Il Quaternario
Italian Journal of Quaternary Sciences
***18**(1), 2005 - Volume Speciale, 257-266*

MAP OF THE GEOLOGICAL AND GEOMORPHOLOGICAL SITES OF THE MALFATANO COAST IN SW SARDINIA: A CONTRIBUTION TO THE KNOWLEDGE OF THE ISLAND'S GEODIVERSITY

Cataldo Cannillo, Felice Di Gregorio & Antonio Eltrudis
Dipartimento di Scienze della Terra - Università degli Studi di Cagliari
Laboratorio di Geologia Ambientale - Via Trentino, 51 - 09127 Cagliari – geoam@unica.it

ABSTRACT: C. Cannillo *et al.*, *Map of the geological and geomorphological sites of the Malfatano coast in SW Sardinia: a contribution to the knowledge of the Island's geodiversity*. (IT ISSN 0394-3356, 2005).
The area between Cape Malfatano and Cape Spartivento is emblematic of Sardinia's geology, especially with respect to the Palaeozoic basement, whose lowermost part, the Bithia formation (Precambrian-lower Cambrian?), crops out in this sector. Compared to the tectonic setting typical of the outer zone of the Sardinian segment of the South-European Hercynian chain, this sector constitutes an anomaly, in which the metamorphism and deformation are more pronounced than in the Sulcis-Iglesiente region as a whole. Another interesting feature of this area is the granitoid rock outcrop (Cape Spartivento orthogneiss) dated to the Sardic Phase of the Middle Ordovician that, elsewhere in the Sardinian Hercynian basement, is represented essentially by volcanic products.
The geosites have been classified according to genetic processes (stratigraphic, metamorphic, magmatic, structural) whose importance has been evaluated on the basis of their being exemplary of geological evolution, of their chronostratigraphic, palaeoenvironmental and educational value.
Based on these criteria a number of geosites have been identified, where the following features can be observed:
- the Cape Spartivento orthogneiss, of special interest because of the effects created by intense Hercynian deformation (penetrative schistosity with pronounced stretching lineation of the deformed crystals);
- the lithologic sequences of the Bithia Formation, with mylonitic and cataclastic bands, outcrops of stretched pebble metaconglomerate, again produced during Hercynian deformation phases, and layers of metalimestone;
- the significant genetic, magmatic and lithologic aspects of Hercynian granites;
- the intrusive relationships of the Hercynian granitoid rocks with the metamorphic basement and of later dyke intrusions intersecting the contacts;
- ductile deformation structures in the Hercynian basement with multiphase folding especially at the mesoscopic scale;
- brittle deformation structures sometimes with well exposed slickensides and slickenside striae;
- unconformity between the Hercynian basement of the Bithia Formation and the conglomerate and eolianite deposits, evidence of ancient marine levels and palaeoclimates during the Late Pleistocene different to present day climates.

The geomorphological sites identified in the area have been grouped together according to the genetic processes that created them (fluvial, meteoric, gravitational, littoral, eolian, etc.).
On the map a symbol is used to denote the type of geomorphological site (point, linear or areal) defined according to its physical features and level of importance (local, regional, etc.). Sites are numbered and a brief description is provided.
The level of importance has been assigned according to the following evaluation criteria:
- exemplary of geomorphological evolution;
- palaeo-geomorphological evidence;
- educational value;
- scenic value.

As for the geographical and physical features, the geomorphological forms in the Malfatano area were created largely by littoral, eolian, fluvial, slope and gravitational processes, influenced by littoral processes.
A number of areas have also been delineated on the map that stand out not so much for their specific forms but rather for their landscape qualities and geomorphological interest as a whole. These include the Malfatano Ria, a cove where the coastline is submerging, the Bay of Tuaredda and some tracts inland, the extension of the submarine relief, characterized by ridges, peaks, deep incisions and bizarre forms of erosion on meta-sandstone and meta-siltstone, granite and orthogneiss.
The map of the geological and geomorphological sites described summarizes the results of a comprehensive investigation that entailed accurate small scale surveying and photointerpretation of the geo- and geomorphic sites along the Malfatano coast. A number of interesting examples have been identified that are evidence of the area's significant geodiversity.

RIASSUNTO: C. Cannillo et al*.,* Carta dei geositi e geomorfositi della costa di Capo Malfatano nella Sardegna sud-occidentale: un contributo alla conoscenza della geodiversità dell'isola*. (IT ISSN 0394-3356, 2005).*
L'area tra Capo Malfatano e Capo Spartivento rappresenta un settore emblematico della geologia della Sardegna, soprattutto per quanto riguarda il basamento paleozoico, di cui affiora la parte basale, costituita dalla Formazione di Bithia (?Precambriano-Cambriano inf.). Questo settore, infatti, costituisce un'anomalia nel quadro metamorfico-deformativo che caratterizza la Zona Esterna del segmento sardo della catena ercinica sud-europea, in quanto presenta un metamorfismo ed una deformazione più accentuati, rispetto a quelli della più ampia regione del Sulcis-Iglesiente.
Un altro aspetto che rende l'area particolarmente interessante è la presenza di affioramenti di rocce granitoidi (Ortogneiss di Capo Spartivento) riferibili alla Fase Sarda dell'Ordoviciano medio che, altrove, nel basamento ercinico della Sardegna, manifesta essenzialmente prodotti vulcanici.
La classificazione dei geositi è stata effettuata in base ai processi genetici (stratigrafico, metamorfico, magmatico, strutturale) nell'ambito dei quali si è operata una valutazione sulla base dell'esemplarità evolutiva geologica, dell'interesse cronostratigrafico, paleoambientale e dell'esemplarità didattica.
In base a tali criteri è stato individuato un certo numero di geositi nei quali è possibile osservare:
- *gli Ortogneiss di Capo Spartivento, interessanti soprattutto per gli intensi effetti deformativi riconducibili alle fasi tettoniche erciniche (scistosità penetrativa con marcata lineazione di allungamento dei cristalli deformati);*
- *le sequenze litologiche della Formazione di Bithia, con fasce cataclastico milonitiche, affioramenti di metaconglomerati con fenomeni di allungamento di clasti, sempre per effetto delle fasi deformative erciniche e livelli di metacalcari;*

