Geogr. Fis. Dinam. Quat.
34 (2011), 223-234, 9 figg.

DOI 10.4461/GFDQ.2011.34.20

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LATE QUATERNARY PALEOLANDSCAPE OF SUBMERGED INNER CONTINENTAL SHELF AREAS OF TREMITI ISLANDS ARCHIPELAGO (NORTHERN PUGLIA)

ABSTRACT: MICCADEI E., MASCIOLI F., ORRÙ P., PIACENTINI T. & PULIGA G., *Late Quaternary paleolandscape of submerged inner continental shelf areas of Tremiti Islands archipelago (northern Puglia).* (IT ISSN 0391-9838, 2011).

The Tremiti Islands archipelago, located north of Gargano promontory's coast, is part of a complex geological area within the Adriatic basin, facing the junction between central and southern Apennines. This area is well known for Neogenic-Quaternary stratigraphic, tectonic and seismologic aspects and is crucial for the definition of Late Quaternary Adriatic basin evolution.

This work gives a contribution of geomorphological data concerning the inner continental shelf around the islands. It incorporates bathymetrical analysis and side scan sonar survey, focused on the recognition of main submerged landforms, from coastline down to about 70 m b.s.l. Geophysical acquisitions were improved with direct observations, carried out by means of a two year scuba-dive geomorphological survey.

The study of continental shelf outlines a geomorphologic setting that includes marine and coastal features, but also tectonic, fluvial, karst and slope landforms. The correlation of the below sea level geomorphological features, with landforms and deposits of above sea level areas, provide a contribution to the reconstruction of Late Quaternary landscape and geomorphological evolution, as the result of tectonics, sea-level fluctuations and marine, coastal, and continental geomorphological processes.

KEY WORDS: inner continental shelf, geomorphology, paleolandscape, Tremiti Islands, central-southern Adriatic Sea.

RIASSUNTO: MICCADEI E., MASCIOLI F., ORRÙ P., PIACENTINI T. & PULIGA G., *Paleopaesaggio tardo quaternario delle aree di piattaforma continentale prossimale circostanti l'arcipelago delle Isole Tremiti (Puglia settentrionale).* (IT ISSN 0391-9838, 2011).

L'arcipelago delle Isole Tremiti, ubicato a nord delle coste del promontorio del Gargano, rientra in un'area geologicamente complessa del bacino Adriatico e di notevole importanza in relazione all'evoluzione tettonica del fronte appenninico. L'area è ben nota dal punto di vista stratigrafico neogenico-quaternario, tettonico e sismologico.

Il presente lavoro fornisce un contributo di dati geomorfologici della piattaforma continentale prossimale circostante l'arcipelago. Lo studio è stato realizzato attraverso analisi batimetriche e rilevamenti *side scan sonar*, volti al riconoscimento delle principali forme sommerse comprese tra la linea di costa e una profondità di circa 70 m. Le acquisizioni geofisiche sono state integrate e dettagliate mediante osservazioni dirette, realizzate in circa 2 anni con rilevamenti geomorfologici in immersione subacquea.

Lo studio della piattaforma continentale prossimale evidenzia un assetto geomorfologico caratterizzato da forme marine e costiere, e dalla diffusa presenza di forme tettoniche, fluviali, di versante e carsiche. La correlazione tra le morfologie sommerse e le forme e i depositi presenti nelle aree emerse, fornisce un contributo alla scansione spaziale e temporale dei principali eventi geomorfici tardo quaternari, quale risultato di processi tettonici, variazioni del livello marino e alternanze di processi marini, costieri e subaerei.

TERMINI CHIAVE: Piattaforma continentale prossimale, Geomorfologia, Paleopaesaggio, Isole Tremiti, Adriatico centro-meridionale.

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The authors wish to dedicate this work to Friend Prof. Giovanni Palmentola.

Moreover, they thank Prof. Giuseppe Mastronuzzi for the useful scientific discussions and suggestions. Laura Cambiotti and Dr. Claudio Berti (Earth and Environmental Science Department of Lehigh University, Pennsylvania) are thanked for the useful suggestions on the English version of the manuscript.

This work funded by MIUR grant of Leandro D'Alessandro and Enrico Miccadei (60% Faculty founds, 2006 and 2007).

The article is the result of a research carried out by: Enrico Miccadei (research guideline, geomorphological analyses), Francesco Mascioli (scuba-dive and side scan sonar geomorphological survey), Paolo Orrù (team leader of scuba-dive and side scan sonar geomorphological field survey), Tommaso Piacentini (geomorphological analysis) and Giuseppe Puliga (scuba-dive and side scan sonar geomorphological field survey). Synthesis of the geomorphological data, discussions and conclusions are the result of the collaboration of all the authors.

INTRODUCTION

The Tremiti Islands archipelago lies in the central-southern Adriatic Sea, in northern Apulia, at about 20 km north from Gargano promontory coast. It includes San Domino, San Nicola, Capraia and Cretaccio islands, and La Vecchia rock; Pianosa island, also belonging to the archipelago, is 11 miles away from the main ones towards NE (fig. 1). Being located around the centre of the Adriatic basin, and facing the junction between central and southern Apennines, the islands lie in a complex geological area, crucial for the study of Quaternary Adriatic basin evolution, strongly driven by eustatic processes and tectonics along well known regional faults (fig. 1; Favali & *alii*, 1993; Doglioni & *alii*, 1996; Del Gaudio & *alii*, 2007; Scrocca, 2006). They are the above sea-level part of one of the main structural high within the Adriatic basin, well studied for erosional/depositional processes on the continental shelf due to Late Quaternary tectonics and eustatic sea-level changes (Ridente & Trincardi, 2002; Cattaneo & *alii*, 2003). The Quaternary history, strongly related to tectonics and eustatism, is also outlined by recent studies focused on the above sea-level areas, that define the geomorphological features of the archipelago and provide a reconstruction of late Middle Pleistocene paleolandscape (Miccadei & *alii*, 2011).

