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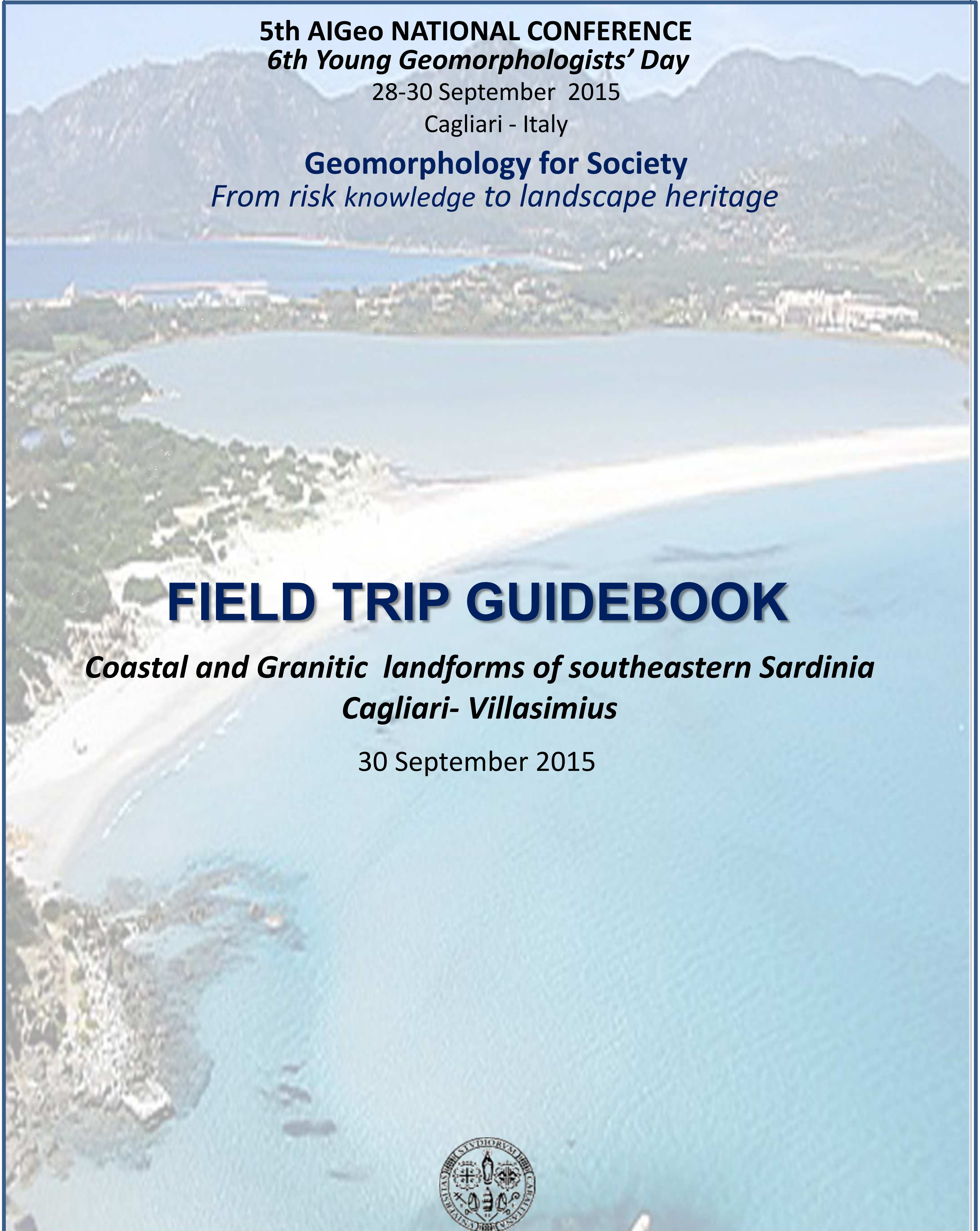

5th AIGeo NATIONAL CONFERENCE

6th Young Geomorphologists' Day

28-30 September 2015

Cagliari - Italy

Geomorphology for Society

From risk knowledge to landscape heritage

FIELD TRIP GUIDEBOOK

Coastal and Granitic landforms of southeastern Sardinia

Cagliari- Villasimius

30 September 2015

University of Cagliari

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FIELD TRIP GUIDEBOOK

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Contents

1. Introduction

The objective of this field-trip is to analyse the costal and granitic landforms and to point out the costal landscape evolution of the southeastern Sardinia during the Quaternary. This guidebook shows in its initial part an overview of the Sardinia geological and geomorphological settings, and in the second part the itinerary and stop descriptions.

2. Regional geologic setting *(Rita T. Melis)*

The island of Sardinia ((24,089 Km^2 and 1,849.2 km of coastline, a quarter of the total length of Italy's coasts) offers an extraordinary array of geological features in a relatively small area. The present-day position of the Sardinia Island is the result of a complex geological history that testifies, more or less completely, some of the greatest geodynamic events occurred in the last 400 Ma (Variscan, Thetys and evolution). Like its neighbouring island Corsica, Sardinia represents a segment of the south-European plate that was separated during the Oligocene-early Miocene with an anticlockwise rotation (Cherchi and Montardert, 1984; Doglioni et al., 1999).

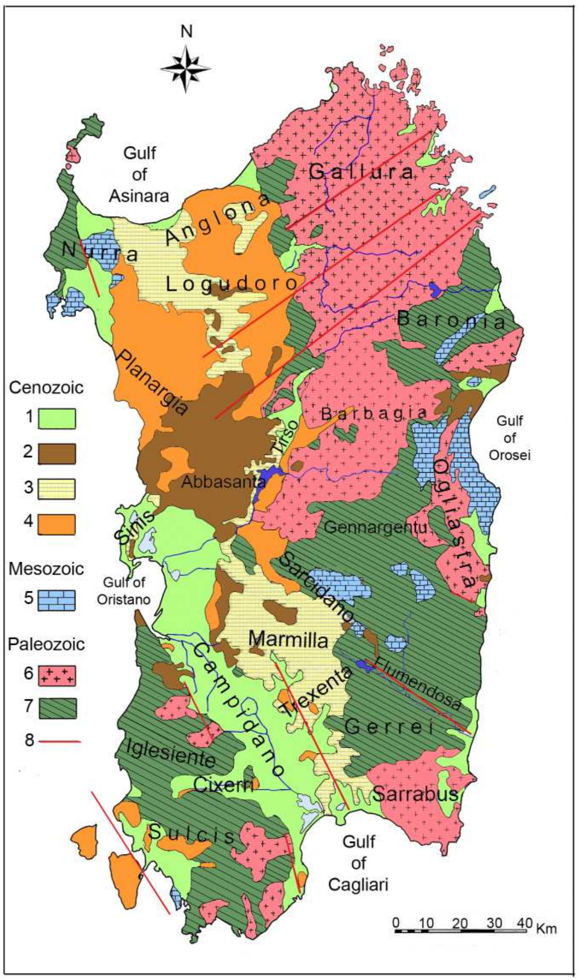

Fig. 1. Schematic geological map of Sardinia. Cenozoic: 1 Continental and marine deposits (Pleistocene-Holocene), 2 alkaline volcanic cycle (Plio-Pleistocene), 3 marine succession and continental deposits (Miocene), 4 calkaline volcanic cycle (Oligocene–Miocene). Mesozoic: 5 limestones, (Upper Cretaceous, Middle Triassic, Lower Cretaceous). Paleozoic: 6 intrusive complex (equigranular leucogranites, equigranular monzogranites, and tonalites) (Upper Carboniferous, Permian), 7 Varisican metamorphic complex (shales, micashistes, metasilstones, metasandstones, metalimestones, and limestones) (Carboniferous, Devonian, Ordovician, Silurian, Cambrian), 8 faults (modified after Depalmas and Melis 2011).

Palaeozoic. During the Palaeozoic Sardinia passed through two great orogenies: the Caledonian, which affected Cambrian and Silurian sediments, and the Varisican, which also affected Devonian and Carboniferous deposits. During this era, lithologically-varied sedimentary sequences, attaining a thickness of thousands of meters, were deposited, intruded by granite. The Palaeozoic palaeogeography strongly indicate close relationships with Iberian Ranges (N Spain) and Montagne Noire (S France) within the Northern Gondwanan margin as suggested by tectono-sedimentary evolution. After the final phase of the Varisican orogenic cycle, the island was only affected by isostatic adjustment as a consequence of prior disequilibrium. ***Mesozoic.*** Contrary to the Palaeozoic, Mesozoic Sardinia behaved as a cratonic area. In this times Sardinia has been affected by repeated transgressions of epicontinental seas, maily documented in western (Nurra, Sulcis) and eastern (Orosei Gulf) of the island. Only in the Middle Jurassic did marine conditions prevail over the whole island. At the end of the Mesozoic Sardinia completely emerged. The continental phase lasts until the Palaeocene. ***Cenozoic.*** A phase of very widespread tensional tectonics of Late Oligocene age seems to be the responsible the counter-clockwise rotation of the Corsica-Sardinia block due to the opening of the western Mediterranean back-arc basin and the subdution of Neotethyan oceanic crust to the east of Sardinia (Carmignani et al., 1995; Casula et al., 2001). These extensional movement led to the formation of the Oligo-Miocene rift system (the so-called Fossa Sarda) that crosses the whole Western Sardinia from north to south with a length of about 220 km. The heterochronous transgression occurred during the Aquitanian - Burdigalian and was controlled by both tensional tectonic and the pre-transgressive volcanic morphology. Horsts, grabens and tilted blocks show the intensity of the extensional mechanisms. Extensive marine transgression affected previously emerged areas (Anglona, Bosano, Tirso valley and Logudoro), where sediments of the Middle Burdigalian covered the “Lacustre” Fm. Auct. peaking during the Late Burdigalian. 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. Quaternary is represented by continental and marine sediments and by volcanic rocks. These latter are related to the distensive tectonic regime that give rise to the central-south Tyrrhenian oceanic Basin. The tensional tectonic is responsible, among other, of the origin of the NW-SE Plio-Quaternary Campidano Graben, wich is filled by more than 600 m of syntectonic continental deposits (Samassi Fm.). The Campidano graben stretches in length more than 100 Km, from Cagliari Gulf to Oristano Gulf, and is about 40 km in width. The tectonic activity ended at the beginning of the Pleistocene when alkaline volcanic complexes developed in North Sardinia. The continental phase, which started during the Middle Pliocene, ends with the first marine deposits of the Upper Pleistocene. These marine fossil rich deposits crop out along the Sardinian coast; their relationships and correlations are frequently not established and matter of debate.The type locality of the Tyrrhenian stage has been established at Calamosca-is Mesas (outskirts of Cagliari) by Issel (1914), who recognised the Strombus levels of Gignoux (1913) in the biocalcarenitic marine deposits. Alluvial deposits, travertine, aeolianites and lagoonal sediments also occurs in several areas.

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3. Overview of Sardinia landscapes *(Rita T. Melis)*

The great variety of the landscapes that characterize the island of Sardinia is strongly linked to the complex geological history of the island. The great variety of the landscapes that characterize the island of Sardinia is strongly linked to the complex geological history of the island. In effect, travelling along its territory, shapes that characterize the different landscapes can be recognized. The current configuration of the island is linked by the Alpine orogenis that divided the metamorphic and granitic structure into isolated blocks and graben. The metamorphic and granitic substrate is mainly characterised by rugged reliefs dug by deep incisions, with interrupted peaks by flat summits. The strong volcanic activity during the Holocene and Plio-Pleistocene gave rise to rugged hills and extended highlands (plateau) along the edges of *Rift sardo.* Instead, the landscapes developed in Miocene deposits are marked by cuestas and gentle hills, whereas the alluvial and coastal plains are delimited by strongly carved alluvial cones. The coastal landscape is characterized by high cliffs, interrupted by deep bays, rocky promontories and long beaches with extended fields of dunes.

