

In more recent years Comaschi Caria (1959) compiled a comprehensive review of the whole Sardinian Palaeozoic to Tertiary fossil flora: she reviewed the Arcangeli collection, adding personally collected samples of many species, some of them new for Sardinia. Cocozza (1967) analysed in detail the San Giorgio basin deposits (Iglesiente), collecting and describing a rich Late Stephanian macrofloral assemblage. The most significant taxa included *Pecopteris arborescens*, *Annularia stellata*, *Neuropteris planckardi*, *Dicksonites plunecketi*, and other forms.

A number of macrofloral remains were found by Francavilla *et al*. (1977) close to the Mulargia Lake area (Orroli, Sarcidano); the presence of *Callipteris conferta*, *C. naumanni*, *Lebachia* cf. *hypnoides*, and so on, allowed the first above author to ascribe this association to the Early Permian (late? Autunian).

In Nurra, Pecorini (1962, 1974) recorded for the first time a rich "Upper" Autunian macroflora assemblage from the Punta Lu Caparoni as well as the presence of *Equisetum mugeotii* in the Arenarie di Cala Viola, thus assigning at least in part the Sardinian Buntsandstein to the Lower Triassic. In the first of these localities, Gasperi & Gelmini (1980) also collected a number of macroflora imprints which led these authors to confirm an Early Permian age for the Punta Lu Caparoni Fm.

Additional research on Early Permian flora was carried out by Spano (1976), who reviewed the Lovisato collection in the Cagliari University Museum (from Seui, Ingurtipani and Lake Mulargia fossil sites) as well as examining some forms collected from new localities in central and southeastern Sardinia (Genna Acca, S'Abba e Ferru and Perda Pera).

Some years later, an up-to-date bibliographical review of the entire palaeobotany of Sardinia was produced by Filigheddu (1985).

In Broutin *et al*. (1996) and in Ronchi *et al*. (1998) are described the new and abundant Autunian macrofloral finds mainly in the Perdasdefogu Basin (Pl. 1); amongst the most significant are *Autunia conferta, Rhachiphyllum schenkii, Rhachiphyllum lyratifolia, Dichophyllum flabelliferum, Gracilopteris strigosa* and *Taeniopteris abnormis*. In this basin, permineralised plants from the silicified strata of the cherty-carbonate member have also been described by Galtier *et al.* (1998) and, due to their peculiarity, included in this volume.

Reported in Ronchi *et al*. (1998), Freytet (1997) and Freytet *et al*. (1999) is the presence within the Escalaplano Basin (Gerrei) of two new freshwater algae species: *Toutinella sardiniana* and *Toutinella radiata*.

Late Palaeozoic palynological assemblages are recorded both from southwestern (Iglesiente and Sulcis) and from northwestern and southeastern areas of Sardinia. Del Rio (1973) described a Late Carboniferous association, yielding *Calamospora pallida*, *Triquitrites bransoni*, *Punctatosporites minutus*, *Florinites parvus*, *Wilsonites kosankei*, and so on, from the siliciclastic deposits of San Giorgio Basin (Iglesiente).

In the Cugiareddu well of Nurra, Pittau and Flaviani (1982) discovered in the lower part of the Triassic Arenarie di Cala Viola a palynofloral assemblage consisting of *Enzonalasporites leschikii*, *Microcachrydites fastidiosus*, *Sulcatisporites splendens*, *Triadispora crassa*, cf. *Stellapollenites muellerii* and *Voltziaceosporites heteromorphus*. According to Pittau (2000), the only single specimen ascribed to *S. muelleri* does not confirm the presence of this species in the above association, for which, however, based on the taxa list, an Olenekian or more probably an Early Anisian age may be suggested. The overlying rich and well-preserved palynomorphs, which derived from some Röt-like varicoloured shales (15-20 m-thick) with the concurrent presence of *Stellapollenitis muelleri*, *Dyupetalum vicentinense* and *Cristianisporites triangulatus*, allow us to correlate the above lithological unit to the Late Anisian (Pelsonian and Illirian).

A very rich, early Autunian microflora has been recorded in the lower sedimentary units of the Guardia Pisano sequence (Sulcis) by Barca *et al.* (1992) and Pittau *et al.* (2000a). The sporomorphs include monosaccate pollen grains with *Potoniesporites novicus* and *P. bhardwayi* (both dominant), together with *Latensina trileta*, *Cordaitina* sp., *Candidispora candida* and *Florinites*.

