The Triassic of the Nurra region (Northwestern Sardinia, Italy)

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During the Triassic, the Corsican-Sardinian block was located on the stable southern continental margin of Europe, between western Liguria and the northeastern part of Spain, with the Nurra region facing the Provence (Southern France) (Cassinis & Ronchi, 1999 with references). The Nurra was therefore near the southern extremity of the Burgundy gate, a corridor which allowed the migration of the late Anisian and Ladinian marine biota from the Tethys to the Germanic Basin (Kozur, 1974; Urlichs, 1978; 1997; Urlichs & Mundlos, 1985; Hagdorn, 1991) (Fig. 1). This paleogeographic position determined in Sardinia a Triassic sedimentary evolution with the classical tripartition of the strata (Buntsandstein, Muschelkalk and Keuper), defined already in the Germanic basin, and used by all the stratigraphers who have dealt with the Triassic of Sardinia. Open marine formations bearing ammonoids occur only in the northwestern region (Nurra area), while marginal marine environments are recorded in central and southwestern Sardinia (Gandin *et al*., 1982).

The first report of the Triassic in the Nurra region was made by Lovisato (1884), who discovered some typical fossils of the Germanic Muschelkalk (e.g. *Encrinus liliiformis, Lima striata, Mytilus eduliformis*) at the Monte Santa Giusta. Few years later, in a dolomite unit cropping out near Alghero, De Stefani (1891) cited the occurrence of "*Halobia lommeli, H. simplex* and *Daonella styriaca*", whose determination is doubtful because these bivalve species have never been found in the Nurra since then. The pioneering research continued with the discovery by Tornquist (1901) of "*Ceratites* ex aff. *evolutus*" at Monte Santa Giusta, who compared it with specimens coming from the Germanic basin, Provence, Romania and Southern Alps (Recoaro). Immediately after, the same author described in detail the succession of Monte Santa Giusta (Tornquist, 1902) and that of Alghero (Tornquist, 1904a, b), now known as Punta del Lavatoio section. In the latter, two ammonoid horizons were discovered. In the upper horizon, Tornquist cited the occurrence of *Protrachyceras longobardicum*, a Longobardian (Late Ladinian) ammonoid of the Alpine Province. Unfortunately, this specimen has never been illustrated and Tornquist's collection, housed in Strasburg, was destroyed during the Second World War (M. Urlichs, pers. com.). Therefore, the occurrence of this ammonoid in the Nurra is not proved. These pioneering phases, concerning the Nurra Triassic succession, ended with the works of Deninger (1907) and Oosterbaan (1936), who described the most important outcrops of the Buntsandstein, Muschelkalk and Keuper.

Unfortunately, the Triassic formations of Nurra are affected by strong tectonics and bad exposure conditions, as a result, the whole succession is mostly known on the basis of borehole data (e.g. Cugiareddu well, Pomesano Cherchi, 1967; Pittau Demelia & Flaviani, 1982), as well as on very few continuous outcrops (e.g. Monte Santa Giusta; Tornquist, 1902; Bartusch, 1985; Carrillat *et al*., 1999). The present description of the Nurra Triassic sequence is mainly based on the synthesis of Cherchi & Schroeder (1985, 1995).

