Geogr. Fis. Dinam. Quat.
40 (2017). 1-1, 9 figg.; 2 tab.

DOI 10.4461/ GFDQ 2017.40.8

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GEOMORPHOLOGICAL MAP OF THE ITALIAN COAST: FROM A DESCRIPTIVE TO A MORPHODYNAMIC APPROACH

Abstract: Mastronuzzi G., Aringoli D., Aucelli P.p.c., Baldassarre M.A., Bellotti P., Bini M., Biolchi S., Bontempi S., Brandolini P., Chelli A., Davoli L., Deiana G., De Muro S., Devoto S., Di Paola G., Donadio C., Fago P., Ferrari M., Furlani S., Ibba A., Lupia Palmieri E., Marsico A., Melis R. T., Milella M., Mucerino L., Nesci O., Orrú P. E., Panizza V., Pennetta M., Piacentini D., Piscitelli A., Pusceddu N., Raffi R., Rosskopf C. M., Sansó P., Stanislao C., Tarragoni C., Valente A., *Geomorphological map of the Italian coast:from a descriptive to a morphodynamic approach* (IT ISSN 0391-9839, 2017).

This study was conducted within the framework of the "Coastal Morphodynamics" Working Group (WG) of the Italian Association of Physical Geography and Geomorphology (AIGeo), according to the Institute for the Protection and Environmental Research (ISPRA) for the updating of the legend for the "Geomorphological Map of Italy". The WG deals with the legend for the coastal areas, focusingits work on marine, lagoon and aeolian landforms, processes and deposits. In particular, the legend aims to classify coastal landforms in order to contribute to hazard and risk assessment,for supportingland-use planning and management. The legend allows the mapping of each landform in function of its genesis as well as its evolution and present dynamics, providing information about morphological characteristics at small and large scales. The relict morphological features and the active ones are reported along with the quantitative parameters useful for the description of the present wave/climate conditions and morphodynamics. As a result of the activities and experiments carried out by the "Coastal Morphodynamics" AIGeo WG during the last years, some examples of coastal geomorphological mappings at different scales (1:5,000 and 1:25,000) have been developed and are presented in this paper. The maps focus both on littoral plains and rocky coast dynamics as well as on the interactions with anthropic modifications.

Key words: coastal dynamics, coastal morphology, cartography.

Riassunto: Mastronuzzi G., Aringoli D., Aucelli P.P.C., Baldassarre M. A., Bellotti P., Bini M., Biolchi S., Bontempi S., Brandolini P., Chelli A., Davoli L., Deiana G., De Muro S., Devoto S., Di Paola G., Donadio C., Fago P., Ferrari M., Furlani S., Ibba A., Lupia Palmieri E., Marsico A., Melis R. T., Milella M., Mucerino L., Nesci O., Orrú P. E., Panizza V., Pennetta M., Piacentini D., Piscitelli A., Pusceddu N., Raffi R., Rosskopf C. M., Sansó P., Stanislao C., Tarragoni C., Valente A., *Carta Geomorfologica della costa italiana: da un approccio descrtittivo ad uno morfodinamico* (IT ISSN 0391-9839, 2017).

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Questo lavoro è stato condotto nel quadro delle attività che il gruppo di lavoro "Morfodinamica costiera" dell'Associazione Italiana di Geografia Fisica e Geomorfologia (AIGeo) ha svolto nel più ampio contesto della cooperazione con l'Istituto per la Protezione e la Ricerca Ambientale (ISPRA) per l'aggiornamento della legenda della "Carta Geomorfologica d'Italia". In particolare è stata sviluppata una legenda per la realizzazione di carte geomorfologiche delle aree costiere, anche degli ambienti lagunari ed eolici, considerando le forme del paesaggio e i processi tutt'ora in atto. La leggenda si propone di individuare, caratterizzare e cartografare le forme del paesaggio costiero con il fine fornire uno strumento che permetta di contribuire alla valutazione della pericolosità costiera e di supportare la pianificazione e la gestione del territorio. Essa permette la mappatura delle forme del paesaggio costiero in funzione della genesi, della loro evoluzione e della loro dinamica, alle piccole e grandi scale. Le caratteristiche morfologiche relitte e quelle attive sono riportate accanto ai parametri quantitativi utili per la caratterizzazione delle condizioni meteomarine dei paraggi considerati. Grazie alle attività ed esperienze condotte dal gruppo di lavoro "Morfodinamica costiera" nel corso degli ultimi anni, alcuni esempi di cartografia geomorfologica a diversa scala (1:5.000 e 1:25.000) sono presentati. Essi si concentrano sia sulle piane costiere che sulle coste rocciose e, quindi, sulle possibili interazioni con le dinamiche antropiche.

Termini chiave: dinamica costiera, morfologia costiera, cartografia.

INTRODUCTION

The present morphology of the coastal zone and its organization into more or less complex systems is the result of the coexistence of landforms according to the law of morphostratigraphic superposition (Dramis & Bisci 1998 and references therein). These landforms, largely shaped by currently inactive processes, have left their fingerprints in the landscape without being critical for the present-day morphogenesis. Whether by antecedence or inheritance, it is evident that the architecture of the coastal zone is the result of polygenetic processes acting to produce polyphasic landforms. A complete approach to the classification of coastal landforms should take into account the original processes (i.e., including primary landforms), but should mainly focuson the present processes which interact to modify the organization of the coastal area and characterise the modern dynamics. Indeed, time and scale are concepts needed to define the coastal area as part of the environment, both above and below sea level, which extend for several kilometers on either side of the shore/coastline. It includes subaerial and submarine features where active physical and biological processes could modify the physical environment (i.e.: McGill, 1958; Joly, 1997; Finkl, 2004). As a consequence, since lithospheric, atmospheric, and hydrospheric processes interact in the coastal zone, influencing biological processes, a very large assemblage of landforms is still being modelled here (i.e.: Threnaille, 1987; Carter & Woodroffe, 1994; Sunamura, 1992 and references therein).

Well-defined morphodynamic processes are typical of the coastal area, but they donot correspond to well-defined spatial limits over time, whether in the short, medium, or the long term. These processes donot produce landforms of the same size all along the coast. Inevitably, all together they produce a morphogenetic system with smoothed, dynamic, limits with respect to the coastline/shoreline. All these numerous, different mini-systemsshare the same landforms, but differ in size. They are globally influenced by the relief energy which is continuously changing due to climate and sea level changes. Excluding inherited landforms, currently presentalong coastal zonesresulting from morphogenetic or morphoclimatic systems different from the present ones in the coastal area (i.e.: karstic caves, structural slopes, glacial landforms), it is clear that relative sea level changes playa fundamental role in coastal evolution. This imposes a change, in time and space, of the area in which sea, atmospheric and lithological masses unleash their respective energies (i.e.: Mastronuzzi & *alii*, 2005). Sea level varies according to different time scales in response to eustatic, isostatic, and tectonic factors, so that the coastal zone can retain "continental" landforms. These are produced during low relative sea level stands, as well as "coastal" landforms shaped in correspondence to high relative sea level stands, and both may have been remodeled. Sequences of coastal landforms are distant from the sea and from the coastal areas, such as in Calabria or in the Basilicataregions, affected by uplift in the last 125 kyr. On the contrary, "stable" regions show superimposition of fossil/inactive landforms of different ages at the same altitude, such as in Sardinia or in Apulia. Landforms and deposits formed in the same span of time are well below the present sea level, such as in the Po river delta or in the Gulf of Trieste, due to generalized sedimentary loading and/or tectonic subsidence of those areas. Actually, the altimetric distribution of such landforms is in function of the local tectonic and isostatic history, and is specificto each coastal region (Ferranti & *alii*, 2006; Antonioli & *alii*, 2009; Anzidei & *alii*, 2014; Furlani & *alii*, 2014a). Coastal systems continuously reorganize themselves in response to climatic and sea-level changes, onthe one hand, and to the growing anthropic pressure, both on coast and inland, on the other. The sum of vertical ground movements (global isostatic adjustment, tectonic, volcanic and natural or anthropogenic accelerated subsidence), interrelated with eustatic and climate change, can heavily modifythe relative energy affecting a coastal area even in the short term,thusinducing the reorganization of coastal systems (i.e.: Bruun, 1962; Pirazzoli, 1996; Mörner, 1996; Douglas & *alii*, 2001; Lorenzo-Trueba & Ashton, 2014).Therefore, it is important

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This study has been produced by the AIGEO working group "Coastal Morphodynamics". It has been conductedwithin the framework of the Flagship Project RITMARE – The Italian Research for the Sea – coordinated by the Italian National Research Council and by the Italian Ministry of Education, University and Research within the National Research Program 2011-2013, and by the PRIN MIUR 2010-2011 'Response of morphoclimatic system dynamics to global changes and related geomorphologic hazard' *(National coordinator: C. Baroni; Local Coordinator UNIBALE: G. Mastronuzzi).*

We would like to thank Prof. Victoria Sportelli for improving the English form of this paper, as well as two anonymous referees for contributing to the improvement of thescientific content of the same.

The present paper is a contribution of AIGeo to the project IGCP 639 - International Geological Correlation Programme 'Sea-level change from minutes to millennia' by UNESCO-IUGS.

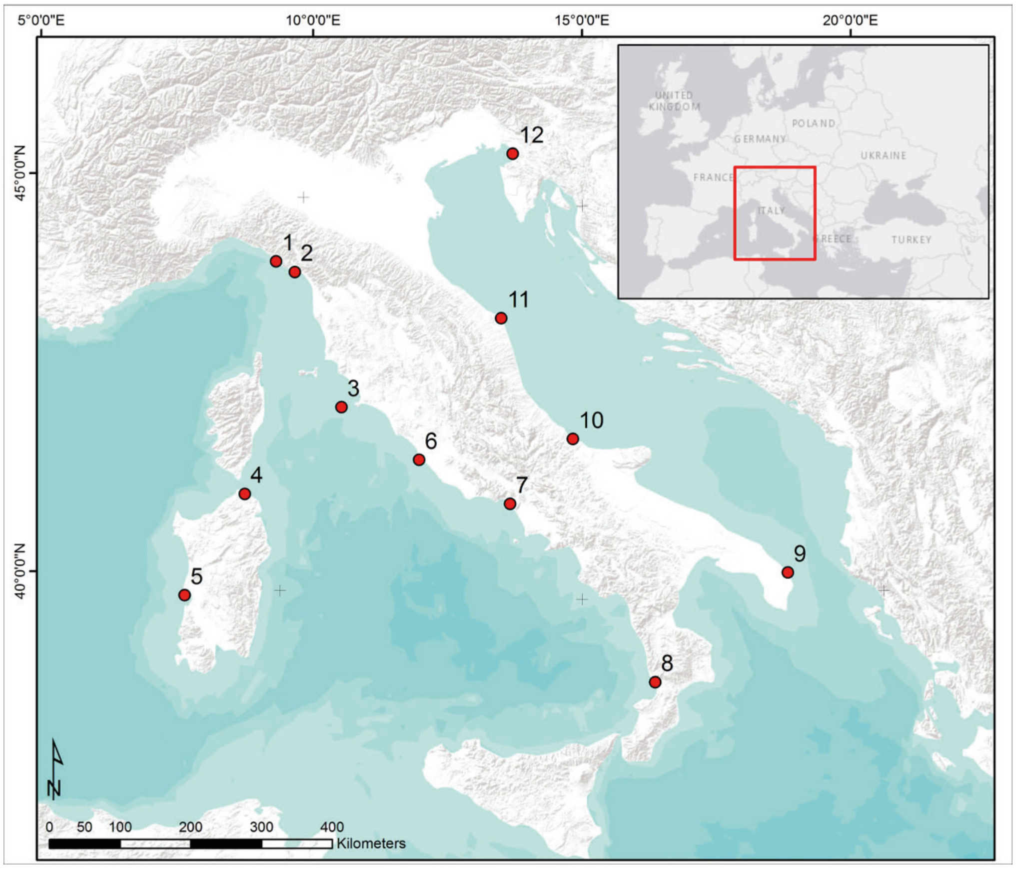


FIG. 1 - Case studies: 1) Bonassola-Levanto rocky coast and embayed Beach; 2) Tellaro rocky coast; 3)the Franco Promontory and the Campese Bay; 4) Isola dei Gabbiani Tombolo; 5) the coastal area of Torre San Giovanni - Capo San Marco; 6) the Tiber River Delta; 7) littoral of the Garigliano River Mouth; 8) the La Vota paralic system; 9) the Roca – S. Andrea coast; 10) the Northen sector of the Molise Coast; 11) the Northern coastal sector of the Mt. Conero Promontory; 12) the rocky coasts of the Gulf of Trieste.

to stress that modern coastal zone mappings should focus on both the morphological and morphometric features of present landforms together withtheir dynamics as a function of active (waves, currents, tides) and passive (lithology, structure, relict landforms) factors, as well as on mass budget and biological change. In this paper, the proposed legend for a new morphodynamic map of the coasts of Italyis illustrated by means of 12 case studies (Fig. 1) in which a correlation between shapes, waveclimate data, and dynamics is presented. The aim is to summarise the most recent results in mapping the coastland morphology within the context of a long cultural process, involving the Italian scientific community's recent perspectives for studying coastal geomorphology.

PRINCIPLE AND METHOD

The legend described in this paper is the result of two important studies concerning geomorphological mapping of the coasts of Italy produced by researchers from the former *National Group of Physical Geography and Geomorphology* (Gruppo Nazionale di Geografia Fisica e Geomorfologia), currently called *Italian Association of Physical Geography and Geomorphology* (Associazione Italiana di Geografia Fisica e Geomorfologia). More specifically, the legend is based on the results of the "Conservazione del suolo", "Dinamica dei litorali" sub-project, reported in the Atlas of Italian Beaches (Atlante delle Spiagge Italiane; Aa.Vv., 1997) and on the edited guide to geomorphological mapping of Italy at the scale 1:50,000 (Gruppo di Lavoro per la Cartografia Geomorfologica, 1994). The legend here proposed collects recent research advancements carried out by the community of Italian coastal geomorphologists as well as the results of an articulated scientific discussion developed by the Coastal Morphodynamics Workgroup established by AIGeo in 2013.

The study focuses on the entire coastal perimeter of Italy in the Mediterranean climate region. Although the coastal zone includes different geodynamic areas, ranging from those characterised by high uplift rates to those stable or subsiding, it is considered as a single morphoclimatic zone. The latter aspect considersthe sea energy as "homogenous", being only affected by lithology and exposure/fetch of each area. Other aspects, relevant to coastal processes, are somewhat less straightforward: ì) the role of inherited landforms (i.e. hillslope or karst cave in submerged areas); ìì) the role of volcanic processes which can characterise a coastal area, but are not coastal processes; ììì) the role of continental processes in coastal areas (i.e.: landslides triggered by non-marine processes); ìv) the role of anthropogenic factors. In order to address these issues, the primary task of this study has been to createa classification of coastal landforms which, compared to any previous descriptive/genetic approaches, would be quantitative and dynamic in relation to causative process. Thus, coast-

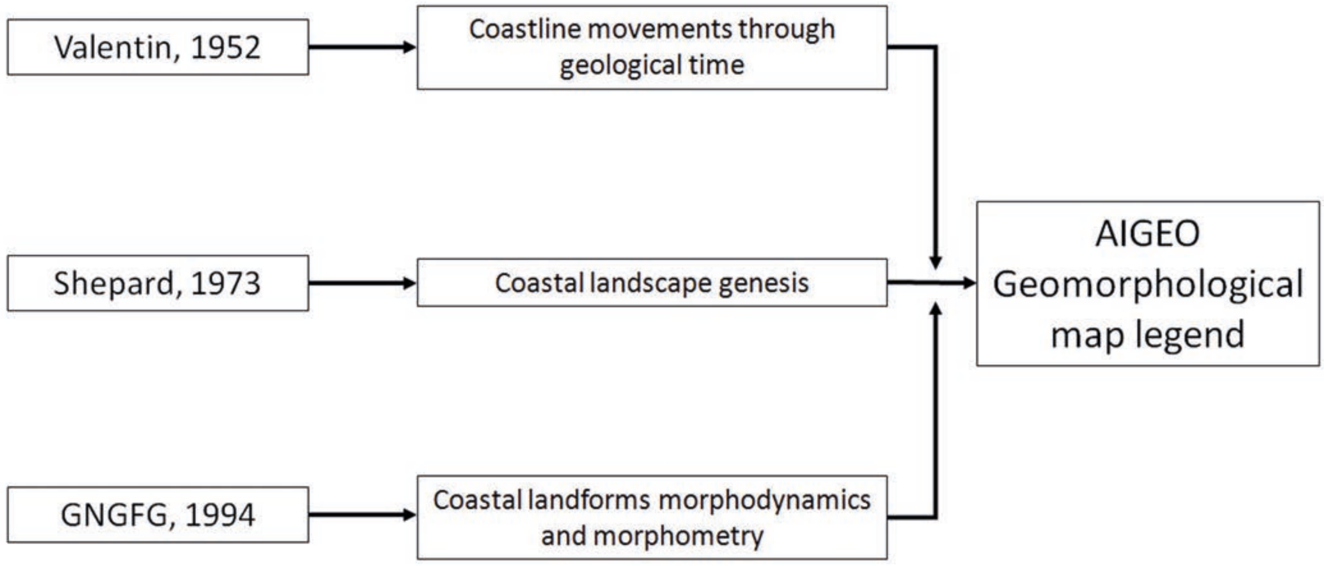


FIG. 2 – Theoretical flow-chart explaining the construction of the proposed legend;it has been obtained starting from a coastal landscape analysis, recognizing the landform genesis at a regional scale, while considering their evolution and present dynamics (SHEPARD, 1973) in relation to the sea-level history and evolutive trends of shore/coast-line (VALENTIN, 1952).

al landforms aremainly classifiedin function of the genetic mechanism still active in their dynamics, while also taking into considerationinheritance, spatial and temporal scales, as well as potential changes in the architecture of the coastal landscape. As a consequence, the leading principle, upon which the surveys producing the legend were based, has been: "... *it is necessary to identify the morphogenetic processes and to classify them since the changing balance of energy and masses induces changes in the landform arrangement*..."; any descriptive non-genetic term has been ignored. Unlike the vast majority of existing coastal maps, this paper suggests replacing the descriptive approach of "morphographic" maps with onethat produces "morphodynamic" maps, enriched by hydrodynamic features, sedimentological and ecological data, evolutive trend etc. This may be achievedbyimplementingthe model producedby researchers involved in this study (i.e.: De Muro & *alii*, 2016a,b; 2017)., considering the proposed legend not an an endpoint, but rather a new starting pointto be refined over time. To this purpose, the proposed legend is divided into different thematic layers and at different map scales, reporting morphogenetic, morphometric, and morphodynamic data, and thereby facilitating their input into a Geographical Information System (GIS). In this way, data reported on geomorphological mapscan be used for a variety of purposes by different stakeholders, ranging from researchers interested in the long-term evolution of the coastal landscape to land-use planners requiring quantitative analyses of active processes to formulatedecisions on appropriate land-use at human time scales.