Later, Ronchi *et al.* (1998) reported the presence of Autunian microfloral assemblages in the lacustrine shales of Perdasdefogu (Ogliastra) as well as of Lu Caparoni (Nurra). The forms of both these localities fall in the biozone "A3" of Doubinger (1974) for the Autunian of Europe. They yield *Potonieisporites novicus-bhardwayi*, *Florinites* spp., *Nuskoisporites* cf. *klausii*, *Protohaploxypinus* sp., *Vittatina ovalis*, *Vittatina* sp., *Costapollenites* sp., and so on.

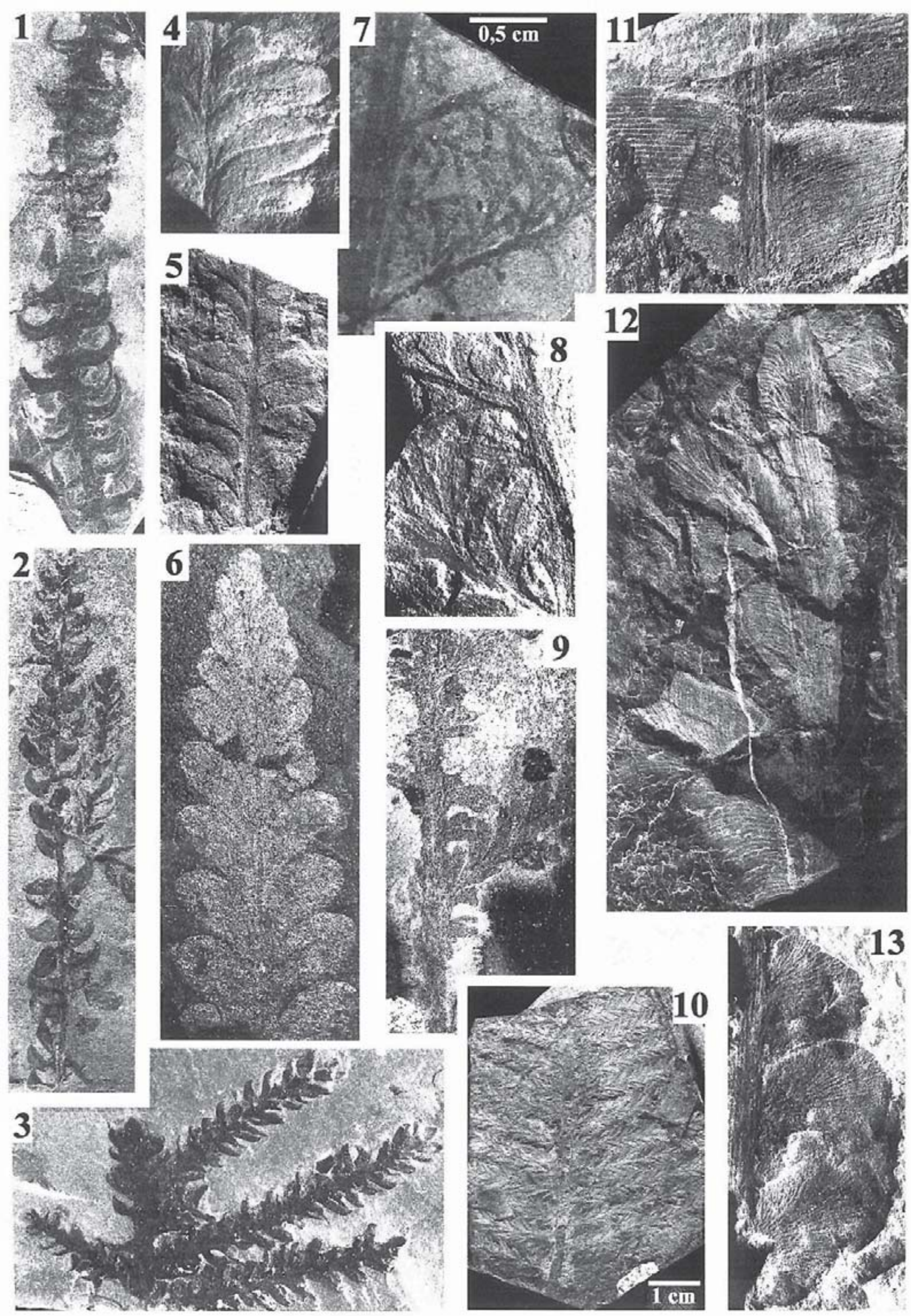
Recently, Pittau *et al.* (2000b) ascribed the abundant palynological associations from the siliciclastic unit of the Escalaplano and Arcu de Is Fronestas outcrops (near the village), which mainly consist of coniferous pollen (80%), to a Late Anisian age. *Triadispora* is the most common taxon. According to Pittau, as in Nurra the presence of *Stellapollenites muelleri* and *Dyupetalum vicentinense* indicates the correlation of these palynofloras to the "*vicentinense-muelleri* phase" recognised in the Alpine, Transdanubian and Southern European areas (Visscher & Brugman, 1981; Van der Eem, 1983; Brugman, 1986). The further presence in the assemblages of *Cristianisporites triangulatus*, marker of the Pelsonian on the Moesian Platform (Antonescu & Tangourdeanlanz, 1973), stresses the age assignment to the Late Anisian.