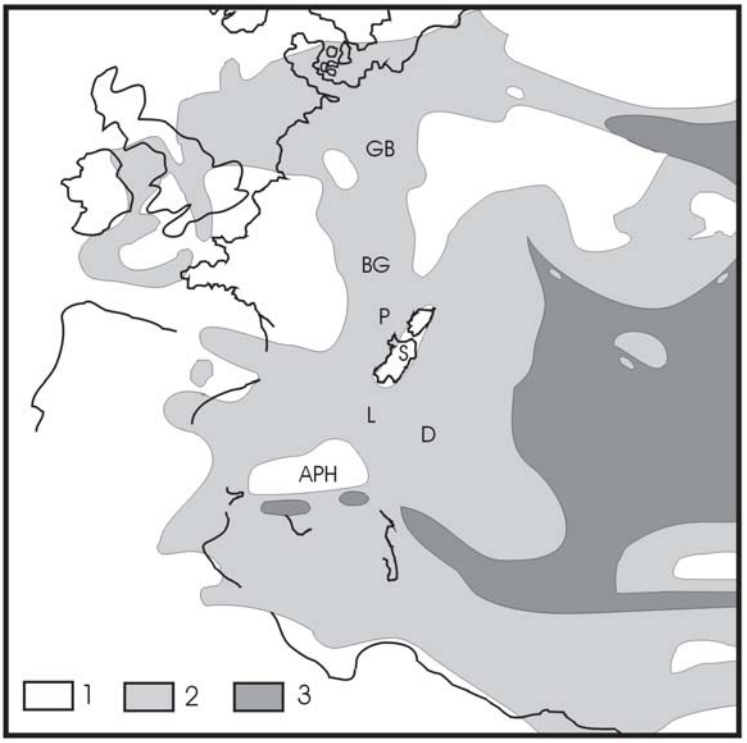

Fig. 1 - Paleogeographic setting of the Corsican-Sardinian block (S) during the Early Ladinian (after Gaetani, 2000, simplified). Symbols: APH, Appennine High; BG – Burgundy gate; D – Dolomites; GB – Germanic Basin; L – Lombardy; P – Provence; 1 – terrestrial areas; 2 – epicontinental and shallow seas; 3 – oceanic basins.

"Buntsandstein" (Permian – Upper Anisian)

The Permian and Lower-Middle pp. Triassic of Nurra is constituted by a continental siliciclastic succession, with pyroclastic lenses (tuff and ignimbrite) of varying thicknesses (Verrucano *Auct*., maximum about 250 m thick), which records an environmental evolution ranging from an alluvial plain to a shallow marine setting with tidal influx (Cassinis *et al*., 1998). The succession is divided into two cycles (Cassinis *et al*., 1998). The lower (Punta Lu Caparoni Fm., 45 m thick, Gasperi & Gelmini, 1980) contains an Autunian (Lower Permian) flora. The upper cycle (more than 200 m thick) probably spans a wide time interval ranging from ?Autunian to late Anisian (Cassinis *et al*., 1998), but the scarcity of fossils makes it impossible to draw a detailed chronostratigraphic division and to recognize the Permian-Triassic boundary.

The top of the upper cycle outcropping in Cala Viola beach, already attributed by past authors to the "Buntsandstein" (e.g. De Stefani, 1891; Tornquist, 1904b; Oosterbaan, 1936; etc.), contains plant remains (*Equisetites mougeoti* Brongnart) and estherias, on the basis of which a Lower Triassic age was suggested (Pecorini, 1962). However, such a chronological attribution requires further research, as the lowest palynomorph association found in the Cugiareddu well (from a level situated 10 m above the second volcanic complex, and correlated with the base of the "Arenarie di Cala Viola" complex, about 90 m thick) appears to suggest "an Olenekian or more probably an Early Anisian age" (Pittau, 1999).

In the Cugiareddu well, the transition from a continental to marine environment is recorded by 15-20 m of sandstones, gypsum shales and marls (Röt facies) containing a Late Anisian (Pelsonian - Illyrian) palynological assemblage (Pittau, 1999).

"MUSCHELKALK" (FASSANIAN – LONGOBARDIAN P.P.)

A complete succession of the Muschelkalk of Nurra is only detectable in the Cugiareddu well (Pomesano Cherchi, 1967) and Monte Santa Giusta (Cherchi & Schroeder, 1985; Carrillat *et al*., 1999). The classical Punta del Lavatoio outcrop, which has so far been used as the reference section for the Muschelkalk of Nurra (Tornquist, 1904a, b, Oosterbaan, 1936; Gandin, 1978, etc.), is a short, overturned segment (detected only now) of the succession, affected by strong tectonics; the lithostratigraphic units of the Nurra Muschelkalk based on this section must therefore be reconsidered.