Furthermore, the GIS project can be easily integrated and/or modified using new data sets with different spatial and time scales deriving from new research or improvements of the survey techniques. A GIS may allow an interested stakeholder to efficiently retrieve information about a specific landform in the coastal landscape extending beyond cartographic data, such as pictures, morphometric, and morphodynamic data, geological and bibliographic references and so on, or to combine these data to produce derivative mapswhich, for example, might describe a particular coastal hazard.

The construction of the legend was the result of a theoretical approach based on the critical analysis of the pieces of information derived from classifications proposed during the last century (i.e.: Johnson, 1919; Cotton, 1952; Valentin, 1952; Inman & Nordstrom,1971; Shepard, 1937; 1973; Hayden & *alii*, 1984; Joly, 1997; Finkl, 2004 and references therein), synthetically expressed by the flow chart reported in Fig. 2. Indeed, on this basis, it can be asserted that the legend has been built starting from a coastal landscape analysis, recognizing the landform genesis at a regional scale, while considering their evolution and present dynamics (Shepard, 1973) in relation to the sea-level history and evolutive trends of shore/coast line (Valentin, 1952). The authors believe that this approach allows to consider the coastal morphology not only as a 2D view focusingexclusively on the shore/coast line, but, more extensively, as the entire coastal area taking into considerationa 3D view related to space (inland and seaward) and time. The morphological and morphodynamic legend reported in Fig. 3 represents only a small part of a more complex geodatabasebecause it delineates and maps the present coastal landforms as point, line, and polygonal elements at scales ranging from 1:50,000 to 1:5,000;some examples at these scaleshave been developed.

Data were derived by direct field surveys together with the analysis of aereophotogrammetric and LIDAR surveys; morphological data were acquired with references to the WGS84 Geographic Coordinate System, elevation above mean sea level and depth belove expressed in metres. Sym-

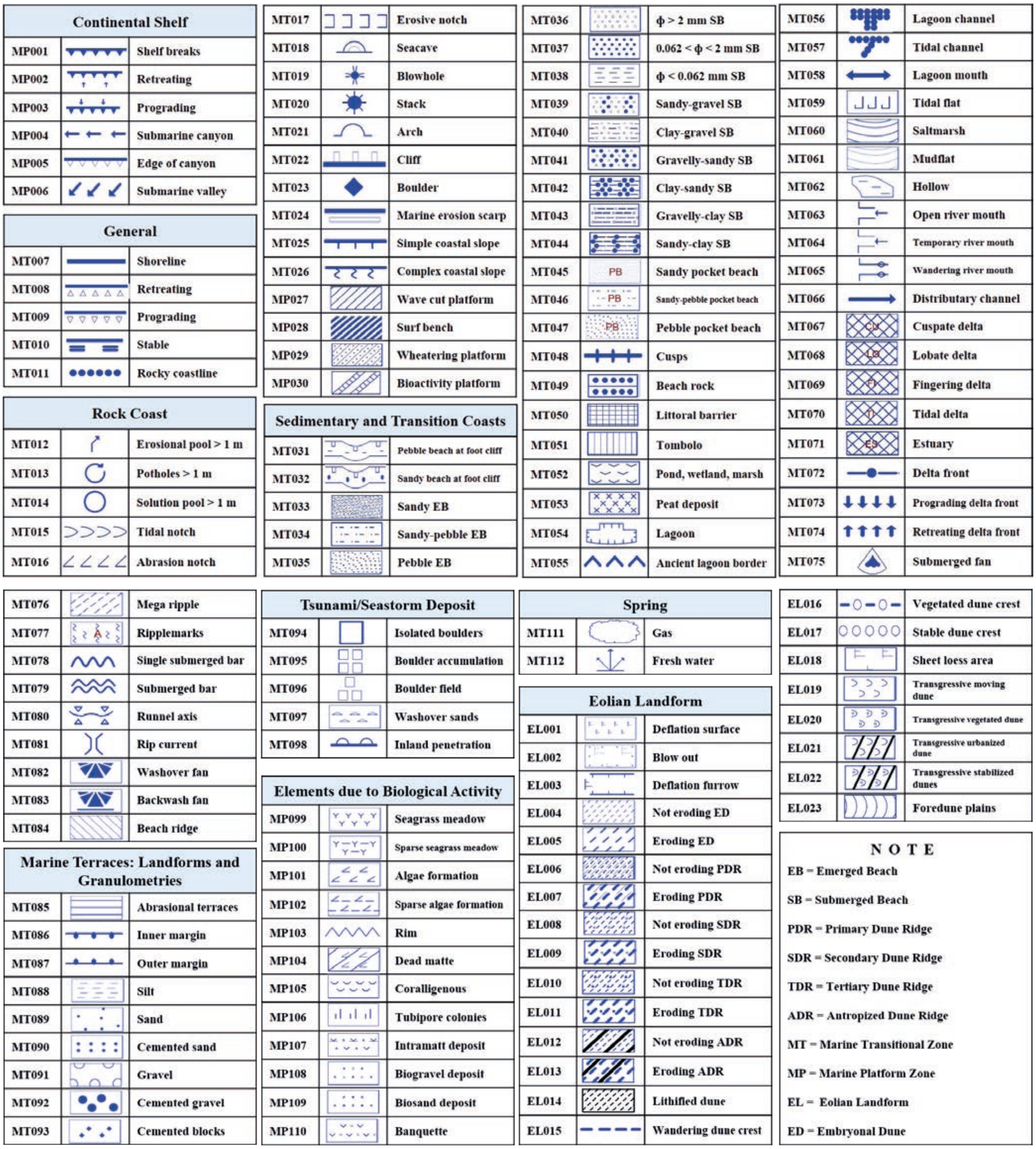


FIG. 3a,b - The legend.

bols have been reported by each local research group on the topographic regional maps integrated in a GIS compatible in a CAD environment; the adoption of this methodology allows to change graphical symbols according to the consideredscale. However, thenew legendmay be considered more useful for coastal planners and stakeholders because it describes both the genesis and evolution of coastal landforms. In the final GIS project, two further informative layers will contain tables regarding morphometric and waveclimate/mareographic data.

BONASSOLA-LEVANTO ROCKY COAST
AND EMBAYED BEACH
(BRANDOLINI P., MUCERINO L., FERRARI M.)

Geological and geographical settings

The stretch of coastline discussed here is oriented NNW-SSE, and extends for about 7.5 km along eastern Liguria (NW Italy) (Fig. 4). This coast is characterised by very steep coastal slopes and a continuous seacliff interrupted only by two embayments corresponding to small fluvial-coastal beaches where the villages of Bonassola and Levanto are located (Terranova, 1987). From Wto E, the geology of the coastal zone is characterisedby outcrops of several ophiolitic and sedimentary lithotypes belonging to Internal Ligurid Units (Giammarino & *alii*, 2002): gabbros (Upper Jurassic) all around the Bonassola bay between Punta della Madonnina and Punta Levanto; serpentinites (Middle-Upper Jurassic), along the western sector of the Levanto bay; a small outcrop of basalts and breccias (Upper Jurassic) and shales with siliceous micritic limestone and sandstone (Upper Cretaceous), along the eastern sector of the Levanto bay.

Waveclimate, currents and tide

The wave climate data, summarised in Table 1, have been retrieved from the La Spezia RON buoy (Rete Ondametrica Nazionale), in the period 1987-2007., located at (43°55'.7 N, 009°49'.6 E Gr) 16.7 Nautical Miles from the study area, at awater depth of 90 metres. Wave datasets have been transposed according to De Girolamo & *alii* (1998). Effective fetch was evaluated using Effective Fetch Calculation (CERC 1977), while the sizigial tide amplitude value was supplied by the *Istituto Idrografico della Marina*.

Coastal evolution and present landscape

The rocky coast is mainly characterised by active seacliffs subject to rockfall and slide phenomena (Brandolini & *alii*, 2009). On average, the seacliffs range between 10-20 m in height, in some cases up to 50-60 m (Bonassola

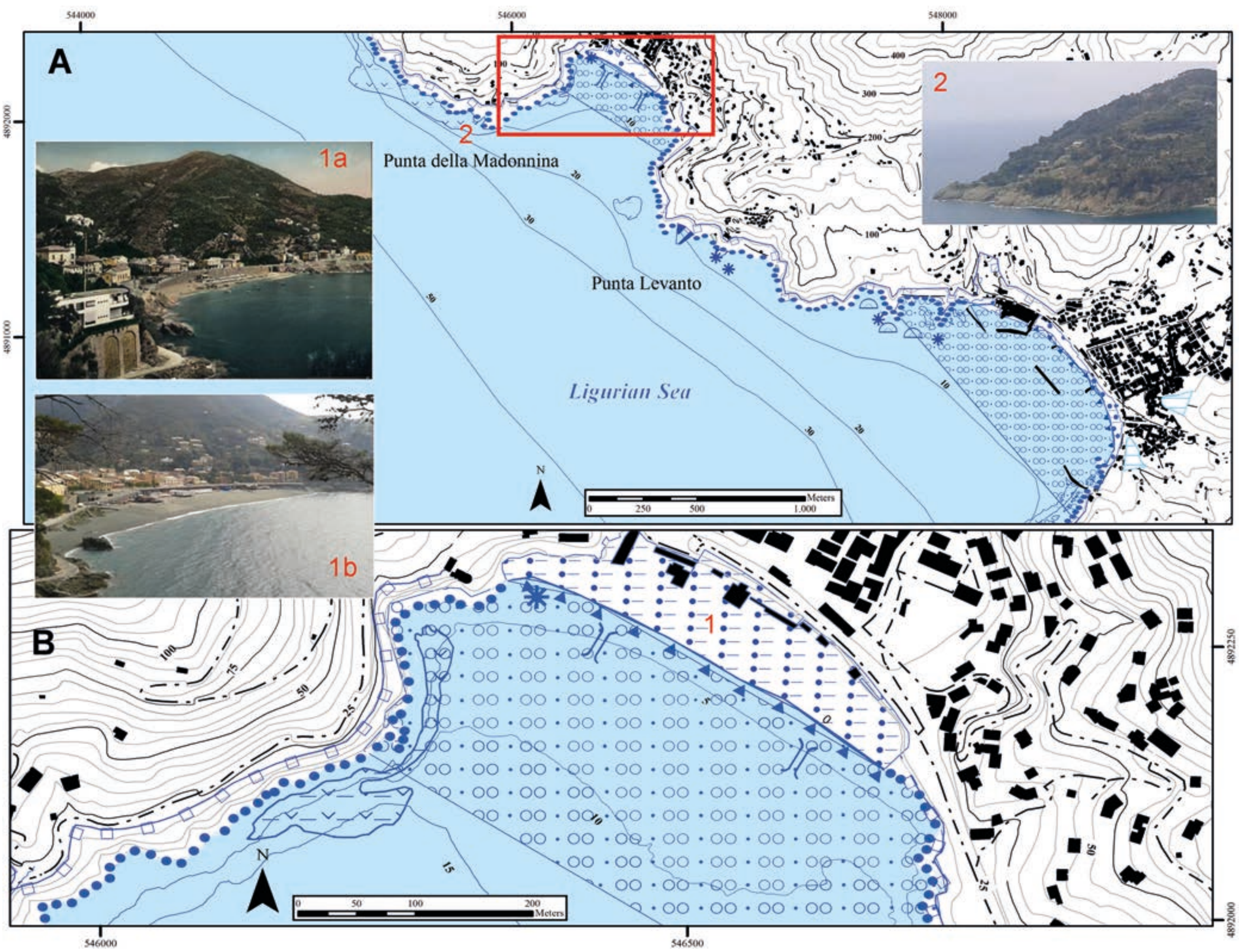


FIG. 4 - Geomorphologic maps of the Bonassola-Levanto rocky coast and embayed beaches (A at a scale of 1:25,000, and B at a scale of 1:5,000): (1a) Bonassola beach evolution between 1960 and (1b) 2015; (2) rocky coast and marine terrace in correspondence of Punta della Madonnina.

TABLE 1 - Main wind and wave climate featuresof the Bonassola-Levanto area.

Recording period	Prevailing wind (°N)	Dominant wind (°N)	Main wave direction (°N)	SWH* (m)	Wave period (s)	Wave length (m)	Secondary wave direction (°N)	Effectivefetch (km)	Closure depth** (m)	Sizigial tide amplitude (m)
1987-2007	0-45	0-45	240	4.2	7.8	88	150	675	7.55	0.40

(* =significant wave height, ** = according to Hallermeier, 1981)

bay), and, in one case, up to 100-130 m (Levanto bay). The interaction between wave action from the SW dominant direction and the different types of highly faulted and fractured bedrock producedan almost continuous indentation or scalloping of the coastline. Due to intense erosion along the main fractures, faults, and weathered zones, particularly at the junction point between gabbros and serpentinites, some sea caves formed. Moreover, sea stacks and stack stumps can be observed along the coast. Small wave-cut platforms, corresponding to gabbro outcrops between Bonassola and Levanto (Fig. 4), are also present. Evidence of sea-level changes and/or uplift are visible at Punta della Madonnina, where a flat surface, probably a relict marine terrace having an inner margin at 23 m and an outer margin at 10 m a.s.l. (Fig. 4.2), is located. On the eastern slope of the Levanto Bay, three small relict marine terraces are foundhaving inner margins ranging between 30 and 40 m and outer margins between 20 and 35 m a.s.l.

The Bonassola beach, located in a bay delimited by the promontories of Punta Madonnina to the West and Punta Levanto to the East, is fed by alluvial materials, eroded from the San Giorgio and Rossola catchments (5.7 km^2 area in total), where mainly gabbros, serpentinites, basalts and ophiolitic breccias crop out. The Levanto Beach, 1.4 km in extension, is located in the bay bordered by the promontories of Punta Gone,to the West, and of Punta Piccetto,to the East, (Brandolini & *alii*, 2002). The beach is mainly fed by alluvial deposits coming from the Ghiararo stream basin (16.4 km^2). The catchment is characterised by bedrock composed of shales, limestones, and sandstones in its upper part, and by serpentinites and gabbros in its lower part. The Levanto Beach is divided into three sectors by two groins; the western sector (150 m long, 35 m wide) and the central sector (240 m long, 35 m wide) undergo a slight erosion, while the eastern one (400 m long, 43 m wide) is stable. The western and eastern groins are respectively 40 m and 45 m long. Coastal structures include not only groins, but also a detached low-crested structure. The breakwater, built in the central sector, is approximately 65 m away from the shore and extends for almost 100 m alongshore (Schiaffino & *alii*, 2015). Both beaches experienced a large supply and expansion due to a new railway construction in 1960. In particular, the Bonassola beach increased up to 100 m (Fig. 4.1a,b).

Coastal dynamics

The geomorphological map (fig. 4) shows the current morphodynamics of the Bonassola and Levanto beaches. The Bonassola beach has steep and typically concave profiles with slopes increasing up the beach face, according to pebble grain size of the beach. Rip currents occur in the beach, highlighted by the presence of some cusps (Corradi & *alii*, 2012; Balduzzi & *alii*, 2014).

The nearshore has an 8.3% slope, circa, from the shoreline to a 10 m water depth, and becomes 5.5% at water depths of 10 to 30 m. The offshore beach is composed of sandy-gravel, and, at the boundaries, close to the promontories where bedrock outcrops, it is covered by sea-grasses (*Posidonia oceanica* and *Cymodocea nodosa*). As shown by the geomorphological map and in relation to meteomarine data, the beach is retreating and partially protected by wave attack from the SE and SW. In fact, the sedimentary dynamics is closed in the bay due to the presence of the two extended promontories.

The geomorphological map highlights the presence of a mixed sand-gravel beach near Levanto.whoseprofile indicates a gentler slope compared to the Bonassola beach. Sediment grain-size varies along the beach both in cross-shore and long-shore directions. In the beach step, the sediment grain-size ranges between medium sand and pebble, decreasing in the offshore direction to fine sand. The nearshore has a slope of 3.8 % and 2.5 % at the offshore zone. Thewestern sector of the beach is retreating, while theeastern sector, due to the flooding events whichoccurred in 2011 and 2014, is prograding (Brandolini & Cevasco, 2015; Brandolini & *alii*, 2016).

THE TELLARO ROCKY COAST (LIGURIA) (BINI M., CHELLI A.)

Geological and geographical settings

The Gulf of La Spezia (fig. 5.1) is a deep embayment present in the easternmost part of the coast of Liguria formed by two NW-SE-oriented promontories which are, two folds belonging to the Northern Apennines. These promontories also represent two horsts bounding the graben of the Gulf of La Spezia. Indeed, the latter is a portion of the Magra River – Vara River graben system, developed in the inner side of the Northern Apennines ~~as of~~the late Miocene-early Pliocene (Bertoldi & *alii*, 1994; Baroni & *alii,* 2015) during an extensional tectonic regime. Various faults and fault systems affect this tract of coast, mainly a NW-SE extensional fault system, and NE-SW – oriented faults, roughly perpendicular to the previous ones.

In the studied area, the rocks belong to the Tuscan Nappe (Falda Toscana Auctt.), and are composed of a sequence of Triassic to Cretaceous sedimentary limestones and of Scaglia Toscana and Macigno formations.