This work gives a further contribution to the reconstruction of Late Quaternary morphoevolutive stages by the analysis of geomorphological features of inner continental shelf. The correlation of surveyed underwater landforms with eustatic sea-level changes and geomorphological features of above sea-level areas, outlines the spatial and temporal distribution of geomorphological processes affecting inner continental shelf during Late Quaternary and a possible paleolandscape reconstruction.

GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

The Tremiti Archipelago is characterised by a Cenozoic marine sedimentary succession (Paleocene - Middle Pliocene), made of calcareous, dolomitic calcareous and marly calcareous rocks (Selli, 1971; Pampaloni, 1988; Lirer & *alii*, 2002; Dall'Antonia, 2003). The marine succession is overlain by a complex Quaternary continental succession, composed of several units (breccias, conglomerates and sandy deposits) related to different Middle Pleistocene clastic sedimentation cycles, in slope, fluvial, and aeolian environment. These deposits are interbedded by late Middle - early Upper Pleistocene soil calcretes, followed by Upper Pleistocene aeolian sands. The continental succession ends with Holocene eluvial and colluvial deposits (Pasa, 1953; Selli, 1971; Miccadei & *alii*, 2011).

The marine succession shows a SE dipping homocline structural setting, consistent with the location of the archipelago on the SE side of a NE-SW trending regional anticline (Selli, 1971; Argnani, 1998). Homocline structure is affected by a series of pre-Quaternary fault systems, striking E-W and NE-SW, with strike-slip kinematics and local evidences of dip-slip reactivations. Other strike-slip fault systems have orientation varying from NW-SE to N-S (Montone & Funiciello, 1989; Brozzetti & *alii*, 2006; Miccadei & *alii*, 2011).

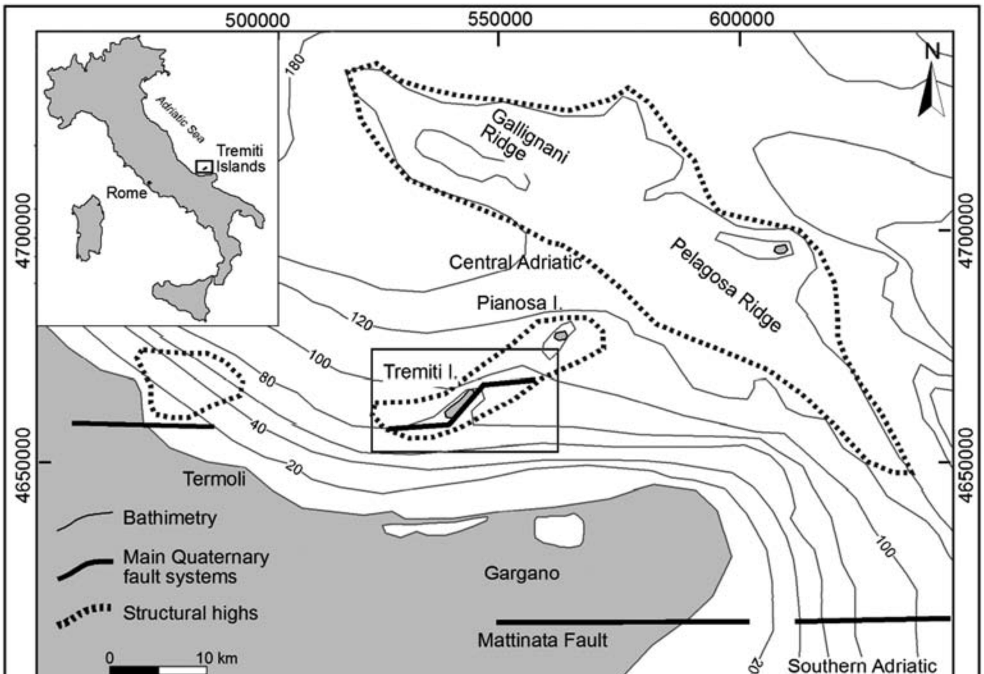

FIG. 1 - Physiographic and geological scheme of north-garganic Adriatic sector, interested by three main structural highs and faulted by regional Quaternary tectonical systems (from Ridente & Trincardi, 2002). The black line box indicates the study area.

Main previous geomorphological studies are focused on sea cliff erosional processes (Andriani & Guerricchio, 1996; Cotecchia & *alii*, 1996; Cotecchia, 1999; Lollino & Pagliarulo, 2008) and just few notes provide detailed information about karst landforms (Pasa, 1953; Regnoli, 1974; Cresta & *alii*, 1999). Recent studies analyze the relationships occuring between landforms, processes, Quaternary deposits and tectonic features (Andriani & *alii*, 2005; Miccadei & *alii*, 2011). The geomorphology of the inner continental shelf highlights the relationships between long-term geomorphological evolution, Late Quaternary tectonics, and eustatic sea-level changes. The major control comes from coastline variations due to both regional uplift (Mastronuzzi and Sansò, 2002; Ferranti & *alii*, 2006) and Pleistocene-Holocene eustatic sea-level changes (Ridente & Trincardi, 2002; Antonioli & Vai, 2004), that led to alternate periods of emersion and submersion of the area between the islands and the Italian coast of the Gargano promontory area.

