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SCIENCE

The geological map of Sardinia (Italy) at 1:250,000 scale

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ABSTRACT

Over the last 25 years the Italian national geological mapping program of the Italian Geological Survey (CARG Project, italian: Progetto Carta Geologica) at 1:50,000 scale has led to significant improvements in the geological knowledge for the Island of Sardinia (Italy). As a result, about one half of the island now is covered by new geological maps with 1:10,000-1:25,000 accuracy and geological maps at the 1:50,000 scale whose explanatory notes are available electronically. At the beginning of the CARG Project a geological map for Sardinia Island at 1:200,000 scale was published [Carmignani, L. (1996). Carta Geologica della Sardegna (1:200.000). Servizio Geologico Nazionale, Regione Autonoma della Sardegna], summarizing all the geological information available at that time, and a book with explanatory notes for the map was later published [Carmignani, L., Oggiano, G., Barca, S., Conti, P., Salvadori, I., Eltrudis, ... Pasci, S. (2001). Geologia della Sardegna: Note Illustrative della Carta Geologica della Sardegna in scala 1:200.000, Memorie Descrittive della Carta Geologica d'Italia (Vol. 60). Roma: Servizio Geologico d'Italia, 283 pp]. The enclosed Geological map of Sardinia at 1:250,000 scale incorporates all maps of the CARG Project, unpublished author studies and recently published maps and represents the most updated synthesis of an area characterised by a complex geological evolution that, with few exceptions, can be considered continuous during the last 540 Ma. The main events that influenced the geology of the island are the Variscan orogen that deeply involved the passive margin of North Gondwana and then the complex episodes that occurred in the present-day Mediterranean area after the accretion of Pangea up to the opening of the Tyrrhenian basin.

1. Introduction

Sardinia Island is located in the middle of the Central-Western Mediterranean (Figure 1) and, together with Corsica Island, is a 30 km-thick crustal block bounded by two areas affected by extensional tectonics: the Liguro-Provençal basin to the West and the Tyrrhenian basin to the East, where the crust has been stretched in the last 20 and 8 Ma, respectively. Sardinia represents a puzzle of very different tectonic, stratigraphic and paleontological features that have fascinated geologists. Considering the occurrence of important metallic ores mainly hosted in the Paleozoic basement, the interest on Sardinian geology can be dated to the Phoenician civilization and up to pre-historic people in the second millennium BC.

Following the first known geological map published by La Marmora in 1856 (Figure 2), and the first metallogenic map in 1870 by Quintino Sella, the first modern geological map of the whole Island was compiled by Vardabasso (1950) at 1:750,000 scale. This map did not introduce many differences with respect to the maps edited one century before, except for the southwestern part of the Island, where geological knowledge was greatly improved due to the economic interest in lead and zinc ores (Figure 3). After that, only Cocozza, Jacobacci, Nardi, and Salvadori (1974) published a geological map at 1:500,000 scale, with significant improvements and with explanatory notes that, for more than 20 years has been the reference text book for the main lineaments of Sardinia's geology. A further map at 1:250,000 scale was later published by Cherchi et al. (1982) (Figure 4).

In the 1980s Carmignani, Cocozza, Ghezzo, Pertusati, and Ricci (1987) published the Structural map of the Variscan basement of Sardinia at 1:500,000 scale, that may be considered the first synthesis of modern knowledge about tectonics of the Sardinian Variscan basement. Subsequently a 1:200,000 geological map of Sardinia (in two sheets) was edited by Carmignani (1996), followed in 2001 by a comprehensive explanatory booklet (Carmignani et al., 2001). The map presented here (see Main Map) is at 1:250,000 scale and is based on the 1:200,000 map published by Carmignani (1996), but takes into account and includes all the results of the Italian Geological Survey Mapping Project of Italy (CARG Project), carried out over the last 25 years in Sardinia, as well as other maps and information published by other authors.

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KEYWORDS

Sardinia; Italy; Variscan basement; Mesozoic cover; tectonics; stratigraphy





Figure 1. Location map of the Island of Sardinia (Italy).

2. Geological outline

The enclosed geological map provides an overview of the geology of Sardinia, where rocks of all the Periods belonging to the Phanerozoic Eras crop out in an island which is large at about 24,000 km². These rocks record some of the most important geological global events that occurred over the last 540 Ma: the evolution of the passive margin of the Gondwana continent (Precambrian–Ordovician), the opening and closure of the Rheic ocean (Ordovician–Devonian), the Variscan orogeny and the following assembly of Pangea (Carboniferous–Triassic), the opening of the Tethys ocean and its closure related to Alpine orogeny (Jurassic–Oligocene), the opening of the Liguro-Provençal and Corsica basins (Lower Miocene) and, finally, the opening of the South-Tyrrhenian basin (Late Miocene).

The Island can be subdivided into four main geological units (Figure 5):

 The largest part consists of a Variscan basement, composed of anchizonal to high grade metamorphic rocks deformed during the Early Carboniferous, and of a Permo-Carboniferous batholith emplaced between 340 and 280 Ma (Carmignani et al., 2001, for a general framework; Di Vincenzo, Carosi, & Palmeri, 2004). The oldest rocks with paleontological records are Early Cambrian in age and crop out in the southern part of the island. Most of authors agree that Sardinia was part of the southern branch of the European Variscan chain (Arthaud & Matte, 1977; von Raumer & Stampfli, 2008; Westphal, Orsini, & Vellutini, 1976, and references therein). Stratigraphic and paleogeographic data allow placing most of the Sardinian crust on the northern margin of the Gondwana plate, which was involved in continental collision with the Laurasia plate. However, there are still many questions to be answered regarding this event. According to Matte (2001) the northeast part of Sardinia belongs to the Armorican microplate, whilst von Raumer, Stampfli, and Bussy (2003) include the whole of Sardinia in the Hun superterrane.

(2) A Permian to Oligocene sedimentary succession was deposited when Sardinia was part of southern Europe and underwent an evolution typical of a passive margin. The Mesozoic opening of the

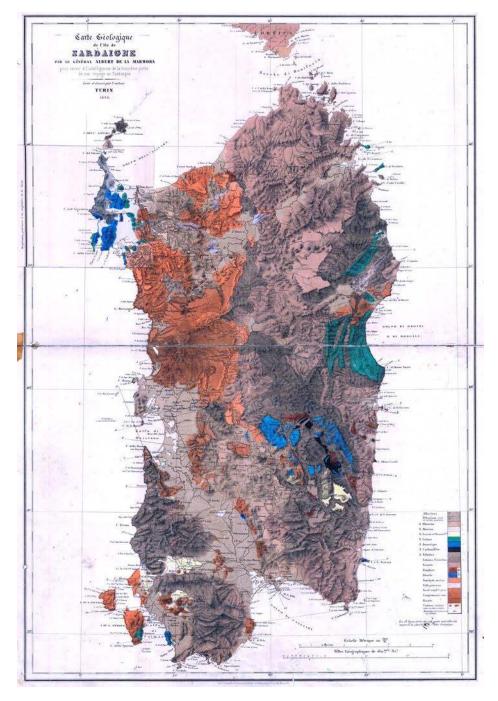


Figure 2. Geological map of Sardinia at 1:1,500,000 scale by La Marmora (1858).