From the faunal point of view, only some tetrapod footprints are recorded from the San Giorgio Basin by Fondi (1979): according to this author, the lowermost deposits cropping out here should be Westphalian D(?)–Stephanian. Freshwater fauna (ostracods, gastropods) were highlighted by Pecorini (1974) from some limestones in the Escalaplano Basin (Gerrei). Within the lacustrine deposits of Perdasdefogu (Ogliastra), a number of amphibians and fish remains (Ronchi & Tintori, 1997) as well as ostracods, gastropods and bivalves have recently been collected (Ronchi *et al.*, 1998).

Plate 1

Autunian macrofloral remains from the Perdasdefogu and P.ta Lu Caparoni basins (SE and NW Sardinia, respectively). (From Ronchi, *in* Cassinis *et al.*, 2000a).

Figs 1, 2 - *Ernestiodendron filiciforme* (Sternberg) Florin. 1: Perdasdefogu, 2: Lu Caparoni;
Fig. 3 - *Feysia minutifolia* Broutin & Kerp. Perdasdefogu;
Figs 4, 5 - *Autunia conferta* (Sternberg) Kerp. 4: Perdasdefogu, 5: Lu Caparoni;
Fig. 6 - *Rhachiphyllum schenkii* (Heyer) Kerp. Perdasdefogu;
Fig. 7 - *Gracilopteris strigosa* (Zeiller) Kerp, Naugolnykh & Haubold. Perdasdefogu;
Fig. 8 - *Dichophyllum flabelliferum* (Weiss) Kerp & Haubold. Perdasdefogu;
Fig. 9 - *Rhachiphyllum lyratifolia* (Goeppert) Kerp. Perdasdefogu;
Fig. 10 - *Walchia piniformis* Sternberg. Perdasdefogu;
Fig. 11 - *Taeniopteris abnormis multinervis* Gutbier. Perdasdefogu;
Fig. 12 - *Neuropteris osmundae* (Artis) Kidston (= *Odontopteris dufrenoyii Brongniart*). Perdasdefogu;
Fig. 13 - *Odontopteris* cf. *subcrenulata* Rost. Lu Caparoni. Figs 1-9, 11-13 same scale as Fig. 7. (From Broutin *et al.*, in Cassinis *et al.*, 2000a, p. 79).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13

From ?Early-Late Permian p.p. to Early p.p .- Middle Triassic (Anisian) times

In contrast with the abundant Autunian fossils, the overlying fluvial red clastics, which correspond to the "Saxonian" and "Thuringian" (or the "Saxono-Thuringian") of the French authors, have not so far yielded any fossil evidence. In this case, only for comparison with the well-studied French and Spanish Permian sections, the age of these red-beds could be highlighted; also the stratigraphical position between the Autunian and the Lower-Middle Triassic Buntsandstein contributes to a hypothetical temporal distribution for the corresponding units. Recent reseach by Cassinis *et al.* (2000b, 2001 and in press b) led to a correlation of the Nurra section with that of Southern Provence (Toulon-Cuers Basin), mainly based on the very similar geological affinities of both these regions. The local Buntsandstein and Röt (?) deposits highlighted locally, *e.g.* in the Escalaplano and Cala Viola areas, contain a number of Anisian palynomorphs; however, the presence in the latter of *Equisetum mougeotii* led Pecorini (1962) to assign the onset of the Sardinia Buntsandstein to the Lower Triassic.