METHODS

This work is based on a detailed geomorphological characterization of inner continental shelf sea bottom, between coastline and about 70 m b.s.l., incorporating: 1) bathymetrical analysis, 2) side scan sonar survey and 3) scuba-dive geomorphological survey.

Bathymetrical analysis has been performed processing and interpolating data from nautical cartography of Istituto Idrografico Militare, Piano Nautico n. 204 «Isole Tremiti e Pianosa» (scale 1:15.000). Resulting map has a detail that enables to analyse main morphological features and to discriminate flat areas and scarps.

Bathymetrical data allowed for plan geomorphological survey, carried out by means of a ~9 km^2 side scan sonar records (scale 1:5.000), during 2006-2007 years. Data acquisition has been realized using an E272 tow-fish transducer apparatus, with 100 kHz frequency, linked together with E260 analogical recorder and RTK mode GPS positioning.

Side scan sonar records have been calibrated and improved with scuba-dive geomorphological survey, up to a depth of ~50 m b.s.l., allowing for a detailed direct observation of the inner continental shelf landforms (scale 1:1000) and the observation of below sea-level cliff portion and caves.

RESULTS

Bathymetrical features

General sea floor bathymetric features are characterized by a pronounced asymmetry between south-eastern (narrower) and north-western (wider) areas of the inner continental shelf (fig. 2). The bathymetry allows for outlining

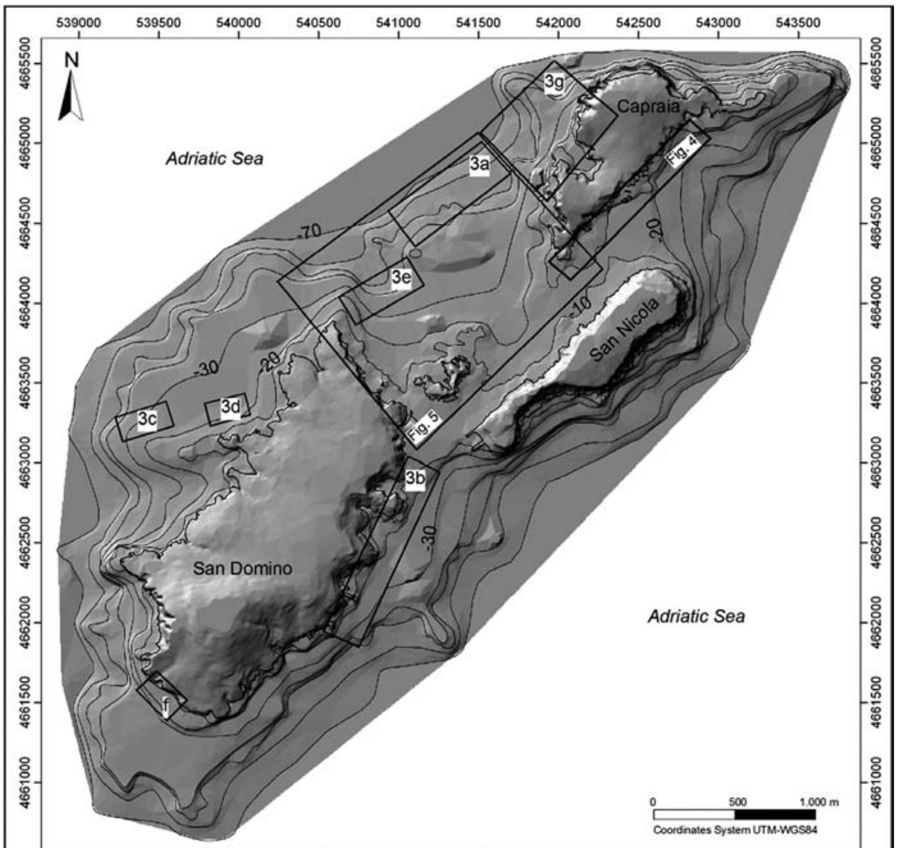

FIG. 2 - Bathymetry and hillshade of inner continental shelf around Tremiti Islands, showing flat surfaces at 8-10, 20-25, 50-55 m b.s.l. and E-W and SE-NW incisions; boxes indicate the location of side scan sonar records of fig. 3, 4, 5.

three main flat surfaces at 8-10 m b.s.l., at 20-25 m b.s.l., and at 50-55 m b.s.l., more evident in the north-western areas. The surface at 20-25 m b.s.l. shows the largest extension and lateral continuity all around the archipelago. These flat surfaces are bounded by scarps and subvertical slopes, providing a step-like morphology to the inner continental shelf.

More in detail, the north-western sector is characterized by several incisions. The main one is a pronounced E-W incision up to >10 m deep, extended from sea-level to 60 m b.s.l.. Other incisions develop in SE-NW orientation, in the bathymetric range of 30-60 m b.s.l., sloping down from the flat surface at 20-25 m b.s.l..

Side scan sonar geomorphological survey

Geomorphological survey shows sea-bottom areas covered by incoherent deposits alternating to bedrock outcropping areas, affected by tectonic landforms and shaped by erosional and depositional landforms mainly due to karst, fluvial, slope and coastal processes (figg. 3, 4, 5).