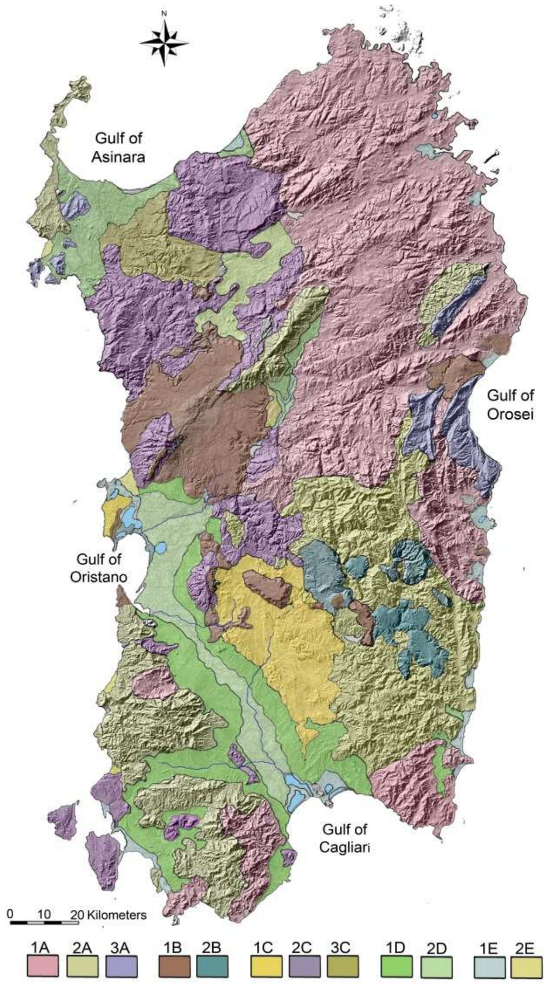

Fig. 2 Shematic Geomorphological Units map of Sardinia. A Montain Landscape: 1A peneplain remains, ridges, escarpments, mountains on predominantly granitic Palaeozoic rocks; 2A peneplain remains, smooth summits, ridges, escarpments, mountains on predominantly metamorphic Palaeozoic rocks; 3A ridges, escarpments, mountains on predominantly limestones Mesozoic rocks. B Plateau landscape:1B basaltic plateaux (Plio-Pleistocene); 2B limestone plateaux (Mesozoic). C Hill landscape: 1C complex hills on predominantly marine sedimentary Cenozoic rocks; 2C complex hills on predominantly volcanic Cenozoic rocks; 3C predominantly tabular hills on marine sedimentary Cenozoic rocks. D Plain Landscape:1D dissected allivial fans, piedmont palin (Pleistocene), 2D alluvial palin (Pleistocene- Holocene). E Coastal Landscape: 1E Coastal plain (Pleistocene–Holocene), 2E Coastal dune (Pleistocene –Holocene) (modified after Depalmas and Melis 2011).

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4. Climate of Sardinia *(M.A. Pulina)*

The climate of Sardinia is generally classified as *Internal Mediterranean*, due to its characteristic of having mild winters and relatively rainy and hot and dry summer (Chessa and Delitala, 1997). This peculiarity is related to the geographical position of the Mediterranean itself, located in the transition zone between the tropical belt, where seasons are well defined by the pluviometric conditions, and the temperate belt, where seasons are characterized by temperature variations.

Therefore, the basic characters of the climate can be traced on the basis of generally more studied meteorological parameters such as temperature and precipitations, whose regime is tied to the seasonal variations of the atmospheric circulation.

Temperature The spatial distribution of the annual average temperatures is illustrated in figure 3a. It is strongly affected by orography: in fact the plains of the Campidano and the Nurra are clearly identified , with values higher than 16°C, as well as the mountainous areas (Gennargentu, Limbara) of the East-Central part of the Island, where the values are lower than 12-13 °C.

Precipitations In figure 3b, relative to the annual precipitations, four zones with greater rainfall are identified (Gennargentu, Limbara, the plateau of Campeda and Iglesiente). The plains of the

Campidano and of the Nurra present themselves as dry zones. The average annual rainfall is lower than 500 mm in the Campidano of Cagliari, while it exceeds 1300 mm on the higher areas of the Gennargentu (Punta La Marmora, 1.834 m s.l.m.). Higher rainfall occur in December, with values that exceed on 200 mm in the mountainous zones. Concerning the rain intensity, the most elevated values in the 1951-80 period, exceed 400 mm/day, are registered in both the Central-Eastern and South–Eastern zones of the island: Arzana (825 m slm), 544 mm on the 16/10/1951 e 470 mm on the 15/10/1951; Flumendosa (658 m slm), 451,5 mm on the 15/10/1951; Monte Acuto (55 m slm), 450 mm on the 26 /9/ 1971. The main characteristics of the area object of the excursion can be deduced from the analysis of Figure 4.

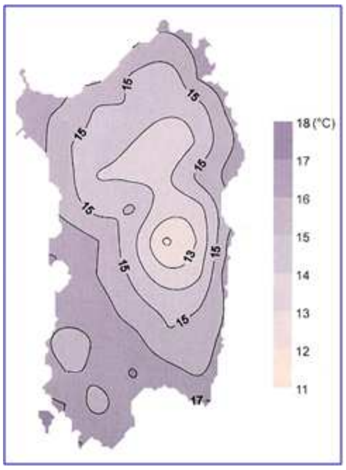

Fig.3a. Annual value of the mean temperatures (Chessa et al1997).

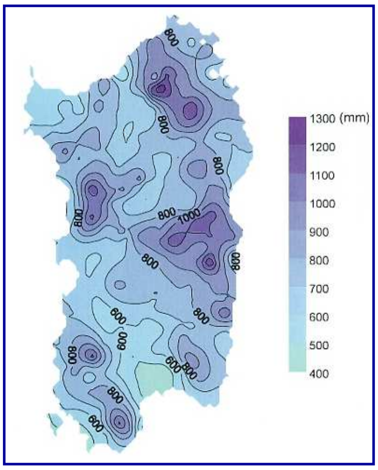

Figure 3b.Annual value of the mean precipitations (Chessa et al 1997).

It reports the annual and monthly values of temperature and precipitations of two meteorological stations of the Southern and South-Eastern belt of Sardinia : Cagliari/Elmas (39°14’36’’ N; 9°03′36″ E; altitude: 5 m asl) and Capo Carbonara (39°06’13’’ N; 9°30′49’’ E ; altitude : 118 asl). These stations belong to the Military Aviation network. The climatic values refer to the 1971-2000 period. According to the climate classification system of Koppen, the climate of Cagliari/Elmas is indicated as *Csa*, Mediterranean climate with dry summer and average temperature of the hottest month > 22°C, while the climate of Capo Carbonara is indicated as *BSk*, semiarid climate with T (average annual temperature) < 18°C.

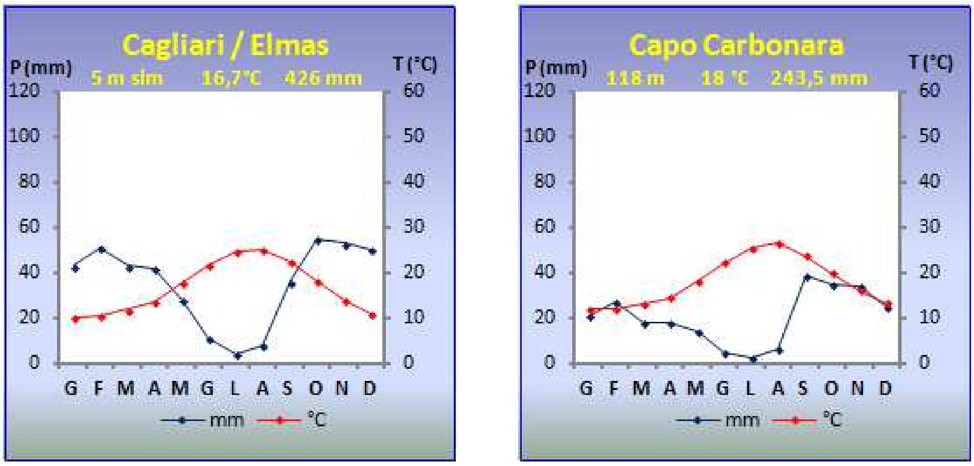

Fig.4. Bagnouls & Gaussen diagram relative to the considered stations.

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5. FIELD TRIP ITINERARY

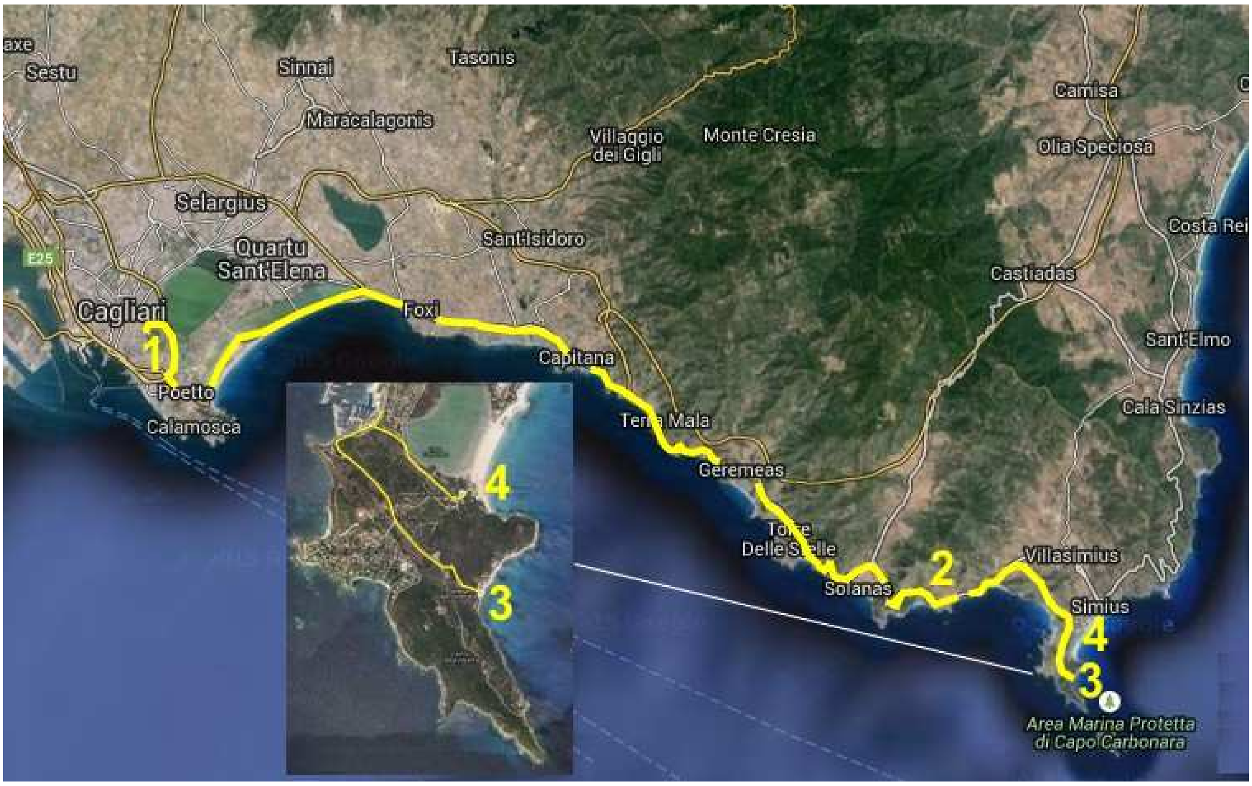


Fig. 5. Fild trip itinerary from Cagliari to Villasimius (stops 1- 4).

5.1 From Monte Urpinu hill to Poetto beach.

From city centre you reach Monte Urpinu hill to the southeastern of the district of Castello. From the hilltop you can see a panorama of the city and its gulf.