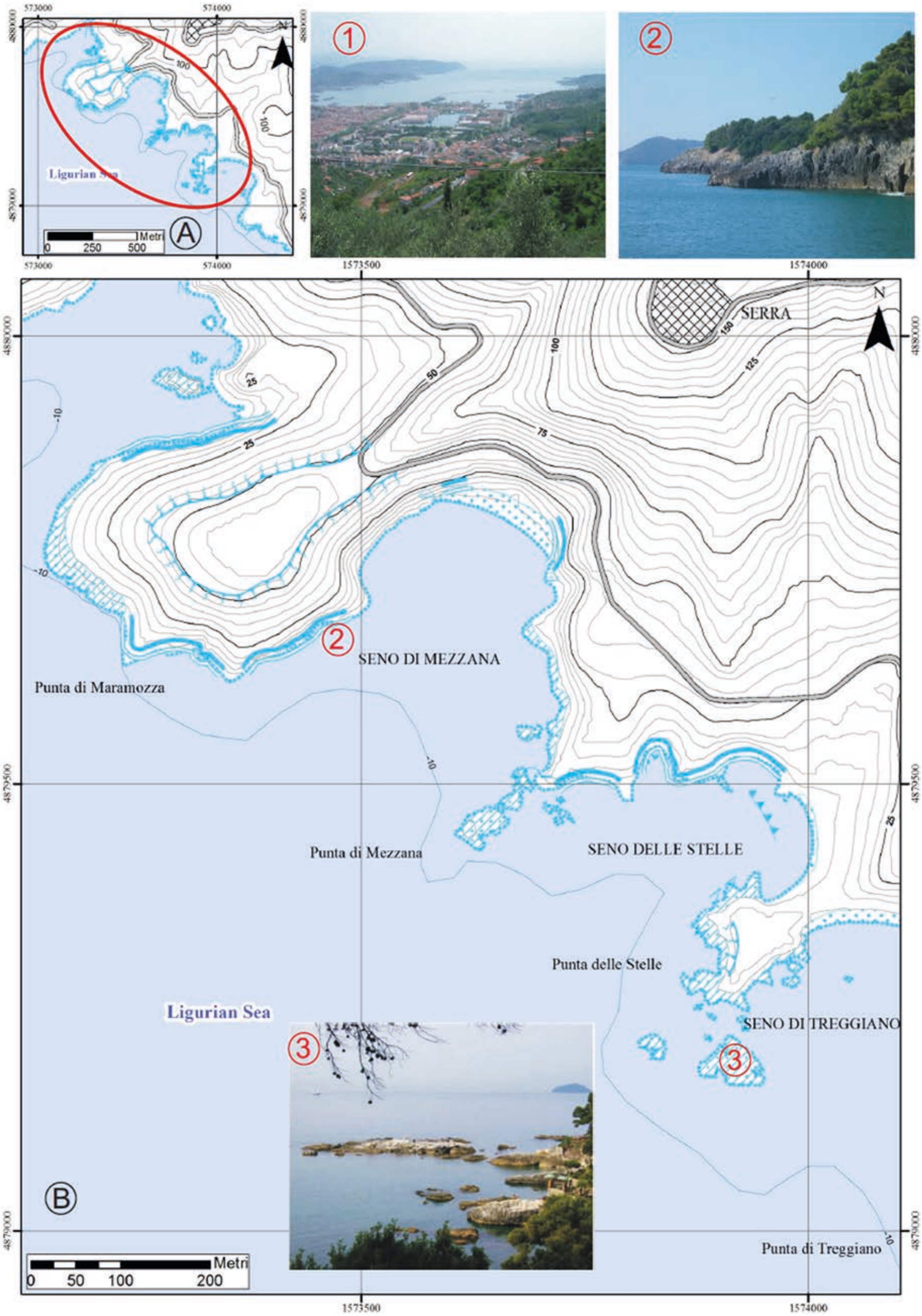


FIG. 5 - Geomorphologic maps of the Tellaro Rocky coast (A at a scale of 1:25,000, and B at a scale of 1:5000): (1) the Gulf of La Spezia; (2) marine erosional scarps at Punta di Mezzana; (3) Punta delle Stelle weathering platfoms and stacks.

TABLE 2 - Main wind and wave climate features of the Tellaro coasts.

Recording period	Prevailing wind (°N)	Dominant wind (°N)	Main wave direction (°N)	SWH* (m)	Wave period (s)	Effective fetch (km)	Closure depth** (m)	Sizigial tide amplitude (m)
2010-2015	10-30	125-145	190	2.4	12.7	211	5.25	0.5

(* =significant wave height, ** = according to Hallermeier, 1981)

Waveclimate, currents and tide

The waveclimate conditions of the studied area are summarised in Table 2. They were derived from the wind gauge on the Island of Palmaria (201 m a.-m.s.l. (= above mean sea level)) and from the wave gauge 10 km offshore of the Gulf of La Spezia. Incoming main waves are parallel to the coastline. Nearshore wave transformations are limited, mainly in the most external part of the gulf, where the sea bottom is deep near the coast. Thus, waves rarely break on the rocky coast, as they are rather generally reflected.

Coastal evolution and present landscape

The gulf has a tectonic origin, and was a fluvial valley during the MIS4 when the sea-level dropped by about 130 m below the present-day sea-level. Some near-horizontal topographic surfaces, located between 10 and 20 m a.m.s.l. characterise different areas of the gulf. They were interpreted as marine terraces (Federici, 1987), even if clear proof of their marine origin has never been identified. The coast of Tellaro is shaped like a succession of bays and headlands resulting in an indented coastline. Promontories, within their first 15 m above sea-level, are characterised by cliffs (fig. 5.2), ramps, stacks, rock ledges, and platforms, while gravelly pocket beaches characterise the embayments. Owing to the wide outcrops of carbonate rocks, the karst terrains are largely diffused. Both surface and subsurface karst landforms are strongly affected or controlled by tectonic features (faults, fractures, foliation) in the bedrock.

Landslides are widespread, mainly in the most prominent part of the eastern promontory (Chelli, 2000; Chelli & Tellini, 2001) where the hillsides display slope-over-wall profiles, and staircase morphologies (Federici, 1987).

Coastal dynamics

The cartographic sketches (fig. 5) show the portion of the eastern coast of the La Spezia Gulf, between the villages of Lerici and Tellaro. Shore platforms are widespread in the NW side of the headlands composed of carbonate rocks, while cliffs and small beaches characterise the SE side of some headlands and the inner portion of the bays, respectively. The shore platforms are generally narrow and gently dipping towards the sea (10° on average), truncated seawards by a scarp plunging into the sea and backed by a cliff or a slope (Chelli & *alii*, 2010). They are mainly due to weathering of rock surfaces (weathering platforms) that often represent remnants of tectonic (fig. 5.3).

Owing to the progressive erosion of platforms, many stacks are presently at a short distance from the coastline. In addition, landforms,such as natural arches and caves, are present due to cliff dissection. In summary, the geomorphological maps and the sea condition allowed to infer that the considered tract of coast is characterised mainly by erosive processes as demonstrated by the presence of landforms, such as cliffs and shore platforms. It is a clear example of a coastal slope characterised by inherited landforms resulting from different processes (karstic, tectonic, slope processes) currently reshaped by marine processes. Therefore, the geomorphological mapping proved to be an efficient tool to determine the morphodynamics features of the rock coast as found in other parts of the eastern Ligurian coast (Chelli & Pappalardo, 2008).

The changing of the cartographic scale from 1:5,000 to 1:25,000 determines a change in the use of map symbols. In particular, several features change from a polygon to linear representation, including several shore platforms or beach deposits which are represented as polygons in the cartographic sketch at a 1:5,000 scale, but become linear features in that at 1:25,000. Moreover, a few significant variation in deposits recorded along the coastline in the 1.5,000 scale map cannot be reported in the 1:25,000 scale map (see the area N of Seno del Treggiano). Finally, some closely spaced lines in the map at 1:5,000 (i.e. cliff and shore platforms in the areas of Seno delle Stelle and Seno del Treggiano) cannot be reported in the map 1:25,000 due to an overlapping of the two symbols.

THE FRANCO PROMONTORY AND THE CAMPESE BAY, W GIGLIO ISLAND (ARINGOLI D.)

Geological and geographical settings

The Franco Promontory is situated in the western side of the Giglio Island; in its northern part, through a series of sea stacks (one in particular, the Faraglione), delimits a large bay encompassing one of the most characteristic beaches of the Tuscan Archipelago (figg. 6.1 and 6.2). Today, the beach of Campese represents a major tourist attraction, but in past centuries, the entire bay was very important for commerce and mining activities, not to mention that it was a natural and beautiful red coral field.

Approximately 90% of the Giglio Island extension is formed by plutonic monzonitic granitoids, and its uplift was related to the tectonic phase following the formation of the Apennine structures. This tectonic period produced episodes of mainly acidic magmatism, such as the one that led to the formation of the Giglio Island pluton about 5.0 million years ago (Rossetti & *alii*, 1999; Westerman & *alii*, 2003).

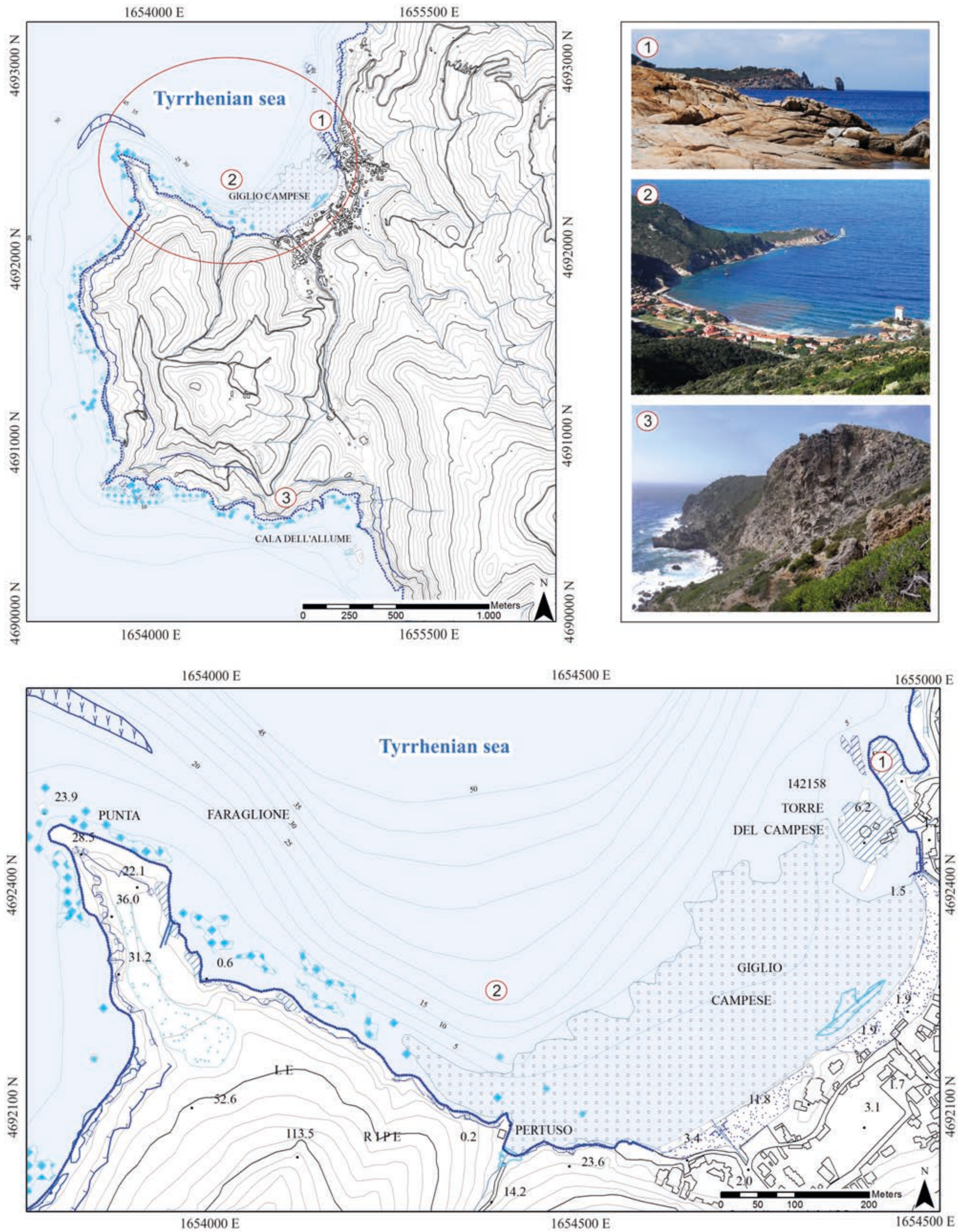


FIG. 6 - Geomorphologic maps of the western coast of Giglio Island (A at a scale of 1:2,.000, and B at a scale of 1:5,000): (1) view from the northeast of the closing edges of the Campese Bay; (2) panoramic view of the Campese village and the southwest margin of the bay; (3) the "Cala dell'Allume" and southern part of the Franco promontory.

The only non-plutonite/plutonicpart of the island is found in the western sector, forming the Franco promontory, southwestward of the Campese village, both subjects of this note (fig. 6.2). In this area of about 2 km^2, a set of metamorphic and sedimentary Mesozoic rocks crops out. These are divided into two structural units called Upper Unit, consisting of grey shales and metagabbros, and Lower Unit, with outcrops of Crystalline Limestones, Cavernous Limestone and Verrucano formation (Capponi & *alii*, 1997). The contact between these units and granites is a set of sub-vertical normal faults oriented NNW-SSE, located along the Ortana valley, southwest of Campese.

The main deposits in the study area consist of: ì) debris accumulations (Holocene), materials originated by alteration and weathering of both igneous and sedimentary rocks and soils resulting from excavations and earthworks; ìì) alluvial/colluvial deposits (Holocene), lentiform alternations of sands and yellow-ocher gravels with calcareous cement; ììì) completely uncemented sands and gravels of the present coast (Holocene), which also form the beach of Campese.

Waveclimate, currents and tide

The wind and wave climate data reported in Table 3 were obtained and elaborated from the MedAtlas, an electronic atlas of winds and waves of the Mediterranean Sea prepared by the CNR-ISMAR. The station considered in the present study is located between the Elba and Giglio islands. The data were processed to a cross sector of 250-350°N, corresponding to the Campese beach. The morphodynamics of the West coast of the Giglio Island is mainly driven by winds and waves approaching from NNW and SSE, generating a significant wave refraction breaking on the entire promontory of the Franco. An important longshore current is also generated there, flowing inside the Campese bay. Low tidal amplitudes characterise the island.

Coastal evolution and present landscape

The geomorphology of both the island andthe considered coastal sector is heavily influenced by bedrock lithology and its dense joints system. In the area of the Franco promontory, there are features mainly related to gravitational processes, such as landslides by sliding and fall, whose accumulations strongly interact with the coastal dynamics (Aringoli & *alii*, 2009). The island has very few flat areas, usually connected to the sporadic beaches. The largest of theseis that of Campese (fig. 6.2), located at the confluence of the valleys, draining a small western portion of the island. The end of the related riverbed has been extensively modified by man, and its mouth is located at the northern edge of the beach. This valley also represents a potential flooding area. Debris/earth flows are often surveyed. They generate material, supplied in the inland areas, that move dangerously towards the coast. Rockfalls and topples of large rocky portions are also common along the cliffs. These phenomena generate high hazard and risk conditions, especially when trekkers and bathers frequent the cliffs and their bottoms, as in the case of Cala dell'Allume (fig. 6.3; Aringoli & *alii*, 2009).

Enormous rotational-translational failures, present in the most exposed sector of the Franco Cape, have strongly influenced the development of this part of the coast. Moreover, they are not active today; their toe, consisting of very coarse material, is barely reworked by wave motion (Aringoli & *alii*, 2009).

Coastal dynamics

The coast is affected by heavy erosion in the southern and western parts of the promontory, while a tendency towards sedimentation characterises the wide bay to the North.Presently, the coastal landscape is shaped mostly by wave action. This is more intense in the sectors exposed to dominant winds blowing from the southern sectors marked by a long fetch, so that wave action along the promontory interacts closely with the above-mentioned slope dynamics (undermining, collapse, removing material at the base of the cliffs, etc.), while the beach of Campese, exposed to the NW prevailing winds, shows a regressive coastline trend, documented as of the 1960s.

The collapsed/eroded material locally determines the development of mostly submerged coastal platforms that disperse the wave energy creating a possible transient protective action. In addition to more typical shoals, these submerged materials form shallow areas., such as the the Secca dei Pignocchi, very close to the North coast of Campese. The shoal morphology is slightly elongated, and parallel to the shoreline, formed by large granite blocks that extend froma depth of only a few metres to 35m. The many blocks as well as the impressive sea stack, located near the southwestern tip of the Campese bay, are typical feature of the study area; the stark contrast between its morphology and the beachseems to emphasize the different evolutive dynamics of these two adjacent coastal environments.

TABLE 3 - Main wind and wave climate featuresof western Giglio Island.

Recording period	Prevailing wind (°N)	Dominant wind (°N)	Main wave direction (°N)	SWH* (m)	Wave period (s)	Wave length (m)	Secondary wave direction (°N)	Effectivefetch (km)	Closure depth** (m)	Sizigial tide amplitude (m)
1999-2004	320 ÷ 350	130 ÷ 170	240 ÷ 290	3.0 ÷ 3.5	8.72 ÷ 9.22	118.6 ÷ 132.6	0 ÷ 30	75	4.5 ÷ 5.5	0.4

(* =significant wave height, ** = according to Hallermeier, 1981)

THE CASE OF THE TOMBOLO OF THE ISOLA DEI GABBIANI, NE SARDINIA (DE MURO S., IBBA A., PUSCEDDU N.)

Geological and Geographical setting

The study area, known as Bocche di Bonifacio, is located in the western Mediterranean Sea, near the Arcipelago of La Maddalena (NE Sardinia), between Porto Pozzo and Punta Sardegna. The geology of the area is primarily connected to the structure of the Sardinian-Corsican batholith and the late stages of the Hercynian orogeny (VV.AA., 2008). The outcropping rocks are composed almost entirely of late Hercynian intrusive masses and post-tectonic masses (intrusive units of Arzachena, Bocche di Bonifacio and Barrabisa), with outcrops of metamorphic rocks (diatexites of Cala Capra and orthogneisses of Golfo Aranci) (VV.AA., 2008). The dyke complex developed preferentially in the NE-SW and NNW-SSE directions, and is predominantly characterised by a basic and acid composition (basaltic, transitional, rhyolite, alkaline rhyolite, rhyodacite and dacite; CARMIGNANI & *alii*, 2008). The Quaternary cover is mainly made up of (Upper Pleistocene? - Holocene?) alluvial, colluvial and coastal deposits. In the N-E part of Cavalli Island, conglomerates and sandstone in the facies of the beach rocks also crop out. According to previous studies (De Muro & Orrù, 1998), their presence is due to the stand of the sea-level at -1÷-5 m during the Middle Holocene (1500÷3000 years BP). The coastal morphology is controlled by the structure of the crystalline basement and subsequent tectonic stages (N-S, NNE-SSW, and NNW-SSE), also reflected in the stream setting. During the Quaternary period, a cyclical process of erosion-transport-sedimentation, related to marine transgressive and regressive stages, shaped the coast.

The coastal area shown on the map extends for a total of 8 km and includes the rias of Porto Liscia and Porto Pollo, as well as three main beaches: Porto Liscia, Porto Pollo, and Padula Piatta. It also encompasses the geomorphology of Porto Pollo Tombolo. The first beach extends for 3 km, whileboth the second and third for 1 km. The three main beaches receive siliciclastic sediment from Riu deluCalone, Riu Val di Mela, Riulu Banconi, and Fiume Liscia, and have developed, on the W-E, NW-SE and SW-NE axes, respectively.

Waveclimate, currents and tide

The Porto Pollo Tombolo maintains its arrangement in an environment of a microtidal wave-dominated Mediterranean beach (Table 4) where the closing boundary towards the inner shelf is controlled by the presence of a *Posidonia oceanica* meadow. This is the result of the convergence of longshore currents and sediment transport into the shadow zone behind the island (Isola dei Gabbiani), due to wave refraction and diffraction, creating a swash-aligned morphology.

Coastal evolution and present landscape

Based on the earliest classification schemes, the study area under the submergence coast can be categorised because the drowned river valley of the Liscia River (fig. 7.1) is very clear (Bartole & De Muro, 2009; De Muro & Bartole, 2010; De Muro & *alii*, 2010). We can, therefore, classify the area as a ria (role of sea-level variations), based on the role played by sea-level changes during the Quaternary, and use the terminology adopted by Johnson (1919). However, using the SHEPARD (1973) scheme, the area can be classifiedas primary coast (resulting mainly from non-marine processes, including drowned river valleys and rocky and deltaic coasts). At the end of the Holocene, the coastline evolved into secondary coasts, as evidenced by the presence of beach rocks. Indeed, from this point onwards, their evolution was mainly controlled by the presence of marine processes. Consequently, at the end of the Holocene, a context, dominated by fluvial environments, was established on this primary coast (ria). This system is characterised by a discrete accumulation of terrigenous sediment, thereby creating a wave-dominated delta (characterised by a relatively high exposure to an open-sea swell).