Tectonic landforms such as sub vertical scarps and bedrock outcrop alignments, connected with high fracturation zones, outline main fault systems. A first fault system is characterized by E-W orientation and is well represented between San Domino and Capraia islands (fig. 3a, 4, 5) and

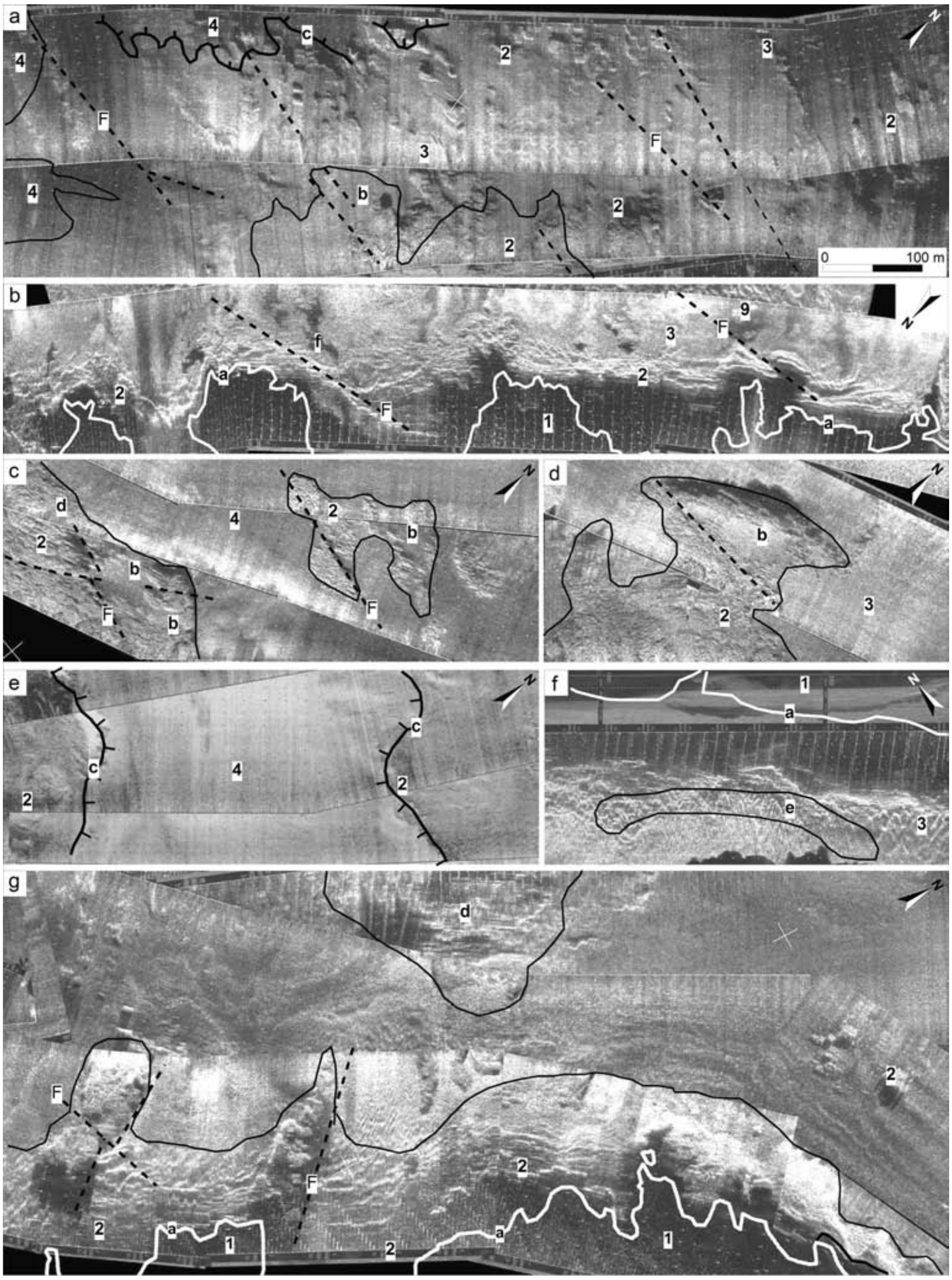

FIG. 3 - Side scan sonar 100 kHz records (locations in fig. 2). *Lithology*: **1**-Carbonate bedrock, of above sea-level area (horizontal section at sea level); **2**-Carbonate bedrock; **3**-Gravelly deposits; **4**-Sandy deposits. *Tectonics*: **F**-Inferred tectonic features. *Landforms*: **a**-Coastline; **b**-Karst landforms, dolines and minor depressions; **c**-Scarps; **d**-Landslide decametric boulder deposits; **e**-Bioconstructions, continental shelf seaweeds; **f**-Posidonia oceanica.