Radiometric analysis of these red-beds does not give suitable chronological data for their age-assessment.

Radiometric Data

A large number of radiometric analyses have been performed in the last 20 years on the Late Palaeozoic volcanic rocks cropping out in various parts of Sardinia, as well as on the late- to post-orogenic dykes cutting the Variscan basement (Tab. 1).

K/Ar measurements, both on whole rocks and on mineral separates, were undertaken by Cozzupoli *et al.* (1971), Edel *et al.* (1981) and Lombardi *et al.* (1974) on volcanic rocks (mainly ignimbrites) in the north, northwestern, central and southeastern areas of the island. On the whole these results, giving an age-range from 325 Ma to 140 Ma, were considered by those authors to be strongly influenced by alteration processes.

The K/Ar ages (whole rock, WR) obtained by Cozzupoli *et al.* (1984) from the Permian ignimbrites of Galtellì (Orosei, central-eastern Sardinia) have yielded a more significant age of 284 ± 15 Ma. Del Moro *et al.* (1996) performed Rb/Sr isotopic analysis of mineral separates (Ms and Bt) for sandstones at the base of the Permian volcano-sedimentary sequence between Coghinas Valley and Aggius village (Anglona, north Sardinia), and measured ages of 286 ± 3 and 288 ± 3 Ma. An age of 288 Ma (Rb/Sr on WR) was obtained for the overlying rhyolites.

A number of Rb/Sr and Ar-Ar age determinations (WR and MS) were performed by Vaccaro *et al.* (1991) on many Late Palaeozoic dykes intruding the Variscan batholith. The data obtained led the cited authors and others, like Atzori and Traversa (1986), to hypothesise that this type of magmatism in Sardinia has been largely heterochronous, both preceding and following the Early Permian effusive activity. The dyke activity took place during two phases: the first one, represented by calc-alkaline, normal to high potassium and peraluminous anatectic lithotypes, developed during two different stages, 298–289 Ma and 270 Ma; the second phase, characterised almost exclusively by basaltic products and rare peraluminous rhyolitic dykes (subalkaline and transitional types are found in central-southern Sardinia, while alkaline types are restricted to the north) show ages of approximately 230 Ma.

Recent SHRIMP data from the volcanic breccias intercalated in the lower portion of the Lower Permian Guardia Pisano (Sulcis) section yielded 295 ± 5 Ma (Pittau *et al.*, 2000a, p.44).

