Mem. Descr. Carta Geol. d'It.
LXXXVII (2009), pp. 15-28
figg. 14

Geomorphology, environmental geology and natural-cultural heritage of Palmaria, Tino and Tinetto Islands (Portovenere Park, Italy)

Geomorfologia, geologia ambientale e patrimonio naturale-culturale nelle Isole della Palmaria, del Tino e del Tinetto (Parco di Portovenere, Italia)

BRANDOLINI P. (*), FACCINI F. (*),
PICCAZZO M. (**), ROBBIANO A. (*)

ABSTRACT – The islands of Palmaria, Tino and Tinetto represent the western limit of the Gulf of La Spezia. They constitute the seaward extension of the Portovenere Promontory, part of the site inscribed on the UNESCO World Heritage List. The three islands comprise a small archipelago, which has been protected since 2001 as part of the Natural Park of Portovenere. Geomorphological features and numerous traces of the historic quarrying of the precious Portoro marble characterize the islands. The geology is marked by an overturned fold, with overlapping dolomitic limestone rock strata, affected by karstic phenomena that are also of archaeological importance. The geomorphological modeling is conditioned by the structural arrangement and the tectonic lineations: the processes in progress are mainly related to wave undercutting, which determines a cliffed coastal profile on the slopes facing SW and SE, while the other island sectors present coves with pocket beaches. The islands of Palmaria and Tino are well known for the extraction of Portoro marble during the Roman period. Portoro, quarried mostly underground, is a black marble with gold, white and rose-colored veining, utilized as ornamental stone. The islands are basically visited for hiking excursions and beach outings, and the environmental heritage they represent is of great value for tourism. Initiatives aimed at the valorization and protection of this heritage are needed. Based on the geological and geomorphological aspects, geotourist map of the Palmaria islands was prepared to promote an understanding of the landscape and to valorize the environmental values.

KEY WORDS: Geomorphology, Environmental geology, Cultural heritage, Palmaria Island, Ligurian sea.

RIASSUNTO – L'arcipelago delle isole Palmaria, Tino e Tinetto, ubicato al limite occidentale del Golfo di La Spezia (Liguria orientale), costituisce la naturale prosecuzione del Promontorio di Portovenere e rappresenta un sito di grande interesse geomorfologico-culturale, con importanti aspetti scientifici, paesaggistici, socio-economici e storici, in particolar modo legati alla plurisecolare attività estrattiva, anche in sotterraneo, del pregiato marmo Portoro.

Dal 1997 l'arcipelago è stato riconosciuto come Patrimonio Mondiale dell'Umanità dall'Unesco e dal 2001 è tutelato dal Parco Naturale Regionale di Portovenere.

L'assetto geologico-strutturale è caratterizzato da una piega anticlinale rovesciata con asse NW-SE nella quale si riscontra la sovrapposizione di strati calcareo-dolomitici, interessati da diffusi fenomeni carsici. Tra Palmaria, Tino e Tinetto sono infatti censite una trentina di cavità naturali, alcune delle quali di importanza anche archeologica, come la Grotta dei Colombi.

Il profilo costiero delle isole è condizionato dall'assetto tettonico ed in particolare le falesie che caratterizzano i settori sud-occidentali delle isole della Palmaria e del Tino sono impostate lungo una faglia diretta orientata NW-SE. I versanti nord-orientali degradano a mare con pendenze relativamente più modeste e si presentano bordati da piccole spiagge ghiaioso-ciottolose.

Tracce di modellamento dei versanti dovuto a processi gravitativi sono presenti soprattutto sulle pendici sud-occidentali dell'Isola della Palmaria, dove si osservano falde detritiche, talora frammiste a depositi colluviali. In alcuni casi questi depositi sono debolmente cementati e rappresentano un'interessante testimonianza di variazioni climatiche del passato.

(*) Dipartimento di Scienze dell'Antichità, del Medioevo e Geografico-ambientali, University of Genoa, Italy
(**) Dipartimento per lo Studio del Territorio e delle sue Risorse, University of Genoa, Italy piccazzo@dipteris.unige.it

Sulla base degli aspetti geologici, geomorfologici e geoambientali rilevati, è stata preparata dapprima una carta geomorfologica-ambientale e successivamente una carta geoescursionistica dell'Isola della Palmaria, con lo scopo di favorire la comprensione del paesaggio e la sua valorizzazione estendendone la fruizione a diverse tipologie di escursionismo: didattico, scientifico, sportivo e turistico-culturale.

Lungo la rete escursionistica sull'Isola della Palmaria (sul Tino la visita è ad oggi interdetta per attività militari) sono stati evidenziati i principali geositi, con particolare riferimento a quelli connessi alla geomorfologia culturale. I sentieri, suddivisi secondo una scala semplificata di difficoltà, sono stati esaminati in rapporto ai pericoli naturali che possono coinvolgere l'escursionista, spesso associati a particolari condizioni meteorologiche, ed agli elementi di vulnerabilità legati alle loro caratteristiche strutturali (esposizione, larghezza, tipo di fondo).

Per la fruizione degli aspetti geomorfologico-culturali si propone la realizzazione di alcuni itinerari guidati: nell'Isola della Palmaria si può distinguere un percorso legato all'impiego dei materiali lapidei nell'architettura civile e militare ed uno storico-geominerario. Le peculiarità geomorfologiche delle isole, con particolare riferimento ai processi legati al modellamento costiero, possono essere infine pienamente apprezzate attraverso un percorso a mare.

PAROLE CHIAVE: Geomorfologia, Geologia ambientale, Patrimonio culturale, Isola Palmaria, Mar Ligure.

1. – INTRODUCTION

The archipelago of the islands of Palmaria, Tino and Tinetto (Ligurian Sea) represents a site of exceptional geomorphological and cultural value. The site's important scientific, scenic, socioeconomic and historical features offer an opportunity to broaden our understanding of geomorphological and geoenvironmental issues (BENNETT & DOYLE, 1997; PANIZZA & PIACENTE, 2003; GRAY, 2004).

The islands are characterized by a high rocky cliff on the western and southern slope, whereas the remaining coastline is more jagged, with small promontories and pocket beaches. There are many cave openings, including both karstic and sea caves, in the limestone and dolomite, which constitute the bedrock of the three islands. Some of these caves, such as the *Grotta dei Colombi*, have been object of research in the past and are of great importance not only in terms of their historical and archeological value, but also in terms of their scientific value, as they contain valuable evidence of past climatic variations (CIGNA, 1967). Settlements on the islands date back to prehistoric times. The islands were the seats of important monastic communities in the Middle Ages, and of military defense and naval bases starting from the end of the 19th century, when major defense works were built, including the *Punta della Scola*, the *Batteria Semaforo* (today a center for environmental education), *Forte Cavour* and *Forte Umberto I*.

The islands also took on social and economic importance, owing to their geomine features: extraction of the precious Portoro marble has been traced back to the Roman period, and continued on through to the end of the 20th century.
For these reasons, there has been recent growing interest in educational and recreational activities made possible through and linked to the development of geomorphological and geomine trails (BRANDOLINI *et alii*, 2005; ROBBIANO *et alii*, 2005). The islands of Palmaria, Tino and Tinetto have been protected by the *Cinque Terre* network of protected areas in the Liguria Region since 1985 (BRANDOLINI & ROLLANDO, 1995). As of 2001, they have represented part of the Regional Natural Park of Portovenere, and in 1997, the archipelago was recognized as a World Heritage Site by UNESCO. These places have fascinated Romantic and contemporary poets and have served as inspiration for literary works, musical compositions and paintings. In fact, the area is of exceptional value, one that reveals the relationship between humankind and nature, the source of a landscape of extraordinary scenic beauty.

The objective of this work is to broaden the knowledge of the geology and geomorphology of the area as cultural elements of the landscape, as well as their interaction with the presence and activities of humans, with the aim of valorizing the area culturally and in terms of tourism.

Additionally, existing geomorphological hazards that could affect the numerous visitors along the hiking trails in Palmaria Island, were also taken into consideration, with the objective of guaranteeing sustainable tourism and helping tourists become informed and aware; Tino and Tinetto islands were not examined because they are military zone.