The Muschelkalk of Nurra is about 180 m thick in the Cugiareddu well, while a very different thickness is reported in literature for Monte Santa Giusta sequence, which is considered about 60 m thick by Carrillat *et al*. (1999) versus about 190 m by Bartusch (1985; *fide* Cherchi & Schroeder, 1995) (Fig. 2). The Muschelkalk sequence of the Monte Santa Giusta has been divided by Cherchi & Schroeder (1995) into the following four lithological units

Lower Dolomitic unit (10-15 m thick). It is made up of dolomitic marls and grey bioturbated dolomites. It corresponds to the Cugiareddu well segment, between samples A 349 and A 356 (Fig. 2), with gypsiferous dolomitic shales, marls and dolomites, containing a palynological assemblage which suggests a Fassanian age (Cherchi & Schroeder, 1995; Pittau, 1999). In Monte Santa Giusta, palynomorphs occurring at the base of the calcareous unit, located 20 m below the appearance of the conodont *Budurovignathus truempyi* (Hirsch), suggest a similar age (Carrillat *et al*., 1999).

Lower Calcareous unit (42 m thick). It is mostly composed of limestone, with *Rhizocorallium* and oolitic horizons in the upper part. In the Cugiareddu well it corresponds to the interval placed between A 339 and A 348 (Pomesano Cherchi, 1967; Cherchi & Schroeder, 1995). Dasycladacean beds are present both at Mt. Santa Giusta (mu 2b) and Cugiareddu well (sample A 343) (Fig. 2). The conodont data of Bartusch (1985, *fide* Cherchi & Schroeder, 1995) concerning the Monte Santa Giusta outcrop show the appearance of *B. truempyi* already from subunit *mu 2a*, and both *B. truempyi* and *B. hungaricus* (Kozur & Végh) from subunits *mu 2d* and *mu 2c*. The *B. truempyi* Zone has been correlated by Kozur (1999) to the *Eoprotrachyceras recubariense* Subzone, uppermost Fassanian in age. However, in the Bagolino area (Southern Alps) it occurs in a bed located above *Eoprotrachyceras margaritosum*, and included in the *Protrachyceras gredleri* Zone, lowermost Longobardian in age (Nicora & Brack, 1995), in the same position so far proposed by Hirsch (1987). Hence, the fully marine sedimentation of Nurra began in the latest Fassanian or lowermost Longobardian. Thus, as already remarked by Kozur (1999), the division of the Nurra "Muschelkalk" into lower, middle and upper units does not correspond with those of the German Muschelkalk. The stratigraphical position of the Punta del Lavatoio section, so far correlated in literature with this unit, will be discussed later.

Upper Dolomitic unit (30 m thick). It is made of by light-grey dolomitic marls and dolomites with dolomitic limestone intercalations. This unit yields the conodonts *Hindeodella* sp. and *Ozarkodina tortilis* (Bartusch 1985, *fide* Cherchi & Schroeder, 1995) and corresponds with the Cugiareddu well segment between A 324b and A 338 (Cherchi & Schroeder, 1995) (Fig. 2).

Upper Calcareous unit (ca. 100 m thick). It corresponds to the segment of the Cugiareddu well between A 293 and A 324 (Cherchi & Schroeder, 1995). At Monte Santa

Giusta the following three subunits have been distinguished (Fig. 2) (Bartusch 1985, *fide* Cherchi & Schroeder, 1995).

mo 1 - approximately 40 m of massive grey limestone with dolomitic limestone at the base; this subunit yields dasycladacean beds and abundant crinoid remains in the upper part. The conodonts are represented by *B. truempyi*, *B. hungaricus* and transitional forms between the two species.

mo 2 – unfossiliferous thick bedded reddish cellular dolomites, 8-10 m thick.

mo 3 – about 50 m of massive grey limestone with some dasycladacean levels. The thin horizons b and d yield a rich fossiliferous content which is characterized by *Coenothyris vulgaris* (Schlotheim), *Plagiostoma striatum* (Schlotheim), and *Encrinus liliiformis* (Schlotheim) (Tornquist, 1902). From this subunit only *B. hungaricus* is cited, which occurs in the *Protrachyceras steinmanni* (Mojsisovics) bed (Lower Longobardian) of Bagolino (Nicora & Brack, 1995).