Fig. 6. Cagliari itineray from Monte Urpinu to Poetto

5.1.1 Stop 1. Cagliari city and Gulf of Cagliari

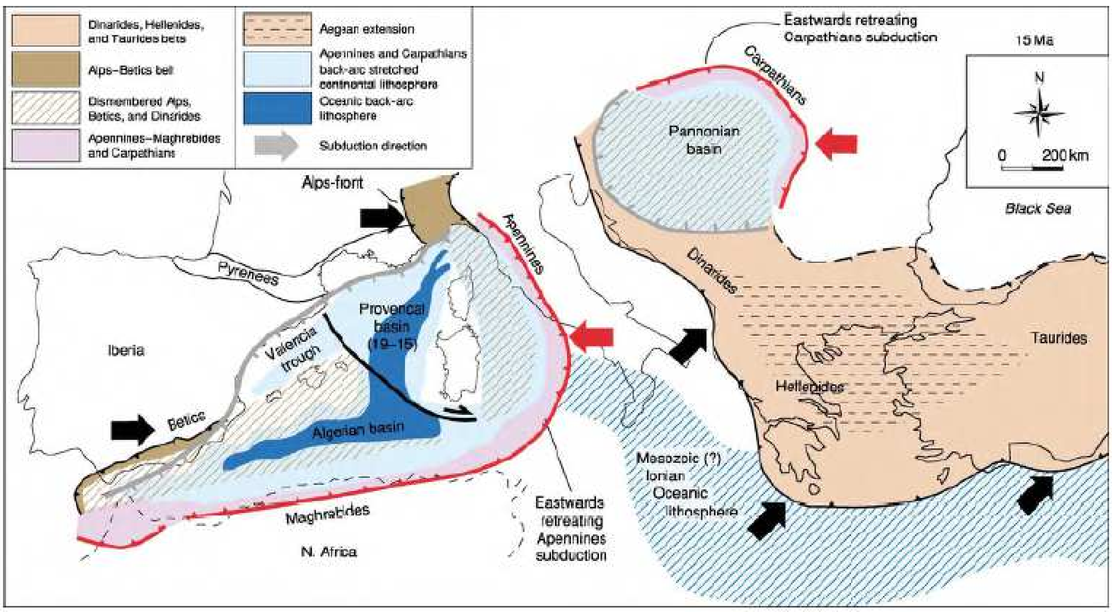
5.1.2 Stop 1a.Upper Pleistocene–Holocene coastal plain evolution of Cagliari *(Paolo Orrù)*

5.1.2.1 Geological setting of Cagliari Gulf (Paolo Orrù)

The Gulf of Cagliari has evolved at the horst-graben system in the southern Campidano whose edges are represented by the reliefs and crystalline metamorphic Paleozoic Sulcis and Sarrabus, while at the tectonic central pillar that breaks the continuity of the flat surfaces series sandstone and carbonate-marl hills of Cagliari (Pecorini et al. 1969; Cherchi et al.1978). The first setting of the graben that is attributable to the rift system, which affects with geodynamic relaxing (Aquitanian-Burdigalian) the Western Mediterranean (Cherchi & Montadert, 1982) by which the basin oligo-Miocene Sardinian "Fossa Sarda" is the extreme eastern edge (Carmignani et al.1992).

In the continental shelf of the basin it is bounded by Cagliari lineations East-West and controlled by tectonic blocks of the continental margin (Fanucci et al. 1076). In particular, the area of Campidano undergoes, in the Messinian part of a general tectonic context distensional, events that generate lower compressive structures in Flower (Casula et al. 2001); at the same time on the edges of the horst-Gerrei Sarrabus and the Sulcis they are affected by dislocations differential and modest swiveling (Cherchi et al.1978); relative tectonic stability is documented for the southern Sardinia from the Middle Pleistocene (Ulzega & Ozer 1982), confirmed by the stability of the coastal shares in levels 5e (Ulzega & Hearty, 1986, Kindler et al. 1997; Bordoni & Valensise 2002).

Small vertical movements to be paid by Holocene deposits, attributed to processes of sediments constipation plastic and peat, have been documented both in the continental shelf, where the two rows of sandstone-conglomerate rock beach of the Versilia have lowered by fracture systems in tiers for some meters (Ulzega et al. 1986), which along bands perilagunari, where the high-medieval settlement of Santa Igia shows lowering average of about 1.5 meters (Pecorini, 1986). Recent GPS measurements showed translational movements in southern Sardinia with prevailing direction West-S.Ovest with speeds ranging from 3.1 mm / year. (Oldow J.S. et al. 2002).



Palaeogeodynamics at about 15 Ma. Note the 'eastward' vergence of both the Apennines Maghrebides trench and the back arc extensional wave. The Liguro Provençal basin, the Valencia trough, and the North Algerian basin were almost completely opened at 10 Ma. The Dinarides subduction slowed down, owing to the presence of the thick Adriatic continental lithosphere to the west, whereas to the south the Hellenic subduction was very lively owing to the presence in the footwall plate of the Ionian oceanic lithosphere. The Carpathians migrated eastwards, generating the Pannonian back arc basin, with kinematics similar to those of the Apennines. Provencal basin (19 15) Age of the oceanic crust.

Fig. 7. Mediterranean Sea geodynamic scheme at 15 Ma (Carminati & Doglioni 2005)

The coastal sector of Cagliari and Campidano is subdivided into the western coastal plain, which hosts the Laguna Santa Gilla system, and the eastern coastal plain represented by the Molentargius Pond system, the Is Arenas littoral palaeo-cordon, the Saline Lagoon, and the Poetto littoral cordon (Fig.2). This "Quartu Plain" flanks the slopes of Cagliari's carbonate hills (of Serravallian-Tortonian age (Medium-Upper Miocene), which exhibit tectonic control (second lines NW-SE) particularly evident on the Sella del Diavolo promontory. The western edge is represented by the crests of Pitz'e Serra marly-arenaceous cuestas of Burdigalian–Langhian age (Lower-Medium Miocene) (Doglioni et.al. 2004).

The Cagliari coastal plain evolved concurrently with the southern Campidano graben-horst system, whose margins are represented by crystalline and Palaeozoic metamorphic relief in Sulcis and Sarrabus. Modest subsidence has been attributed to crustal loading with Holocene sediments, resulting in compaction of clays and peaty sediments, both on the continental shelf (Segre, 1968; Ulzega et al. 1986) and along the perilagoonal belt (Orrù et al., 2004). Adjacent to the Sella del Diavolo promontory is the Sant'Elia promontory, where a stratigraphic section is preserved since the research of Lamarmora in 1856, that represents the type locality at the global level (Issel, 1914) named the "*piano tirrenico*" (Tyrrhenian plain). Subsequently, these deposits have been correlated with the peak last interglacial (Ulzega and Ozer, 1982) and confirmed as MIS 5.5 with AAR and U-series data (Ulzega and Hearty, 1986; Ferranti et al. 2006). The landscape and structure of the Quartu Plain is a conspicuous and extraordinary morphostratigraphic record of the successive sea-level events during the Pleistocene-Holocene (Fig. 8). The maximum marine transgression relative to MIS 5.5 is observed along about 6000 metres of the coast at the highest altitude of about +6 m. The ancient inner margin of the shoreline is represented by an erosional bench or notch incised in the Mid-Upper Pleistocene alluvial deposits (Fig. 2). During the maximum MIS 5.5 highstand, the Sant'Elia and Sella del Diavolo carbonate landforms joined to become an island about 1.5 km seaward of the Cagliari headland. Subsequently, a deep bay formed and sedimentation by the two tributary rivers (names of rivers) resulted in the emergence of an imposing littoral spit that enlarged to become a massive baymouth bar oriented NE-SW now known as Is Arenas. Associated barrier islands about 0.8 km wide and up to 10 m high extended about 4 km across the bay. The Is Arenas barrier sedimentary system formed a palaeo-lagoon with a sub-circular plan (Molentargius pond), with the palaeo mouth behind Monte Urpinu (Fig. 3). Samples of *Persistisstrombus latus* associated with a rich Senegalese fauna and numerous other taxa were extracted from a sand cave at an elevation of +4 m in a in the axial zone of the Is Arenas coastal barrier bar. During this same interval of MIS 5.5, a palaeo-tombolo connected Cagliari's hills with the palaeo-island of Sant'Elia. With lowering of sea level during MIS 4 and 2, the palaeo-lagoon of Molentargius emptied, and a valley was deeply incised at the ancient mouth of Sa Perda Bianca. These events were mirrored in Santa Gilla lagoon to the west side of Cagliari city (Fig.8). Also during glacial lowstands at Sella del Diavolo-Marina Piccola and Sant Elia promontories, the exposed shelf and coastal sediments of MIS 5 were buried by slope deposits and dunes adjacent to the Tyrrhenian cliffs. In the offshore platform proximal to Cagliari, the Holocene transgression left six tiers of beach-rock from - 45 m, 10.7 ka cal BP (Orrù et al. 2004) with more recent sand foresets preserved at -0.5 m along the existing beach. Perhaps as 5-7 ka ago, the stabilization of sea level near present led to the accumulation of sediments and formation of the actual beach barrier system at Poetto and La Playa. Eastward coastal baymouth barrier growth severed the Saline lagoon from the sea. The development of the coastal barriers at both Poetto and La Playa beach developed according to the evolutionary model of barrier islands. All geodynamic research indicates that southern Sardinia is one of the most stable regions of the Mediterranean since the late Pleistocene through the Holocene (Doglioni et al., 2004). Preserved in the Gulf of Cagliari are well-defined geomorphological elements indicating the formation of two distinct lagoon-barrier systems during interglacial highstands of MIS 5.5 and MIS 1 at Molentargius–Is Arenas and Saline–Poetto, respectively. All field evidence and stratigraphical considerations exclude tectonic uplift, ESR analyses confirm once again a MIS 5 age for the Is Arenas marine deposit, and that Sardinia areas has remained stable since 125 ka.

Fig. 8. .Aerial photograph of the coastal plain east of Cagliari showing the main geomorphological features: 1) carbonate (Serravallian-Tortonian) 2) *cuesta* with marl and sandstone (Burdigalian-Langhian) 3) MIS 5.5 palaeo-shoreline; 4) MIS 5.5 palaeo-beach of Is Arenas; 5) MIS 5.5 Molentargius palaeo-lagoon and mouths watercourses current; 6) palaeo-mouth of the lagoon of Sa Perda Bianca (MIS 5), palaeo-valley (MIS 2), 7) Saline lagoon (MIS 1), 8) Poetto beach (MIS 1), 9) Holocene marine sediment fill and MIS 2 palaeovalley (borehole Holocene data: (Orrù et al., 2004)

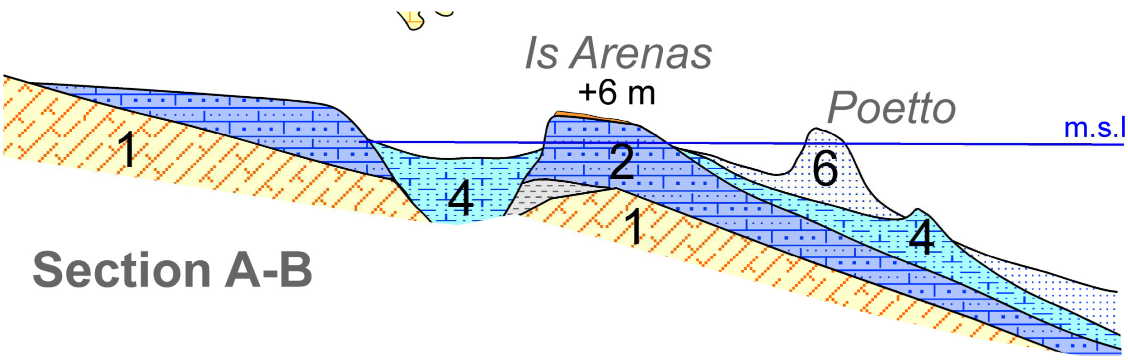
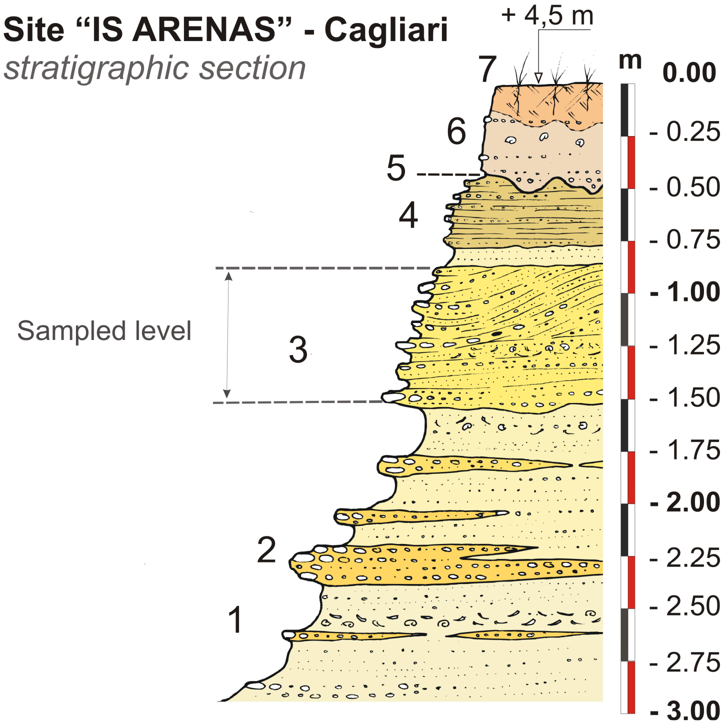


Fig. 10. Pre-Quaternary substratum, sandstone, limestone and marly limestones (Aquitaine–Upper Tortonian), 2) sandstones, fossiliferous sands and gravels (MIS 5); 3) aeolian cross-lamination (MIS 4 – MIS 2), 4) fossiliferous sandstones and silty sand fill (MIS1), 5) alluvial sands and gravels, 6) sand and gravel of present shoreline.