2. – GEOGRAPHIC FRAMEWORK

The islands of Palmaria, Tino and Tinetto are located along the western limit of the Gulf of La Spezia in eastern Liguria (fig. 1). They constitute the natural extension of the Portovenere Promontory (fig. 2). In fact, the islands present an approximately NW-SE alignment and the possibility that at least Tino and Tinetto were once joined cannot be excluded (CIGNA, 1967).

The island of Palmaria, Liguria's largest island with a land area of 1,65 km^2, has an approximately triangular shape with three sides that are about 3 km in length. The maximum elevation (about 190 m) is found in the central-southern sector, where the *Fortezza* (*Batteria Semaforo*) was erected. The SW

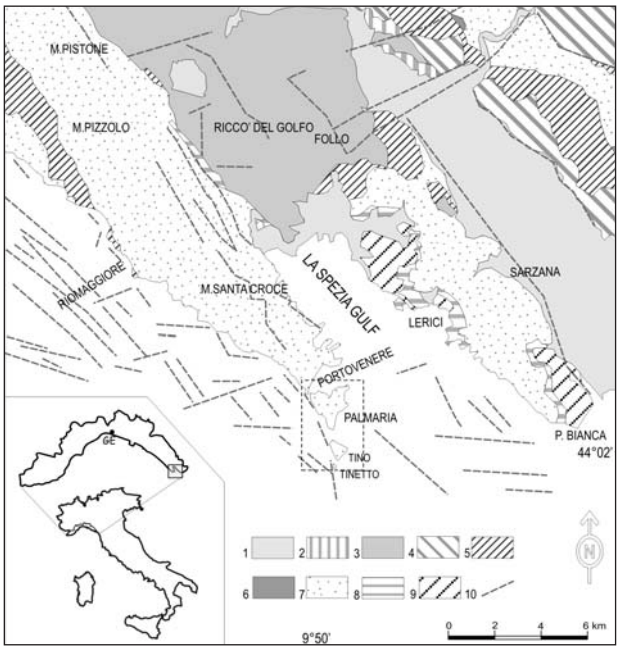

Fig. 1 – Geological sketch map of Portovenere Promontory and surrounding areas: (1) Olocenic covers; (2) Mt. Antola Tectonic Unit; (3) Mt. Gottero T.U.; (4) Ottone T.U.; (5) Canetolo T.U.; (6) Marra T.U.; (7) Tuscan Nappe (*Falda Toscana*); (8) Tectonic breccias; (9) Massa T.U.; (10) Fault. The dashed rectangle indicates the study area.
– *Schema geologico del Promontorio di Portovenere e delle aree circostanti: (1) coperture Oloceniche; (2) Unità Tettonica del M. Antola; (3) Unità Tettonica del M. Gottero; (4) Unità Tettonica di Ottone; (5) Unità Tettonica di Canetolo; (6) Unità Tettonica di Marra; (7) Falda Toscana; (8) Brecce tettoniche; (9) Unità Tettonica di Massa; (10) Faglia. Il rettangolo tratteggiato indica l'area di studio.*

side, with its characteristic cliff, is rectilinear with some inlets of modest dimensions in the southern part. In comparison, the SE and N sides are very indented, with a low rocky coast with accumulated sediment locally, which permits vessels to berth in the bay known as the *Seno del Terrizzo* and the cove known as *Cala del Pozzale*.

The island of Tino is located about 500 m S of Palmaria and it extends in a NW-SE direction, with a maximum length of 700 m and a width of 350 m. The highest point reaches an elevation of 99 m, where the lighthouse is located. Today the island is still a base for military operations. The SW and W sectors present an impressive cliff, whereas the remaining sectors are more indented, especially to the NE and S.

Tinetto, 150 m long and 18 m high, is little more than a rock ledge; it represents the south-eastern border of the carbonate sequence outcropping in the Ligurian sea.

The climatic characteristics of the islands are shown in figure 3, according to data recorded at the station located on Palmaria Island at 190 m ASL during the 1949 - 1985 observation period.

The annual mean is about 900 mm of rainfall and annual mean temperature is about 15°C. The mean monthly rainfall pattern in the observation

Fig. 2 – Southern cape of the Portovenere Promontory, as seen from Palmaria Island. – *Punta meridionale del Promontorio di Portovenere, visto dall'Isola Palmaria.*

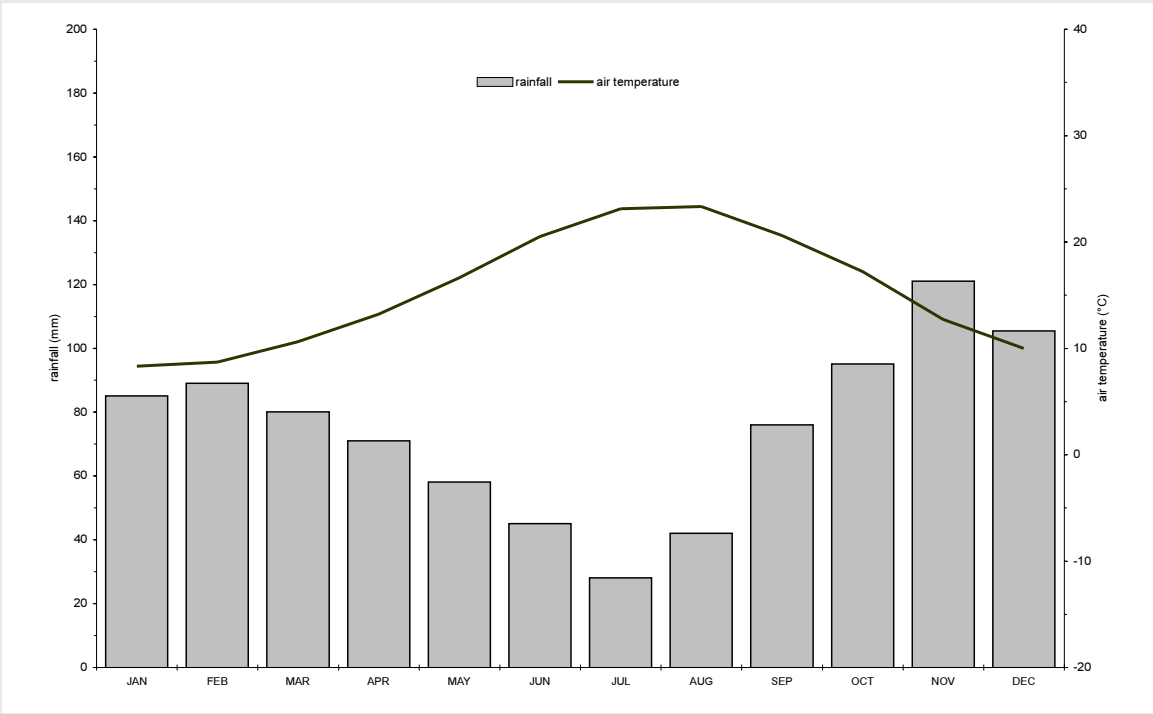

Fig. 3 – Climatic diagram, referring to 1949-1985 observation period of Palmaria Island meteorological station data (190 m asl).
– *Diagramma climatico, riferito al periodo di osservazione 1949-1985, della stazione meteorologica dell'Isola Palmaria (190 m slm).*

period shows an absolute maximum in October (120 mm) and a relative maximum in February (89 mm), while the minimum proved to be in July with values below 30 mm. Air temperature data for the same period showed a minimum in the winter months of January and February (i.e., 8-9°C) and a maximum in the months of July and August (i.e., slightly above 23°C).

The above mentioned data indicate a Mediterranean climate (POTENTI & VITTORINI, 1995).

Intense, but brief rain storms are frequent in autumn, when in just a few days the amount of rainfall can reach at least half the annual total. These events are generally the triggering factor leading to geomorphological instability phenomena.

As explained below in further detail, the geomorphology of the three islands indicates strong modeling by the action of sea waves. The wind velocity spectrum at the ground surface indicates that there are less than 30 calm days (velocity of less than 6 km/h) in a year, while the modal value ranges between 30 and 40 km/h. Wind directions are mainly from NE and SW quadrants, and to a lesser degree from the SE, while winds from NW are obviously blocked by a natural barrier, the Promontory of Portovenere.

