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SARDINIAN PALAEOZOIC BASEMENT AND ITS MESO - CAINOZOIC COVERS (ITALY)

Leaders: S. Barca, A. Cherchi

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Front Cover:

Overview of the Middle Cambrian carbonate platform (“Metallifero” Auct.) at Nebida (Iglesiente - SW Sardinia)

Leaders: S. Barca, A. Cherchi

Introduction

This field trip will allow examination of the most significant tectono-sedimentary events in Sardinia during the early Caledonian, Hercynian and Alpine cycles, from Early Cambrian to Late Cenozoic times.

The Palaeozoic successions, from Cambrian to Permian, show a great variety of facies, from rich fossiliferous to highgrade metamorphic bodies, allowing the study of peculiar features (Cambrian biotas and their relationships to sequence stratigraphy, and structural geology). Within the post-Hercynian sequences, several tectono-sedimentary units have been identified. The presence of biota, especially microfossils, led to a precise chronostratigraphical definition and palaeogeographical reconstruction of both the sequences and the recorded tectonic events. Among these, particular emphasis is given to the evolution of the Mesozoic platform (Middle Triassic to Late Cretaceous). The Cenozoic history of the Corsica-Sardinia block is closely linked to the geodynamic evolution of the Western and Central Mediterranean area and to the role of tensional tectonics. The itinerary will cross the Southwestern (Sulcis, Iglesiente), Central (Gerrei, Quirra, Trexenta, Sarcidano) and Northwestern (Nurra) regions. In selecting the outcrops, a good exposure of sequences and their easy accessibility have been considered. Therefore, some areas have been privileged, either for their historical significance, or because they have been the matter of detailed studies.

Regional geological setting

S. Barca & A. Cerchi

Palaeozoic basement (S.B.)

It has long been well known that the Palaeozoic Basement of Sardinia is part of the Southern European Hercynian Chain. This is evidenced both by the stratigraphic and structural affinities with other Hercynian massifs of Southern Europe, as well as by palaeomagnetic data indicating the same structural and sedimentary evolution as Southern France up to Oligocene-Early Miocene times, when the Corso-Sardinian block detached and drifted towards South-East (Barca and Cherchi, 2002 and references therein). The Hercynian Orogeny affected the whole Sardinian Basement (Fig. 1), with varying degrees of deformation and metamorphism, followed by important and extended post-collisional magmatism.

From the stratigraphical point of view, the Sardinian Basement is constituted by a rather continuous Palaeozoic succession. In particular, in the "External Zone" and in the "External Nappe Zone", thanks to weak tectonic deformations and low grade metamorphism, the original lithological features and the palaeontological content have not been destroyed. Therefore, a reconstruction can be made of the stratigraphic sequences (from Late Precambrian?/Early Cambrian to Earliest Carboniferous), with paleoenvironmental and paleogeographic interpretations. Furthermore, here it is possible to distinguish in detail a "Caledonian Sedimentary Cycle" (from the Late Precambrian? to the Early Ordovician) and a "Hercynian Sedimentary Cycle" (from the Late Ordovician to the Earliest Carboniferous). These important cycles are divided by a gap, Middle Ordovician in age (Barca *et al*., 1987), evidenced by a strong angular unconformity due to the compressive movements known in the Iglesiente-Sulcis area as the "Sardic phase" (Stille, 1939), and in the Sarrabus-Gerrei area as the "Sarrabese phase" (Calvino, 1972).

In the External Zone of the Iglesiente-Sulcis the angular unconformity of the Sardic phase is very clear in the field (Nebida, Domusnovas, etc.) thanks to the very weak Hercynian tectonics. However, in the Nappe Zone the strong Hercynian deformations have often completely destroyed and transposed the Caledonian structures (the Sarrabese phase). A geodynamic model (Carmignani *et al*., 1992) seems to indicate that the "Sardic – Sarrabese phase" is related to the compression of the Cambrian-Ordovician back-arc basin, i.e. the Iglesiente-Sulcis area, originated by the shifting of the Ordovician volcanic arc towards the North Gondwana continental margin. The more complete Palaeozoic sequences of the Sardinian Basement crop out in the so-called "Autochthonous" units of the External Zone (Sulcis-Iglesiente), and in the structurally higher "Allochthonous Units" of the External Nappe Zone. In fact, in these metamorphic lower grade areas a stratigraphic reconstruction of these rather continuous Cambrian - Carboniferous successions has been possible on a palaeontological basis. The oldest lithostratigraphic unit of the low-grade metamorphic succession of the External Zone is the Bithia Fm. (Upper Precambrian?- Early Cambrian) followed by three sedimentary units: the Nebida Group, the Gonnesa Group and the Iglesias Group (Rasetti, 1972; Cocozza, 1979; Junker and

Schneider, 1979; Pillola,1991; Pillola *et al.*, 1995), ranging in age between the Early Cambrian and the Early Ordovician. The Bithia Fm. is prevalently formed by metasandstones, meta-argillites, meta-greywackes, metalimestones and metaconglomerates (thickness about 2000 m). These metasediments are related to slope and terrigenous shelf environments, placed along the north-Gondwana continental margin. The only fossil evidence consists of scarce and poorly preserved acritarchs (Pittau Demelia and Del Rio, 1982); therefore a Late Precambrian age is inferred mainly on the basis of its stratigraphic relationship with the overlaying Matoppa Fm. of the Nebida Group (Lower Cambrian); the Matoppa Fm. may also make lateral, transition to the upper part of the Bithia Fm. (Carannante *et al.*, 1984; Gandin, 1987; Gandin *et al.*, 1987). The lower boundary of the Bithia Fm. is tectonic, and therefore the lowest part of this unit is not known.

The Cambrian-Lower Ordovician succession has been revised by Pillola, 1991 and Pillola *et al.* 1995, 1998, 2002. The Nebida Group (400-500 m thick) is represented by arenaceous-argillitic sediments, subordinately carbonatic, bearing rich fossiliferous levels (trilobites: Rasetti, 1972; Pillola and Gross, 1982; archeocyathids: Debrenne, 1964, 1972; Debrenne *et al.*, 1979, Debrenne and Gandin, 1985) yielding an Early Cambrian age. It is subdivided into two units: the lower Matoppa Fm. and the upper Punta Manna Fm. The Nebida Group is thought to have been deposited during a tendentially regressive deltaic-marine system, where the Matoppa Fm. represents the prodelta area, with oolitic shoals, lagoon and beach. The Punta Manna Fm., on the other hand, may have represented the proximal delta, with facies of backshoal evolving from lagoonal to tidal flat conditions, under a hot, tendentially more arid, climate. The Cambrian sequence of Sulcis-Iglesiente continues with the metalimestones and metadolostones of the Gonnesa Group (200-500 m thick); this is subdivided into two units: the Santa Barbara Fm. ("Dolomia rigata" *Auct.*) and the San Giovanni Fm. ("Calcare ceroide *Auct.*). The Santa Barbara Fm. is related to tidal flat environments under hot-dry conditions. The paleontological content, represented by Lower Cambrian calcimicrobes and archeocyatids, is very low. Characteristic of the San Giovanni Fm. are carbonatic facies with ooids and/or pisoids, bioclasts and "vadose pisolites", relatable to supra- to subtidal environments. The transition from the Gonnesa Group to the overlying Iglesias Group is usually marked by a subaerial erosional surface evidenced by weak karstic features and by breccia horizons related to rapid subsidence and drowning of the platform due to extensional movements. The Iglesias Group (up to 400 m thick) is subdivided into two units: the Campo Pisano Fm. ("Calcescisti" *Auct.*) and the Cabitza Fm. (mainly metargillites and metasiltstones). In the Campo Pisano Fm., deposed in a shallow water environment, trilobites, brachiopods, echinoderms, sponges, hyolitids, foraminifers and microproblematica have been found. On the basis of trilobites this formation has been ascripted to the lowest part of the Middle Cambrian (Rasetti, 1972; Gandin and Pillola, 1985; Gandin, 1987; Pillola, 1986, 1991). The transition to the Cabitza Fm. is gradual; in this unit, sedimentary structures such as cross- and convolute laminations, ripple-marks, flute casts, as well as trace fossils can be observed. The lowest part contains brachiopods, carpoids and trilobites of

Figure 1 - Main structural elements of the Sardinian Basement. 1. Post-Hercynian cover; 2. Hercynian Batholith; 3. High Grade Metamorphic Complex (HGMC); 4. Internal Nappes; 5. External Nappes; 6. External Zone; 7. Posada - Asinara Line; 8. Major thrusts (after Carmignani et al., 1986, mod.).

Middle Cambrian age. Trilobites also attest to a Late Cambrian age for the middle-upper part of the unit, while an Earliest Ordovician (Tremadoc) age has been deduced for the highest part of the sequence on the basis of graptolites and acritarchs (Barca *et al*., 1987; Pillola and Gutierrez-Marco, 1988).

In the External Zone of the Sulcis-Iglesiente the metasediments of the "Caradocian transgression" overlie the Cambrian-Earliest Ordovician sequence. This angular unconformity is related to the Sardic phase, which is also responsible for the development of a continental environment from Arenig to Caradoc. A transgressive cycle, which probably started during the Late Caradocian, was favoured by a new extensive tectonic event connected to the collapse of the Ordovician magmatic arc and with related thermic crustal subsidence (Carmignani *et al*., 1992). The basal part of the post Sardic phase transgressive sequence is represented by the typical clastic deposits of the Mt. Argentu Fm. ("Puddinga" *Auct.*; Leone *et al*., 1991, 2002), deposed in a continental environment (Cocozza *et al*., 1974). Enormous scattered carbonatic boulders ("Olistoliti" *Auct*.), probably fell along slopes controlled by synsedimentary faults. Towards the top of the sequence, the grain of the deposits decreases, passing to the finer sediments of a distal floodplain to a transitional-littoral environment (Martini *et al*., 1991). In this facies the only fossils recovered belong to one species of soft bodied, trilobite-like arthropod (Hammann *et al*., 1990). The post Sardic phase sequence continues with shallow marine metasediments deposed on a neritic platform, often containing a rich Caradocian-Ashgillian fauna (bryozoans, brachiopods, cistoids, trilobites and conodonts). The uppermost part is characterized by alternations of micaceous sandstones and meta-argillites, with parallel and wavy lamination, containing scattered clasts ranging from centimetric to millimetric in size, interpreted as glacio-marine deposits (Cocozza *et al*., 1974; Leone *et al.*, 1991). These are similar to and coeval with the so-called "paratillites", well known in the perimediterranean region, related to cold oceans bordering the Ordovician inlandsis of Northern Gondwana. This sequence has been subdivided into 4 units (Leone *et al*., 1991): the Mt. Orri Fm., the Portixeddu Fm., the Domusnovas Fm., and the Rio San Marco Fm. A Caradoc-Ashgill age of such units has been affirmed by using several groups of fossils, e.g. trilobites (Leone *et al*., 1991; Hammann and Leone, 1997), conodonts (Ferretti and Serpagli, 1999), brachiopods (Havlicek *et al*., 1987) and graptolites (Leone *et al*., 1994). In SW Sardinia Silurian and Devonian sedimentation is characterized by a pelagic sedimentation over wide areas, in places under euxinic conditions at the bottom and oxygenated ones on the surface; three units have been identified: the Genna Muxerru Fm., the Fluminimaggiore Fm. and the Mason Porcus Fm. (Gnoli *et al*., 1990). A shallow high energy deposition occurred during the cephalopod limestone sedimentation (Ferretti, 1989; Ferretti and Serpagli, 1996; Ferretti *et al*., 1998).

In the External Nappe zone the Palaeozoic sequence begins with thick terrigenous metasediments known either as "Arenarie di San Vito" *Auct*. (Sarrabus-Gerrei regions; Calvino, 1960), or the Solanas Fm. (Sarcidano-Barbagia, Minzoni, 1975). These units (thickness of more than 500 m) are characterized by alternations of micaceous metasandstones, quartzites, metasiltites and metapelites, deposed in a wide submarine fan-delta system, characterized by turbidity current depositional processes (Barca and Di Gregorio, 1979; Barca and Maxia, 1982). The age is comprised between Middle Cambrian and Early Ordovician (Tremadoc-Arenig), on the basis of an acritarch association (Barca *et al*., 1981, 1984, 1988; Albani *et al.*, 1985; Naud and Pittau Demelia, 1987; Albani, 1989; Di Milia, 1991 and references therein). The Cambrian-Ordovician siliciclastic sediments are unconformably overlain (the Sarrabese phase) by volcanites, volcanoclastites and epiclastites, up to 400-500 m thick. In the Gerrei Unit, the Middle Ordovician volcanic sequence is represented by metavolcanites and "Porfiroidi" *Auct*. (Carmignani *et al*., 1992). During Late Ordovician time, the end of the subduction and the following gravitative collapse of the magmatic arc produced extensional tectonics, which favoured the Caradocian marine transgression. In the External Nappe Zone (Sarrabus, Gerrei, Arburese) the Caradoc-Ashgill marine successions (150-200 m thick) are constituted by quartzites, metasandstones and metaconglomerates, metasiltites and meta-argillites (Punta Serpeddì Fm.), sometimes with carbonate content. Placer levels and fossiliferous horizons occur (bryozoans, brachiopods, trilobites, and gasteropods; Giovannoni and Zanfrá, 1978; Conti, 1990; Loi *et al.*, 1992). Carbonatic metasediments of Ashgill age (up to tens of metres thick) bear a fossiliferous association (conodonts and echinoderm remains). In the Sarrabus these sediments, ascribed to the Tuviois Fm. (Barca and Di Gregorio, 1979) are partially or totally silicified owing to submarine hydrothermal phenomena, and therefore they are also called "Quarziti" or "Calcari silicizzati" *Auct*. (Barca and Maxia, 1982). The most complete Silurian-

Devonian successions of the Nappe Zone crop out in the Gerrei (Corradini *et al*., 1998; 2002a); incomplete sequences are discontinuously present also in Sarrabus and the Arburese. In the Gerrei tectonic Unit, the older Silurian sediments are black shales (Lower Graptolitic Shales) with typical siliceous levels (radiolarites) known as "lydite". Spherical organic microfossils have also been found (Pittau *et al*., 2002). The age of this complex (30-40 m thick) is comprised between Llandovery and Early Ludlow, even if not all the graptolite biozones have been documented (Jaeger, 1976, 1977; Barca and Jaeger, 1990). The Upper Silurian sediments, occurring in the Ockerkalk facies (Corradini *et al*., 2002b), are represented by ochraceous nodular limestones, bearing lobolites, conodonts (Barca *et al*., 1995a) and rare nautiloids (Gnoli, 1993). The Silurian-Devonian boundary could be placed in connection with the transition from the "Ockerkalk" to a new black shale sedimentation (Upper Graptolitic Shales), dated to the Lockovian on the basis of graptolites (Jaeger, 1976). The two black shale facies, characteristic of anoxic conditions at the bottom, as well as the Ockerkalk one, developed in open marine conditions with scarce sedimentary supply from land. The sequence ends with massive pelagic metalimestones (200-300 m thick), known as "Calcari di Villasalto" or "Calcari a Clymenie" (Lovisato, 1894), biostratigraphically calibrated on the basis of conodonts (Olivieri, 1965, 1970; Corradini, 2002 and references therein). Recently, Lower Carboniferous (Tournaisian) beds have been documented on the basis of conodonts (Barca *et al*., 2000; Corradini *et al*., 2003).

In Southern Sardinia, thick siliciclastic sequences (hundreds of metres thick), formerly regarded as Cambrian-Silurian in age, have been recently dated as Lower Carboniferous and interpreted as synorogenic deposits accumulated in foredeep basins located between the advancing nappe front of the Sardinian Hercynian Chain and the foreland or External Zone (Iglesiente-Sulcis area; Barca, 1991; Barca and Olivieri, 1991; Barca *et al*., 1992a; Barca and Eltrudis, 1994). In the Gerrei a stratigraphic transition between the Upper Devonian – Early Carboniferous limestones and the Hercynian flysch ("Conglomerato di Villasalto", Teichmüller, 1931) is described by some authors (Spalletta and Vai, 1982; Barca and Spalletta, 1985; Barca *et al*., 2000). These synorogenic deposits are represented by metasandstones, quartzites and metasiltites, with intercalations of polygenic metaconglomerates, metabreccias bearing clasts of Silurian "lydite", and metavolcanites (Barca, 1991). The deposition was mainly turbiditic in type, as also proved by exotic megablocks (olistolithes and olistostromes) up to hundreds of metres in size. On the basis of conodonts it has been possible to date such exotic blocks at various Devonian intervals (Spalletta and Vai, 1982; Barca and Spalletta, 1985; Barca and Olivieri, 1991) and indirectly infer a post-Devonian age for the "Sardinian Hercynian flysch".

Magmatic activity, related to extensional post-collisional tectonics of the Sardinian Hercynian Orogen, took place between the Late Carboniferous and Permian (radiometric age: 307-275 My) (Del Moro *et al*., 1975; Oggiano and Di Pisa, 1988; Macera *et al*., 1989). The Late Hercynian extensional movements were responsible for the birth and evolution of fluvio-lacustrine molassic basins, where terrigenous sediments, bearing a Stephanian-Autunian floristic association (Cassinis *et al*., 2000, and in this volume, Cassinis and Ronchi 2002, Freytet *et al*., 2002; Pittau and Del Rio, 2002b) and vertebrate remains (microsauria, Fondi, 1980; amphibians, Ronchi and Tintori, 1997) accumulated.

Post-Palaeozoic covers (A.C.)

The Permo-Carboniferous continental deposits are unconformably overlain by Meso-Cenozoic sequences (estimated thickness about 6000 m), sometime associated with volcanites and volcanoclastites (Fig. 2). The Mesozoic succession is built up by a complete Triassic transgressive-regressive cycle in typical "German" facies, starting with terrigenous continental deposits (Buntsandstein) and ending, after a fossiliferous shallow marine carbonate level (Muschelkalk), with marly-clayey sediments with gypsum (Keuper). Both the distribution of outcrops and of the sedimentary facies supports a western provenance for the Triassic transgression (Cherchi, 1985a; Barca *et al*., 1995b, c). In Mesozoic time, Sardinia was undergoing regional extension, which favoured shallow marine transgressions, starting from the west (Muschelkalk in Nurra and Sulcis) and heading east (Dogger in the Gulf of Orosei). Only in the Middle Jurassic did marine conditions prevail over the whole island. In the central part the Jurassic cover ("Tacchi" or "Tonneri" *Auct*.) horizontally lies above the Palaeozoic basement, often with an intervening basal quartzitic conglomerate. Extensional tectonic features were also present during the Early and Middle Jurassic; some authors (Monleau 1986, with enclosed bibliography) support the idea of mainly NE-SW trending tensional tectonics in this chronostratigraphic interval, which would have been active in Provence, Sardinia and the Maritime Alps. The same tectonic feature at the Lias-Dogger transition has been documented in Corsica, too. In Northwestern Sardinia (Nurra),. detritic quartz are present in limestones, found at three different levels (Early Pliensbachian, Aalenian and Bajocian; Cherchi and Schroeder, 1985c). In the Nurra region two cycles may be distinguished in the Triassic-Jurassic successions. The first ranges from the Middle Trias to Lias (frequent hardgrounds develop in Upper Aalenian). In Eastern Sardinia, where sedimentation started later, the first cycle ranges from Bathonian to Lower Callovian, and is bounded at the top by hardgrounds with iron ooids marking a major regressive episode (Dieni and Massari, 1985). The regressive regime begins more or less contemporaneously around the whole island: in Nurra during the Bajocian (Cherchi and Schroeder, 1985c); in Central Sardinia (Del Rio, 1985) and in Eastern Sardinia (Dieni and Massari, 1985) during the Bajocian-Bathonian. The last cycle starts from the Oxfordian transgression, particularly marked in eastern Sardinia; it ends in the basal Cretaceous (Lower and Middle Berriasian) with the establishment of the Purbeckian facies that represents the acme of this regressive event. Marine conditions start again in latest Berriasian – earliest Valanginian (Cherchi and Schroeder, 2002) and continue without interruption with neritic platform deposits (Urgonian facies) at least up to the Lower Aptian in Western Sardinia, and up to the Lower Albian in Eastern Sardinia (Wiedmann and Dieni, 1968). A great stratigraphic gap, accompanied by the genesis of bauxite deposits, occurs in Western Sardinia: in Nurra it clearly overlies all the sediments of the Upper Aptian-Upper Cenomanian interval. The hiatus was related to a Middle Cretaceous compressive phase which was responsible for an angular unconformity between the Middle-Upper Cretaceous and the underlying pre-bauxite Mesozoic deposits. The hiatus gradually increases from east to west. It is minimal on the outskirts of Eastern Sardinia (Orosei), where the unconformity comes within the pelagic Albian (Wiedmann and Dieni, 1968; Dieni and Massari, 1985); an angular unconformity separates the Lower Cretaceous succession from the subsequent discontinuous Upper Albian conglomerate with phosphatic and glauconitic pebbles, characterized by rich, condensed, ammonite fauna. In the Anglona region (Central-Northern Sardinia) the neritic limestones of the Upper Cenomanian unconformably cover the Middle Triassic (Cherchi and Schroeder, 1976a). The progressive reduction of the hiatus, accompanied by bathymetric conditions, which gradually become more pelagic, indicates the eastern origin of the transgression. A general emersion, affecting the whole island, is found in the uppermost Cretaceous. It starts earlier in the west than in the east of Sardinia. In the west, the latest marine sediments are of Campanian age (Cherchi and Schroeder, 1995), whilst in the east there are Lower Maastrichtian marine sediments(Busulini *et al*., 1984).

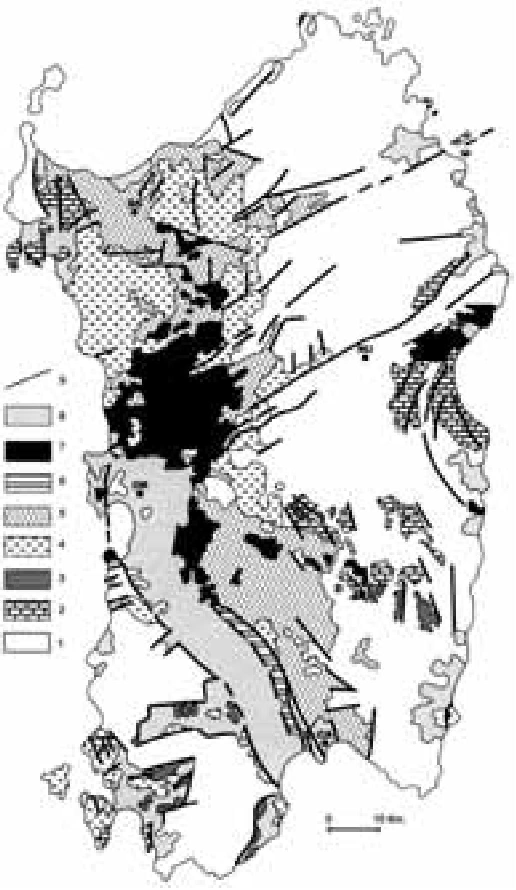


Figure 2 - Main geological features of the post-Palaeozoic covers: 1. Palaeozoic basement; 2. Upper Carboniferous - Permian to Mesozoic; 3. Palaeocene – Eocene; 4. Oligo - Miocene volcanics; 5. Oligocene to Neogene deposits; 6. Pliocene continental deposits; 7. Plio-Quaternary volcanics; 8. Quaternary; 9. faults (after Cherchi and Montadert, 1982, mod.).

During the Mesozoic and the Paleogene, Sardinia and Corsica formed an integral part of the southern margin of the European plate. Separated from it during the Burdigalian because of spreading of the Provençal Basin and the anticlockwise rotation, Corsica and

Sardinia shared the geological history of Western Europe (Iberian Peninsula – Southern France) up to the Early Burdigalian.

At the end of the Mesozoic Sardinia completely emerged. The continental phase lasts until the Palaeocene; marine fossil pebbles of the Dano-Montian, Thanetian and Early Ilerdian ages are contained in the Tertiary conglomerate cropping out in Eastern Sardinia (Dieni *et al.*, 1979, 1983).

Deep wells in the Sulcis lignitiferous basin (Southwestern Sardinia) indicate the presence of the marine Ilerdian at the base of the Eocenic succession (Cherchi, 1983). The Ilerdian has recently been identified also in other regions (Matteucci, 1985; Murru, 1990; Murru and Matteucci, 2002). Supratidal miliolitic limestones ("Miliolitico" *Auct.*) of Late Ilerdian age in the Sulcis Palaeogene basin suggest the beginning of a gradual regression. These sediments are first interbedded and then overlain by a paralic facies characterized by thick coal seams of Early Cuisian – Lutetian age, as palynological studies indicate (Pittau Demelia, 1977; Murru and Salvadori, 1990). This sequence unconformably overlies (Laramic phase) various lithological complexes ranging in age from Palaeozoic to Late Mesozoic (Barca and Costamagna, 1997, 2000). The further compressive Middle Eocene tectonic phase (Cherchi, 1979; Letouzey *et al.,* 1982; Cherchi and Tremolières, 1984; Barca and Costamagna, 1997) is responsible for the basal unconformity of the Cixerri Fm. (Middle - Upper Eocene), which truncates them from the Palaeozoic to Lower Eocene beds. This continental formation crops out in Southwestern Sardinia and has a regional palaeogeographic importance, as it represents a late emerged land preceding the opening of the Western Mediterranean basin. The occurrence in the Cixerri Fm. of conglomerates containing Middle-Cretaceous endemic species of the Iberian – Provençal domain (Cherchi, 1979; Cherchi and Schroeder, 1976b), and the direction of their transport (Barca and Palmerini, 1973), offer further evidence of the geographic contiguity of the Corso-Sardinia block with the European continent during the Paleogene.

A phase of very widespread tensional tectonics of Late Oligocene age, seems to be the origin of the rift system affecting the Western Mediterranean area. The Sardinian Oligo-Miocene basin s.l. represents one of the easternmost branches of this tensile system (Cherchi and Montadert, 1982, 1984). These movements began in a continental environment, before the marine transgression. Thick, clastic, syn-rift sediments (the Ussana Fm.) emphasize the role of the faults, active in the Sardinian rift. The heterochronous transgression occurred during the Aquitanian - Burdigalian and was controlled by both tensional tectonic and the pre-trangressive volcanic morphology. Horsts, grabens and tilted blocks show the intensity of the extensional mechanisms (Casula *et al*., 2001). The first post-rift sediments are represented by a few meters of azoic sandstones (Lower Burdigalian?). In Middle Burdigalian time, a clear post-rift sedimentation is characterized by a hemipelagic succession associated with frequent turbidite deposition. Extensive marine transgression affected previously emerged areas (Anglona, Bosano, Tirso valley and Logudoro), where sediments of the Middle Burdigalian, with planktonic foraminifers, covered the "Lacustre" Fm. *Auct.*, peaking during the Late Burdigalian (Cherchi, 1985b). This marine sedimentation continued in the basin into the Late Miocene. The Messinian regression, with lagoonal and continental facies, was accompanied by the formation of palaeosoils (Cherchi *et al*., 1978). Upper Miocene deposits are very limited due to intensive erosion during the Messinian regression and the later Middle-Late Pliocene continental phase. The angular unconformity of the Lower Pliocene marine transgressive deposits on the Messinian substratum (Sinis) is related to the compressive movements of Late Miocene age, also evidenced by microtectonic features (Cherchi and Tremolières, 1984). Messinian erosion is furthermore particularly evident in the seismic profiles (Casula *et al*., 2001).

The superimposed Plio-Quaternary Campidano Graben, related to the opening of the Tyrrhenian Basin, contains more than 600 m of syntectonic continental deposits (the Samassi Fm.). It consists of redeposited Miocene and Lower Pliocene sediments, eroded from the eastern flank of the trough, thus emphasizing the importance of deep Middle - Late Pliocene erosion. The continental phase, which started during the Middle Pliocene, ends with the first marine deposits of the Upper Pleistocene.

Field itinerary

DAY 1

Stop 1.1:

Early Cambrian mounds at Cuccu Egai, Gonnesa (Matoppa Fm., Nebida Group, SW Sardinia)

G.L. Pillola, A. Loi & F. Leone

Studies on the calcimicrobial-archeocyathan mounds cropping out east of Gonnesa were provided by

Stop locations: 1.1 – Cuccu Egai (Gonnesa); 1.2- Nebida; 1.3 – Porto Flavia; 1.4 – Campo Pisano and Cabitza (Iglesias); 1.5 and 1.6 – S. Giorgio (Iglesias).