Persististrombus latus from Is Arenas litoral deposits (MIS 5.5)

Fig. 9. Significant "Is Arenas" MIS 5.5 stratigraphic sections: 1) medium and fine sands with parallel lamination with intercalated fossiliferous horizons, 2) planar-parallel coarse sand and gravel lenses and layers, 3) polygenic gravels and sands alternating with fossiliferous horizons, to inclined lamination and fore-sets (sampled level); 4) coarse sand with parallel lamination, 5) irregular erosional surface; 6) silty sands with pulmonate gastropods, 7) soil.

In the West coastal Cagliari plane, in front of Santa Gilla Lagoon the infilling of the ancient fluvial valleys is characterised by material related to the last phases of the Holocene transgression. This consists of muddy fluvial and delta sediments, containing more gravel in the lower part and becoming muddy upwards. Littoral sandy-gravel bodies inserted between peat beds (*Posidonia oceanica* leaf deposits) and related to the last transgressive Holocene episodes can be reconstructed in the sectors close to the provincial road S.P.195. Locally, greyish carbonate sandstones related to the Holocene transgressive sequence rest upon the Upper Pleistocene sandstones and are associated with beach-rock sandstones and conglomerates outcropping in strips on the submerged beaches of Giorgino and Margine Rosso (-1,5 m).
Sandstones and conglomerates of surface beach-rocks, -1/-1.5 m, were found in the submerged beach of Poetto of Quartu. These sediments are also present in limbs at Margine Rosso in bar facies, while these facies represent the closure of the Holocene transgressive cycle in the back of the Bay of the western Gulf (Giorgino beach). Small strips of sandstones of peri-lagoon beach and beach-rock with characteristics of a sebkha environment (El Sayed 1988) are present on the borders of the Santa Gilla lagoon.
These sebkha facies of Santa Gilla, were frequently surveyed in the past on the borders of the Islet of Sa Illetta and on the internal borders of the Giorgino bar. They are composed of strips of weakly cemented carbonates and strongly fossiliferous (*Cardium*, *Cerastoderma*) sandstones with a grey muddy sandy matrix, and at elevations of +0.1/+0.3 m in the foreshore area of the lagoon, mainly conserved thanks to the burial by muddy lagoon sediments.
The upper levels also include some beds of gypsum-containing muds, interpreted as a result of contraction periods of the lagoon basin, triggering evaporitic processes along the borders, thus causing the consolidation and the gradual mixed cementation of the peri-lagoon beaches by carbonates and sulphates.

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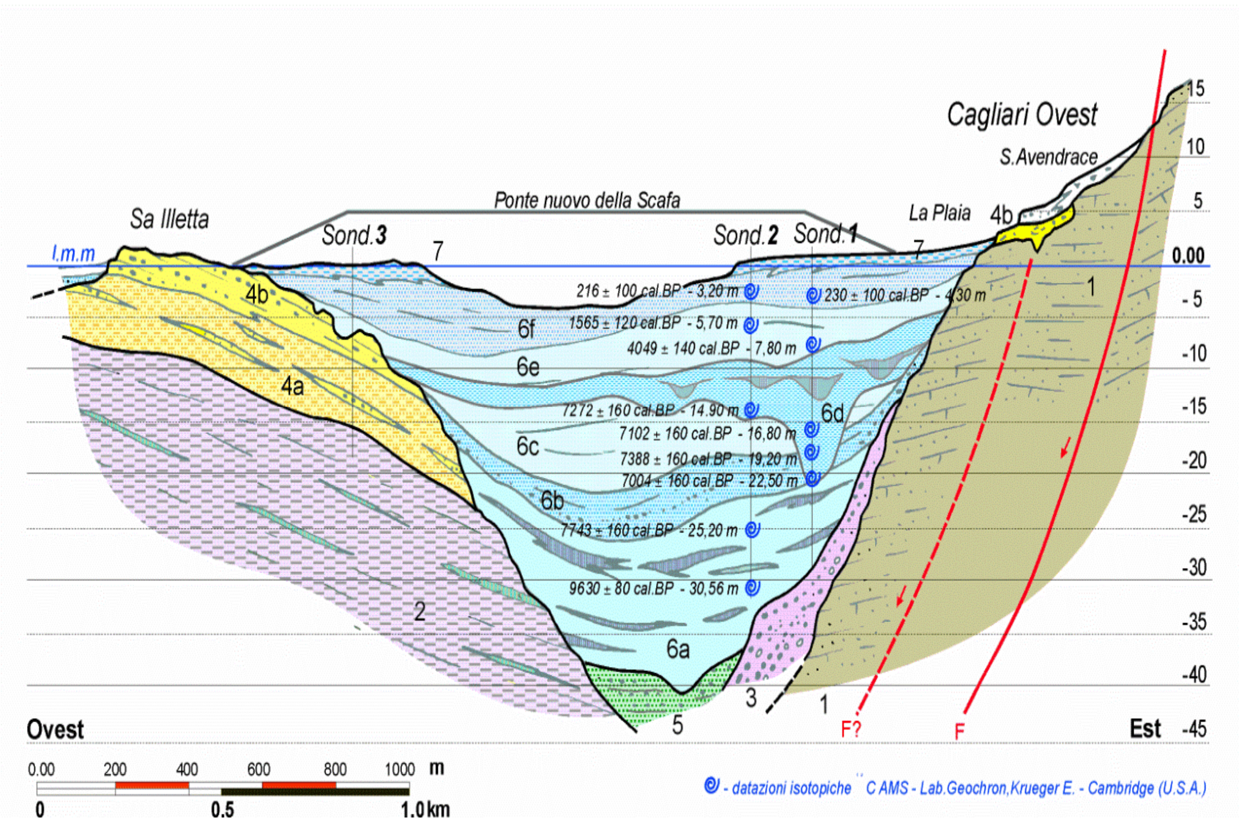

Fig. 10. Geological section at the mouth of the Santa Gilla lagoon; three stratigraphic surveys provide a breakdown of filled Holocene (Orrù et al., 2004) of the deep valley of the River Mannu paleo - Cixerri (MIS 2 - Upper Pleistocene) during the Holocene eustatic rise. Legend: 1) sandstone and marl sandstones (Miocene); 2) deltaic complex in silt and sandy silt with clay and sand with *Ostrea sp.* in lenses (Middle Pleistocene); 3) polygenic gravels in clay matrix (middle Pleistocene); 4a) weakly cemented sands and silty sands yellowish to bioturbation and *Strombus bubonius* (MIS 5 - Upper Pleistocene); 4b) sandstones and microconglomerati with *Cladocora coespitosa* - 149 ± 10 kyr BP (Ulzega & Hearty, 1986) (MIS 5e - Upper Pleistocene); 5) polygenic gravel with sandy matrix (MIS 2 - Upper Pleistocene); 6a) deltaic silt and sandy silt paralic (Yunger Dryas); 6b) littoral sandy silt and silty sands with interbedded peat in *Posidonia oceanica*; 6c) alternating littoral fine sands and silty sand lagoon; 6d) succession of erosional surfaces and filled with sandy silt and sand bioclastic lagoon; 6e) for marine-coastal sands with interbedded thin peaty *Posidonia oceanica*S; 6f) lagunar organogic sands and organic silts; 7) silt and organic and anthropogenic deposits.

5.1.3 Stop 1b. Overview of urban Cagliari landforms and archaeology *(Rita T. Melis)*

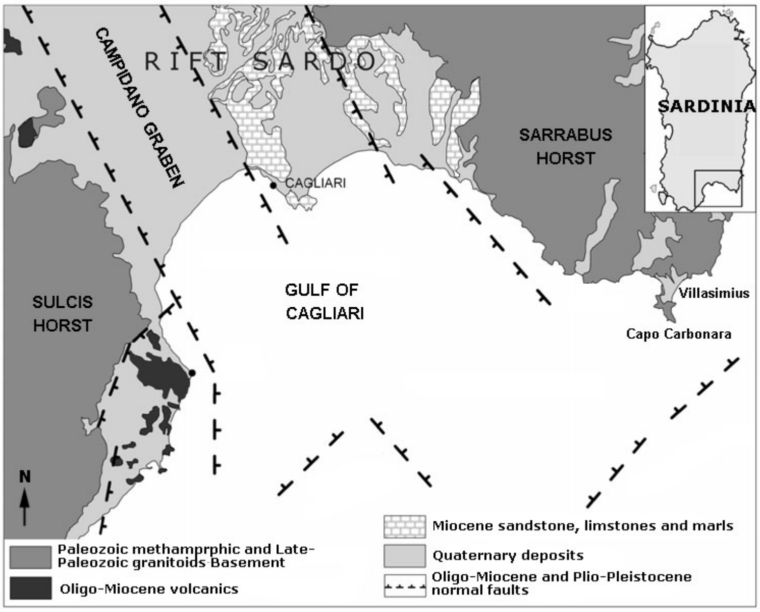

Fig.11. Schematic geological map of Southern Campidano horst-graben.

Cagliari, the Capital of the Sardinia, is situated in the middle of the Gulf of Cagliari (Gulf of Angels), bordering the southern part of the Campidano Graben between the tectonic blocks of the Sulcis, to the west, and Sarrabus, to the south (Fig.6). The most significant morphologic feature are the ten hills, that though not particularly high (140-60 m), clearly emerge with their trapezoidal profile from the fairly flat zone just a little above sea level.

The hills are tectonic blocks composed primarily of sedimentary sub-horizontal layers of the transgressive Miocene sandstone-limestone sediments. The low hillslopes, where the lower arenaceous strata of the series crop out, are for the most part gently sloping, while the largely flat hilltops, composed of benches of calcarenites and biohermal limestones, often have vertical or sheer walls, generally coinciding with fault planes or disused quarry faces. The original morphology has been transformed by human activities, as the hills were quarried for building materials from ancient times up until a few decades ago.
Although the Cagliari substrata are calcareous, there are not natural caves, except for the *Grotta dei Colombi* located at the foot of the cliff of the Capo San'Elia promontory. However, there are numerous artificial cavities made by man over the centuries. The exploitation of the underground began in the Punic period, as illustrated by Tuvixeddu necropolis, one of the most important of this type in the Mediterranean. The exploitation continued during the Roman period with the creation of cisterns to store rainwater.In the medieval period, tunnels, cisterns and wells are also built. During WWII (World War II), underground shelters were built as refuge from raids.
The widespread presence of cavities in the underground of Cagliari, filled with inconsistent natural and anthropic clastic deposits, is sometimes responsible for instable conditions of the structures aboveground. There are also numerous Punic and Roman quarries in the limestone.

Karalis, was founded in the 6th century BC by the Phoenicians, who created a commercial port of call within the S. Gilla lagoon. The imposing remains of the ancient Punic city's necropolis are located on the Tuvixeddu hill. Occupied by the Romans, the ancient Karalis developed to east in the Marina e Stampace district, between the hills and the sea.

Fig. 12. The four hold district of Cagliari in a print of 1580.