3. – GEOLOGICAL OUTLINE

The outcropping Formations on the islands of Palmaria, Tino and Tinetto belong to the *Falda Toscana* (fig. 1) and they are represented, from bottom to top, by the La Spezia Formation, which is subdivided into the Mt. Santa Croce Limestone and Marl Member and the Portovenere Limestone Member, and by Portoro and Mt. Castellana Dolomites; the Formation has been attributed to the Upper Triassic (Norian-Rhaetian-Hettangian).

The Mt. Santa Croce Limestone and Marl Member is present in the eastern and central sectors of the islands. It is made up of strata and beds of dark grey limestones irregularly alternating with grey and yellowish marly layers. There are also interlayers of beds of whitish, saccharoidal dolomites and of oolitic-bioclastic limestones; storm-graded layers with sea snails and prevalent pelecypods are frequent.

The Portovenere Limestone Member prevails in the southwestern sectors of the islands. This member is made up of layers, of thicknesses in the range of decimeters, composed of dark grey limestones alternating with fewer marly or dolomitic layers and very infrequently, layers of storm de-

posits with sea snails; the *Strati di Grotta Arpaia* lithofacies is distinguishable at the top.

The latter strata are made up of sholes and blackish marls, which are sometimes nodular, and thin interlayers of sea snails.

The western portion of the islands, represented by the impressive subvertical cliff, is characterized by the Mt. Castellana Dolomites at the base, including saccharoidal dolomitic limestones that are whitish or yellowish, and massive or coarsely stratified (fig. 4). The Portoro marble is found intercalated between the Mt. Castellana Dolomites at the base and the La Spezia Formation at the top. The Portoro consists of beds of dark grey to black limestones that are nodular and have white- and yellow-colored dolomitic vein patterns. These beds alternate with beds in the range of meters, consisting of whitish and yellowish, coarsely crystalline dolomites (SERVIZIO GEOLOGICO D'ITALIA, 2004).

The structural pattern of the Promontory of Portovenere, including the three islands, is characterized by an overturned anticlinal fold with Tyrrhenian vergence and a fold axis dipping NW-SE. (CIARRAPICA & PASSERI, 1981; FEDERICI, 1987). This zone is distinguished by a system of normal faults that is also oriented in a NW-SE direction, and by an approximately orthogonal system oriented NE-SW. The latter has determined the pattern of the limited drainage system on Palmaria Island and defined the channels that separate the islands themselves and the islands from the Promontory (FEDERICI & RAGGI, 1975).

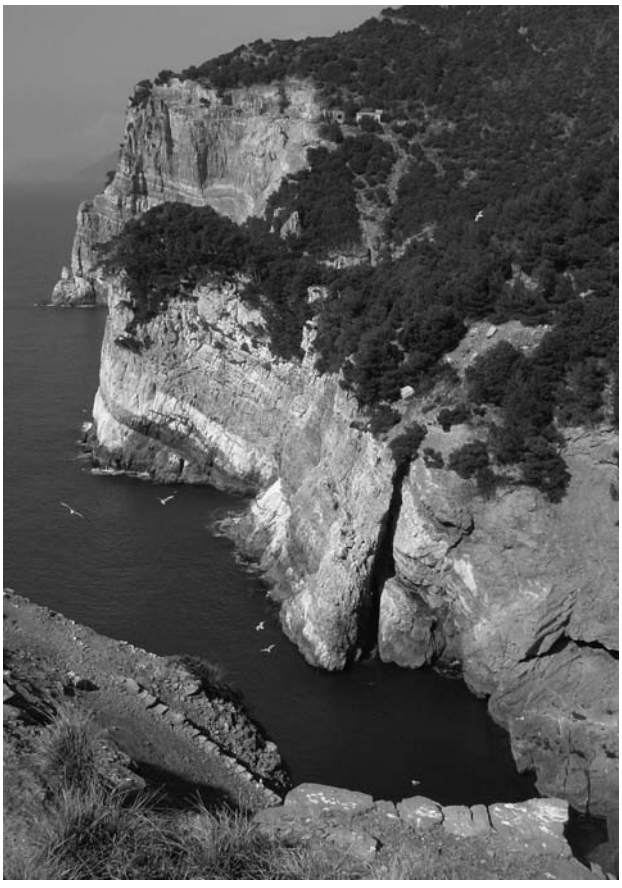

Fig. 4 – Palmaria Island cliff modeled in the Mt. Castellana Dolomites (*Caletta*). – *Falesia dell'Isola Palmaria modellata nelle Dolimie di M. Castellana (Caletta).*

Depending upon the stratigraphy and tectonic style of the area, the valuable Portoro layer outcrops discontinuously solely in the western sectors of the islands. In addition, it is only found between dolomites and dolomitic limestones at the base and marly limestones at the top.

Portoro layer consists of a deep black matrix with very fine-grained, uniform micrite with veining of another color, called *macchie* in commercial terms. There may be yellow veins, owing to the presence of limonite and sulphides, in which the pigmentation appears in the form of intergranular veining between the dolomite crystals, violet veins consisting of dolomitic mosaics that have zones more intensely colored by a hematitic pigment, and veins of recrystallized calcite.

Commercially, a basic distinction is made between two main types of Portoro marble: Portoro *a macchia larga* (i.e., with a wide vein pattern) and Portoro *a macchia fine* (i.e., with a thin vein pattern). These two types are also subdivided into four different quality grades, making for a total of eight types, based on the intensity of color of both the vein pattern and the matrix; current restrictions have limited commercial distribution and not all of the eight types are available on the market (CIMMINO *et alii*, 2003).

4. – DETAILED GEOMORPHOLOGICAL CHARACTERISTICS

The geomorphological modeling is conditioned by the structural arrangement and tectonic lineation: the processes in progress are mainly related to marine, gravity and running water activities, subordinately to karstic phenomena. Man-made landforms related to quarry and mine, agricultural terracing and military structures are also very important.

4.1. – SLOPE LANDFORMS AND DEPOSITS DUE TO GRAVITY AND RUNNING WATERS

Evidence of morphological modeling of slopes due to gravitational processes is mainly visible on the southwestern slopes of Palmaria (fig. 5). In particular, above *Cala Grande* and *Caletta*, at about 175 m, below the *Fortezza*, a wide scarp edge is identifiable; it is carved into the limestone and marly layers with a prevalently unfavorable structural orientation. Several scree slopes have formed,