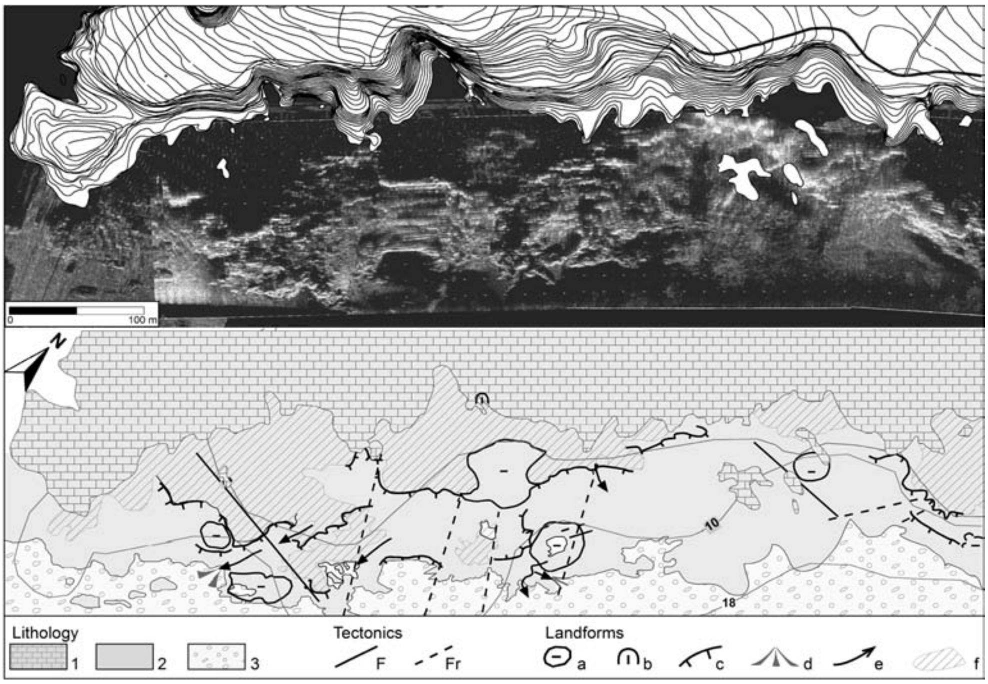

FIG. 4 - Capraia island, geomorphological scheme from side scan sonar records 100 kHz (location in fig. 2). *Lithology*: 1-Carbonate bedrock, of above sea level area (horizontal section at sea level); 2-Carbonate bedrock; 3-Gravelly deposits. *Tectonics*: F-Faults; Fr-Fractures. *Landforms*: a-Karst dissolution landforms, dolines and minor depressions; b-Karst-littoral submerged caves; c-Marine scarps; d-fan; e-Incisions; f-Shore platforms.

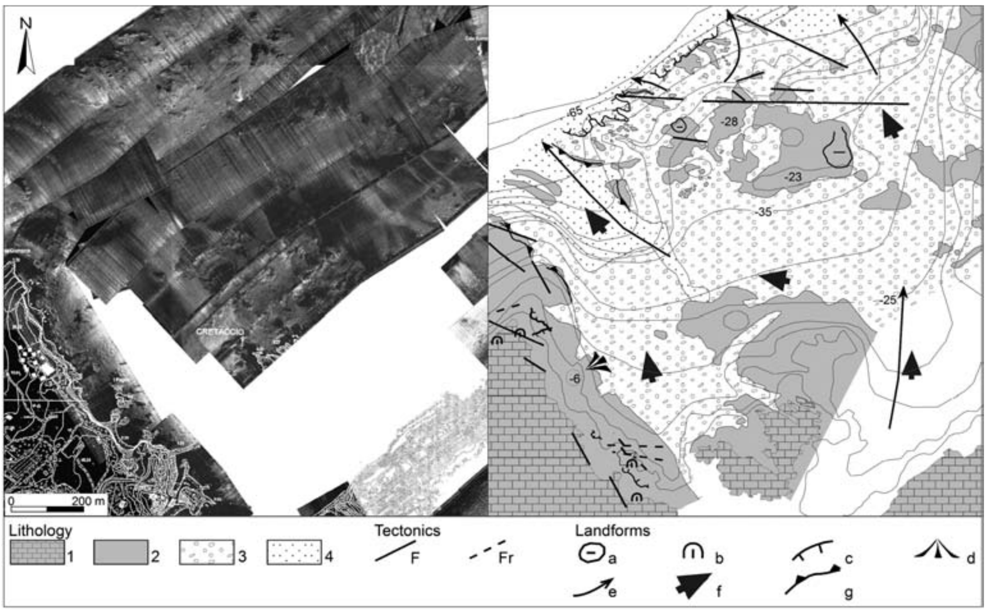

FIG. 5 - Area between San Domino, Cretaccio, San Nicola e Capraia, in north-western part of archipelago; geomorphologic scheme from side scans sonar record 100 kHz (location in fig. 2). *Lithology*: 1-Carbonate bedrock, of above sea level area (horizontal section at sea level); 2-Carbonate bedrock; 3-deposits; 4-Gravelly deposits. *Tectonics*: F-Faults; Fr-Fractures. *Landforms*: a-Karst dissolution landforms, dolines and minor depressions; b-Karst littoral submerged caves; c-Marine scarps; d-Alluvial fans; e-Incisions; f-Paleodrainage; g-Fluvial scarps.

in northern and southern San Domino sectors (fig. 3b). A minor fault system is outlined by NE-SW alignments on the northern submerged slope of San Domino island (fig. 3c). These two fault systems seem to displace a third one with WNW-ESE to NW-SE orientation, mainly affecting the northern San Domino area (fig. 3c,d).

Karst landforms are located at different bathymetric ranges, affecting rocky sea floor areas on carbonate rocks, and in some cases covered by marine deposits. Interpretation of side scan sonar records along southern coast of Capraia island (fig. 4) shows dolines occurring at 9-15 m b.s.l., partly filled by gravel deposits. Along the same coastal sector, dolines and potholes are located also at sea-level and are intensely reshaped by marine erosion. In deeper sea floor areas (25-35 m b.s.l.) dolines, over 100 m wide, filled by sandy and gravelly deposits, are present (fig. 5). They are located between San Domino and Capraia islands (fig. 3a) and north of San Domino island (fig. 3c,d). Landforms related to karst-littoral processes are present from sea-level to 20 m b.s.l., consisting of erosion-dissolution channels developed along main high fracturation bedrock zones.