A different conodont taxonomy is used by Carrillat *et al*. (1999), who consider *B. hungaricus* as junior synonym of *B. truempyi*. This classification is mostly based on the occurrence of transitional forms and overlapping of these two species in the Monte Santa Giusta succession, first reported by Bartusch (1985). Carrillat *et al*. (1999) found *B. truempyi* only in the lowermost conodont bed (located 20 m above a palynological assemblage which suggests a Fassanian age), where *Carinella japonica* (Hayashi) also appears. The latter conodont shows a wide stratigraphical distribution and characterizes the middle part of the section, about 20 m thick. *C. japonica* has a stratigraphic distribution ranging from the top of the *Gredleri* Zone to the base of the *Archelaus* Zone, and is thus considered an index of the lower Longobardian (Krystyn, 1983). Among palynomorphs, the first Carnian form (e.g. *Patinosporites densus* Scheuring) appears 10 m above the last *C. japonica* bed (Carrillat *et al*., 1999).

Punta del Lavatoio is a historical outcrop of the Nurra Muschelkalk (Tornquist, 1904a, b; Deninger, 1907; Oosterbaan, 1936), which has an abundant fossiliferous content. The succession, about 60 m thick, yields two ammonoid horizons ("untere" and "obere Nodosen-Horizont" of Tornquist, 1904b) in which species of Germanic (e.g. *Ceratites muensteri* Diener) and Alpine affinity [e.g. *Protrachyceras longobardicum* (Mojsisovics)] were cited. However, the most common fossils are represented by bivalves, of which the highest diversified assemblage (10 species, see Posenato in this volume), dominated by the Limoid *Plagiostoma* ? cf. *striatum* (Schlotheim) and the Bakevelliid *Hoernesia socialis* (Schlotheim), occurs in the clayey horizon (= "obere Nodosen-Horizont") located in field at the top of the outcrop but, if the sequence is "overturned" to its original position, settled at the base of the succession. This part of the succession records the maximum deepening and the more open marine conditions of the sequence, and was formed in a deep ramp sedimentary environment (Posenato, 1995).

The lower clayey horizon is followed by yellowish or grey nodular limestones and massive grainstone banks. The latter contain abundant dasycladacean remains, which were deposited in very shallow agitated marine water. Upwards, the grey or blackish nodular limestone and yellowish dolomitic marl alternations are characterized by a high frequency of fossil traces ("Rizokorallienkalke" and "obere Nodosen-Horizont" of Tornquist, 1904b), while the taxonomical diversity of the bivalve assemblages decreases. The most common taxa are here represented by Bakevelliids (*H. socialis*) and Costatoriids [*Costatoria goldfussi* (Alberti)]. Fossils of the latter group form monospecific shelly pavements accumulated by storm waves (tempestites). The decrease of taxonomical diversity and the mass occurrence of small-sized shells of Costatoriids, a eurytopic group typical of Triassic hyperhaline environments, suggest a restricted subtidal environment.

