



Geomorphological analysis of the San Domino Island (Tremiti Islands, Southern Adriatic Sea). Results from the 2019 Geomorphological Field Camp of the MSc in Geological Science and Technology (University of Chieti-Pescara)

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Geomorphological analysis of the San Domino Island (Tremeti Islands, Southern Adriatic Sea). Results from the 2019 Geomorphological Field Camp of the MSc in Geological Science and Technology (University of Chieti-Pescara)

Marcello Buccolini ¹, Cristiano Carabella ², Giorgio Paglia ³, Alessandro Cecili ¹, Gianluca Chiarolanza ¹, Camilla Cioria ¹, Camilla Conicella ¹, Antonio D'Alonzo ¹, Laura De Viti ¹, Fedora Di Carlo ¹, Fausto Di Francesco ¹, Mattia Di Luzio ¹, Cristina Di Mango ¹, Elena Di Nardo ¹, Concezio Di Nino ¹, Ludovica Di Renzo ¹, Antonio Di Tollo ¹, Carmela Epifani ¹, Gianluca Esposito ¹, Piero Farabollini ¹, Massimiliano Fazzini ¹, Simone Gioia ¹, Francesco Incani ¹, Vania Mancinelli ¹, Martina Orlando ¹, Davide Pantanella ¹, Davis Peca ¹, Cristiana Picchi ¹, Chiara Puricelli ¹, Alessia Ricci ¹, Federico Serra ¹ and Enrico Miccadei ¹

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ABSTRACT

The 2019 Geomorphological Field Camp at San Domino Island (Tremeti Islands, Southern Adriatic Sea) is the result of geological and geomorphological field work activities carried out by a group of students attending the Geomorphological field mapping course of the Master's Degree in Geological Science and Technology (University of Chieti-Pescara). The main map (1:5000 scale) was obtained through an integrated approach that incorporates morphometric analysis, geological and geomorphological field mapping, and geomorphological profiles drawing. Activities were carried out by all students, divided into six working groups of three to four persons each. The field camp and field work activities made it possible to produce a detailed thematic map, as a scientific tool to depict the San Domino Island landscape, and to outline some geomorphological issues in terms of possible constraints to landscape evolution, geomorphological processes distribution, and natural hazard assessment.

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1. Introduction

Geomorphological mapping can be a helpful tool for the interpretation of landforms at almost any spatial scale (Dykes, 2008). Geomorphological maps can be considered graphical inventories of a landscape, depicting landforms and surfaces, as well as subsurface features. Sketches and maps have been fundamental methods to analyze and visualize landscape features ever since early geomorphological research (Verstappen, 2011). The widespread distribution and extended graphical capabilities of Geographic Information Systems (GIS), as well as the availability of high-resolution remote sensing data and Digital Elevation Models (DEMs), has led to the recent rejuvenation of the methodologies of mapping. Geomorphological maps can act as a scientific tool for land management and geological-geomorphological risk management, as well as providing baseline data for other applied sectors of environmental research and studies (Bozzano et al., 2020; Carabella et al., 2019; Lee, 2001; Melelli et al., 2012; Otto & Smith, 2013; Reddy, 2018). These

thematic maps may either focus on selected landscape features, for example only depicting the morphology of active processes, or deliver a full view on the landscape composition and its evolution (Dramis et al., 2011; Knight et al., 2011; Verstappen, 2011). However, teaching how to map the geomorphology of an area cannot be performed in a satisfying manner only in the lecture room but requires practical exercises in the field (de Waele et al., 2012). This paper is the result of a field mapping campaign carried out at Tremeti Islands (Puglia Region, Southern Adriatic Sea), by a group of students attending the Geomorphological field mapping course held as part of the Master's Degree in Geological Science and Technology at University of Chieti-Pescara. Geological and geomorphological field work activities have strengthened the awareness of the power of field observations, surveys, and mapping for the understanding of natural processes at different spatial and temporal scales: from the long-term landscape evolution to the short-term development of a landslide or coastal retreat inducing