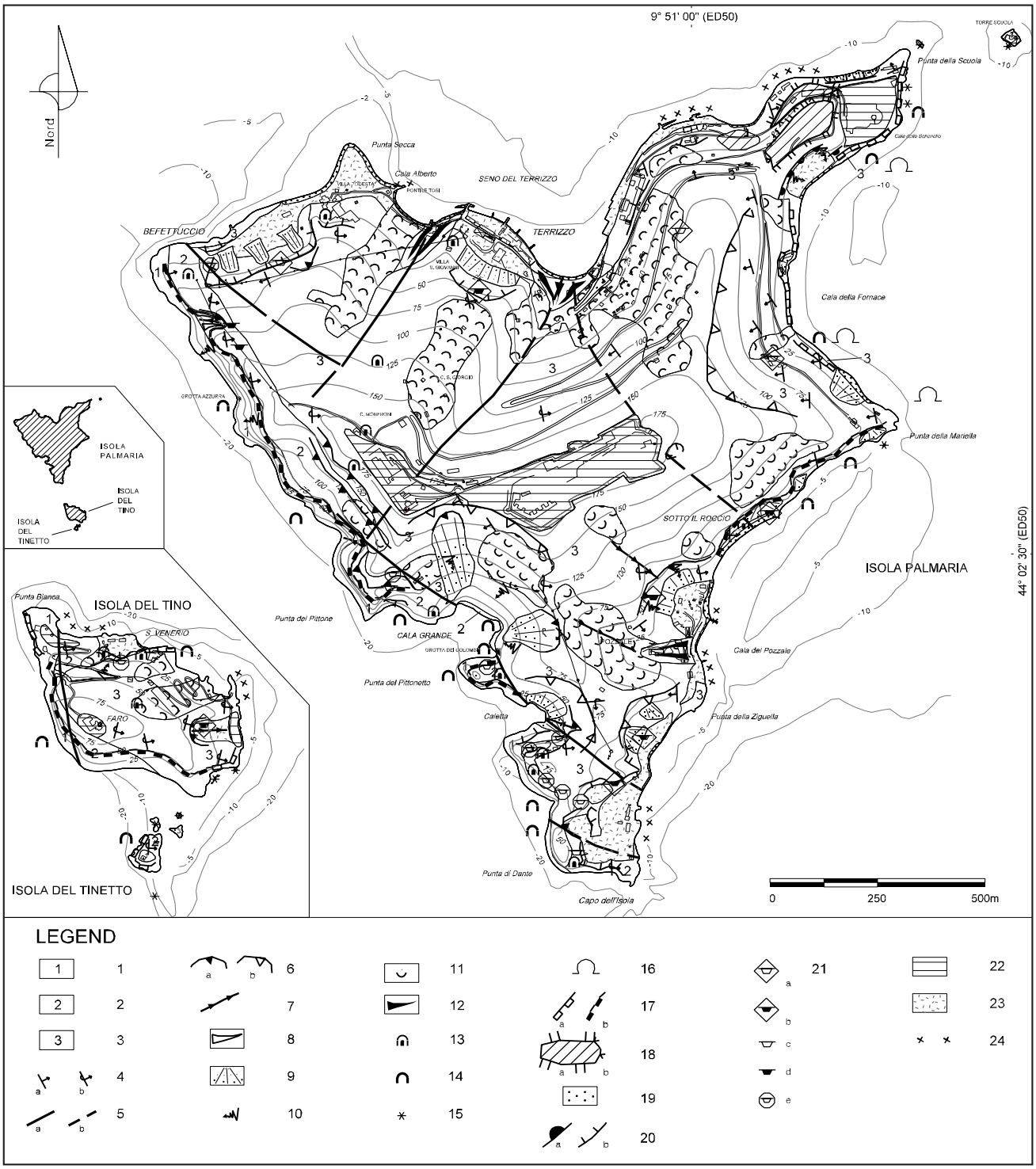

Fig. 5 – Geomorphological and geo-environmental map. Legend: GEOLOGICAL DATA - 1. Calcareous dolomite; 2. Portoro marble; 3. Limestone and marly limestone; 4. Attitude: a. dipped; b. overturned; 5. Fault: a. certain; b. assumed or covered; SLOPE LANDFORMS DUE TO GRAVITY AND RUNNING WATER – 6. Edge of scarp: a. active; b. dormant; 7. Small rock valley crossed by debris flow; 8. Talus cone; 9. Scree slope, sometimes mixed with debris flows and landslides; 10. Area affected by rill wash; 11. Colluvial deposit with agricultural terraces; 12. Alluvial fan; KARST LANDFORMS – 13. Cave; MARINE LANDFORMS – 14. Sea cave; 15. Stack; 16. Notches; 17. Edge of scarp due to wave erosion: a. h<25 m; b. h>25 m; 18. Planation surface: a. edge; b. root; 19. Pebble and gravel beaches; MAN-MADE LANDFORMS – 20. Edge of scarp due to: a. waste; b. quarry; 21. Abandoned quarry: a. limestone used for dam blocks and lime; b. only for lime; c. opencast Portoro, *macchia larga* quality; d. opencast Portoro, *macchia fine* quality; e. underground Portoro, *macchia larga* quality; 22.Denudational area; 23. Areal embankment, land reclamation, waste; 24. Protective structure along the shoreline.

– Carta geomorfologica e geo-ambientale. Legenda: DATI GEOLOGICI – 1. Dolomie calcaree; 2. Marmo di Portoro; 3. Calcari e calcari marnosi; 4. Giacitura: a. strati inclinati; b. strati rovesciati; 5. Faglia: a. certa; b. presunta o coperta; FORME DI VERSANTE DOVUTE ALLA GRAVITÀ E ALLE ACQUE CORRENTI – 6. Orlo di scarpata: a. attiva; b. quiescente; 7. Canalone di roccia con scariche di detrito; 8. Cono di detrito; 9. Falde di detrito, talvolta mescolate a debris flows e frane; 10. Area interessata da dilavamento diffuso; 11. Depositi colluviali con terrazzamenti coltivati; 12. Cono alluvionale; FORME CARSICHE – 13. Grotte; FORME MARINE – 14. Grotte marine; 15. Faraglione; 16. Arco, ponte naturale; 17. Orlo di falesia: a. h<25 m; b. h>25 m; 18. Spianata di erosione: a. orlo; b. base; 19. Spiagge di ciottoli e ghiaia; FORME ANTROPICHE – 20. Orlo di scarpata dovuta a: a. discarica; b. cava; 21. Cava abbandonata: a. calcare usato per blocchi per sbarramenti e per la calce; b. solo per calce; c. cava a cielo aperto di Portoro, qualità macchia larga; d. cava a cielo aperto di Portoro, qualità macchia fine; e. cava in sotterraneo di Portoro, qualità macchia larga; 22. Area di sbancamento; 23. Terrapieno, area di bonifica, area incolta; 24. Strutture di protezione lungo la costa.

sometimes intermingled with colluvial deposits, associated with rockfall and toppling phenomena, some of which are still active.

In some cases, these deposits appear to be weakly cemented and comparable to slope breccias (CIGNA, 1967). As for the period of formation, by analogy with similar deposits found on the nearby Promontory of Monte Marcello, they are probably attributable to the early Middle Ages, a period characterized by a cold, damp climate (CHELLI & TELLINI, 2001).

NE of *Punta del Pittone*, active edges of landslide scarps were found at about 125/150 m, affecting the outcrops of limestones and of Portoro. The debris deposited on the slope below has been largely redistributed by mass movements triggered by running water (debris flow) or transferred to the foot by marine erosion.

The drainage system on the island of Palmaria is not extensively developed, limited as it is to first order stream that flow into the *Seno del Terrizzo* or *Cala del Pozzale* inlets. These watercourses are rectilinear; the alluvial fans of limited sizes that they form are partly reworked by wave cutting. With particularly heavy rains, the sharp steepness of the longitudinal profile and the presence of debris in narrow and small valleys trigger quick flows that can become hazardous.

On the island of Tino, there are only a few watersheds that drain into the sea only with heavy rainfall. Lastly, relatively moderate colluvial deposits are present in the sectors that are not as steep, where the availability of soil led to widespread terracing of the slopes for agricultural purposes.

4.2. – KARST LANDFORMS

The island's name Palmaria is thought to have originated from the Ligurian etymon *balma*, the meaning of which, *grotto*, is clearly indicated in literature and by the existence of the term *barma* or *arma* referring to grottoes. *Isola della Palmaria* (or *Balmaria*) would thus mean *island of the Grottoes*. In fact, about thirty natural caves have been inventoried on the islands of Palmaria, Tino and Tinetto; these caves are part of the karst site *SP-2, Lama di La Spezia* defined by Regional Law no. 14/1990. The site consists of a narrow outcrop of Mesozoic limestones that extends in a NW-SE direction (*Lame della Spezia*). The outcrop is characterized by karstifiable rocks in which caves develop, frequently with swallow-hole entrances, as do surface landforms, like the doline fields of Mt. Parodi and the extensive closed depressions of *San Benedetto* and *Caresana* (FEDERICI, 1970; SOCIETÀ SPELEOLOGICA ITALIANA, 1987).

Surface karstic phenomena are not very evident on the islands in the gulf, for karstic phenomena are more limited to microforms of corrosion. As concerns the hypogenic landforms, the caves are always of modest dimensions, at least compared to what has developed on the mainland. Although most of these caves are of karstic origin, some cases are related to the effects of marine erosion of the clayey and/or marly fraction and to subsequent collapses.

The caves always appear to fossil forms and together with the limited dimensions of the caves, this aspect leads us to think that the karstification process lasted for a limited period of time – only about ten caves extend further than 25 m and an analysis of the distribution of the cave entrance elevations shows that most entrances are found between sea level and 50 m ASL (CIGNA, 1967).

The cave entrances are essentially located along the coast of the western sector, where the bedrock outcrops over vast areas, in the Formation of the Mt. Castellana Dolomites and in the Portoro, both of which are characterized by a very high carbonate content.