Concerning fluvial landform a well developed gully system is constituted by SE-NW incisions from 30 m to over 60 m b.s.l. in the northwestern side of San Domino, Cretaccio and San Nicola (fig. 5). They are characterized by sub-vertical scarps on carbonate bedrock, and are partially filled by gravel to sand deposits, particularly moving towards deepest sectors (fig. 3e, 5). Alluvial fan are located on the 20-25 m b.s.l. surface at the outlet of shallower fluvial incisions (fig. 4, 5).

Below sea-level, slope landforms are well represented in north-western Capraia island sector. Paleolandslides are located between 30 and 40 m b.s.l., and are made of decametric calcareous blocks (fig. 3g).

Scuba-dive survey

Scuba dive survey allowed for detail geomorphological investigations of karst landforms, fluvial landforms, flat surfaces and coastal landforms.

Concerning karst landforms, direct survey enabled the mapping of 40 caves, located between sea-level and 50 m b.s.l. About 30 of them are half-submerged (fig. 6a), with bottoms at a 3-7 m b.s.l. depth, covered by centimetre and decimetre-size subrounded pebbles. Towards deep areas,

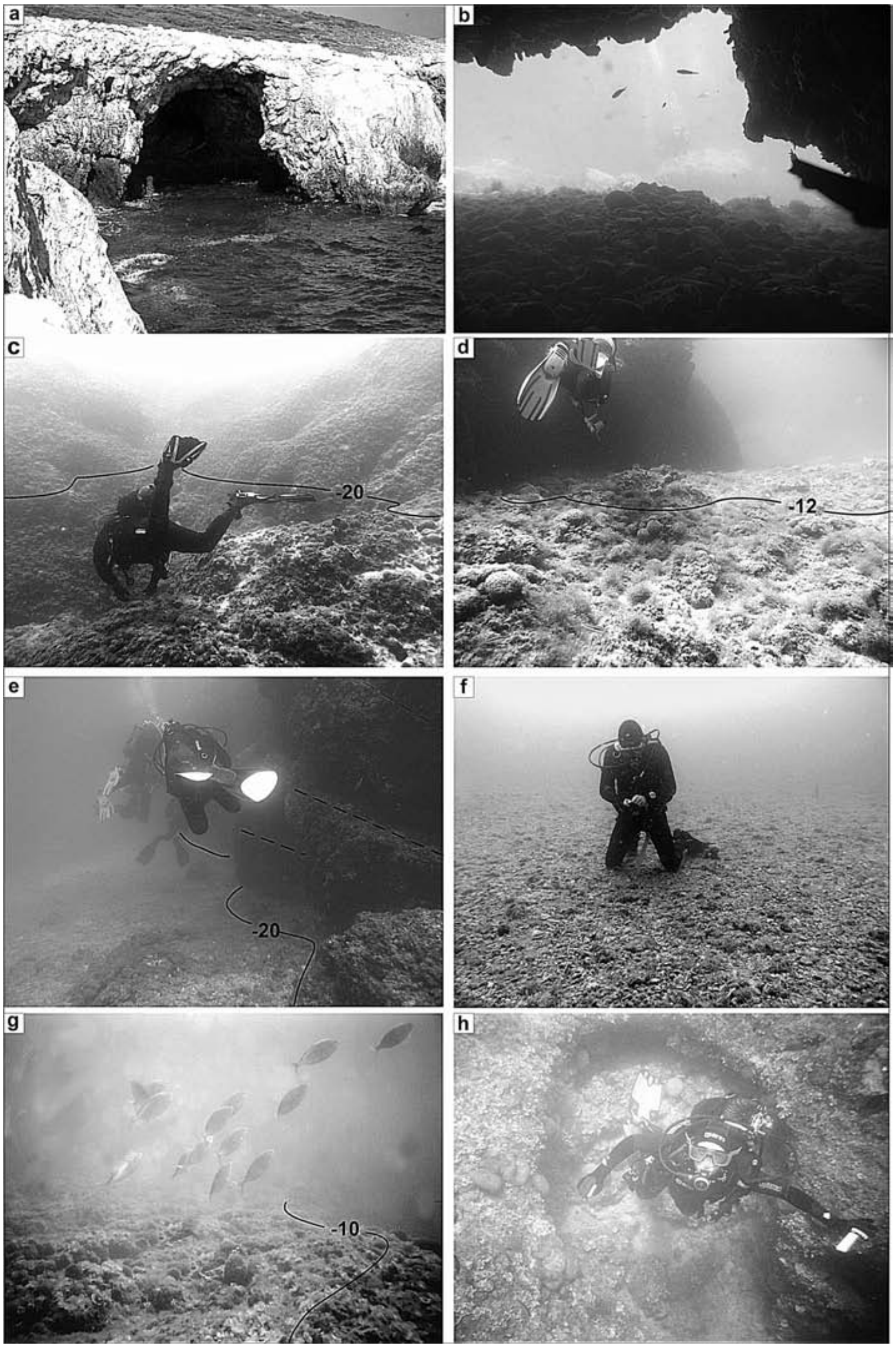

FIG. 6 - Submerged landforms surveyed by scuba-dive observations (numbers indicates depth). a-San Domino island, cave at sea-level extending down to 8 m b.s.l. b-San Domino island, submerged cave at 10 m b.s.l. c-Capraia island, incisions and erosional features, between sea-level and about 20 m b.s.l. d-San Domino island, detritic fan with centimetric and decimetric calcareous elements, sub-rounded, fossilized by algal fouling. Fan top is located at about 8 m b.s.l.; the base lies on the flat surface at 20 m b.s.l. e-Capraia island, inner margin of flat surface observed by bathymetrical analysis, at about 20 m b.s.l. f-Capraia island, flat surface developed between 20 and 25 m b.s.l. g-Capraia island, shore platform at 8 m b.s.l. h-Metric sub-rounded coastal rockpools, at 8 m b.s.l.

caves are linked to pronounced channels incised on the carbonate bedrock, down to the flat area at 20-25 m b.s.l. Other submerged caves are located along main subvertical rocky scarps between the main flat surfaces, at depth ranges of 8-18 m and 25-45 m b.s.l. (fig. 6b). Most of them have small entrance and are mostly developed in the first 25 m of length, without wide hall. In some cases vertical sections are present up to 5-6 m long. Bottoms of caves located at 8-18 m b.s.l. have centimetre-size rounded pebbles coverage, overlaid by pelitic deposits towards the inner part. The deepest cave bottoms (25-45 m b.s.l.) show a prevailing pelitic deposits coverage.