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geomorphological hazards. This has encouraged constant efforts in teaching field work activities to young geologists, trying to combine contemporary hardware and software tools provided by technological advancements with traditional field methods (Miccadei et al., 2016). The Geomorphological Field Camp was held on September 30 – October 4, 2019, at San Domino Island (Tremeti Islands). The study area was chosen because of its peculiar geomorphological features, linked to landslide processes and coastal erosion, which are the expression of a complex and long-term landscape evolution. For these reasons, the Tremeti Islands can be considered a significant laboratory for geological and geomorphological studies, showing an outstanding wealth of ancient and present terrestrial and marine landforms. The islands are characterized by landforms originated from marine and continental geomorphological processes, such as gravitational, fluvial, and karst processes (Miccadei, Mascioli, and Piacentini, 2011). These landforms preserve the record of a long Quaternary landscape evolution driven by the dynamic interaction between climate, tectonics, and sea-level changes (Mastronuzzi & Sansò, 2002; Miccadei, Mascioli, Orrù, et al., 2011). Finally, the main purpose of this paper was to outline the fundamental role of field work in the analysis of the landscape and land management. The overall field activities enhanced the crucial role of field-based learning for young geomorphologists that allows them to acquire a strong sensitivity, describing the main geomorphological issues in terms of possible constraints to landscape evolution, geomorphological processes distribution, and natural hazard assessment.

2. Study area

The Tremeti Islands are located in the central-southern Adriatic Sea, about 20 km offshore of the Gargano coast

(Figure 1). They include San Domino, San Nicola, Capraia, and Cretaccio islands; Pianosa island also belongs to the archipelago, but is located about 17 km away from the main islands towards NE. The overall morphology rises from a gentle underwater slope, that ranges between 50 and 70 m b.s.l., reaching the maximum altitude (>110 m a.s.l.) at San Domino Island. The archipelago is characterized by a Cenozoic marine sedimentary succession, made up of calcareous, dolomitic, and marly-calcareous rocks. This succession is overlain by a Quaternary continental succession, composed of different units (breccias, conglomerates, and sandy deposits) belonging to slope, fluvial, and aeolian depositional environments. It also includes eluvial-colluvial deposits and soils (Miccadei, Mascioli, & Piacentini, 2011; Selli, 1971). The tectonic setting is linked to the presence of main fault systems, showing E-W, WSW-ENE and NE-SW directions; they are characterized by strike-slip kinematics and by strong seismicity, as confirmed in the neighboring Gargano area, with earthquakes along E-W to SW-NE tectonic discontinuities, associated with strike-slip and transpressive focal mechanism and magnitude up to 4.0 (Argnani et al., 1993; De Alteriis, 1995; Del Gaudio et al., 2007; Di Bucci et al., 2007; Favali et al., 1993; ISIDe Working Group, 2007; Rovida et al., 2019). The geomorphological features of the archipelago are the superficial expression of Quaternary tectonics, regional uplift, and eustatic sea-level changes (Parlagreco et al., 2011; Ridente & Trincardi, 2002). The landscape is characterized by landforms due to gravitational, fluvial, karst, coastal and marine processes which outline a complex long-term evolution resulting from the superimposition of marine, coastal, and subaerial processes. In detail, the present-day morphodynamics of the islands is characterized by the complex interaction of gravitational and marine processes that induce the instability of marine cliffs (Miccadei et al., 2012).



Figure 1. (a) Location map of the study area in Southern Italy; (b) satellite image of Gargano promontory's coast (ESRI Satellite, World Imagery). In the red zoomed box, there is the orthophoto image of the Tremeti Islands (Puglia Region, <http://www.sit.puglia.it>).