Tethys ocean led to the deposition of a widespread carbonate platform. During the Paleogene, clastic deposition prevailed in a transitional environment and marine deposition is recorded by small outcrops of Lower Eocene limestones (Matteucci, 1985; Matteucci & Murru, 2002).

(3) An Upper Oligocene to Upper Miocene volcanosedimentary succession was deposited in several basins of the so-called 'Sardinian Rift' (Cherchi & Montadert, 1982). An eastward drifting and counterclockwise rotation of the Sardinia–Corsica block away from Europe are well constrained as occurring during the Aquitanian–Burdigalian (Alvarez, 1972; Carmignani, Funedda, Oggiano, & Pasci, 2004; Chamot-Rooke, Gaulier, & Jestin, 1999; Montigny & Edel, 1981; Speranza et al., 2002; Vigliotti & Langenheim, 1995). The geodynamic setting and structural evolution for this time span is debated in the literature. Some authors relate the opening of the basins, filled by Upper Oligocene to Serravallian sediments, to a progressive stretching of the crust during rotation, and identify pre-, syn- and post-rift volcano-sedimentary deposition (Casula, Cherchi, Montadert, Murru, & Sarria, 2001; Cherchi & Montadert, 1982). Other authors distinguish pre-rotation basins related to the coeval northern Apennine collision, and a post-collisional extension and

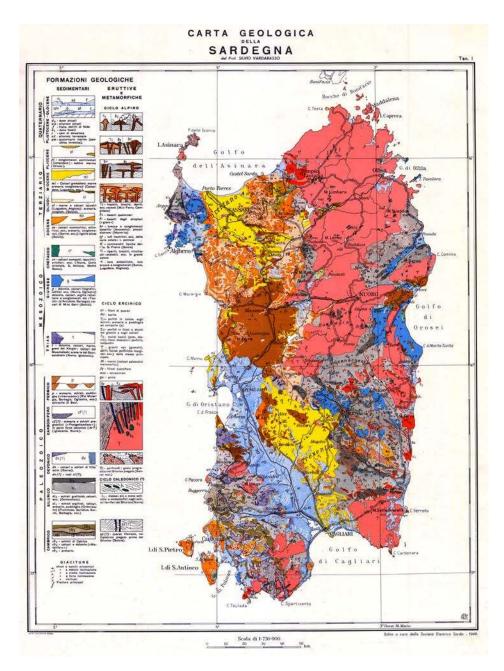


Figure 3. Geological map of Sardinia at 1:750,000 scale by Vardabasso (1950).

rotation that led to the opening of the Balearic basin (Carmignani et al., 1994, 1995; Carmignani et al., 2001; Faccenna, Speranza, Caracciolo, Mattei, & Oggiano, 2002; Funedda, Oggiano, & Pasci, 2000; Oggiano, Funedda, Carmignani, & Pasci, 2009). According to the latter hypothesis Sardinia drifted away from Europe during Upper Burdigalian time; the Northern Apennines drifted away from Sardinia–Corsica in post-langhian times, this is the age of extension provided for the Corsica basin (northern Tyrrhenian Sea) (Mauffret & Contrucci, 1999).

(4) After the Late Tortonian the eastern margin of the Sardinia–Corsica block became a passive margin related to the opening of the south-Tyrrhenian Sea (Mascle & Rehault, 1990). These extensional tectonics, which continue, led to the development of N-S striking normal faults both on the inland and on the continental shelf (Fabretti, Sartori, Torelli, Zitellini, & Brancolini, 1995). During Tortonian and Messinian times carbonate-mixed siliciclastic deposition occurred in shallow marine and transitional environments. In the middle Pliocene–early Pleistocene time interval the Campidano half-graben developed in southern Sardinia. This late extensional evolution was probably coeval with the alkaline-subalkaline effusive magmatic activity producing large plateaux of intra-plate basalts (Beccaluva, Deriu, Savelli, & Venturelli, 1977).

2.1. Variscan basement

Considering the distribution of the main tectonic units (Figure 6), emplaced with a tectonic transport direction

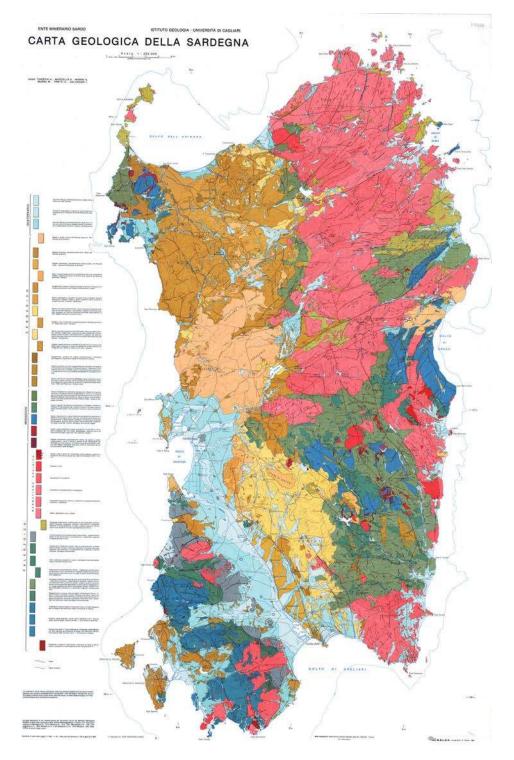


Figure 4. Geological map of Sardinia at 1:250,000 scale by Cherchi et al. (1982).

top-the-SW, and an associated general increase of metamorphism and deformation from SW to NE, the Variscan metamorphic basement has been partitioned as follows: (1) a 'Greenschist and sub-greenschist facies Variscan metamorphic complex' cropping out in the External zone in the Iglesiente-Sulcis area, in the External nappes (Sarrabus unit, Gerrei unit, Sarcidano unit, Arburese unit, etc.) and in the Internal nappes (Barbagia unit, Anglona units, Nurra units, etc.); (2) a 'Variscan metamorphic complex with dominant amphibolitefacies assemblages' cropping out south of the Posada-Asinara line (Baronie, Southern Anglona, Nurra region, Asinara); and (3) a 'Variscan migmatitic complex' cropping out north of the Posada-Asinara line (Gallura, Northern Anglona, Asinara).

In the 'External fold and thrust belt' and the 'Nappe zone' stratigraphic successions can be subdivided into: (1) a Cambrian–Lower Ordovician succession cut at the top by an angular unconformity well recognizable in the field ('Sardic unconformity'); (2) an Upper

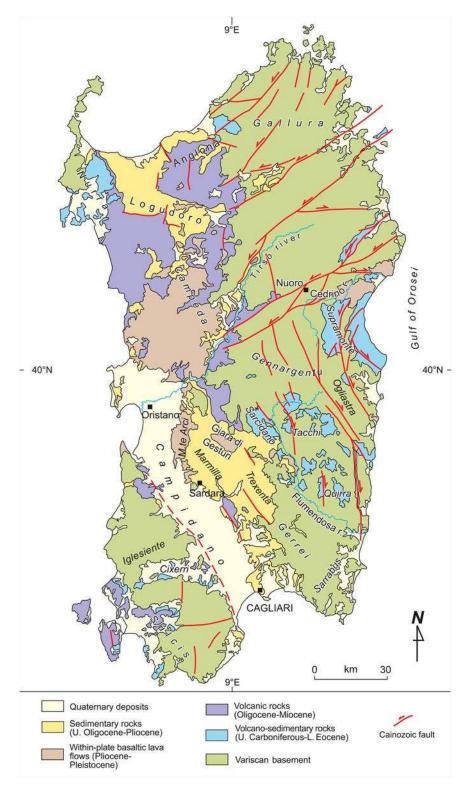


Figure 5. Geological map of Sardinia.