In addition, in the late Middle Ages, the town, called Santa Igia, was built near the S. Gilla lagoon. Later the Pisans raised a line of defence
around the limestone hills dominating the gulf. Conquered after a siege by the Aragonese in 1326, it became the capital of the Regnum Sardiniae (Kingdom of Sardinia).Today the old city lies between the port and the Marina district, with the Stampace district to the west, and the Villanova district to the east, at the foot of the cathedral, the white towers of the central Castello quarter overlooking them (Fig.7).

5.2 From Poetto beach to Costa degli Angeli (Capitana) *(Melis R.T.)*

After leaving Colle di Monte Urpinu, the route proceeds along the edge of Molentargiu park (http://www.cagliariturismo.it/en/places/places-of-nature-318/green-areas-16/park-of-molentargius-139) towards the hill of Sella del Diavolo. From there, the route follows the Poetto sandbar where you enjoy a view of Cagliari Saline on the left and the long Poetto beach on the right.

Saline. *The history of the Saline is closely linked to the Regional Park of Molentargius (the donkey, carrying salt, in Sardinian was called "on molenti"). The park is one of the most important wetlands across Europe, and it is a real green lung to the citizens. It is not known the moment when salt extraction began in Sardinia but there is evidence that show that many of its invaders, from the Pisans to the Spaniards, have contributed to the history of salt extraction in Cagliari. The installation of the "Salt City" (città del sale), as we know it today, was designed and built by the Piedmontese in the first half of 1800 to increase the Saline revenues and productivity. Until that moment, in fact, the activity was limited to the simple extraction of the salt that crystallized spontaneously at the edges of ponds. In this way the Saline, source of economic wealth for the entire Cagliari and Sardinia, were transformed into a veritable industry of salt. However, the incessant and frenetic activity of the salt marshes of Cagliari was suspended in 1985 for environmental, health and pollution reasons, but the memory of the hard work under the hot sun in the summer and at the mercy of the cold and wet winds during the winter is still alive in the memory of Cagliari.*

Poetto. *Until 1900 Poetto beach was not frequented by the Cagliari people who instead preferred the beaches of Sa Perdixedda (in Sardinian "small stone") and Giorgino at west side of the gulf. It was during the first decades of the 20th century that people began to appreciate the white dunes of Poetto. A number of casotti (coloured wooden constructions halfway between a dressing room and a tiny house on the seashore) were built. The casotti, however, were entirely removed in 1986 for sanitation reasons. Due to their removal, the overcrowding, and a lack of erosion prevention work, there was gradual dispersal of sand and a fast erosion of the shoreline in the nineties.*

At the end of the Poetto beach, the route follows the southeastern edge of the *Rift Sardo* between the *Campidano graben* to the west and the granite Sarrabus horst to the east.

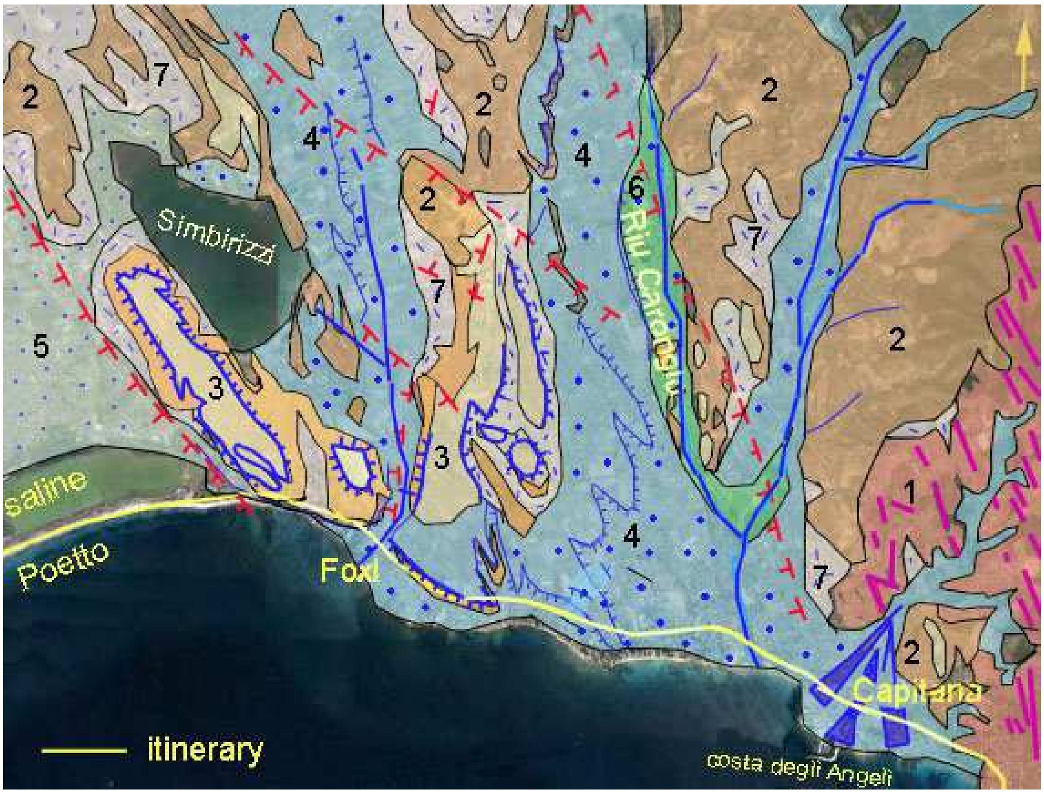

Fig.13 Schematic geomorfological map of the southeastern edge of *Rift Sardo*. 1) Paleozoic Granite basement; 2) Miocene sedimentary rocks and cuestas; 3) Pleistocene alluvial deposits; 4) Holocene alluvial terraces; 5) Holocene beach deposits; 6) Early Holocene alluvial deposits; 7) Holocene eluvio-colluvial deposits

The morphology of this area is characterized by the cuestas set on Miocene marine sediments. On top of cuestas, remains of the alluvial fans from the Sarrabus Paleozoic reliefs are found These terraced remains degrade gradually from 200 m to the sea. The quaternary deposits of alluvial fans, up to ca 10 m in thickness, that are truncated by marine cliffs and river incision. The top of the Late Pleistocene Rio Corongiu terraced alluvial fan, to the east of the Poetto beach, is preserved for ca 10 km from the apical zone (205 m), to the rear of the coastline (m. 28) (Coltorti et al. 2007). Soil with well developed argillic horizons and with profiles are locally preserved. Incised into the Pleistocene terraced deposits, there is a Holocene alluvial gravelly terrace locally containing polmonates and thin buried soil. It is cut by a coastal cliff sealed with alluvial or beach deposits (Coltorti et al. 2007).
The dates of the alluvial deposits are still limited, but it is possible that the incision of the alluvial fans had already started in the late-glacial (Allerod Bolling). The base of the subsequent alluvial units, instead, are consistent with the cold event of Younger Dryas.
The remains of the terraces are not always perfectly connectable, suggesting the occurrence of dislocations or modest fault activity after their emplacement(Coltorti et al. 2007).

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5.3 From Costa degli Angeli to Villasimius

The route proceeds along the granitic coast of Sarrabus. It is possible to see the panorama of the coast characterised by high rocky coast interbedded by small bays with beaches.

5.3.1 Stop 2. Sarrabus Granitic landscape and landforms (*Rita T. Melis*)

The Sarrabus granitic area (about 400 km^2), located at the SE extremity of Campidano graben offers a variety the landscape and landforms. Geologically the Sarrabus basement is a granite

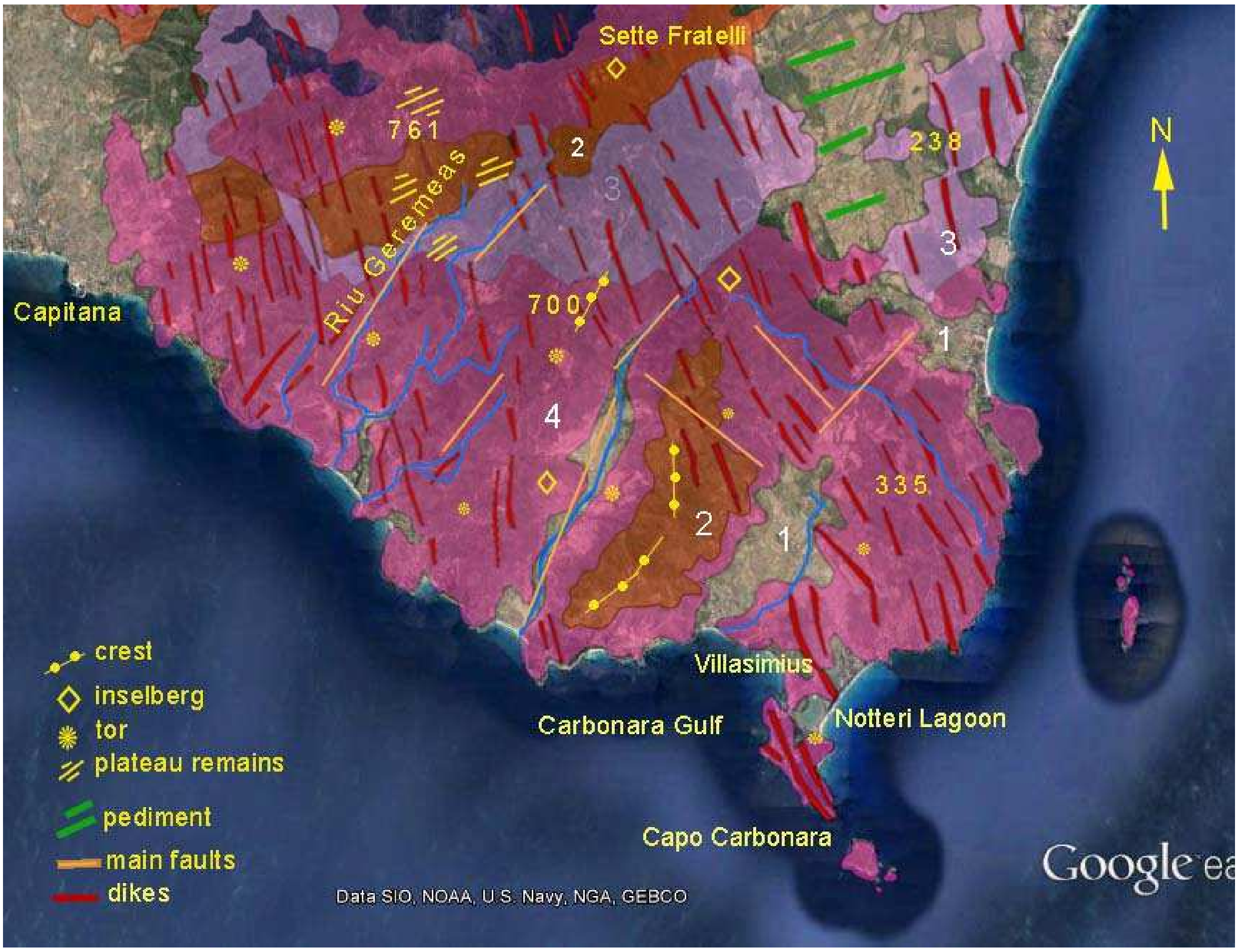

Fig 14. Schematic geomorphological map of Sarrabus. 1) eluvio-colluvium deposits; 2) leucogranites; 3) fayalite biotite granites (Mt. Sette Fratelli); 4) granodiorites

stock intruded into the metamorphic basement during Variscan orogeny and subsequently tilted during the east-rotation of Sardinia (Cenozoic). The lithology of this granitoid bodies is represented by monzogranites and granodiorites with minor amounts of gabbroic and tonalitic rock-types.

The evolution of landscape was influenced by the structural-geological context. To the east the landscape, which was tectonically lowered, is characterised by reliefs with elevations of 300 m isolated by shallower valleys, whereas the landscape to the west is characterized by high rugged reliefs (800 m), dissected by deep valleys. In this area remains of the post Variscan peneplian (plateau) are present. The difference between these two landscapes can also be noted by the different trend of the coast: high and rocky to the south-west, more irregular with numerous islands, wide bays and rocky promontories to the south and south-east.