Debrenne (1964); later on, both faunal composition and sedimentological analysis allowed us to propose a more detailed framework for these complex bioconstructions. The calcareous body of Cuccu Egai has been chosen for this stop mostly for logistic reasons, as it does not differ significantly from those cropping out elsewhere in many localities of central and western Iglesiente. This buildup shows the classical arrangement described at the nearby locality of Serra Scoris (Pillola *et al*., 1995, 2002, and references therein), and, although the tectonic disturbances are particularly severe (upturned and locally faulted sequence), the vertical succession can be followed after distinguishing the massive, basal, black-grey, calcimicrobial-dominated limestones, up towards abundant light-grey to white limestones, with local archaeocyathan-rich portions, until the terrigenous deposits at the top of the bioconstruction. Laterally, siltstones, finer sandstones and rare limestones, often dolomitized, occur; the latter are usually rich in archaeocyathans, rare trilobites, and stenothecoids.

Except for rare trilobite debris, chancellorid rosettes, sponge spicules, probable hyolithids and brachiopods, the bulk of organisms which built up the mounds are calcimicrobes such as *Epiphyton*, *Renalcis*, rare *Girvanella* and a variable amount of archaeocyathans (Cherchi and Schroeder 1985a).

The reoccurrence of these calcareous bodies within the cyclic, siliciclastic dominated succession of the Matoppa Fm. has been studied in order to clarify the mechanisms of onset of carbonate deposition. The deposits investigated show different orders of cyclically-arranged depositional sequences, their hierarchy clearly indicates a eustatic control of depositional dynamics (Fig. 3). More developed mounds occur in correspondence to noteworthy accelerations of sea level rise of the medium-frequency sequences. Finer terrigenous facies,which pass laterally to the mounds (assigned to the middle and distal portions of the upper offshore), attest to their more rapid deepening compared to the underlying deposits (coarse to medium grained sandstones with HCS, SCS, etc., indicating a shoreface environment). In this context, the mounds can be considered an espression of condensation linked to medium-frequency eustatic rises. The top of each mound horizon represent a maximum flooding surface, which are of high stratigraphic value (isochronous and correlatable surfaces).

The onset of widespread development of archaeocyathan-calcimicrobes mounds is triggered by rapid eustatic rise, which induces (a) the strong reduction of terrigenous input, and (b) the subsequent stabilisation of the sea bottom by calcimicrobes.

Calcimicrobes and archaeocyathans settle this firm bottom and may coexist with silty-clay material, which can fill empty spaces not previously occupied by primary constructors and/or cements. Later on, the massive lenticular limestones, dominated by *Epiphyton*, *Renalcis*, with minor archaeocyathans, develop. These massive bodies may also have reoccurrences within the interconnected archaeocyathan floatstones in more complex bioconstructions (Pillola *et al*., 1995).

Stop 1.2:
The Sardic Ordovician unconformity
S. Barca

In the Hercynian anchi-epimetamorphic basement of Southern Sardinia an "eo-Caledonian" important angular unconformity, referable to a compressive tectonic phase, has long been known. This unconformity, as we have said above, has been named the "Sardic Phase" in SW Sardinia (Iglesiente-Sulcis), and the "Sarrabese Phase" in the SE (Sarrabus-Gerrei) (Barca, 2002, and references therein).

On the basis of new findings of *Dictyonema* and Acritarch studies, Barca *et al*. (1987) referred the

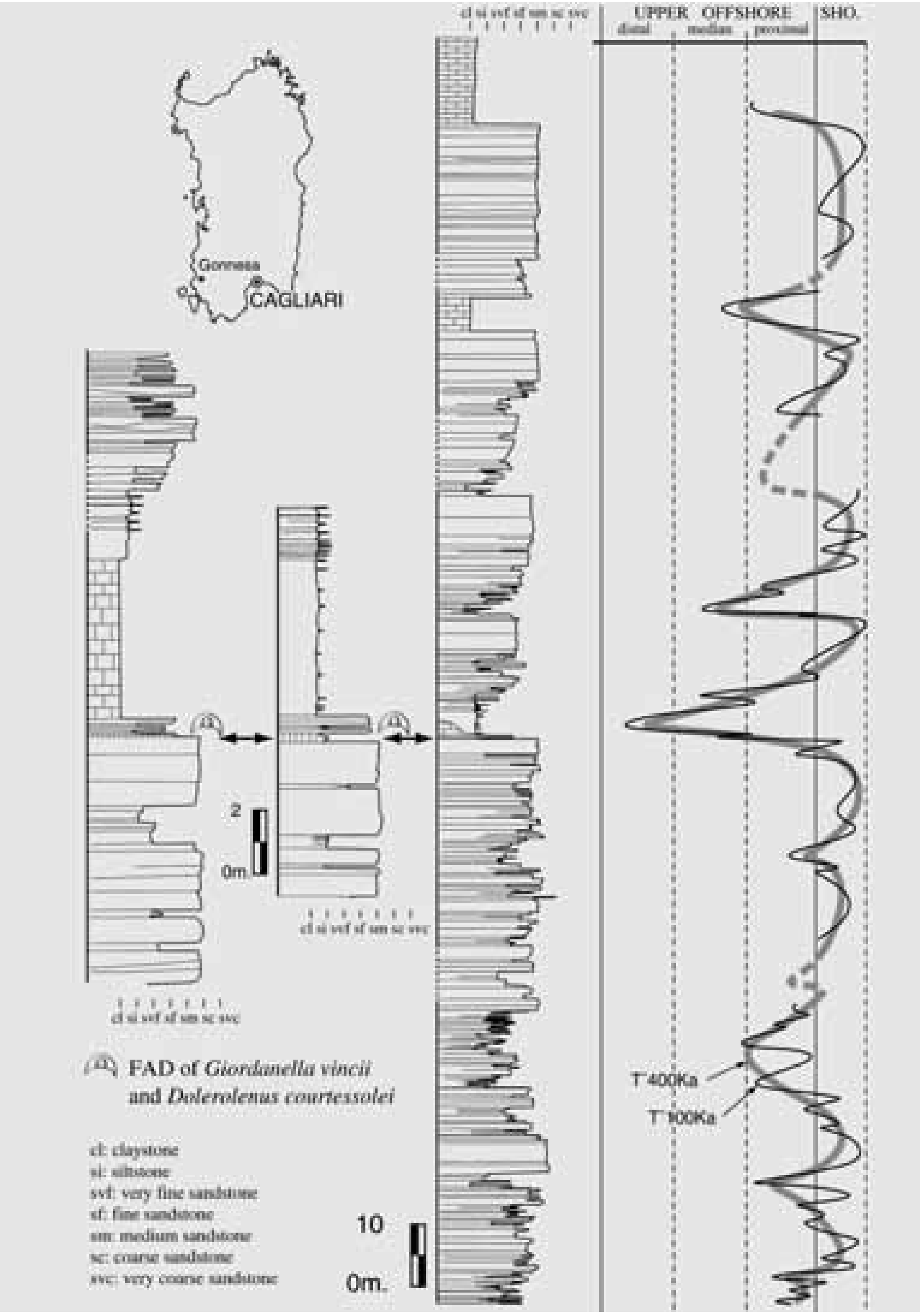


Figure 3 - Log and stacking pattern diagram of genetic sequences of the Sa Tuvara Mb. (Matoppa Fm.) in the Serra Scoris Section, (Gonnesa) (after Pillola et al., 2000 mod.).

upper part of the "Cabitza Slates Fm." (Iglesias Group: Pillola *et al*., 1998) to the Early Ordovician (Tremadocian-Arenigian), and in this way they fit the Sardic Phase between the Early and the Late Ordovician (Caradocian-Ashgillian: the age of the first fossiliferous sediments covering the unconformity), thus allowing its close correlation to the "Sarrabese Phase of SE Sardinia (Barca *et al*., 1988, and references therein).

The Sardic Phase of SW Sardinia

In the autochthonous Palaeozoic basement of the Iglesiente-Sulcis, corresponding to the External Zone of the Sardinian segment of the Southern European Hercynian Chain (Carmignani *et al*., 2001 and references therein), the authors agree with the presence of a deformation phase preceding the Hercynian Orogeny, as formerly mentioned, named the Sardic Phase. This tectonic phase involved the pre-Late Ordovician formations that had been compressed in E-W folds and deeply eroded before Caradocian times. The occurrence of important "eo-Caledonian" deformations in the Iglesiente-Sulcis area is adequately documented by the marked angular unconformity between the Early Cambrian – Early Ordovician succession (Nebida, Gonnesa and Iglesias Groups : Pillola *et al*., 1998) and the overstanding Middle? – Late Ordovician "Puddinga" coarse clastic metasediments ("Formazione di M. Argentu" *pars*: Laske *et al*., 1994).

This unconformity is of regional importance because of its evidence, both at outcrop scale in several localities of SW Sardinia (Nebida, Masua, etc.), and at cartographic scale. In fact the wide E-W folds (*e.g.* Iglesias Syncline, Gonnesa Antycline), involving the Early Cambrian – Early Ordovician formations, are cut towards W, where they are covered unconformably by the "Puddinga" metaconglomerates. The "eo-Caledonian" age of these wide E-W folds, and their preceding of the main Hercynian N-S compressive structures, which also interested the post-Sardic Phase successions which are Late Ordovician to Early Carboniferous in age, was demonstrated by the refolding of the E-W folds' axial surfaces by the Hercynian N-S folds.

The "Puddinga" deposits

The post-Sardic Unconformity Ordovician succession starts with the "Formazione di M. Argentu", made up by the typical "Puddinga" deposits, or "Membro di Punta sa Broccia". This member is formed by polygenic and hetherometric metaconglomerates and metabreccias, containing clasts varying in size from 10 to 100 cm, and arenaceous hematitic cement, red to purplish in colour. The clasts derive mainly from the erosion of the "Cabitza Slates Fm.", subordinately from the metalimestones and metadolostones of the Gonnesa Group, and still more rarely from the metasandstones of the Nebida Group. In the "Puddinga" deposits, cropping out with up to 150 m of thickness along the Nebida-Masua cliffs, variously sized (up to 100 m) carbonatic "olistholites" and megabreccias are included. Towards the top are metamicroconglomerates cemented by pelites and hematite, gradually changing to the "Membro di Riu Is Arrus", formed by alternations of greyish metasandstones and metasiltites, locally fossiliferous (Arthropoda, Algae) and rare, coarse metaconglomerate lenses.

The Mt. Argentu Fm. terminates upward with the "Membro di Medau Murtas", made up of metasiltites, metapelites and rare metaconglomerates, with a typical purplish colour with greenish bands and rare fossil tracks. The total thickness of the Mt. Argentu Fm. is estimated between 200 to 320 m.

Lacking significant fossils, the chronostratigraphic attribution of the Mt. Argentu Fm. is defined at the base by the age of the Sardic Unconformity (Early Ordovician, Barca *et al*., 1987), which cuts the top of the Cabitza Slates Fm.,the top by the fossils (Late Caradocian – Ashgillian) found in the overlying Mt. Orri and Portixeddu Formations (Laske *et al*., 1994). Recently Martini *et al.* (1991) improved our knowledge of the syntectonic features of the "Puddinga" metaconglomerates in the Nebida area, and made a detailed sedimentary analysis, distinguishing at the base alluvial fan-deltas, gradually passing to shallow littoral plains, and, finally, to coastal alluvial plains.

The Sarrabese Phase of SE Sardinia

While in the Iglesiente – Sulcis (External Zone) the deformation stuctures induced by the Sardic Phase are clearly recognizable, since in this area the subsequent Hercynian deformations were weak, in Eastern Sardinia (Nappe Zone), the effects of the pre-Hercynian deformations and metamorphism referable to the Sarrabese Phase are not so clearly recognizable in the outcrops, because of stronger Hercynian deformations that have hardly obliterated the eo-Caledonian structures.

Nevertheless, in Eastern Sardinia there are some important elements comproving well-defined eo-Caledonian tectonic deformations Middle Ordovician in age. These are the following:

1) The angular unconformity ("Discordanza sarrabese" *Auct*.) that in the Sarrabus separates the "Arenarie di San Vito" Fm., Middle Cambrian – Early Ordovician in age based on Acritarch studies (Barca *et al.,* 1988), from the overlying Middle Ordovician volcanic complex.

2) In all the "Nappe Zone" a thick and widespread subaerial calc-alkaline magmatism from post-Tremadocian to pre-Late Caradocian is present. The magmatic complex covers the local Cambrian-Early Ordovician successions (the "Arenarie di San Vito" in Sarrabus-Gerrei, and the equivalent "Formazione di Solanas" in Central Sardinia).

3) The Sarrabese unconformity is diffusely marked by coarse metasandstones and polygenic metaconglomerates overlaying the "Arenarie di San Vito", so attesting to wide, extended emersions during Middle Ordovician times.

Geodynamic significance of the Sardic Ordovician Unconformity

The thick metavolcanic complex that in the whole "Nappe Zone" of Central and South-Eastern Sardinia unconformably covers the Cambrian–Early Ordovician metasediments, developed between the Arenigian and the Caradocian, generating effusive and pyroclastic rhyolitic to andesitic products, as well as intrusives. These magmatites have a calc-alkaline affinity, and are related tovolcanic arc activity.

This magmatic cycle must be related to an important and wide-spread Ordovician geodynamic event, which took place accompanied by tectonic movements, unconformities and magmatic activity with analogous composition, features and age in almost all of the Hercynian South European massifs (Carmignani *et al.*, 2001). The hypothesis of the development of a volcanic arc posed on continental crust is well documented. The volcanic arc progressively shifted from NE to SW during Arenigian to Caradocian times, in the geodynamic framework that developed during the convergence of Gondwana and Armorica.

The South-verging gradual shift of the magmatic arc caused compressive movements along the north-Gondwanian margin, where Sardinia was then located. These movements determined here the development of folding, emersion and sub-aerial erosion phenomena on the Cambrian-Lower Ordovician formations.

In the supposed Ordovician arc-trench system (Fig. 4) the Iglesiente-Sulcis area should correspond to a back-arc basin, characterized by the absence of volcanism and by rapid syntectonic sedimentation with wide olistholites (the "Puddinga" deposits). This area was deformed throughout with thrusts and folds (Sardic Phase) due to the migration of the magmatic arc towards SW.

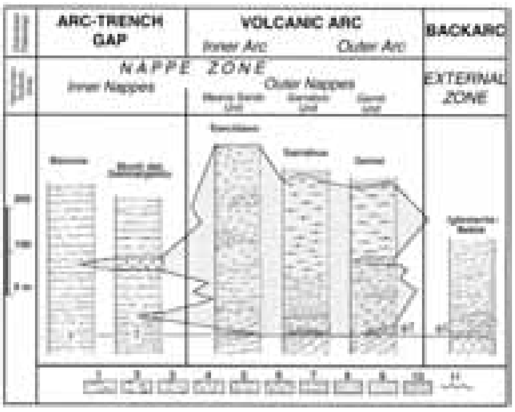


Figure 4 ***- Sardinian Ordovician successions framed in their relative palaeogeographic positions before the Hercynian thrusting. The grey colour evidences the Middle Ordovician Volcanic Complex: 1. Metarhyodacites with an "augen" structure ("Porfiroidi" Auct.). 2. Metadacytes and metarhyodacites. 3. Metarhyolites. 4. Metandesites and metadacites. 5. Metamorphic products from reworked volcanics. 6. Metamorphic products from reworked, intermediate volcanics. 7. Metasandstones and schists. 8. Metaconglomerates. 9. Metarkoses and quartzites. 10. Cambro-Lower Ordovician succession of the "External Zone" (Iglesiente-Sulcis). 11. the Sardic Unconformity: F1= the Sardic Phase; F2= the Sarrabese Phase (after Carmignani et al., 1992, mod.).***

The importance of these compressive "eo-Caledonian" tectonics and of their related deformations probably decreased towards the arc zones, corresponding to the Outer Nappe Zone (Sarrabus, Gerrei, etc.), characterized by thick volcanic successions, by thin conglomerates without olistholites, and by a sedimentary hiatus (the Sarrabese Unconformity) interposed between the Ordovician volcano-sedimentary complex and the lower succession which is Cambrian – Early Ordovician in age ("Arenarie di San Vito").

The subduction processes were interrupted during Late Ordovician times. Consequently, the magmatic arc and the neighbouring areas collapsed; this promoted the late Caradocian marine transgression. The deposits linked to this new sedimentary cycle (the "Hercynian Sedimentary Cycle") cover both the arc volcanic products (the Outer Nappe Zone), and the Iglesiente-Sulcis Cambrian- Early Ordovician sedimentary formations (the “Caledonian Sedimentary Cycle”).

Stop 1.3:
Industrial archaeology at Porto Flavia (IGEA SpA)
I. Salvadori

This mining site is located near Masua (Iglesias) along the southwestern coast of Sardinia.

Porto Flavia (Fig.5), which takes its name from its designer’s first daughter, was built in 1924 by digging up a mountain for about 600 metres. In the lower of its two galleries, placed one on top of the other, a conveyor belt received the ore from the underground deposits, and by means of an ingenious mobile arm, transferred it directly into the holds of cargo ships at anchor.

At that time this clever solution managed to revolutionize the system of loading ores, which till then had been transported in baskets on the shoulders of “galanze” from Carloforte and carried onto 20-30 ton sailing boats. Visitors may now admire this example of engineering and construction set in particularly fascinating scenery.

Figure 5 - the Porto Flavia mine

IGEA S.p.A., in addition to the mining site of Porto Flavia, has also made enjoyable several mining sites, such as the “Galleria Henry” and the Santa Barbara Cave (Iglesiente).

The Galleria Henry is the most important structure of the Planu Sartu mine (1865). It was used to transport ore on rail to the washeries.

It is located at 50 metres above the sea level, immediately above the village of Buggerru. Its uniqueness was due to its repeated opening onto the cliffs looking over the sea through small galleries and passages carved in the rock, which allowed suggestive views of the coast with its overhanging rocks and breathtaking scenery.

The Santa Barbara Cave is situated inside the San Giovanni mine; it was discovered by chance in April 1952, while excavating a riser. Dark brown barite tabular crystals that completely cover the walls characterize it.

Stop 1.4:
The Cambrian at Campo Pisano and Cabitza: boundaries, biotas and palaeoenvironments
G.L. Pillola, F. Leone & A. Loi

We will visit more in detail the upper part of the Lower and Middle Cambrian outcrops of the Cabitza and Campo Pisano Fms (Iglesias Group) and their boundaries, already described in previous papers (Pillola *et al*. 2002 and references therein); however, for the completeness of the stratigraphical context, data on the Upper Cambrian and Tremadocian of this area are briefly proposed. For the general geological setting see the “Introduction” portion.

This section crops out close to the by-pass road cut of SS 130, 2 km from the centre of Iglesias, about 450 m south of the abandoned Cabitza railway station (Campo Pisano mine) and its surrounding hills.

The Campo Pisano and lower Cabitza Formations

The Campo Pisano Fm. overlies the “grey dolomites” (diagenetic equivalent of the Lower Cambrian San Giovanni Fm., Gonnesa Group) that is constituted of more or less silicified, fine grained dolomites. The succession is about 80 m thick (Fig. 6) with the lowest 20 m mainly composed of alternations of marls with dispersed, often dolomitised nodules (3-5 cm in size), and of grey silty-shaly beds as well as weathered, massive marls. This lower part of the sequence is overlain by a 50-m-thick succession of nodular limestone (nodules 0,5 to 3 cm in size) with yellowish, light-green or pink-violet, terrigenous material. The top of the Campo Pisano Fm. is characterised by white to light-grey, massive bioclastic limestone. Main sedimentary and palaeoecological features of the Campo Pisano Fm. have recently been studied by Elicki (2001, and cited references) who suggests deposition happened in a morphologically–weak, differentiated subtidal shelf environment. After that author, the nodular texture of the Campo Pisano Fm. is a result of complex, and mainly late diagenetic, processes. Data on microfaunas from several localities have recently been published and new investigations are in progress (Elicki and Wotte 2003; Elicki and Pillola, in prep.). Additional palaeobiological content, originated from the Iglesias Group, has been analysed by Loi *et al.* (1995), while an updated correlation with time equivalent successions in Northern Gondwana regions and their palaeogeographical relationships has been given by Alvaro *et al*. 2003.

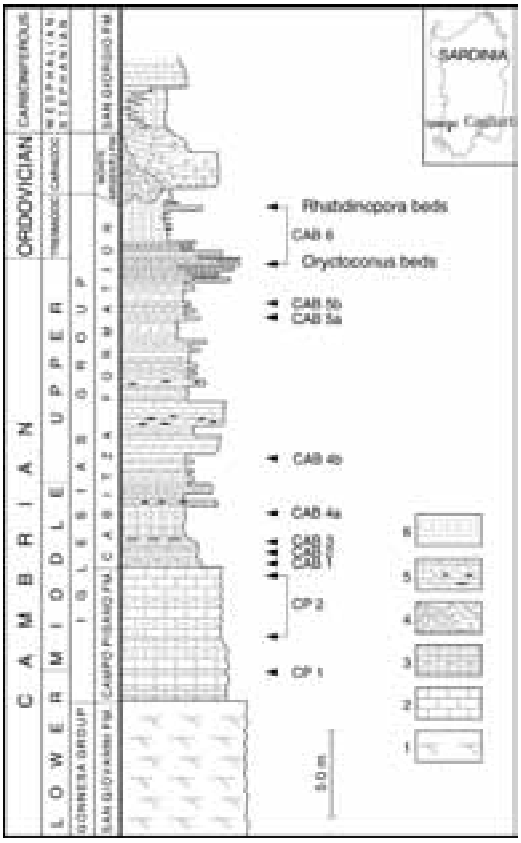


***Figure** 6 - Schematic sequence of the Iglesias Group in the Campo Pisano-Cabitza area: 1. dolomites; 2. limestone;, 3. marly and nodular marly limestones; 4. conglomerates; 5. sandstones and coarse siltstones; 6. siltstones and shales. The Mt. Argentu and the San Giorgio Fms are not in scale.*

In the Campo Pisano and Cabitza sections, few *Protolenus* (*Protolenus*) *pisidianus* and unassigned brachiopods occur in the lower 20 m (CP1 assemblage, Fig. 6). The overlying part of the section is very fossiliferous (the CP2 assemblage), but, except for microfossils (sponge spicules, echinoderm plates, chancelloriids, forams, problematics and rare tiny trilobites) no larger remains have been collected.

The transition to the Cabitza Fm. is well exposed in a track cut a dozen metres toward the north, and at the base of the mine's main dump. Fossiliferous marls and weathered marly limestones (two m thick) are overlain by pink-ochraceous unfossiliferous marls and dark grey-yellowish siltstones (2,5 m). The fossiliferous marls contain, together with echinoderm plates, the following trilobite taxa (CAB 1 fauna): *Solenopleuropsis* (*Manublesia*) *ribeiro*, *Ctenocephalus* cf. *coronatus* and *Paradoxides* sp.

The overlying, thick bedded, white-beige marls and weathered marly limestones (2,5 m) contain well preserved fossils (CAB 2 assemblage). The following trilobites have been found: *Paradoxides* (*Eccaparadoxides*) cf. *pusillus*, *P.* (*E.*) *mediterraneus*, *P.* (*E.) brachyrachis*, *Conocoryphe* cf. *brevifrons*, *C.* sp., *Peronopsis* sp., *Corynexochus* and agnostids. Echinoderms are represented by *Decacystis*, *Gyrocystis* and "*Eocystites"*. The overlying red-violet siltstones and shales (5 m), with rare nodules or small calcareous lenses, yield the bulk of the CAB 3 assemblage. The following trilobites have been found: *Paradoxides* (*E.*) *mediterraneus*, *P.* (*E.) brachyrachis*, *C. brevifrons*, *Conocoryphe* sp., *Jincella prantli*, *Liosolenopleura* cf. *serventi*, *Ctenocephalus* (*Harttella*) cf. *terranovicus*, *Bailiella* sp., ?*Elyx* sp., *Anopolenus* cf. *henrici, Peronopsis* cf. *fallax*. Echinoderms are again represented by *Decacystis*, *Gyrocystis* and *Ceraticistis*; rare brachiopods and trace fossils can be found as well. Unfragmented carapaces are not rare; however most of the fossils are randomly dispersed or concentrated in thin layers, within a very calm environment.

The CAB 4 informal assemblage was previously considered to be Middle Cambrian in age; however, the trilobite fauna composed of *Paradoxides* (*M.*) cf. *macrocercus*, *Jincella* sp. and *Agraulos* sp., is confined to the CAB 4a beds and clearly identified only in 15-18 metres of grey-green siltstones in the Cabitza area. In higher levels, only unidentified debris were collected in correspondence to dissolved marly or thin sandy layers between the old Cabitza railway station and the hill located near Case Cabitza. The first violet brownish deposits showing dissolution voids (CAB 4b) within the sandy beds of the CAB 4 succession, have yielded

Prochuangia sp., *Koldinioidia* sp. and two unassigned taxa, and acrotretacean brachiopods, which strongly suggest an Late Cambrian age.

Late Cambrian CAB5 faunas within a tide-dominated delta environment

This section is located along a pipe line excavation close to the old railway; the sedimentary features and the position of the fossiliferous beds CAB 5A and CAB 5B, belonging to the CAB 5 association, can be observed.

Four main facies have been distinguished in the Upper Cambrian and early Tremadoc sequence (Loi *et al.,* 1995; 1996): Facies 1, sandy siltstones with ripple-drift cross-lamination; Facies 2, laminated shales and fine sandstones (tidal bundle); Facies 3, HCS sandstones and planar to weakly inclined lamination in supercritical flow; Facies 4, shale and siltstone "graded rhythmites". We can observe the delta tide-dominated deposits characterised by the structures observed in facies 1 and 2 and their vertical evolution. The beds are overturned and plunge 70° towards SE; their typical alternation of red and green is displayed.

This section is continuously exposed for about 30 m. In detail, we can observe: at 11 m from the base, the fossiliferous CAB 5a beds (only brachiopods) and, just below, the manganiferous bed; at 22 m from the base, the CAB 5b beds (yielding trilobites, hyolitids and rare echinoderms). Facies 1 and 2 characterise this lower part of the sequence.

The *Acerocare* Regressive Event and the Cambrian/Ordovician boundary

The best exposure of this portion of the Cabitza section crops out in an excavation close to the by-pass road and the pipeline crossing. On the southwestern side of this excavation, sandstone beds, with silty-clayey intercalations, show extended load-casted basal surfaces, containing abundant, often dissolved bioclasts.

On the northeastern side several sedimentary features can be observed (Facies 3 and 4). Particularly pertinent is the presence of several sandstone levels with HCS (Hummocky Cross Stratification), indicating a relevant regressive event, carbonatic layers (bioclastic dominated) and, in the upper part, the transition to the graded rhythmites. Upwards the sequence contains several red dominated beds as intercalations within the pervasive green-grey graded rhythmites facies, well exposed on the main road cuts. The first reddish intercalation, at Case Lai, yields several colonies of *Rhabdinopora flabelliformis* and trace fossils. The facies evolution of this portion of the Cabitza Fm. together with its widespread occurrence through the Iglesiente and Sulcis, indicates a variety of sedimentary environments and relative depths, from "delta tide dominated" to shoreface and distal upper offshore, which can be interpreted in terms of sea level changes; the regressive event which occurs within the *Orictoconus* beds appears equivalent to the ARE (*Acerocare* Regressive Event; Loi *et al*., 1995; 1996).

Stop 1.5:

The Hercynian unconformity in the Upper Carboniferous San Giorgio Basin.

S. Barca

In several parts of Sardinia, Late Palaeozoic (Upper Carboniferous-Permian) sedimentary or volcanic-sedimentary successions that deposited in a continental environment rest unconformably on the Hercynian basement. These principally siliciclastic and subordinately carbonate sediments were deposited in small tectonic depressions during the extensional tectonic phase following the main collisional events of the Sardinian Hercynian orogeny (Barca *et al*., 1995b and references therein).

The formation of these intra-chain basins, often having very different stratigraphic sequences, generally began in the Westphalian-Stephanian and often continued throughout the Permian.

Similar basins also formed on the Hercynian basement in other areas of southern Europe (Corsica, Provence, Pyrenees, etc.).

The San Giorgio basin, situated near Iglesias in SW Sardinia, is one of these Late Hercynian molassic basins (Barca and Costamagna, 2003 and references therein). The well-stratified terrigenous and carbonate detrital sediments that crop out for about 45-50 m have been dated to the Stephanian, based on the well preserved microfloristic association contained in the clays in the uppermost part of the succession, and maybe also to the Westphalian, based on tetrapod footprints discovered in the lower part (Del Rio and Pittau, 1999 and references therein; Del Rio *et al*., this guidebook).

The Upper Carboniferous succession does not contain volcanic material, being composed chiefly of polygenic conglomerates, coarse sandstones, carbonates breccias, silty dolostones, bioturbated and reddish dolomitic marls, associated with laminated siltites and argillaceous blackish silty clays containing plant remains.