Ordovician–Lower Carboniferous volcano-sedimentary succession, lying unconformably above; (3) the Culm-like siliciclastic deposits, which, in turn, rests unconformably onto the last succession. All these rocks were deformed and metamorphosed during Variscan events (Visean).

The main tectonic features related to the Variscan orogeny (red in the map) are ductile and brittleductile overthrusts developed during the continental collision between Gondwana and the Armorica Terranes Assemblage. Low- to high-angle normal faults developed during collapse of the thickened crust in the final stages of the Variscan orogeny, in part during emplacement of the plutonic complex, the dyke complex and development of a volcano-sedimentary complex of Upper Carboniferous–Lower Triassic age.

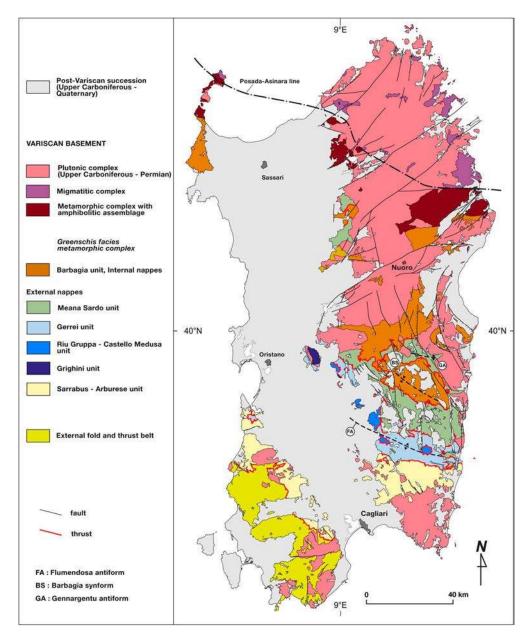


Figure 6. Tectonic units in the Variscan basement of Sardinia.

2.2. Volcanic and sedimentary cover (Mesozoic–Cenozoic)

Unconformable above the Variscan basement lies a thick Mesozoic–Cenozoic volcano-sedimentary succession containing different sedimentary and volcanosedimentary complexes ('lithostratigraphic complexes' of Salvador, 1994) linked to the evolution of the present-day Mediterranean area. Following geodynamic criteria, we distinguished:

- (1) 'Autochthonous cover of the ancient south European passive margin', with transitional and marine successions of Middle Triassic-Lower Eocene age;
- (2) 'Complex related to the west-dipping subduction of Adria', with continental, transitional and marine deposits of Middle Eocene–Lower Miocene

age ('1st Miocene cycle') and associated volcanic rocks belonging to the Oligocene–Miocene calcalkaline volcanic cycle, represented by prevailing andesitic suites;

- (3) 'Complex related to the opening of the Algero-Provençal and North Tyrrhenian basins' ('2nd Miocene cycle'), with marine and continental deposits of Upper Burdigalian–Lower Serravallian age, and associated volcanic rocks (from calcalkaline to peralcaline), with prevailing rio-dacitic suites;
- (4) 'Complexes related to the opening of the S-Tyrrhenian basin', ('3rd Miocene cycle') with Pliocene continental and (rare) marine deposits covered and partially interlayered with intraplate basaltic lava flows, alkaline, transitional and

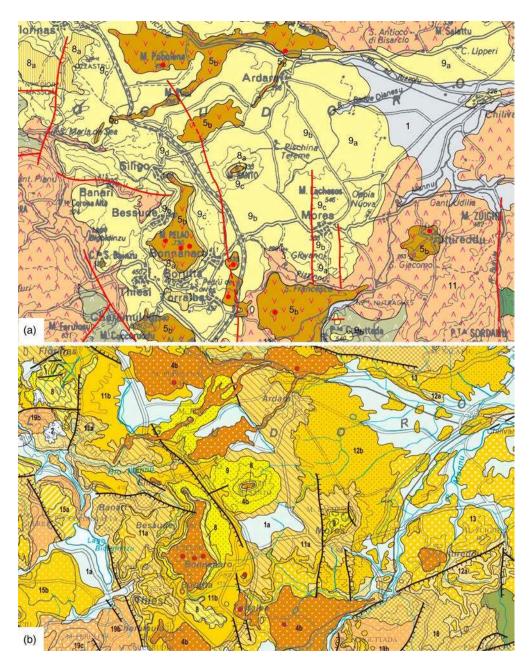


Figure 7. The Oligo-Miocene tectono-sedimentary cycles in central Sardinia, Terralba area. (a) Geology from the Carmignani (1996) map. (b) Geology from the new 1:250,000 enclosed geological map.

subalkaline volcanic cycle and linked with extensional tectonics that affected at that time the south-Tyrrhenian area.

The Quaternary is mostly represented by continental deposits and by subordinate lagoon and marine-littoral deposits.

3. Methods

The map has been compiled using both published and unpublished data, as reported in the map reference list. As common in the compilation of geological maps that overcome the local scale, one of the critical problems has been represented by the definition of the legend. We decided to group the geological formations and rock types mapped at larger scale adopting a non-interpretative criteria based on lithostratigraphic complexes bounded by regional unconformities.

All the data have been added keeping in mind that the final size of the lithostratigraphic units in the printed map does not conflict with the readability of the map. Finally, colors were chosen partially taking into account the international color chart. Colors for the Mesozoic and younger rocks are taken from the international color chart, but to allow better readability of the complex structures inside the Variscan nappe zone, the dark green to brown colors typical of Paleozoic rocks in most chromatic tables have been avoided.

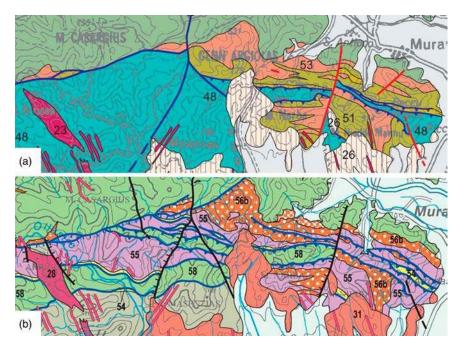


Figure 8. The external nappes in the area located south-west of Muravera (SE Sardinia). What was previously (Carmignani, 1996) considered as an 'undifferentiated' large outcrop of Lower Carboniferous Culm-like flysch (a), in the new map is now reinterpreted as the westward prolongation of the well known embricated thrust structure of M. Narba (b).