The numerous fractures, deep weathering and water erosion have influenced the landforms: evolution: tors, crumbling boulders, rocky stone, *tafoni*, inselberg characterize Sarrabus granite landscape. The pediment surface, developed on the monzogranite and granodiorite bedrock in

the eastern landscape, is covered by weathering deposits affected by pedogenesis. It crops out in some parts or is covered by a thin layer of debris and sand. Small residual inselbergs, partly covered by prairie or thick Mediterranean scrub, emerge from the plain
To the south, in the territory of Villasimius, differential erosion processes have isolated numerous acidic dikes that dissect the granodiorites outcrops in this area. In fact, the relief crests and parallel valleys are all oriented according to the NW-SE arrangement of the dikes. This marked orientation is found also in the relief of the typical triangular promontory of Capo Carbonara, linked to the coast by sand bars in which the splendid Notteri lagoon nestles.

Fig. 15. Tors in the granitic Sarrabus landscape

5.3.2 Stop 3. Continental shelf geomorphology of Capo Carbonara Area *(Paolo Orrù)*

For what concern the morphological setting of Capo Carbonara shelf, it consists of a system of irregular surfaces that develop at different elevations. An irregular and slightly seaward sloping paleo-surface resulting from flattening of the continental shelf is visible at depths comprised between 40 and 60 metres. This surface is characterized by residual forms of tors and inselbergs that make up some of the largest rock outcrops in the area. These landforms cannot be chronologically dated with accuracy but their evolution conditions suggest they were shaped over very long time frames, probably during the pre-Quaternary period characterized by humid-hot climatic conditions and sea levels lower than today. Landforms in subaerial environments that changed more rapidly and are currently submerged include extensive tafonis with domed roof chambers; these submerged landforms occur frequently throughout the area at elevations of between –15 and –30 m. In the southern bay of the Isle of Cavoli, at an elevation of –15 m, lies an irregular erosion surface fossilized by cross laminate aeolian sandstones, with sedimentological characteristics similar to the aeolianites occurring in the coastal belt. Other strips of sub-horizontal surfaces with homogeneous characteristics are concentrated in specific bathymetric ranges. Active marine abrasion surfaces at elevations of between –1 and –3 metres, edge all the main promontories in the study area. Rising from these surfaces are acid dykes highlighted by differential erosion processes.

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5.3.3 Stop 3a. Capo Carbonara continental shelf geomorphology *(Valeria Panizza, Paolo Orrù)*

The southern margin of Sardinia is the most European forward block. The Sardinian-Tunisian and the Sardinian-Sicilian valleys run along the limit between this margin and the north of Maghrebian chain. They are the result of the Oligo-Miocene converging movements between the Sardinian block and the Kabylo-Peloritan unit (Tricart et al. 1994). Later, during the upper Miocene, all the southern Sardinian margin was affected by extensional tectonic inversion and gravity collapse. More recent tectonic movements, related to Pliocene-Quaternary opening processes of the southern Tyrrenian basin, structured the margin into several horst blocks, bounding the marginal basins of Malfatano and Cagliari, both located on subsident blocks. In particular, the Cagliari basin is located along the south eastern submarine continuation of the Oligo-Miocene Rift (Cherchi & Montadert 1982) and of the Plio-Quaternary Campidano Graben (Cherchi & Murru 1985). In the deepest sector this basin is controlled by tectonic movements in response to the opening of the Southern Tyrrenian basin. This resulted in a half graben structure with the master faults located at the foot of Sarrabus and Ichnusa horsts (Lecca et al. 1998). The relative movement of these large tectonic blocks, displaced by high-angle normal faults, has produced a series of basins located both in the actual shelf and in the continental slope.
The shelf-basin system of Cagliari receives the fluvial sediments coming from Sardinian rift, Campidano Graben, Sarrabus and Sulcis horsts. In the shelf environments these terrigenous components are accompanied by carbonate materials, typical of Mediterranean shelves. In the basin, three main shelf model have been defined:

1) The shelf of Cagliari, receiving moderate supply of sediments;
2) The shelf of Sarrabus, receiving poor sediment input;
3) The shelf of Su Banghittu, an isolated carbonate platform, receiving no sediments.

The Holocene Cagliari shelf shows an evident depositional tripartite zonation, where siliciclastic littoral sands exist in the inner part, *Posidonia oceanica* biocoenosis produces large amounts of bioclastic sediments in the middle part and distal sandy muds slightly prograding close to the shelf edge.
The shelf-to-basin transition is constituted by a slightly prograding wedge subject to canyon tributary system erosion and gravity induced processes. Canyons are characterized by average width of about 1-2 Km and depth of up to 100 m. The canyon system includes, from west to east, the Pula Canyon, the Sarroch Canyon and the S. Elia-Foxi Canyon, all tributaries of the north-east south-western major system of the Carbonara Canyon, in direct connection with Sardinian-Tunisian Canyon. The turbidity currents, channelized in the canyon heads, flow towards the deepest zones with tractive energy. The well incised valley of Carbonara Canyon indicates that the channelized transport along this canyon is the most active sediment discharge of the basin.
In the upper continental slope sector there are significant size gravitational phenomena, in particular were found two main systems, generated by various events which affects not only the upper slope but also the shelf edge area.
These landslides interests large volumes of sediments, in order of tens of millions of m3 each, showing deposits characterized by gibbous surface and creep which spills over the landslide foot,

inside the erosive meandering canyon system. In the sparker seismic record is shown a system of normal faults that displace sediments related to the Plio-Pleistocene depositional series. The morphological high of "Banghittu "is a residual strip of continental shelf located in the central sector of the Gulf of Cagliari. The edge of the relief is affected by gravitational movements involving the bedrock; the resulting deposit mainly consists of blocks of considerable size (up to 250 m) (Deiana et al., 2012).

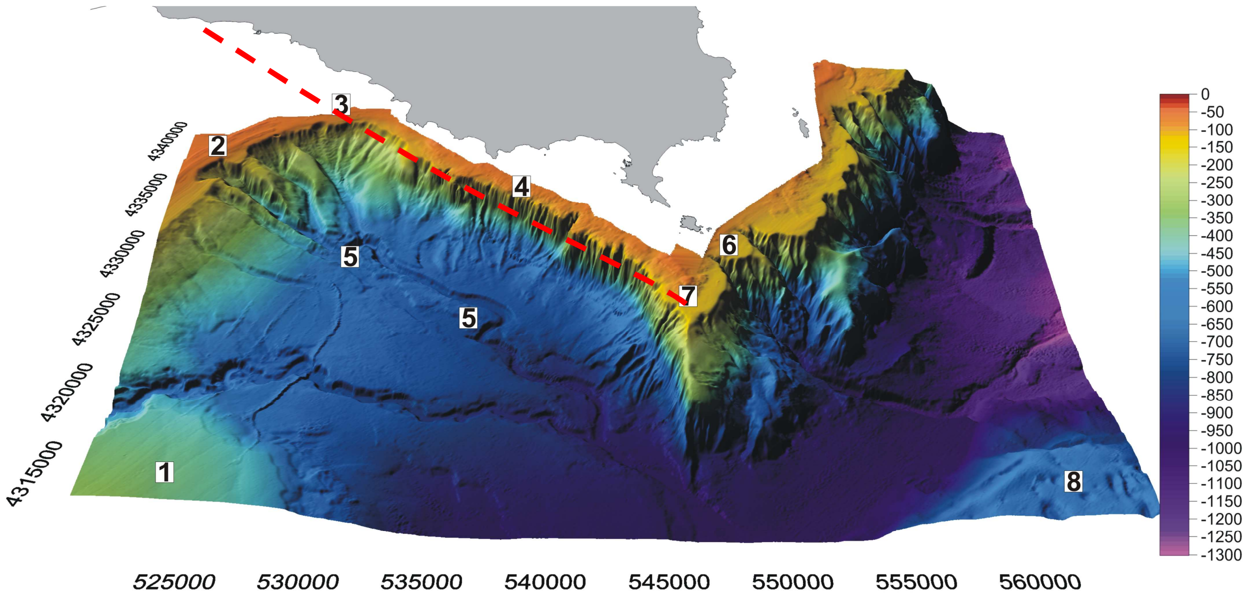
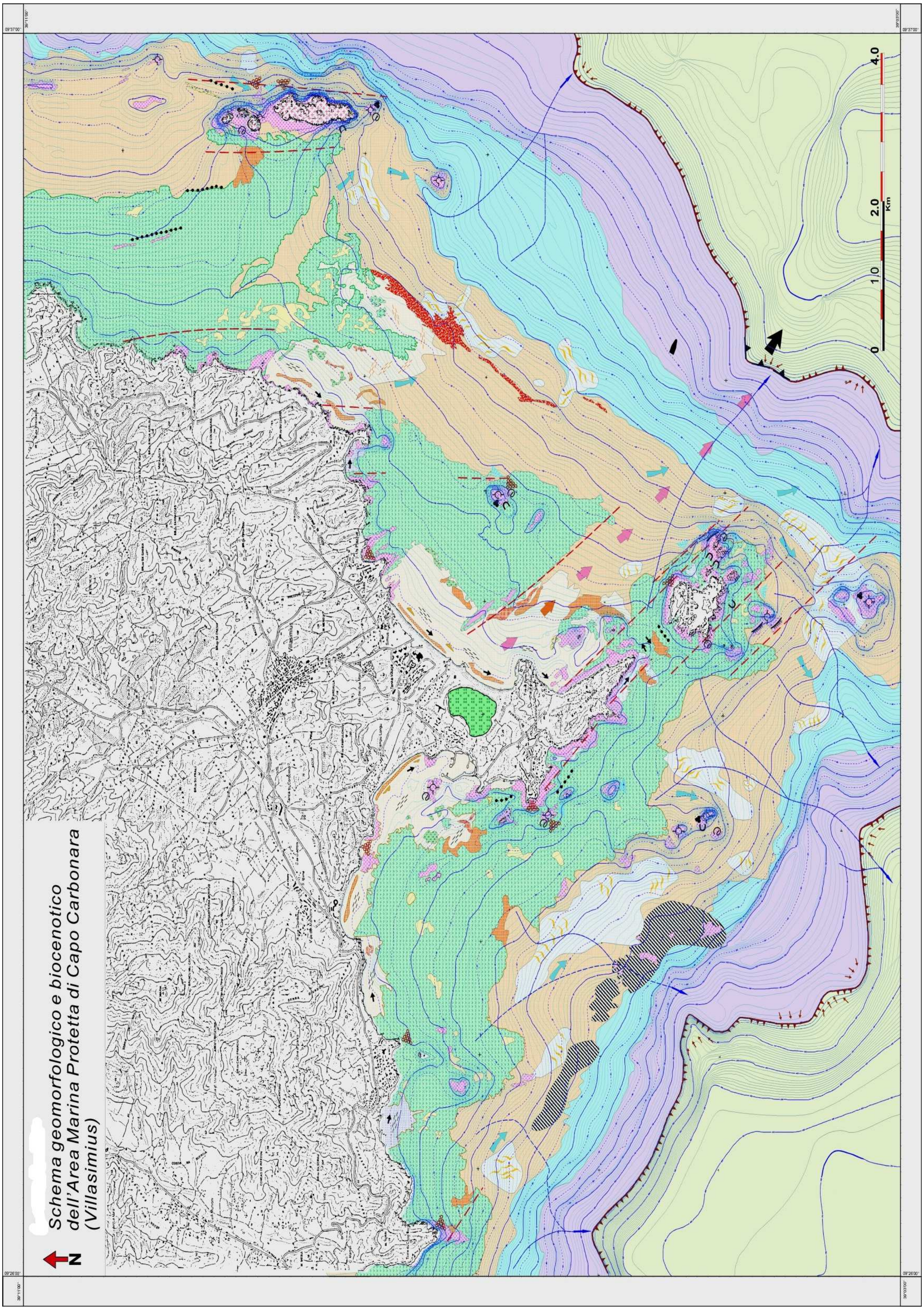