3. Methods

The geomorphological analysis of San Domino Island was based on an integrated approach that incorporates morphometric analysis, geological and geomorphological field mapping, and geomorphological profiles drawing. Activities were carried out by all students, divided into six working groups (Table 1) of three to four persons each. The mapping procedure included three main stages: (i) pre-field camp (pre-mapping) preparatory steps to describe the geological-geomorphological setting of the area and to identify the field mapping protocol to be used, (ii) the field work (during the five-day mapping campaign) to observe and map geomorphological features, focusing on the solution of a specific geomorphological issue, and (iii) post field camp activities (post-mapping) to recognize landscape features, identify geohazards, and draw the final geomorphological map, using GIS software.

The Main Map presented in this paper includes three main sections:

- (1) Morphometry section (in the upper right part);
- (2) Main geomorphological map section (in the central part);
- (3) Geomorphological issues section (in the lower part).

Vector topographic data (1:5000 scale) were retrieved from the Cartographic office of Puglia Region (<http://www.sit.puglia.it>). The morphometric analysis, as well as the mapping, was carried out with the GIS software (QGIS 2019, version 3.10 “A Coruña” and ArcMap® 10.6). It involved the analyses of the main orographic features such as elevation, slope, aspect (Strahler, 1952) and local relief (sensu Ahnert, 1984, elevation range in a 500 m² window). These primary DEM attributes were extracted from LiDAR data (1 m resolution), provided by Ministero dell’Ambiente e della Tutela del Territorio e del Mare (<http://www.minambiente.it/>). Geological and geomorphological analyses were based on field work activities integrated with orthophoto interpretation. In this process, each of the six groups was assigned a specific geomorphological issue (Table 1) and a field survey area of about 1 km² (see red boxes on the Main Map).

Table 1. Specific geomorphological issues for each working group.

Group 1	Site selection for a new nautical-touristic port
Group 2	Site selection for the realization of a new hotel
Group 3	Site selection for a suitable reservoir area
Group 4	Definition of valuable activities for a geotouristic enhancement
Group 5	Site selection for a water captation work
Group 6	Site selection for a dump construction

Field mapping was carried out at the 1:3000 scale to investigate the outcropping bedrock lithology, tectonic features, superficial deposits, and the distribution of structural, gravitational, karst, marine, fluvial and anthropogenic landforms, using a common legend. Mapping was performed according to the guidelines of the Geological Survey of Italy and AIGeo (Italian Association of Physical Geography and Geomorphology) (ISPRA, 2007; ISPRA & AIGEO, 2018) and was also in accordance with the literature concerning geomorphological mapping (e.g. Calista et al., 2016; GNGFG, 1994; Miccadei et al., 2012; Otto et al., 2011; Smith et al., 2011). After the field work, each group presented a 1:5000 preliminary map of the field survey area, geomorphological cross-sections, photo documentation, and a discussion of the specific assigned issue. The individual maps were checked, summarized and then assembled to form a unique geomorphological map.

4. Results

The enclosed map shows the main features of the area and is made up of three sections, described in the following paragraphs.

4.1. Morphometry

A morphometric analysis of the Tremiti Islands was carried out as a part of the preliminary activities and allowed to outline the main landscape features of the area to be verified and mapped by means the geomorphological field work.

The study area reaches its maximum altitude (>110 m a.s.l.) in correspondence of the tabular summit of San Domino Island. Other islands show moderate altitude that reaches ~80 m a.s.l., at San Nicola Island and ~60 m a.s.l., at Capraia Island. The area shows a rather homogeneous aspect exposure distribution, with northwest and west exposed slopes most frequent than the south and southeast ones, especially at San Domino. The local relief distribution ranges from 40 to 120 m, with the highest values (between ~140 and >160) located in the SW sector of San Domino and the northernmost sector of Capraia. San Domino is characterized by a slightly rugged morphology, with elevation ranging from 11 to 110 m a.s.l., bordered by cliffs. It shows a homogeneous slope distribution (values between 2° and 10°) with the highest values (>30°) along the cliffs. San Nicola shows a tabular morphology with an elevation around 70 m a.s.l. Slope values range from ≤2° to 5° on the summit tabular surface with high values (>30°) along the surrounding sub-vertical cliffs. Capraia shows an irregular morphology with elevation ranging from 11 to 50 m a.s.l. and a homogeneous slope distribution (values between 2° and

15°) with the highest values (> 30°) in the northernmost sector.