4. Conclusions

The new edition of the Geological map of Sardinia at 1:250,000 is an up-to-date state of knowledge for having an overview of the main geological lineaments of Sardinia. The map develops from a geodatabase that can easily upgraded in the future, to produce new editions. The map includes all the recent geological informations delivered by the mapping project of the Italian Geological Survey (CARG Project).

Compared to Carmignani (1996) and earlier maps, in this new map some lithostratigraphic units not mapped before are described. In the Variscan foreland zone, both the Lower Cambrian and the Upper Ordovician successions are more detailed. The Cenozoic volcano-sedimentary successions are now described with more details, improving the merely lithologic criteria adopted in previous maps (Figure 7); it is now possible to distinguish the three tectono-sedimentary cycles in the Neogene succession, and their relationships with the Neogene volcanic rocks.

Significant progress in the geological knowledge has been made, for example in the Variscan tectonic units west of Laconi, that are now reinterpreted changing the position of several ductile thrusts. The same is true for the Variscan basement south of Muravera, where original data from field survey at 1:10,000 scale have been interpreted on the basis of new paleontological and structural data (Figure 8).

The aim of the authors is to produce explanatory notes to aid the description of a complex but beautiful geology that represents the last 600 Ma.

Software

All data were first processed to compile a geodatabase using Esri ArcGis. The lines were imported in to Adobe Freehand and Adobe Illustrator to allow a classical cartographic design; in this phase the polygons were closed and the lines (imported from ArcGis in different thematic layers) symbolized.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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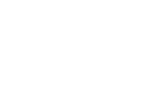
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


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GEOLOGICAL MAP OF SARDINIA (ITALY)

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Landslides. Main ancient and recent landslides. Pleistocene-Holocene 3b: Ancient continental deposits. Alluvial deposits, travertines and eolianites. Pleistocene
 3a: Ancient marine deposits. Coastal to littoral conglomerates, sandstones and biocalcarenites ("Panchina tirreniana"). Pleistocene VOLCANIC AND SEDIMENTARY COVER Pliocene-Pleistocene alkaline, transitional and subalkaline volcanic cycle (0.14-5.3 Ma) 4b: Alkaline basalts. Alkaline to transitional basalts, basanites, trachibasalts and hawaites in large lava flows (Giare and Gollei), locally bearing peridotitic nodules, scoriaceous cones (Basalti delle Giare-Logudoro; Golfo di Orosei; Campeda; Marmilla; Ogliastra; Trexenta). Pliocene-Lower 4a: Trachytes and phonolites. Lava domes, lava flows and rarely scoriaceous levels with trachytic, phonolitic-trachytic, phonolitic, thephritic-phonolitic and phonolitic-thephritic composition (Montiferro; Sarrabus: Capo Ferrato). Pliocene-Lower Pleistocene Continental deposits. Conglomerates, sands and shales of fluvio-lacustrine environment (N.ghe Casteddu Fm.-Montiferro; Campeda; Baronie: Orosei; Marmlla); eolian sandstones (Capo Mannu Fm.-Sinis). Upper Pliocene-?Lower Pleistocene Monte Arci internediate to acid volcanic rocks. Lava domes and flows, with interlayered rare pyroclastic deposits, with rhyolitic to rhyodacitic composition, from aphyric to shallow porphryic texture, with obsidianaceous and perlitic structure; glassy and vesicles-rich porphiritic dacites (Marmilla: M.te Arci). Pliocene Pliocene marine deposits. Coarse sandstones, bearing marine fossils (Fuile Fm.-Baronie: Orosei). Marine conglomerates, breccias and sands (N.ghe Baboe Fm.-Sinis). Lower Pliocene Upper Miocene sedimentary succession Marine deposits of the third Miocene sedimentary cycle. Fenestrae-rich limestones and breccias of supratidal and intertidal environment, with benthic foraminifers, echinoids, molluscs, balanides, algae (Torre del Sevo Fm.-Sinis); evaporitic, fine-grained limestones, sublittoral maris and bioclastic limestones, with foraminifers and molluscs (Calcari Laminati del Sinis; Capo S. Marco Fm.-Sinis). Messinian Shelf limestones and marly sandstones, with foraminifers, molluscs, annelids (Sinis); limestones with hermatypic corals, molluscs, foraminifers and algae (Monte Santo Limestones-Logudoro: M.te Santo, M.te Pelao). Tortonian-Messinian Continental deposits of the third Miocene sedimentary cycle. Conglomerate with clayey matrix and sandstones of alluvial environment, illitic-caolinitc shales (Nurra). Tortonian-Lower Messininan Coarse silici-clastic sands with caolinitic matrix of fluvio-marine environment (Sabbie di Florinas-Logudoro: Florinas, M.te Santo, Codrongianus); marly sandstones, siltstones often with carbonatic matrix, of sublittoral environment, with planktonic foraminifers, molluscs (Arenarie di Pirri-Campidano: Cagliari). Serravallian-Messinian? Lower-Middle Miocene volcano-sedimentary succession Upper lava flows of the second Miocene volcanic cycle. Lava flows with rhyolitic to dacitic composition and peralkcaline affinity (comendites), locally with well exposed ropy structures ("Comenditi" fm. p.p.; Su Ruvu Mannu Group-Sulcis: Sant'Antioco Island and San Pietro Island); calkalkaline lavas in neck and crypto-domes, with a andesitic to rhyodacitic composition ("andesiti terminali-a3"-Logudoro: M.te Larenta, Mara; Anglona). Upper Langhian-?Serravallian 11b: Marine deposits of the second Miocene sedimentary cycle. Epibathyal marls and marly sandstones, with planktonic foraminifers, pelagic and benthic molluscs, corals (Argille di Fangario-Campidano: Cagliari). Upper Langhian-?Serravallian
 1b Sandy and silty marls, sandstones, conglomerates and siliceous sands of sublittoral-epibathyal environment, with planktonic foraminifers, pelagic molluscs, echinoids, corals (Marne di Borutta; Marne di Gesturi; Marmilla fm. p.p.-Marmilla; Trexenta; Campidano; Logudoro; Sassarese; Gallura). Upper Burdigalian-Middle-Upper Langhian
 11a: Littoral carbonatic deposits of the second Miocene sedimentary cycle. Sands, carbonatic sandstones and calcarenites (Calcari di Mores-Logudoro: Ardara. Mores, Thiesi; Sassarese: Sassari, Sennori; Anglona: Sedini). Upper Burdigalian 12b: Continental deposits of the second Miocene sedimentary cycle. Conglomerates and sands with clayey matrix and clasts from the Variscan basement and Tertiary volcanites (Oppia Nuova Fm.-Logudoro: Mores, Tula; Sulcis: Masainas, Santadi); deltaic conglomerates and sandstones (Baronie: Orosei). Upper Burdigalian-Langhian

LEGEND

QUATERNARY DEPOSITS

12a 12a: Epiclastites of the second Miocene sedimentary cycle. Continental deposits: pomiceous pyroclastic rocks, poorly welded, tuffs and ashes ("Lacustre" p.p.-Goceano; Logudoro: Mores; Anglona: Perfugas, Laerru). Burdigalian