These continental Carboniferous deposits overlie, in strong angular discordance, the Middle Cambrian-Lower Ordovician metashales cropping out at the core of a broad E-W trending "Eo-Caledonian" syncline (the Cabitza Syncline), on which tighter N-S trending synschistose folds of the main Hercynian deformation phase are superimposed.

At least two sedimentary cycles, separated by as many erosion stages, can be distinguished in the Carboniferous succession of the San Giorgio Basin. These represent the formation, progressive subsidence, and subsequent rapid final infilling (progradational-retrogradational cycle) of the intrachain molassic basin.

The sediments were deposited in an alluvial plain environment with intermittent palustrine and lacustrine sedimentation, probably during major episodes of basin subsidence. Unfortunately, today a large part of the outcrops is buried beneath waste from the Campo Pisano Pb-Zn mine.

Nevertheless, the San Giorgio Basin represents the most complete and thickest dated Upper Carboniferous sedimentary succession cropping out in Sardinia.

In a Sardinian regional geological context the basin is of major significance in that the oldest undeforming and unmetamorphosed sediments crop out within it, unconformably overlying the Hercynian metamorphic basement. These sediments allow us to determine the upper chronostratigraphic boundary of the main folding and metamorphic Hercynian events that involved the whole Lower Cambrian-Lower Carboniferous succession of the Sardinia Massif.

Stop 1.6:

The Upper Carboniferous San Giorgio Basin

M. Del Rio & P. Pittau

The small basin of San Giorgio (Fig. 7), about 3 km², crops out close to Iglesias, along the national road SS 130, near the Cabitza station. It is actually composed of small hillocks separated by short valleys that converge in the Rio San Giorgio. The lacustrine basin's transgressive surface overlays the Cabitza Fm. shale which exhibits undulating morphology. The deposition age is Late Carboniferous (Westphalian D/Early Stephanian).

Historical outline and lithology

The first studies date back to the end of the 19th Century when Gambera (1897) and Arcangeli (1901) described the plant deposits near Iglesias. Novarese (1917) and Novarese and Taricco (1923), on the basis of the presence of *Annularia stellata, Cordaites* cf. *principalis, Walchia piniformis* and *Walchia filiciformis*, assigned the fossil flora to the Autunian.

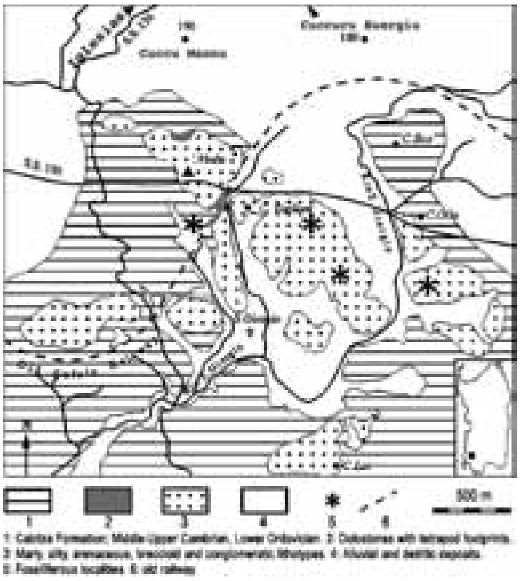


Figure 7 - **Geological sketch map**

More precise information was provided by Cocozza (1967), who described several foliage species and proposed a Late Stephanian age for these remains. An older, Stephanian B age was given by means of sporomorph assemblages recorded in the marly layers (Del Rio, 1973; Del Rio and Pittau, 1999; Pittau and Del Rio, 2002); while, the recovery of the tetrapod footprints (Fondi, 1980), belonging to the ichnospecies *Salichnium (Saurichnites) heringi*, suggested a Westphalian D age, after comparison to Sassonia (Germany) ichnofaunas.

The succession of the San Giorgio basin is about 40 m thick, and can be subdivided, from the bottom to the top, into three main lithotypes (Fig. 8):

Unit A: (0-13 m). Heterometric breccias, made up of polygenic carbonatic-dolomitic elements, angular shaped with dolomitic cement. This unit may locally be thicker or absent.

Unit B: (6-15 m). Yellow-grey dolostones alternating with sandstones and lenticular microconglomerates evolving to platy dolomites, dolomitic siltstones and carbon-rich clays, finely laminated.

Unit C: (6-11 m). Polygenic heterometric conglomerates, alternating and interfingering with sandstones, with local concentration of plant remains and *Calamite* trunks in life position.

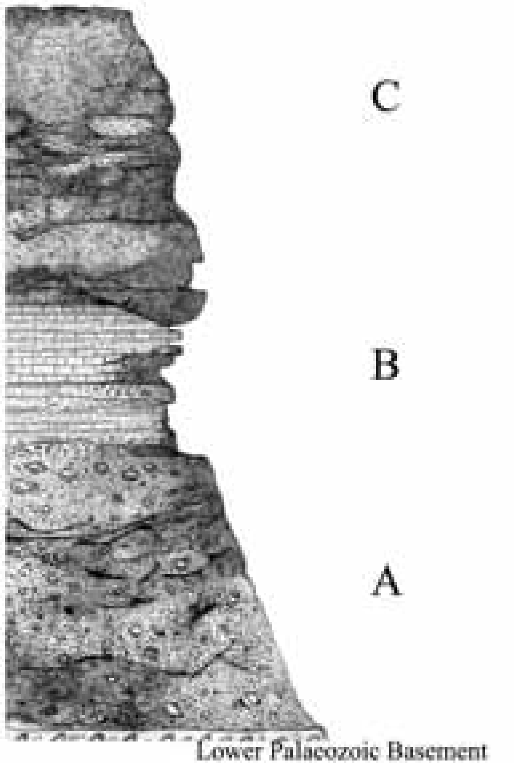


Figure ***8 - Stratigraphic section***

Paleobiological content

MACROFLORA

The foliage compression and pit casts are indicative of the following botanical groups:

<u>Sphenopsida</u>: *Annularia stellata*, *A. pseudostellata*, *Sphenophyllum emarginatum*, *Calamites cistii*, *C. gigas*, *C.* cf. *leioderma*, *C. suckowii*, *C.* sp.

Ferns: *Asterotheca* sp., *Pecopteris arborescens, P. polymorpha*, *P. subelegans, Sphenopteris rotundiloba*, *S.* sp. <u>Pteridospermopsida</u>: *Alethopteris* cf. *ambigua*, *Dicksonites pluckeneti* f. *sterzeli*, *Neurocallipteris planchardii*, *Odonthopteris* sp.

<u>Cycadopsida:</u> testified by the presence of *Taeniopteris* sp. Gymnosperms: Cordaitales (*Cordaites* sp.). and Voltziales (*Ernestiodendron* sp.).

SPOROMORPHS

The following taxa have been recorded (Fig. 9; Del Rio, 1973; Del Rio and Pittau, 1999; Pittau and Del Rio, 2002).

<u>Monolete spores</u>: *Laevigatosporites vulgaris*, cf. *Latosporites globosus*, *Punctatosporites granifer, P. minutus*.

<u>Trilete spores:</u> *Apiculatisporites abditus*, *Calamospora laevigata*, *C. pallida*, *Convolutispora tessellata*, *Crassispora* sp., *Cristatisporites* sp., *Leiotriletes tumidus*, *L.* sp., *Lycospora deforma*, *L. orbicula*, *Microreticulatisporites microreticulatus*, *Pustulatisporites pustulatus*, *Raistrickia aculeata*, *Savitrisporites camptotus*, *S. cingulatus*, *Triquitrites arculatus*, *T. bransoni*, *T. sculptilis*, *T. rugosus*, *T. verrucosus*, *T.* sp., *Vestispora fenestrata*, cf. *V. laevigata*.

<u>Monosaccate and disaccate pollen grains</u>: *Cordaitina* cf. *donetziana*, cf. *C. bractea*, *Florinites florin*i, *F. parvus*, *F. pellucidus*, *F. similis*, cf. *F. pumicosus*, *Potonieisporites novicus*, *P. unilabiatus*, *P.* sp., *Limitisporites* sp., *Pityosporites reticulatus*, *P. westphalensis*, *Vesicaspora* sp., *Wilsonites* cf. *delicatus*, *W. kosankei*, *W. vesicatus*.

<u>Megaspores</u>: *Apiculatisporites* sp., *Calamospora* sp., *Laevigatosporitse reinschii*, *L.* sp., *Pseudovalvisisporites nigrozonalis*, *Valvisisporites auritus*, *V.* sp., *Zonalesporites brasserti*, *Z. ovalis*.

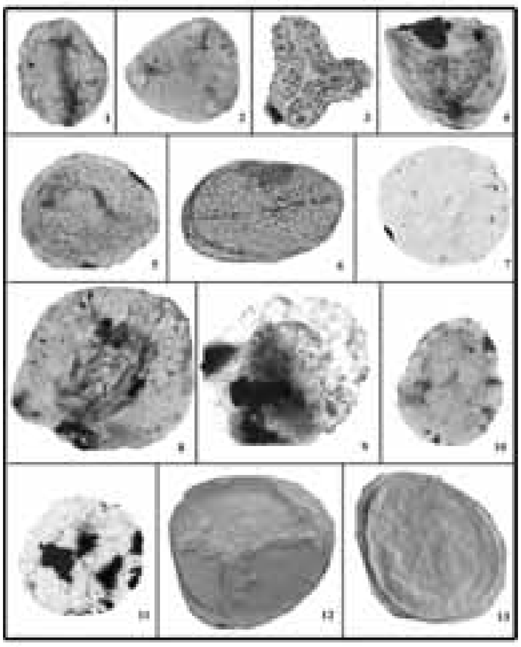


Figure ***9 - 1. Laevigatosporites vulgaris; 45 µm. 2. Leiotriletes tumidus; 35 µm. 3. Triquitrites rugosus ; 35 µm. 4. Savitrisporites camptotus; 55 µm. 5. Convolutispora tessellata; 53 µm. 6. Potonieisporites unilabiatus; 90 µm. 7. Florinites pumicosus; 70 µm. 8. Florinites similis; 68 µm. 9. cf. Cordaitina bractea; 66 µm. 10. Lycospora orbicula; 53 µm. 11. cf. Florinites pumicosus; 60 µm. 12. Zonalesporites ovalis; 700 µm;.13. Calamospora sp.; 900 µm.***

TRACE AND BODY FOSSILS

Tetrapod footprints have been recorded in the lower portion of unit B (Fondi, 1980). They belong to *Salichnium (Saurichnites) heringi* and are comparable to those described in the Westphalian of Sassonia, as said above. In addition, two arthropod remains have been recorded in the upper portion of unit B (Benedetti *et al*. 2002): one represents a nearly complete specimen of Arnthracomartid, likely belonging to the genus *Anthracomartus*; the second consists of a blattoid wing.,.

Stop locations: 2. and 2.2 –Silius; 2.3 and 2.4 - Villasalto; 2.5 – Isili. A. Archaeological site of Pranu Mutteddu (Goni).

DAY 2

Stop 2.1:

The "Ockerkalk" limestone (Late Silurian) from the Silius area: palaeobiological content and biostratigraphy.

C. Corradini, A. Ferretti & E. Serpagli

The Genna Ciuerciu Section, which will be visited in the present stop, is located in the Silius area, just along the Sant'Andrea Frius-Silius road. Together with the nearby Silius I° Section, located 300 m north-east, the Genna Ciuerciu Section represents a reference section for the Sardinian "Ockerkalk" (see below). Both sections, in fact, enabled the first detailed stratigraphic assignment of the Ockerkalk, formerly dated only indirectly on the basis of the graptolite content present below and above the unit. The recent description of a rich conodont fauna has in fact documented a Ludlow-Pridoli age (*Oz. e. hamata* to the *O. e. detortus* zones; Barca *et al*., 1994, 1995a; Corradini and Olivieri, 1997; Corradini *et al*., 1998, 1999, 2000, 2002a, 2002b; Serpagli *et al*., 1998).

A sequence of over 25 metres of nodular limestone in typical Ockerkalk facies is exposed in the Genna Ciuerciu Section (Fig. 10). The base of the unit is not present in the section, which spans therefore a more limited range (*P. siluricus* to *Oul. el. detortus* conodont zones) than elsewhere. The Ludlow/Pridoli boundary is visible in the section between levels 13 and 14. The Genna Ciuerciu Section is continuous only up to the top of the hill (levels 0 to 24). As evidenced by the repetition of some conodont biozones, upper beds cropping out on the eastern slope of the hill (levels 25 to 33, for a thickness of about 10 metres) are only apparently continuous, being separated from the lower part of the section by a local overthrust.

The "Ockerkalk" limestone

Silurian rocks are exposed in Sardinia only in the south. Two distinct and peculiar situations occur in the SW part (Iglesiente and Sulcis) and in the SE part (Gerrei and Sarrabus) of the island. They are reminiscent mainly of the Silurian sequences exposed in Bohemia and Thuringia respectively. Their mutual relationship is still unclear.

The Ockerkalk (25 m thick) is an argillaceous flaser

Figure 10 - Panoramic view of the Genna Ciuerciu Section

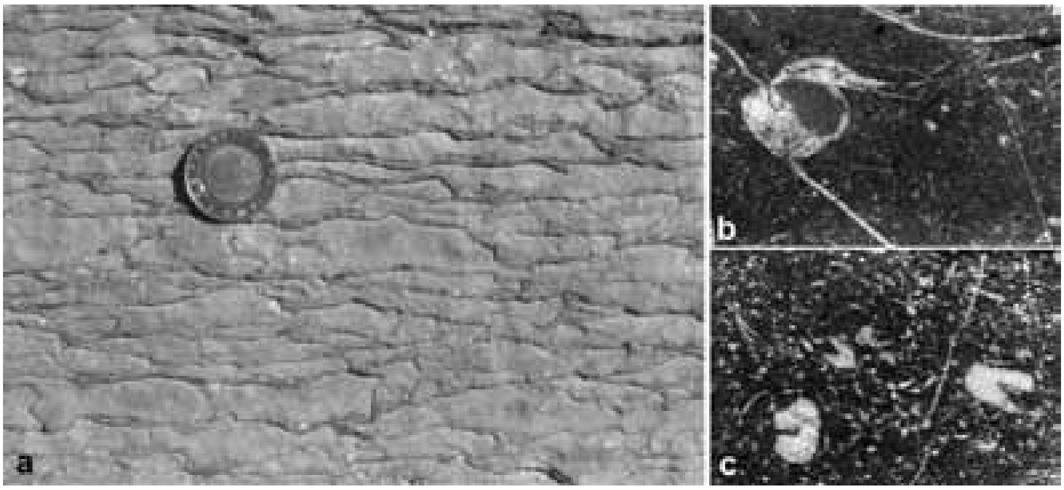


Figure 11 - Macroscopic and microscopic views of the Ockerkalk limestone. a. Distinctive flaser-texture of the Ockerkalk limestone; b. Mudstone with a cephalopod shell on the left and sparse biodebris, level 16; 6 x; c. Crinoidal wackestone, level 18; 12 x.

limestone, exposed in SE Sardinia, having a blue-grey colour weathered to ochre, from which its name is derived (Fig. 11a). The unit represents a calcareous "intermezzo" between two shaley units, the "Lower Graptolitic Shales" and the "Upper Graptolitic Shales". Loboliths and crinoid stems, all parallel to bedding, are the only macrofossils clearly visible in outcrop, as well as a few cephalopods. Trace fossils and very small solitary corals were also reported (Jaeger, 1977).

The limestone is mostly exposed in massive sequences of fine micritic mudstones with millimetric shell-lags of disarticulated debris (Fig. 11b-c). The poor fauna is mainly composed of rare ostracodes, brachiopods, thin-shelled bivalves, gastropods, trilobite fragments, crinoids, rare small cephalopods and sponge spiculae (Barca *et al*., 1995a; Ferretti and Serpagli, 1996). The conodont fauna includes twenty-six multielement species, belonging to twelve genera (Corradini *et al*., 1998). Phyllocarids (mainly mandibles) have been recovered from the conodont heavy-fraction. A crinoidal content increase is observable in thin sections across levels 16 and 18, belonging to the bank which ends up in a peculiar lobolith-level.

This lobolith-horizon, bearing the bulbous holdfasts of the giant pelagic scyphocrinoids and well known across the Silurian/Devonian boundary along the Northern Gondwana margin, occurs in the upper part of the section. Loboliths, with well-preserved local geopetal structures, occur with their typical ovoidal outline in level 18 (Fig. 12). The diameter of their bulbous holdfasts may be as much as 20 cm, in full agreement with other reports. Unfortunately, owing to matrix lithification, they cannot be isolated differently from those found in the Fluminimaggiore area (Iglesiente; Southwestern Sardinia) in a slightly younger horizon. The lobolith bearing horizon is assigned to the *Oul. el. detortus* conodont Zone in good stratigraphic agreement with other scyphocrinoid records in SE Sardinia (reported but not stratigraphically assigned by Jaeger, 1977 and Barca and Jaeger, 1990) and with the uppermost Silurian lobolith-horizon known in Europe and in North Africa (Haude, 1972, 1992).

The Ockerkalk limestone documented for the first time in Sardinia the *Pedavis latialata*, *Ozarkodina snajdri* and *Ozarkodina crispa* conodont biozones. The same biozones are not represented in the southwestern part of the island, where a calcareous unit, the Fluminimaggiore Fm. (Gnoli *et al*., 1990), known to older authors as "*Orthoceras*" limestone for the abundant cephalopods occurring in some levels, spans the Late Llandovery-Earliest Lochkovian.

Palaeoenvironment

A quiet pelagic environment below normal wave-base and with bioclastic input variable in time and probably in space, especially in the crinoidal fraction, has been suggested (Barca *et al*., 1995a). Interestingly, the crinoidal enrichment is higher in the present section if compared to the nearby Silius I° Section (Corradini *et al*., 1998).

Palaeogeography

The Ockerkalk limestone is reported, besides in Sardinia, also from Thuringia, Spain, the Carnic Alps and the western Czech Republic. These areas were, at that time, located at mid-latitudes in the southern hemisphere, fringing the outer margin of Northern Gondwana.

Stop 2.2:

Silius: geological overview on the Hercynian External Nappe Zone.

S. Barca & A. Funedda

The External Nappe Zone of the Sardinian Hercynian chain crops out between the Eastern Iglesiente region (SW Sardinia) and the Barbagia region (Central Sardinia); it represents the outermost part of the nappe building emplaced in the foredeep basin.

In SE Sardinia a nappe stack pile has been studied over the past twenty-five years (Carmignani *et al*., 1994, and references therein); it originated as a result of several stages of nappe imbrication during the Early Carboniferous phases of the Hercynian orogeny. The crustal shortening caused regional SSW and W directed thrusting, greenschist facies metamorphism and open to isoclinal polyphase folding. The final stage of shortening produced large-scale antiforms and synforms. Post-collisional deformation resulted in inversion of earlier thrusts as normal faults, development of low angle normal faults, and refolding of earlier foliation and thrust planes by asymmetric folds with subhorizontal axial planes (Conti *et al*., 1999). The deepest tectonic unit is the Riu Gruppa-Castello Medusa Unit; above this lies the Gerrei Unit, overridden by the Meana Sardo Unit, which, in turn, was overthrusted by the Barbagia Unit (Fig. 13). All these tectonic units are emplaced with a roughly “top-to-the-S” transport (Carmignani *et al*., 1978; Carmignani *et al*., 1994; Carosi *et al*., 1991); a thick mylonitic zone developed in between (Conti *et al*., 1998). The Sarrabus Unit is the southernmost tectonic unit of Southeastern Sardinia and lies above both the Gerrei and the Meana Sardo units.

The lithostratigraphic succession is similar in all the tectonic units. It begins with Cambrian-Lower

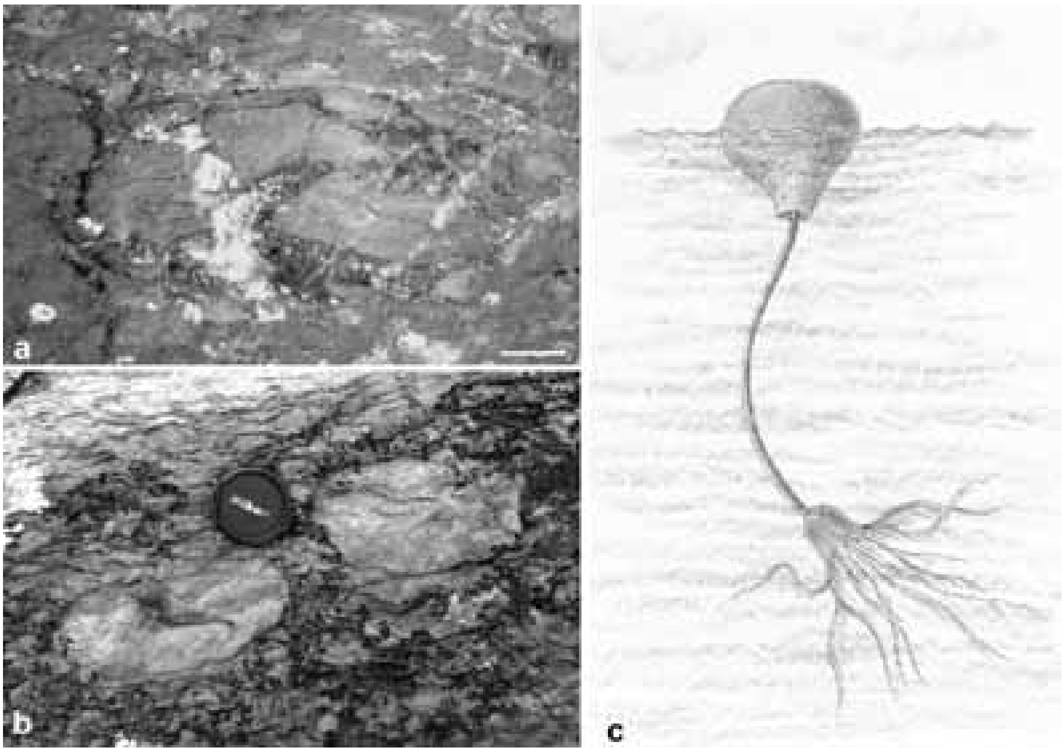


Figure 12 - Loboliths of the Sardinian Ockerkalk. a. A lobolith from level 18. Scale bar = 2 cm; b. Loboliths from the Baccu Scottis Section, located about 40 km east; c. Reconstruction of scyphocrinoid mode of life (drawn by G. Leonardi, Modena University).

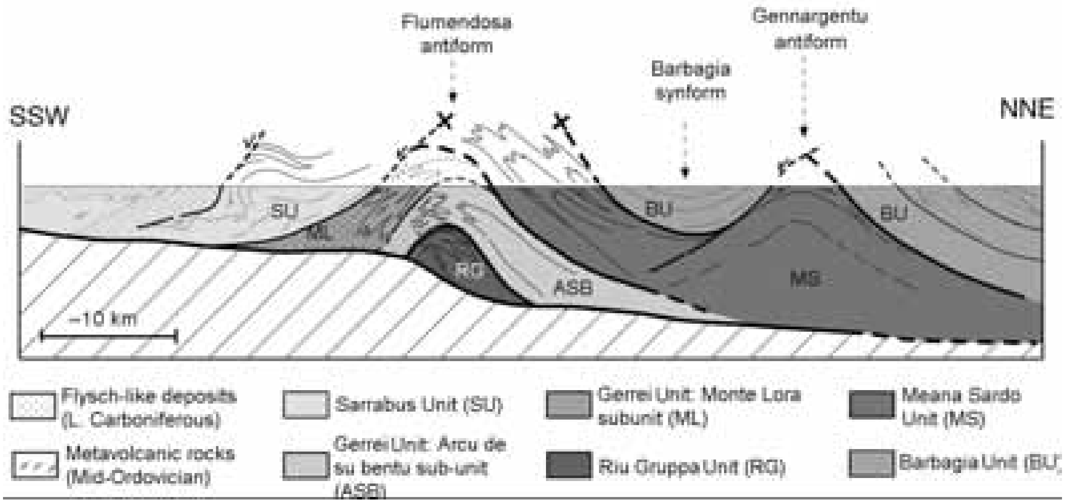


Figure 13 - ***Schematic profile across the external nappe zone of SE Sardinia (from Carmignani et al., 2001, modified).***

Ordovician metasandstones, phyllites and quartzites (Arenarie di San Vito Fm.) at the base, followed by discordant continental metaconglomerates and, up section, by metavolcanic rocks (metarhyolites, metandesites, metatuffites, metabasites, etc.; “Porfiroidi” and M. Santa Vittoria Fms) of Middle Ordovician age. The transgressive Upper Ordovician is characterized by fossiliferous metarkoses and metasiltstones (Rio Canoni Shales, Punta Serpeddì and Tuviois Fms.), passing into Silurian-Lower Devonian graptolithic black shales, phyllites and nodular metalimestones. Middle-Upper Devonian is represented by thick bedded metalimestones, covered by Lower Carboniferous synorogenic flysch deposits (metaconglomerates, metasandstones, phyllites and quartzites with large olistolithic bodies; Pala Manna Fm.).

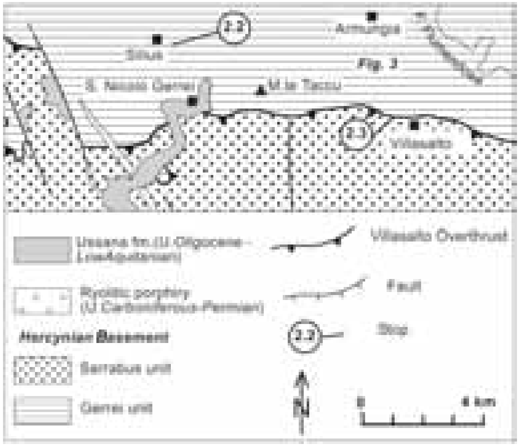


Figure 14 - ***Geological sketch map of the area between Silius and Villasalto.***

The Silius panoramic viewpoint (Fig. 14) clearly shows the Cambrian to Lower Ordovician “Arenarie di S. Vito” of the Sarrabus Unit overlying the Upper Devonian-aged (conodonts, Clymeniae, etc.) metalimestones of the Gerrei Unit, through the Villasalto Overthrust (see next stop, 2.3). The highland visible towards ESE, is Mt. Taccu: the upper part is mainly made up by metalimestones (the whitish rocks) Late Devonian in age (Barca *et al*., 2000) On the top of these small outcrops of synorogenic Pala Manna Fm., which is at the core of close synclines overturned to the south, are well exposed. The flyschoid deposits mainly consist of fine grained metasandstones and metaconglomerates, with intervening thin levels of black lydite (radiolarites cherts). Below the metalimestones, Silurian black shales crop out, and in the valley between the view point and Mt. Taccu we can find the Upper Ordovician shales and Middle Ordovician metavolcanic rocks folded in a close syncline. All these rocks, from the top of Mt. Taccu to the north, belong to the Gerrei Unit.

The southern slope of Mt. Taccu (to the right of the observer) is made up by Cambro-Lower Ordovician metasandstones (“Arenarie di San Vito”) from the Sarrabus Unit. In the valley a syncline with “” porphyroids and Late Ordovician metasediments is observable. Behind the Mt. Taccu relief the Flumendosa river runs, which from Late Pliocene time caused the strong erosion that allows us to recognize the Hercynian nappe building.

From this outlook we can also observe post-Hercynian rocks: some of the smoothed hills in front of us are made up of paleogenic conglomerates (Ussana Fm., Pecorini and Pomesano Cherchi, 1969), the flat relief observable in the background towards the north (lefthand of the observer) is Mt. Cardiga, made up of Lower Eocene clastic and carbonatic rocks, and the relief in the background towards the south (righthand of the observer) is the Mt. Genis leuco-granites intruded into the Cambro-Ordovician formations.

Moving on to San Nicolò Gerrei to reach the next stop near Villasalto, we first cross shales and metalimestones bearing typical Silurian-Devonian fossils, then near San Nicolò we cross the Ussana Fm.'s reddish conglomerates. Going on to Villasalto the road crosses the Arenarie di San Vito Fm., and if we take a look to the north-northwest, we can see again the tectonic contact between the Sarrabus and Gerrei Units; there the dark metaconglomerates and metasandstones of the Pala Manna Fm., lying on the whitish Devonian metalimestones, can be easily recognized.