On the map, we can clearly distinguish three main morphological units: a delta plain, a delta front, and a pro delta (De Muro & *alii*, 2000; Bartole & De Muro, 2012). The delta plain is the sedimentary platform corresponding to the most recent coastal progradation and aggradation by the incoming river. This river sediment causes the delta front to prograde seawards through deposition of the coarsest sediment closest to the coast at the edge of the coastal plain, and finer sediment further seawards on the pro delta.

Coastal dynamics

The Porto Pollo Tombolo (fig. 7) has been shaped since the end of the Holocene. It results from the sediment contributions of the Liscia River, confined offshore by a dense and continuous *Posidonia oceanica* meadow (De Muro & *alii*, 2003; De Muro & *alii*, 2004; Pusceddu, 2009). Its morphological evolution is linked to the local fluid dynamics and sediment transport, influenced by wave climateand tide regime.

TABLE 4 - Main wind and wave climate featuresof Isola dei Gabbiani Tombolo.

Recording period	Prevailing wind (°N)	Dominant wind (°N)	Main wave direction (°N)	SWH* (m)	Wave period (s)	Wave length (m)	Secondary wave direction (°N)	Effectivefetch (km)	Closure depth** (m)	Sizigial tide amplitude (m)
1979-2012	90	90	310	1.1	5,2	45	295	300	12	0.6

(* =significant wave height, ** = according to Hallermeier, 1981)

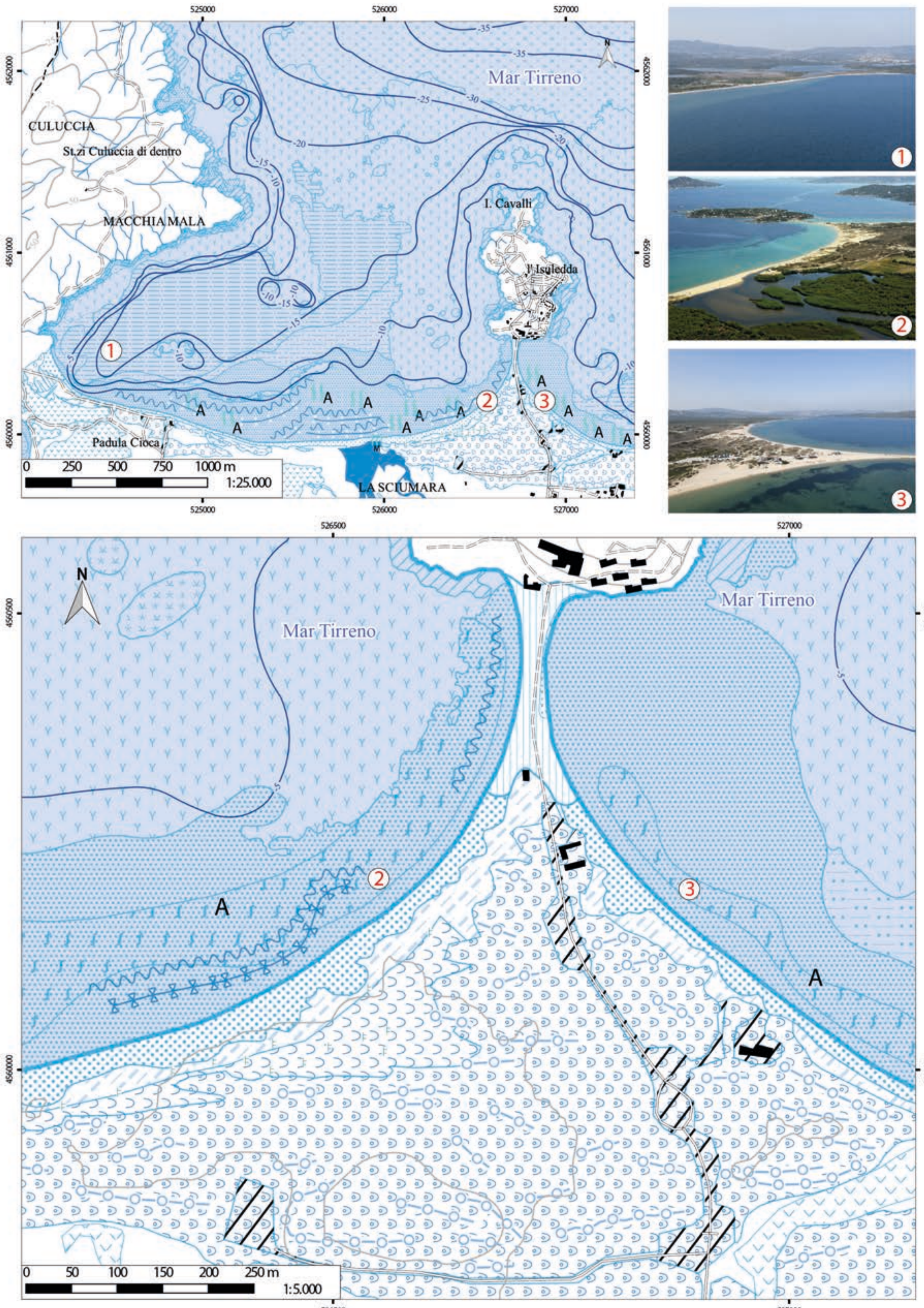
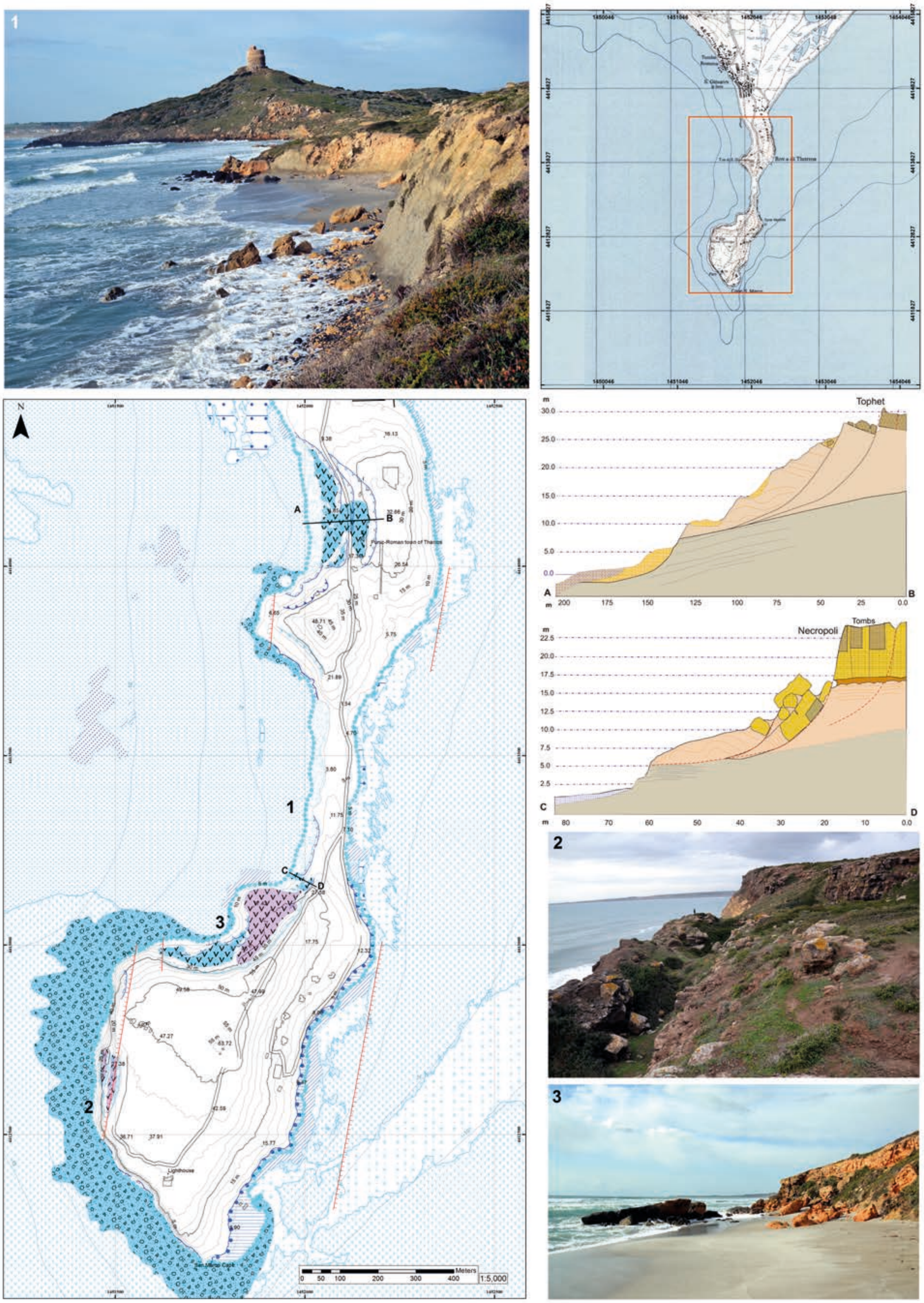


FIG. 7 - Geomorphologic maps of the Tombolo of the Isola dei Gabbiani (A at a scale of 1:25,000, and B at a scale of 1:5,000): (1) beach view from the north-east between the Liscia River mouth and the Culuccia Peninsula; (2) South-western view showing the Liscia River mouth and the Isola dei Gabbiani Tombolo; (3) Eastern view of the Isola dei Gabbiani Tombolo showing the dune zone.


1
Tophet
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Punic-Roman town of Tharros
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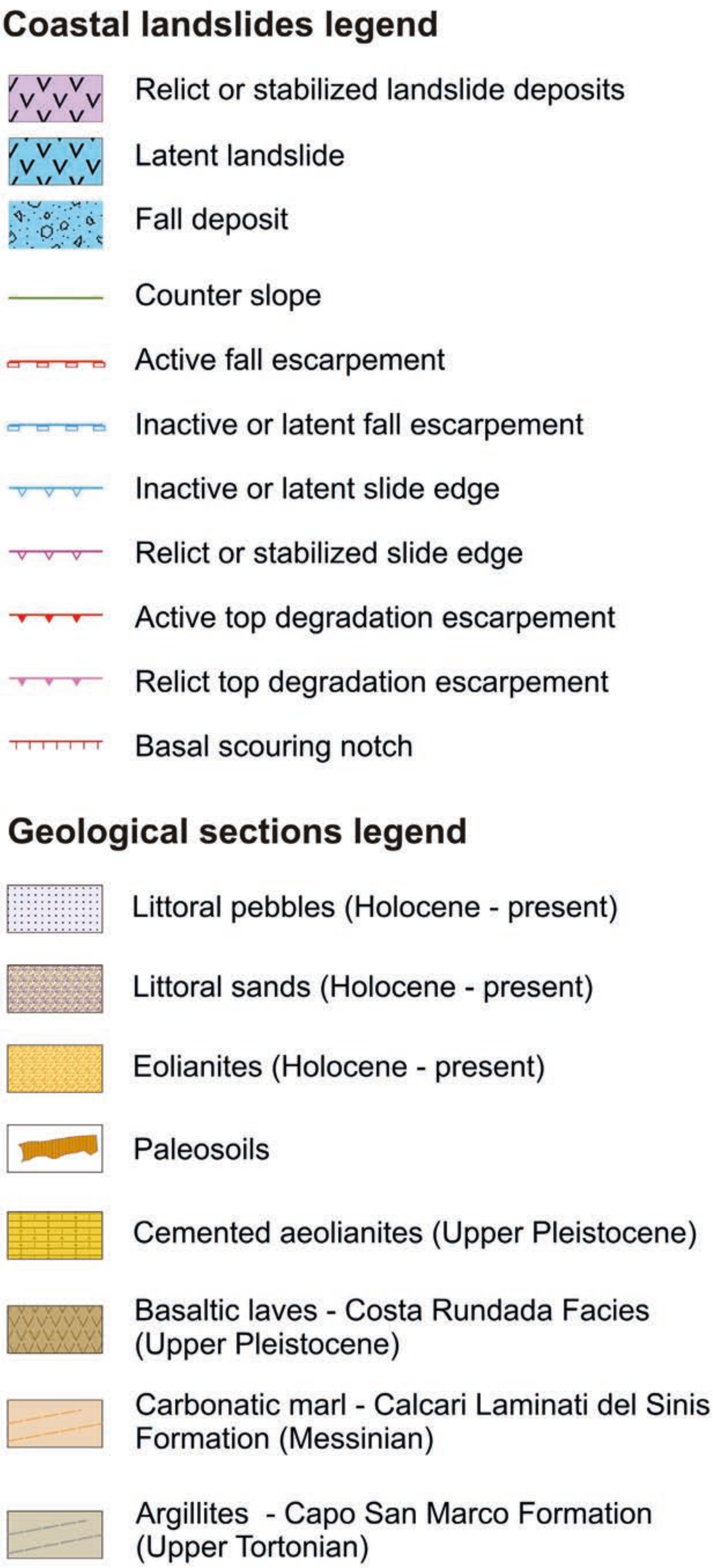

FIG. 8 - A: Geomorphologic maps of Torre San Giovanni-Capo San Marco area at a scale of 1:5,000: (1) paleotombolo of the Capo San Marco Promontory; (2) rotational landslide edge on Capo San Marco basalts; (3) fall landslides by extreme wave scouring; AB - rotational landslides of Tophet, Punic city of Tharros; CD - rotational landslides and the collapse of the Necropolis; B: legend geomorphological section.

In particular, according to Davies (1980), who identified coastal types based solely on wave height and tidal range, the Porto Pollo Tombolo (fig. 7.2,3) can be defined as a microtidal wave-dominated beach system and, according to De Muro & *alii* (2016a,b), as a microtidal Mediterranean wave-dominated beach system controlled by the *Posidonia oceanica* meadow.

The Porto Pollo Tomboloshows a swash-aligned morphology. Beaches have a morphodynamical status ranging from reflective to intermediate, with at least four basic conditions established by Wright & Short (1984), i.e. a longshore bar and trough (LBT), a rhythmic bar and beach (RBB), a transverse bar and rip (TBR), and a low-tide terrace (LTT). The backshore is characterised by dunes, evolved through the transformation from incipient to foredunes (on the western sector of the Liscia River mouth) and in transgressive dunes (parabolic with blowouts) in the easternmost part of the Tombolo. In this area, dunes provide sediment supply to the beach (De Muro & *alii*, 2016b).

The study area is represented in an innovative map integrating a range of processes (aeolian, bar and trough morphodynamics, shore face habitat mapping) of present and past timeframes,as well asthe main human impact on the coastal dune systems. It is an area of semi-pristinenature, and an important tourist destination facing, likemany coastal Mediterranean settings, environmental pressures.

THE COASTAL AREA OF TORRE SAN GIOVANNI - CAPO SAN MARCO, W SARDINIA (MELIS R.T., ORRÙ P.E., PANIZZA V., DE IANA G.)

Geological setting

The stratigraphic succession cropping out along the coastal area of Torre San Giovanni, the Capo San Marco promontory (fig. 8), in Sinis (West central Sardinia), is characterised at the base by Messinian marl and limestone (Cherchi & *alii*, 1978), unconformably overlain by Pliocene clays and mudstones with foraminifera, radiolarians, and sponge spicules (Pecorini, 1972). The marine series is interrupted by a continental erosive surface fossilised by alluvial conglomerate and middle Pliocene clay colluvium, andclosed by basaltic volcanics, arranged in different flows, for an overall thickness of about 30 metres, representing the residual strips of the vast Sinis "plateau" (Carboni & Lecca, 1995).

In this area, the Pleistocene sequence (section AA' and BB' in fig. 8) is particularly complete, and represented by eolian sandstones and colluviums with MIS6 vertebrates, transgression conglomerates and beach successions of the Last Interglacial (MIS 5.5), and by cold phase cross-laminated sandstones (MIS4/MIS2) (Lecca & Carboni, 2007; Carboni & *alii*, 2014). An MIS 5 littoral and the subsequent eolian deposits formed a tombolo linking Torre San Giovanni with Cape San Marco. Fine quartz feldspar sand-pocket beaches, and, upwards, a progressive transition towards more dominantly continental environments, capped with deposits of eolian sandstones relating to the regressive phase (MIS 4/2),are found here.On the eastern side of the Torre Sinis promontory, stands the city of Tharros, one of the most important Phoenician-Punic settlements in the Mediterranean.

Waveclimate, currents and tide

The wind and wave climate data reported in Table 5 have beenobtained from the National Sea-Level Measurement Network (Rete Mareografica Nazionale, RMN), Carloforte Station, and the National Sea Waves Measurement Network (Rete Ondametrica Nazionale, RON), Alghero station, currently inactive (Atzeni & *alii*, 2007; Atzeni, 2011).

The morphodynamics of the Torre San Giovanni - Capo San Marco promontory is mainly driven by winds and waves approaching from the NW and SE, with a prevailing wind sector 4° wide, producing a logshore current flowing NW-SE along theSan Giovanni coast, and N-S along the West coast of Capo San Marco. The refraction of the wave crest generates forward S-N longshore currents in the eastern leeward coast of the promontory. During storms with a3°wind sector, inverselittoral drift currents occur. The tidal amplitudes of this area (0.30 m - Table 1) identify a microtidal environment.

Coastal evolution and present landscape

The high coast of Capo San Marco is conditioned by major NS-trending lineations which, in turn, control two important rotational palaeo-landslides whose foot may be related to low sea-level stands (fig. 8). In the northern sector of Capo San Marco, there is evidence of a landslide detachment divided into two parts, but, because little remains of the landslide deposit itself, an even older movement is suggested.

Rockfalls and collapse topplings characterise the retreat of the Capo S. Marco pseudo-cliffs, reaching aheight of 80 m (Antonioli & *alii*, 2015). The fracture network of the columnar basalt facilitates the gravitational movements. The peri-coastal abrasion platforms extend several

TABLE 5 - Main wind and wave climate featuresof - Torre San Giovanni - Capo San Marco locality.

Recording period	Prevailing wind (°N)	Dominant wind (°N)	Main wave direction (°N)	SWH* (m)	Wave period (s)	Wave length (m)	Secondary wave direction (°N)	Effectivefetch (km)	Closure depth** (m)	Sizigial tide amplitude (m)
1982-2014	100 ÷ 270	110 ÷ 240	100 ÷ 125	7.20	–	120	240 ÷ 260	533	10	0.30

(* =significant wave height; ** = according to Hallermeier, 1981) hundred metres out to sea up to 7m depths, and are partially covered by tilted megaprisms and hetero-metric collapsed blocks; deeper, to the South and East, fan-shaped landslide deposits develop with rounded, always basaltic, megablocks.