Pyroclastic flows of the second Miocene volcanic cycle. Pyroclastic flows in one or more flow units, with rhyolitic and dacitic composition, with vitrofiric and brecciated levels ("trachiti superiori-12"-Cala Lunga and Monte Sirai Groups; Logudoro; Iglesiente; Sulcis). Upper Burdigalian-

Dikes of the second Miocene volcanic cycle. Dikes with basaltic composition (Arburese: M.te Arcuentu). Upper Oligocene-Lower-Middle Miocene

15b: Rhyolitic lavas of the second Miocene volcanic cycle. Lava flows of rhyolitic-dacitic composition ("andesiti superiori-α2" p.p.-Mejlogu: M.te 15b Traessu, M.te Frusciu, Cossoine; Planargia). Burdigalian-Serravallian

15a 15a: Andesitic lavas of the second Miocene volcanic cycle. Lava flows and autoclastic breccias of andesitic composition ("andesiti superiori-α2" p.p.;Carbonia group-Sulcis; Arburese: M.te Arcuentu; Valle del Temo: M.te Unturzu). Burdigalian

Upper Oligocene-Lower Miocene volcanic-sedimentary succession

16b: Marine deposits of the first Oligo-Miocene sedimentary cycle. Sandstones, conglomerates, tuffites, with planktonic foraminifers, benthic molluscs, corals, echinoids, etc. ("Arenarie di Gesturi"; Nurallao Fm.; Marmilla Fm. p.p.-Sarcidano: Isili; Trexenta: Gesturi; Marmilla; Logudoro; Anglona: Castelsardo; Arburese: Funtanazza) ichthyolitic clayey marls, sandstones and siltstones with benthic molluscs ("Marne di Ales"-Marmilla; Arburese: Funtanazza). Upper Oligocene-Lower Burdigalian
 16a 16a: Littoral carbonatic deposits of the first Oligo-Miocene sedimentary cycle. Hermatypic limestones and carbonatic sandstones, with interlayered rare silici-clastic sediments, with molluscs (Calcari di Villagreca; "Calcari di Isili"-Trexenta: Villagreca; Sarcidano: Isili). ?Upper Oligocene-Lower

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17b: Lacustrine deposits of the first Oligo-Miocene sedimentary cycle. Continental conglomerates and sandstones, with interlayered cherts, with plant remains ("Lacustre" p.p.-Barigadu: Lago Omodeo; Anglona); cherty limestones, siltstones, sandstones alternating with rhyolitic tuffs, with ostracods, plant remains, algae, molluscs ("Lacustre" p.p.-Logudoro: Oschiri, Berchidda; Anglona; Arburese: Funtanazza; Nurra: Porto Conte). 17b Aguitanian-Burdigalian

17a 17a: Continental deposits of the first Oligo-Miocene sedimentary cycle. Polygenic conglomerates and sandstones of fluvial environment (Ussana Fm.-Logudoro: Piano Ladu; Anglona: Casteldoria; Marmilla; Trexenta: Monastir, Nuraminis; Sarrabus: M.te Genis; Gerrei: S. Nicolò Gerrei; Sarcidano: Villanovatulo); continental poligenic conglomerates, carbonatic sandstones with reworked macro-foraminifers (Conglomerato di Cuccuru 'e Flores-Baronie: M.te Albo, La Caletta, M.te Tuttavista, Lanaitto). *?Oligocene-Aquitanian*

Pyroclastic flows of the first Oligo-Miocene volcanic cycle. Pomiceous and lithic pyroclastic flows, weakly or strongly welded, with a rhyolitic-dacitic composition ("trachiti inferiori- τ₁"; Piroclastiti di Siliqua-Planargia; Goceano; Logudoro; Anglona; Valle del Cixerri). Aquitanian-Burdigalian

19c: Acid lavas of the first Oligo-Miocene volcanic cycle. Lava flows of rhyolitic dacitic composition (Logudoro: M.te Pizzinnu di Romana).

19b: Andesitic lavas of the first Oligo-Miocene volcanic cycle. Lava flows and rare hypoabyssal lava bodies, with alternating rare pyroclastic deposits, of andesitic composition (Serbariu di sopra group-Sulcis: Serbariu; Barigadu; Planargia; Campeda; Logudoro; Anglona). Aquitanian
 19a 19a: Hypoabyssal lava bodies of the first Oligo-Miocene volcanic cycle. Lavas in stocks and necks, of quartzo-andesitic-tonalitic-dacitic composition, with widespread hydrothermal alteration and related mineralization of Au and Cu (Complesso vulcanico di Siliqua; Andesiti di Monte Perda-Valle del Cixerri: M.te Silixanu, Acquafredda, M.te Exi, P.ta de su Ferru; Sulcis: Sarroch; Nurra: Calabona). Upper Oligocene

Paleogene marine to transitional successions

Paleogene succession of Sulcis and Campidano

20b: Continental deposits. Clayey reddish siltstones and sandstones, of continental environment, at the base locally ematitic conglomerates with clasts of the Variscan basement (Cixerri Fm.-Iglesiente; Sulcis; Campidano: Monastir). *?Middle-Upper Eocene-Oligocene* 20a: Paralic deposits. Littoral to transitional limestones with characee, ostracods, macro-foraminifers ("Calcari a macroforaminiferi"; "Miliolitico"-Sulcis); marly limestones, marls, shale of continental and paralic environmental, with carbonaceous deposits, bearing characee, palinomorphs, carophytes, ostracods ("Lignitifero"-Sulcis; Cixerri). *?Paleocene-Middle Eocene*

Eocene succession of Eastern Sardinia

21b: Marine deposits. Sublittoral limestones, marly limestones and clayey marls, with corals, echinoids, macro-foraminifers ("Calcari a nummuliti"; Monte Cardiga Fm. p.p.-Sarrabus; Gerrei; Salto di Quirra: M.te Cardiga; Baronie: Orosei). Lower Eocene
 21a: Continental deposits. Sandstones and polygenic ,more or less quartzitic, conglomerates of fluvio-deltaic environment, with ceritides and oysters at the bottom of the "Calcari a nummuliti" (Monte Cardiga Fm. p.p.-Sarrabus; Gerrei; Salto di Quirra: M.te Cardiga Fm. p.p.-Sarrabus; Gerrei; Salto di Quirra: M.te Cardiga). ?Upper Paleocene-

Mesozoic sedimentary successions

Upper Cretaceous marine successions

 22b: Middle-Upper Cretaceous succession of Western Sardinia. Carbonatic shelf deposits: limestones, marls and glauconitic calcarenites of sublittoral environment with benthic foraminifers, algae, rudists, locally lacustrine limestones with carophyts (Capo Caccia Fm.; Nurra; Anglona); in Nurra with a bauxite-rich layer at the base (Nurra: Olmedo). *Middle-Upper Cretaceous (Cenomanian-Campanian)* 22a: Middle-Upper Cretaceous succession of Eastern Sardinia. Carbonatic shelf deposits: limestones and marls, cherty limestones, detritic glaucophane sandstones, of circa-infralittoral environment, with planktonic foraminifers, rudists and inoceramids (Baronie: M.te Tuttavista, Lanaitto, Gorropu). *Middle-Upper Cretaceous (Upper Albian-Maastrichtian)* 22b