REGION	SITE	AGE	ISOTOPIC METHOD	ROCK TYPE	AUTHOR
NW SARDINIA (Nurra)	Mt. Santa Giusta	197+/- 6Ma 204+/- 6Ma	K-Ar (WR) "	alkaline rhyolitic ignimbrites	Lombardi *et al.*, 1974
		297+/-9 Ma 244+/-9 Ma 296+/-8 Ma	K-Ar (Bt) K-Ar (Fs) K-Ar (Bt)	rhyolitic ignimbrites	Edel *et al.*, 1981
N-NE SARDINIA (Gallura-Anglona)	Azzagulta-Li Reni	247+/- 7Ma 211+/- 6Ma 226+/- 6Ma 258+/- 7Ma 267+/- 7Ma 262+/- 9Ma 249+/- 7Ma 260+/- 9Ma	K-Ar (WR) K-Ar (Fs) K-Ar (Fs) K-Ar (Fs+Q) K-Ar (Fs+Q) K-Ar (Q+ Fs) K-Ar (Fs+Q) K-Ar (Fs+Q	rhyolitic ignimbrites	Westphal *et al.*, 1976
	Coghinas Valley-Aggius	286+/-3Ma 288+/-3Ma 288+/-11Ma	Rb-Sr (Ms) Rb-Sr (Bt) Rb-Sr (WR)	arcosic sandstones " rhyolitic ignimbrites	Del Moro *et al.*, 1996
		268+/-8 Ma 289+/-9 Ma	Rb-Sr (WR) "	dyke	Vaccaro *et al.*, 1991
(Goceano)	Concas	273+/-9 Ma 282+/-9 Ma 280+/-9 Ma 210+/-115 Ma	Rb-Sr (WR) Rb-Sr (WR) Rb-Sr (WR) Rb-Sr (WR)	dyke	Vaccaro *et al.*, 1991
	Mt. Lerno	281+/-10 Ma	Rb-Sr (WR)	dyke	Vaccaro *et al.*, 1991
(Baronie)		291+/-9 Ma	Rb-Sr (WR)	dyke	Vaccaro *et al.*, 1991
CENTRAL-E SARDINIA (Barbagia)	Sorgono	298+/-9 Ma	Rb-Sr (WR)	dyke	Vaccaro *et al.*, 1991
	Galtellì (Orosei)	268+/-10 248+/-9 275+/-11 238+/-11 280+/-7Ma	K-Ar (WR) " " " "	rhyolitic ignimbrites	Cozzupoli *et al.*, 1984
	Mt. Perdedu-Mt. Alastria	260+/-5Ma 212+/-5Ma	K-Ar (WR) "	quarzlatitic subvolcanites	Cozzupoli *et al.*, 1971
	Seui-Seulo	255+/-5Ma 250+/-5Ma 262+/-5Ma	" " "	rhyolitic ignimbrites	
		255+/-6Ma 265+/-5Ma	" "	Trattalas Diorite	
		220+/-4Ma 225+/-5Ma 250+/-6Ma 255+/-8Ma	" " " "	rhyolitic lavas	
		259+/-7Ma 261+/-8Ma	K-Ar (Pl) K-Ar (Fs)	ignimbrites ignimbritic tuffs	Edel *et al.*, 1981
(N Ogliastra)	Talana-Villagrande Strisaili	301+/-8Ma 281+/-10 Ma 308+/-11 Ma	K-Ar (Bt+Cl) K-Ar (Pl) K-Ar (Pl)	dyke ignimbrites "	Edel *et al.*, 1981
		235+/-7 Ma 228+/-5 ma 251+/-5 Ma	K-Ar (WR) " "	rhyolitic ignimbrites	Lombardi *et al.*, 1974
		289+/-9 Ma	Rb-Sr (WR)	dyke	Vaccaro *et al.*, 1991
CENTRAL-SE SARDINIA (S Ogliastra)	Baunei	281+/-10 Ma 291+/-11 Ma 137+/-9 Ma 290+/-5Ma	K-Ar (Pl) K-Ar (Pl) K-Ar (Fs+Q) K-Ar (Cl+Bt)	ignimbrites	Edel *et al.*, 1981
	Perdasdefogu	220+/-5Ma 218+/-6Ma	K-Ar (WR) "	quarzlatitic lavas (dacites)	Lombardi *et al.*, 1974
	Escalaplano	230+/-5Ma 197+/-7Ma	K-Ar (WR) "	latitic lavas (andesites)	Lombardi *et al.*, 1974
		295+/-8Ma	K-Ar (Bt)	andesites	Edel *et al.*, 1981
	Mt.Ferru di Tertenia	223+/-7Ma	K-Ar (WR)	rhyolitic ignimbrites	Lombardi *et al.*, 1974
		211+/-8Ma 252+/-8Ma	K-Ar (Fs+Q) K-Ar (Pl)	ignimbrites	Edel *et al.*, 1981
SW SARDINIA (Sulcis)	Capo Teulada	260+/-5Ma 228+/-6Ma	K-Ar (WR) "	rhyodacitic lavas quartzlatitic lavas	Lombardi *et al.*, 1974

Tab. 1 - Radiometric data from Upper Palaeozoic volcanic rocks and dykes of Sardinia (after Ronchi, *in* Cassinis *et al.*, 2000a).

Radiometric analyses on the Upper Palaeozoic plutonic rocks of the Sardinian–Corsican batholith are summarised in Beccaluva *et al*. (1985), Castorina and Petrini (1989) and Del Moro *et al*. (1975, 1991). Dating of the Mt. Santa Giusta alkaline ignimbrites is in progress.

Key Observations on the Palaeogeography of Sardinia from the Late Palaeozoic to Early Mesozoic

Geological, palaeomagnetic, stratigraphical and structural evidence shows that Variscan and post-Variscan Sardinia was linked to stable Europe (see *e.g.* Alvarez, 1972; Westphal *et al*., 1973, 1976; Zijderveld *et al*., 1970; Chabrier & Mascle, 1974, 1975; Bellon *et al*., 1977; Arthaud & Matte, 1977; Edel *et al*., 1981; Broutin *et al*., 1994). Owing to the general affinity of the Late Palaeozoic to Early Mesozoic scenario, the Corsican-Sardinian block presumably occupied an area between southern France (Provence) to western Liguria and the northeastern part of Spain (Catalonian Pyrenees) (Fig. 3).