- gli aspetti significativi degli affioramenti di graniti ercinici, genetici magmatici e litologici;
- i rapporti intrusivi dei granitoidi ercinici con il basamento metamorfico e quelle delle successive intrusioni di corpi filoniani che ne intersecano i contatti;
- le strutture deformative duttili nel basamento ercinico, presenti con pieghe polifasiche soprattutto alla scala mesoscopica;
- le strutture deformative fragili presenti talora con specchi di faglia ben esposti e relative strie;
- la discordanza tra basamento ercinico della Formazione di Bithia e depositi conglomeratici ed eolianitici che testimoniano antichi livelli marini e paleoclimi del Pleistocene superiore differenti da quelli attuali.
I geomorfositi rilevati nell'area sono stati raggruppati sulla base del processo genetico che ha determinato la loro formazione (Fluviale, Meteorico, Gravitativo, Litorale, Eolico, ecc.).
Ciascun geomorfosito è indicato sulla Carta da un simbolo che identifica il tipo (puntuale, lineare o areale) in funzione delle caratteristiche fisiche, ed il livello di importanza (locale, regionale, ecc.). Un numero di identificazione rimanda ad una specifica descrizione sintetica.
Il livello di importanza è stato definito in base ai seguenti criteri di valutazione:
- esemplarità evolutiva geomorfologica (processi);
- testimonianza paleo-geomorfologica;
- esemplarità didattica (forme);
- valenza scenica.
In relazione alle caratteristiche geografico-fisiche, nell'area prevalgono numericamente i geomorfositi ricondicibili a processi litorali, eolici, fluviali e di versante, gravitativi con influenza di processi litorali.
Nella Carta sono state anche delimitate alcune aree che si distinguono non tanto per le specifiche forme presenti, quanto per il loro interesse paesaggistico e geomorfologico d'insieme. Tra queste, la Ria di Malfatano, insenatura testimoniante l'evoluzione di una costa di sommersione, la Baia di Tuaredda e alcuni tratti dell'entroterra caratterizzati dall'evoluzione subaerea del rilievo, con crinali, culminazioni, incisioni vallive e peculiari su metarenarie e metasiltiti, graniti e ortogneiss.
La Carta dei geositi e dei geomorfositi rappresenta la principale sintesi grafica di un'analisi integrata condotta tramite accurati rilevamenti di dettaglio e fotointerpretazione dei geositi e dei geomorfositi dell'area costiera di Malfatano, ove sono stati riscontrati interessanti elementi che ne documentano una elevata geodiversità.

Keywords: Geosites, Geomorphosites, Geodiversity, Malfatano coast, South Sardinia.

Parole chiave: Geositi, Geomorfositi, Geodiversità, Costa di Malfatano, Sardegna meridionale.

1. INTRODUCTION

The purpose of this work is to illustrate the map of the geological and geomorphological sites of the Malfatano coast in SE Sardinia. The map, which is one of the first examples of its kind on a large scale, has been drawn up using data gathered from accurate field observations and from photointerpretation which formed the basis for the identification, classification and evaluation of the different sites of geological and geomorphological interest.

2. GEOLOGICAL-STRUCTURAL FEATURES OF THE HERCYNIAN BASEMENT IN SARDINIA

A complete section of the Southern European Hercynian chain crops out in Sardinia (which forms its ancient basement) stretching from the outer zones in SW Sardinia to the inner zones, cropping out in the NE of the island. The NW-SE trending chain is characterized by shortening and by a tectonic-metamorphic zoning typical of orogenesis resulting from continental collision. The polarity of metamorphic rocks changes gradually from the anchizone in SW Sardinia to the amphibolite facies in the NE, accompanied by an equally well-defined change in structural style.

Structurally the bedrock is characterized by SW striking Hercynian thrust (Carmignani *et al.*, 1987), interposed between the metamorphic complex for the most part in the amphibolite facies of N Sardinia and a highly deformed but essentially autochthonous outer zone with thrusts and folds that crop out in the SW of the island.

In the outer zone, which crops out extensively in the Iglesiente region, the pre-Middle Ordovician succession attests to the passage from a lower Cambrian terrigenous shelf (Bithia Formation, Nebida Formation; Cocozza, 1979) interbedded with basic-to-intermediate volcanic rocks likely associated with simultaneous rifting, to a lagoonal environment with oolitic bars (uppermost part of the Nebida Formation).

The mostly terrigenous sediments of the Nebida Formation pass upwards into the thick carbonate sequence of the Gonnesa Formation, composed of tidal flat dolomites and limestones, broken up by extensional tectonics into basins and structurally high areas (Rasetti, 1972; Gandin *et al*., 1974; Boni & Cocozza, 1978; Vai, 1982; Cocozza & Gandin, 1990). This formation is overlain by the Cabitza Formation that demarcates drowning of the carbonate shelf (Gandin & Pillola, 1985; Cocozza & Gandin, 1990).

3 THE OUTCROPPING PALAEOZOIC BASEMENT OF MALFATANO AREA

3.1 Bithia Formation

The most extensive part of the study area is composed of a succession of metamorphic rocks belonging to the Bithia Formation that crops out in the SW tip of the island along a narrow belt girding the Cape Spartivento orthogneiss. Because of intense tectonization, the actual thickness of this formation is uncertain though apparent thickness is more than 600 m.

This is a siliclastic succession composed largely of phyllite, metaquartz arenite and metasandstone interbedded with metaconglomerate and marble.

Outcrops of metaconglomerate up to a few metres thick are located near to the coast between Punta de s'Ega de su Tramatzu and Cala de su Senzu, originally poorly sorted polygenic conglomerate. The

highly deformed clasts, embedded in an arenite quartz-feldspar matrix, are composed mostly of fragments of grey and black (lydite) quartzite from vein quartz. Outcrops of pale grey marble are scattered throughout the area. These range from the metre-thick layers near Sa Bidda Beccia, Monte Corilla, P.ta de Isurderas to 15-20 m thickness at Cape Malfatano. The Bithia Formation is interpreted as a regressive trend terrigenous succession that formed on a continental margin (Junker & Schneider, 1983; Gandin, 1987; Gandin *et al*., 1987). A very low grade, upward decreasing (Junker & Schneider, 1983) Hercynian metamorphism has been described for this formation (Palmerini & Palmerini Sitzia, 1978).