Scuba diving survey allowed for analysing fluvial landforms already defined by side scan sonar. Some pronounced incisions and erosive channels slope down from the sea-level and appear to be connected to linear incisions in emerged areas (fig. 6c). Towards the lower termination, they are characterized by alluvial fans, constituted by decimetre-size sub-angular pebbles and cobbles, generally fossilized by algal fouling coverage (fig. 6d). Alluvial fans lie on the inner part of the wide flat surface at 20-25 m b.s.l.. Fluvial incisions affect also slopes and scarps between 20-25 m and 50-55 m b.s.l. and those below 50-55 m b.s.l.

The direct survey allowed for defining as shore platforms the three flat surfaces outlined by bathymetric analysis. The flat surface at 20-25 m b.s.l. is covered by gravelly and sandy deposits (fig. 6f) and by alluvial fans (see also fig. 4, 5), with scattered carbonate bedrock outcrops. The inner margin is given by a subvertical or steep rocky scarps (fig. 6e). Locally, it is characterized by reefs sub-parallel to bathymetrical trend, morphologically similar to beach-rocks, characterized by a thick seaweed coverage, well outlined also by side scan sonar records (fig. 3f).

The shallower flat surface shows shore platforms edges located between 8 and 10 m b.s.l., with good inner margin bathymetric correlation and externally bounded by scarps with well defined or irregular and rounded edges (fig. 6g).

The deeper surface (50-55 m b.s.l.) is covered by sand and gravel deposits and is mostly bounded by rounded edges slightly incised by fluvial landforms.

Shore platforms surfaces appear to be strongly affected by small erosional landforms, circular coastal rockpools, with diameters varying from some decimeters to over one meter, often open towards deeper areas and connected to drainage channels and coastal erosion landforms (fig. 6h).

DISCUSSION

The present geomorphological setting of inner continental shelf of the Tremiti Islands archipelago is characterized by fluvial, karst and marine-coastal processes (fig. 7). The relationships between these processes and related landforms outline a complex landscape evolution resulting from alternate phases of continental and marine environment due to emersion and submersion periods.

Three flat surfaces identified as shore platforms characterize the north-western inner continental shelf at 8-10 m b.s.l., 20-25 m b.s.l., and 50-55 m b.s.l., while in the southeastern area are very narrow or absent (fig. 7, 8).

The shore platform at 20-25 m b.s.l. is generated by policyclic coastal and littoral processes and is consistent with paleo-shorelines evidences recognized in Mediterranean area at the same depth (Antonioli & Ferranti, 1996; Parroni & Silenzi, 1997; Mastronuzzi & Sansò, 1998; Antonioli & *alii*, 2004; Chiocci & *alii*, 2004; De Pippo & *alii*, 2004; Mastronuzzi & *alii*, 2007; Rovere & *alii*, 2011). Moreover, it is consistent with chronological attribution of littoral deposits, observed in two borehole along north-garganic coast, at 20-25 m b.s.l. and dated to mid Upper Pleistocene (Ricci Lucchi & *alii*, 2006). So, the shore platform at 20-25 m b.s.l. can be confidently attributed to mid Upper Pleistocene.

Shore platforms at 50-55 m b.s.l. and 8-10 m b.s.l. are due to further paleo sea-level during the Holocene rise, consistently with other studied sectors (Orrù & Ulzega, 1987; Colantoni & *alii*, 1990; De Pippo & *alii*, 2004; Mastronuzzi & Sansò, 1998).

The shore platform at 20-25 m b.s.l. cut the deepest SE-NW fluvial incisions and is itself covered by alluvial fans, while shore platforms at 50-55 m b.s.l. and 8-10 m b.s.l. cut all types of fluvial landforms that are preserved only along their edges or scarps (fig. 8). These cross relationships suggest a first phase of fluvial incision with the development of a SE-NW paleodrainage network during the late Middle Pleistocene sea-level lowstand, followed by coastal processes during Late Pleistocene sea-level highstand (particularly evident at ~20-25 m below the present sea level) and by a new phase of fluvial erosive-depositional processes occurred during Late Pleistocene sea-level lowstand. Landforms due to higher sea-level highstands (Tyrrhenian) are not identified and are not supposed to be preserved, mostly because of recent coastal erosional processes. Evidences of these processes and their timing come also from above sea level landforms and deposits, indicating that first fluvial incision predates the end of Middle Pleistocene while following phases postdate (Miccadei & *alii*, 2011).