Fig. 16. Geomorphological features of the Eastern sector of Cagliari Gulf - Capo Carbonara – DTM from MAGIC Project data: 1)Banchittu's residual strip of continental shelf; 2) Sant'Elia canyon headscarp, indented to the continental shelf for about 900m, reaches the depth of -80m, showing inside a creeping surface; 3) Foxi canyon headscarp were can be observed gravitative movements and "crescent-shaped bedforms"; 4) The fault wall, set above the continuation on the continental shelf of a Campidano graben's eastern side fault, is affected by diffused erosive processes on the edge; 5) Carbonara canyon's meandering bed; 6) Simius canyon headscarp; 7) The continental shelf edge lies at the average depth of -120m; 8) The Ichnusa Seamount.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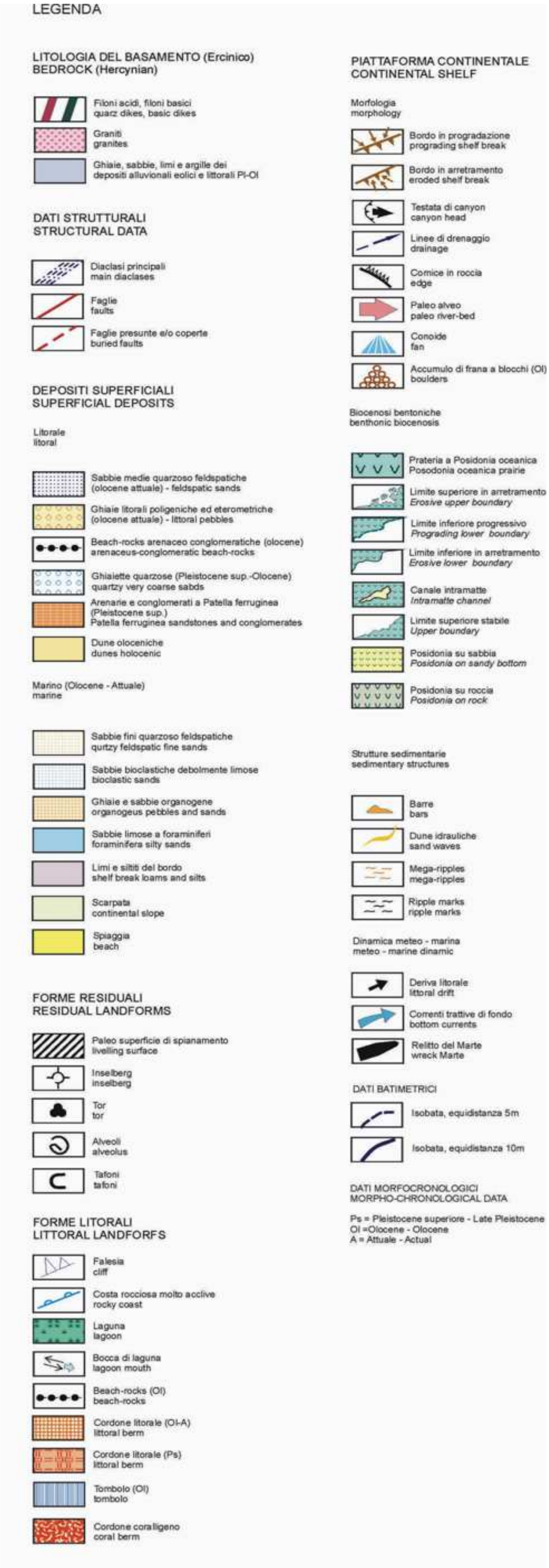

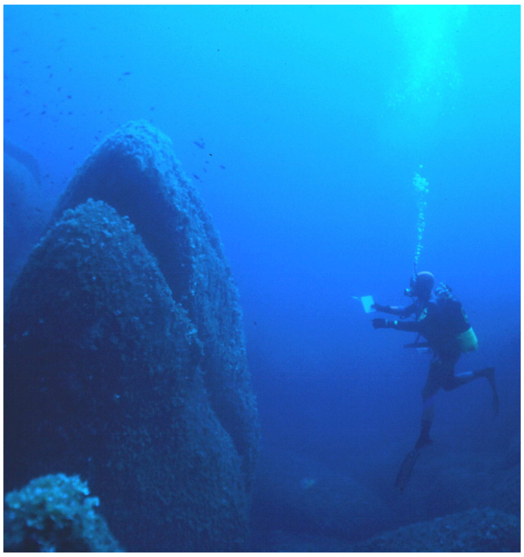

Fig. 17. Simius Bay – Berni shallow. Diving image at – 15 m. Residual pinnacles and sub-spherical blocks on the border of Tor relief.

Fig. 18. Serpentara Island – East coast. Diving image at – 25 m. Subvertical fault surface.

5.3.4 Area marina protetta *(Fabrizio Atzori)*

"Capo Carbonara" Marine Protected Area was established by Ministry of the Environment and Protection of land and sea, by means of the Ministerial Decree issued on September 15th, 1998, amended in 1999 and then overwritten by the Ministerial Decree issued on February 7th, 2012 (Official Gazette n° 113 on May 16th, 2012). The Marine Protected Area is entrusted the management to Villasimius Municipality. Capo Carbonara Marine Protected Area is located in the south-eastern portion of Sardinia. The area includes the coastline extending from Capo Boi, in the western sector within the Gulf of Cagliari, to Punta Is Proceddus at north-east. The MPA is divided in three zones with different degree of protection: the Zone A (4% of the entire area) is the integral reserve (no-take, no-entry zone); the Zone B or general reserve (14%) is the buffer or restricted use zone; the Zone C or partial reserve (82%) is the multiple use management zones. The two main rocky islands, Cavoli and Serpentara, are respectively the southernmost and easternmost portions of the coast. A number of rocky islets and submerged reefs are scattered all around the coast and main islands: Piscadeddus, S. Stefano, S. Caterina, S. Elmo, Berni are the most relevant. The coastline is washed by both the Sardinian Channel and the Southern Tyrrhenian Sea and it has different degrees of exposure to winds and waves. The coastal morphology is irregular and articulated, with rocky granitic cliffs, blocks, boulders and pebbles alternated by large and small beach systems. A small, inland barrier lagoon (Notteri lagoon, about 34 ha), adjacent to the MPA and separated to the sea by a small sand barrier, is the most important wetland spot for migratory birds. The landscape in the Capo Carbonara-Villasimius area is mostly dominated by the presence of morphological highs, where granite is the main lithology. These features are broadly observed all along the coast of the MPA, shaping the landscape with large portions of rocky coastline. Granite rocks are subjected to a characteristic alteration named hydrolysis and its derived morphologies (such as tors, inselberg, tafoni, split and caves), particularly in the main islands; it is also remarkable, due to the previously mentioned selective alteration of silicates, the occurrence of quartzo-felsphatic beaches and wide dune systems. In the coastal area of interface between the continental and submerged environment, the main components of the geo-environmental system of beaches are: i) secondary dune systems, mainly stabilized with natural or artificial vegetation; ii) primary dune systems; iii) emerged beach areas; iv) wet systems of backshore and river mouth.In the submerged area, several geo-environmental systems have been recognized by morpho-sedimentary features: i) wide submerged beaches, with quartzo-felsphatic sands, medium to fine granulometry; ii) sandy deposits mixed with rocky bottoms and extensive beach-rock formations at different depths (-27 m; -35 m, -45 m), with a locally high content of biogenic grains (rhodoliths and free melobesiae); iii) rocky bottoms corresponding to old terraces of abrasion colonized by marine vegetation; iv) rocky outcrops emerging from the seabed corresponding to surfaces generated by marine abrasion. The presence of particular granitic morphologies (such as tors, inselberg, split and caves) as well as extensive Posidonia oceanica meadows on both sandy and rocky beds, increases the seascape value and offer a number of niches, hides, nest and nursery areas for marine flora and fauna. Due to the high level of habitat heterogeneity and complexity, fish abundance and species diversity are also significant.The coastal area immediately adjacent to the sea as well as the main islands, Cavoli and Serpentara, are home for a number of terrestrial habitat and species that are relevant for conservation purposes; actually, these coastal areas are part of Special Protection Areas and Special Areas for Conservation of Natura 2000 Network.

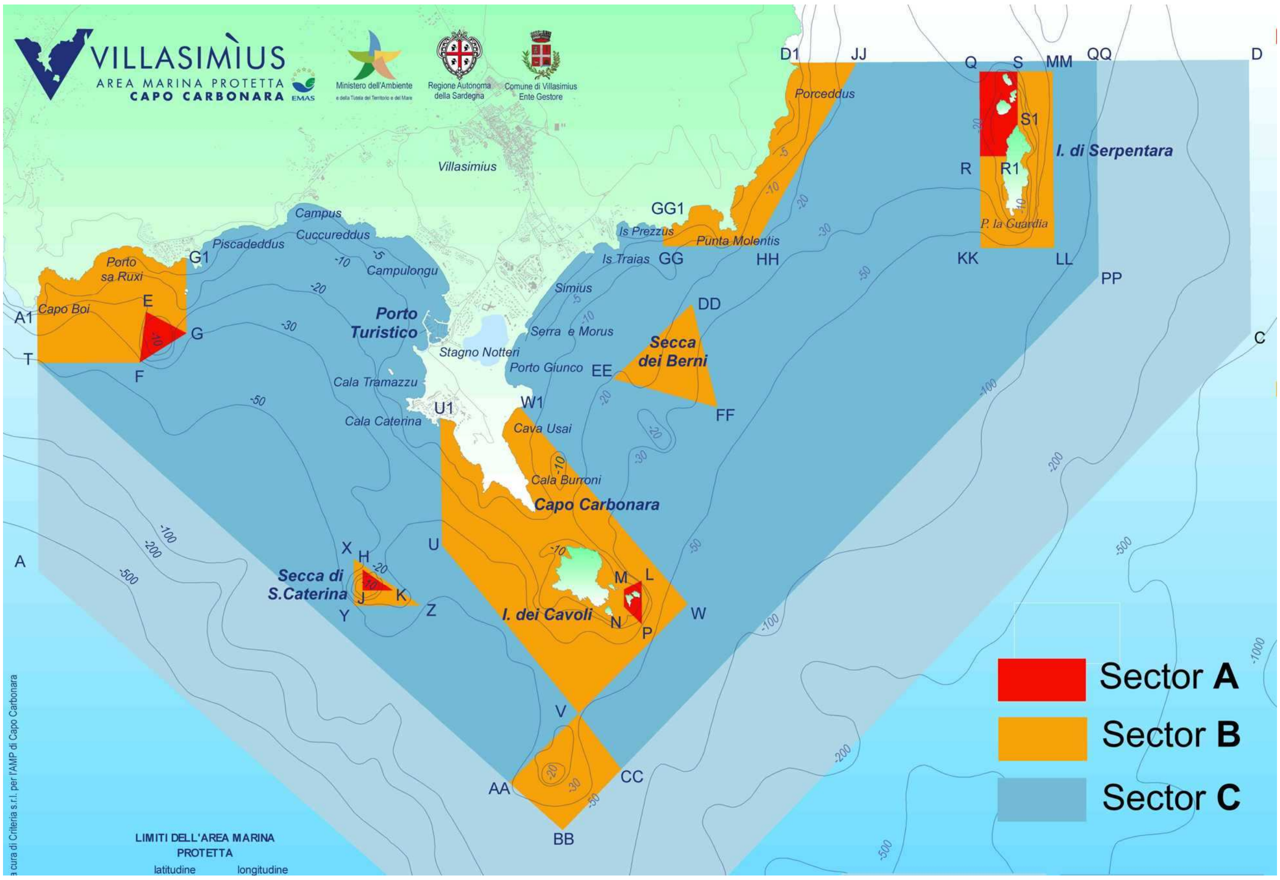

Fig. 19 . Map of Capo Carbonara Marine Protect Area.