Based on its stratigraphic position beneath the InfraCambrian Nebida Formation (Junker & Schneider, 1979; Minzoni, 1981; Carannante *et al.*, 1984), and on the correlations with Precambrian formations elsewhere in Europe, the Bithia Formation has been dated to the Upper Precambrian (Cocozza, 1979). A tentative Precambrian age has also been reported based on a few poorly preserved acritarchs (Pittau Demelia & Del Rio, 1982), though the echinoderm plates discovered within the interbedded carbonate rocks also suggests a lower Cambrian age (Gandin, 1987).

On the whole, the main schistosity of the Bithia Formation forms a dome (Cape Spartivento dome) with a radius of roughly 10 km and gently north-dipping axis. In the middle of this dome-like structure the more strongly metamorphosed complex crops out.

Carmignani *et al*. (1994) interpret the dome at Cape Spartivento as the metamorphic core complex which formed following a major deformation phase associated with the crustal thickening resulting from tectonic shortening during the Hercynian, which occurred in the rest of the Outer Zone.

3.2 Cape Spartivento Orthogneiss

The orthogneiss crops out near to Cape Spartivento and Tuaredda, and is also referred to in the literature as “Monte Filau orthogneiss”. These orthoderivatives in amphibolite facies of granitoids, dated to the Ordovician magmatism that affected the whole island, were transformed into orthogneiss by the Hercynian tectonic-metamorphic event as the radiometric age of 280 Ma determined for the biotite indicates. The U-Pb zircon age of 478±16 Ma for the orthogneiss (Delaperrière & Lancelot, 1989; 449 Ma: Ludwig & Turi, 1989), dates these magmatites to the Ordovician.

The orthogneiss complex at Cape Spartivento intrudes into the M. Settiballas schists and is tectonically related with the overlying Bithia Formation (Sassi & Visonà, 1989; Sassi, 1990).

The gneiss formation is composed largely of medium-to-coarse grained orthogneiss having a schisty-augen texture in which the quartz and K-feldspar phenocrystals, with grain size normally over 1 cm, are oriented in the same direction and embedded in phylosilicates (biotite and to a lesser degree muscovite). Centimetre-to-metre size fine-grained banded aplitic gneisses (original dykes) also occur within the orthogneiss. These contain fusiform blackish andalusite aggregates that give rise to a pronounced stretching lineation and blastomylonitic and cataclastic gneiss. The latter forms the outermost portions of the gneiss body, in direct contact with the overlying Bithia Formation.

The Cape Spartivento orthogneisses crop out regularly throughout the central-eastern part of the study area and in a few isolated outcrops, including those near to the Padiglioni islet.

3.3 Hercynian magmatism

The Hercynian magmatism is represented both by intrusive rocks and dyke complexes. The intrusive rocks are essentially granodioritic and leucogranitic in composition, the former cropping out in the southern part of Capo Spartivento, the latter in the northern part. The sub-vertical chiefly NW-SE trending dyke complex, which intrudes the metamorphic basement and the Hercynian granitoid rocks, is composed of sporadic quartz, rhyolite and andesite-basalt dykes.

4. QUATERNARY DEPOSITS

The oldest outcrops of Quaternary deposits in the area are dated to the Upper Pleistocene and are represented by the “ancient alluvia” and marine-littoral sediments. The predominantly alluvial cone/plain fluvial sediments consist of more or less compacted conglomerate, gravel and sand often with abundant reddish silty-clay matrix. In the areas comprised between the hills and the small coastal plains these deposits are reincised and terraced. This coarse clastic material contains angular or slightly rounded on average centimetre to decimetre sized clasts within an abundant reddish clayey-ferruginous matrix. They are believed to have been deposited in wet and cold climatic conditions by glacial runoff during the Pleistocene. On the pediment (or *erosion glacis*) developed mostly on Palaeozoic crystalline rocks, these debris aprons are fairly discontinuous and thin (from a few decimetres to a few metres thick).

Locally, in the most sheltered coves, marine-littoral sediments of the Tyrrhenian have deposited directly on the Palaeozoic basement, generally perched up to 3-4 m above the actual sea level (“Strombus-containing Tyrrhenian Bench” Auct.) (Vardabasso, 1956; Ulzega & Ozer, 1982), composed of conglomerate and calcareous cemented sandstone and biocalcarenite, generally containing a warm sea fossil association of lamellibranchs, gastropods, coelenterates, algae. The Tyrrhenian marine deposits were followed by a regressive phase represented by eolian Würmian sediments with interbedded palaeosoils. Outcrops of fossil dunes of Würmian age occur especially in proximity of Cape Malfatano and around the Piscinnì Tower, where there is interesting and clear evidence of an ancient Roman quarry. Numerous blocks of these hardened dunes were removed in Roman times.

Holocene deposits consist above all of valley floor and alluvial plain gravel-sand deposits, of beach sands and gravels, of backbeach eolian sands (Tuaredda Cove), in some places with dune formations extending a few kilometres inland, and of the silty-clayey deposits of the Malfatano lagoon. The angular detritus and more or less coarse detritus deposits at the foot of the steepest slopes can also be dated to the Holocene.

5. GEOMORPHOLOGICAL FEATURES

The topography of the study area, along the coastal belt and inland, is hilly to mountainous, though of moderate elevation, below 400 m. However energy levels are fairly high on account of the alternation of mountainous/hilly areas with fluvial incisions, in some places narrow and deep with steep rocky slopes, in others taking the form of broad valleys or ledges with almost flat or gently sloping bottom. Some of these valleys taper into the sea and in the coastal belt often give way to marshland and lagoons (Stagni di Pianu Spartivento, Stagno di Piscinnì) bounded seawards by littoral ridges bordering small beaches and sand dunes. The terrain is extremely varied, featuring rocky headlands (e.g. Capo Malfatano and Schiena del Siciliano), wide bays and small coves with sandy and pebbly beaches, some with islets of various sizes a short distance from the shore.