Coastal dynamics

Low-angle large planar landslides, whose failure surface is set in Lower Pliocene clayey mudstones, affect the eastern side of Torre Sinis. The movements also displace cross-laminated eolian sandstones covers, which had already affected the aqueduct, roadway and habitationsof the city of Tharros during the Punic epoch. On the eastern side of the Torre Sinis tombolo, the sequence includes Pleistocene sediments related both to intertidal and emerged low energy beach environments and lagoon environments, characterised by a wide range of lithofacies and/or biofacies and, towards the top, the succession testifies a progressive transition from submerged beach environments to more dominant continental environments, having deposits of eolian sandstones, relating to the regressive phases,at the top (Carboni & *alii*, 2014). In the eolian sandstones, a Punic necropolis with large rooms separated by a central columnwas excavated. Cross-laminated eolianites, heavily cracked, are undermined by wave action, triggering processes of collapse, bending and tilting, as well as the failure of large sandstone blocks. The presence of high erodibility levels in the lower part of the succession, often bearing the weight of the overlying banks, plays a fundamental role in the overall instability of the sequence. This determines the jutting structure of the upper stone blocks and the frequent tilting of large portions (Carboni & *alii*, 2010). The gravitational phenomena also affectthe necropolis. Indeed, the rectangular pitscan easily be identified, either inthe blocks still in place or in some of collapsed ones. Different types of landslides, actived by sea action or continental processes, involve different lithology. In particular, planar and rotational slides on the Miocene series and block falls and topples on the Pliocene basalts and Pleistocene eolianites can be observed. Slope instability processes (fig. 8.1,2,3) are strongly controlled by structural lineations dislocating the different sectors of the peninsula as well asby the lithological sequences and stratigraphic unconformities, in particular, between the Miocene marls and the Messinian limestones. Many different types of landslides are present in the area, some of which pose a threat to many archaeological sites, most notably, the Phoenician-Punic city of Tharros. Extreme high-energy meteomarine events may occur here, registering waves more than 10 metres high with an annual energy of 130/150 GNm/m (Atzeni, 2011). The map points out a few complex gravitational movements, some active, and othersnot. Their representation does not always correspond completely to the proposed symbology as the legend of slope and gravitational landforms is out of the task of the present paper (fig. 8B). In this specific study, the map may represent a key tool for coast management as it highlights the geomorphological hazards, representing the first step towards coastal risk assessment.

THE TIBER RIVER DELTA, LATIUM (DAVOLI L., RAFFI R., BALDASSARRE M.A., BELLOTTI P., BONTEMPI S., TARRAGONI C.)

Geological and Geographical setting

The delta of the Tiber River (fig. 9) started its progradation about 6000 years BP when the post-glacial rate of the sea-level rise approached 1mm/y (Milli & *alii*, 2013). Between 6000 and 2700 years BP, the first cusp developed, and two coastal lakes formed. They were situatedto the North (Lago di Maccarese) and to theSouth (Lago di Ostia) of the Tiber River that flowed 3 km North of the present main channel (Fiumara Grande). Between 2700 and 1900 years BP, an abrupt southward migration of the river occurred (Giraudi, 2004; Bellotti & *alii*, 2011). A new cusp prograded quickly, and the city of Ostia was founded there (IV century B.C.). Between the I and II centuries A.D., the harbours of the Emperors Claudius and Trajan, both located to the north of the Fiumara Grande, were built, and an artificial mouth of the Tiber River was dredged (the present Canale di Fiumicino) 3 km North of the main one. Most of the present delta quickly prograded during the Little Ice Age up to the end of the XIX century; in the second half of the XX century, the delta was affected by marked erosion processes triggered by adecrease in the Tiber River solid discharge, as a consequence of the anthropic workscarried out on the drainage basin (dams, dredging, landslide-retaining devices). The complex evolution of the Tiber delta over the last 6000 years indicates that sub-Milankovitch climatic variations as well ashuman activities affected the evolution of the delta more than sea-level rise; estimates in this area areabout 0.80 m during the last 2000 years, with a rate lower than 0.5 mm/y (Milli & *alii*, 2013).

The hydrological regime of the Tiber River closely follows the seasonal rainfall pattern incentral Italy: the maximum annual discharges are recorded from November to February, and the minimum from June to August. The mean annual water discharge measured at the hydrometric station of Rome (1921-2000) was 230 m^3/s, the absolute maximum and minimum discharges were 2750 m^3/s and 70m^3/s, respectively. The Fiumara Grande and Canale di Fiumicino discharges at the mouth represented80% and 20% of the entire water flow, respectively.

Waveclimate, currents and tide

The wind and wave climate data reported in Table 6 have beenobtained from four anemometric stations (Roma Fiumicino, Pratica di Mare, Latina and Ponza), and from the marigraphic station at Ponza.

The morphodynamics of the Tiber delta is mainly driven by winds and waves approaching from the W and SW with a prevailing 190°-wide wind sector, producing wave train refraction and generating two longshore currents that flow along the northern and southern wings of the delta. The study area is characterised by a low tidal range.

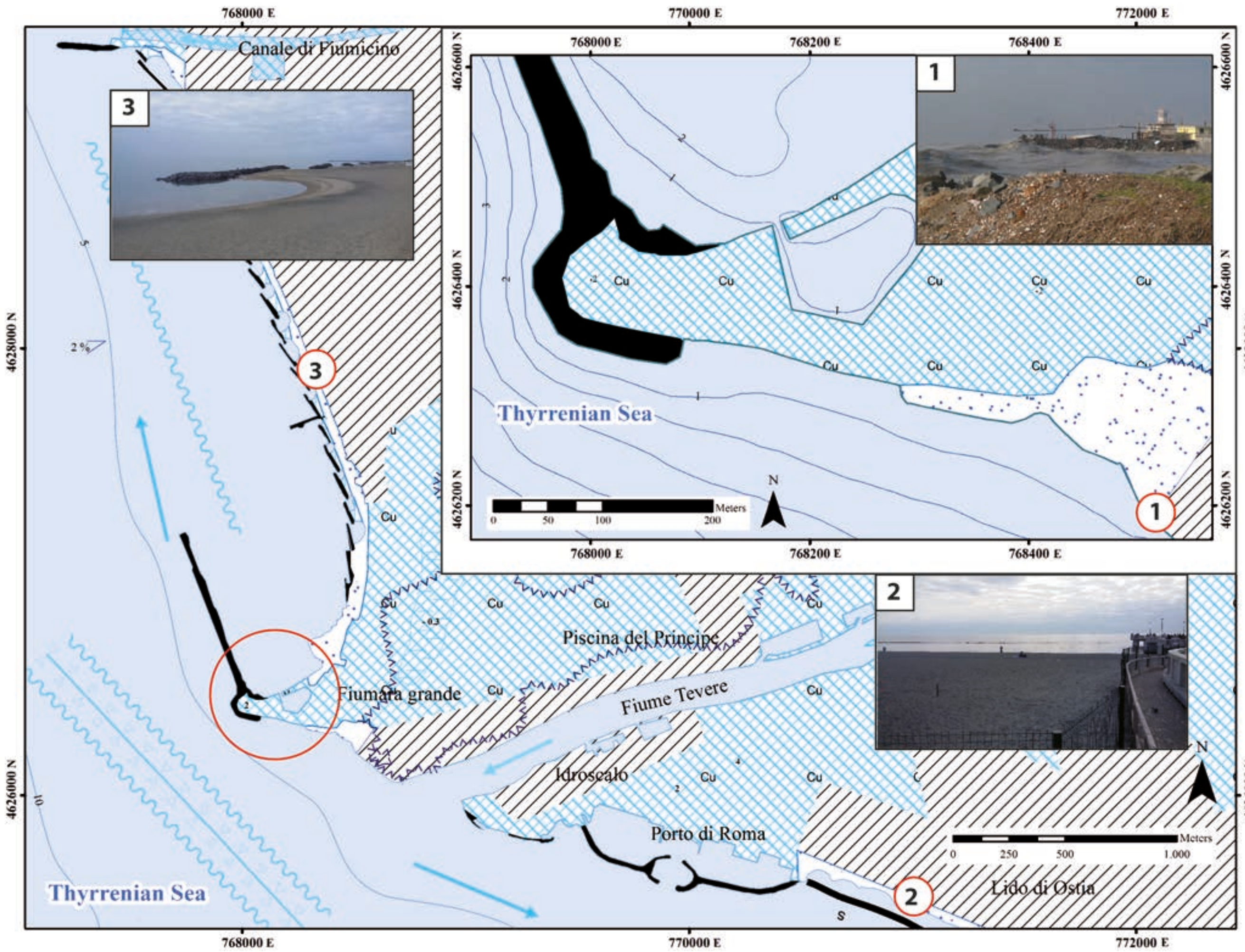

FIG. 9 - Geomorphologic maps of the Tiber River Delta (A, at a scale of 1:25,000, and B at a scale of 1:5,000): (1) the main Tiber River mouth and the Fiumicino lighthouse, presently inactive; (2) artificially nourished beach in Lido di Ostia; artificial barrier emerges at low tide; (3) the Fiumicino beach: series of breakwaters between the two mouths of the Tiber River.

TABLE 6 - Main wind and wave climate featuresof the Latium coasts.

Recording period	Prevailing wind (°N)	Dominant wind (°N)	Main wave direction (°N)	SWH* (m)	Wave period (s)	Wave length (m)	Secondary wave direction (°N)	Effectivefetch (km)	Closure depth** (m)	Sizigial tide amplitude (m)
1951-2011	180 ÷ 255	225 ÷ 270	250 ÷ 290	3.9	9	126.4	200 ÷ 250	394	7.6	0.4

(* = significant wave height; ** = according to Hallermeier,1981)

Coastal evolution and present landscape

The area is strongly impacted by two Tiber mouths. At present, the shoreface slopes between 1.1% and 2%, North and South of the mouth of Fiumicino, respectively. Backshore width ranges between 190 m (with a 2%slope) at the northern stretch, and 25 m at the southern one (13%slope). The northern stretch of the delta is marked by the presence of a foredune about 2 m highwith the sea-sloping side about 21%.

The northern stretch is characterised by an intense urbanization, by the archeological remains of the Roman Harbours Claudius and Trajan, and by longitudinal and transverse coastal defencestructures. Mouth bars form in correspondence to the main mouth, and are periodically dredged in order to allow river navigation (fig. 9).

The southern wing of the delta is characterised by the presence of a new marina (the "*Roma*"), protected by curved piers, and by the municipality of Lido di Ostia.

The shoreface currently has a slope of 2.1% and, compared to 1981records, shows a slight, but significant steepening; such erosion is also suggested by the total absence of bars. The backshore width ranges between 40 m in correspondence to the *Roma* marina, and 77 m in front of Lido di Ostia; the slope average is 3.5%. The widebeach in front of Lido di Ostia is the direct effect of artificial beach nourishment, protected with submerged groins and breakwaters, reconstructed several times since the 1990s.

Coastal dynamics

The main wave direction from 250° ÷ 290°N (Table 6) strongly affects the cuspate morphology of the delta and produces a littoral drift that is divergent to the main mouth of the Tiber River (fig. 9.1). Along the northern wing, the shoreface and backshore show morphometric and morphodynamic characteristics which essentially depend on the degree of urbanization to which the area has been subjected. In the last 30 years, the shoreface of the northern stretch has been kept stable with multiple bars. The longitudinal protecting structures, built in order to mitigate a marked shoreline retreat, have produced cusps and small circular beaches (fig. 9.2,3). The above-described morphometric and morphodynamic parameters indicate that the examined area presents beaches with high vulnerability values, especially in correspondence to the Canale di Fiumicino (Tarragoni & *alii*, 2014). Other vulnerable areas are found to the Northand to the South of the Fiumara Grande. They are the remnants of ancient lagoons, and are prone to floods becausethey are partially located below sea-level. In the last decades, a strong anthropic pressure has occured. This can be detected all along the coast threatened by such significant erosive phenomena which have made it necessary to construct different types of defense structures, as well asa protected beach nourishment along the coast of Lido di Ostia.

LITTORAL TO THE SE OF THE GARIGLIANO RIVER MOUTH, CAMPANIA (PENNETTA M., STANISLAO C., VALENTE A., DONADIO C.)

Geological and geographical settings

The coastland to the SE of the Garigliano River mouth (fig. 10), in the Gulf of Gaeta, is a long littoral formed by sandy dune ridges and a sandy bar along the seabed, both parallel to the shoreline. The coastal-marine *facies* along the emerged beach (Abate & *alii*, 1998) are characterised by a Holocene dune and by dune deposits related to the Tyrrhenian highstand (125 kyr BP). In the middle of this dual dune system, a depression developed in which the wetland of Pantano di Sessa formed. This coast is characterised by a wide sandy beach, a river mouth system, and a large anthropised coastal plain. The Garigliano River shows a sinuous riverbed towards the mouth with a NW-SE direction due to influence of prevailing littoral drift. It had a crucial role in littoral prism modeling: although its current sediment discharge has diminished, and supply to coastal sediment budget results negligible, it still has the capacity to transport sediment, even coarse as shown by pebbles dispersed at its mouth and along the submerged beach, down to a 1 m depth. Pebbles discharged by the mainstem and tributaries to the river mouth vary from blackish ones, eroded from Roccamonfina volcanic rocks, to whitish ones of dolomitic limestone, and subordinately to terrigenous deposits from Mount Aurunci.

Waveclimate, currents, and tide

The wind and waveclimate data reported in Table 7 were collected from the Ponza anemometric-marigraphic station. Littoral morphodynamics is mainly driven by winds and waves approaching from SW and W, with a prevailing wind sector over 60° wide, generating a NW-SE drift (Pennetta & *alii*, 2016a) due to longshore currents. Other parameters derived from De Pippo & *alii* (2008).

Coastal evolution and present landscape

The submerged sandy beach inshore is characterised by a longshore bar down to 4 m in depth, at 120-150 m from the coastline, with a crest of between 2 and 2.5 m deep. The seabed morphology, articulated in the bar zone due tothe presence of rip current channels transversal to the coast, regularly slopes offshore with low gradient down to an11 m depth (Pennetta & *alii*, 2011, 2016a). Using the new geomorphological legend, the mapped coastal area (fig. 10) appears diffusely affected by erosion processes linked to both natural and various anthropogenic factors which caused an almost complete erosion of the foredune. Erosion processes caused a significant shoreline retreat in 55 years (1954-2009), gradually from about 90 m in the North to 35 m southward (Pennetta & *alii*, 2011 and references therein), along withthe loss of cultural heritage as well as the alteration of successions and vegetation assemblages of the Mediterranean maquis.

The 1954aerial photos show that the mouth morphology had beenalmost completely dismantled. To the NW, the coastline is generally stable, while, to the SE, a slight progradation compared to that of 1909 occurred, with increasing magnitude southward up to 2 m/y. The retreating rate over the 1954-2009 period is estimated between 1.5 and 0,6 m/y. Even the secondary dunes are undergoingdismantling, while only 50 years ago they were tertiary and stable. The most recent erosion processes could be related to a decrease insediment supply from the Garigliano River, due to the presence of two dams; the construction of river protection structures;coastal defenses in the northernmost sector of the littoral which intercept longshore sediment transport from the NW.An important erosional factor contributing to shoreline retreat and coastal floodingis local subsidence (Pennetta & *alii*, 2016b) whichaffects incoherent sediments filling the *graben* of the Garigliano River plain. The natural process is accelerated by intense human activity along the coastal plain. Overpumping of aquifers, building structures on the dune systems, land reclamation, regulation and river embankment triggered the rapid erosion of the dunes, with a huge loss in the wildness of the territory.

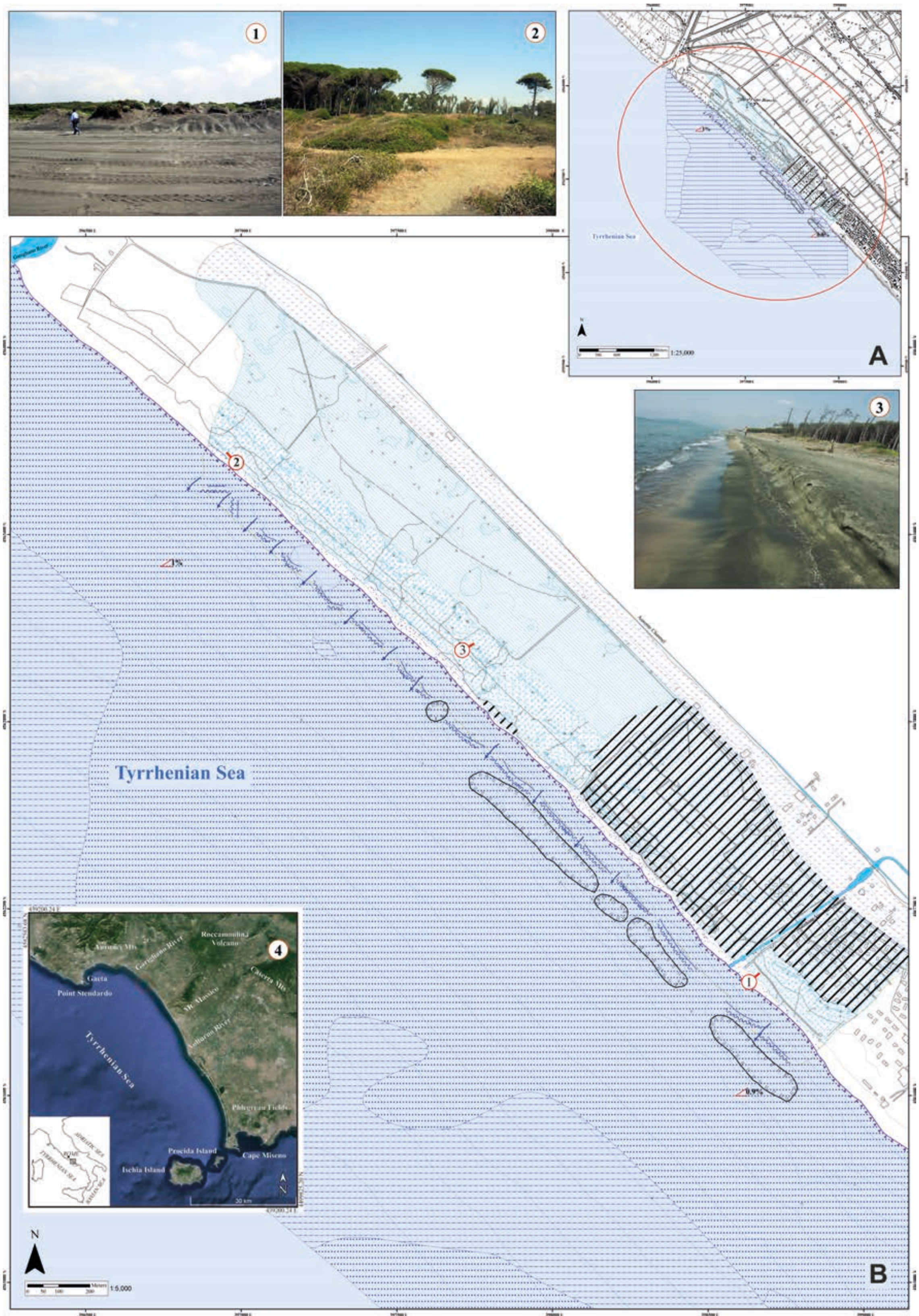

FIG. 10 - Geomorphologic maps of the SE of the Garigliano River Mouth (A, at a scale of 1:25,000 and B at a scale of 1:5000): (1) anthropogenic remodeling of the beach due to cleaning and widening by mechanical vehicles; (2) blowout in the coastal dune modeled by wave erosion and airflow over the crest; (3) erosion scarp due to coastline retreat and consequent inland migration of beach-dune system; (4) coastal physiography of the Gulf of Gaeta. Circle indicates the location of the study area.