4.2. Main geomorphological map

On the Main map, the following lithological and geomorphological elements are included.

Lithologies are subdivided into calcareous bedrock and superficial deposits.

- (a) Bedrock units are represented by dolomitic limestone, nummulitic limestone, and calcarenitic limestone and marls, stratified or in massive setting, pertaining to a Paleogene-Pliocene marine succession. In detail, dolomitic limestone mainly outcrops in the southernmost sector of the island between Grotta delle Viole and Punta Secca. Nummulitic limestone widely outcrops along the north-western coastline and calcarenitic limestone and marls are widespread along the cliffs between Cala Matano and Molo di San Domino. Cataclastic rocks, representing the backbone of vertical cliffs at I Pagliai, were also classified as bedrock units.
- (b) Superficial deposits are represented by deposits related to slope, fluvial, aeolian, and karst depositional environments, mainly pertaining to a Pleistocene-Holocene continental succession; specifically, breccias, calcretes, aeolian sands, eluvium-colluvium deposits, soils, and landslide deposits were identified. These deposits are generally exposed from sea-level up to the summit of San Domino island, more than 100 m a.s.l., with a maximum thickness of about 40 m. Eluvium-colluvium and soil deposits are largely widespread in the inner areas consisting of argillaceous and dark reddish-brown deposits (Miccadei et al., 2012).

The geomorphological features of the study area are classified according to their morphogenetic processes in structural, gravitational, karst, marine, fluvial, and anthropic landforms. A specific focus was devoted to these elements. They are widely described in the following paragraph to highlight their role played in the main geomorphological issues. Moreover, their arrangement is summarized in the geomorphological cross-sections (see Group boxes on the Main Map), which graphically shows their spatial distribution on the island.

4.3. Geomorphological issues

The combination of preliminary activities, detailed field work activities, and drawing and analysis of geomorphological cross-sections allowed each working

group to analyze and discuss the specific geomorphological issue assigned.

4.3.1. Site selection for a new nautical-touristic port

The field survey area (see Group 1 box on the Main Map) is in the northernmost sector of San Domino island and it covers the area of Molo di San Domino, where is currently located the nautical-touristic port. In order to outline the available criteria to expand the port's area or to select sites for a new port, specific and detailed geological and geomorphological field investigations (Figure 2(a)) were performed. Gravitational landforms are represented by landslide deposits with associated landslide scarps. These deposits refer to rockfalls and topple and consist of small- to medium-size calcareous blocks located especially at the base of the cliffs at I Pagliai. Local processes related to viscous deformation of shallow material (creep and/or solifluction) affect the slopes or portions of slopes surrounding the port's area, where the eluvial-colluvial cover is thicker, and the erosive action of running waters is greater. Karst landforms are represented by sub-circular dolines (5–10-m wide), partially filled by superficial deposits, at heights ranging from 30 to 40 m a.s.l. and doline edges along the eastern coast. Caves, partly or completely submerged by seawater, are also present. Coastal landforms are represented by a cliff edge, continually extended along the coastline showing an NW-SE direction and by stacks and emerged rocks in the marine area. Finally, anthropic landforms are widespread throughout the area, mainly represented by anthropic surfaces and scarps. The main geomorphological hazard affecting the area, in combination with NW-SE and E-W-oriented tectonic features, is the complex interaction of gravitational and marine processes which induce the instability, retreat, and evolution of the vertical cliffs along the north coast of the port, also facilitated by the erodibility of the cataclastic rock outcropping in the area. For these reasons, the nautical-touristic port should not be expanded moving towards the NW direction.

4.3.2. Site selection for the realization of a new hotel

The field survey area (see Group 2 Box on the Main Map) is in the southernmost sector of San Domino Island. The geological and geomorphological field mapping performed to select a site for the realization of a new hotel, highlighted the presence of several geomorphological landforms. Gravitational landforms, mainly present in the NW sector of the study area, are represented by landslide deposits at Grotta del Bue Marino and Faro di San Domino. Karst landforms are represented by doline edges and caves, largely widespread along the coastline at Grotta delle Viole, Grotta del Bue Marino, and Punta di Zio Cesare.