Middle Triassic-Lower Cretaceous marine and transitional successions

23b: Lower Cretaceous succession of Western Sardinia. Carbonatic shelf deposits: limestones, dolomitic limestones, oolitic limestones and bioclastic limestones of sublittoral environment (facies "Urgoniana"; Dragonara Fm.), with benthic foraminifers, algae, rudists, bryozoan, serpulids; at the base: paralic marly limestones and marls (facies "Purbeckiana"), with charophytes and ostracods (Cala d'Inferno Fm.-Nurra; Sant'Antioco Island), Lower Cretacous (Berriasian-Lower Aptian)

23a: Lower Cretaceous succession of Eastern Sardinia. Carbonatic shelf deposits: bioclastic limestones and marly limestones, oolitic and cherty a limestones ("Facies "Urgoniana"; Gorropu Fm.), with cephalopods, brachipods ; at the base: paralic marly limestones and marls (facies "Purbeckiana"; Orudè Fm.), with charophytes and ostracods (Barbagia; Supramonte; Baronie: Lanaitto, Orosei, M.te Albo). Lower Cretacous (Berriasian-Lower Albian)

24c: Jurassic succession of Western Sardinia. Carbonatic shelf deposits: dolostones and dolomitic limestones, bioclastic limestones, oolithic and oncoid limestones, cherty limestones, mudstones, marly limestones and marls, with algae, crinoids, brachiopods, bivalves, cephalopods, coprolites (pollens, spores, ostracods; at the top: transition to the facies "Purbeckiana" with dolostones and lacustrine black dolomitic limestones

(Nurra: Olmedo, M.te Doglia; Sulcis: Porto Pino). Liassic-Malm. 24b: Upper Jurassic succession of Eastern Sardinia. Bioclastic limestones, oolitic cherty limestones and mudstones, of littoral-circalittoral b environment, with algae, benthic foraminifers and nerineids (Monte Bardia Fm.; Tului Fm.: Supramonte; Baronie: M.te Albo, M.te Tuttavista).

4a: Middle-Upper Jurassic succession of Eastern Sardinia. Dolostones, sandy dolostones, dolomitic limestones of littoral to circalittoral environment, with benthic and planktonic foraminifers, calcisphaeras, calcareous algae, cephalopods, echinoderms (Dorgali Fm. - Baronie: M.te Albo; Supramonte; Sarcidano; Ogliastra); at the base: fluvial and deltaic conglomerates, quartz-sandstones, siltstones, mudstones, alternating lignitiferous layers with plants remains and sporomorphs ("Genna Selole Fm." - Baronie; Sarcidano; Supramonte; Ogliastra). Middle-Upper Jurassic (Dogger-Malm)

Triassic succession. Dolostones, marly dolostones, marls with gypsum and mudstones ("Keuper"), with palynomorphs, agglutinated foraminifers, gasteropods, brachiopods (Nurra: Ghiscera Mala, P.ta Dei Visti; Sulcis: Porto Pino). Carbonatic shelf deposits of circalittoral to transitional environment: dolomitic limestones and dolostones, sandy dolostones, limestones and marly limestones, with rare gypsum intercalations, with conodonts, cephalopods, bivalves, brachiopods, crinoids, algae, sporomorphs, ichnofossils ("Muschelkalk"; P.ta Su Nuraxi Fm.-Nurra: Alghero, M.te S. Giusta; Iglesiente: Campumari; Arburese: Capo Pecora; Sarcidano: M.te Majore di Nureci; Sulcis: Porto Pino). Red-violet silty mudstones, micaceous and quartz-rich sandstones and alluvial conglomerates, with silicified limestones intercalations in the Arburese and Iglesiente regions, with plants remains, sporomorphs and pollens ("Buntsandstein"; "Verrucano sardo", P.ta S'Arridelli Fm.-Nurra: Cala Viola; Gerrei: Escalaplano; Arburese: Capo Pecora). *Middle-Upper Triassic*

Upper Carboniferous-?Lower Triassic continental succession

28 29 30

Volcano-sedimentary succession. Conglomerates, sandstones, with alternating epiclastic rocks, volcanic breccias, lacustrine limestones, with cherty levels and anthracite lenses, shales, with plants remains, sporomorphs and pollens, ostracods and amphibians (Ru su Luda Fm.-Barbagia: Seui, Seulo; Ogliastra: Perdasdefogu; Gerrei: Lago di Mulargia); alluvial conglomerates, sandstones and siltstones, with plants (P.ta Lu Caparoni Fm.-Nurra: P.ta Lu Caparoni); sandstones, conglomerates, siltstones and fine laminated shales, with silicified limestones intercalations, locally with acidic lavas, tuffs and volcanic breccias, with sporomorphs and pollens, pteridophytes, ichnofossils, (Iglesiente: San Giorgio, Guardia Pisano; Arburese:Tuppa Niedda). Westphalian D (?)-Autunian

27b: Rhyolitic-dacitic volcanites. Pyroclastic flows and lava flows of rhyolitic and rhyodacitic composition, subordinate dacitic lava flows (Gallura: P.ta Salici; Baronie: Galtelli; Ogliastra: Perdasdefogu, M. Ferru near Tertenia; Gerrei : Escalaplano; Arburese: P.ta Acqua Durci); alkaline rhyolitic ignimbrites (Nurra: M. S. Giusta). Upper Carboniferous-Upper Permian-?Lower Triassic a 27a: Andesitic volcanites. Lava flows, porphyritic subvolcanic bodies and breccias, with andesitic composition. Upper Carboniferous-Upper

Permian-?Lower Triassic

VARISCAN BASEMENT

Upper Carboniferous-Triassic dike complex

29: Basic dikes. Calkalcaline, transitional and alkaline basaltic dikes. 30: Hydrothermal dikes. Quartz-rich dikes and subvolcanic bodies, often mineralised with sulphides, barite, fluorite, gold and silver, etc. Upper Carboniferous-Lower Triassic

Upper Carboniferous- Permian plutonic complex

Leucogranites. Generally equigranular granites, with microgranitic and porphiric facies (Gallura: Limbara; Sarrabus: Rio Picocca, San Vito; Sulcis: M.te Arcosu, Teulada); locally Grt-bearing leucogranites (Baronie: P.ta Tepilora). Upper Carboniferous-Permian

Monzogranites. Equigranular to inequigranular monzogranites with Kfs phenocrysts (Goceano: Buddusò, Bortamelone; Gallura: Costa Paradiso) (Gallura: Calangianus, Arzachena; Barbagia: Olzai); rare Na-rich sienites (Sarrabus: Villasimius). Upper Carboniferous-Permian

Granodiorites. Equigranular monzogranitic granodiorites (Gallura: S. Antonio; Barbagia: Gavoi) and inequigranular granodiorites (Gallura: Monti; Barbagia: Orotelli); disequigranular tonalitic granodiorites (Marghine: Bolotana; Barbagia: Mamoiada; Ogliastra: Villagrande; Goceano: Benetutti). Upper Carboniferous-Permian