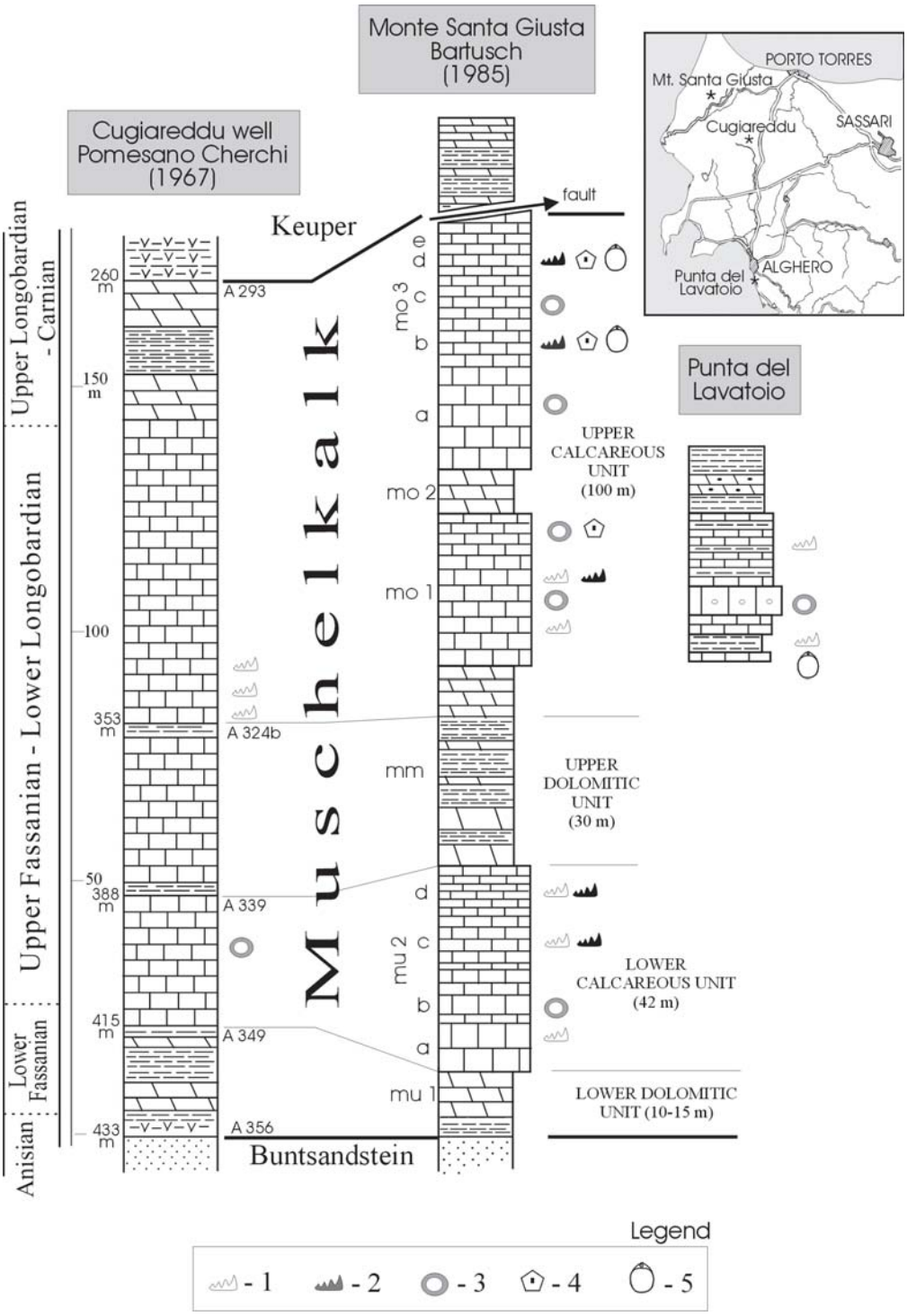

Fig. 2 - Stratigraphic columns of the Triassic succession of the Nurra area (NW Sardinia) (after Cherchi & Schroeder, 1985, modified). Symbols: 1. *Budurovignathus truempyi*; 2. *B. hungaricus*; 3. Dasycladaceans; 4. Crinoids; 5. Brachiopods (*Coenothyris vulgaris*).

The succession ends with about 20 m of hard yellowish dolomitic marls and bioclastic dolomitized banks in which only sparse valves of Costatoriids are present (Gandin, 1978).