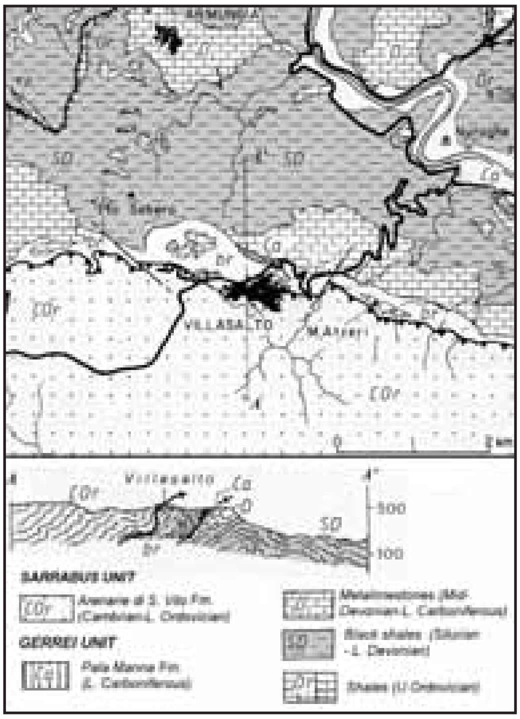


Figure 15 - Geological map and geological section of the Villasalto area (after Carmignani et al., 1986, modified).

Stop 2.3:

Su Suergiu mine (Villasalto): the Villasalto overthrust.

S. Barca & A. Funedda

The Villasalto overthrust, previously known as the "Villasalto Fault" (Teichmüller, 1931; Calvino, 1960), is one of the most important Hercynian tectonic features in SE Sardinia. It crops out for 40 km, running roughly E-W, from the Tyrrenian coast in the east, near capo San Lorenzo, to the eastern border of the Miocene rift near san Basilio in the west. Recently it has been interpreted as an overthrust surface of regional importance, produced during the shortening event of Hercynian orogeny (Carmignani and Pertusati, 1977; Carmignani *et al*., 1978). Along this surface the Sarrabus Unit overthtusts on the Gerrei Unit, and a foliated cataclasite, up to 300 m thick, made up mainly of Silurian shale fragments, developed. Inside the cataclastic belt big slices are incorporated, sometimes with sizes up to 500 m, derived from the surrounding formations. The analysis of kinematic indicators along the thrust surface indicated a top to the west transport direction, which predates the emplacement of the lower tectonic units (Gerrei, Meana Sardo and Riu Gruppa-Castello Medusa Units).

Microstructural analysis (Conti and Patta, 1998) shows that cataclastic flow was the primary deformation mechanism; it produced fine-grained foliated black cataclasites, with larger quartz and feldspar porphyroclasts. Evidence for low temperature crystal plasticity (undulose extinction, deformation bands and subgrain rotation) is restricted to large quartz porphyroclasts. The younger rocks of the underlying tectonic unit (Gerrei Unit) involved are Culm-like clastic deposits, aged Lower Carboniferous (Barca *et al*., 2000).

The present-day geometry of the Villasalto Overthrust, generally dipping towards south, was reached during the last movements of the Hercynian shortening phase -- the same that were responsible for the large antiform and synform framework of the nappe stack in the Flumendosa area. Often the Villasalto overthrust, as well as most of the D1 structures in SE Sardinia, has been reactivated as a normal fault during post-collisional extension. Even during extension the Villasalto Overthrust has been involved in asymmetrical folds with large overturned limbs, so, locally, its surface dips towards north. Furthermore the Villasalto Overthrust is locally cross-cut by normal faults, both late Palaeozoic and "Alpine" in age.

The stop is near the village of Villasalto (Figs. 14 and 15), close to the ancient "Su Suergiu" mine, where the overthrust is very well exposed and where, for the first time, it was recognized because of the mining activities for lead and antimony. There, the Cambrian-Lower Ordovician metasandstones of the base of Sarrabus Unit overlie the Upper Devonian metalimestones of the Gerrei Unit. Between them a wide cataclastic belt is exposed, made up by fragments of Silurian black shales, metamorphic quartz veins, often strongly deformed, and big boulders of porphyroids, metalimestones and Cambrian-Lower Ordovician metasandstones.

Along the road that leads to Sant'Andrea Frius the Gerrei Unit crops out again in some tectonic windows, because of local erosion of the overlying Sarrabus Unit. One of the best exposed is near the Planu Sanguini plateau at the 41 km mark, in a valley south of the road; following a narrow path, we'll come to Cambrian-Ordovician metasandstones ("Arenarie di San Vito") in the hanging wall which overlie black phyllites and metalimestones of Silurian-Devonian age. A cataclastic zone, up to 20 m thick, containing fragments of the underlying Gerrei tectonic Unit, marks the tectonic contact.

Stop 2.4:

The "Clymeniae limestone" in the Villasalto area.

C. Corradini

The calcareous sediments of Late Devonian-Early Carboniferous age of Southeastern Sardinia are mainly represented by massive limestone. These rocks are informally named "Clymeniae limestone", because of the occurrence of ammonites in some levels.

The Corona Mizziu Sections, which will be visited in the present stop, are located a few hundred meters northeast of Villasalto and can be reached with a few minutes' walk from the road to the old abandoned antimony Su Suergiu Mine. The name of the sections, Corona Mizziu I and II (CM I and CM II, respectively), is after the local name of this area. More than 30 m of massive limestone are exposed only apparently in continuity, as biostratigraphic analysis demonstrates that the strong tectonics of the area also affected these sections. The well known "Villasalto overthrust", one of the major tectonic features of SE Sardinia separating the Sarrabus Tectonic Unit from the Gerrei Tectonic Unit, lies only a few dozen metres southward from the outcrops.

This locale has been well known for many years. Lovisato (1894) recorded the occurrence of clymenids and goniatites in limestones cropping out between the Su Suergiu Mine and the Villasalto village. Furthermore, the first conodonts from Sardinia were recovered here (Pomesano Cherchi, 1963) and rich faunas from these outcrops have been studied by Olivieri (1965, 1970) and Corradini (1998a, b, c).

Palaeobiological content

Macrofossils are very rare in both the Corona Mizziu Sections, where only a few ammonites and rare crinoid stems occur in the central part of the CM I Section (layers from CM I 19 to CM I 23; Lower *trachytera* to Middle *expansa* Zone); it should be noted that ammonites are abundant only in the latter bed. In weighty percentages, besides conodonts, very rare brachiopods and fish teeth are present.

Conodonts are quite always abundant throughout the sections. Ninety-five taxa, belonging to twelve genera, have been recovered from this locality. The state of preservation is generally quite good, but in some layers specimens are sometime incomplete or deformed. The conodont association is dominated by *Palmatolepis*, which in some layers represents more than 90% of the fauna; *Polygnathus* is always present, but it is very abundant only in the upper part of the *postera* Zone, while the occurrence of bispathodids and icriodids is significant only in some levels.

The microfacies is always represented by a "poorly fossiliferous micrite", with a few fossil remains only in the ammonite-bearings beds. Here ostracodes, small shells (brachiopods?, bivalves?), fragments of echinoderms and gastropods, as well as rare trilobites can be observed.

Biostratigraphy

Sixteen conodont zones in continuous sequence from the Lower *crepida* to the Lower *praesulcata* have been recognised in this locality. Only in the *postera* interval is it impossible to split between the Early and Late *postera* Zone, because the marker of the latter is missing, as well as any other stratigraphically important taxon.

The Corona Mizziu I Section ranges from Lower *rhomboidea* to Lower *praesulcata* Zone (level CM I 26), but the upper part (CM I 27-36) is reversed, because of tectonics. Such deformation has been evidenced only by the biostratigraphic study of conodont fauna, which showed that the same conodont association occurs both at the base and at the top of the outcrop. The Corona Mizziu II Section is slightly older: in fact, it ranges from the Lower *crepida* Zone to the Lower *trachytera* Zone; however the uppermost *marginifera* Zone has not been documented, probably owing to the lack of exposure between levels CM II 9 and CM II 10.

It should be pointed out that recently, a Tournaisian age for the topmost levels of the unit in the Mt. Taccu area, a few km west of Villasalto, has been documented (Barca *et al*., 2000; Corradini *et al*, 2003, in press). Furthermore, Frasnian conodonts have been recovered from a few different localities (Corradini, unpubl. data). Therefore, the age of the "Clymeniae Limestone" spans from the Frasnian to Tournaisian (Late Devonian-Early Carboniferous).

Palaeoenvironment

A pelagic deposition environment may be supposed for the "Clymeniae limestone", both on the basis of microfacies and the absence of benthonic fauna; furthermore, also the conodont biofacies indicate an off-shore environment (Corradini, 1998a, c). During the Early Carboniferous, owing to a decrease of typical pelagic genera, the condont biofacies analysis suggests a very slight shallowing (Corradini *et al*., 2003, in press).

Stop 2.5:

Miocene carbonate factories in the Isili area.

M. Murru & L. Simone

Active tensional tectonics characterised the Western Mediterranean region during the Oligo-Miocene; an articulated rift system developed in relation to complex crustal dynamics. As a result, synrift sedimentary basins formed on blocks, where intense tectonic activity, relative sea level changes and localised ecological factors contributed to the formation of complex depositional sequences. Rift-related break-up unconformities bounded these sequences at the base where carbonate sediments are frequently intercalated and/or associated with immature terrigenous deposits.

The sedimentary successions in the syn-rift sub-basins of Sardinia document the onset of marine conditions in the early syn-rift phases. In the Isili area (Fig. 16), a fault-block, rotation-controlled, sedimentary basin is recognisable due to its distinctive sedimentary bodies. Palaeomorphological controls acted strongly on this depositional system, resulting in complex calcareous bodies covering an area of over 30 km^2 with a total thickness of as much as 200 m.

Carbonate factories developed during the Aquitanian times in these tectonically-controlled, small, depositional sub-basins, where terrigenous input might have been significant because of erosion of the uplifted pre-Neogene substrata. Terrigenous deposits generally acted as passive substrata for pioneer communities of rhodalgal-type (red algae, ostreids, bryozoans) and locally evolved into coral-dominated assemblages. Carbonate facies' composition and distribution were mainly controlled by local syn-sedimentary tectonics and eustasy, as well as by climate. Although the inception of the carbonate factories was presumably not synchronous, their growth represented the response to a relative regional rise of the sea level, subsequent to impressive episodes of clastic supply, the expression of an early syn-rift stage.

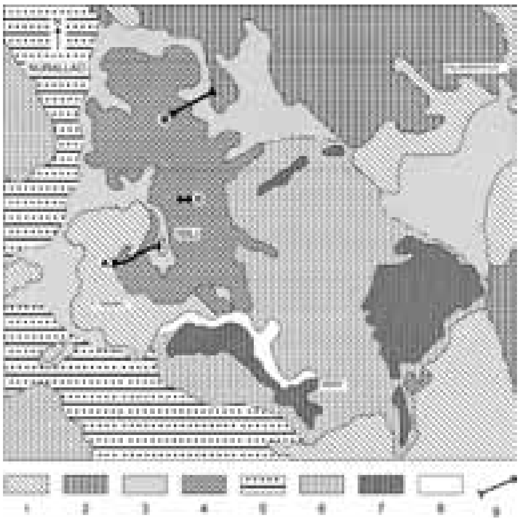


Figure 16 - Geological sketch-map of the Isili area: 1. Palaeozoic basement; 2. Jurassic dolostones; 3. Miocene clastic deposits; 4. Miocene limestones; 5. Miocene silty-marls; 6. Miocene marls; 7. Pliocene basalts; 8. Quaternary deposits; 9. Section traces: A=Punta Trempu, B=Industrial area, C= Carbonate channel network.

Carbonate production areas close to uplifted blocks, as well as along the articulated basement margins, developed according to organic colonization and facies characteristics, strongly depending on environmental peculiarities.

In areas devoid of (or with a very reduced) terrigenous supply, open carbonate factories grew with an aggradational-progradational trend. The resulting pure calcareous successions are organized into sequences, bounded by primarily tectonic-related discontinuity surfaces (e.g. the Isili area). Palaeomorphological controls acted strongly on the related depositional systems, thus resulting in complex calcareous sedimentary bodies. Carbonate production areas (carbonate factories) were generally located on morphological highs (e.g. the Punta Trempu, Nurallao areas) where up to 200 m of pure, skeletal, neritic limestones accumulated, resting over clastic wedges and/or Palaeozoic substrata. Lithofacies within the carbonate factory sequences show foramol associations (*sensu* Lees, 1975 and Lees and Buller, 1972) particularly rich in red algae and pelecypods (rhodalgal assemblages *sensu* Carannante *et al.,* 1988). These limestones are coarse, rhodolith-rich, skeletal grainstones to rudstones, with a matrix of grainstone and silty packstone. Skeletal components of the matrix are mollusks, bryozoans, barnacles, benthonic foraminifers and, in some cases, planktonic foraminifers. Organic assemblages dwell in their own detritus, largely produced by bioerosion processes (Cherchi *et al.*, 2000). Foramol/rhodalgal deposits were laid down forming a loose sediment sheet in open depositional settings. Ostrea banks spread over patchy areas, often covering discontinuous hardgrounds or erosive surfaces. Both of these discontinuity surfaces, which intercalate into the carbonate succession, may suggest repeated relative sea level variations. Tectonic activity interacting with sea level changes are to be considered as a major control over the factory growth and skeletal sand supply to marginal areas, where impressive sand bodies were developing. Displaced skeletal fragments constitute the bulk of these structures, in which only minor *in situ* carbonate production by local assemblages presumably occurred. Field analysis evidenced that productive areas were recurrently shaved with major redepositional events occurring mainly during relative sea level drops.

In the Isili area, skeletal calcareous strata document the presence of a Miocene carbonate submarine channel system. The channels were supplied by two source areas (Punta Trempu and Nurallao), which were temperate-type, open-shelf carbonate factories, characterized by foramol/rhodalgal assemblages. These pass laterally into marginal areas where large amounts of coarse bioclastic sediments were deposited in high-energy conditions. An active hydrological regime controlled off-shelf transportation of the sediments and their deposition in large cross-stratified bodies. The marginal areas were drained by multiple transverse incisions which acted as tributaries of the main channel (the Isili Channel). Channels vary in dimensions from a few metres wide with deep scours, up to 1-km-wide and 60-m-deep channels. Complex geometries characterise the channel system and its related architectural elements (e.g., levee, margin overbank, tributaries). Giant bedforms progradated towards the channel axis and down-channel within the main channel, while proximal fan deposits with a complex distributary channel-network occur downcurrent of the feeder zone in more distal settings.

Detailed analysis has led to the reconstruction of the internal geometry and architecture of these carbonate bodies and to the determination of the main controlling factors. The dimensions and distribution of channel-- and channel related – bodies have been accurately determined. This information provides a useful tool for analysing less-extensively exposed analogues, and for modelling temperate-type carbonate channelised margins.

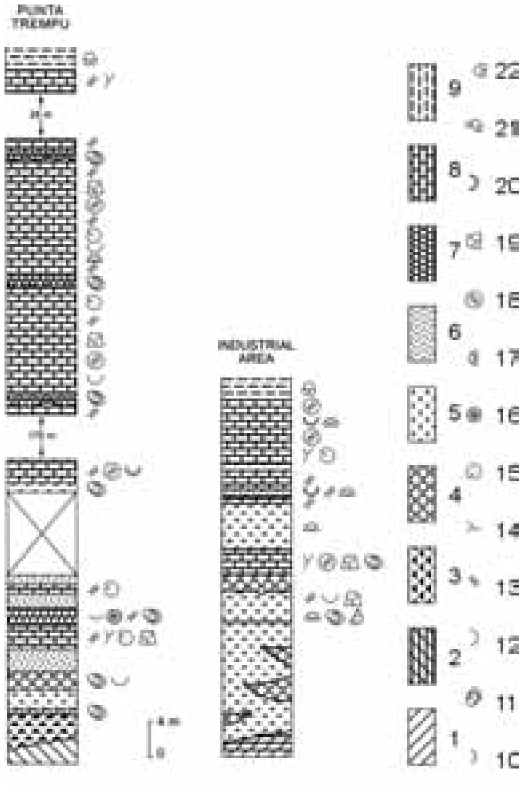


Figure 17 - Lithological columns of the Isili area (Punta Trempu and Industrial area sections): 1. Palaeozoic basement; 2. Jurassic dolostones; 3. Breccias; 4. Miocene conglomerates; 5. Miocene tuffaceous sandstones; 6. Miocene sandstones; 7. Miocene Ostrea-rich skeletal rudstones; 8. Miocene red algae-rich limestones; 9. Miocene marls; 10. Lithophagid bore holes; 11. Ostreids; 12. Bivalves; 13. Red algae; 14. Bryozoans; 15. Benthonic foraminifers; 16. Corals; 17. Echinoids; 18. Rhodoliths; 19. Barnacles; 20. Burrows; 21. Gastropods; 22. Planktonic foraminifers.

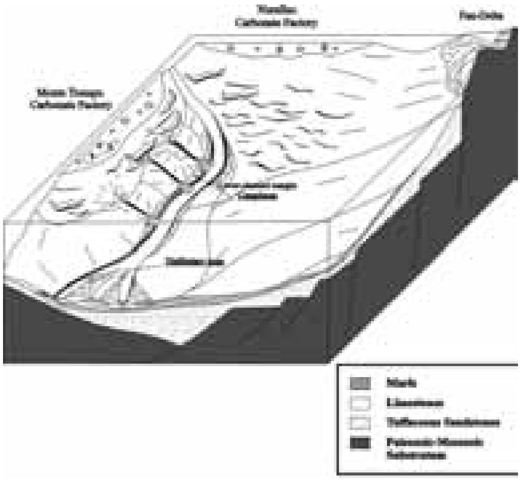


Figure 18 - Block diagram of the Isili railway dam.

This stop is subdivided into three parts:

A: Panoramic overview of the Miocene Isili carbonate factory. View of the Miocene neritic succession (Punta Trempu section) from the Isili terrace (Piazza Funtana Manna). About 200 m of Miocene neritic limestones (Fig. 17) are well exposed above the Palaeozoic metamorphites, overlain by a few meters of discontinuous breccia. The latter consist of coarse, polygenic, variously sized breccias with 10-120 cm, subangular to angular clasts embedded in a reddish sandy matrix. Breccia deposits have erosive basal boundaries and are normally-graded passing to fine conglomerates and breccias with a marine skeletal grainstone-rudstone matrix intercalating into tuffaceous layers. Early marine conditions can be recognised in these clastic wedges. In the skeletal matrix, ostreid and pectinid fragments associate with internal calcite molds of pristine aragonite mollusc shells. Ostrea banks intercalate into the upper terrigenous succession, resulting in stabilised substrata. Coarse sands with microconglomerate lenses intercalate into the first calcareous strata underlying 180 m of pure skeletal limestones. Repeated and complex, reddened surfaces and, in some cases, well-developed, bored hard-grounds intercalate into the succession defining discontinuity surfaces. Lithofacies within the sequences reflect open-shelf, foramol deposits rich in red algae and pelecipods (rhodalgal assemblages *sensu* Carannante *et al.,* 1988).

B: Calcareous beds in early marine siliciclastic deposits of the Isili industrial area.

The industrial area section crops out along the road that connects the village of Isili with the Colonia Penale area, located on the eastern sector of the Isili sub-basin.

In this locality the pre-Tertiary basement crops out, with Jurassic dolostones covered by about 20 m of poorly-lithified tuffaceous sandstones with lenses of paraconglomerates (Fig. 17). Clasts are usually well-rounded but poorly sorted and primarily Mesozoic dolomites, with frequent pelecipod borings, to a lesser extent Palaeozoic metamorphic rocks. A few calcareous clasts are composed of Miocene skeletal rudstones containing fragments of *Pinna*-type shells and bryozoans. A rich benthonic assemblage, made up of molluscs (preserved ostreid shells plus small pristine aragonite-shelled pelecipod and gastropod molds), echinoids, barnacles and red algae, is evidence of marine dwelling on sandy bottoms which periodically received terrigenous input, often in the form of coarse fractions.

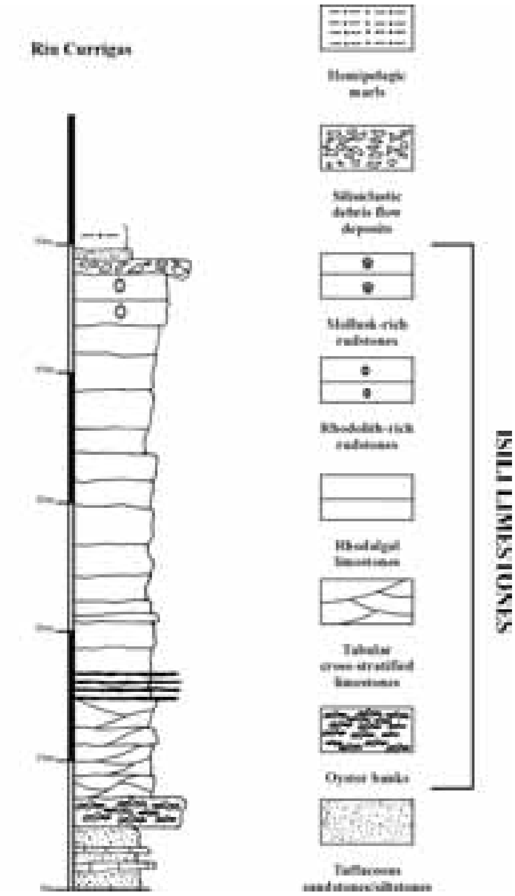


Figure 19 - Lithological column of the Isili railway dam.

A marine interpretation for these terrigenous wedges is clearly substantiated by admixed marine skeletal material in the matrix, and by the large number of pelecypod borings in the conglomerate clasts. Meter thick intercalations of skeletal limestones characterise the next 20 m of tuffaceous sandstone strata. These strata exhibit a general fining upward trend with only subordinate intercalations of microconglomerate. Limestones are algal floatstones in a deeply burrowed matrix of silty skeletal packstones. The main constituents are small rhodoliths and fragments thereof, and adjunctive encrusting red algae. Encrusting bryozoans and foraminifers are the major rhodolith builders. Bryozoans, ostreids and barnacles abound in the silty-arenitic matrix. This neritic succession terminates with a 10–m-thick, calcareous bank containing abundant rhodoliths, up to several centimeters in size, and bryozoan fragments.

A sequence of alternating laminated silty marls and sandstones follows. The sandy, graded laminae contain poorly-rounded quartz grains and smaller amounts of skeletal fragments of benthonic organisms. In the thin pelitic intercalations rare planktonic foraminifers have been observed (top N5 zone, Early-Middle Burdigalian).

C: Overview of the complex carbonate channel network cropping out north-eastward of Isili village. Panoramic viewpoint at km 50 along the Isili-Nurallao road. On a large scale the observed carbonate succession is 40 m thick and is tabular bedded, cut by a large, flat, bottom incision in the middle and most convex portion of the section. Strata geometry and interpretations are shown in Fig. 18, while the described sequences are in Fig. 19. Detailed analysis of both facies and the internal geometry allowed us to interpret the area as corresponding to the right channel margin-levee complex of what is thought to be the Miocene Isili Channel. Multiple hardgrounds, as well as erosive and reactivation surfaces, indicate that multiple construction phases occurred throughout the channel's life.

DAY 3

Stop 3.1:

Regional geological overview on Central-Eastern Sardinia at Escalaplano.

S. Barca & E. Sarria

Today's trip takes us to central-eastern Sardinia, where a geological cross section of the Palaeozoic basement overlain by Permian, Triassic, Jurassic and Eocene deposits, can be observed. The SW-NE trending cross-section lies at right angles to the Hercynian basement structures and falls almost entirely within Map Sheet 541 Jerzu of the new 1:50.000 Geological Map of Italy (CARG project) compiled in the '90s (Pertusati *et al.*, 2003a).

Stop locations: 3.1, 3.2 and 3.3 –Escalaplano; 3.4 – Punta Guardiola (Perdasdefogu); 3.5 – S. Antonio Church; 3.6 – Sa Canna (Seui).

Only the last two stops are not included in the Map Sheet, but are situated in a geologically similar area.

The landscape, one of the most beautiful in Sardinia, comprises a series of plateaux, increasing in elevation from 600 m in the S to over 1000 m northwards. These ancient surfaces were inherited from the peneplanation of the Hercynian chain, and are overlain primarily by Jurassic carbonate rocks in a typically slightlysouthwards dipping tabular relief ("Tacchi" or "Tonneri").

These plateaux were incised profoundly by the Rio Flumineddu and the Quirra stream, following the strong uplift produced by the mainly extensional tectonics during the Tertiary.

To the east, the area overlooking the Tyrrhenian Sea is composed of a rugged relief that forms a N-S ridge culminating in Mt. Ferru (875 m), bounded to the west by the broad Quirra alluvial valley.

The Palaeozoic basement in this area is composed of low-to-medium grade metamorphic rocks belonging to the Nappe Zone of the Sardinia Hercynian Chain. Outer and inner nappes are both present (Carmignani *et al.*, 1992, and references cited therein).

The outer nappes are composed of metamorphic rocks, their often fossil-rich protoliths dating to the Cambrian-Early Carboniferous. The main Hercynian deformation phase is manifested by strongly non-cylindrical recumbent isoclinal folds at all scales, often overlapping, showing axial, planar, penetrative schistosity and marked extension lineations. Synkinematic metamorphism varies from anchizone to greenschist facies.

The deformation history of the inner nappes is more complicated, involving two isoclinal folding events and a greater degree of metamorphic recrystallization. Furthermore, the stratigraphic successions contain few Ordovician metavolcanites and Silurian-Devonian limestones. In particular, in this area the inner nappes are represented by a thick epimetamorphosed complex composed of an azoic terrigenous succession (Gennargentu Tectonic Unit).

In central-eastern Sardinia the nappe pile is folded into three regional fold structures, notably from SW to NE: the Flumendosa Antiform, the Barbagia Synform, and the Gennargentu Antiform. The SW portion of the Jerzu map sheet also incorporates part of the Flumendosa Antiform, the Gerrei unit occupying its core; the NE sector comprises the SE flank of the Barbagia Synform.

Late Palaeozoic volcanic-sedimentary successions lie with angular unconformity on the metamorphosed basement rocks in Late Palaeozoic continental basins formed during the post-collisional extension phase, accompanied by exhumation of the metamorphic rocks and emplacement of the granitoid batholith and its dyke swarm (Upper Carboniferous-Permian).

Three of the numerous small continental basins of Permian age existing in this region (Escalaplano, Perdasdefogu, Mt. Ferru) are included on the Jerzu map sheet, the other two fall outside the map sheet: Lake Mulargia to the West and Seui to Northwest. The continental basin at Seui is included in the afternoon stops.

Mt. Ferru is a magmatic basin, while the others are composed of continental fluvial-lacustrine deposits with associated basic to acid volcanic rocks having calc-alkaline affinity (Cassinis *et al.*, 2000 and references therein).

The Seui and Perdasdefogu basins were mined for their anthracite, their production reaching a peak in the period between the two world wars. Today all the mines have been closed down and projects are under way for conserving and enhancing the tourist-cultural value of the ancient mine sites.

Overlying the Permian deposits, or resting directly on the Hercynian basement, we can see:

- Triassic deposits from a transitional environment (Upper Anisian) and neritic deposits (Lower Ladinian);
- Jurassic deposits from a fluvial-deltaic environment (Dogger) and neritic deposits (Dogger-Malm);
- Eocene deposits from a deltaic and coastal environment (Ilerdian).

The post-Hercynian, and especially Oligo-Miocene and Plio-Pleistocene, tectonics in this area did not significantly alter the structure emplaced in the Late Palaeozoic. The post-Hercynian sedimentary formations have a maximum dip of a few degrees. Slight angular unconformities exist between the different sedimentary cycles of the Meso-Cenozoic covers that can only be recognized at the mapping scale.

In this regard, the situation in the Escalaplano area, in the SW corner of the Jerzu map sheet, is unique. Above the Hercynian metamorphosed basement and the Permian continental deposits are three slight angular unconformities at the base of the Triassic, Jurassic and Eocene successions.

Stop 3.2:

The Middle Triassic deposits of Escalaplano.

S. Barca, M. Del Rio & P. Pittau

The first post-Palaeozoic marine transgression flooded the folded, metamorphosed and smoothed Hercynian basement in the Southwestern, Northwestern and eastern part of the island. The central Sardinia was a structural high that progressively was submerged by the maximum eustathic flooding, during Ladinian time. The Triassic, in Sardinia, is characterized by a threefold lithologic subdivision: Buntsandstein, Muschelkalk and Keuper. Traditionally the lithostratigraphic units were also incorrectly employed as chronostratigraphic units. The palynological characterization of these deposits has permitted it to be correlated to the Alpine standard stages and substages (Pittau Demelia and Flaviani, 1982b; Pittau *et al.*, 1999; Pittau and Del Rio, 2002). In the Sarcidano-Gerrei area (Eastern Sardinia) the Triassic deposits are siliciclastics (the Escalaplano Fm.) and carbonate (the Mt. Maiore Fm.), in turn, disconformably covered by Middle Jurassic or

Eocene, marine and alluvial formations.

Locally, the transgressive sediments overlay the continental siliciclastic and carbonate successions with associated volcanic products, accumulated in the fluvial-lacustrine basins formed during the extensional phase of the late Hercynian tectonics (Late Carboniferous-Early Permian; see successive stops). The modest thickness of the Triassic sections is due to long and intense Mesozoic and Cenozoic erosional phases.