TABLE 7 - Main wind and wave climate featuresof the Campania coasts.

Recording period	Prevailing wind (°N)	Dominant wind (°N)	Main wave direction (°N)	SWH* (m)	Wave period (s)	Wave length (m)	Secondary wave direction (°N)	Effectivefetch (km)	Closure depth** (m)	Sizigial tide amplitude (m)
1954-2009	210 ÷ 270	255 ÷ 270	200	2	7.5	88	190	400	8.5	0.35

(*significant wave height; **according to Hallermeier, 1981)

Coastal dynamics

Currently, the front dune consists of embryo dunes, leaning against a secondary dune, generally well-vegetated, with protected species of great value, such as juniper (*Juniperus oxycedrus* ssp. *macrocarpa*). This system shows evidence of erosion in the last 20 years, related to wave attack at the foot of the dune, and occasionallyto anthropogenic factors, such as cleaning and widening the beach by means of mechanical vehicles (fig. 10.1), with windward slopes steeper (30°) than downwind ones. The dune ridge has a crest ranging from 2 to 4 m. Many access roads and paths to the sea for tourism, and cup-shaped or trough-shaped depressions (blowouts) fragment the dunes, thereby accelerating the demolition process. Blowouts arecommon in coastal dune environments subjected to erosion: they are modelled by wave erosion and airflow acceleration over the dune crest in response to climate change, vegetation variation (fig. 10.2), and human impact (Pennetta & *alii*, 2011). The coastline retreat (fig. 10.3) determined the migration of the beach-dune system inland with a major loss incultural heritage structures. Significant erosion has also caused the contraction, with intersections and overlaps, of the psammophile vegetation communities gradually more structured. Finally, sediments eroded from the emerged beach were partially deposited along the facing submerged beach where longshore and rip currents act, changing the seabed morphology and reducing the inshore depth of the bar zone. Surveys of sedimentary aspects of the submerged beach show, in the proximal zone, a system of bars and troughs, consisting of medium sands ($1\ \phi < Mz < 2\ \phi$); fine sands ($2\ \phi < Mz < 3\ \phi$) which characterise the southern sector of the study area and a stretch of the central one.The anomalous presence of fine sands in these shallow stretches, rather than medium sands as found in the northern sector, maybe relatedto reworking linked to anthropic activities, among which indiscriminate removal of sediments from the seabed for beach nourishment of the facing sections of the emerged beach.

THE LA VOTA PARALIC SYSTEM IN CALABRIA (DAVOLI L., RAFFI R., BALDASSARRE M.A., BELLOTTI P., LUPIA PALMIERI E.)

Geological and geographical settings

The study area (figg. 11) is located in the northernmost part of the Golfo di Sant' Eufemia in central Tyrrhenian Calabria. The shoreline stretches for about 6 km between Capo Suvero and the hamlet of Gizzeria Lido. The area shows a series of small continuously evolvinglacustrine and/or lagoonal basins, and is the only example of coastal lakes along the Tyrrhenian coast of the Calabria Region. The coastal evolution from 1870 to the present has beenreconstructedby means of historical maps, aerial photographs, and direct field surveys (D'Alessandro & *alii*, 1987; Baldassarre & *alii*, 2008). In 1870, some small coastal lakes already existed; the largest one, named Lago La Vota, was located more to the North.

During the 1870-1939 period, the whole area underwent an important reclamation programme which caused a remarkable impact. As a consequence, two coastal lakes, linked together by a narrow canal, formed, and the former spit of Maricello underwent a pronounced progradation along the central part of the coast. During the following period, from 1939 to 1958, there was a clear, yet partial alignment of the shoreline caused by a further progradation of the spit in the northernmost area. The 1958-1978 period recorded a slight trend inversion during whicha gradual retreat of the shoreline occurredaffectingthe two areas corresponding to the more extended basins (D'Alessandro & *alii*, 2002). From 1978 to 1998, a new progradation of the shore took place with the eventualclosing-up of the southern basin.

The 1998-2005 period showed a new trend inversion of the shoreline. A new retreat took place along the whole sector, even if more accentuated in the northernmost part. During the last considered period, from 2005 to 2008, a new inversion trend occurred with the progradation and alignment of the shoreline. The evolution of this littoral sector shows a high dynamism supported byboth more or less pronounced changes in the historical reconstruction, and accentuated changes recorded in very short time periods. The high dynamism is due to the littoral drift directed from North to South. Sediments, mostly coming from the Fiume Savuto mouth, located about 3 km North of Capo Suvero, flow southward, and settle just pastthe cape thereby producingadiffraction of the prevalent wave. The sedimentary supply from rivers flowing into the Golfo di Sant'Eufemia is negligible.

The lacustrine/lagoonal basins show very important differences in their evolution, and, above all, in thedegree of anthropic influence (Baldassarre & *alii*, 2008). The Lago La Vota, located in the northern sector of the area, may be considered as the most "pristine". Its sediments are mainly composed of mud, demonstrating a low-energy environment,whereas the southern lake is characterised by relatively coarse material,suggesting a high-energy environment. In the past, the southern basin had been utilised as a pisciculture system, and, more recently, as a private marina.

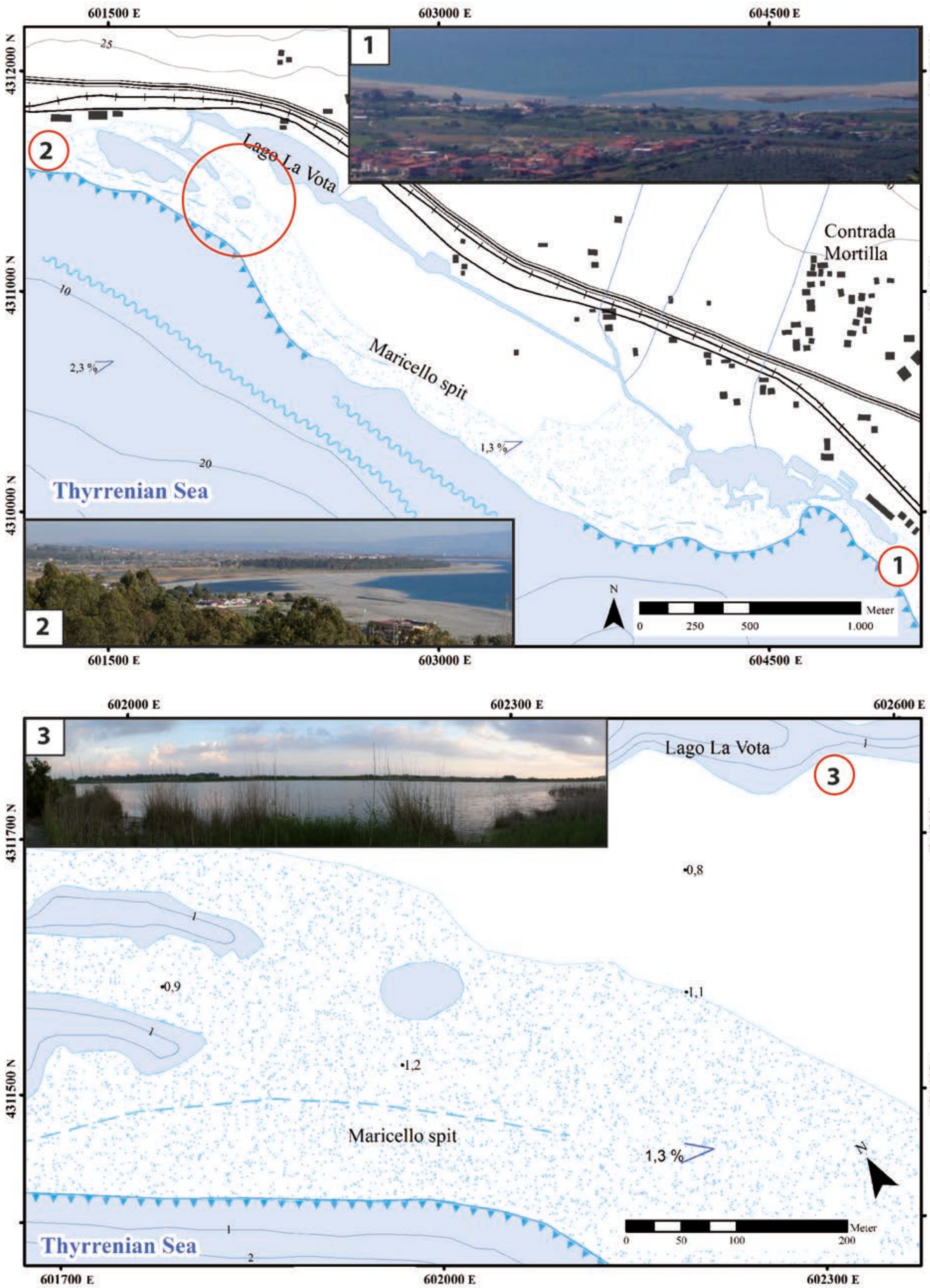

FIG. 11 - Geomorphologic maps of La Vota Paralic System (A, at a scale of 1:25,000, and B at a scale of 1:5,000): (1) the southern part of the Maricello spit; (2) the La Vota paralic system seen from Capo Suvero; (3) Lake La Vota, the innermost coastal basin of the La Vota paralic system.

TABLE 8 - Main wind and wave climatefeatures the *La Vota paralic system*.

Recording period	Prevailing wind (°N)	Dominant wind (°N)	Main wave direction (°N)	SWH* (m)	Wave period (s)	Wave length (m)	Secondary wave direction (°N)	Effectivefetch (km)	Closure depth** (m)	Sizigial tide amplitude (m)
1951-2011	180 ÷ 270	180 ÷ 270	255 ÷ 285	5.23	5.9	54.3	240 ÷ 255	645	10.38	0.4

(* = significant wave height; ** = according to Hallermeier, 1981)

TABLE 9 - Main wind and wave climate featuresestimated for the *La Roca - S. Andrea localities*.

Recording period	Prevailing wind (°N)	Dominant wind (°N)	Main wave direction (°N)	SWH* (m)	Wave period (s)	Wave length (m)	Secondary wave direction (°N)	Effectivefetch (km)	Closure depth** (m)	Sizigial tide amplitude (m)
1989-2008	300 ÷ 340	340 ÷ 20	60 ÷ 100	3.42 (5.2)***	–	–	–	1000	6.76	0.63

(* = significant wave height; ** = according to Hallermeier, 1981, *** = maximum wave height)

In 1995, the Lago La Vota coastal system was included in a European Protection Program, and considered as "a proposed system having community importance (pSIC)". It is part of the Natura 2000 Network.

Waveclimate, currents and tide

The wind and wave climate data shown in Table 8 were obtained from the anemometric records of the CNMCA, Capo Palinuro station (recording period 1951 - 2011), and from the marigraphic records of the ISPRA-National Marigraphic Network,Cetraro station (recording period 1999-2008).

The morphodynamics of the La Vota paralic system is mainly driven by winds and waves approaching from the NW and W with a prevailing 77° widewind sector. This producesarefraction of the wave trains and generation of a longshore current flowing in a NS direction, and a progressive accretion of the Maricello spit towards the SE (Baldassarre & *alii,* 2008). The study area is characterisedby low tidal amplitudes (Table 8). Thus, the action of the tidal currents is extremely low.

Coastal evolution and present landscape

The area is strongly characterised by the presence of the Maricello spit (fig. 11.1). The shoreface presents medium sand and has, to this day, a slope between 5%, in front of the spit, and 10% opposite the hamlet of Gizzeria Lido (Lupia Palmieri & *alii*, 1981). In the last 30 years, the shoreface of the Maricello spit as deep as 5 m presents erosion and a slope between 1.8% and 5%; the southern stretch, in front of Gizzeria Lidois also strongly deepening, and has a slope between 4.8% and 10%. Along the shoreface of all the examined stretch, between - 5 m and the closure depth, the recorded morphology is flatter and articulated by the presence of multiple bars (fig. 11.2). The spit shoreline follows a sandwavetrend, between 100 m and 150 m long, that represents a littoral drift. The gravelly-sand backshore has a width between 150 m (slope of 1.3%) in the central stretch of the spit and 30-40 m in Capo Suvero (slope greater than 10%). The stronger natural character of the central stretch is represented by the presence of a foredune that is about 2-3 m high, while the southern stretch is characterised by an intense urbanisation (Gizzeria Lido).

Coastal dynamics

The main wave direction from 255° ÷ 285° N, also indicated in Table 8, producesa southeastern drift, and causedthe progradation of spits. This bound past lagoons and lakes that later changed into marshes. The phenomenon repeated over time up to recent years. Overall, in recent years, the Maricello spit has been characterised by anaccretion of the beach whichcaused the evolution of the La Vota paralic system (D'Alessandro & *alii*, 2002) with the formation of smaller coastal basins as well as the partial infill of the marina of Gizzeria Lido, presentlyabandoned.

THE ROCA-SANT'ANDREA (SOUTHERN APULIA) COASTAL MORPHOLOGY
(SANSÒ P., FAGO P., MILELLA A., MARSICO A., PISCITELLI A.)

Geological and geographical settings

The Roca-Sant'Andrea coastal tract stretches for about 5 km along the Adriatic side of the Salento peninsula in southern Apulia (fig. 12). Upper Pliocene calcarenites crop out in the area; they show gently dippingseaward strata, and are affected by sub-vertical joints strengthened by laminated calcite concretions. Joints can be grouped into four sets with NNW-SSE, NE-SW and, subordinately, WNW-ESE and ENE-WSW strikes.

Waveclimate, currents and tide

In the southern Adriatic Sea, winds blow mainly from the N-NW and only subordinately fromthe S-SE. They

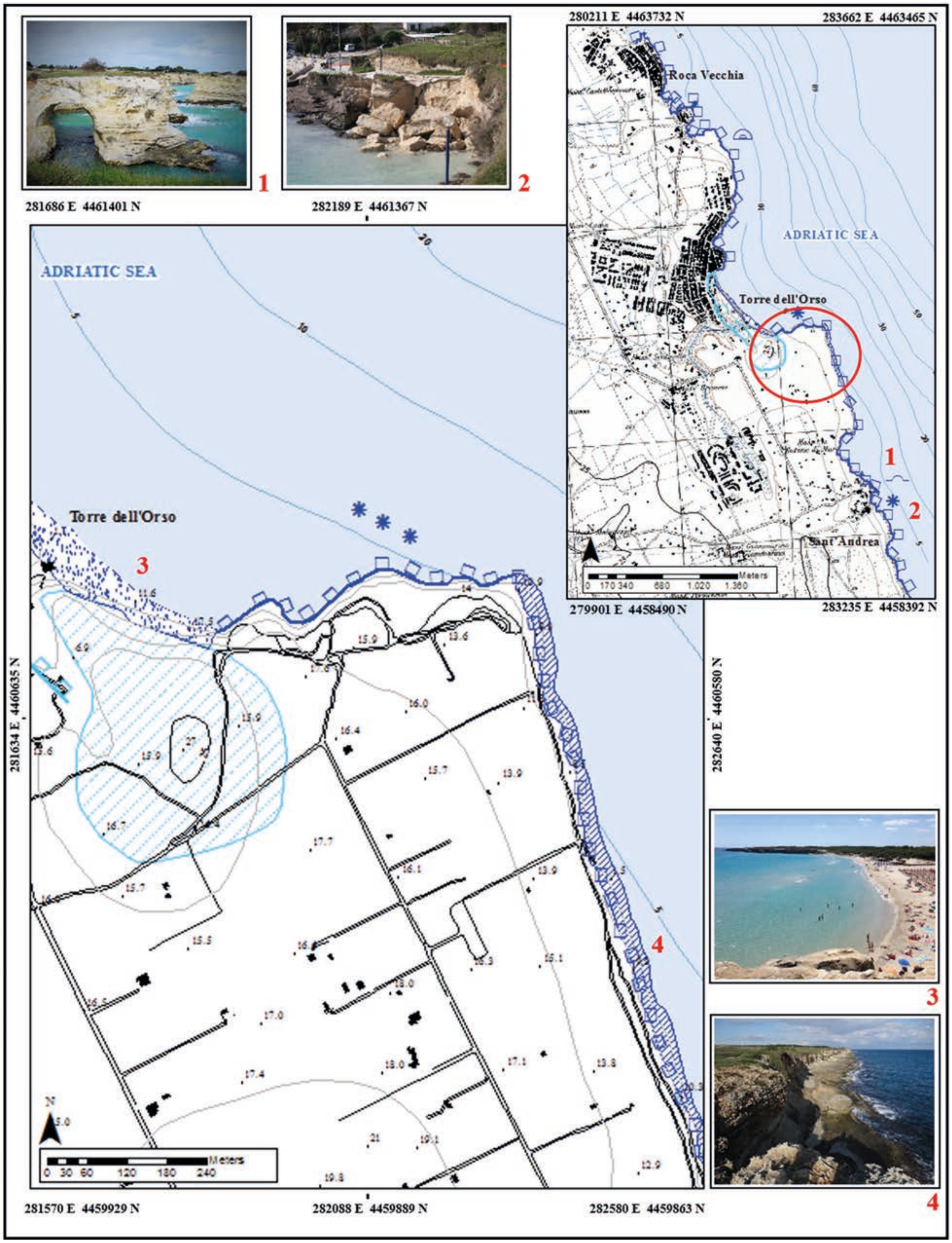

FIG. 12 - Geomorphologic maps of the Sant'Andrea rocky coast (A, at a scale of 1:25,000, and B at a scale of 1:5,000): (1) a sea-arch makes the coastal landscape, along a tract constituted by fast retreating cliffs, particularly impressive; (2) cliff retreat is due to rockfalls induced by the rapid development of notches near Torre S. Andrea; (3) a general view of the pocket beach at Torre dell'Orso; (4) an approximately 40 m wide platform,elevated up to 3 m, and stretched at the foot of a high cliff near Torre dell'Orso.

induce a similar pattern in the local wave climate with the most frequent waves coming from the N-NW and, to alesser extent, from the S-SE. More than 61% of generated waves are marked by a height lessthan 0.5 m, whereas only 0.9% is higher than 2.5 m. The longshore drift of sediments occurs from the NW to the SE (Caldara & *alii*, 1998).

In this area, the mean tidal range is a few decimetres, as recorded by tide gauges. In particular, Pagliarulo& *alii* (2012), based on data recorded by the Bari tide gauge during the year 2009, calculated a tidal range of 38 cm.