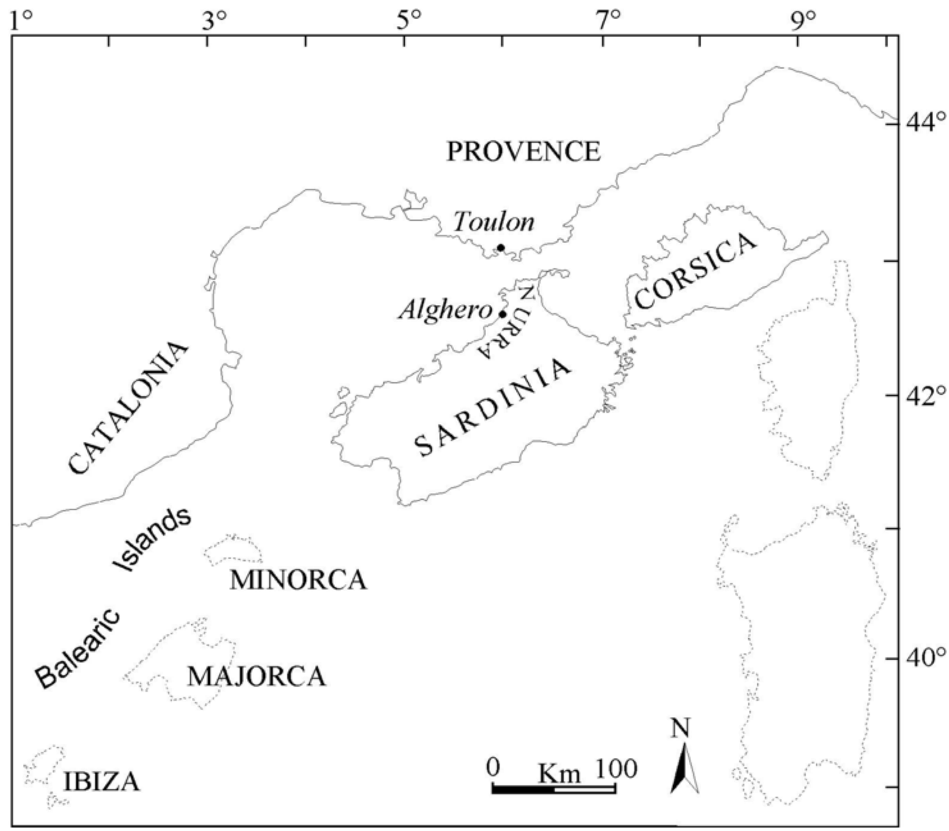

Fig. 3 - Palaeoposition of Sardinia-Corsica block throughout the Triassic times, before its drift towards the present Tyrrhenian. This reconstruction is in accordance with a 60° counter-clockwise rotation with respect to the present-day position (dotted lines). According to the current stratigraphical research, the remarkable similarities between the Permian-Triassic continental successions of the Nurra and Toulon basins allow us to place them closely facing one another, and consequently to place the southern part of Sardinia near the eastern Pyrenees, and northwest Corsica in front of Estérel.

Later, the Corsican-Sardinian massif spread towards the Tyrrhenian owing to geological events, and assumed its present position through a counter-clockwise rotation that mostly occurred during Late Oligocene to Early Miocene times (*e. g.* Westphal *et al.*, 1976, and others). Nevertheless, there is still discussion both on the original position of this microplate with respect to stable Europe, and on possible relative movements within the same block throughout the Late Palaeozoic and younger times.

From a stratigraphycal point of view, we would like to point out that the affinity with the above-mentioned French and Spanish regions is especially highlighted in central-northeastern Sardinia by the widespread distribution of Variscan intrusives (granites, diorites, etc.) with radiometric ages in Ogliastra and Gallura between 297 and 279 Ma (Del Moro *et al.*, 1975), as well as by palaeontological features (Autunian floras and vertebrates). Also the Permian–Triassic continental sequence in Nurra, northwest Sardinia, confirms this similarity with the coeval deposits of southern France (Cassinis *et al.*, 2001 and in press b).

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