Stratigraphic units

The Escalaplano Fm. crops out along the national road SS 128 at the southern entrance of Escalaplano. The succession represents the basal portion (about 15-20 m thick) of the transgressive Triassic sedimentation in Buntsandstein facies. It passes to a carbonate lithofacies (Muschelkalk *Auct*.) in its upper part.

The deposition environment changed from fluvial and continental flood plain (Buntsandstein) to transitional salted lagoons, forecasting the marine (Muschelkalk) transgression.

Historical outline

Dorn (1940) assigned the succession outcropping at Escalaplano to the Keuper (Late Triassic) due to the presence of gypsiferous shales. Later, several authors working on this section suggested a Middle Triassic age, on the basis of regional stratigraphy (Damiani and Gandin, 1973; Pecorini 1974; Fazzini *et al*., 1974). The sporomorph content permitted the Escalaplano Fm. to be ascribed to the Upper Anisian (Pittau Demelia and Flaviani, 1982b; Costamagna *et al.,* 2000) and, very recently, also to the Lower Ladinian in its upper portion (Pittau and Del Rio, 2002).

Lithology

The succession, from its base laying on violet schists of the basement, shows the following lithofacies:

- (1 m thick). Polygenic conglomerates and breccias, with quartz pebbles, angular elements of the metamorphic basement and Permian volcanites (Fontana *et al*., 1982) in a sandy matrix alternated with reddish sandstones. This unit is missing northwestwards in the area.
- (10 m thick). Alternating centimetric to decimetric layers of red, green and grey marly shales, siltites, sandstones and thin layers of light dolomitic marls. In the upper part there are alternating beds of dark claystones, siltstones and centrimetric irregular layers of pink and white gypsum.
- (3 m thick) light pink and grey, irregularly bedded, limestones and dolomitic limestones. A coarse fluvial Eocene deposit covers uncomformably the carbonate rocks.

Paleobiological content

The Buntsandstein deposit (Escalaplano Fm.), except for the presence of palynomorphs, is barren of fossils.

Pollen and spores are yielded by three black shale levels and the assemblages are very rich both in terms of number of species as in terms of number of specimens. They are characterized by the abundance of conifer-producing *Triadispora* pollen, for the most part *T. crassa*; by the occurrence of *Angustisulcites klausii, Illinites chitonoides, Microcachrydites* spp. and *Voltziaceaesporites heteromorpha,* and a very few amount of hygrophytic (spore taxa) species. The assemblages' composition reflects a distinct xerophytic vegetation, comparable to those observed in the subsurface of Northwestern Sardinia (Pittau Demelia and Flaviani, 1982b; Pittau and Del Rio, 2002) and in the Röt-3 phase of the Germanic basin (Brugman, 1986). The co-existence of *Cristianisporites triangulatus*, *Dyupetalum vicentinense* and *Stellapollenites muelleri* indicates the assemblage may be equated to the *muelleri-vicentinense*, of the Alpine Pelsonian and Illyrian (Anisian), most likely the more xerophytic *vicentinense-crassa* sub-phase (Illyrian). The younger assemblage, only recently observed (Pittau and Del Rio, 2002), is ascribable to the earliest Fassanian, for the first appearence of *Ovalipollis pseudoalatus*.

Stop 3.3:

Escalaplano: A nummulite-rich Lower Eocene outcrop.

R. Matteucci & M. Murru

Geological setting

In Central-Southern Sardinia (Fig. 20) the onset of the Tertiary is characterized by a continental phase, recorded by various paleosols to ironstones (Murru and Ferrara, 1999), microcodium-rich levels (Matteucci and Murru, 2002) and freshwater algal deposits (in prep.). Local marine transgressions are recorded in the Late Paleocene; however, only in Early Eocene (Ilerdian) times an extensive and well-documented marine transgression took place (Murru *et al*., 2003). In Central-Southern Sardinia the remnants of a presumably extensive sedimentary cover, generally of modest thickness and extension and usually with sub-horizontal bedding, are today

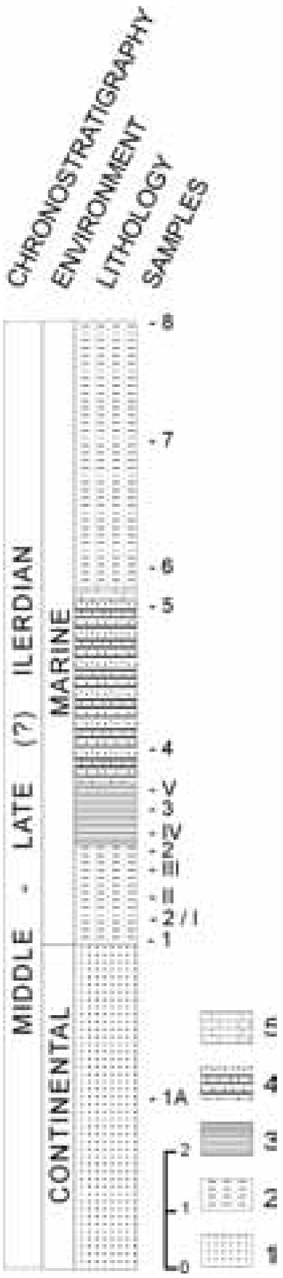


Figure 20 - Sketched geological map of Central-Southern Sardinia: 1. Palaeozoic-Mesozoic basement; 2. Paleocene-Eocene; 3. Oligocene-Miocene; 4. Pliocene-Pleistocene basalts; 5. Quaternary deposits; 6. Faults.

found at different altitudes, ranging from 539 m at Mt. Ixi to 78 m at Santu Miali (Fig. 21). These differences in present-day altitude are due to extensional tectonics affecting Sardinia in Late Oligocene-Early Miocene times. The sediments of these deposits are mainly terrigenous (sandstones, marls, shales, conglomerates), with sub-horizontal bedding and either scarcely fossiliferous, or yielding

Figure 21 - Simplified geological cross-section from the east to west coast of Sardinia: 1. Palaeozoic; 2. Paleocene-Eocene; 3. Eocene- (?) Oligocene continental deposits (the Cixerri Fm.); 4. Oligocene-Miocene andesites; 5. Miocene; 6. Pliocene basalts; Pliocene-Pleistocene deposits; 7. Faults.

nummulitids, mollusks (mainly, potamidids and ostreids), and ostracods.

In Southwestern Sardinia (Sulcis) the marine flooding started in the Thanetian, and continued in the Ilerdian (Fig. 22), with mainly carbonate (“Miliolitico” *Auct.*) shallow-water deposits (Matteucci *et al.,* 2000). In Southeastern Sardinia the Ilerdian terrigenous marine deposits are generally followed by clastic continental sediments (conglomerates and sandstones), well exposed at Mt. Cardiga and Orroli. Also in the Sulcis basin there are arenitic and conglomeratic deposits at the same stratigraphic level; they may belong to the same erosional phase and are tentatively correlated with the clastic complex found in Southern France (Poudingues de Palassou), related to the “pre-Pyrenaic” tectonic phase.

In Cuisian times, whereas in the Sulcis lagoonal and marsh environments are widespread leading to the deposition of conspicuous and economically

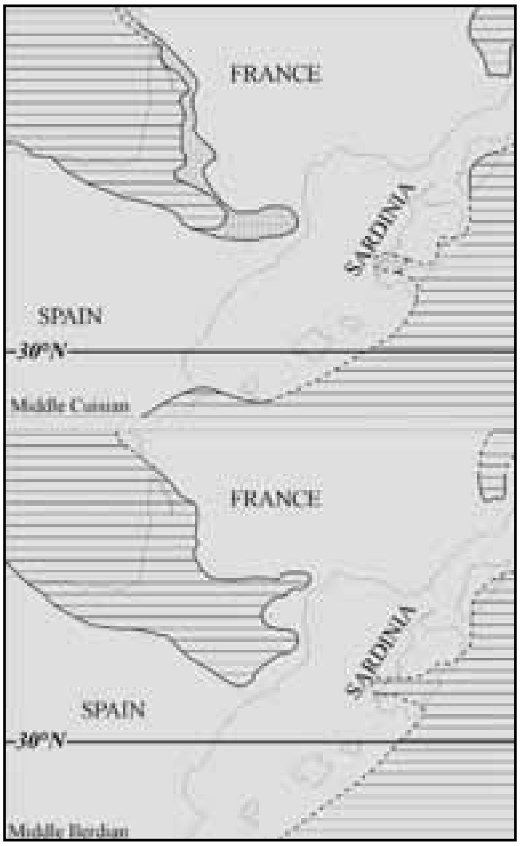


Figure 22 – Sketched paleogeographic evolution of Sardinia-Corsica, Southern France and Spain: 1. Marine sedimentation, 2. Continental sedimentation. Paleolatitude: the 30° N latitude corresponds to the position of Southern Morocco and most of the Sahara region today.

important lignite levels (“Lignitifero” *Auct*.), in other parts of Central-Southern Sardinia, scattered and locally thick, mainly terrigenous marine deposits were formed (Orosei, Nuraghe Sioco, Orroli and Is Cantonis). However, in the vicinity of Orroli, carbonate clasts rich in Cuisian larger foraminifera (Alveolinidae, Orbitolitidae, Nummulitidae) have been recently found within the Miocene Ussana Fm. These clasts record different facies from a now completely-obliterated, shallow-water carbonate coastal system. This evidence suggests a large Cuisian embayment, extended far towards the west, possibly connected with the lagoonal and marsh environments of the Sulcis area. The environments of the latter area can be compared with the present-day Everglades, probably with open marine settings towards the east (Matteucci *et al.,* 2003).

In Central-Western Sardinia the conglomerates of the Cixerri Fm. testify to the onset of an ensuing erosional continental phase from the Lutetian onwards.

The nummulitid outcrop at Escalaplano

The outcrop at Escalaplano consists of a Middle Ilerdian fossiliferous marine deposit intercalated within a thick continental conglomerate-sandstone succession. The thickness of the conglomerate complex outcropping near Escalaplano is very variable, from ca. 5-6 m in the vicinity of the village along the road to Ballao, to about 100 m at Is Pranus, at the intersection with the road to Perdasdefogu–Esterzili. The basal conglomerate complex is spectacularly exposed at the Escalaplano ring-road. Here, the deeply incised Mesozoic substrate and the coarse sediments, consisting of sand, gravelly sand and sandy gravel, alternating with finer levels (sandy silt and silt) can be observed. The clasts are generally well rounded and heterometric, including components from the Palaeozoic substrate and less abundant Mesozoic carbonates. The lenticular or irregular geometry of the layers, often with an erosional base, the occurrence of plane, oblique and concave cross-laminations, and the absence of fossils suggest an interpretation of the deposit as a fluvial-braided channel, possibly with small point bars.

The marine nummulitid-yielding succession, cropping out at km 38 of the provincial Escalaplano–Perdasdefogu road, is underlain by gravelly and sandy deposits, and consists of alternating sandy-bioclastic levels rich in quartz granules, and in nummulitids, locally strongly bioturbated, along with greyish-greenish more clayey levels, with scattered nummulitids, often preserved only as ferruginous remnants; dark green grains (glauconite?) are very

Figure 23 - Lithostratigraphic column: 1. Sandstones and conglomerates; 2. Marly shales and sandstones; 3. Marls; 4. Sandy marls and marly siltstones; 5. Limestones.

abundant (Fig. 23). Glauconite commonly infills the chambers of the larger foraminifera shells, and many glauconite granules show the morphology of inner chambers of tests. The fossiliferous component is formed almost exclusively by nummulitids, with scarce bivalves (ostreids and cardiids) and irregular echinoid spines.

The nummulitids are represented by a reduced number of species, among which the dominant form is *Assilina pustulosa*, along with *Nummulites globulus*, *N. spirectypus*, *A. canalifera*, *Assilina* sp., and rare discocyclinids (*Discocyclina* and *Nemkovella*).

The assemblage is typical of the Middle Ilerdian (SBZ 8 in the Shallow Benthic Zonation by Serra-Kiel *et al.*, 1998), and characteristic of terrigenous facies rich in *Nummulites globulus* of the Middle Ilerdian of the Pyrenées.

Stop 3.4:

The Lower Permian volcanic and sedimentary sequence of the Perdasdefogu Basin (Punta Guardiola).

G. Cassinis, L. Cortesogno, L. Gaggero, A. Ronchi & E. Sarria

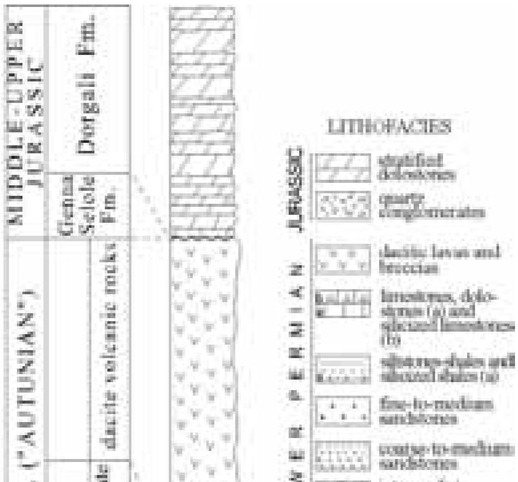


Figure 24 - Stratigraphic column of Punta Guardiola.

Stratigraphy and structure

In the Perdasdefogu Basin (Ogliastra region, Central-Southeastern Sardinia) Permian volcano-sedimentary deposits crop out over an area of about 25 km^2 and underlie the Jurassic rocks (Fois, 1939; Sarria, 1987, Ronchi, 1997).

The 250- to 300-m-thick Permian sequence begins with a basal reddish conglomerate, bearing poorly elaborated fragments provided by the local Variscan metamorphic basement. The "Basal Conglomerate" rarely exceeds 30 m in thickness, the contact with the basement being marked by unconformity.

A sequence of mainly lacustrine deposits follows above ("Rio Su Luda Fm."; Ronchi, 1997), subdivided into two lithozones (Punta Guardiola section; Fig. 24).

The lower "shaly-sandy" lithozone, locally exceeding 100 m, is made up of grey-dark laminated fluvial-lacustrine sandstones, siltstones, and shales. In the sequence, thin conglomerates, volcaniclastic breccias, with intermediate-to-acidic calcalkaline components, and lavas are intercalated.

This lithozone is frequently overlain by a "cherty-carbonate" unit (generally 30 to 50 m, up to 70 m) composed of lacustrine limestones and dolostones affected by diffuse silicisation, and intercalated with silicified pyroclastic products (Ortu Mannu section, Fig. 25B). Silicized fine-grained pyroclastic deposits, sometimes hyaloclastic, crop out at the top of the sequence.

Decimetric conglomerates and thin anthracite layers also occur in the carbonate beds. The anthracite has been exploited for over a century (bibliography in Sarria, 1987). Algal oncolites and stromatolitic domes frequently occur as well within the carbonate strata.

The finer laminated sediments and the carbonate layers, referred to a very shallow lacustrine environment, yielded macrofloras, silicified plants, palynomorphs, amphibians, algal stromatolites, ostracods and fish teeth (Ronchi *et al.*, 1998; Freytet *et al.*, 2002). According to Broutin, Galtier, Schneider, Werneburg, Tintori, Freytet and Lethiers (Ronchi *et al.*, 1998; Werneburg 1989, 1999; Broutin *et al.*, 2000 Freytet *et al.*, 2002; Cassini *et al.*, 2003) the age relates to the Early Permian (Autunian).

The sequence is covered by a dacite unit up to 180 m thick (Bruncu Santoru, Fig. 25A). To the NW, rhyolitic tuffs and a large ignimbritic body occur. Dacite and rhyolite dykes are widespread in the

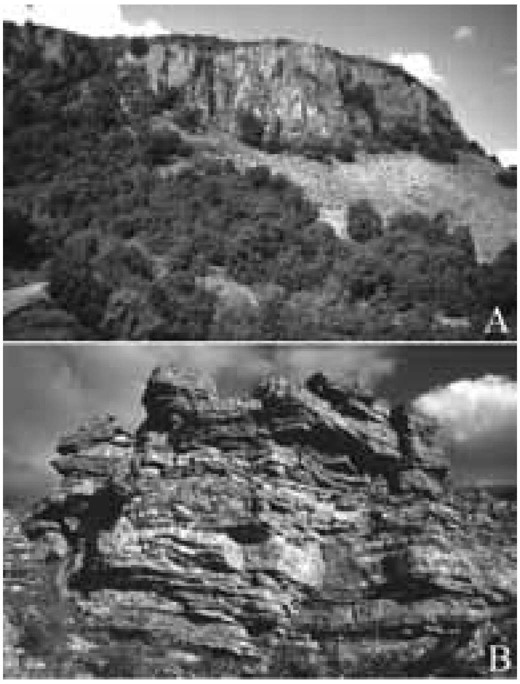


Figure 25 - A. The Bruncu Santoru dacites; B. Lacustrine limestones in the Ortu Mannu Section.

Variscan basement and in the overlying units.

Coarse grained conglomeratic beds (Genna Selole Fm.) and/or dolostones (Dorgali Fm.) of Middle Jurassic age top the sequence.

The Perdasdefogu Basin is a half-graben with a clearly asymmetric inner structure, controlled by major normal faults and tilted blocks, and by transverse structures, as shown by a recent drilling campaign in the basin (Sarria, 1987).

A longitudinal, normal, master fault defines the western edge: the Nuraghe S. Pietro Fault, 10 km in length, trends N160°E to N-S, is east dipping, and downthrows ENE, with a maximum vertical displacement of several hundred meters. The eastern edge of the basin is characterized by a gently dipping WSW facing monocline, interrupted by NNW to N-S striking normal faults, mostly antithetic west-dipping, with an "en echelon" pattern.

Longitudinal normal faults, both antithetic and synthetic, and with original dips between 60 and 80°, are also associated with the master fault; they propagate along the entire basin zone though segmented and offset by transfer faults.

Palaeontological content

A synthesis of the most important fauna and flora findings is hereafter reported (for a complete list see Ronchi *et al*., 1998; Broutin *et al*., 2000 and Freytet *et al*. 2002).

Macroflora: in the last years a rich palaeontological record has been found both within the shales of the siliciclastic unit and the cherty limestones of the calcareous unit of the Lower Permian Rio su Luda Fm. According to Broutin this association is comparable to that recorded in the "Assise de Millery" (Upper Autunian) of the typical Autun Basin. *Autunia conferta*, *Rhachiphyllum lyratifolia*, *R. schenkii, Dichophyllum flabellifera*, *Lodevia nicklesii*, *Gracilopteris strigosa*, and *Taeniopteris abnormis* are amongst the most significant taxa.

Permineralized plants were recently found in the silicified horizons of the cherty-carbonate unit (Rio su Luda Fm.) and studied by J. Galtier (Galtier *et al*., 1998; Freytet *et al*., 2002). The arborescent marratialean ferns are the dominant elements, with the vegetative and fertile leaves *Pecopteris* and *Scolecopteris*. The calamitean sphenopsids are the second in abundance.

Palynomorphs: the palynological assemblage of Perdasdefogu Basin, which is similar to that occurring at the Punta Lu Caparoni Fm. in Nurra (Northwestern Sardinia), is comparable to that defined by Doubinger (1974) in the "A3" Autunian biozone for Europe. It yields *Potonieisporites novicus-bhardwajii*, *Florinites* spp., *Nuskoisporites* cf. *klausii, Protohaploxypinus* sp., *Vittatina ovalis*, *V.* sp., *Costapollenites* sp., and so on.

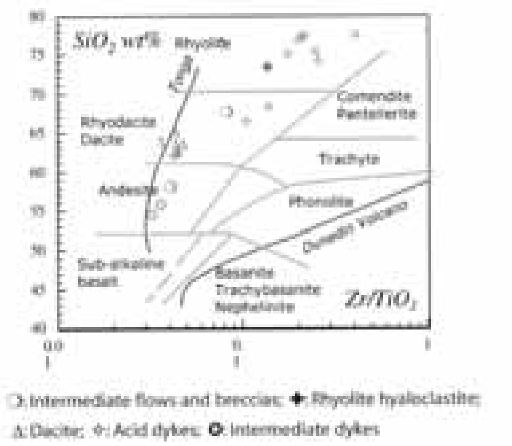


Figure 26 - Zr/TiO2 – SiO2 (after Winchester and Floyd, 1977) for the Perdasdefogu Basin volcanic lithologies.

Ostracods: three species of fresh water ostracods have been recorded within the Perdasdefogu Basin: *Candona* n. sp., cf. *planidorsata* Cooper, 1946; *Paleodarwinula* sp. and *Whipplella carbonaria* Scott, 1994. Taking into account our knowledge of the first and third species, F. Lethiers proposes an Autunian, more precisely a Middle Autunian, age for the Perdasdefogu ostracods.

Amphibians: a rich amphibian fauna has been recently described from the Perdasdefogu Basin (Ronchi and Tintori, 1997); fossiliferous layers have yielded several *Branchiosaurus* cf. *"B." petrolei* specimens, often in repeated mass mortality assemblages. Based on new samples, Werneburg (1989) preliminarily points out the presence of the following taxa: *Melanerpeton eisfeldi*, *Apateon kontheri*, *A. flagrifera***.** Interestingly, the same association of species is known from the famous amphibian locality "Gottlob", in the Upper Goldlauter Fm. of the Thuringian Mountains (East Germany).

Fish teeth and remains: the presence of xenacanth teeth and acanthodian spines has also been reported from the lacustrine limestones of the Rio su Luda Fm. (Ronchi and Tintori, 1997). Later on, Schneider (in Freytet et al., 2002) recorded the following fauna of aquatic vertebrates: *Xenacanthus* sp. (rare), Bohemiacanthus type Om to Ogo (very common), *Acanthodes* sp.

Based on the xenacanth teeth-zonation of Schneider (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 uppermost Ghzelian to Lower Asselian of the global scale.

Volcanic activity

In the Perdasdefogu Basin, above the basal conglomerate, the early volcanic record is represented at the SSE margin of the basin by intermediate volcanic breccias that occur with variable thickness (0-50 m), interbedded within the pelitic-siltitic lower unit, and at the boundary between the lower and the upper carbonatic unit.

Black, silicified decimetric beds of reworked fine-grained vitroclastic materials are widespread in the upper unit; the black color of such levels is related to the inclusion of abundant vegetal material. Several dykes with rhyolite and dacite composition cut the sedimentary sequence. The rhyolite extrusions associated with the dykes have explosive features. A thick (up to 180 m) dacite body occurs at the SE margin of the basin (Bruncu Santoru). The remarkable textural and relative compositional homogeneity, the tabular subhorizontal setting and the development of evident subvertical cooling joints could be consistent with an emplacement as subsurface sill. The volcanic sequence shows a subalkaline calc-alkaline character (Figs. 26, 27).

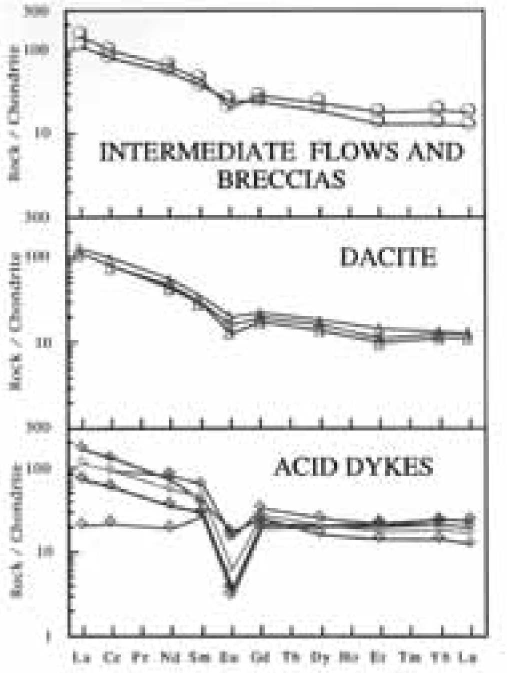


Figure 27 - REE patterns (normalized to Nakamura, 1974) for the Perdasdefogu Basin volcanic lithologies (symbols as in Fig. 26).

Stop 3.5:

Geological overview of the middle Jurassic platform ("Tonneri") at S. Antonio Church.

S. Barca & A. Sarria

Overall the morphology and landscape of this region consist of elevated plateaux, generally corresponding to the ancient post-Hercynian erosion surface. This peneplain was re-exhumed during the major uplifting produced during the Tertiary tectonics, when the Jurassic and Eocene sedimentary cover was stripped away by erosion. Small table-topped plateaux of Jurassic age, with sub-horizontal to gently inclined bedding known locally as "Tacchi" or "Tonneri", rise above the post-Hercynian peneplain (Pertusati *et al.*, 2003 and references cited therein).

Figure ***28 - Simplified geological map and location of stops in the Seui Basin.***

The Jurassic sedimentary succession begins with the Bajocian–Bathonian (?) Genna Selole Fm. (Amadesi *et al.*, 1961; Dieni *et al.*, 1983), formed in a fluvial to lacustrine-palustrine continental environment (Barca and Palmerini, 1974), composed at the base of monogenic quartz conglomerates, associated with quartz arenites and whitish clays, followed by grey to blackish clays and siltite abounding in plant fossil remains (Del Rio, 1977). Overall thickness is 30-40 m. Palaeosoils rich in iron oxides and hydroxides ("Ferro dei Tacchi" *Auct.*), sometimes crop out at the base of the conglomerate. These lateritic palaeosoils derived from the Palaeozoic basement rocks after long pedogenetic processes in a hot, humid climate.

The Genna Selole Fm. is overlain by the carbonate beds of the Dorgali Fm. (Amadesi *et al.*, 1961) (Dogger – Lower Malm), which deposited in a neritic platform environment. The lowermost part of this formation is composed of marly limestones and marls interbedded locally with sandstones and siltite-argillites. These are overlain by metre- to tens-of-metres thick beds of fossil-bearing (brachiopods, belemnites, ammonites, echinoderms, calcareous algae, foraminifers, etc.) dolostone and dolomitic limestone. The thickness of the formation varies considerably, reaching up to around 300 m.

The plateaux are usually furrowed by deep and narrow valleys that cut into the Palaeozoic basement. As they gradually widen out, these valleys divide the Jurassic plateaux up into a number of flat-topped, or almost flat-topped, elevations, the largest of which can actually be considered *mesas* (Tacco di Jerzu). Where the sedimentary cover has been largely stripped away there are remnants of the typical relief or pinnacles (the most well known is Sa Perda Liana, NW of Jerzu). Though, on the whole, they have preserved their tableland appearance, the upper surfaces of the plateaux have in many places been reshaped by the erosion processes (fluvial, slope and karst), so that the landscape appears to be cut by dry, blind and hanging valleys, benches, caves and underground conduits.

Along the outer edges, near the southern end of the "Tacchi", at the contact with the impermeable metamorphic basement, are springs, waterfalls and travertine waterfalls or small travertine terraces. Only occasionally are these terraces, which have formed at different levels and have a total height of around 150

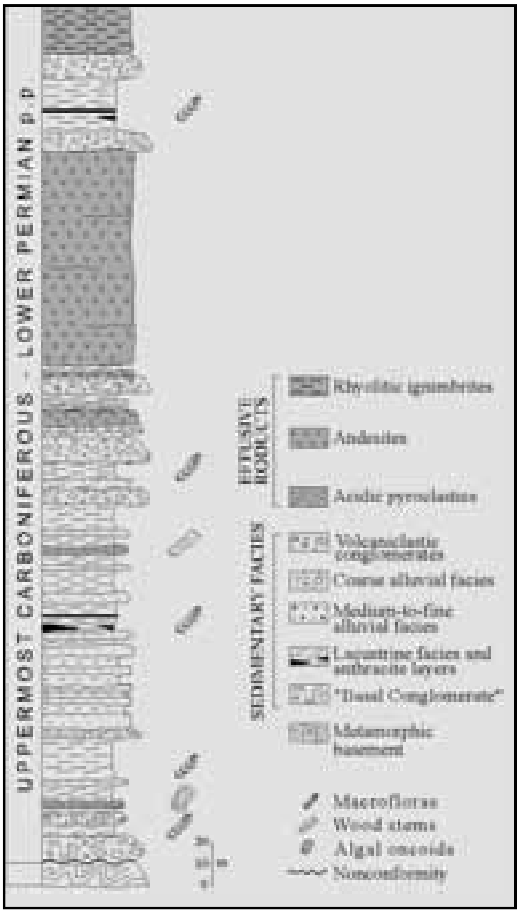


Figure ***29 - Representative section of the volcanic and sedimentary deposits in the Seui Basin (after Cassinis et al., 2003).***

Figure 30 ***- Panorama and geological sketch of the Seui Basin from the San Sebastiano area. VB: Variscan basement; "VB": allochthonous basement slices; BC: Basal Conglomerate; Sed: Permian sediments; And: andesitic lavas; PQ: rhyolitic and dacitic domes; Ign: rhyolitic ignimbrites***

m, more than ten metres thick (e.g. S.Barbara, W of Jerzu).