Coastal evolution and present landscape

Cliffs are the most common feature of thelocal coastal landscape. They have sub-vertical faces, up to 17 m high, cut into Upper Pliocene calcarenites. Cliffs can be subdivided into two groups according to the water depth at the cliff base. The first group comprises cliffs havingtheir foot at several meters below mean sea level (plunging cliff). Often, they show a complex profile due to the occurrence of type B shore platforms (Sunamura, 1992). According to Mastronuzzi & *alii* (1994), indeed, two platforms between 6.5-11 m and 2-6 m below m.s.l. can be recognised at the cliff's foot. Wide platforms placed up to 3 m above m.s.l. in several places also mark the subaerial tract of the cliff. At present, these cliffs are the most stable tracts of the coast, so that they are small heads.

Cliffs belonging to the second group are marked by a type A shore platform (Sunamura, 1992) at their foot. They are rapidly retreating because of rockfalls induced by the rapid development of solution notches and caves at sea level. Active solution processes are promoted by fresh water/salt water mixing.

Small pocket beaches alternate withcliffs. The longest one, about 700 m, is located at the Torre dell'Orso inlet (fig. 12.3). Beach sediments consist of medium sands composedof calcite (64%), quartz (24%), heavy minerals (6%), and other minerals (6%). A continuous dune belt, up to 16 m high, separates an inactive cliff from the inner marginof the beach.Recent research has allowed the late Holocene coastal evolution to be reconstructed as follows: ì) a cliff recession phase occurred during a relative sea-level stand at about 3.5-4 m below its mean present position which promoted the development of deep solution notches due to hyperkarst processes; this phase wasresponsible for the enlargement of the Torre dell'Orso inlet, starting from a box-shaped relict valley (sensu Mastronuzzi & Sansò, 2002); ìì) a subsequent rapid sea-level rise produced the development of plunging cliffs; active retreating cliffs formed only along the most unstable tracts(Sansò *et alii*, 2016); ììì) during the last four centuries, a considerable flow of sediments, coming from the Ofanto River, has affected the Adriatic coast of the Salento peninsula (Mastronuzzi & Sansò, 2014); ìv) at the Torre dell'Orso inlet, a beach and a high dune belt formed at the foot of the plunging cliffwhich subsequently became inactive.

Coastal dynamics

As shown on the map, coastal dynamics is currently-conditioned by solutional processes linked to the main freshwater discharge lines and points occurring along the coast. Mixing waters produce deep solutional cavitiies in which intersecting joints and fractures cause diffused rockfalls. Thus, thecoastline is articulated by sea caves, sea arches and stacks, showing a rapid morphological evolution (fig. 12.1,2). More or less evident inlets,mark the coastal landscape; the widest of them is represented by the Torre dell'Orso bay that hosts a pocket beach and a high dune belt (fig. 12.3).

NORTHERN SECTOR OF THE MOLISE COAST (AUCELLI P.P.C., DI PAOLA G., ROSSKOPF C.M.)

Geological and geographical settings

The Molise coast has an extension of about 36 km and a general NW-SE orientation. It falls within the physiographic unit P.ta Penna - P.ta Pietra Nere (Aucelli & *alii*, 2009) and is separated into two sub-units by the small Termoli promontory. Its boundariesare the mouths of the Formale del Molino channel and the Saccione River which, mark the confineswith the Abruzzo and Apulia regions,respectively. The Molise coastline is characterised by a generally low coast consisting alternatively of (ì) alluvial coastal plains built on fine, clayey-silty deposits, and (ìì) sandy, locally gravelly beaches (Aucelli & *alii*, 2009). However, its central part is about 14 km long, and is represented by a coastal slope shaped on a clayey, sandy and conglomeratic sequence of the Pliocene-Pleistocene age (Bracone & *alii*, 2012).

The presented coastal stretch (fig. 13.A) is part of the low coast stretching for about 8 km southward to the Trigno River mouth; its southernmost coastal tract, approximately 1 km long, is shown in the map at a scale of 1:5000 (fig. 13.B). As most of the Molise coastline, this stretchis affected by significant anthropic modifications mainly due to the presence of hardcoast defense structures tcovering approximately 50% of its length. Its northern tractcorresponds to the coastal alluvial plain of the Trigno River (fig. 13.1), while the remaining coastline is characterised by a 40 to 120 m wide beach-dune system (figg. 13.2 and 13.3), bordered landwards byan alternating low-lying littoral plain and a marine terrace staircase bordered-seawardsby an inactive cliff. The intermittent Mergola (fig. 13.3) and Colle degli Ulivi streams and the mobile mouth of the Tecchio Stream (fig. 13.4) are minor stream mouths.

Waveclimate, currents and tide

The Molise coast is under the influence of a microtidal regime with an ordinary tidal range of 30-40 cm. The wind and wave climate data, shown in Table 10, were obtained from the Termoli station (42°00'15"N; 014°59'47"E) and the buoy located off Ortona (42°24'25''N; 014°32'10''), respectively. Sediment transport occurs from North to South and is more intense within the sector located southward to the promontory of Termoli (Aucelli & *alii*, 2007a).

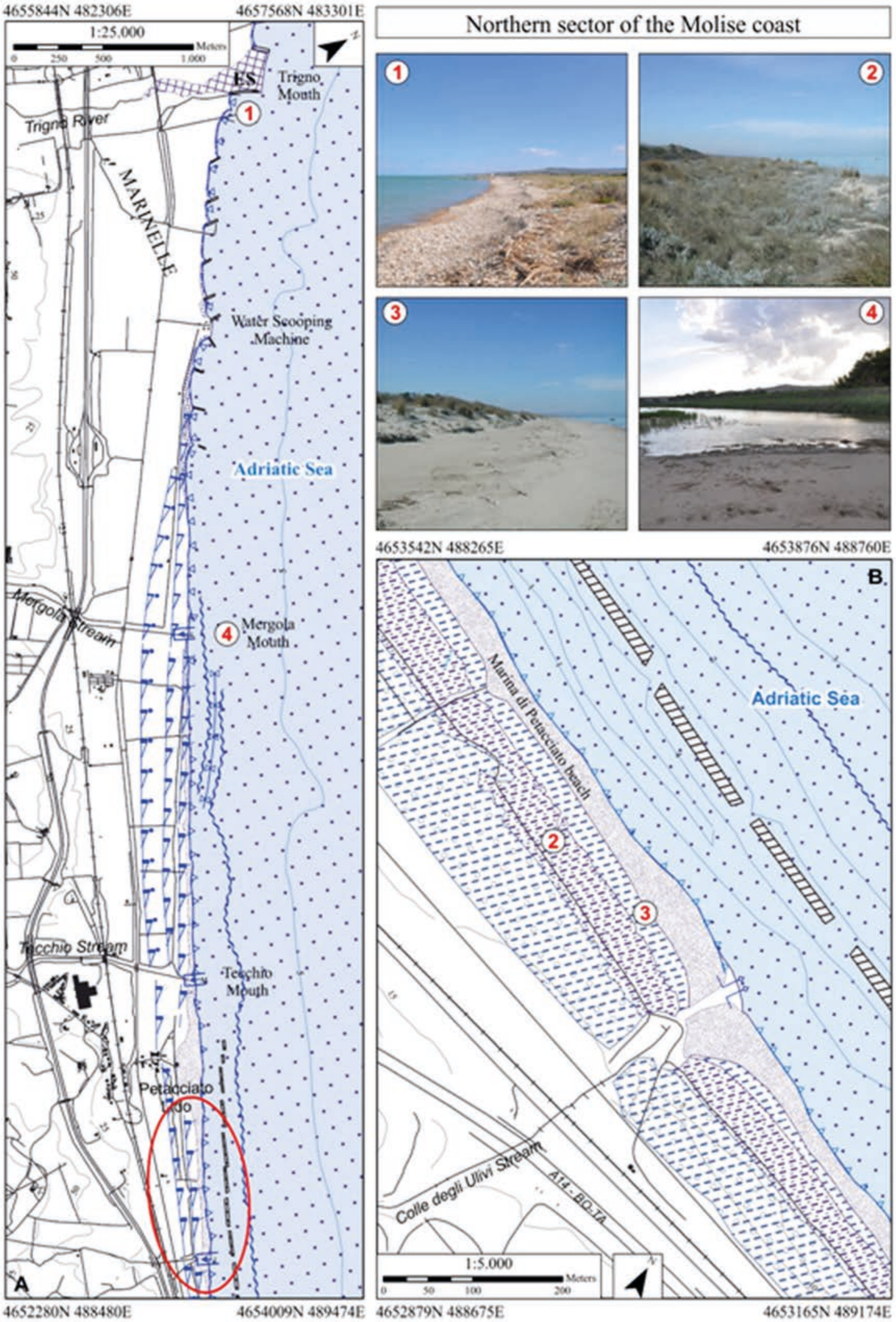

FIG. 13 - Geomorphologic maps of the Norther sector of Molise coast (A at a scale 1:25000 and B at a scale 1:5000): (1) the high-energy beach within the northern margin, (2 and 3) the active dune and the dune-beach systems in the southern portion, (4) the minor, intermittent mouth of the Mergola Stream. Groins and detached submerged breakwaters present in the study area are added in the maps.

TABLE 10 - Main wind and wave climate featuresestimated for the Molise coast.

Recording period	Prevailing wind (°N)	Dominant wind (°N)	Main wave direction (°N)	SWH* (m)	Wave period (s)	Wave length (m)	Secondary wave direction (°N)	Effectivefetch (km)	Closure depth** (m)	Sizigial tide amplitude (m)
1989-2008	270 ÷ 15	270 ÷ 360	350	3.5	6.6	68	90	476	6.03	0.40

(*=significant wave height: ** = according to Hallermeier, 1981)

Coastal evolution and present landscape

During the last century, the Molise coast wassubjected to prevailing erosion which, at first, affected the major river deltas (Trigno and Biferno rivers), then, partial areas of other coast sectors (Aucelli & *alii*, 2009 and references therein). Between 1954 and 2003, shoreline retreat caused an overall land loss of about 1,100,000 m^2 (Aucelli & *alii*, 2009) that mostly damaged the coastal stretch comprisingthe Trigno and Biferno mouths. On the other hand, most of the Molise coast advanced slightly between2003 and2007, allowing the recovery of a small portion of the previous land loss.

Considering the entire period 1954-2007, an overall land loss of about920,000 m2 occurred. The Trigno and Biferno mouths were affected by maximum annual erosion rates of – 2.66 and – 3.25 m/y, respectively.

Between1954 and 2003, the northern portion of the mapped coastal stretch (Trigno mouth–Mergola mouth) underwent severe erosion (2.79 m/y, Aucelli & *alii*, 2009) leading to the present morphology of the Trigno mouth (fig. 13A).Thiscaused analmostcomplete destruction of the active dune system, along with most of the pine forest behind it. Conversely, the central portion (Mergola mouth-Tecchio mouth) and the southern portion (southwards of the Tecchio mouth) were marked byprogradation.

Coastal dynamics

The active coastal dynamics of the mapped coastalstretch is dominated alternatively by erosion and progradation. In particular, the northern portionis characterised by an average annual retreat of 1.7 m/yand maximum annual retreat rates of up to 9.0 m/y between the Water Scooping Machine of Montenero di Bisaccia (fig. 13.A) and the Mergola Mouth (2007-2014). A rapid shoreline retreat caused the detachment of groins and, especially, in the sector North of the water scooping machine, the substitutionof the larger sandy beaches with narrow and steep beaches,composed mainly of gravels (fig. 13.1).

On the contrary, progradation prevails largely Southof the Mergola mouth (fig. 13. A), with a maximum annual rate of 2.1 m/yalong the Marina di Petacciato beach (fig. 13.B), protected by detached submerged breakwaters ever since the beginning of the 1990s.In the area to the South of the Tecchio rivermouth, the dune system bordering the beach is strongly anthropized and excavated annually to nourish the beach of Petacciato Lido. South of the Petacciato Lido (fig. 13.B), the dune system, part of the best preserved dunes in Molise, consists of three major well-preserved dune ridges, affected only locally by small erosion scarps (fig. 13.3), and some cross cuts due to pedestrian use. This dune system has a high ecological value owingto the typical habitats characterising both the embryonaldune and the dune ridges (fig. 13.2).

NORTHERN COASTAL SECTOR OF THE MT. CONERO PROMONTORY (ARINGOLI D., NESCI O., PIACENTINI D.)

Geological and geographical settings

Mt. Conero is a calcareous promontory situtated at the inflection point along the Adriatic coast in central Italy. Here,the coastline shifts from a NW-SE orientation, characteristic of the northern section, to a NE-SW direction in the southern section (fig. 14). Structurally, Mt. Conero is an anticline paralleling the Apennine axis, boundedto the North and to the South by high angle faults, transverse to the fold axis (Aringoli & *alii*, 2014). The area comprises a sequence of prevalently carbonate formations: these range from the Cretaceous (Maiolica, Marne a Fucoidi and Scaglia Bianca), to the Eocene (Scaglia Rossa, including the Marchesini calcarenitic guide level), followed by the calcareous-marly and marly formations of the Oligocene (Scaglia Cinerea) and the Miocene (Bisciaro and Schlier). Northwards, the outcrops consist mainly of pelitic terrigenous lithotypes: marly-silty clays (Colombacci Formation), made up of clayey marls with conglomerate levels (Upper Miocene), the characteristic horizon of Il Trave rock, i.e. a strongly cemented sandstone-calcarenite level (Upper Miocene), and the pelitic and pelitic-sandy lithofacies of the Lower Pliocene (Coccioni & *alii*, 1993).

Wave climate, currents and tide

The wind and wave climate data reported in Tab. 3.11.1 wereobtained from the National Sea-Level Measurement Network (Rete Mareografica Nazionale, RMN) and the National Sea-Wave Measurement Network (Rete Ondametrica Nazionale, RON) for the Italian seas. The Anconastation was the referralfor the present study. The coastal morphodynamics of the Conero study area ismainly driven by winds and waves approaching from the SSE and, subordinately, from the WNW. These generate significant wave refraction affecting the high coast portions, while also producing an important longshore current from the South along the entire study sector of the coast, including the Mezzavalle beach and small pocket beaches. Low tidal amplitudes werealso observed.

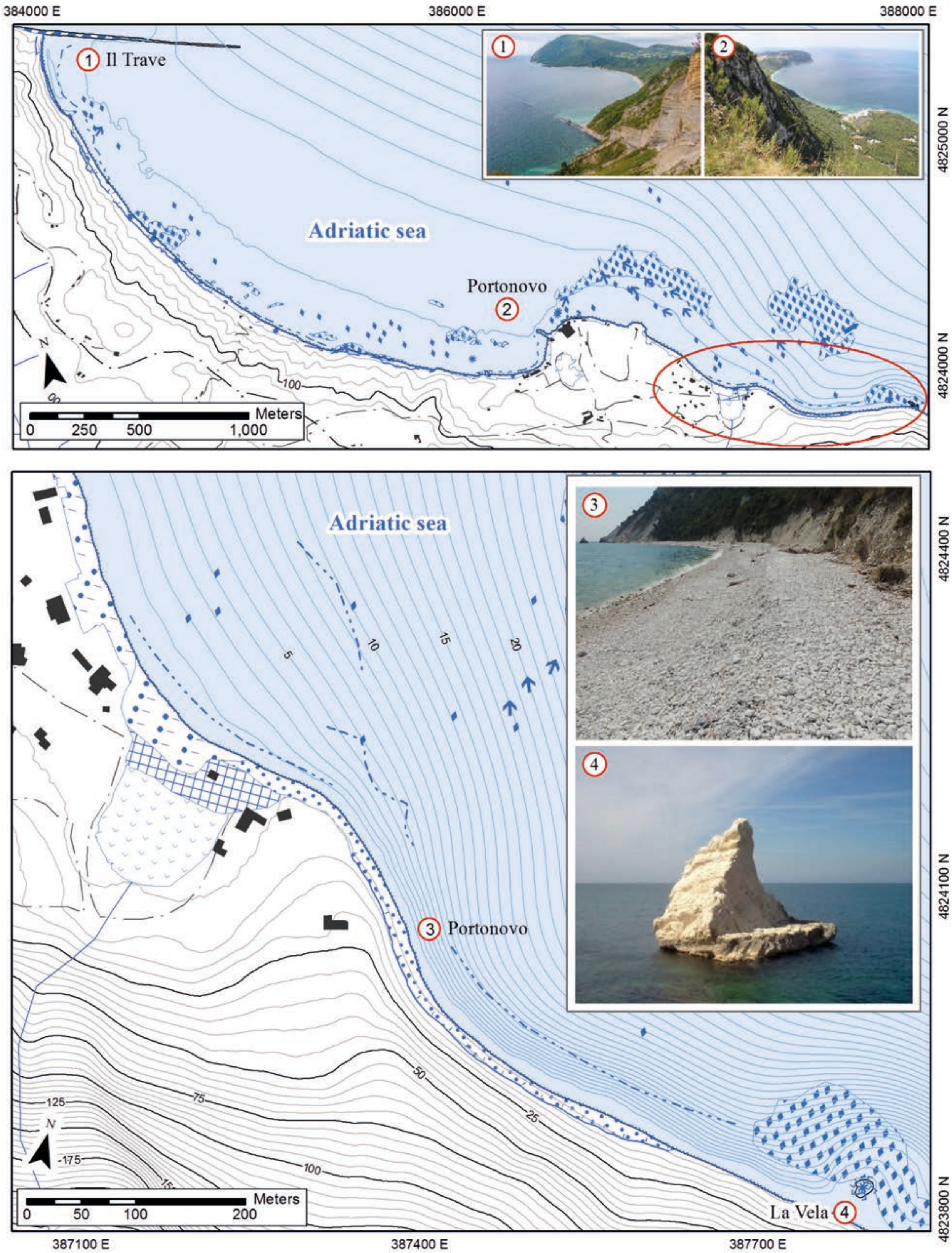

FIG. 14 - Geomorphologic maps of the northern sector of the Mt. Conero Promontory (A, at a scale of 1:25,000, and B, at ascale of 1:5,000): (1) overview from the North of the study area; (2) Portonovo and Mezzavalle viewed from the landslide crown; (3) marine gravels and coarse slope deposits southward of Portonovo; (4) "La Vela" seastack in the southern portion of the study area.

Table 11 - Main wind and wave climate featuresof the Monte Conero promontory.

Recording period	Prevailing wind (°N)	Dominant wind (°N)	Main wave direction (°N)	SWH* (m)	Wave period (s)	Wave length (m)	Secondary wave direction (°N)	Effectivefetch (km)	Closure depth** (m)	Sizigial tide amplitude (m)
Wind RMN Ancona (2010-2016) **Wave** RON Ancona (1999-2006; 2009-2013)	157.5 ÷ 202.5	292.5	112.5 ÷ 157.5	3-3.5	3,5-4	18.3 - 24	0 ÷ 45	227	5.2	0.47

(RMN = Rete Mareografica Nazionale; RON = Rete Ondametrica Nazionale; * =significant wave height; ** = according to Hallermeier, 1981)

Coastal evolution and present landscape

Repeated field surveys carried out between 2005 and2015, accompanied by the interpretation of multi-temporal (1954-2012) aerialphotos, allow the reconstruction ofthe recent geomorphological evolution of the Mt. Conero coastal sector, with particular regards to the identification and classification of active phenomena (Aringoli & *alii*, 2014; Savelli & *alii*,2017).