The caves in the La Spezia Formation, however, are even smaller due to the subhorizontal arrangement of the bedding and the prevalence of the clayey fraction with respect to the carbonate fraction.

The most significant caves are the *Grotta dei Colombi* and the *Grotta Azzurra*. The former, with its entrance at about 32 m asl, extends for just slightly less than 80 m (fig. 6), whereas the entrance to the *Grotta Azzurra* is at sea level and the cave itself extends for about 58 m. The *Grotta dei Colombi* is of great importance because of the information

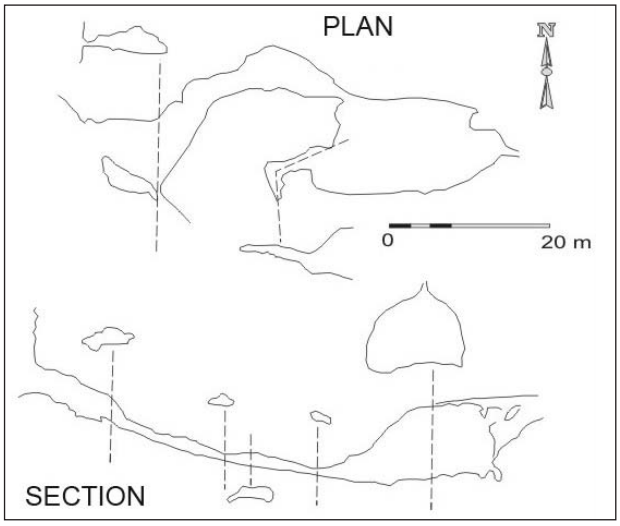

Fig. 6 – *Grotta dei Colombi*, plan and section (modified from SOCIETÀ SPELEOLOGICA ITALIANA, 1987).
– Grotta dei Colombi, in pianta e in sezione (modificata da SOCIETÀ SPELEOLOGICA ITALIANA, 1987).

it has contributed to research in Quaternary Geology and Paleoanthropology. In fact, in this cave, an upper level was found containing human bones attributed to the Eneolithic-Bronze Age, as well as a lower level of Pleistocene age, containing cold-climate faunas (CAPPELLINI, 1896; FORMICOLA, 1983). The *Grotta Azzurra* is particularly fascinating with the special light created inside as sunset nears. It is of karstic origin and the fact that the bottom of the cave is located at a depth of 14 m below sea level, testifies to a rise in sea level occurring after its genesis (CIGNA, 1967).

4.3. – MARINE LANDFORMS

The coastline is interlinked with the geological and structural features of the area, particularly the cliffs characterizing the southwestern sectors of the islands of Palmaria and Tino, sectors lying along a normal fault that has a NW-SW orientation.

Exposed to the swells generated by the *Libeccio*, the south-west wind, these cliffs present retreating scarps with heights that often exceed 100 m and the sea floor become rapidly deep, reaching a depth of 20 m in the nearshore zone (fig. 7).

The rectilinear shoreline in the southwestern sector of Palmaria Island is broken up by two small inlets (*Cala Grande* and *Caletta*), where several bedding-plane sea cave entrances are found; sometimes these caves overlie other caves of karstic origin.

Palmaria's eastern sector has a jagged coastline, with two main inlets, *Cala della Fornace* and *Cala del Pozzale*, which are separated by *Punta della Mariella*. Both inlets are delimited by high cliffs, active also for gravity processes. The cliffs are generally lower in height (20-40 m) and there are some pocket beaches at the base that are supplied by the slope processes (fig. 8).

Fig. 7 – Cliffs on the southwestern slope of the islands of Tino (in the foreground) and Palmaria; the rock walls of the Mt. Muzzerone sea cliff along the Portovenere Promontory (in the background).
– Scogliere nel versante sud-occidentale delle isole di Tino (in primo piano) e della Palmaria; sullo sfondo le pareti rocciose della scogliera del M. Muzzerone lungo il Promontorio di Portovenere.

Fig. 8 – *Cala del Pozzale* beach (Palmaria Island), supplied by debris of thecliff slopes.
– Spiaggia di Cala del Pozzale (Isola Palmaria), seppellita dai detriti provenienti dai versanti della falesia.

The sea floor slopes more gently here and is characterized by two morphological elevations of the bedrock, to a depth of 5 and 10 m at about 150 m from the shore, linked to the tectonic style of this area.

A small marine abrasion platform is observable at the bottom of the cliff in the northern part of *Cala della Fornace*; it overlies calcareous subhorizontal bedding surfaces. In addition to causing constant cliff retreat, the convergence of swells from the S and SE, particularly against the southeastern *Punta della Mariella* sector, has contributed to the formation of a number of sea caves.

At *Punta della Scola*, on the northeastern tip of Palmaria Island, traces of several level surfaces are identifiable. They are found at elevations of 15-40 m and despite the considerable reworking of the original morphology brought about by human activity, their genesis can be traced back to marine erosion.

The presence of several notches at about 10 m ASL on the cliffs in the southern part of the island of Tino (DEL SOLDATO, 1995) provides evidence of sea levels during the Tyrrhenian stage (Silenzi & *alii*, 2004). Beach deposits found in the *Grotta Riparo del Pozzale* at 0.6 m below current sea level also mark an ancient sea level attributable to the Roman period (CHELLI *et alii*, 2005).

Reflecting the bedrock structure, the northern sectors of the three islands present stretches with rock cliffs of a few meters in height, alternating with slopes that are much gentler and bordered seaward by small stretches with accumulated sediments locally, consisting of narrow gravelly-pebbly beaches, sometimes with boulders, alternating with stretches with rock cliffs just a few meters high. Human intervention that has modified the morphology of the coast consists in a number of fill projects along the shores and coastal defence works.

4.4. – Man-made landforms

Landforms that have been affected by anthropic activity on the islands are mainly related to mining and quarry activity, agricultural terracing and military installations. They have led to significant changes in the morphology.

4.4.1. – *Quarry and mining activities*

There are at least ten Portoro marble quarries on the islands of Palmaria and Tino. They are located along the coastal areas facing SW and are now all abandoned sites. For the most part, these deposits consist of the *macchia larga* variety; initially, the deposits were worked in opencast quarries and exploitation continued later using the stope pillar technique. Some of these quarries still bear many visible signs of this historical activity (Cimmino *et alii*, 2006).

Exploitation of the underground deposits began by means of the excavation of an exploratory tunnel using a pick and sledgehammer. More specifically, in the only Portoro quarry existing on the island of Tino, it is possible to observe examples of "*anime*", or vertical pits made at the ends of the blocks, where the quarrymen in charge of block-cutting would place themselves.

On the island of Palmaria, several iron rods can be seen inserted in the rock at the quarry overlooking the *Caletta* inlet. A penetrating pulley system is assembled on the rods to drive the helicoidal wire, which was still used in recent times to cut Portoro marble.

There are recognizable signs of the use of explosives in the quarry located at *Capo dell'Isola,* although blasting was used only to free blocks that had already been cut. Here, there is also a small tunnel that was used to store the explosives.

In the *Cala Grande* area, the old sledge route (*via di lizza*) can still be seen. The pathway was used to lower the blocks of marble on sledges down to the sea. Wooden beams of oak, holm oak or beech were soaped or greased, and placed under the sledge, which the men then guided with the force of their own strength or with the help of hand-powered winches. Hemp ropes were wound around stakes located along the route in order to control and navigate the descent (fig. 9). The blocks were then loaded onto the transport vessels by means of a *bigo*, or derrick; two of these hoisting devices are still present in the southern part of Palmaria Island, and there is another on Tino Island.

Fig. 9 – *Cala Grande* sledge route (Palmaria Island).
– Sentiero a Cala Grande (Isola Palmaria).

The southern part of Palmaria Island is also the location of stone buildings used as shelters for the quarrymen (fig. 10).

As concerns the utilization of the marble, a monolithic Portoro marble column discovered in the 1930s during the excavations of Luni and now housed in the La Spezia Museum of Archaeology is evidence of the interest the Romans had in marble as a material for ornamental use and for use in construction, given the utilization, again in Luni, of small blocks for the amphitheater and slabs used to build the *cardo maximus* and *cardo decumanus* (Del Soldato & Pintus, 1985).