The drainage pattern is prevalently sub-dendritic and/or centripetal, locally angular where it follows the existing tectonic lines. The streams are small and ephemeral.

The main geomorphological structure in the area is the roughly N-S trending flat-bottomed valley depression (Malfatano), a little over 1 km wide, which stretches for 4 km down towards the sea into a deep cove forming the natural Porto di Malfatano harbour. This a classic example of a drowned river valley, the most magnificent on the South coast of Sardinia, that was created by the submergence of a pre-existing river eroded valley during the Versilian transgression. The inner edge of the cove, which is sheltered from the direct action of wave motion, will eventually be filled in by the gradual deposition of silty-sandy sediments at the land/sea interface.

The Malfatano coastal belt displays submerged coast features, moulded by subaerial fluvial sediments. In particular, the Porto di Malfatano is a *ria*, the lower portion of a palaeo-river valley that was drowned during the Versilian transgression.

The geomorphosites identified in the study area have been grouped together by the dominant process involved in their formation (fluvial/wash, atmospheric agents, gravitational, littoral, eolian), each group with a different colour.

Their degree of importance has been determined on the basis of the following evaluation criteria : exemplary of geomorphological evolution (processes); palaeo-geomorphological evidence; educational value (shapes); scenic value.

With regard to the physical/geographic features of the study area, the most numerous geomorphosites are those formed by littoral processes namely beaches (including the well known Tuarredda beach), islets and stretches of cliffs. The extensive Malfatano ria, bears witness to the evolution of a submerged coast.

A number of small dune bars of significant geomorphological interest have been chosen to represent the eolian process, though in terms of morphological evolution and landscape, these could be included in the littoral processes.

The geomorphosites formed by fluvial/wash processes are represented by entrenched valleys or river gorges, most of which are found inland, as well as forms of selective erosion represented by an outcropping dyke and a typical cone-shaped hill.

Landforms moulded by atmospheric agents include examples of rock domes, rugged shapes created by rock piles and of honeycombed rocks sculpted by cavernous weathering.

Only one form of gravitational process is included in the map, represented by a rockfall from the Capo Malfatano cliffs, a fine example of the evolution of gravitational phenomena in a sheer rocky coast.

6. CONCLUSIONS: THE GEOSITES AND GEOMORPHOSITES MAP

In the light of the above considerations, the segment comprised between Cape Malfatano and Cape Spartivento can be regarded as emblematic of Sardinia's geology, especially as concerns the Palaeozoic basement whose lowermost part, the Bithia Formation (?Precambrian-Lower Cambrian) crops out here. In fact within the overall metamorphism/deformation context of the Outer Zone of the Sardinian segment of the South-European Hercynian chain, this area is atypical insofar as the metamorphism and deformation are more pronounced than in the Sulcis-Iglesiente region, of which it is a part.

Another distinctive and geologically interesting feature of this area is the occurrence of granitoid rock outcrops (Cape Spartivento orthogneiss) dated to the Sardic Phase of the Middle Ordovician which elsewhere in the Sardinian Hercynian basement is represented largely by volcanic products.

The geological sites were identified, classified and evaluated according to the method proposed by Barca & Di Gregorio (1991a), Brancucci & D'Andrea M. (2002), Panizza M. & Piacente S. (2002), which considers genetic characteristics (stratigraphic, metamorphic, magmatic, structural). Their importance has been evaluated on the basis of their being exemplary of geological/structural evolution, of their chronostratigraphic, palaeoenvironmental and educational value.

Nineteen geosites (Tab. 1) have been identified having the following distinctive genetic features:

- the Cape Spartivento orthogneisses, of special interest because of their uniqueness in the regional geological context and the intense deformation effects produced during Hercynian tectonic activity (penetrative schistosity with pronounced stretching lineation of the deformed crystals). Though the Provincial Malfatano road 71 cuts across the orthogneiss, near the Sa Tuaredda *nuraghe*, the outcrops are relatively inaccessible by road or foot, given the topography of the landscape. Because of their geological rarity in Sardinia, the geosites have also been chosen according to their accessibility (the road cut near the Sa Tuaredda *nuraghe*, the coast around Padiglioni islet, the ridge near Punta Padenti);
- the lithological sequences of the Bithia Formation (clearly visible along the hairpin bends of the Provincial Malfatano road 71), with cataclastic/mylonitic bands, metaconglomerate outcrops near the coast between Punta de s'Ega de su Tramatzu and Cala de su Senzu, stretched pebbles, again the effect of the

Tab.1 - Geosites in the Malfatano area and relative parameters of evaluation.
Geositi nell'area di Malfatano e relativi parametri di valutazione.

GENETIC PROCESS	FEATURES			DESCRIPTION	EVALUATION			
	Point	Linear	Areal		Exemplary of geological-structural evolution	Chronostratigraphic evidence	Palaeoenvironmental evidence	Educational value
Stratigraphic and Metamorphic			1	Lens-shaped interbedded metalimestone of the Bithia Formation	●	●	●	●
			2	Upper Pleistocene beach deposits evidence of ancient marine level	●	●	●	●
			3	Unconformity between eolinites of the Upper Pleistocene and metamorphic basement	●	●	●	●
			4	Contact between Hercynian metamorphic rocks, granitoids and dykes		●	●	●
			5	Metaconglomerate of the Bithia Formation with metasandstone, quarzite and lydite.	●			●
			6	Cape Spartivento Orthogneiss	●	●		●
			7	Well exposed stratigraphic succession of the Bithia Formation	●			●
			8	Cape Spartivento orthogneiss with well exposed and clearly visibile Hercynian metamorphic and deformation features	●	●		●
Magmatic			9	Well-exposed Hercynian granodiorite outcrops: mineralogic, textural and structural features clearly visible	●			●
			10	Well-exposed Hercynian leucogranite rock outcrops: mineralogic, textural and structural features clearly visible	●		●	●
		11		Sub-vertical basic dyke in the metamorphic rocks of the Bithia Formation	●			
		12		Sub-vertical, NW-SE trending, outcropping granitic dyke, prominent feature of the landscape, intruded between metamorphic rocks of the Bithia Formation and Hercynian leucogranites.	●			●
		13		Sub-vertical, NW-SE trending, outcropping quartz dyke, prominent feature of the landscape intruding the Cape Spartivento orthogneisses	●			●
		14		Well visible, steeply dipping, NE-SW trending granitic dyke intruding the Hercynian leucogranites.	●			●
Magmatic	15			Fold structures in the metalimestones of the Bithia Formation.	●			●
	16			Slickenside showing transcurrent movement	●			
	17			Schistosity and stretching lineations in the Cape Spartivento orthogneiss	●			
	18			Strongly deformed clasts in the Bithia Formation metaconglomerate	●			●
	19			Hercynian late folds in the metasandstone of the Bithia Formation	●			●