Figure 2. Photo documentation of geomorphological field activities: (a) detail of field work at I Pagliai; (b) karst depression on the calcareous bedrock; (c) detail of geomechanical investigations at Cala degli Inglesi; (d) V-shaped gully interrupted by artificial wooden barriers, at Cala Matano; (e) emerged karst cave at Cala della Tramontana; (f) dolomitic limestone outcropping at Punta Secca.

Gullies are mainly due to the running waters and show a NE-SW to N-S direction. Coastal landforms are represented by cliffs consisting of steep slopes (up to 15 m high) developed especially in the western sector of the field survey area. The main geomorphological hazard of the area is the high fracturation of the calcareous bedrock, largely affected by an NW-SE tectonic element and several horizontal caves (Figure 2(b)) especially in the western sectors under the lighthouse of the island. For these reasons, the realization of a new hotel in the lighthouse's site is not allowed because of the geomorphological setting of the westernmost sector of San Domino island affected by instability and retreat of the vertical marine cliffs between Punta Secca and Grotta del Bue Marino.

4.3.3. Site selection for a suitable reservoir area

The field survey area (see Group 3 Box on the Main Map) is in the central-western sector of San Domino

Island and it extends from Punta Vuccolo to Grotta delle Rondinelle. The study area is characterized by the presence of different types of gravitational and fluvial landforms. A landslide scarp with SW-NE direction is well evident at Cala degli Inglesi, highlighting the presence of landslide deposits along the coastline. Local processes of creep and/or solifluction affect portions of slopes in the central sector of the field survey area. Moreover, gullies and ephemeral channels represent the main fluvial landforms. Karst landforms are widespread in the area and are represented by doline edges and caves, partly or completely submerged by seawater. In order to identify the main elements influencing reservoir site selection, a detailed field mapping was performed to analyze and define the interaction between morphological, geomechanical (Figure 2(c)), and geomorphological features. This analysis showed that a suitable site for a reservoir area is the Cisterna dei Benedettini area.

4.3.4. Definition of valuable activities for a geotouristic enhancement

The field survey area (see Group 4 Box on the Main map) is in the central-eastern sector of San Domino island and it is characterized by the presence of an NNE-SSW oriented coastal cliff which extends from the slightly elongated promontory of Cala Matano to Grotta del Sale cave.

The detailed geomorphological survey, carried out along the coastline and around the inner areas, culminated in the identification of landforms referable to gravitational, karst and marine processes. Landslide deposits are located at the base of landslide scarps up to 5 m high, consisting of sparse debris or meter-sized blocks. Karst landforms, particularly abundant along the coast in the surrounding area of Grotta del Sale, are represented by dolines and caves. Most of them have the inner edge preserved and the outer edge missing following a collapse or topple, whereas other dolines are characterized by well-defined edges and usually shorter diameters. Coastal landforms are identified by steep or vertical cliffs with heights ranging from 5 to 15 m. Gullies and V-shaped ephemeral channels, due to the running waters are filled by eluvial-colluvial deposits and soils. These gullies are usually interrupted by a series of artificial wooden barriers (Figure 2(d)). According to its special value in terms of landscape and geological, geomorphological, environmental, and historical features, the whole Tremiti archipelago can be considered as a geomorphosite (Paglia et al., 2020). The field work activities allowed us to select potential sites to further promote a modern and environmentally aware tourism (Piacentini et al., 2019; Reynard & Brilha, 2017). One of the most valuable sites in the area is a small promontory named 'Scoglio dell'Elefante', whose morphology resembles the head of an elephant. Boat trips around the island are regularly organized by the local guides and allow tourists to take a close view of the promontory or dive around it. In order to enhance the geological heritage, the realization of explanatory panels will be useful to establish an easy and guided visual connection between the observers/geotourists and the landscape and natural heritage of San Domino island, highlighting the main lithological, geomorphological, and environmental features.