Fig. 10 – Panoramic view of the Portoro marble quarry situated at the *Capo dell'Isola* (Palmaria Island).
– Panoramica della cava di marmo di Portoro situata a Capo dell'Isola (Isola Palmaria).

In the 12th century, the Genoese made ample use of Portoro to build defense works and for construction of the impressive cathedrals and magnificent villas along the Ligurian coast (PANDOLFI, 1971).

In any case, it was mainly during the Renaissance period that Portoro marble was to see its most important application, that is, in architecture. In fact, it was during this period that the Genoese Senate granted the concession to the sculptor Domenico Casella for the extraction of marble in the region under the jurisdiction of the Podestà of Portovenere (MARCHI, 1994).

However, according to CASELLI (1914), the credit for having opened new and old quarries, also on Palmaria island, should actually be given to a sculptor from Sarzana, Giovanni Morello, for in 1600 signed a contract with the Olivetan monks of the *Santuario delle Grazie*, owners of the island (MORELLO, 1626*)*. The very first blocks extracted from the island's quarries were used for the baptistery of the Church of S. Maria in La Spezia and for the palace of the *Marchesi Castagnola*, and Portoro was used later to embellish the churches of the Jesuit Fathers in Palermo and Genoa (CIMMINO *et alii*, 2003).

There are many later reports regarding the Portoro marble quarries: at the end of the 18th century on the occasion of a visit made by Lazzaro Spallanzani, the scientist and philosopher, to see the numerous quarries on the islands, and in the early 19th century when, upon conclusion of the special mission assigned by Napoleon I to Professor Pierre Cordier, Chief Inspector of the Mine Corps, the latter gave an account of the deposits of ornamental stone existing in the area of La Spezia, among which he cited two particularly important quarrying sites on the island of Palmaria (CAPPELLINI, 1864; 1902).

In the 19th century, CAPPELLINI (1864) provided an inventory and reported on the geographical distribution of the thirty quarries existing in the La Spezia area. One quarry is listed for Tino Island and five for Palmaria Island, all active quarries. Among these, the quarry directly facing Portovenere was named *Cava Carlo Alberto*, to commemorate the King of Sardinia's visit on October 2, 1838.

Extraction of the black marble continued on the islands in the 20th century with alternating periods of good and bad fortune. In the early 1900s, exploitation was quite substantial. Then, at the end of the 1930s the entire Portoro marble industry experienced a crisis (GIACHINO, 1930), with partial recovery only after World War II. In the decades that followed, owing to operative difficulties hindering continuation of further exploitation of the deposits, some of which were nearing depletion, and owing to environmental protection restrictions, quarrying gradually decreased and came to an end in the early 1980s: the last site active was located at *Capo dell'Isola* (fig. 10).

There are also numerous limestone quarries on Palmaria Island. They are mainly situated along the coast and are currently no longer in use. These quarries vary in size, ranging from small borrow pits to large amphitheater-like quarries that have supplied thousands of cubic meters of material.

On the basis of the characteristics of the limestones in terms of stratigraphy, chemical composition and fracturing of the various deposits, the extracted material was utilized to produce lime or the blocks were used to construct offshore structures, above all, La Spezia's outer breakwater.

4.4.2. – *Agricultural terraces*

As in the rest of Liguria, vast sectors of the islands of Palmaria and Tino have been terraced for agricultural use. The dry stone walls made of ashlar of varying dimensions and of local origin, sustain debris that have been leveled in order to obtain level terraces on steep slopes. It has been observed that these man-made terraces are situated on slopes characterized by significant debris covers, prevalently on marly limestones, whereas it is much more unlikely to find terraces built on dolomites, also because of the steepness of such slopes.

A significant example of dry stone walls built with marly limestone ashlar of various dimensions, shapes and dressing, and perfectly laid, can be observed on the southwestern slope of the *Fortezza*, and also in the natural amphitheater behind the *Seno del Terrizzo* inlet. The terraces that are recognizable on the northeastern slope of the island of Tino (DEL SOLDATO, 1995) - part of which have witnessed the effects of geomorphological instability phenomena - are interesting also in relation to the buildings erected in the early Middle Ages by the Olivetan monks. The terraces, an effective defense against soil erosion, are of great environmental value in terms of their structural characteristics, state of preservation, the extension of the area involved, and the modeling of the slopes themselves. They represent part of our cultural and historical heritage, as they continue to stand as evidence of the efforts of humankind to adapt areas for agricultural use.

4.4.3. – *Military structures*

The last aspect that is related to anthropic morphogenesis on the islands concerns military structures and activity on the island of Palmaria and

on Tino Island, starting mainly at the end of the 19th century. In fact, fortifications such as the *Fortezza*, *Forte Cavour* and *Forte Umberto I* required the leveling of extensive surface areas and quarries to be opened to supply the necessary stone. In addition to the construction of landing places, especially in *Seno del Terrizzo*, but also in *Seno del Pozzale* and on Tino Island, landfill projects were also carried out.

One last aspect is less evident, but equally important in terms of modification of the environment. It involves the numerous rapid transit tunnels, passing through extensive stretches of land on both of the larger islands.

5. – GEOTOURISM

Based on the geological, geomorphological and environmental aspects described above, geotourist map of the Palmaria islands was prepared to promote an understanding of the phenomena and to valorize them, broadening utilization options to include various types of excursions based on educational, scientific, sports-oriented, cultural/tourist interests (fig. 11).

The main geosites are marked using specific symbols. Those related to cultural geomorphology have been given particular attention, as concerns the network of hiking trails on Palmaria Island (as yet public access is not permitted on Tino Island because it is a military zone). The hiking paths were subdivided according to difficulty, using a simplified scale. Then, any natural hazards that could affect hikers along the paths were marked; these hazards are often associated with particular weather conditions. Any elements involving vulnerability in connection with the path characteristics were also marked.

Among the geological features on Palmaria Island, we note the significant outcrops of Portoro at *Capo dell'Isola*, at the *Carlo Alberto* quarry (*Befettuccio*) and in the *Cala Grande* inlet (fig. 12).

These are geosites that have been affected by significant exploitation, even in the recent past. Among the geomineral features, besides the various Portoro marble quarries, which have been subdivided into open-cast or underground quarries, the quarry fronts at *Punta della Ziguella* and in the *Seno del Terrizzo* inlet are also indicated; they are often important in terms of their educational value. Among the numerous geomorphological features, above all, we note the magnificent cliff in the southwestern sectors of the islands, a typical example of the evolution of a stretch of rocky coast with carbonate cliffs (figures 13, 14), but also the various beaches tucked into the *Pozzale*, *Fornace* and *Terrizzo* inlets, as typical examples of pocket beaches.

On the slopes above *Cala Grande* and the *Caletta* inlet, hikers walk through cemented scree slope deposits, which testify to ancient gravitational phenomena attributable to climatic conditions differing from current conditions. In addition, the geosites of speleological value appear to be significant; among these we note the karstic caves such as the *Grotta Azzurra* and the *Grotta dei Colombi*, which present important traces of changes in sea level, as well as traces of the presence of man in the Prehistoric Age.

As regards the dense trail network created on the island of Palmaria, we note that several trails present difficulties in connection with sharp steepness, unstable or slippery ground, high steps, and/or narrow paths; among these, we find the trail *dei Condannati*, which climbs up along the northern ridge of the *Batteria Semaforo*, and the one passing by the entrances to the underground quarries along the stretch between *Capo dell'Isola* and *Cala Grande*.

Several geomorphological hazards have been detected along some parts of the trail network. Among these, we note potential rock falls, especially near the vertical fronts of the numerous abandoned quarries, possible triggering of debris flows and lastly, hazards connected with strong sea storms, particularly from the SW and SE. All of these hazards can easily become geomorphological risks, depending upon the tourist influx, particularly when little or poor knowledge of natural phenomena is a component, and extreme weather conditions come into play at the same time (BRANDOLINI *et alii*, 2004).

The first trail departs from *Terrizzo* and heads towards *Punta della Scola*. The first important stop is at the fort, *Fortezza del Mare*, now a maritime museum. Visitors then reach *Forte Cavour* via the steep *Sentiero dei Condannati* and then visit the environmental education center at the Batteria Semaforo at the top of the island. A paved road is used to return back to *Terrizzo*.