deformation phases during the Hercynian, and layers of metalimestone, the major outcrops occurring near the Cape Malfatano tower;
- the significant genetic, magmatic and lithological features of the Hercynian granite rocks;
- the intrusive relationships of the Hercynian granitoid rocks with the metamorphic basement and of later dyke intrusions intersecting their contacts (well exposed in the cliffs near the Cape Spartivento lighthouse);
- ductile deformation structures in the Hercynian basement with multiphase folding especially at the mesoscopic scale (visible along the hairpin bends of the provincial Malfatano road n.71);
- brittle deformation structures sometimes with well exposed slickensides and slickenside striae (a well preserved example can be seen along the path north

of Mount Sa Guardia Manna);
- unconformity between the Hercynian basement of the Bithia Formation and the conglomerate and eolianite deposits, evidence of ancient marine levels and palaeoclimates during the Late Pleistocene different from present day climates (well exposed near the Piscinnì tower).

In geomorphological terms, particularly significant are the landforms associated with littoral processes (high rocky coasts, coasts indented with deep inlets, beaches nestled in coves, tiny islets and rugged cliffs, etc.), landforms associated with fluvial and slope processes and those produced by weathering.

The geomorphological sites surveyed in the area were identified, classified and evaluated following the method proposed by Barca & Di Gregorio (1991b) and Barca *et al*. (1992) based on the genetic process responsible for their formation (fluvial, meteoric, gravitational, littoral, eolian, etc.).

Each geomorphological site is denoted on the map with a symbol that identifies its features (point, linear or areal) and level of importance (local, regional, etc.) according to a measure of its importance at the geographic scale (Barca & Di Gregorio, 1999; Bertacchini *et al.* 2002b). The sites are numbered and brief specific description is provided. The level of importance has been determined adopting the following evaluation criteria:
- exemplary of geomorphological evolution (processes);
- palaeo-geomorphological evidence;
- education value;
- scenic value.

With regard to the geographical-physical features (Tab. 2), the geomorphological sites shaped by littoral processes are by far the most numerous (9) followed by

Tab. 2 - Geomorphological sites in the Malfatano area and relative parameters of evaluation.
Siti geomorfologici nell'area di Malfatano e relativi parametri di valutazione.

GENETIC PROCESS	FEATURES			DESCRIPTION	EVALUATION			
	Point	Linear	Areal		Exemplary of geomorphic evolution	Palaeogeomorphic evidence	Educational value	Scenic value
Fluvial - wash		1		Dyke outcropping near the Sulcitana State Road 195	●	●	●	●
		2		Furradroxiu Addis ravine	●	●		●
			3	Cone-topped hill with elongated base near Riu Perdosu Nuraghe	●		●	●
		5		Dyke outcropping in Perda Longa area	●	●	●	●
			4	Fluvial valley enclosed northwards by Mount de sa Fossa	●	●		
			6	Rio Perdosu enclosed fluvial valley	●	●	●	●
Meteoric		7		Relic forms of meteoric erosion near Arcu Bacca Tidoru	●			●
			8	Monte Corilla granitoid dome	●		●	
			9	Rocca di Corilla granitoid dome	●		●	
	10			Honeycombed metamorphic rocks in the Luas area.	●		●	
			11	Tafoni features and relic forms of meteoric erosion in the granite rocks at Sa Guardia Manna	●		●	●
Gravitational			12	Rockslide with influence of littoral processes near the Cape Malfatano tower	●			
Littoral	13			Tuarredda cuspate beach	●	●	●	●
		14		Cala Antoni Areddu beach with backbeach dunes	●	●	●	●
		15		Pebbly beach facing Ferraglione Islet	●			●
		16		Tuaredda Islet and bay	●	●	●	●
		17		Ferraglione Islet	●	●		●
		18		Padiglioni Islet	●	●		●
			19	Cape Spartivento cliffs	●			●
			20	Cape Malfatano cliffs	●			●
		21		Malfatano ria and lagoon	●	●	●	●
Eolic		22		Dunes on Tuarredda beach	●			●