4.3.5. Site selection for a water captation work

The field survey area (see Group 5 Box on the Main map) is in the northwestern sector of San Domino island, between Cala della Tramontana and Cala Tamariello. The main geomorphological elements are represented by gravitational and karst landforms. Creep and/or solifluction locally affect the eastern sector of the area. Moreover, it is possible to recognize sub-circular dolines, partially filled by superficial deposits, and doline edges along the coastline. Caves,

partly or completely submerged by seawater, are present in correspondence of Cala della Tramontana (Figure 2(e)). Many shallow gullies with an S-N direction represent the main fluvial landforms. The assigned issue was the site selection for a water captation work. The geological-geomorphological setting is characterized by widespread karst processes affecting the emerged and submerged landscape, in combination with NW-SE and ~E-W oriented tectonic elements and the lack of a developed drainage network. A possible solution to this problem is the construction of a rainwater harvesting at Cala Tamariello, taking into consideration the rainfall rate of the area and the waterproofing procedure of the fractured calcareous bedrock.

4.3.6. Site selection for a landfill construction

The field survey area (see Group 6 Box on the Main map) is in the south-western sector of San Domino Island. This sector features the maximum altitude (Poggio del Romito) of the Tremiti Islands and is characterized by an irregular and wavy morphology. The main coastal landform is represented by a vertical cliff, continually extended along the coastline in the western part. Gravitational landforms are widely represented by landslide deposits, consisting of small- to medium-size calcareous blocks located both at the base of the cliff and in the surrounding submerged area. Processes related to creep and/or solifluction largely affect the steep slopes representing the junction areas between the tabular landscape and the vertical coastline. Several gullies, mainly due to running water action, are present along the slopes of the field survey area showing a N-S and ~W-E directions. Karst landforms, such as sub-circular dolines, doline edges, caves are largely present between Punta Secca and Grotta delle Rondinelle. Landfill siting is an extremely difficult task to accomplish because the site selection process depends on different factors and regulations. These latter can be grouped into natural/environmental factors and artificial factor. The decision tree developed for the landfill site selection problem is characterized by the evaluation of topographical, hydrogeological, and geological criteria; but also, criteria related to accessibility and criteria related to infrastructure (Sener et al., 2006). A suitable site is represented by the area of Poggio del Romito, based on the lithology, geomorphological setting, elevation, and slope characteristics. It is located on a structural surface on the summit of the island on eluvium-colluvium deposits covering the calcareous bedrock and it is well served by roads and infrastructure. In other areas, karst processes largely affect the underlying carbonate bedrock (Figure 2(f)) and the dynamic interaction of gravitational and marine processes induce the instability of the cliffs, restraining the landfill siting.

5. Conclusion

The geomorphological mapping and issues outlined in the present paper are the result of the 2019 Geomorphological Field Camp at San Domino Island (Tremite Islands) carried out by a group of students attending the Geomorphological field mapping course of the Master's Degree in Geological Science and Technology (University of Chieti-Pescara). This work aims to enhance the growing legacy of field-based learning for young geomorphologists (Thornbush et al., 2014), allowing them to acquire a strong understanding of geomorphological processes and landscape evolution. The surveying work allowed students to be aware of the key role of field mapping and observation in the solution of specific issues in different geomorphological contexts, such as insular environments. Finally, this work allowed us to produce a detailed geomorphological map, as a scientific tool to depict the San Domino Island landscape, and it was useful to increase the knowledge and role of field observations, surveys, and mapping for the understanding of natural processes at different spatial and temporal scales: from the long-term landscape evolution to the short-term development of a landslide or coastal retreat inducing geomorphological hazards.

Software

The vector/raster data and main map were managed using QGIS 2018, version 3.10 “A Coruña” and Esri ArcGIS * 10.6, with final editing performed using Corel DRAW 2019*.

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Disclosure statement

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