Mass movement is frequent along the edges of the carbonate plateaux. Rockfall talus has accumulated beneath the highest ridges, with large blocks scattered over the slope, several at some distance from the detachment zone.

Stop 3.6:

Latest Carboniferous to Lower Permian terrigenous deposits and associated volcanic rocks of Seui Basin (Sa Canna section).

G. Cassinis, L. Cortesogno, L. Gaggero, A. Ronchi & E. Sarria

Stratigraphy

The Seui Basin (Barbagia region, Central-Eastern Sardinia, Fig. 28) is a small asymmetrical graben covering an area of about 15 km. The basin was infilled by a Lower Permian, 400 m-thick, volcano-sedimentary sequence (Fig. 29).

Coal deposits (anthracite) bearing Autunian floras has been intensively exploited and drilled (Lauro, 1970 and references therein; Accardo *et al*., 1984).

The sedimentation in the basin began with an alluvial "Basal Conglomerate" deposited in fan or foot-slope environments, reworking the Variscan metamorphic basement. The thickness variations of this unit suggest an uneven palaeotopography. Thin layers of rhyolite pyroclastics and reworked pebbles support evidence for coeval volcanic activity.

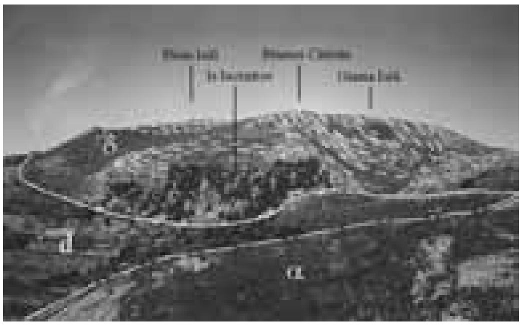


Figure 31 ***- Bruncu Cintoni: composite three-folded structure of the lobate dacite dome (δ).***
Centre, bottom: andesite (α) lavas;
left: detrital covers at Fondu Corongiu (d).

The deposition in the basin is represented by alluvial to lacustrine, fine to coarse-grained terrigenous sediments with intercalated intermediate lavas (andesite). The andesites, fed by plugs cropping out to the S of the basin, emplaced in an active, NE–SW-aligned, asymmetric graben. In the sediments, a broad-upwards coarsening trend reflects the change from a prevalently lacustrine marsh environment to a higher-energy fluvial setting.

Abundant macroflora remains occur in the fine-grained sediments. To the N of the basin, metre-thick rhyolitic ignimbrite layers overlie andesites and terrigenous sediments.

The northern and western sections of the basin are bounded by a structural high, largely represented by dacite domes. The emplacement of the domes within the basement was associated with the superposition of basement slices above the sedimentary sequence, due to gravitational collapse. The domes (Figs 30 and 31) are fed by a large diorite dyke. The calc-alkaline diorite and dacite domes are aligned approximately in an ESE–WNW direction (San Sebastiano church).

Radiometric data, obtained using K/Ar methods by Cozzupoli *et al*. (1971), on rhyolites and dacites, yielded ages between 250 and 265 Ma. Edel *et al*. (1981) also measured by K/Ar systematics ages of 259 ± 7 Ma for the ignimbrites, and 261 ± 8 Ma for the ignimbritic tuffs. Such ages, which contrast with the stratigraphic record, are likely rejuvenated due to the Late Permian thermal rise and related hydrothermal activity, also evidenced by large quartz dykes.

Palaeontological content

The Barbagia di Seulo area, which includes the Seui, Seulo (Ingurtipani) basins and minor outcrops, has been for more than a century the ground of rich macroflora discoveries. Starting from the second half of the 19th century, a large number of species have been identified from this uppermost Carboniferous-Lower Permian succession (for a complete bibliographic list, see Broutin *et al*., 2000). In particular Arcangeli (1901) found and classified 51 macroflora species in the Seui anthracitiferous deposits, mostly attributed to the Late Carboniferous-Early Permian, and a small number exclusively pertaining to Carboniferous or Permian times. A complete review of historic, rich macroflora collections can be found in Comaschi Caria (1959).

Macroflora imprints are reported from the shales in the northern portion of the Seui Basin, west of Senna su Monti (Sa Canna); in the southern area, fossiliferous localities can be found in the Lecci Tancredi mining area. In the central part of the basin, rich sites were found along Riu Croccoladori, near Pinnetta Murreddu, Fondu Corongiu and Corongiu Ladu. From a recent collection of macrofloras (by P. Calzia), Broutin recognised the following species: *Annularia sphenophylloides*, cf. *Pecopteris arborescens*, ? *P. cyathea, P.* sp., *P.* sp. aff. *hemitelioides*, *P. unita*, *Cordaites* sp.

Progemisa drillings and anthracite ore deposits

The coal-bearing Permian Seui Basin is the most important in Central Sardinia in terms of extension and thickness of ore levels, as well as for quality of the coal.

Historical documents from the Archives of the Sardinian Mining District show two periods of maximum mining activity, the first one from the end of the 19th century to the beginning of the 20th century, the second one between the two World Wars (the former for evident autarchic reasons). Mining studies on Sardinian Permian basins renewed in the early '80s, when the Regional Mining Agency (Ente Minerario Sardo – EMSA) planned a Research Programme with the purpose of cataloguing all ore/industrial mineral resources still available in Sardinia.

Thus, during the 80's, the EMSA-owned mining company, PROGEMISA, carried out a wide Exploitation Programme, made up of detailed geological mapping (1/5000 to 1/100), geophysical surveys (mainly geoelectrics), drillings (about 190 boreholes, for a 32,000 m total length), core logging and sampling, as well as microscope and chemical analysis. Their aim was to acquire new data on still- unexploited large areas, mainly in the Seui and Perdasdefogu Basins, where Permian successions could be present below Late-Palaeozoic volcanic units, as well the Mesozoic carbonate covers.

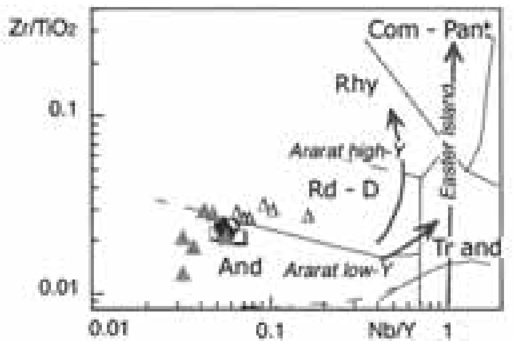


Figure 32 - Nb/Y - Zr/TiO$_2$ (after Winchester and Floyd, 1977). Full circles: andesite plugs; open circles: andesitic lavas; squares: andesite sill; full triangles: diorites, open triangles: dacites.

PROGEMISA's studies confirmed the presence of coal-bearing Permian successions (Sarria, 1987; Sarria and Serri, 1986). Anyway, in spite of the very good quality of the coal (a high-rank anthracite with very low sulphur), the low total size of the deposits (less than 1M tons) and their complex inner framework, associated with the impossibility of open-pit operations, actually hampered any economic interest in the coal-bearing basins from central Sardinia.

Volcanic activity

The igneous activity in the Permian Seui Basin includes intermediate to acidic members, showing a common with medium to high-K calc-alkaline affinity (Fig. 32).

The intermediate volcanic rocks range from basaltic andesites to andesites of weakly metaluminous (less evolved members) to peraluminous character. The feeding dyke has diorite to quartz-diorite compositions, varying from weakly metaluminous to Al-saturated, whereas the domes consist of dacites and rhyolites showing Al-saturated to peraluminous characteristics. Chondrite normalised REE patterns are characterised by LREE-enrichment (Fig. 33); the negative Eu anomaly is low to moderate in andesites (Eu/Eu*=0.59-0.86) and diorites (Eu/Eu*=0.52-0.81) and moderate in dacites (Eu/Eu*=0.38-0.45). Diorites and dacites show very low HREE concentrations, and small degrees of M- and HREE fractionation (Gd_N/ Yb_N= 1.45-1.59 in diorites; 1.44-1.39 in dacites),

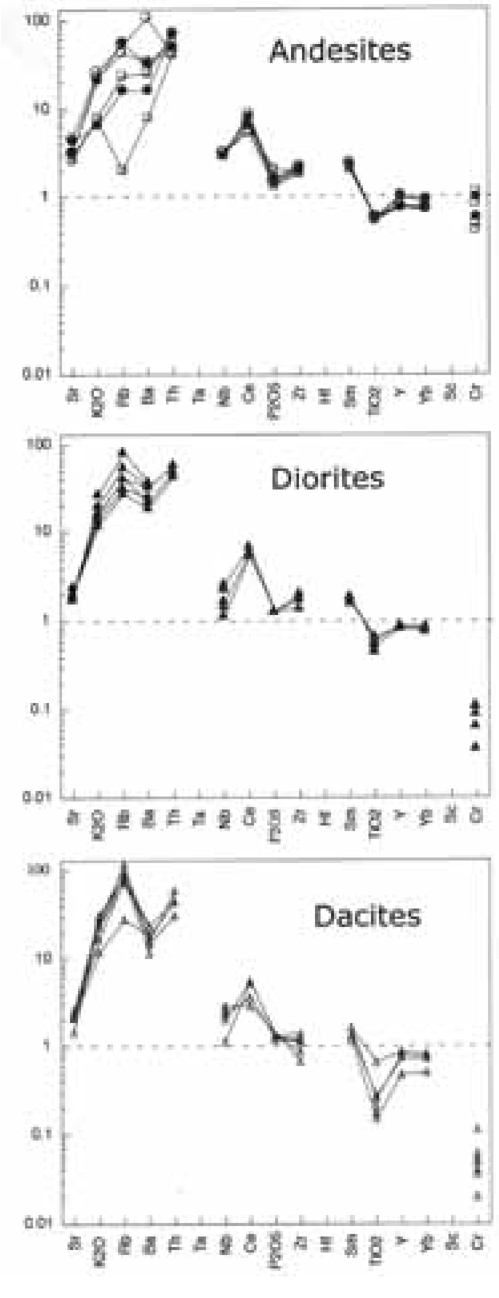


Figure 33 - Rock/MORB spiderdiagrams. Symbols: squares: andesites; full triangles: diorites; open triangles: dacites.

comparable to ratios produced by the melting of garnet-free sources. In andesites, the HREE fractionation is relatively strong and tends to increase in more evolved compositions (Gd_N/Yb_N=1.71-1.74 and Gd_N/Yb_N=1.97-2.15 respectively). The ratios are consistent with values in liquids from garnet-bearing sources (≥ 3). The decreasing ΣREE and increasingly negative Eu anomaly towards more evolved compositions in diorites and dacites is consistent with the fractionation of plagioclase, pyroxene and hornblende.

Tectonic and magmatic events

I) A basal clastic wedge was deposited on a discontinuous morphological surface of the Variscan metamorphic basement followed by sub-aerial deposition of distal ignimbrites.

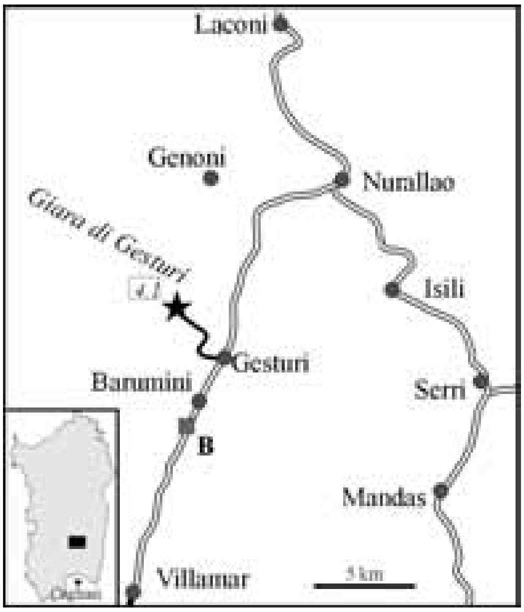
II) Early extensional phases in the southern part are associated with i) the deposition in an embryonic depression, probably not exceeding 1 km^2, of sands, clays and localised channelised conglomeratic intercalations and coal beds; ii) emplacement of small andesite plugs aligned SW-NE, feeding thin lava flows.

III) In the subsiding basin, the terrigenous deposition in alluvial–lacustrine and, locally, marsh environments is associated with huge andesite flows, preserving a general SW-NE alignment.

The asymmetric geometry of major andesite bodies mirrored the tectonic control over basin development. On the SE side, the lavas filling tectonic troughs reached thickness of up to 100 m, and flowed towards the NW in units attaining thicknesses of up to some tens of metres. The stratigraphic relationships between terrigenous sediments and lavas through time suggest a progressive propagation of the extensional tectonics towards the NE. Possibly at the same period, tectonic highs with an E-W alignment limited the basin to the north, while highs with a N-S alignment limited the basin to the west, and were associated with the emplacement of magma bodies that intruded the basement up to the sedimentary cover.

IV) The distal products of a conspicuous ignimbrite flow from the NW were deposited in the NE sectors of the basin above andesites and terrigenous sediments, which were at least temporarily exposed. The Seui-Seulo (trans)tensional basins rotated from a NE–SW to an approximately ESE–WNW trend, emphasised by subvertical NW-SE trending faults in the Sa Canna-Genna Aussa area.

V) A diorite intrusion marked the northern boundary of the basin. The intrusion has an E-W alignment and shows progressive fractionation from diorite to quartz-diorite. The main diorite body intruded both the basement and the overlying terrigenous cover, inducing localised thermal metamorphism.



Stop locations: 4.1 (a, b) - Giara di Gesturi.
B. Archaeological complex of Barumini.

A structural high, induced by the emplacement of cryptodomes within the basement, limited the Seui Basin to the west, which was thus separated from the Seulo Basin. The progressive growth of the domes, fed by progressively more acidic magma batches, developed a complex morphology characterised by mounds, and triggered the gravitational collapse of basement slices.

DAY 4

Giara di Gesturi

Stop 4.1a:

Cainozoic Magmatic Activity in Sardinia. The Basalts of the Giara di Gesturi.

A.M. Garau, G. Macciotta & M. Marchi

During the Cainozoic in Sardinia, there were two principal volcanic cycles, each having different characteristics and different geodynamic significance: the first, Oligo-Miocene, covered an area of about 10,000 km^2, prevalently in western Sardinia, with lava- and pyroclastic products of the *l.s.* calcalkaline series; the second, Plio-Quaternary, outcrops on an area of more than 2,000 km^2, with prevalently subalkaline to alkaline lava-products.

Oligo-Miocene Volcanism

Starting from the Early Oligocene and up to the Mid-Miocene, Sardinia underwent intense volcanic activity whose products were deposited within or at the edges of the *"*Fossa tettonica Sarda*"* (Vardabasso, 1962), extending from the Gulf of Asinara to the Gulf of Cagliari, reaching its greatest thickness (several hundred metres) in the Bosano (Deriu, 1962) and Logudoro regions. The genesis of volcanics, prevalently calcalkaline *s.s.* in character (Beccaluva *et al.*, 1989), with less common tholeiitic, high-K and shoshonitic products (Beccaluva *et al*., 1994), is linked to a subduction zone, with N-NW dip, which led to the spreading of the back-arc Ligurial-Balearic basin (Savelli *et al*., 1979 and references therein).

The first volcanics appeared in the south, in the Cixerri region (30.2±0.9÷28.3±1 Ma), with andesite lava flows, dacite domes and less common hypoabyssal bodies; at nearly the same time they also appeared in the north, at Alghero and Osilo (32.3±1.5 and 27.6±1.5, Ma) in the form of modest outcroppings of microdiorites and andesite lava flows, respectively (Beccaluva *et al.*, 1985 and references therein). Starting from 24 Ma, there was a highly explosive stage, with the emission of pyroclastic products whose chemical composition varied from dacitic to rhyolitic. According to Coulon, 1977, and Savelli *et al.*, 1979, the origin of these magmas is due to the anatexis of the granitoid continental crust, not excluding an origin due to fractionation of basic parental magmas. The period between 20 and 18 Ma witnessed the peak of another eruptive phase, with basic and intermediate subaerial lavas and subordinate pillow lavas and hyaloclastites (Maccioni, 1969). Subsequently, a new intermediate-acid phase occurred, with the emplacement of pyroclastic flows and lava-like ignimbrites, dating between 18 and 16-15 Ma (*e.g.* Logudoro-Bosano, Barigadu, Sulcis). Both effusive and explosive activity ended about 13-11 Ma ago, when the island's volcanic arc became inactive.

Plio-Quaternary Volcanism

After a period of relative tectonic stability and volcanic inactivity of about 5 Ma, a new volcanic cycle began, linked to the tectonic expansion involving the whole Sardinian-Tyrrhenian area between the Early Pliocene and the Late Pleistocene (Selli and Fabbri, 1971; Beccaluva *et al*., 1977). This volcanism, of an intra-plate type, gave rise to vast expanses of principally basic lavas, from subalkaline to alkaline (Macciotta *et al*., 1978) and both sodic and potassic.

Magmatic liquids, rising due to tectonic discontinuity pre-existing in the basement and re-activated during the Plio-Quaternary, gave rise to volcanism of a fissural type (Beccaluva *et al*., 1983). In general, the volcanics are only slightly differentiated, but more evolved products are found near Macomer (Deriu *et al*., 1974; Cinus, 1996), in Montiferro, at Mt. Arci and Capo Ferrato (Beccaluva *et al*., 1984).

The oldest products are found at Capo Ferrato (5.2±0.2 Ma; Beccaluva *et al*., 1985); volcanism subsequently extended to other parts of the island. Among the principal lava outcrops, we cite those in: Central-Southern Sardinia (3.84±0.25÷2.05±0.10 Ma; Assorgia *et al*., 1983); M. Arci (3.7±0.2÷ 2.7±0.15 Ma; Beccaluva *et al*., 1985); Montiferro (3.9÷1.6±0.2 Ma; *in* Massari and Dieni, 1973 and *in* Assorgia *et al*., 1981, respectively); the Campeda-Abbasanta-Planargia plateaux (3.7±0.2÷ 2.02±0.08 Ma; Beccaluva *et al*., 1977 and Macciotta and Savelli, 1984, respectively); the Orosei-Dorgali sector (3.90±0.50÷ 2.04±0.08 Ma; Beccaluva *et al*., 1983) and Logudoro, (3.06±0.19 ÷ <0.12 Ma; Macciotta and Savelli, 1984).

Figure 34 - Structural sketch map: AF = Arci Fault; FF = Fangario Fault; IF = Isili Fault; MVF = Mal di Ventre Fault; MF = Monastir Fault; NF = Nuoro Fault; OF = Omodeo Fault; SaF = Sarroch Fault; SF = Sinis Fault; SmF = Samassi Fault; VF = Villacidro Fault (after Casula et al., 2001, mod.).

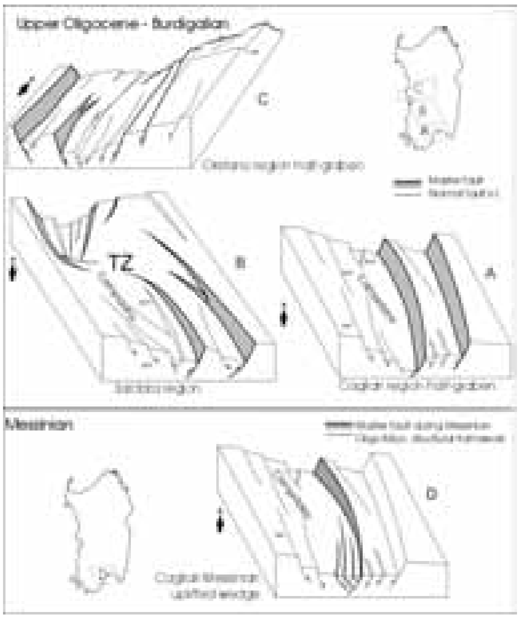


Figure 35 - Schematic block diagram of the Oligo-Miocene structure in the Campidano area. A: the southern Cagliari Region; B: the Sardara Region; C: the Oristano Region; D: Messinian structure in the southern Cagliari Region (after Casula et al., 2001, mod.).

The **Giara di Gesturi** is a plateau of about 42 km^2, roughly elliptical in shape, with its main axis oriented NW-SE; its upper part consists of basaltic lava flows with an average thickness of more than 30 meters. The two major elevations, Zeppara Manna (580 m a.s.l.) and Zepparedda (609 m a.s.l.), make up the only recognizable volcanic centres (2.76±0.11 and 2.05±0.10 Ma; Assorgia *et al*., 1983); petrochemical characteristics indicate alkaline affinity for the products of the former and subalkaline for those of the latter (Assorgia *et al*., 1983). Many hypotheses have been proposed (Lustrino, 2000 and references therein) on the petrogenesis of basalts with different serial affinity from the Marmilla-Gerrei area. Petrographically, the alkalibasalts are holocrystalline porphyritic with olivine, ±plagioclase, ±clinopyroxene phenocrysts; plagioclase megacrysts, gabbroic nodules and abundant peridotite nodules up to one decimeter in size are present. Subalkaline basalts are generally hypocrystalline, aphyric to porphyritic with plagioclase, olivine, ±clinopyroxene phenocrysts; locally abundant granoblastic quartz xenolits up to one decimeter in size are present.

Stop 4.1b:

The Cenozoic graben system and the

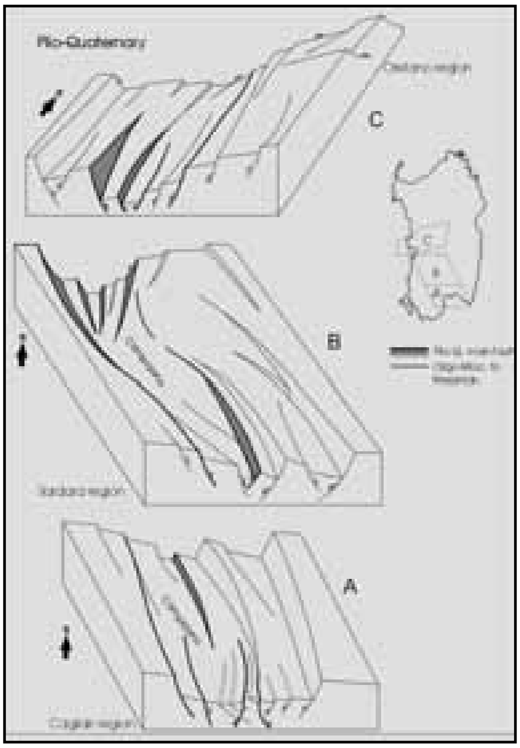


Figure 36- Schematic block diagram of the Plio-Quaternary structure in the Campidano area (after Casula et al., 2001, mod.).

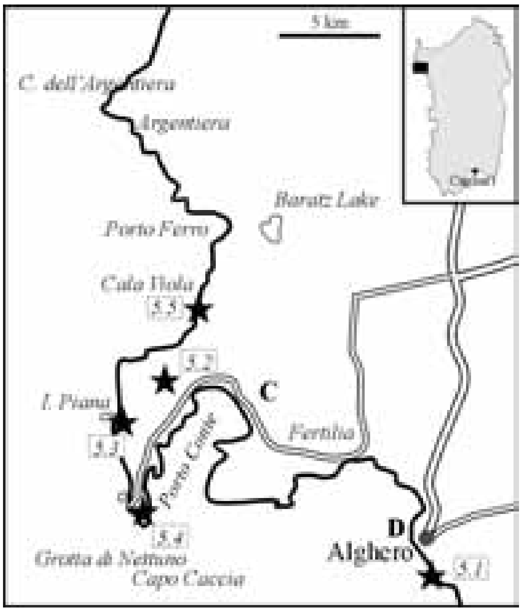
Plio-Quaternary Campidano Graben.

A. Cherchi & E. Sarria

The structural evolution of the Oligo-Miocene Rift system of Southern Sardinia is linked to the general geodynamic evolution of the Western Central Mediterranean. Thus, the extensional Late Oligocene-earliest Burdigalian event is a consequence of an "Apenninic" westward subduction process associated with a volcanic arc. Subduction terminated in the opening of the oceanic Provençal Basin and the rotation of Sardinia-Corsica during the Burdigalian (20-21 to 15-16 My). Within the complex system of Oligo-Miocene rifts of the Western Mediterranean area, the Sardinian rift represents the easternmost branch (Cherchi and Montadert, 1982; 1984 and reference therein); it crosses Sardinia longitudinally and continues offshore into the Gulf of Asinara to the North and the Gulf of Cagliari to the South. Syn-rift sedimentation reflects its initial evolution; it began with continental environment, marked along the margins by the continental to transitional clastic deposits of the Ussana Fm. (Pecorini and Pomesano Cherchi, 1969). The heterochronous transgression occurred during the Aquitanian and the Burdigalian (Cherchi *et al.,* 2002) and was controlled by both tensional tectonics and pre-transgressive volcanic morphology (Casula *et al*., 2001 and references therein).

Marine sedimentation in the basin continued into the Late Miocene (Late Tortonian - Early Messinian ages). Several volcanic events punctuated the evolution of the Sardinian Oligo-Miocene Graben system (Lecca *et al.*, 1997). To begin with, an important calc-alkaline Oligo-Miocene volcanism preceded the transgression and continued in a marine environment up to the Middle Miocene (see Garau *et al*., this volume).

The Southern Sardinia Oligo-Miocene Rift is a complex graben system characterized by a clearly asymmetric inner structure, with opposing-polarity half-grabens, each including several tilted blocks with an average 10-15° dip, separated by a transfer zone (Fig. 34). The latter is characterized by a transfer fault system and a central uplift with a complex structure that involves horst-type twist zones.



Stop locations: 5.1 – Punta del Lavatoio (Alghero); 5.2 – Porto Conte bay; 5.3 – Cala d'Inferno and Punta Malrepos; 5.4 – Capo Caccia peninsula; 5.5 – Cala Viola. C. (tourist) visit to the historical wine factory of Sella & Mosca (Alghero); D. Visit to the old city of Alghero.

During the Messinian, the N140°-160° shortening (Cherchi and Trémolières, 1984) produced inversion structures in the Southern Sardinia Oligo-Miocene rift

(Fig. 35; Casula *et al*., 2001; Cherchi *et al*., 2002).

The Plio-Quaternary Campidano Graben extends overland for about 100 km and is about 30 km wide, related to the formation of the Tyrrhenian Basin. It is restricted to the southern branch of the Oligo-Miocene basin (Casula *et al*., 2001; Murru *et al*., 2002), showing a NNW-SSE orientation ("Campidano trend"; Fig. 36).

About 600 m of syntectonic fluvio-deltaic continental sediments (Samassi Fm., Pecorini and Pomesano Cherchi, 1969) were deposited in the Campidano Graben, subsiding during the Middle Pliocene-Pleistocene interval.

Above these, important, thick, Pleistocene continental deposits lie, followed by Flandrian-Versilian marine and lagoon sediments (*e.g.* S. Gilla, Cagliari). Tyrrhenian deposits are limited inland, occurring principally along coastal areas.

DAY 5

Stop 5.1:

The Ladinian Muschelkalk of Punta del Lavatoio (Alghero)

R. Posenato, L. Simone & P. Pittau

This succession is a short segment (about 60 m thick) of the Ladinian Nurra Muschelkalk *Auct*.

The Punta del Lavatoio outcrop was described for the first time by Tornquist (1904; = *Südlich Alghero*). This pioneering phase ended with the works of Deninger (1907) and Oosterbaan (1936), who described the most important sections and fossils of the Triassic (Buntsandstein, Muschelkalk and Keuper) in the Nurra region. Recently, several authors have worked on this section (*e.g.* Gandin, 1978; Pittau Demelia and Flaviani, 1982b; Cherchi and Schroeder, 1985b; Bagnoli *et al*., 1985a, b; Posenato *et al*., 2002; Barca and Costamagna, 2002).