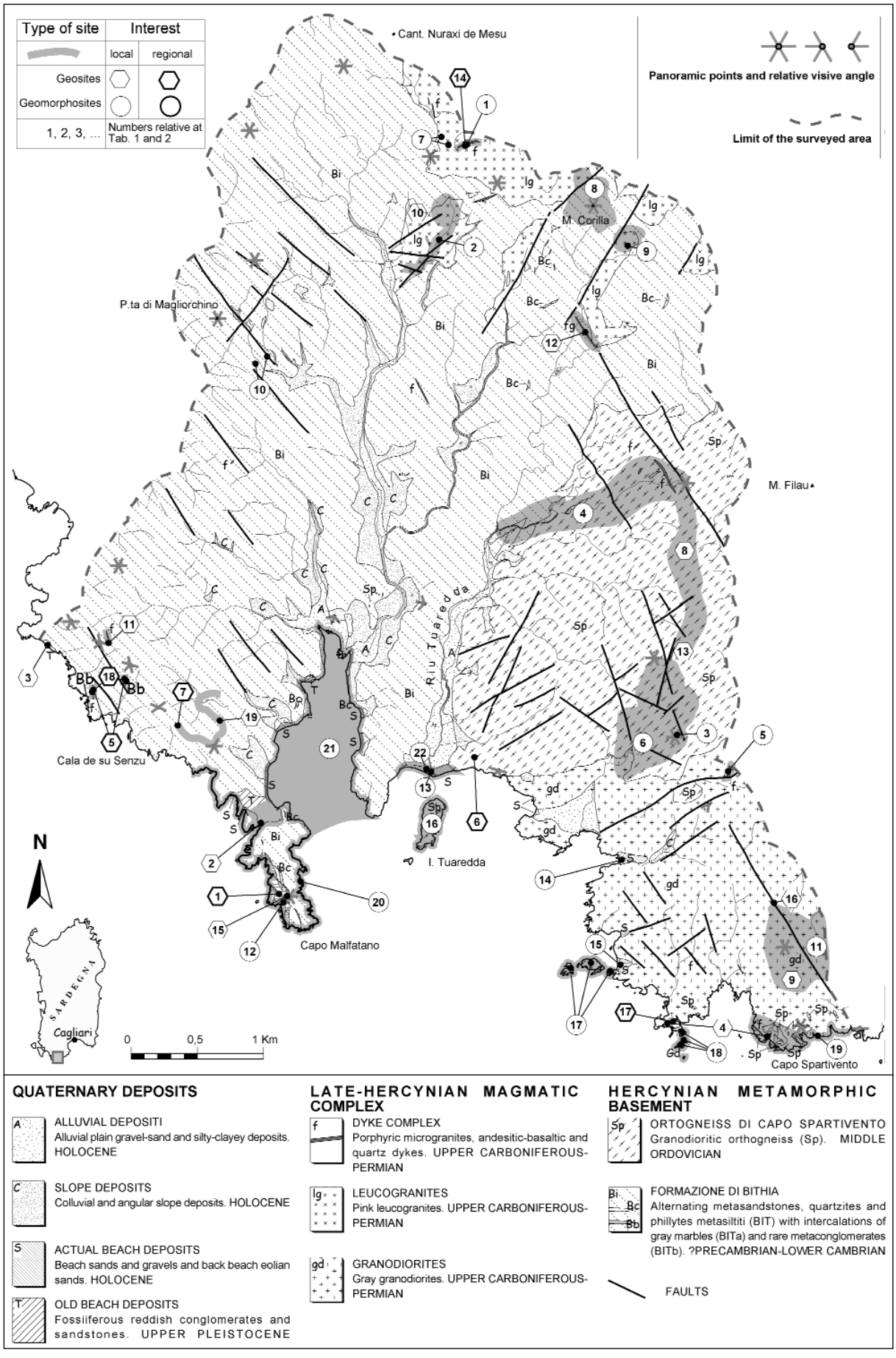

Fig. 1 - Geosites and geomorphosites map of the Capo Malfatano coast and relative level of interest.
Carta dei geositi e geomorfositi della costa di Capo Malfatano e il relativo livello di interesse.

fluvial (6), eolian (1) and gravitational influenced by littoral processes (1).

The geosites and geomorphosites identified in the study area, which bear testament to its great geodiversity, have been mapped in the 1:10.000 scale coloured map of geosites and geomorphosites of the Malfatano area (SE Sardinia), the main product, in graphic terms, of the research project concerned with here. The map provides a fundamental tool for land planning and for environmental impact assessment of man-made works as well as for enhancing the value of the area for public enjoyment and educational purposes.

The 1:10.000 map of geosites and geomorphological sites summarized in Fig. 2, is a concise graphical representation of an analysis conducted by means of accurate and detailed field surveys combined with photo-interpretation of the Malfatano coast. Some interesting features have been identified that bear witness to the geodiversity of the area (Bertacchini M. *et al.*,1999; Carton et al. 2003; Piacente & Poli, 2003). The educational and tourist-cultural value of these geosites and geomorphological sites is as yet little appreciated and suitable measures are required for conserving and enhancing the geologic-geomorphic heritage.

A number of areas have also been delineated in the map, which provides a valuable tool for geotourism and geoconservation (Maciocco, 1988; Poli & Bini, 2002), that stand out not so much for their specific landforms but rather for their landscape qualities and geomorphic interest as a whole. These include the Malfatano Ria, a cove that is testament to the evolution of the submerging coastline, the Bay of Tuaredda, with its breathtaking landscape as well as some inland areas that are the extension of the submarine morphology, characterized by ridges, peaks, deep incisions and bizarre forms of erosion on meta-sandstone and meta-siltstone, granites and orthogneiss.

ACKNOWLEDGEMENTS

Work conducted within the framework of the research project for setting up an experimental laboratory for the geoenvironmental analysis and monitoring of the Malfatano coastal belt, by the Environmental Geology and Thermographic Laboratory at the Department of Earth Sciences, University of Cagliari (Responsible Scientist. Prof. F. Di Gregorio) on behalf of Forma Urbis S.p.A. and National Research Project "I geomorfositi nel paesaggio italiano", National co-ordinator Prof. Sandra Piacente).

REFERENCES

BARCA S. & DI GREGORIO F. (1991a) - *Proposta metodologica per il rilevamento dei monumenti geologici e geomorfologici* - Bollettino dell'A.I.C., n. 83, pp. 25-31.

BARCA S. & DI GREGORIO F. (1991b) - *Conservation et valorisation du patrimoine geologique de la Sardaigne: une proposition metodologique* - 1er Symphosium international sur la protetion du patrimoine geologique, Digne - les - Bains, France 10-16 Giugno 1991, pp. 1-19.

BARCA S., DI GREGORIO F. & CANNILLO C. (1992) - *Rilevamento e valutazione dei monumenti geologici e geomorfologici del Meilogu-Logudoro (Sardegna NW)* - Boll. AIC, n. 86, 1 carta, 1 all., 1 fig., 1 tab..