As regards the chronological setting of the Punta del Lavatoio section, if it is "overturned" to the right position, the clayey horizon, in which Tornquist (1904b) cited *Protrachyceras longobardicum* (Mojsisovics), falls at the base of the succession. The conodont *B. truempyi* was recorded by Bagnoli *et al.* (1985) from the clayey horizon and superimposed layers. However, these conodont specimens have been considered by Kozur *et al.* (1994) as a new subspecies of *B. truempyi*, transitional to *B. hungaricus*, therefore younger than *B. truempyi truempyi*. The recent discovery in the Bagolino area of *B. truempyi* in the *Protrachyceras gredleri* Zone (Nicora & Brack, 1995) suggests a younger upper limit for the *B. truempyi* Zone, so that a Lower Longobardian age for the Punta del Lavatoio succession cannot be excluded.

At present, it is very difficult to make a precise correlation between the Punta del Lavatoio and Monte Santa Giusta sections. The base of the Punta del Lavatoio section, with a rich mollusc assemblage, could be correlated with the fossiliferous beds of the upper part (mo 3) of the Upper Calcareous unit (lower Longobardian). However, as only *B. hungaricus* (or *C. japonica*) is cited in this part, only a taxonomical revision of the Nurra conodonts would solve this question.

NW Sardinia (and Provence) has a middle Triassic conodont fauna with species in common with both the "Westmediterran – Arabischen" and Germanic provinces (Kozur, 1980). The former province corresponds to the Sephardic province (Hirsch, 1972), which includes the southern and western margins of the Tethys (from the Iberian Peninsula to Israel) covered by shallow epicontinental seas, where the classic Germanic trilogy of the Triassic formations is recorded. This province is characterized by a mixture of endemic, Germanic and Alpine affinity taxa (Márquez-Aliaga *et al*., 1986). The occurrence of Germanic-type species (e.g. bivalves) must be mostly correlated to the same environmental factors (i.e. shallow and hypersaline sea) that controlled the immigration of Tethyan stenohaline taxa in the Germanic Basin (Hagdorn, 1991). Tethyan elements (e.g. ammonoids and dasycladaceans) overcame this ecological barrier during the phases of maximum sea level rises. The major Triassic flooding event is recorded in the Lower Ladinian (Fassanian), when a mixture of Tethyan and Alpine ammonoids occurred in both the Germanic and Alpine domains (Urlichs, 1978; Mietto & Manfrin, 1995; Gianolla & Jacquin, 1998). This time corresponds to the beginning of Muschelkalk sedimentation in the Nurra region. According to Aigner & Bachmann (1992), the peak trasgression in the Germanic Basin occurs in the *cycloydes* bank (Upper Muschelkalk) belonging to the Enodis Zone (uppermost Fassanian), in which rare occurrences of *B. truempyi* are reported (Kozur, 1999).

"Keuper" (upper Longobardian – ? Rhaetian)

The Keuper succession of Nurra is strongly deformed because it is mainly formed by plastic evaporitic sediments. This fact, alongside the almost complete absence of fossils, impedes a detailed reconstruction of the stratigraphic succession.

Oosterbaan (1936), mostly on the basis of the Monte Corredda outcrops, divided the Keuper sequence of Nurra into four lithological units (from the base): k1 - série à cargneules (2 m); k2 - série à gypse (3 m); k3 - série à Steinmergel (12 m); k4 - série à dolomies et calcaires (40 m). Unit k2 may reach about 50 m thickness in the outcrop located to the west of Punta del Gallo.

Cherchi & Schroeder (1995) divided the Keuper into two parts. The lower one is mainly represented by strongly folded reddish to greenish gypsiferous shales with collapse

breccias and vuggy dolomites. This unit is represented by the "argille gessifere" in the Cugiareddu well (Pomesano Cherchi, 1967). The upper part consists of grey, sometimes brecciated dolomites with thin intercalations of reddish or greenish shales.

The palynological assemblages suggest to date the transitional beds between Muschelkalk and Keuper should be dated to the late Longobardian (Late Ladinian) and the "Gyps Keuper" mainly to the Cordevolian (Early Carnian), with a probable Julian age for its upper part. The upper unfossiliferous dolomitic unit is attributed to a generic Late Triassic (Pittau, 1999).

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