The second trail route is more difficult, with a higher level of tourist vulnerability. *Pozzale* is the departure point and from there, the trail heads towards *Capo dell'Isola*, where a first stop is possible at the opencast quarry. The trail then continues up a steep climb over the waste due to quarry activities (*ravaneto*) to the mouths of various underground sites of interest at the *Caletta* and *Cala Grande* inlet. The path then continues towards the *Batteria Semaforo* and abruptly descends down to the locality of *Befettuccio*, where the impressive *Carlo Alberto* quarry is found; *Terrizzo* wharf is then reached, just a short distance from there.

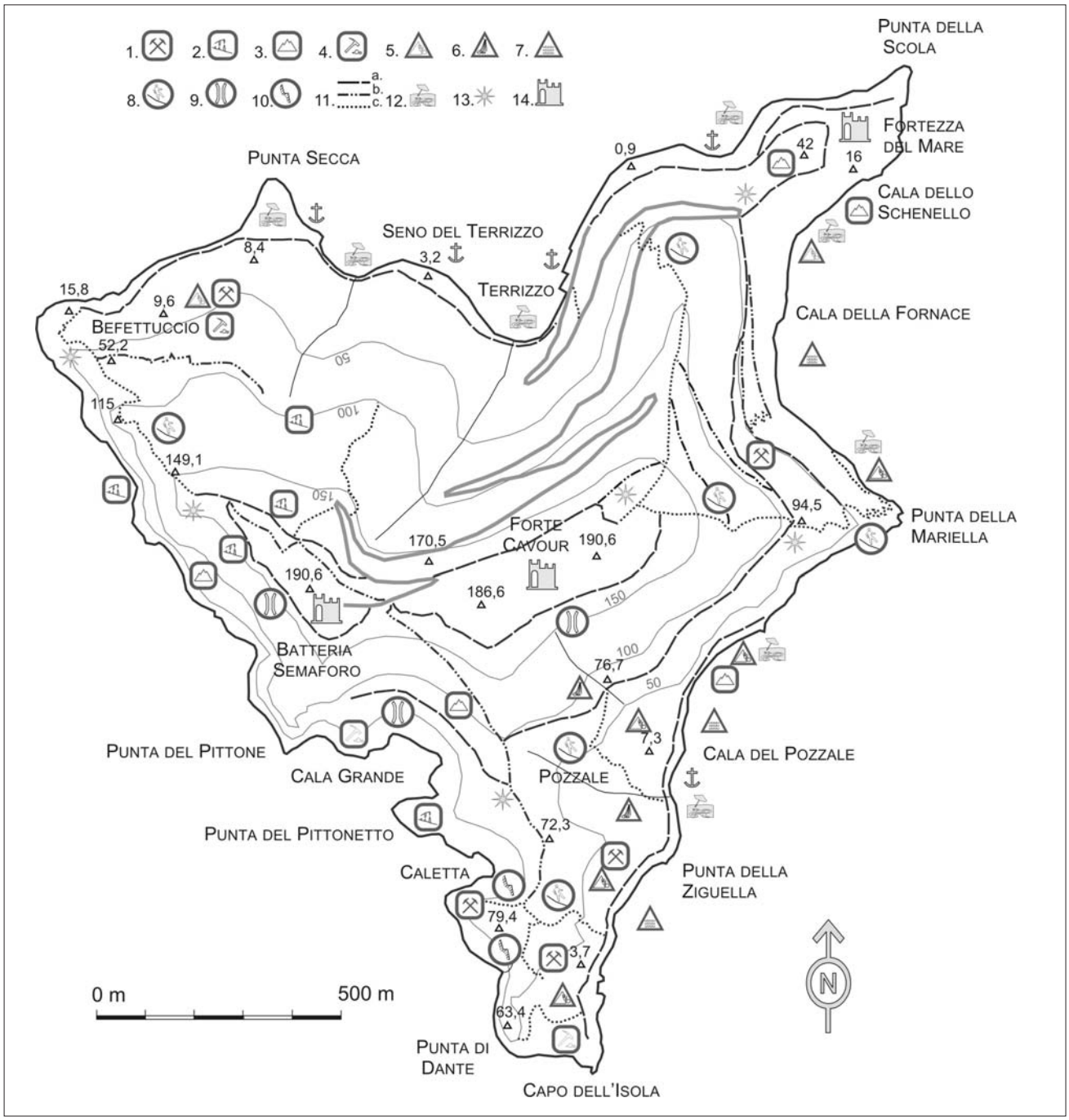

Fig. 11 – Geotourist map of Palmaria Island. Legend: GEOSITES – 1. Geomine; 2. Karstic; 3. Geomorphological; 4. Geological; GEOMORPHOLOGICAL HAZARDS – 5. Rock fall; 6. Debris flow (associated with heavy rainfall); 7. Sea storm; TOURIST VULNERABILITY (hiking path features) – 8. Slippery or rambling track; 9. Narrow trail; 10. Exposed path; 11. Track steepness: a. low; b. medium; c. high; OTHER GEOTOURISTIC EMERGENCES – 12. Beach; 13. Geo-panoramic point; 14. Military structures.

– Carta Geoturistica dell'Isola di Palmaria. Legenda: GEOSITI – 1. Geominerari; 2. Carsici; 3. Geomorfologici; 4. Geologici; PERICOLOSITÀ GEOMORFOLOGICHE – 5. Crolli; 6. Debris flow (in corrispondenza di piogge intense); 7. Burrasca; VULNERABILITÀ TURISTICA (caratteristiche dei sentieri escursionistici) – 8. Tratto sdrucciolevole o sconnesso; 9. Tratto stretto; 10. Tratto esposto; 11. Pendenza del tratto: a. bassa; b. medio; c. alta; ALTRE EMERGENZE GEOTURISTICHE – 12. Spiaggia; 13. Punti geo-panoramici; 14. Strutture militari.

6. – FINAL REMARKS

The islands of Palmaria, Tino and Tinetto constitute the natural seaward extension of the Portovenere Promontory and represent a landscape of exceptional value that simultaneously embodies attributes of a scientific, cultural, socioeconomic and scenic nature.

Over an overall surface area of slightly less than 2 km^2, it is possible to observe examples of morphological modeling linked to marine erosion, gravitational phenomena, running waters, karstic

processes and lastly, to human activities. Many aspects of a scientific nature, but also of educational value and interest at an international level, allow for the observation of models of geomorphological evolution and the investigation of paleogeomorphological evidence related to various climatic stages of the past. In this context, the presence of settlements linked to prehistoric man takes on particular significance and relevancy.

The definition of the historical-cultural value of this area is linked to the ancient monasteries on the three islands, communities that certainly contributed to the atmosphere of spirituality of the islands. However, this value is especially linked to the Portoro marble quarries, which had been exploited as far back as the Roman period. Lastly, the presence of 19th-century military forts also contributes to the valorization of the landscape in historical and architectural terms.

Fig. 12 – Cliff between *Punta di Dante* and *Caletta* (Palmaria Island): note the entrances to the underground Portoro marble quarries in the upper part, the entrance to the *Grotta dei Colombi* in the center, and several bedding-plane sea caves below.
– Falesia tra Punta di Dante e Caletta (Isola Palmaria): da notare gli ingressi alle cave di marmo sotterranee di Portoro nel parte superiore, l'ingresso alla Grotta dei Colombi in centro e numerose grotte lungo i piani di stratificazione nella parte inferiore.

Fig. 13 – Tinetto Island.
– Isola di Tinetto.

Fig. 14 – Rock fall phenomena on southern cliff of Tino Island.
– Fenomeni di crollo nella falesia meridionale dell'Isola di Tino.

In more recent times as a result of the development of seaside vacation activities, the coast has taken on significant socioeconomic value with the creation of bathing establishments and accommodation facilities. Appreciation of all of the features described above is an option made possible through the creation of some guided tour routes, defined on the basis of their geodiversity value: a trail route on the island of Palmaria is based on sites linked to the utilization of stone in architecture, including both civil and military works, while another trail route is based on historical and geomine sites.

Owing to its very small size, the guided trail route through Tino Island covers all of the aspects described above, particularly those related to the geomorphosites and the monastery.