BARCA S., DI GREGORIO F., FLORIS C. & MONTIS M. (1996) - *Rilevamento e valutazione dei monumenti e delle aree di rilevante interesse geologico e geomorfologico nei monti del Sulcis (Sardegna SO). Deputazione di storia patria per la Sardegna – In: Studi di Geografia e Storia in onore di Angela Terrosu Asole*, Cagliari, pp. 189-335.

BARCA S. & DI GREGORIO F. (1999) - *Paesaggi e monumenti geologici della provincia di Cagliari* - Saredit Editore, Cagliari, 417 pp.

BERTACCHINI, CORATZA & PIACENTE S. (2002a) - *I beni geologici come espressione e veicolo culturale per tutti - Un progetto in Emilia Romagna* - Geologia dell'ambiente, N. Speciale "I Geositi" anno X, n. 2/2002, 18-21 pp.

BERTACCHINI, CORATZA & PIACENTE S. (2002b) - *An experimental data sheet for the inventory of Geomorphosites proposed by COFIN 2001 Research Group "Geosites in the italian landscape research, assessment and improvement"* - Proceedings, Workshop "Geomorphological sites: research, assessment and improvement", Poster Session, Modena 19-22 giugno 2002, pp. 36.

BERTACCHINI M., GIUSTI C., MARCHETTI, M., PANIZZA M. & PELLEGRINI M. (1999) - *I Beni Geologici della Provincia di Modena* - Università degli Studi di Modena e Reggio Emilia, Dipartimento di Scienze della Terra, Provincia di Modena, Assessorato Difesa del Suolo e Tutela dell'Ambiente, Artioli Editore, Modena.

BRANCUCCI G. & D'ANDREA M. (2002) - *National project:"Protection of the italian geological heritage". The test form for the geosites inventory*. Proceedings, Workshop "Geomorphological sites: research, assessment and improvement" (Modena, 19-22 giugno 2002), pp. 42-43.

BONI M. & COCOZZA T. (1978) - *Depositi mineralizzati di canale di marea nella Formazione di Gonnesa del Cambrico inferiore della Sardegna* - Giorn. di Geol.: **43**, pp. 1-20.

CARANNANTE G., COCOZZA T. & D'ARGENIO B. (1984) - *Late Precambrian-Cambrian geodynamic setting and tectono-sedimentary evolution of Sardinia (Italy)*. Boll. Soc. Geol. It.: **103**, pp. 121-128.

CARMIGNANI L., CAROSI R., DI PISA A., GATTIGLIO M., MUSUMECI G., OGGIANO G. & PERTUSATI P.C. (1994) - *The Hercynian chain in Sardinia (Italy)* - Geodinamica Acta, **7**, pp. 31-47.

CARMIGNANI L., COCOZZA T., GHEZZO C., PERTUSATI P.C. & RICCI C.A. (1987) - *Structural Model of the Hercynian Basement of Sardinia* - Stabilimento L. Salomone, Roma.

CAROSI R., PERILLO M., PERTUSATI P.C. & GATTIGLIO M. (1995) - *Risultati preliminari dello studio strutturale del complesso del Sulcis meridionale (Sardegna SW)* - Atti Soc. Tosc. Sci. Nat., Mem., Ser. A: **102**, pp. 105-116.

CARTON A. & DE LUIGI E. (1980) - *Itinerari naturalistici e geografici attraverso le montagne italiane* -

Trentino, C.A.I., Arti Grafiche Tamari, Bologna.

CARTON A. CORATZA P. & MARCHETTI M. (2003) - *Methodological proposal for mapping geomorphosites* - Geomorphological sites: assessment and mapping – Workshop Proceedings, Cagliari (Italy), 1-5-October 2003.

CASTO L. & ZARLENGA F. (1992) - *I beni culturali a carattere geologico nella media valle del Tevere* - ENEA, Dipartimento Ambiente – Regione Lazio, Assessorato alle Politiche per la Promozione della cultura, dello spettacolo, del Turismo e dello sport, Centro Regionale Documentazione, pp. 1-165.

COCOZZA T. (1979) - *The Cambrian of Sardinia* - Mém. Soc. Géol. It.: **20**, pp.163-187.

COCOZZA T., CONTI L., COZZUPOLI D., LOMBARDI G., SCHARBERT S. & TRAVERSA G. (1977) - *Rb/Sr age and geopetrologic evolution of crystalline rocks in southern Sulcis (Sardinia)* - N. Jb. Geol. Paläont. Mh.: **1977**, pp. 95-102.

COCOZZA T. & GANDIN A. (1990) - *Carbonate deposition during early rifting: the Cambrian of Sardinia and the Triassic-Jurassic of Tuscany, Italy* - Spec. Publs. int. Ass. Sediment.: **9**, pp. 9-37.

D'ANDREA M. (2001) - *Servizio Geologico Nazionale: Progetto "Conservazione del patrimonio geologico italiano". Nota informativa* - Giornale di Geologia, Se. III, Vol. 62, Suppl., pp.121-124.

DELAPERRIÈRE E. & LANCELOT J. (1989) - *Datation U-Pb sur Zircons de l'orthogneiss du Capo Spartivento (Sardaigne, Italie), nouveau témoin d'un magmatisme alcalin ordovicien dans le Sud de l'Europe* - C. R. Acad. Sci. Paris: **309**, pp. 835-842.

DE WAELE J., DI GREGORIO F. & PIRAS G. (1998) - *Geosites inventory in the Paleozoic karst region of Sulcis-Iglesiente (South-West Sardinia, Italy)* - International Congress PROGEO '98, 7-13 june 1998, Belogradchik, Bulgaria. In Geologica Balcanica 28 (3-4), pp. 173-179.

DI GREGORIO F. & ULZEGA G. (2002) - *The state of the knowledge in the conservation and the valorization of geomorphological sites in Sardinia* - Proceedings, Workshop "Geomorphological sites: research, assessment and improvement", Poster Session, Modena 19-22giugno 2002, pp. 57-58.

GANDIN A. (1987) - *Depositional and paleogeographic evolution of the Cambrian in South-West Sardinia* - I.G.C.P. No. 5 Newsletter: **7**, pp. 151-165.