The study area encompasses a 6 km-long coastal zone located along the NW sector of the Conero promontory bounded by the "Trave" platform to the North (Fig.14.1) and the "Vela" seastack to the South (Fig.14.4). Due to an evident morphological contrast, this area can be divided into two sections with homogeneous geological and geomorphological characteristics: ì) Il Trave - Portonovo; ìì) Portonovo - La Vela. In the formersection, the coast shows a gentle bay configuration, corresponding to the prevalently marly and clayey lithologies. Height differences can be detected on the slopes, varying from 130 m to over 200 m, with average gradients of around 40°; at the foot of the slopes, tiny continental and beach deposits, rarely reaching 50 m in width, are found. Southwards, in the lattercoastal section, the rapid shiftin the geological substrate lithology to more erosion resistant rocks results in steeper slopes. Calcareous slopes frequently reach slopes of 40°-60° up to subvertical; in various points, the relief exceeds 400 m and reaches 572 m at the top of Mt. Conero.

The slope is markedly varied and related to different types of bedrock with the lower part composed of the coalescence of various landslides. Apart from the impressive Portonovo landslide, there is a significant landslide located to the east, between the Church of Santa Maria and the Vela seastack. In addition, the rocky escarpments of the entire areaare cut by short, steep channels, frequently subjected to debris flow phenomena, especially during periods of intense rainfall.

Coastal dynamics

By relating the main weather-marine elements (tab. 11) and the mapped landforms, a good match can be observedbetween them on the examined coast. Indeed, in the eastern sector, the prevalence of winds and waves from the SE generateda major difficulty in the reworking of landslide deposits and blocks resulting from cliff degradation. On the contrary, in thewestern part, the mainly fine materials produced from the slopescanbe easily removed so, avoiding the formation ofa large bay. By adding a fewdetails of the coastal dynamics, it can be seenthat the sea-bottom generally shows a clear convexity with respect to the almost regular portion of the continental shelf. These forms are strongly influenced by the presence of various landslide deposits which modify the sea-bottom geometry. The coastline is generally characterised by an active cliff whose morphology reflects the lithological and structural features of the bedrock. In the northern sector, the beach is very narrow, and there is a remarkable, partially submerged, landform: Il Trave. This last is a platform consisting of a 14 mm-thick calcarenite layer (Trave guide horizon – Upper Messinian) which is slightly less than 1 km, projecting NW-SE from the cliff (fig. 14.1). This landform can be divided into two sectors dominated by different coastal processes: a surf bench and a wave cut platform from inland to offshore, respectively. Due to the "protective" effect of the Trave rock, which limits the dominant currents from the North, the wave motion is unable tocompletely distribute the material supplied by the slope dynamics and contribute to form the Mezzavalle beach. Nearby, to the South, is the 3 km-long gravel beach of Mezzavalle. This beach lies at the base of a steep slope and terminates in proximity to the village of Portonovo. Along both sides of the Portonovo landslides, adjacent to the shoreline, two small lakes (Profondo and Grande) occur. In this area ,a small pocket beach composed of gravels and sand deposits, resulting from the landslide accumulation that protected the beach from marine erosion,has formed.Moving southwards, the coastline is characterised by the accumulation of various types of landslides, with prevalently coarse material and including large blocks (fig. 14.3). The Vela seastack, located in this sector about 30 m offshore from the rocky cliff,iscarved out of the calcareous rocks belonging to the Scaglia Rossa formation (fig. 14.4). The seastack is surrounded by a tidal notch atthe present sea-level (fig. 14.5). The general overview suggests that the investigated stretch of coast is actually in balance, especially the Portonovo pocket beach. Erosive activity is limited to the backwater cliffs characterised by numerous active mass wasting processes, such as earth flows in the northern sector and rock falls in the southern.

ROCKY COASTS OF THE GULF OF TRIESTE (NE ITALY) (FURLANI S., BIOLCHI S., DEVOTO S.)

Geological and geographical settings

The Gulf of Trieste (GOT) is a semi-enclosed shallow marine basin located in the northernmost part of the Adriatic Sea, in NE Italy, with a maximum depth of 25 m. Marine sedimentation is strongly affected by local inputs of freshwater from the Isonzo and Timavo rivers to the North, and minor rivers in the southeastern part of the gulf (Biolchi & *alii*, 2016).

The eastern part of the gulf is delimitedby the classical Karst.Northwards, the Quaternary Friuli Plain occurs, and southwards, the GOT is closed off by the Istrian peninsula. Recently, BIOLCHI & *alii* (2016) have summarised past and recent geomorphological and geological researchstudies conducted along the coasts of the GOT.The gulfbelongs to the External Dinarides, characterised by thrusts, reverse faults, and high-angle faults, often with a strike-slip component. These tectonic discontinuities are NW-SE-oriented, and are responsible forthe shape and orientation of the coast. Moreover, a SE-NW tilting of the Karst plateau has beendescribed by many authors, such as Antonioli & *alii* (2007) and Furlani & *alii* (2011a), who studied vertical tectonic rates using geomorphological, archaeological, and sedimentological markers; the authors suggested that the area is affected by tectonic subsidence.

Waveclimate, currents and tide

Meteoclimatic data are summarized in FURLANI & *alii* (2011a, b, and reference therein). The area is characterised by a prevalence of winds blowing from the first quadrant, mainly from the E-NE (known as the Bora). Southeasterly winds are strongdue to a longer geographical fetch (over 800 km). Tides are semi-diurnal, with mean spring-tide values of 0.86 m in Trieste, and mean neap-tide values of 0.22 m. The coincidence of spring tides, seiches, southeasterly winds, and low atmospheric pressure can cause a sea-level rise of 1.80 m. Mean significant wave height during the year is lower than 0.5 m, while the highest offshore wave height, both for Bora and Scirocco storms, is about 5 m. The highest mean hourly speed for SE winds in the period 1958-1987 was 27.3 m/s. SE winds do not generate waves that enter directly the Gulf of Trieste; they enter only as refracted waves. The Bora lowers sea-level, whereas the winds fromthe SE and NW sectors raise it. This leads to “high-water” phenomena.

Coastal evolution and present landscape

From a geomorphological point of view, coastal landforms are mainly influenced by both tectonic structures and marine processes. The coast is composed oftwo main lithologies: flysch, in the southeastern sector of the gulf, and limestones, in the NW sector. The latter is represented in both the 1:25,000 and 1:5,000 scale maps (fig. 15A, B). Coastal landforms and elements have been mappedusing snorkel and dive surveys within the Geoswim Project (Furlani *et al.*, 2014b), together with boat observations and aerial photo interpretations.

Starting from topographical, lithological and geomorphological characteristics, the coasts can be described by six morphotypes: plunging cliff, sloping coast, shore platform, scree, pocket beach, built-up coast (Biolchi & *alii*, 2016).

Plunging cliffs, up to 70 m high, occur in the northern sector between Sistiana and Duino (fig. 15.5). The depth at the submerged foot of the cliff ranges between 0.5 m and 7 m b.s.l. The geomorphological setting of the coast developed largely as a consequence of several strike-slip vertical faults, N-S-oriented (Furlani & *alii*, 2011a). On the contrary, sloping coasts occur in the northwesternmost sector, between Villaggio del Pescatore and Duino.Here,LateCretaceous limestone beds, inclined about 35° towards the sea, occur.

Shore platforms develop southofSistiana, such as at Marina Aurisina, Filtri and Santa Croce, on Flysch formations, and locally, they may be covered by pebble and gravel beaches (fig. 15.3). Shore platforms extend for some tens of metres offshore, andalso occur below the sea-level (Furlani & *alii*, 2011b) due to the late Holocene sea-level rise.

Screes are characterised by the presence of limestone or cemented scree deposit blocks overlapping flysch, such as at Costa dei Barbariand Marina Aurisina. Here, submerged beachrocks (fig. 15.1) occur between -2 m and -5 m m.s.l. They developed during the Holocene transgression (Furlani *et alli*, 2011a).

Several landslidesaffect cliffs and screes. Rock-falls and block-slides affect limestone slopes, whereas rotational slides occur on flysch and are often related to human activities. A pocket beach occurs at Duino, in the NW sector of the gulf, and consists of carbonate pebbles and gravels.

The southeastern coasts of the gulf, not represented on the maps and extendingfrom Miramare to Muggia, have beencompletely modified by human structures, such as piers and harbour facilities (built-up coasts). However, this sector was originally characterised by cliffs and shore platforms. At Miramare, carbonate blocks are interpreted as olistoliths and are included in the sandstone-marlstone beds of the flysch. They played a crucial role in the coastal development as they reduced local cliff retreat (Biolchi & *alii*, 2016 and references therein), thereby producing the Miramarepromontory.

TABLE 12 - Main wind and wave climate featuresof the Gulf of Trieste.

Recording period	Prevailing wind (°N)	Dominant wind (°N)	Main wave direction (°N)	SWH* (m)	Wave period (s)	Wave length (m)	Secondary wave direction (°N)	Effectivefetch (km)	Closure depth** (m)	Sizigial tide amplitude (m)
1981-1990	60	60	270	0.5-1	–	8	60	150	–	0.86

(* =significant wave height; ** = according to Hallermeier, 1981). Data obtained from Stravisi (1992)Data obtained from Stravisi (1992)

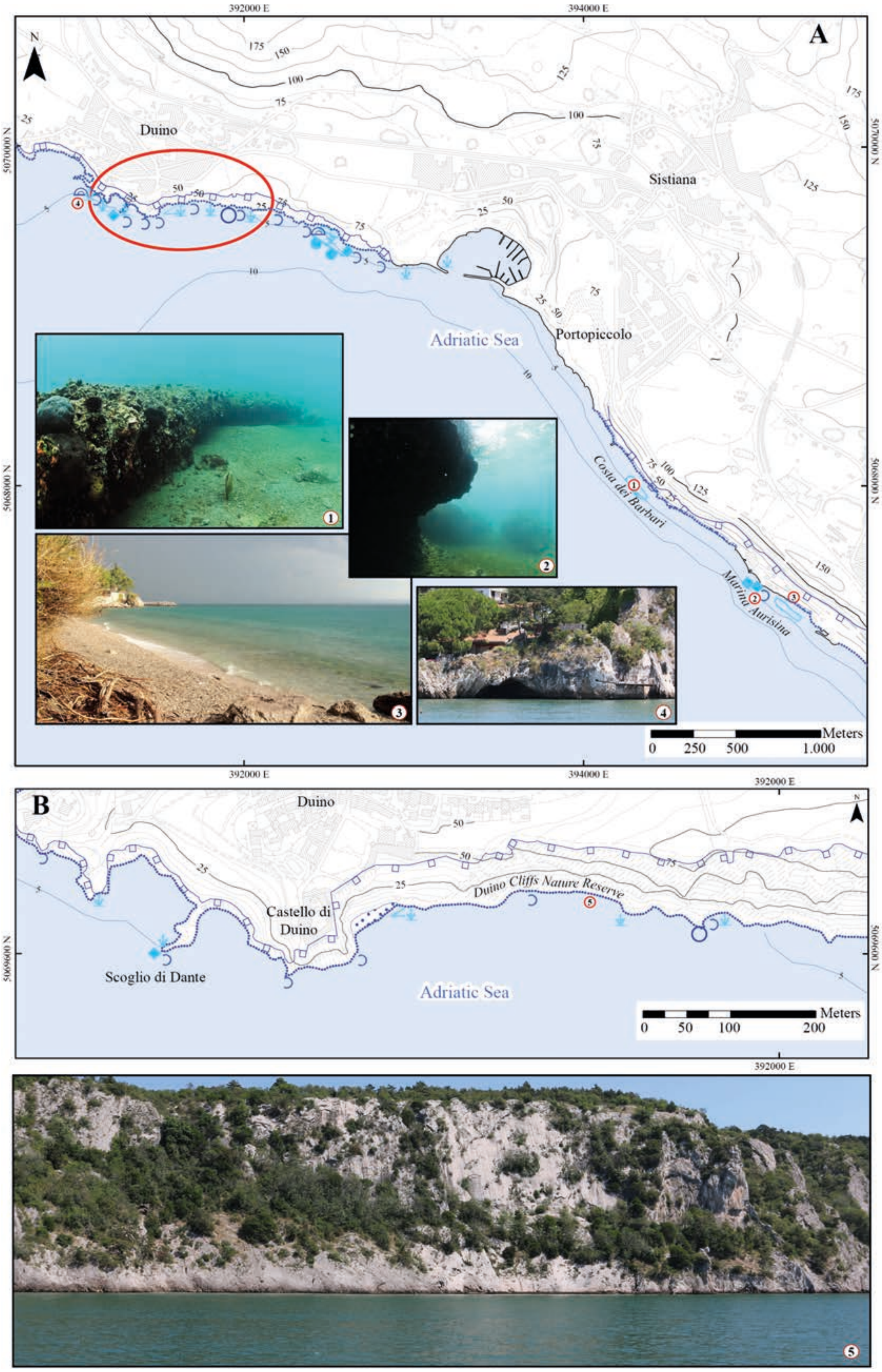

FIG. 15 - Geomorphological maps of the rocky coast of the Gulf of Trieste (A at a scale of 1:25.000 and B at a scale 1:5.000): (1) submerged beachrock (Costa dei Barbari) (2) submerged tidal notch at Marina Aurisina; (3) the pebble beach of Marina Aurisina; (4) asea cave near Duino; (5) the plunging cliff of Duino.

With regards tocoastal landforms, a sea-cave occurs close to the harbour of Duino in the northern sector (fig. 15.4). It has a width of7 m wide, a length of10 m, and a depth of 5 m. A submerged tidal notch outcrops continuously in the NW sector where it developed on the limestone plunging cliff, in correspondence to both the limestone blocks and the Miramare olistoliths (fig. 15.2; Antonioli & *alii*, 2007; Furlani & *alii*, 2011a). Its submerged currentposition is due to the aforementioned tilting and to neotectonic activity, while the present-day notch is not actively being carved (Antonioli & *alii*, 2007; Furlani & *alii*, 2011a). Furlani & *alii* (2014b) suggested that its origin was due to bioerosion, wave abrasion, and was reinforced by the presence of submarine springsthat occur in abundancealong the submerged limestone-flysch contact (fig. 15A). At Duino (fig. 15A, B), a submerged isolated block was carved by a notch, thus forming a mushroom-like rock.

Coastal karst processes also influence the evolution of small-scale landforms (De Waele & Furlani, 2013), such as kamenitza, solution pools, and karren. They occur, in particular, along the plunging cliffs between Sistiana and Duino and the sloping coast at Villaggio del Pescatore, as well as on the limestone olistoliths and collapsed blocks.

Coastal dynamics

The geomorphological evolution of the GOT is the result of processes acting at different spatial and temporal scales, such as marine processes*sensu stricto*, tectonic subsidence and tilting, karst processes of mixing corrosion between seawater and freshwater from submarine springs, mass wasting and eustatic sea-level changes. These processes produced relevant coastal landforms, in part relict, such as the submerged notch, in part active, such as the flysch cliff and shore platforms, and coastal karrens.

DISCUSSION AND CONCLUSION

This paper has summarized the results of several years ofresearch carried out by a community of Italian researchers dealing with coastal morphodynamics. The aim has been to devisean innovative toolto be used in relation to the Italian geomorphological tradition or even on a broader scale. Innovations should respond to the evolving needs of scientists, government, administrators, and land-use planners who require easymethods to manage and utilise information regardingnatural processes affecting coastal areas. Because coastal dynamics is a result of processes whichmaybe either active for thousands of years or occur with paroxysmal phenomena lasting a few hours or minutesand able to produce great changesinthe physical and biological configuration of the coastal environment, planners may find themselvesfacing daily challenges.

With this approach, the required geomorphological analysis of coastal landscapes has to be integrated using qualitative and quantitative data onlandform genesis and dynamics. At first, it appeared useful and necessary to maintain a purely descriptive approachof the coastal landforms and landscapes. However, from the perspective of the actual "end users", itthen became clearly evident that it would be much more useful to provide genetic and dynamic data. For this reason, in both the proposed examples and legend, we included the description and the genesis of inherited landforms along with the description of their current dynamism.

This additional information about inheritance and dynamism is especially useful in scenarios where a landform may not correlate to modern dynamic environment. Landforms occurring in rocky coastal environment, such as sea caves and karst caves, both emerged and submerged, can be found in the same place even if their genesis results from two different morphogenetic systems and processes. For example, a marine cave could be the evolution of a karsticcave shaped in fully continental conditionssubsequently modified by marine erosive/depositional or biochemical processes as the sea-level reached it.

The term *cliff* is generally used to indicate sub-vertical structural surfaces or steep continental surfaces reached by the sea-level during its post-glacial rise. In this paper, the term *cliff* refers only to sub-vertical surfaces resulting from the prevailing action of undercutting caused by waves. Slopes formed by continental processes, subsequently partly drowned, are referred to as a submergence coast.

Finally, a last controversial item often found in coastal morphology publications relates to the use of the term "shore platform". We think it couldbe extremely reductive to use a purely descriptive term when its position, altitude, width and morphological features could suggest its genesis and recent dynamics. For example, a wave-cut platform found wellabove the limit reached by storm waves could indicate some local disturbances due to isostasy or tectonics. For this reason, coastal landform mapping should always be deterministic/quantitative with respect to the present genesis: we prefer this approach over the morphographic/descriptive one especially because the coastal landscape may also consist of inherited landforms presently modified by sea action.

Shore platforms, sloping or near horizontal, maybe derived by different processes; some authors consider this as the most appropriate term because there is no genetic connotation (Stephenson & *alii*, 2013). One or more processes maydisplace a landform from its original position, and indicate the recent occurrence of large-scale phenomena, even paroxysmal, as for example coseismic uplift, which should be evident to the end-users of a coastal map. Therefore, we have chosen to substitute the symbolfor wave-cut platform (Gruppo di Lavoro per la Cartografia Geomorfologica, 1994) using genetic definitions: i) wave-cut platform (almost flat submerged surface shaped by abrasion), ii) surf bench (gently sloping, emerged surface shaped by backwashing waves), iii) weathering platform (gently sloping, emerged surface shaped by weathering) and iv) platform due to bioactivity. This may be consideredan improvement in the suitability of the new legend to distinguish among similar landforms, but producedby differentor prevailingly different processes. Although this approach maybe debatable, the Authors are certainthat any and allresults obtained must be placed at the service of both science and society.

In conclusion, the proposed legend needsto remain open so that new data can be added and updated as required. Because no single legend can be flexible enough to completely represent coastal landforms and their dynamics as expressed above, the legend presented in this paper is considered as a starting point and a work in progress. The previous pages are a contribution to the morphodynamic classification of the coasts around the Mediterranean basin. The usefulness of cartographic instruments depends solely on their suitability tofieldwork, as determined bya-researcher, technician, administrator, i.e., stakeholder. We concur with and reiterate concepte stablished by Finkl (2003): "*Whatever the form of subsequent efforts towards development of a comprehensive coastal classification scheme, the evolving systems should in one way or another deal with the criteria outlined in ...*" these pages, which, in turn, represent the results of previous studies and a new start point towards the improvement of the knowledge.

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