Lithology

Based on sedimentological and taphonomic observations (up-side-down position of many sedimentary structures, overturned geopetal infillings, spatial arrangement of the burrows, overturned shells in life position, among others), the succession appears to be overturned. From its base, cropping out at the top of the cliff, the succession can be divided into the following four units (Fig 37):

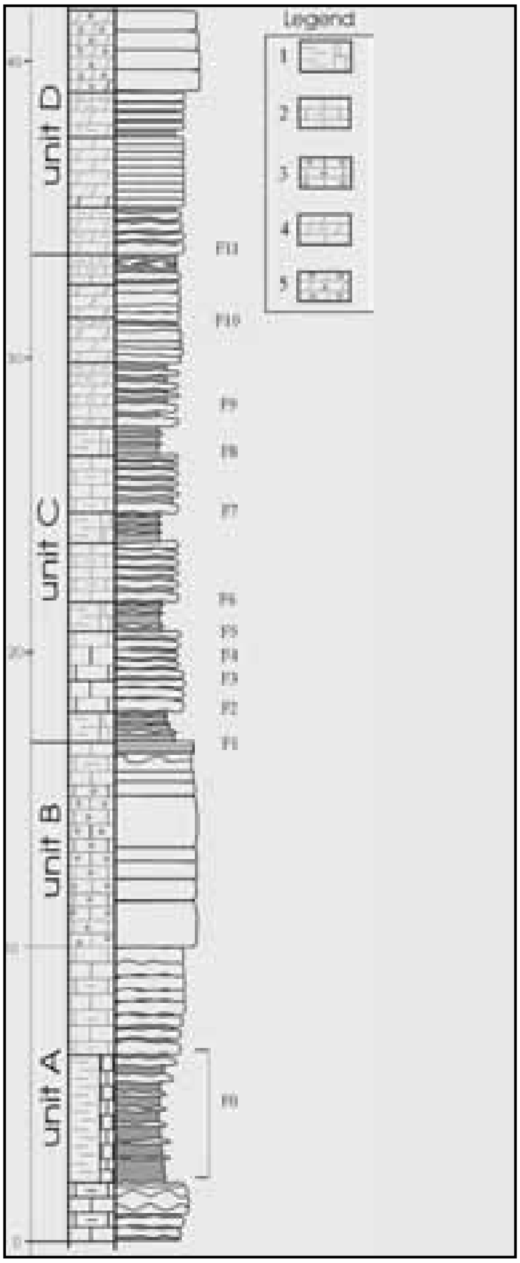


Figure 37 - Stratigraphic column of Punta del Lavatoio section. 1. claystone with mudstone/ wackestone lenses; 2. mudstone/ wackestone with thin claystone intercalations; 3. grainstone/ packstone; 4. dolostone and dolomitic claystone; 5. dolostone with re-crystallized clasts.

<u>Unit A</u> (10 m thick) is made up of a grey nodular limestone and marly limestone bank followed by yellowish claystone/marlstone with thin limestone intercalations. The limestone layers gradually increase in thickness upwards in the succession (downwards in the outcrop), where nodular limestone results as a response to the complex burrow network occurring at the top of the this unit. Diagenetic processes, both early

incipient submarine cementation and pression/solution-related processes, contributed to the nodularity of the bioturbated layers.

Unit B (5.6 m thick) is represented by massive grainstone banks varying in colour from pink to grey.

At the base, a pink bed yields abundant dasycladacean remains, which are well detectable in the field. In addition to some well-developed hummocky structures, bed geometries include cross lamination and soft sediment-related structures (e.g. convoluted and slumped laminae).

Unit C (17.3 m) is made up of grey nodular limestone and yellowish clay/marl intercalations. The clay/marl subunits are more and more dolomitized upwards. Composite beds locally characterize this interval with amalgamated layers. Impressive sole marks (among which spectacular flutes) occur at the base of the reversed beds, and very complex bioturbation networks characterize the bed-tops. This unit ends with a slumped bed, about 1 m thick (below bed F11).

Unit D (about 30 m) grey dolostone (flaser, see Gandin, 1978, Fig. 3b) and dolomitic claystone (1.70 m), grey dolostones and yellow-brownish dolomitic clays (3.5 m). Grey, granular and laminated dolostones with quartz grains (3 m); these layers range in thickness between 5 and 30 cm thick. Thin, centimetric layers of light brownish and hard dolomitic and silicified clays and grey dolostones, about 20 m thick (*fide* Gandin, 1978).

Palaeobiological content

The outcrop is famous for its rich mollusc content, which is dominated by bivalves with Germanic affinities.

Bivalvia. The majority of these are yielded by thin limestone layers, originating from storm accumulations, occurring in the basal clayey horizon F0 (unit A, Fig. 37). The most common species are *Hoernesia socialis*, *Plagiostoma* ? cf. *striatum* and *Enantiostreon difforme*. *Costatoria goldfussi*, *Placunopsis plana* and *Curionia gastrochaena* are less frequent, while *Septifer*? *eduliformis*, *Bakevellia subcostata*, *Costigervillia substriata* and *Pleuronectites laevigatus* are rare. Bivalves are also frequent in the storm accumulations of unit C, but here the taxonomical diversity strongly decreases. The most common species are *Hoernesia socialis* and *Costatoria goldfussi*; rare individuals of *Pleuromya musculoides* in life position have also been discovered (*e.g.* bed F6). Some fossiliferous beds yield only monospecific assemblages dominated by *C. goldfussi*, which is the only bivalve (and mollusc) species occurring at the top of the section.

Scaphopoda are represented by *Laevidentalium laeve*, which is frequent in the F0 horizon, while sparse occurrences are also detectable in unit C.

Gastropoda are rare and mostly represented by smooth internal moulds of turriculated shell (?*Loxonema* sp., horizon F0) and small sized naticoid shells, detected in thin sections from bed F7.

Cephalopoda. Tornquist (1904) identified two cephalopod horizons from Punta del Lavatoio (=*Südlich Alghero*). From the *obere Nodosen-Horizont* he cited, but never drew: *Ceratites muensteri*, *C.* sp., *Protrachyceras longobardicum*, and *Nautilus bidorsatus* (=unit A, Fig. 37); while only "*Ceratites* ex aff. *muensteri* Diener" was recorded from the *untere Nodosen-Horizont* (=unit C, Fig. 37). Tornquist's results have been recently discussed by Urlichs and Posenato (2002), who identified *Germanonautilus* sp. and two ammonoids of the Mediterranean-Arabic Province (=Sephardic Province): *Gevanites cornutus* and *Ceratites* (*Austroceratites*) cf. *toulonensis*.

Brachiopoda are represented by sparse and disarticulated shells of *Coenothyris vulgaris,* only found in unit A.

Foraminiferida and calcareous Algae (Dasycladaceans) were identified by Bagnoli *et al.* (1985b). Dasycladaceans are particularly frequent in the lower part of the pink grainstones banks of unit B.

Conodonta were studied by Bagnoli *et al*. (1985a), who described "*Epigondolella*" *truempyi*, *Algherella riegeli* and *A. uniformis*.

Palynomorphs were studied by Pittau Demelia and Flaviani (1982a, 1982b) The distinct hygrophytic character of the palynoflora highlights the establishment of wetlands (fern spores and Cycadopites grains) with the development of mangrove vegetation (*Aratrisporites* spp.); the influx of coastal salty marsh (*Triadispora* spp.) and inland coniferous plants (alete and monolete bisaccoid grains) is also high. *Uvaesporites gadensis* is the only correlative species with the Fassanian and Early Langobardian Alpine stages.

Fossil traces are abundant in the outcrop, as wide layer surfaces are exposed near the seaside. Despite their abundance, these fossils have never been studied in detail.

Age

The chronological position of the Punta del Lavatoio succession is mostly based on the conodonts and ammonoids, which suggest a Late Fassanian age (upper *curionii* Zone, Bagnoli *et al*., 1985a) or a Latest Fassanian - Early Longobardian (Posenato, 2002).

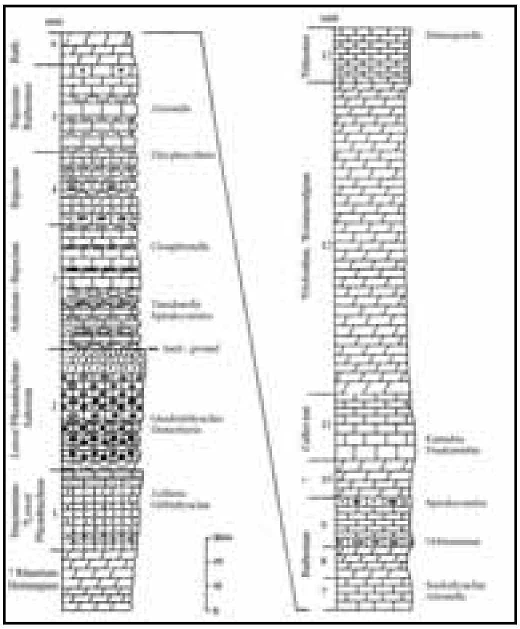


Figure 38 - Stratigraphic section summarising the Jurassic of the Nurra Region (after Cherchi and Schroeder, 1985c).

Stop 5.2:

Jurassic deposits of Porto Conte Bay.

A. Cherchi & R. Schroeder

This stop includes several outcrops that we will visit one after each other.

Through field-work carried out in the Mesozoic areas of Nurra, a preliminary subdivision of the Jurassic succession into 13 units (Cherchi and Schroeder, 1985c, 2002a), which will be briefly described, is possible (Fig.38). At the base of this succession are almost-unfossiliferous, partially-brecciated dolomites, which can be probably assigned to the uppermost Triassic (?Rhaetian) and the lowermost Jurassic (?Hettangian). At Mt. Timidone, the uppermost part of this succession contains echinoderms and pelecypods, indicating the establishment of a marine environment.

Unit 1 (Sinemurian-?Lower Pliensbachian) - Oolitic and bioclastic limestones (50 m). The oosparites and oncosparites with intercalated dolosparites can be assigned to an external platform. The unit is locally very rich in echinoderms, pelecypods, gastropods, corals and hydrozoans. The foraminifers are represented by *Amijiella amiji*, *Vidalina martana*, *Trocholina* sp., *Glomospira* sp., and nodosariid forms. A brachiopod association [*Zeilleria (Z.) quiaiosensis* and *Gibbirhynchia curviceps*], found at the top of the series (Faure and Peybernès, 1983), indicates a latest Sinemurian age. The series are overlain by a succession of limestones with detrital quartz grains (12-15 m). At the base, some levels have a microconglomeratic character (beach sediments). These detrital levels contain pectinids, brachiopods, corals, belemnites and ammonites. The microfauna is limited to small lituolid and ataxophragmiid forms, as well as Ammodiscidae, Textulariidae and Nodosariidae.

Unit 2 (Lower Pliensbachian- Aalenian) - Oncolitic and oolitic limestones (70-100 m) can be lithologically subdivided into three subunits (from bottom to top):

A) Marls and marly limestones (30-40 m). The uppermost part frequently contains oncoids, and is rich in corals, pelecypods, gastropods, brachiopods, and echinoderms. The basal part contains the brachiopods *Gibbirhynchia curviceps?* and *Zeilleria (Cincta) numismalis,* indicating an Early Pliensbachian age. The upper part (Mt. Timidone) has yielded some ammonites of the Late Toarcian: *Hammatoceras?* sp., *Dumortieria subundulata, D. explanata*., and *D. sparsicosta* (upper part of the *pseudoradiosa* zone, Chabrier and Fourcade, 1975; Faure and Peybernès, 1983).

B) Oncoid limestones (30-40 m), rich in pelecypods and echinoderms. The nuclei of the oncoids are frequently surrounded by *Tubiphytes morronensis*. A second level with detrital quartz grains has been locally found in the uppermost part.

C) Oolitic limestones (10-20 m.). This almost-unfossiliferous oosparitic series shows frequent cross-bedding; its basal part is dolomitized. The upper surface of this subunit shows a well-developed hard-ground.

Unit 3 (Aalenian - Bajocian) - The lower half consists of an alternation of marls, marly limestones and bioclastic limestones (packstone and grainstone), sometimes showing birdseyes. The upper part of this lower series contains larger foraminifera indicating an Aalenian age: *Timidonella sarda, Spiraloconulus giganteus*, *Lucasella* n. sp., *Biokovina* cf. *gradacensis* and the dasycladacean alga *Sarfatiella dubari*. The upper part locally shows dolomitized algal laminites (Mt. Timidone) and exceptionally, grey lacustrine deposits (Mt. Doglia). The microproblematicum *Thaumatoporella parvovesiculifera* is not rare within this series; the foraminifers are represented by Ammodiscidae, *Ammobaculites* sp., *Haurania* sp., *Pseudcyclammina ukrainica* and Nodosariidae.

At Mt. Timidone a marly level within the uppermost part of this unit (15 m below the top) has yielded the ostracod genera *Cloughtonella* and *Looneyella* (?), suggesting a Bajocian age.

Unit 4 (Bajocian) - Alternation of frequently cross-bedded oolitic limestones (grain- and packstone) and marls (50-70 m). This unit is mainly characterized by its high quartz-grain content. It is relatively poor in microfossils. At Mt. Timidone a marly level, situated near the top of the unit, has yielded the ostracod genera *Ektyphocythere* and *Kirtonella,* suggesting a Bajocian age.

Unit 5 (Bajocian - Bathonian) – Well-bedded micritic limestones: mud- and wackestones with peloids, intraclasts and bioclasts (60-80 m). Mainly the lower and middle part of the unit contains some thick marly levels rich in *Pholadomya* sp. Towards the top the limestones become more massive and oncolitic; the uppermost part is dolomitized. This unit is very rich in macrofossils: sponge spicules, solitary corals, lamellibranches, gastropods (mainly nerineids), terebratulids, echinoderms, bryozoans. The foraminifers are mainly represented by *Mesoendothyra croatica* and *Haurania amiji*. The presence of *Alzonella cuvillieri* in the middle part indicates a Bathonian age.

Unit 6 (Bathonian) - Dark-brownish massive dolomites (30-40 m). The generally very monotonous and unfossiliferous succession has yielded at Mt. Doglia some “phantoms” of ooids and biserial foraminifers. The stratigraphical position suggests a Bathonian age.

Unit 7 (Bathonian) - Micritic limestones (mudstone and wackestones, 12-20 m), the lower part containing frequent birdseyes. At Mt. Pedrosu and at Mt. Doglia an oolitic level has been observed in the middle part. In the uppermost layers the lituolid foraminifer *Alzonella cuvillieri*, indicates the Bathonian. A very important horizon containing the brachiopod *Sardorhynchia crassa* is situated at the top of the unit.

Unit 8 (Bathonian) - Darkly weathered, yellowish-brown and almost unfossiliferous dolomites (20-40 m: Maristella, Mt. Zirra and at Mt. Doglia). The stratigraphical position suggests a Bathonian age.

Unit 9 (Upper Bathonian) – The lowermost part of this unit (25 m in the region south of Maristella and 50 m at Mt. Doglia), consists of thick-bedded calcarenites with oncoids, bioclasts, and intraclasts, and contains a relatively rich microfauna indicating a Late Bathonian age, characterized by *Orbitammina elliptica*, *Trocholina palastiniensis* and the microproblematicum *Koskinobullina socialis*. At Mt. Pedrosu the upper part of the unit consists of peloidic, oolitic and intraclastic wacke- and packstones, which have yielded the lituolid foraminifer *Spiraloconulus giganteus.*

Unit 10 (?Bathonian, ?Callovian) - Darkly weathered, yellowish-brown dolomites, well-bedded at their base and becoming massive towards the top (20 m at Mt. Pedrosu, 40 m at Mt. Doglia). The age of this unfossiliferous dolomite is uncertain; it is underlain by Upper Bathonian limestones and overlain by the Callovian Unit 11.

Unit 11 (Callovian) - Micritic limestones (mud- and wackestone), being relatively massive in its lower part, but well bedded in its upper part. At Mt. Pedrosu this unit has a thickness of 55 m. Its lower half is very fossiliferous, frequently containing *Cladocoropsis mirabilis,* corals and bivalves, which are sometimes encrusted by *Tubiphytes morronensis*. Abundant benthic Callovian foraminifers are present: *Valvulina lugeoni*, *Praekurnubia crusei*, *Kurnubia palastiniensis*, *Nautiloculina oolithica*, *Trocholina gigantea* and *Chablaisia chablaisensis*.

Unit 12 (?Oxfordian, ?Kimmeridgian) - This unit (200-250 m) is exposed at the steep western coast of Capo Caccia. It consists of sometimes brecciated dolomites. Some early diagenetic dolomitic levels are laminated (?algal mats), showing birdseyes. The age of this unit is uncertain; it can be indirectly deduced from the under- and overlying fossiliferous limestones Units 11 and 13.

Unit 13 (Tithonian) - Well-bedded limestones (40–50 m) are exposed at the steep western coast of Capo Caccia. Some early diagenetic dolomitic layers are intercalated in the basal part. The middle and upper part of the succession shows some thin-bedded marly layers. The generally very homogeneous micritic limestones sometimes contain lithoclasts, bioclasts, peloids and, rarely, birdseyes. In the lower part the dasycladacean algae *Clypeina jurassica*, *C. solkani*, *Salpingoporella annulata*, and *Actinoporella podolica* are present; the upper part contains miliolids, *Ophtalmidium* sp., *Trocholina alpina*, and the coprolite *Favreina prusensis.* The presence of charophytes in the uppermost part of the succession indicates the gradual transition from marine environments to the subsequent lacustrine Berriasian.

Stop 5.3:

Cala d’Inferno: geological overview.

Punta Malrepos: Urgonian transgression on the Purbeckian facies.

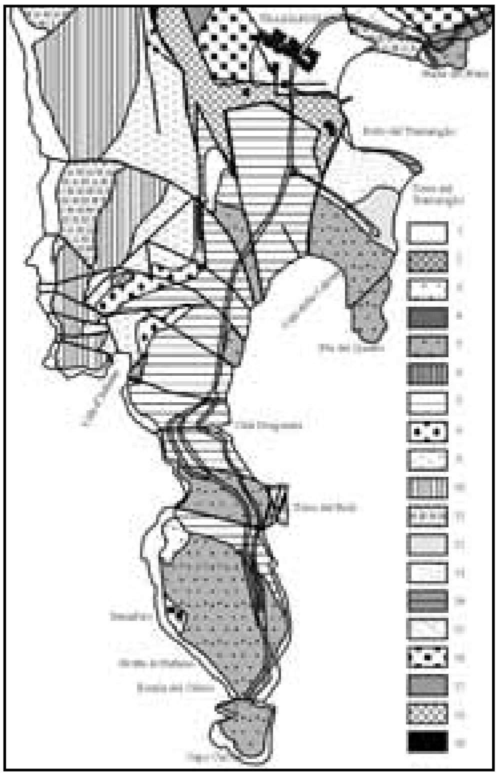


Figure 39 - Geological map of the Capo Caccia region (after Cherchi and Schroeder, 1985d).

A. Cherchi, R. Schroeder & L. Simone

This stop is split in two different outcrops, Cala d’Inferno and Punta Malrepos.

Cala d’Inferno, a small bay on the west side of the Capo Caccia peninsula, owes its origin to the erosion of the Purbeckian marls, which are situated between the hard and well-bedded Tithonian limestones forming the cliff to the west and the escarpment of the massive Urgonian limestones (Punta Malrepos) to the east (Figs 39, 40A, B). Maxia and Pecorini (1963) recognized the existence of a marly Purbeckian facies with ostracods and algae at Cala d’Inferno. After that Pecorini (1972) documented the dasycladacean algae occurring in marine intercalations within the Purbeckian facies and established the microproblematicum *Lacrymorphus catenaeformis sardus* n. subsp.

The following units can be observed (Cherchi and Schroeder 1985c, d; 2002a):

1. Dolomites (Oxfordian – Kimmeridgian). The cliff forming the western part of the steep coast consists, at its base, of grey to dark, sometimes brecciated and nearly unfossiliferous dolomites.

2. Limestones (Tithonian-Lower Berriasian). The dolomites mentioned before are overlain by well bedded, hard micritic limestones (45 m), forming the cliff west of Cala d’Inferno. The fossil content, mainly consisting of dasycladaceans and foraminifers, increases towards the top of the succession. In the lower part, the dasycladaceans algae *Clypeina jurassica*, *C. solkani*, *Salpingoporella annulata*, and *Actinoporella podolica* are present; in the upper part miliolids, *Ophtalmidium* sp., *Trocholina alpina*, and the coprolite *Favreina prusensis* have been found. The upper part of these limestones contains some marly, charophyte-bearing intercalations, indicating the gradual transition from the marine environment to the subsequent lacustrine Purbeckian facies.

3. Marls and marly limestones (Berriasian). The contact between the above limestones and the stratigraphically-next Purbeckian succession is a nearly vertically-directed faulted zone (Fig. 40B),

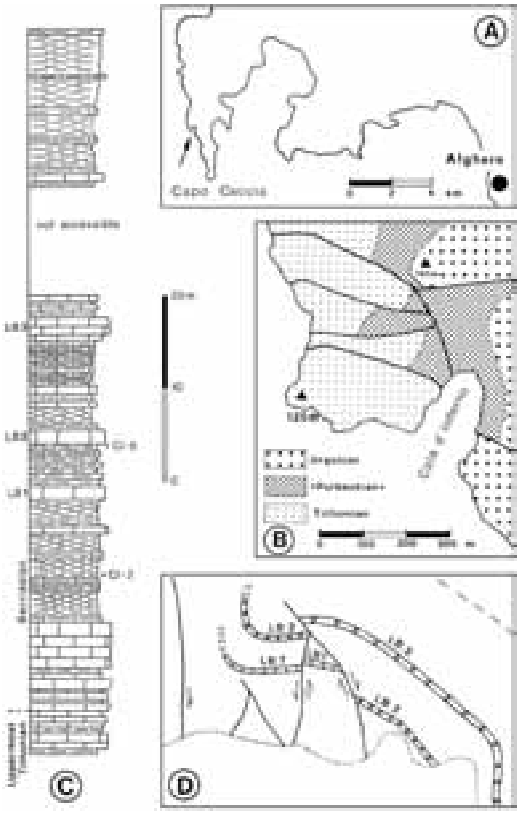


Figure 40 - Cala d’Inferno A. Location (arrow); B. Geological sketch; C. Stratigraphical section of the Purbeckian series; D. tectonics within the Purbeckian (after Cherchi and Schroeder, 2002b).

so that the transition between these two units cannot be observed at this locality. The lower part of the Purbeckian beds (30 m) consists of predominantly lacustrine, green-greyish or light-grey marls or marly limestones, in part unfossiliferous, but frequently very rich in charophytes and ostracods. The upper part of this subunit is marked by a 1.5-m-thick, yellowish marly limestone bank (horizon LB 2; see Fig. 40B). A second key horizon is a hard and dark grey-brownish limestone ledge (1.5 m thick), which is situated approx. 7 m below the top of the subunit; it is characterized by abundant charophyte remains (horizon LB 1). A light-grey, soft marly bed, situated approx. 17 m below the top of the lower subunit of the Purbeckian succession, has yielded the ostracod *Fabanella boloniensis*. Yellowish marly limestones with abundant charophytes and ostracods, situated immediately at the base of the key horizon LB 2 (= top of the lower subunit of the Purbeckian), contain the following taxa:

Charophytes: *Musacchiella maxima*, *Flabellochara* aff. *grovesi*, *Perimneste micrandra*, *Globator nurrensis*.

Ostracods: *Cypridea tumescens meridionalis*, *C.* cf. *vidrana*, *C.* cf. *protogranulosa*, *C. dorsoinclinata*, *Theriosynoecum sardum*, *Dictyocythere* gr. *mediostricta*, *Protocythere* cf. *divisa*. This horizon is the type level of the ostracods *Cypridea tumescens meridionalis*, *C. dorsoinclinata* and *Theriosynoecum sardum*.

The upper part of the Purbeckian deposits (45 m) consists of grey-greenish, detritic, sometimes pseudoolitic marls, marly limestones and hard limestones. This part is characterized by numerous, relatively short, brackish or marine intercalations, which become more frequent towards the top of the succession.

4. Basal Urgonian limestones (uppermost Berriasian? – lowermost Valanginian). The Purbeckian beds are overlain by hard Urgonian limestones; their basal part forms a well-marked morphological ridge running up to Punta Malrepos.

With reference to the age of the above-mentioned units the following remarks can be made. Dolomites (unit 1) at the base of the steep coast can be indirectly deduced from the under- and overlying fossiliferous limestone as Oxfordian – Kimmeridgian. The dasycladaceans association (unit 2) indicates a Tithonian to Early Berriasian age. Near Punta Cristallo, in the transitional beds between the marine unit 2 and the lacustrine Purbeckian (unit 3), the dasycladacean algae *Salpingoporella annulata* and *Heteroporella lemmensis* are present. The transition between units 2 and 3 took place at the Tithonian - Berriasian boundary. The age of the lower part of the Purbeckian (unit 3) can be specified by the ostracod fauna and the charophytes. *Fabanella boloniensis* (sample CI-2; see Fig. 40C) appears in the Berriasian and ranges up to the Aptian. The ostracod fauna of sample CI-5 is of Berriasian age. The charophyte assemblage of sample CI-5 lacks elements of the early Berriasian flora; this association has been attributed to the late Berriasian. The age of the terminal Purbeckian beds (unit 4) and the basal part of the overlying Urgonian is described below.

Punta Malrepos (141 m) is the highest elevation of the basal Urgonian limestones cropping out as a marked ridge to the east and north of Cala d'Inferno (Figs 39, 40B). The Purbeckian cropping out immediately west of Punta Malrepos is tectonically strongly reduced. Generally, it consists of marls and marly limestones, rich in ostracods and charophytes. The upper part of this series is characterized by occasional, relatively short, marine intercalations within the lagoonal sediments, which can be interpreted as episodic storm deposits. These intercalations forecast the successive continuous neritic milieu of the Urgonian (Cherchi *et al*., 2002).

One of these intercalated marine levels is located some meters above the base of the Urgonian. It refers to a 10-cm-thick grainstone bank containing a large quantity of reworked greenish Purbeckian material. This bank is very rich in dasycladaceans and foraminifers.

Algae: *Arabicodium* cf. *jurassicum*, *Cayeuxia* sp., *Sarfatiella sarda*, *Actinoporella durandelgai*, *Salpingoporella* sp.

Foraminifera: "*Cribellopsis* sp.", "*Trochamminidae* n. gen.", Miliolidae, *Nautiloculina bronnimanni*, *Trocholina* cf. *sagittaria*, *T.* sp. Other microfossils: *Favreina* sp., *Aeolisaccus dunningtoni*.

Resting on the grey-greenish marls with charophytes from the topmost levels of the Purbeckian, neritic calcareous deposits (Urgonian facies) appear. A detailed study of these limestones shows the main sedimentological and micropaleontological aspects characterizing the Valanginian transgressive event. The transition from the brackish, lacustrine-lagoonal sediments of the Purbeckian facies to the subsequent open-marine sediments is gradual. As we have seen, the former show repeated intercalations of grainstones (episodic contributions by storms) made up of benthic

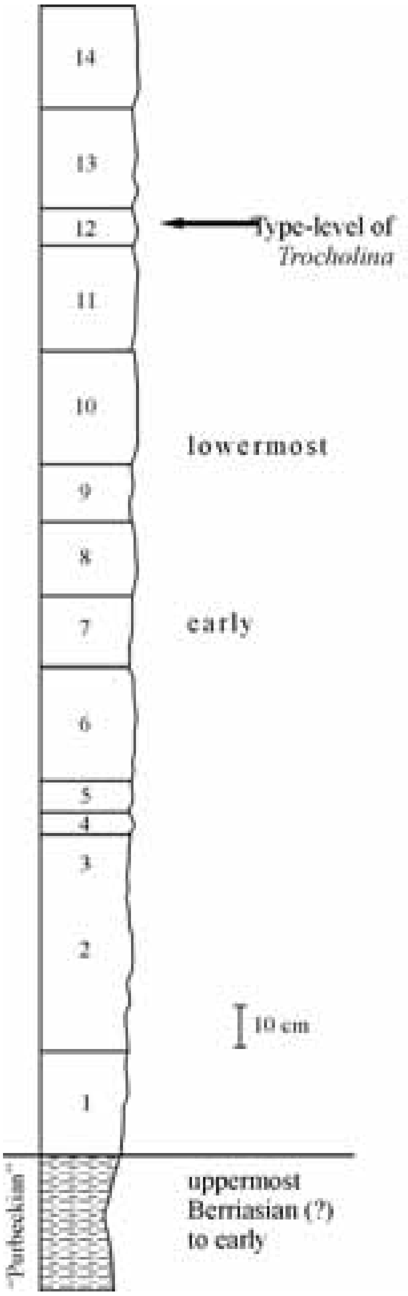


Figure 41 - Section of the uppermost Berriasian? to early Valanginian (after Cherchi et al., 2002).

marine skeletal grains plus rounded intraclasts, rich in green algae, benthic foraminifers and bioeroded pelecypods and echinoderms. The studied outcrop (beds 1 to 14; altogether approx. 3 m; see Fig. 41) show from the bottom to the top the following succession. Pellettiferous wackestones are characterized by a slight lamination and dolomitization (beds 1-2). These partially dolomitized limestones contain pelecypods, rare miliolids and *Nautiloculina bronnimanni*. Wackestones-packstones with rounded intraclasts and a few benthic skeletal grains follow (bed 3) and pass to bioclastic packstones (green algae, benthic foraminifers, ostracods, pelecypods and echinoderms). The first significant marine contributions (upper part of bed 3, lower part of bed 4) are represented by *Macroporella embergeri*, *Nautiloculina bronnimanni*, *Trocholina* sp., Miliolidae, which contribute to form graded packstones-grainstones. A thin level of silty wackestones-mudstones with rare ostracods (upper part of bed 4) seems to end the fresh water influx preluding the bio-intraclastic grainstones containing large clasts of the above mudstones with gastropods and echinoderms and few superficial ooids (bed 5). Micropaleontological content is similar to the preceding bed (number 4). Large to very large rounded intraclasts and minor, rounded and bioeroded skeletal fragments characterize the following deposits (beds 6-7). They change from silty, mud-supported to grain-supported sediments, whose palaeontological content does not change compared to the underlying bed (number 5). Packstones-grainstones follow, in which rounded intraclasts and bioclasts, peloids and coated grains have been found (beds 8-9). No changes in the palaeontological content occur. Upwards in the succession, clean bio-, intraclastic grainstones follow. The benthic components become richer and variated. Green algae, benthic foraminifera, bryozoans, gastropods, and serpulids characterize these grainstones and still show well-rounded, sharp and abraded margins; in addition, large bioeroded intraclasts and pelecypods are recognizable (bed 10). In the subsequent layers, coarse grainstones and packstones (beds 11-14) among the benthic foraminifer *Trocholina cherchiae* becomes particularly abundant. Bed 10 is the type-level of this species. These foraminifers are frequently at the core of well-rounded, muddy intraclasts associated with superficial ooids. Ooid-rich grainstones characterize the top of the studied interval. From the above observations, evidences of repeated and locally-intensive reworking episodes can be recognized in a depositional setting, in which oolitic and bioclastic shoals were formed during a progressive increase of the water energy. In the following we present a list of the microfossils found in the studied intervals:

Algae: *Macroporella embergeri*, *Salpingoporella annulata*.