5.3.5 Stop 3b – Littoral Upper Pleistocene of "Cave Usai" *(Paolo Orrù)*

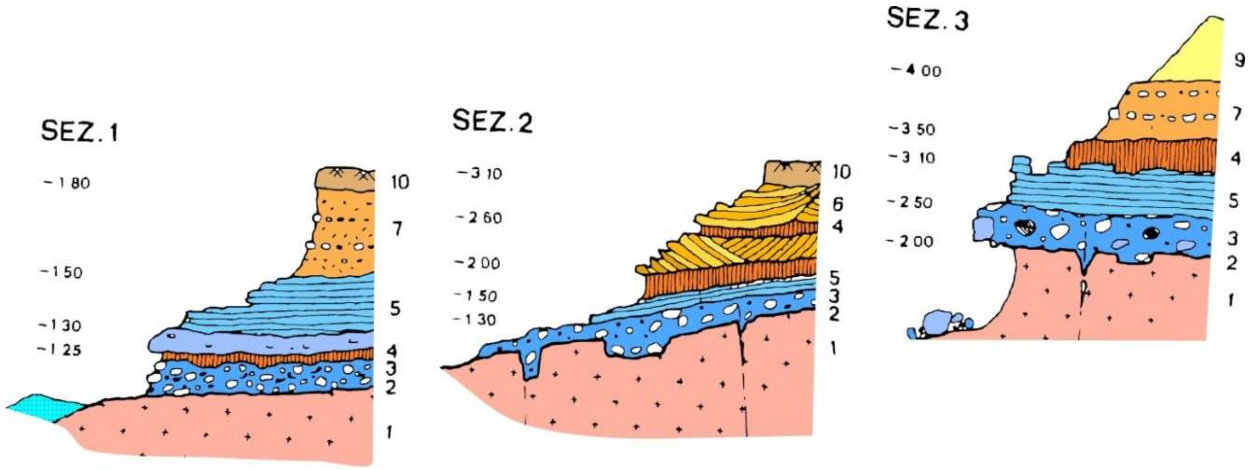

Fig. 20. Stratigraphic sections of Pleistocene deposits of Capo Carbonara and "Cave Usai": 1) crystalline granitic substratum and differentiated dikes; 2) irregular erosional marine surfaces at + 4m; 3) polygenic coarse heterometric conglomerates, and microconglomerates with fossil remains – (MIS 5.5) ; 4) redden clyey palaeo-soil, by warm-humidc subaerial stasis; 5) high beach laminated sandstones (MIS 5.5); cross laminated aeolian sandstones, fossil dunes of cold climatic (MIS 2 ?); Holocenic slope and aeolian deposits; 9) aeolian present dune; 10) present soil.

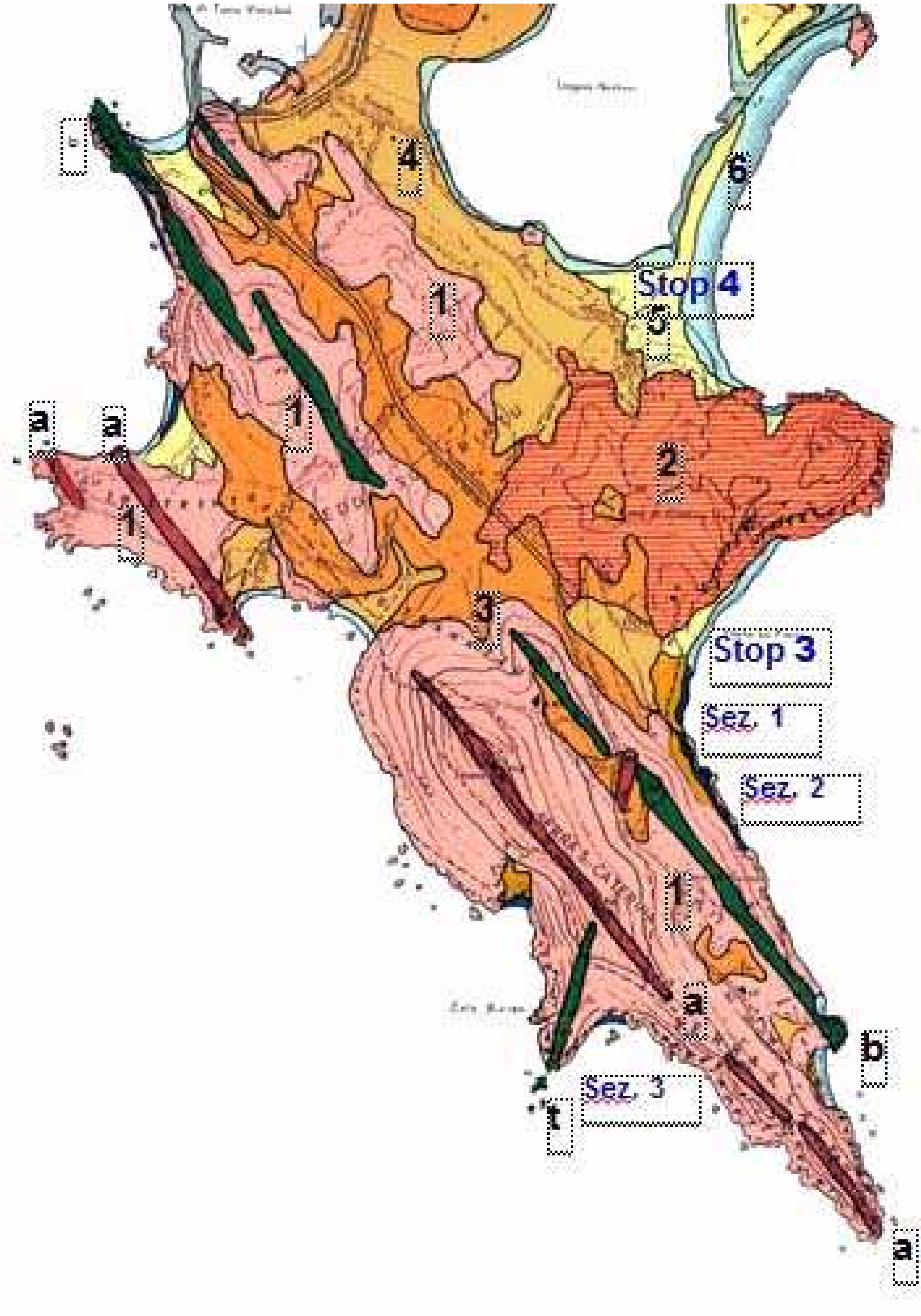

Fig. 21. Capo Carbonara (Villasimius) Geological scheme: **1**) granodiorite; **2**) leucogranite; **a**) acids lodes ; **b**) basic lodes; **t**) tourmaline lodes; **3**) alteration granite deposits deposits; **4**) aeolian deposits (Pleistocene); **5**) sand dune (Holocene current); **6**) littoral sands.

5.3.6 Stop 4 - Porto Giunco lagoon-barriere system and aeolian morphology

(Giacomo Deiana,)

5.3.6.1 *Aeolian morphologies (Porto Giunco)*

Porto Giunco beach consists of a sandbar which extends for about 800 meters NE-SW oriented, which borders the rear Notteri pond area, unique relevant wetland detectable inside Simius Porto Giunco-Is Traias physiographical unit. The northern and southern limits of the beach are defined by the presence of granitic lithologies promontories.

In particular Porto Giunco littoral system consists of:

-Backshore: the beach has an extended backshore area characterized by the presence of the pond of Notteri. In the southern sector is detected a wide area of dunes, partly affected by the presence of both psammophilic and shrub vegetation.

The dunes area with loose wind sediments, it is home to naturalistic engineering and triangular plant cells.

- Foreshore (Emerged Beach): the body of the beach, is characterized by medium and fine siliciclastic sands mainly originated from the decomposition of granitic lithologies; locally at the shore line cusps of coarser sediments can be found, granitic substrate outcrops in the extreme north and south of the beach.

- Shoreface (Submerged beach): is characterized by the presence of coarse to fine siliciclastic sands; its limit to offshore is defined by the presence of the upper limit of the *Posidonia oceanica* meadow.

Fig. 22. Ortophoto A.I.M.A. 2008 RAS of Porto Giunco coastal area.

5.3.6.2 Critical issues related to the presence of man-made structure

The development of the coastal dunes is determined by a number of environmental factors, among which, to a larger scale will recognize the availability of the sediment, the variation in the sea level, the conditions of both the emerged and submerged beach, and not last in importance, even the tectonic and structural area (Carter et al, 1992); on shorter space and time scales (months, years and especially the scale of the individual apparatus dune), the availability of sediment is probably the most important factor of control, while at the regional level and on time scales larger (centuries and millennia) the change in sea level becomes the discriminating factor (Carter, 1988).
The morphology of a coastal dune is mainly controlled by two factors: the amount of available sand for deflation processes (determined by the processes agents on the beach and function especially of the Effective Fetch), and the degree of interaction between the campaign plan (including its natural irregularities in terms of roughness - roughness), and the wind.
Here we can observell typical morphologies can be finded, those ephemeral aspect of the upper beach (avanduna) to the more stable and consolidated innermost (dunes stabilized by psammophilic and shrub vegetation).

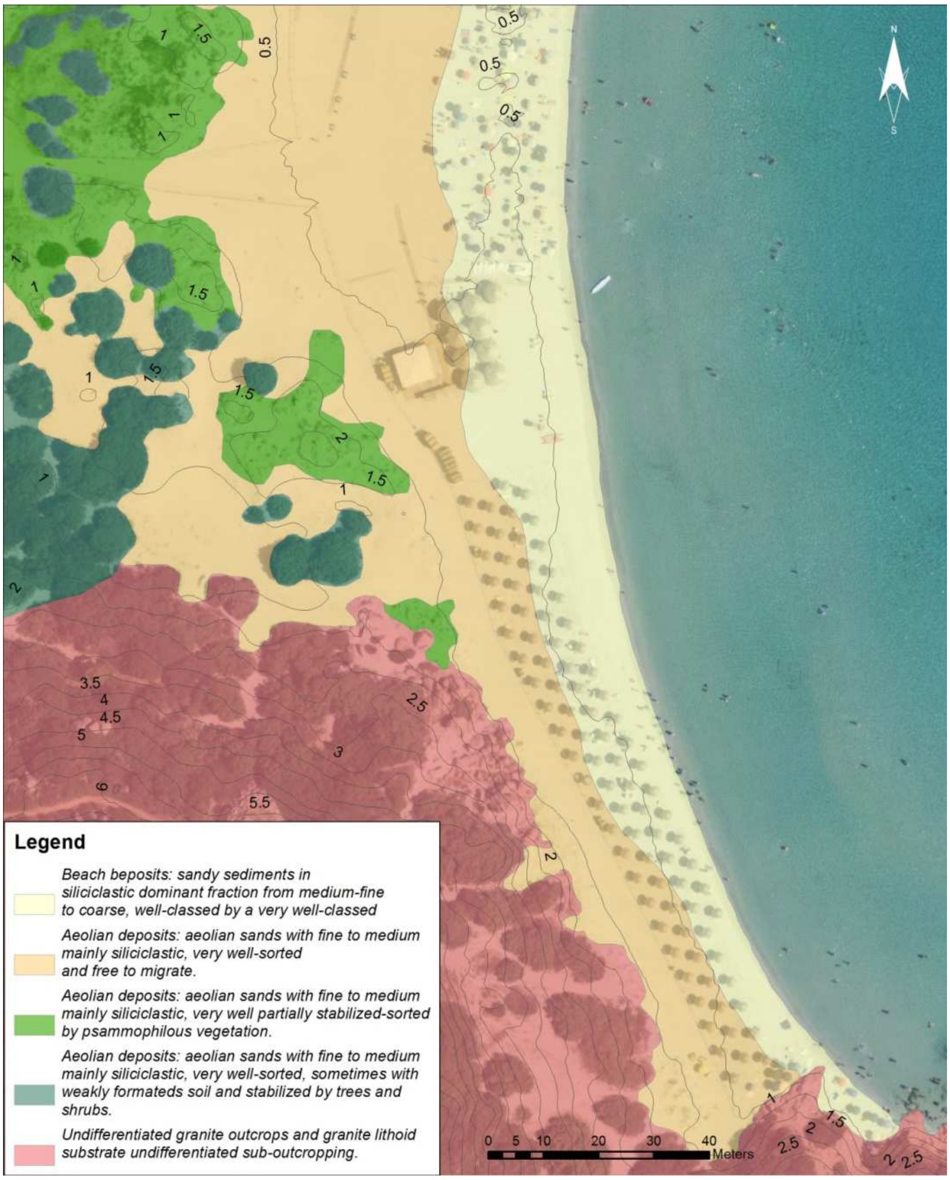

Fig. 23. Schematic geomorpholgical map, 1: 1000 scale of the southern sector of Porto Giunco beach based on AIMA 2008 R.A.S. orthophotos. Contour lines with equidistance 0.5m made based on DTM RAS cell with 1 m.