Quarzodiorites and gabbros. Granodioritic tonalites and gabbro-tonalites (Barbagia: Oniferi; Marghine: Burgos, Ottana; Mandrolisai: Ortueri); Gabbros and gabbro-tonalitic bodies (Gallura: P.ta Falcone, Bortigiadas; Goceano: Osidda; Sarrabus: Solanas). Upper Carboniferous-Permian

Peralluminous granites. Crd-bearing granites (Nuorese: Rio Isalle). Upper Carboniferous-Permian

Sin-kinematic granites. Foliated granitoids, mostly tonalitic granodiorites and tonalites (Goceano: Pattada; Gallura: Bortigiadas, N.ghe Ola; Baronie: M.te Senes). Upper Carboniferous-Permian

Anatectic granitoids. Anatectic leucogranites and granodiorites, strongly foliated (Gallura: Barrabisa, S. Maria Island, Golfoaranci; Anglona: Tarra Padedda; Mandrolisai: M.te Grighini). Carboniferous

Variscan migmatitic complex

Orthogneisses. Granodioritic and monzogranitic orthogneisses (Asinara; Baronie: Tanaunella. Porto Ottiolu; Gallura: Valle del Liscia; Anglona: Tarra Padedda). ?Upper Ordovician

Migmatites. Diatexites and metatessites with orthogneiss, locally with calc-silicates lenses (Gallura: Golfaranci, Palau; Anglona: Tarra Padedda; Baronie: Brunella, Straula; Asinara). ?Precambrian-?Lower Paleozoic

Amphibolites. Lenses of amphibolites and ultramafic amphibolites, with granulitic relics, derived from layered basic complexes (Gallura: Montigiu Nieddu, M.te Plebi; Asinara: P.ta Scorno). ?Precambrian-?Lower Paleozoic

Variscan metamorphic complex with dominant amphibolite-facies assemblage

Amphibolites with eclogite relics. Amphibolites with relics of eclogite paragenesis (Gallura: P.te del li Tulchi; Anglona: Giuncana). Middle Ordovician

42 Granodioritic orthogneisses. Granitic and granodioritic orthogneisses (Ortogneiss di Lodè; Gneiss occhiadini" - Baronie). Ordovician

Paragneisses, Grt±St ±Ky micaschists. Paragneisses and quartzites of amphibolite-facies, medium pressure metamophism, widespread amphibolite- to greenschist-facies mylonites (Baronie: Posada; Anglona: Giuncana). ?Paleozoic

HT-LP rocks. Paragneisses, micaschists and quartzites of amphibolite-facies metamorphism, affected by a high-temperature metamorphic overprint (And±Sil±Crd) (Asinara; Anglona). ?Paleozoic

Micaschists and paragneisses. Micaschists and paragneisses with Grt±oligoclase paragenesis (Baronie: Siniscola; Nurra: Stintino, Asinara) and Grt±Ab paragenesis (Baronie). ?Paleozoic

> Greenschist and sub-greenschist facies variscan metamorphic complex INTERNAL NAPPES (Gennargentu, southern Nurra)

Upper Ordovician-Lower Carboniferous succession

Marbles. Gray marbles, rare dolomitic marbles, with interlayered phyllites, locally fossiliferous, with crinoids, conodonts (Ogliastra: Arcu Correboi, Genna Silana). Devonian

47 Metagabbros. Alkaline metagabbroes (Nurra: Biancareddu, Canaglia, M.te Rugginosu). Upper Ordovician-?Lower Silurian

Ordovician-Silurian terrigenous successions. Dark phyllites, locally carbonaceous, metasiltstones, black quartzites ("lidite") with alternating intercalated thin marble layers, and locally diamictite levels and ironstones (Nurra: Canaglia). Upper Ordovician-Silurian

Middle Ordovician volcano-sedimentary complex

49 Calcalkaline metavolcanites. Basic to acid metavolcanites, metaepiclastites and metagraywackes (Nurra; Gennargentu). Middle Ordovician

Terrigenous successions of uncertain age

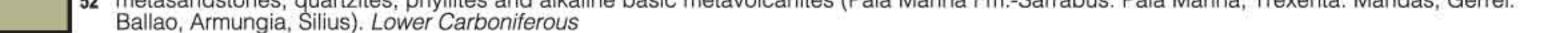
Bt-rich micaschists. Bt-bearing metasandstones and phyllites (Barbagia: Orune; Nurra), of supposed Cambrian-Lower Ordovician age and locally of Devonian-Lower Carboniferous age. Paleozoic

Lower Paleozoic terrigenous succession. Metasandstones quartzites and phyllites with alternating interlayered acid metavolcanic rocks ("Postgotlandiano" - Gennargentu; Barbagia: Seulo; Ogliastra; Goceano; Baronie; Nurra). Lower Paleozoic

EXTERNAL NAPPES (Goceano, Sarcidano, Quirra, Gerrei, Sarrabus, Arburese, Iglesiente-Sulcis p.p.)

Upper Ordovician-Lower Carboniferous succession

Culm-like flysch deposits. Metaconglomerates with clasts of "lydites", olistoliths and olistostromes of the Ordovician-Devonian succession; metasandstones, quartzites, phyllites and alkaline basic metavolcanites (Pala Manna Fm.-Sarrabus: Pala Manna; Trexenta: Mandas; Gerrei:





Devonian carbonatic succession. Metalimestones, locally nodular, with crinoids, ammonites ("Calcari a Clymenie"; Calcari di Villasalto - Sarrabus: M.te Lora; Gerrei: Villasalto, M.te Taccu); in the lowermost tectonic units: marbles, dolomitic marbles and calcschists, with crinoids (Sarcidano: Asuni; Sarrabus: Rio Gruppa; Salto di Quirra: Castello di Quirra; Trexenta: Mandas; Goceano: Illorai, Silanus; Ozieri). Middle Devonian - Lower

Black shales with graptolites and tentaculites. Dark, carbonaceous metapelites with graptolites ("Scisti neri a graptoliti" - Gerrei: Goni; Sarrabus: Baccu Scottis), at the base black cherts ("lydites"). 54a: lenses of nodular metalimestones, with orthoceratids, crinoids, pelagic tentaculites and 54a conodonts ("Calcari ad Orthoceras"; "Ockerkalk"-Gerrei: Goni, Armungia; Sarrabus: Baccu Scottis, M.te Lora). Silurian Thin levels of metalimestones and metasiltstones with tentaculites ("Scisti a tentaculiti" - Trexenta: Mandas; Sarrabus: Ballao). Upper Silurian-Lower Devonian

Upper Ordovician terrigenous succession. Metaconglomerates, metarkoses, metasiltstones, metagraywackes, with bryozoans, brachiopods, trilobites, gasteropods; locally in the upper part: diamictites (P.ta Serpeddi Fm.; Orroeledu Fm.; Rio Canoni shales-Sarrabus: Brecca, P.ta Serpeddi; Gerrei: Rio Canoni; Barbagia: Bruncu Nieddu, Orroeldu); metacalcarenites and metalimestones often silicified (Br. Su Pitzu Fm.; "Quarziti del Sarrabus"; Tuviois Fm.); in the upper part: alkaline metabasalts (Sarrabus: Bruncu Nieddu close Brecca; Gerrei: Silius, San Basilio). Upper Ordovician (Katian-Hirnantian)