GANDIN A., MINZONI N. & COURJAULT-RADÉ P. (1987) - *Shelf to basin transition in the Cambrian-Lower Ordovician of Sardinia (Italy)* - Geol. Rundsch.: **76**, pp. 827-836.

GANDIN A., PADALINO G. & VIOLO M. (1974) - *Correlation between sedimentation and ore prospecting. Sedimentological and ore-genesis studies of Cambrian "arenarie" and "dolomia rigata" formations (Sardinia, Italy): deposition and concentration of barite in a evaporitic environment* - Rend. Soc. It. Min. Petr.: **30**, pp. 251-303.

GANDIN A. & PILLOLA G.L. (1985) - *Biostratigrafia e sedimentologia della Formazione di Cabitza nell'Iglesiente. "Evoluzione stratigrafica, tettonica, metamorfica e magmatica del Paleozoico italiano"* - Riunione scientifica, Siena 13-14 Dicembre, pp. 30-31.

GISOTTI G. & MASSOLI-NOVELLI R. (1997) - *I Geotopi nella pianificazione territoriale* - Atti IX Congr. Ordine Nazionale Geologi, Roma, aprile 1997, pp. 307-311.

JUNKER B. & SCHNEIDER H.H. (1979) - *L'infracambriano della Sardegna sud-occidentale* - Mém. Soc. Géol. It.: **20**, 461 pp.

JUNKER B. & SCHNEIDER H.H. (1983) - *The Infracambrian Bithia Formation - Its facies development in Southwest Sardinia* - N. Jb. Geol. Paläont. Mh.: **24**, pp. 369-384.

LUDWIG K.R. & TURI B. (1989) - *Paleozoic age of Capo Spartivento orthogneiss, Sardinia* -Chemical Geology: **79**, pp. 147-153.

MACIOCCO G. (1988) - *Elementi di metodo operativo per la costruzione di una geografia di valori ambientali. Una applicazione alla Sardegna nord-occidentale* - In: *Atti del colloquio internazionale "Metodi di valutazione nella pianificazione urbana e territoriale. Teoria e casi di studio*, Capri – Napoli, pp.135 - 147.

MASSOLI-NOVELLI R. (2001) - *Inventari di geositi in Italia: stato dell'arte* - Geologia dell'Ambiente, 1, SIGEA, Roma, pp.10-13.

MINZONI N. (1981) - *Il Precambriano del Sulcis meridionale (Sardegna)* - Mineralogica et Petrographica Acta: **24**, pp. 51-56.

PALMERINI V. & PALMERINI SITZIA R. (1978) - *Le facies pelitiche della Formazione di Nebida (Cambriano inf. sardo)* - Boll. Soc. Geol. It.: **97**, pp. 7-71.

PANIZZA M. & PIACENTE S. (2002) - *Geositi nel paesaggio italiano: ricerca, valutazione e valorizzazione. Un progetto di ricerca per una nuova cultura geologica* - Geologia dell'ambiente, Vol. 2/2002, pp.3-4.

PITTAU DEMELIA P. & DEL RIO M. (1982) - *Acritarchi e loro significato stratigrafico nelle successioni paleozoiche della Sardegna* - In: L. Carmignani, T. Cocozza, C. Ghezzo, P.C. Pertusati & C.A. Ricci (eds.), *Guida alla Geologia del Paleozoico Sardo. Guide Geologiche Regionali*, Società Geologica Italiana: pp. 33-35.

POLI G. (eds.) 1999 - *Geositi, testimoni del tempo*. Regione Emilia-Romagna, Bologna, p.259.

POLI G. & BINI M. (2002) - *Geositi un laboratorio di comunicazione e valorizzazione*. In: *Atti del convegno "La geologia ambientale: strategie per il nuovo millennio"*, Genova 27 – 29 giugno 2002.

RASETTI F. (1972) - *Cambrian Trilobite faunas of Sardinia* - Atti Acc. Naz. Lincei, Mem. Cl. Sc. Fis. Mat. e Nat.: **11**, pp. 1-100.

SASSI F.P. (1990) - *Caratterizzazione petrografica delle Formazioni di Nebida e di Bithia nel Sulcis, con particolare riguardo alla fascia limite* - Ente Minerario Sardo, Relazione inedita, Cagliari, 38 pp.

SASSI F.P., MAZZOLI C., SASSI R. & VISONÀ D. (1990) - *The Capo Spartivento-M. Filau puzzle and structure of SW Sardinia* - Plinius: **3**, Milano.

SASSI F.P. & VISONÀ D. (1989) - *Gli gneiss di Monte Filau ed i loro rapporti con le rocce circostanti - Progemisa S.p.A. (relazione inedita)*, Cagliari, 38 pp.

TUCCI P. (1983) - *Le metamorfiti dinamometamorfiche di Capo Malfatano (Sulcis, Sardegna)* - Period. Min.: **52**, pp. 149-176.

ULZEGA A. (1995) - *Geomorphology and stratigraphy of Late Quaternary* - In: A. Cherchi (ed.), *6th Paleobenthos International Symposium, Guide-Book*, Cagliari, October 25-31, Rend. Sem. Fac. Sc. Univ. Cagliari (suppl. vol. 65, 1995): pp. 11-24.

ULZEGA A. & OZER A. (1982) - *Comptes-Rendus de l'Excursion-Table Ronde sur le Tyrrhénien de Sardaigne* - INQUA: pp. 1-87.

VAI G.B. (1982) - *Fasi di "rifting", nuovi dati stratigrafici e conseguenze paleogeografiche nel Paleozoico inferiore* - In: L. Carmignani, T. Cocozza, C. Ghezzo, P.C. Pertusati & C.A. Ricci (eds.), *Guida alla Geologia del Paleozoico Sardo*, Società Geologica Italiana, Guide Geologiche Regionali, pp. 93-195.

VARDABASSO S. (1956) - *Il Quaternario della Sardegna* - Atti IV Congr. Int. Quaternario, Roma-Pisa 1953, pp. 995-1018.

ZARLENGA F. (1996) - *I geotopi, dalla ricerca scientifica alla pianificazione, controllo e gestione* - Geologia dell'ambiente, Vol. 4,2, pp. 3-6.