A double looped route along the coast allows for full appreciation of the geomorphological features specific to these islands, particularly concerning the coastal modeling processes. The route starts from Portovenere; first the waters separating Portovenere and Palmaria are crossed, offering an immediate view of the high cliff with the quarry sites at the top and the sea caves at the base. Then the route continues through the channel between Palmaria and Tino, to circle the two smaller islands, offering a direct comparison of the different morphology characterizing the western and eastern coasts. The last part of the route follows the eastern coastline of Palmaria, to observe the *Pozzale* and *Fornace* inlets, and then heads back to Portovenere after reaching *Punta della Scola*.

In conclusion, the islands of Palmaria, Tino and Tinetto present an intrinsic scenic component, while also constituting a preferential observation point with reference to the southwestern sector of the Portovenere promontory. Owing to all of these aspects, the archipelago can be considered an important cultural and scenic asset, an asset that

fully justifies its protection as part of the Natural Park of Portovenere, as well as its valorization as part of our World Heritage.

Acknowledgement

This paper was prepared as part of the MIUR-COFIN 2004 project entitled "Il Patrimonio geomorfologico come risorsa per un turismo sostenibile" (National Coordinator: Prof. M. Panizza, University of Genoa O.U. Coordinator: Prof. M. Piccazzo).

REFERENCES

BENNETT M.R. & DOYLE P. (1997) – *Environmental geology*. Wiley, Chichester.

BRANDOLINI P. & ROLLANDO A. (1995) – *Emergenze geomorfologiche ed ambientali nel sistema di aree protette del Braccо-Mesco/Cinque Terre/Montemarcello*. Atti IV Convengo internazionale di studi "pianificazione territoriale e ambiente", Sassari-Alghero, 1993, Pàtron, 189-204.

BRANDOLINI P., MOTTA M., PAMBIANCHI G., PELFINI M. & PICCAZZO M. (2004) – *How to assess geomorphological risk in tourist areas*. 32° International Geological Congress, Florence 20-28 August, Abstracts 1, 29.

BRANDOLINI P., FACCINI F., PICCAZZO M. & ROBBIANO A. (2005) – *The islands of Palmaria, Tino and Tinetto (Ligurian Sea, Italy): geomorphology, georesources and cultural heritage*. Abstracts Volume, 6th International Conference on Geomorphology, September 7-11, 2005, Zaragoza (Spain), 407.

CAPPELLINI G. (1864) – *Descrizione geologica dei dintorni del Golfo della Spezia e Val di Magra inferiore*. Tip. Gamberini e Parmigiani, Bologna, pp. 152.

CAPPELLINI G. (1896) – *Caverne e brecce ossifere nei dintorni del Golfo della Spezia*. Mem. R. Acc. Sc. Sc, Ist. Bologna, ser. S., **6**, 199-215.

CAPPELLINI G. (1902) – *Note esplicative della Carta Geologica nei dintorni del Golfo di Spezia e Val di Magra inferiore*. Tip. Nazionale di Giovanni Bertero & C., Roma.

CASELLI C. (1914) – *La Spezia e il suo golfo. Notizie storiche e scientifiche*. 8°, La Spezia, pp. 208.

CHELLI A. & TELLINI C. (2001) – *Scree slope deposits during a cold-damp climatic phase in the early middle ages in the Gulf of La Spezia (Liguria, Italy*). Geogr. Fis. Dinam. Quat., **24**, 25-28.

CHELLI A., FEDERICI P.R. & PAPPALARDO M. (2005) – *Geomorphological and archaeological evidence of Roman times shoreline in the La Spezia Gulf*. Geogr. Fis. Dinam. Quat., Suppl. 7, 97-103.

CIARRAPICA G. & PASSERI L. (1981) – *La litostratigrafia della serie triassica del promontorio occidentale del Golfo di La Spezia*. Mem. Soc. Geol. It., **21**, 51-61.

CIGNA A.A. (1967) – *Ricerche speleologiche nelle Isole Palmaria, del Tino e del Tinetto*. Rass. Speleol. It. Mem., **8**, pp. 66.

CIMMINO F., FACCINI F. & ROBBIANO A. (2003) – *Stones and coloured marbles of Liguria in historical monuments*. Per. Mineral., 73 (Special Issue 3: a showcase of the Italian research in applied petrology), 71-84.

CIMMINO F., FORNARO M., LOVERA E. & ROBBIANO A. (2006) – *Evoluzione delle tecniche estrattive nelle cave storiche di Portoro sulle isole Palmaria e Tino (Portovenere – Liguria orientale)*. Volume speciale GEAM, 189-194.

DEL SOLDATO M. (1995) – *Le Isole del Tino e del Tinetto e l'insediamento monastico, ambiente naturale e problemi storico-geologici*. In: FRONDONI A. (Ed.): *Archeologia all'Isola del Tino, il Monastero di San Venerio*. Ed. Sagep, Genova, 101-110.

DEL SOLDATO M. & PINTUS. S. (1985) – *Studio geologico-storico delle attività e delle tecniche estrattive nella Liguria orientale (Area compresa tra Genova e La Spezia)*. Mem. Accad. Lunigian. Sci., **45**-**40**-**47**, pp. 138.

GIACHINO G. (1930) – *Il marmo portoro*. Mem. Accad. Lunigian. Sci., **8**, 17-32.

FEDERICI P.R. (1970) – *Sui rapporti fra fenomeni carsici e tettonica nella Liguria orientale*. Mem. Accadem. Sc. Lunig. Sc., **40**, 7-18.

FEDERICI P.R. (1987) – *Uno sguardo alla struttura ed alla morfologia del Golfo della Spezia*. In: TERRANOVA R. (Ed.): *Atti della Riunione, Guida alle escursioni, Note scientifiche integrative del Gruppo Nazionale Geografia Fisica e Geomorfologia, Sestri Levante 22-25 giugno 1987*. Quaderni dell'Istituto di Geologia della Università di Genova, n. 5, 293-306.

FEDERICI P.R. & RAGGI G. (1975) – *Una nuova interpretazione della tettonica dei Monti della Spezia*. Boll. Soc. Geol. It., **94**, 945-960.

FORMICOLA V. (1983) – *L'uomo. I ritrovamenti antropologici. Preistoria nella Liguria orientale*. Soprintendenza Archeologica della Liguria. (Ed.) R. Siri.

GRAY M. (2004) – *Geodiversity. Valuing and conserving abiotic nature*. Wiley, Chichester, pp. 434.

MARCHI P. (1994) - *Pietre di Liguria*. Sagep (Ed.), Genova, pp. 383.

MORELLO G. (1626) – *Relazione degli Ill.mi della m. da farsi al Collegio Ill.mo supra la supplica del mastro Gio Morello, li 1626 a 6 luglio*. Archivio di Stato Genova, Finanza Pubblica Atti f. 175.

PANDOLFI D. (1971) – *Il marmo Portoro*. L'Industria Mineraria, 9, 491-500.

PANIZZA M. & PIACENTE S. (2003) – *Geomorfologia culturale*. Ed. Pitagora, Bologna, pp. 360.

POTENTI L. & VITTORINI S. (1995) – *Carta climatica della Liguris*. CNR, Centro studi per la geologia strutturale e dinamica dell'Appennino.

ROBBIANO A., BRANDOLINI P., FACCINI F. & PICCAZZO M. (2005) – *The ancient portoro marble extraction sites on Palmaria Island (Gulf of La Spezia, Italy*). Epitome Geoitalia 2005, 5° Forum italiano di Scienze della Terra, 21-23 settembre, Spoleto, 30.

SERVIZIO GEOLOGICO D'ITALIA – *Carta Geologica d'Italia in scala 1:50.000 - Foglio n. 248 La Spezia (2004)*.

SILENZI S., DEVOTI S., GABELLINO M., MAGALETTI E., NISI M.F., PISAPIA M., ANGELELLI F., ANTONIOLI F. & ZARATTINI A. (2004) – *Le variazioni del clima nel Quaternario*. Geoarcheologia, **1**, 15-50.

SOCIETÀ SPELEOLOGICA ITALIANA (1987) – *Le nostre grotte*. Guida Speleologica Ligure. Sagep (Ed.), Genova, pp. 176.