Middle Ordovician magmatic and volcano-sedimentary complex

56b: Acid metavolcanites. Calkalkaline metapyroclastites with rhyolitic-dacitic composition, porphiric texture with mm-cm sized Qtz Kfs phenocrysts ("Porfidi grigi del Sarrabus"; Porfiroidi-Sarrabus: Brecca, Muravera, Baccu Locci; Gerrei: Silius, Goni); locally at the base: alternating quartzite, metasandstones and polygenic metaconglomerates with clast of intermediate-basic metavolcanites (Su Muzzioni Fm.-Sarrabus: Brecca, Baccu Scovas; Gerrei: Mulargia Lake). *?Middle Ordovician* 56b 56a: Intermediate to basic metavolcanites. Calkalkaline metavolcanites, metaepiclastites and metagraywackes with intermediate and rarely basic composition ("Serra Tonnai Fm."-Sarcidano: M.te S. Vittoria, Mulargia Lake; Sarrabus: Brecca, Riu Gruppa); metaconglomerates with prevaling clasts of acid volcanic rocks ("Manixeddu Fm."-Sarcidano: M.te S. Vittoria, Mulargia Lake; Sarrabus: Riu Gruppa); rhyolitic metavolcanites, metatuffites and metaepiclastites ("Monte Corte Cerbos Fm."; "Porfidi bianchi"-Sarcidano: M.te S. Vittoria; Sarrabus: Muravera). At the base lenses of polygenic coarse metaconglomerates ("Conglomerato di Rio Ceraxa"; Metaconglomerato di Muravera-Sarrabus: Muravera, Brecca, Baccu Locci; Salto di Quirra: M.te Ollasteddu). *?Middle Ordovician*

Metadolerites. Dikes and subvolcanic bodies of dark porphyric mafic rocks, with basic composition, with phenocrysts of calcic amphibole and
 palgioclase, doleritic texture, foliated, intruded in the Arenarie di San Vito (Sarrabus: Porto Corallo; Salto di Quirra: Riu San Giorgio; Sarcidano: M.te S. Vittoria; Trexenta: Mandas). *?Middle-Upper Ordovician*

Pre-Middle Ordovician succession



Cambro-ordovician terigenous succession. Micaceous metasandstones and quartzites, interbedded with metapelites and rare quartzitic metaconglomerates and marbles in the upper part, with sedimentary structures, ichnofossilis, trilobites, jellyfish prints, and acritarchs ("Solanas Fm."; Arenarie di San Vito-Sarrabus: Rio Ollastu, Br. Laccoi, Riu Ceraxa, S. Vito; Sarcidano: Laconi, Villanovatulo; Gerrei: Br. Maresusus; Salto di Quirra: Rio S. Giorgio; Arburese). Middle Cambrian-Lower Ordovician

> EXTERNAL FOLD AND THRUST BELT (Iglesiente, Sulcis)

Middle Ordovician-Lower Carboniferous succession

- Culm-like flyschoid deposits. Alternating quartzites, metasandstones, metapelites, metaconglomerates, metabreccias and metaconglomerates; olistolithes, olistostromes with large clasts of the Silurian-Devonian sedimentary sequence ("Culm") (Pala Manna Fm.-Sulcis: Rio Lilloni, Pula mountain). Lower Carboniferous
- Devonian carbonatic succession. Nodular metalimestones with conodonts and pelagic tentaculites (Mason Porcus Fm.-Sulcis: M.te Padenteddu; Iglesiente: Su Nuargi, Mason Porcus, Perda S'Altari). Middle Devonian Metalimestones, with graptolites, conodonts, cephalopods, crinoids ("Calcari ad Orthoceras"; Fluminimaggiore Fm.-Iglesiente: Xea S. Antonio, Mason Porcus; Sulcis: M. Padenteddu, Casa Sais). Upper Silurian-Lower Devonian

Black shales with graptolites. Graphitic black shales, with graptolites and black cherts at the bottom ("lydites") ("Scisti neri a Graptoliti"; Genna Muxerru Fm.-Iglesiente: Fluminimaggiore, M.te Linas, M.te Cortoghiana Becciu, Genna Quadroxius; Sulcis: Capoterra). Lower Silurian

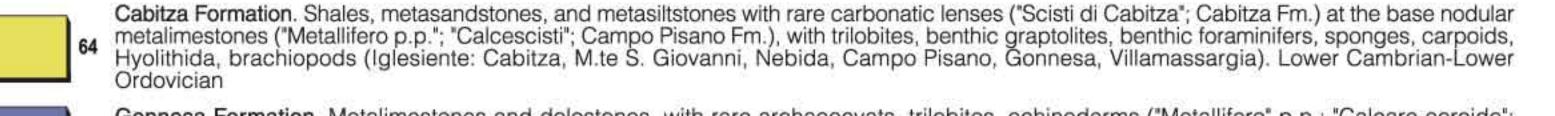
62b: Upper Ordovician terrigenous succession. Metasiltstones and metasandstones with rare interbedded basic metavolcanites, with bryozoans, brachiopods, tentaculites, graptolites, crinoids, trilobites (Monte Orri Fm.; Portixeddu Fm.; Domusnovas Fm.; Rio San Marco Fm.-Iglesiente: Rio San Marco; Sulcis: Bacu Abis, M.te Orri). Upper Ordovician (Katian-Hirnantian)

2a 62a: "Ordovician Puddinga". Metaconglomerates with olistoliths and clasts of Cambrian limestones and dolostones, alluvial and coastal violet-reddish slates and metasandstones ("Puddinga"; Monte Argentu Fm.-Iglesiente: Portixeddu, Buggerru, Fluminimaggiore, P.ta S'Argiola, P.ta Su Amadori, Mason Porcus, Rio Cannamenda, Caput Aquas; Sulcis: Narcao, Rosas). Middle-Upper Ordovician

Middle Ordovician magmatic complex

Capo Spartivento Orthogneisses. Coarse-grained granodioritic orthogneisses, with Qtz and Kfs phenocrysts. ?Middle-Upper Ordovician

Pre-Middle Ordovician succession



Gonnesa Formation. Metalimestones and dolostones, with rare archaeocyats, trilobites, echinoderms ("Metallifero" p.p.; "Calcare ceroide"; 65 "Dolomia grigia"; San Giovanni Fm.-Iglesiente: Is Ollastus, Acquacadda, S. Giovanni); stromatolitic metadolostones and metalimestones, with rare archaeocyats ("Dolomia rigata"; Santa Barbara Fm.-Iglesiente: Planu Sartu, Arcu Biasterria, S. Barbara). Lower Cambrian

66b Nebida Formation ("Arenarie Fm."). 66b: Punta Manna Mb. Metasandstones with carbonatic cement, metadolostones, oolitic metalimestones, micritic metalimestones, with trilobites, archaeocyats, algae, brachiopods, lingulids, rare Hyolithida and echinoderms. Lower Cambrian. 66a 66a: Matoppa Mb. Metasandstones and silty metasandstones with rare metalimestone intercalations, with algae, archaeocyats. Lower Cambrian

67 M. Settiballas schists. And-bearing micaschists (Sulcis: Chia). ?Precambrian

Symbols



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