Foraminifera: *Glomospira* sp., “Trochamminidae n. gen.”, *Choffatella pyrenaica*.
Miliolidae, *Nautiloculina bronnimanni*, *Trocholina cherchiae, T.* cf. *sagittaria*, *Melathrokerion* cf. *valserinense.*
Microproblematica: *Koskinobullina* cf. *sarda*, *Aeolisaccus dunningtoni*.

The marine intercalation within the uppermost part of the Purbeckian series does not contain any important marker which could give a precise age. *Actinoporella durandelgai* was correlated to the Berriasian – early Valanginian of the eastern Betic Chains (S. Spain). In the Spanish Pyrenées, *Nautiloculina bronnimanni* appears in the Late (?) Berriasian. The orbitolinid section can be assigned to the Late Berriasian and Early Valanginian of the Southern Jura Domain (France). All these data suggest an uppermost Berriasian (?)–Early Valanginian age for the studied marine intercalation.

The stratigraphically most important species of the foraminiferal association in the lowermost 40 m of the overlying Urgonian series is the orbitolinid *Valdanchella miliani*. This species occurs in southern France (Provence) together with *Pfenderina neocomiensis*, *Pseudocyclammina lituus* and *Pseudotextulariella salevensis*. in the Early Valanginian (dated by ammonites and calpionellids), and actually it is regarded as an excellent marker of this stratigraphic interval. At Punta Malrepos, the studied basal Urgonian section with abundant Trocholinas is located below the *Valdanchella miliani* beds (Chabrier and Fourcade, 1975; Azèma *et al*., 1977). Also on the Island of San Antioco (SW Sardinia), a level with rare *Valdanchella miliani* is underlain by micritic limestones (35 m) containing abundant “*Trocholina alpina*” (=*T. cherchiae*?); above the middle part of these limestones, Early Valanginian calpionellids have been found. On the basis of all this data it becomes clear, that the installation of the Urgonian platform in both regions started in the Early Valanginian.

Stop 5.4:

Transgressive Coniacian on the Urgonian. Santonian limestones in the Capo Caccia peninsula.

G. Carannante, A. Cherchi, R. Schroeder & L. Simone

This stop includes two different outcrops.

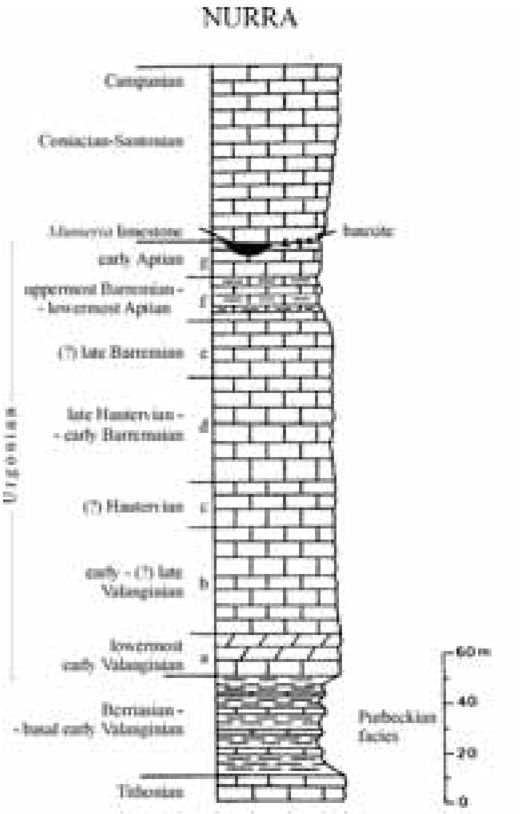


Figure 42 - Schematic stratigrasphic section of the Cretaceous of Nurra (after Cherchi and Schroeder, 1985c, mod.).

Pecorini (1965) described the transition between the Early and Late Cretaceous in the Capo Caccia peninsula. In the road cut on the surface of the Urgonian (dated as Upper Barremian or Lower Aptian) he observed pockets filled with bauxite. At the base of the Late Cretaceous (dated as Turonian-Senonian) he found a breccia of dark-grey limestone pebbles containing *Munieria baconica*, *Planorbis* and *Valvata*. The first biostratigraphical analysis of this outcrop was published by Cherchi and Schroeder (1985e). Later on, the series was redescribed by Carannante *et al.* (1995a, 2002). The outcrop can be subdivided (Fig. 42) as follows (from bottom to top):

1. Pre-bauxite substratum limestone made up of massive, light grey to beige bioclastic grainstones of Urgonian facies with slightly opaque, originally aragonite marine cements. Among the bioclasts, corals, hydrozoans, chaetetids, pelecypods, echinoids, benthic foraminifera (Orbitolinidae rich assemblages) and green algae are particularly abundant. The bioclasts show frequently bioeroded margins. In the uppermost intervals, a silty matrix may be present. The dissolution of originally aragonite shells and the occurrence of clear calcite cement are detectable. The rich microflora and –fauna of the uppermost 10 m of

the series contain the following taxa (Cherchi and Schroeder, 1985e).

Algae: *Heteroporella* (?) *paucicalcarea*, *Praturlonella danilovae*, *Salpingoporella genevensis*, *S. muehlbergii*.

Foraminifera: *Earlandia* (?) *conradi*, *Glomospira urgoniana*, *Rheophax* (?) *giganteus*, *Arenobulimina* sp., *Nezzazatinella macovei*, *Pseudolituonella gavonensis*, *Choffatella decipiens*, *Praereticulinella cuvillieri*, *Paracoskinolina maynci*, "*Paracoskinolina*" *hispanica*, *Paleodictyoconus cuvillieri*, "*Orbitolinopsis*" *flandrini*, *Orbitolinopsis debelmasi*, *O. subkiliani*, *Montseciella algherensis*, *Valserina* sp., *Eygalierina turbinata*, *Cuneolina hensoni*, *C.* aff. *laurentii*, *Nummoloculina* sp., *Quinqueloculina histri*, *Derventina filipescu*, *Nautiloculina cretacea*, *N. bronnimanni, Trocholina* sp.

2. A fracture network, with superimposed karst phenomena, is observed at the top of the Urgonian limestones. Reduced, whitish, pellettiferous bauxite and angular Urgonian fragments fill this cavity system.

3. The Urgonian limestones are disconformably overlain by transgressive Upper Cretaceous limestones beginning with a discontinuous level of breccia (up to 1 m thick). The elements of this breccia are mainly blackish angular calcareous clasts and reworked bauxite fragments. The black fragments contain fresh-water gastropods, abundant charophytes (*Munieria grambasti sarda*) and/or thin-shelled miliolids. All these elements are embedded in a mud-silty matrix with larger miliolids and *Dicyclina* sp. In adjacent areas (Punta del Frara), along the sea coast, black lacustrine-brackish to schizohaline limestones, rich in fresh-water gastropods and charophytes (*Munieria grambasti sarda*), crop out still preserved in lens-shaped bodies, up to 7 m thick, resting on eroded, dolomitized Jurassic limestones (Bathonian in age) and on their bauxite cover, underlying, through a bioeroded and fissured hard-ground, the Coniacian rudist limestones (Cherchi *et al*., 1981).

4. Senonian stratified bioclastic, grey to beige or blue-greyish limestones follow. Approx. 5 m above the base of these limestones a sample has yielded the following foraminifers (Cherchi and Schroeder, 1985e): *Flabellocyclolina laevigata*, *Martiguesia cyclamminiformis*, "*Choffatella*" *rugoretis*, *Orbitolinopsis senonicus*, *Dictyopsella kiliani*, *Cuneolina conica*, *Dicyclina schlumbergeri*, *Rotalia reicheli*. On the basis of rudist and foraminifer assemblages these limestones are Coniacian in age (Philip *et al*., 1978; Cherchi and Schroeder, 1985e). In this interval a sharp change in the lithofacies occur (Carannante *et al*., 1995b): after about 5 m of wackestones, rich in benthic foraminifers (miliolids, *Dicyclina*, *Cuneolina*), green algae, echinoids, pelecypods and a few corals, grainstones and rare packstones, with a silty matrix, trend to prevail. In the latter, coralline red algae (*Sporolithon*) and bryozoans can be episodically very abundant. The subsequent Santonian limestones are made up essentially of bioclastic grainstones and locally show cross lamination. Echinoids and benthic foraminifers (which still include very large miliolids and *Lamarmorella sarda*) increase; bryozoans and red algae, which may form small rhodoliths, become dominant, while the green algae totally disappear. In the upper part of this sequence, nearly 45 m above the base of the Cretaceous limestones, a level containing large radiolitids occurs, embedded in a matrix of bioclastic grainstones (rudist floatstones). Calcarenites situated approx. 20 m above the base of the Late Cretaceous have yielded the larger foraminifers (Cherchi and Schroeder, 1985e) *Broeckinella neumannae*, *Cuneolina conica* and *Rotalia reicheli*. Bioclastic calcarenites, situated approx. 43 m above the base of the Late Cretaceous and 2 m below the before-mentioned level of large radiolitids, contain the foraminifers: *Dictyopsella kiliani*, *Pseudocyclammina sphaeroidea*, *Dicyclina schlumbergeri*, *Lamarmorella sarda*, *Vidalina hispanica*, *Nummofallotia cretacea*, "*Nonion*" *senonicus*, *Rotalia reicheli*.

The orbitolinid fauna of the uppermost 10 m of the Urgonian cropping out at the road to Capo Caccia is characterized by *Montseciella algherensis* and *Eygalierina turbinata*. These species indicate an early Barremian age (Cherchi and Schroeder, 1985e; 1999). The lacustrine-brackish *Munieria* limestone was deposited after the ante-Cenomanian tectonic movements and before the ingression of the Coniacian sea. A Turonian age for these limestones may be envisaged; however, we cannot completely exclude that they were already deposited in Cenomanian times. According to Philip *et al*. (1978), the basal portion of Late Cretaceous limestones overlying the bauxite and the lacustrine *Munieria* limestone, respectively, contains a biostrome with *Vaccinites giganteus*, *Vaccinites moulinsi* and *Radiolites* cf. *sauvagesi*; this assemblage is characteristic of the Coniacian. The occurrence of *Orbitolinopsis senonicus*, situated 5 m above the base of the Late Cretaceous, also indicates a Coniacian age. The foraminiferal associations of the two before-mentioned levels, situated approx. 20 m and 43 m, respectively, above the base of the Late

Cretaceous, are of Santonian age. This site shows well the evolution of the area during Barremian-Santonian times. The following events can be distinguished (Fig. 42):

- Deposition of the Urgonian limestones at least ranging to the Lower Aptian (at the neighbouring Torre del Bulo; Cherchi and Schroeder, 1985e).
- Weak folding during the Albian (Cherchi and Tremolières, 1984) leading to widespread emersion and a subsequent karstification with deposition of bauxite.
- Formation of lacustrine-brackish to schizohaline *Munieria* limestones indicating the first Late Cretaceous transgressive phases (Cherchi *et al.*, 1981).
- Emersive episods leading to complex erosive surfaces and reworking of the blackish *Munieria* limestones (Pecorini, 1965).
- Coniacian transgression and deposition of a discontinuous level of breccia, which filled the surface karst morphology and related fissures (Cherchi and Schroeder, 1985e).
- Early Senonian evolution from neritic limestones characterized by chlorozoan assemblages and few non-skeletal grains to foramol *sensu lato* bioclastic grainstones (Carannante *et al*., 1995b, 2002).

In drillings in Eastern Nurra, marine Campanian sediments have been discovered (Cherchi and Schroeder, 1995).

In the cliff that bounds the northern side of the Capo Caccia Promontory, along the narrow trail and the steep stairs going from the “Grotta di Nettuno” to the corresponding parking area, Senonian limestones disconformably cover the Urgonian substratum. Weak ante-Cenomanian folding led to a widespread emersion and a subsequent karstification with deposition of bauxite (Pecorini,1965; Cherchi and Schroeder, 1995; Philip *et al*., 1978; Carannante *et al*. (1995a, b). Here, the first meters of the Lower Senonian succession are characterized by strongly packed rudists, in which Philip *et al*. (1978) recognized: *Vaccinites giganteus*, *Biradiolites* cf. *angulosus*, *Radiolites* cf. *sauvagesi*, *V. moulinsi*. The uppermost part of the Scala del Cabirol crosses some meters of limestone, which are rich in the miliolid larger foraminifer *Lamarmorella sarda*.

Stop 5.5:

Permian and Triassic deposits at Cala Viola - Torre del Porticciolo.

G. Cassinis, M. Durand, D. Fontana, C. Neri, P. Pittau, A. Ronchi, C. Stefani.

Stratigraphy

For more than a century the Upper Palaeozoic-Lower Mesozoic continental succession of Nurra (Fig. 43) attracted the interest of many researchers for its spectacular outcrops (*e.g.* Pecorini, 1962; Vardabasso, 1966; Gasperi and Gelmini, 1980) and its subsurface deposits (Pomesano Cherchi, 1968; Pittau, 2000). Recently, detailed stratigraphical, sedimentological and petrographical studies have focused on the Permian-Triassic siliciclastic and volcanic deposits of the region, and on its correlation with the coeval succession of Provence, Southern France (e.g. Cassinis *et al*., 1996, 2002, 2003; Cortesogno *et al*., 1998; Fontana *et al*., 2001).

According to the above-mentioned studies, the post-Variscan continental record of Nurra may be subdivided into three distinct tectono-sedimentary cycles (Fig. 44).

The oldest cycle, dated to the Autunian on the basis of its mega- and microfloras, consists of a thin (15-20 m) fluvio-lacustrine unit (Punta Lu Caparoni Fm.), interfingered and locally covered by volcanic products of presumed calc-alkaline affinity. *Autunia conferta*, *Ernestiodendron filiciforme*, *Otovicia hypnoides, Rachiphyllum lyratifolia*, *Remia pinnatifida, Walchia piniformis*, are the most significant taxa.

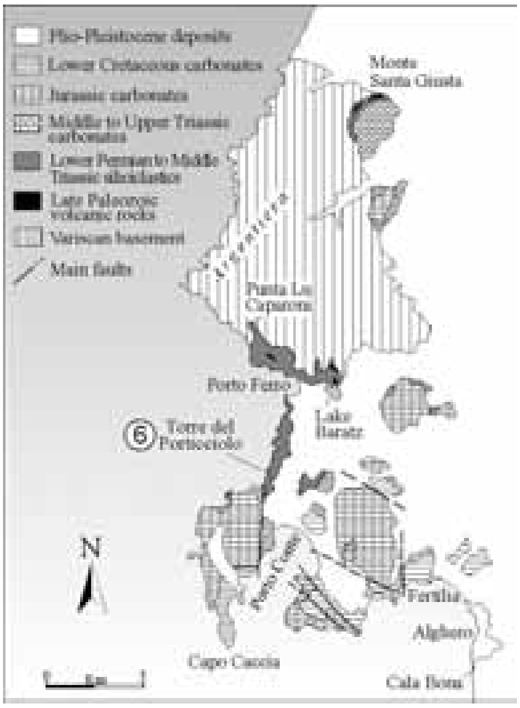


Figure 43 - Location of the Permian and Triassic continental siliciclastic deposits of Nurra.

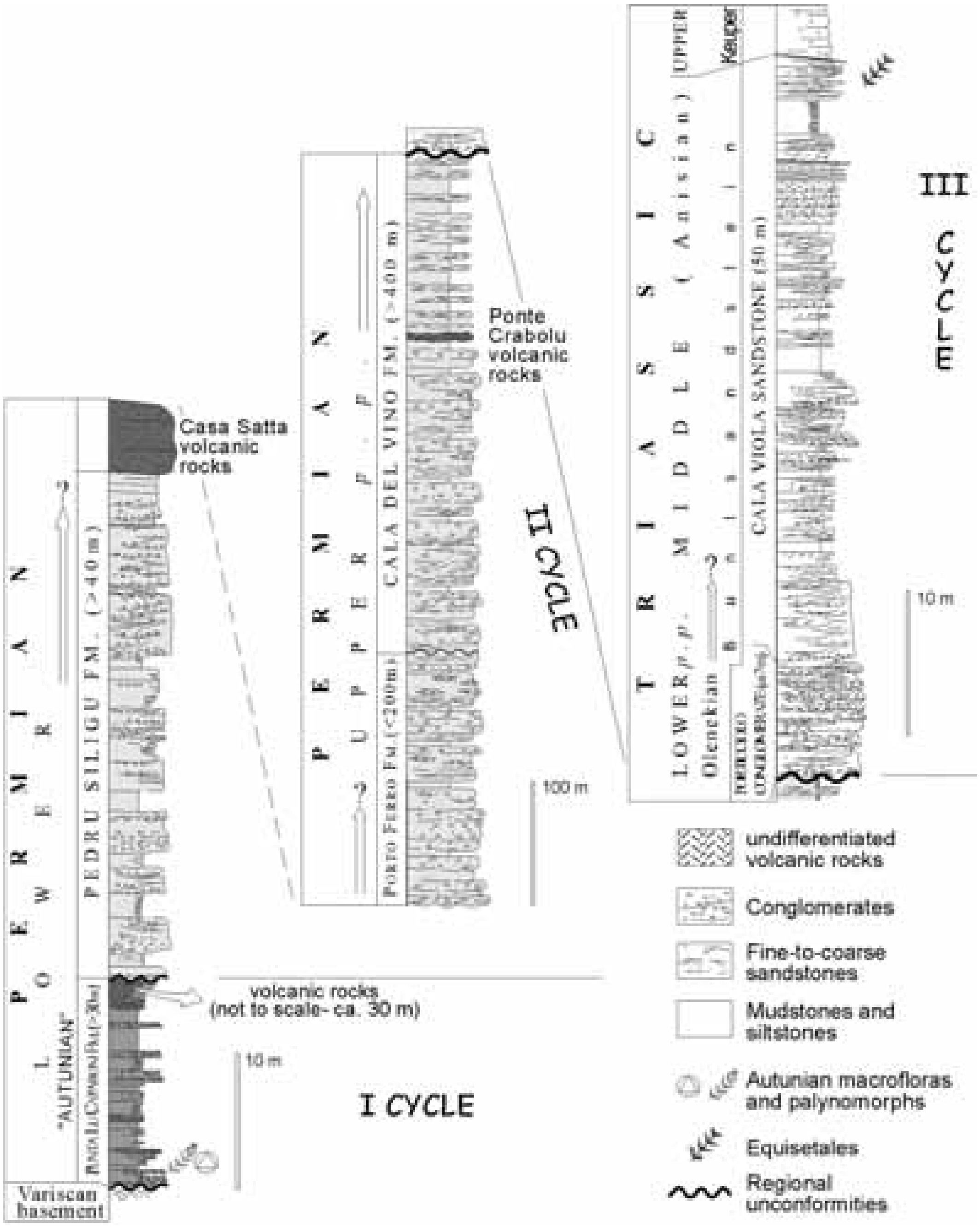


Figure 44 - Schematic and composite logs of the Permian-Triassic cycles in Nurra (after Cassinis et al., 2002).

These deposits are unconformably overlain by ca 700 m of coarse- to fine-grained alluvial, reddish, siliciclastic deposits ("Verrucano Sardo" *sensu* Gasperi and Gelmini, 1980); the chronological extension of the associated gap is unknown. This younger succession has been recently subdivided by Cassinis *et al.* (2002, 2003) into five stratigraphic units pertaining to cycle II (the Pedru Siligu Fm., Porto Ferro Fm. and Cala del Vino Fm. referred to Early-Late Permian *p.p.*) and cycle III (Porticciolo

Conglomerate, Cala Viola Sandstone, referred to ?Olenekian-Anisian *p.p.*) (Fig. 44). Volcanic rocks, generally of uncertain nature, are locally intercalated into the sedimentary succession of the 2nd cycle.

The excursion concerns the succession cropping out in the Torre del Porticciolo area (Fig. 43). Here, the Porticciolo Conglomerate overlies the Cala del Vino Fm. through a distinct disconformity which, very likely, marks the presence of a significant gap (at least persisting from Latest Permian to Earliest Triassic). This thin, but extremely characteristic, unit can be followed from its type locality to Cala Viola, and consists of a well-sorted quartz-conglomerate, about 5-8 m thick, upwards evolving to trough, to cross-bedded, coarse, red sandstones. The pebbles show typical features indicating fluvial transport over a long distance, interrupted by long periods of aeolian wear, as suggested by the occurrence of *dreikanters*. They testify to the onset of arid climatic conditions over the studied area (Durand *et al.*, 1989), also confirmed by several pieces of evidence from other European localities, where this event is probably datable to mid-"Scythian".

The Cala Viola Sandstone represents the uppermost unit of the Permian-Triassic succession of Nurra. In the area studied this unit, about 50 m thick, mainly consists of well-stratified, medium-grained, reddish sandstones, with minor pelite, forming decimetric to metric-size cross-bedded sets. The main sedimentary structures are represented by medium-scale trough cross-bedding, even lamination, climbing ripples, and centroclinal cross-stratification (Underwood and Lambert, 1974). Differing bioturbations, paleosoils and centimetric-size caliche nodules frequently occur. These nodules may be reworked as intraclasts at the base of high-energy deposits. The sedimentary facies indicate that the deposition occurred in a flood-plain setting where a number of terminal fan lobes were formed by ephemeral streams.

In the area of stop 1, the Cala Viola Sandstone is truncated by a fault and tectonically overlain by Keuper deposits. The not-exposed tract of the succession is, however, partly preserved within a negative flower-structure, a few hundred metres north of Cala Viola, where thin-bedded silty dolomite with halite pseudomorphs occurs. Moreover, the transition between Cala Viola Sandstone and the Muschelkalk lagoonal to shallow marine carbonate deposits may be observed at Mt. Santa Giusta (Fig. 43) (Neri & Ronchi, 2000).

Palaeobiological content and age discussion

No firm dating is available for a great part of the examined Permian and Triassic continental sedimentary section. At Cala Viola, Pecorini (1962) found estherias and plant remains ascribed to *Equisetum mougeotii*, and attributed such deposits to the Lower Triassic. A greenish silty layer with abundant but poorly-preserved equisetales imprints, and referable to the same horizon cited by Pecorini, occurs in the uppermost strata.

We argue that the Cala Viola Sandstone could pertain to the Early Anisian, on the basis of detailed lithostratigraphic correlation to the "Grès de Gonfaron" of Provence, which yielded a palynofloral assemblage ascribed to this age. However, further considerations may be made on the basis of core-data (Pittau, 2000) from the Cugiareddu well (Pomesano Cherchi, 1968), suggesting that all of the terrigenous deposits overlying volcanics ("Arenarie di Cala Viola" *sensu* Pittau, 2000), are Triassic in age. In the subsurface section, two distinct palynofloral associations were identified (Pittau, 2000): the first, within variegated sandstones just a few metres above the younger volcanic unit, would assign that portion to the "Scythian" and Lower Anisian; the second association, from a "Röt" facies (15-20m) consisting of sandstones with intercalations of red and black gypsum-bearing shales and marls, interlayered between the preceding continental unit and the overlying Muschelkalk, as well as including rich and well-preserved palynomorphs, allowed Pittau to ascribe this unit to a Late Anisian (Pelsonian and Illyrian) age.

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field trip itinerary

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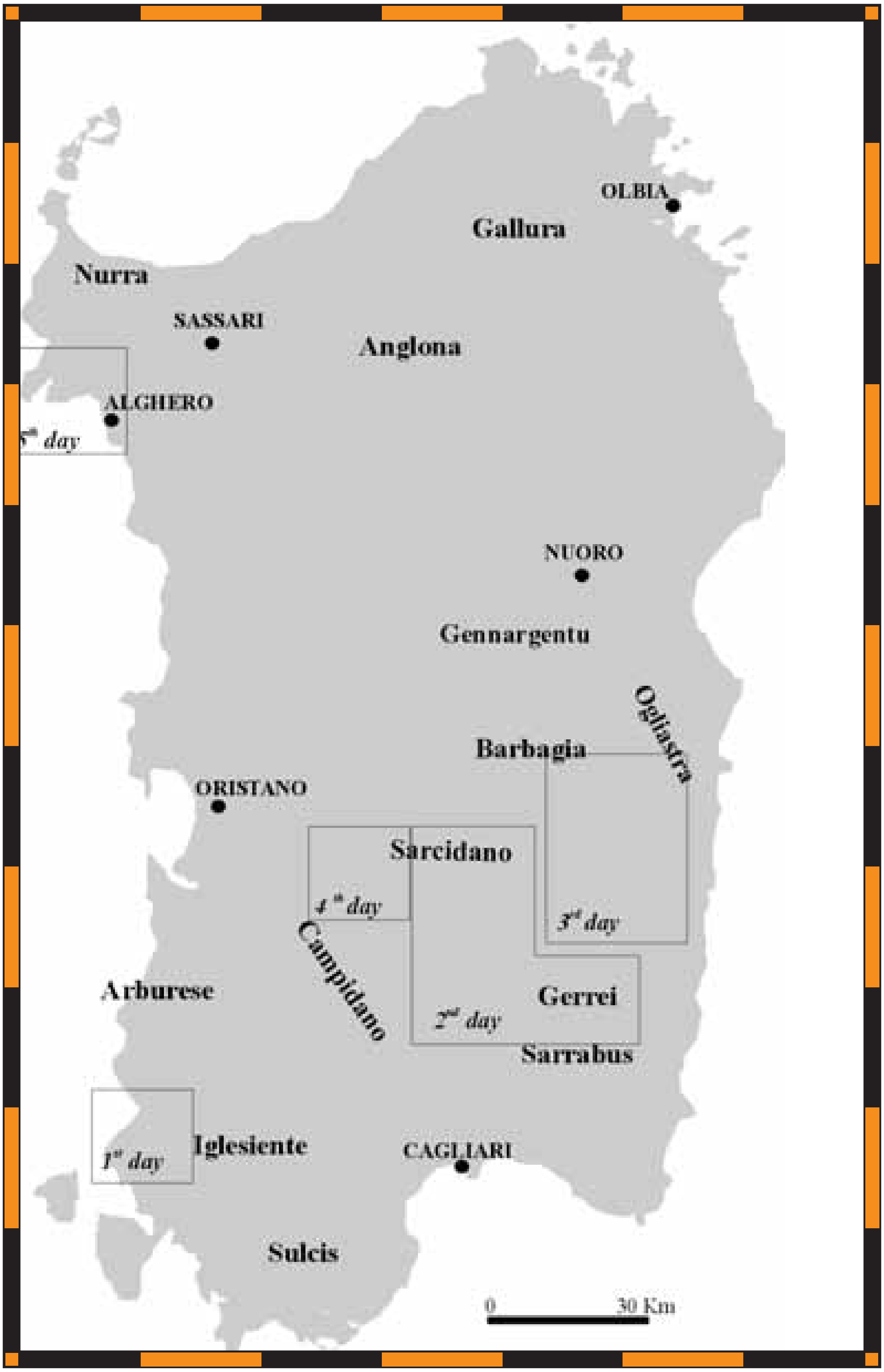
FIELD TRIP MAP



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