The occurrence of tectonic landforms outlines NE-SW and E-W tectonic systems that displace and interrupt shore platforms integrity. These are mostly evident on 20-25 m b.s.l. shore platform and in some cases are correlated to faults on the above sea-level part of the islands. The geomorphological setting suggest the possible Late Pleistocene activation of NE-SW and E-W tectonic systems. These systems intersect the older one characterized by NW-SE to WNW-ESE orientation, related to main Neogenic-Quaternary orogenic stages (Montone & Funiciello, 1989; Brozzetti & *alii*, 2006). These features together with the strong asymmetry of the inner continental shelf (SE area steeper than NW one and with narrow shore platforms) suggest Late Pleistocene tectonics to induce a general lowering of the south-eastern area of the islands and the downthrown of the hilly landscape between the archipelago and the Gargano promontory, as hypothesized by Pasa (1953) and confirmed by surface landforms and deposits analysis (Miccadei & *alii*, 2011).

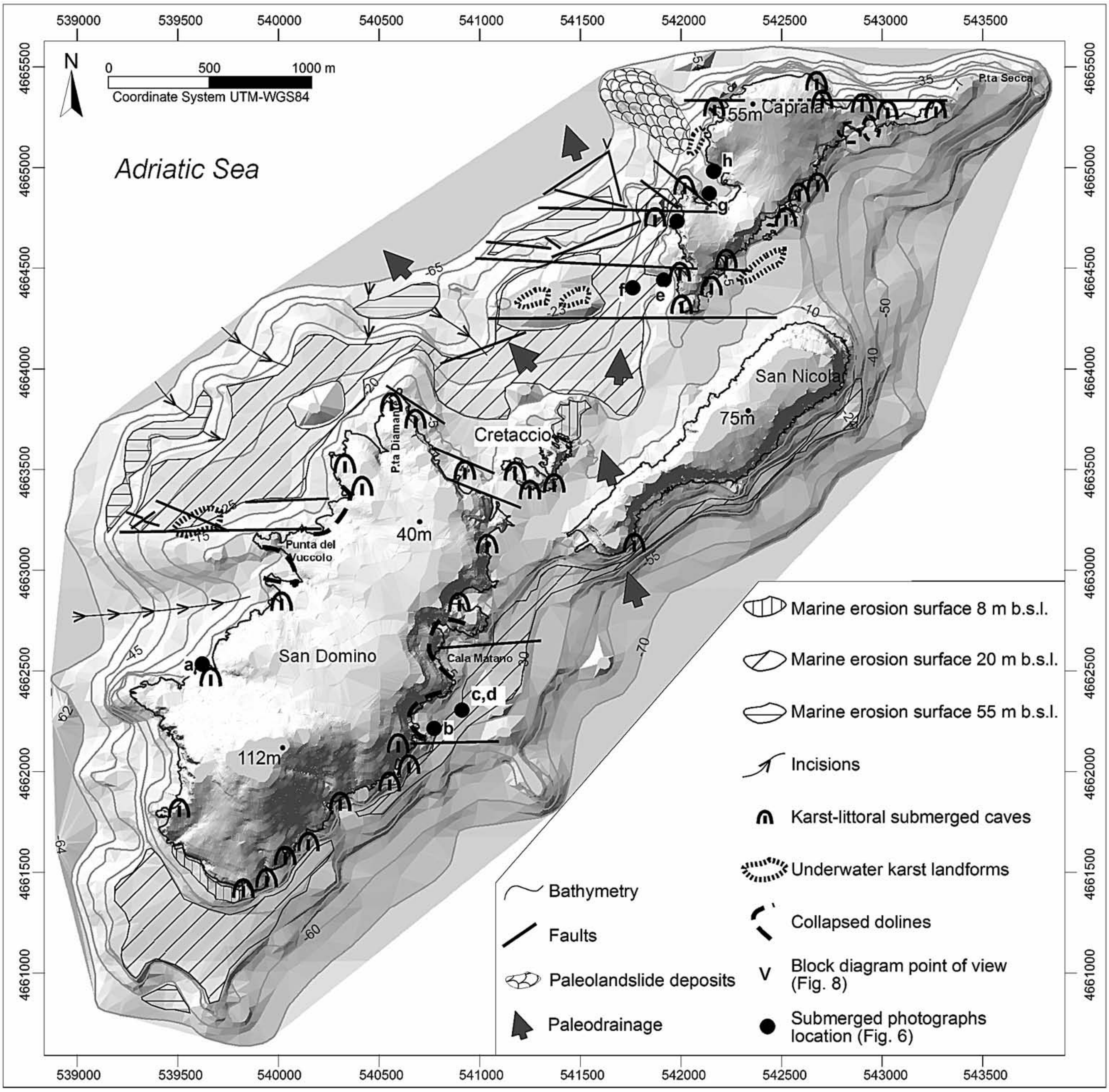

FIG. 7 - Geomorphlogical scheme of inner continental shelf of Tremiti Islands.

Caves and dolines are the result of several phases of karst activity starting from Eocene (Grassi, 1982; Cadara & Palmentola, 1993) and mostly developed along main tectonic discontinuities (fig. 7). Submerged karst landforms affect the shore platform at 20-25 m (fig. 8), suggesting the reactivation of karst processes during Late Pleistocene sea-level lowstand together with fluvial processes. This chronological attribution is also supported by the occurrence of karst landforms on early Upper Pleistocene calcretes in above sea-level areas, by the sealing of dolines with mid Upper Pleistocene aeolian deposits (Miccadei & *alii*, 2011), and by comparison with other continental shelf areas (Orrù & Ulzega, 1987; Antonioli & Vai, 2004). Finally, caves and dolines along the modern cliffs are affected by recent erosive marine and slope processes inducing rock fall and collapses (fig. 7).

A thin gravel and sand marine deposit covers Late Pleistocene landforms (fluvial and karst landforms, shore platforms) and is supposed to be deposited on the inner

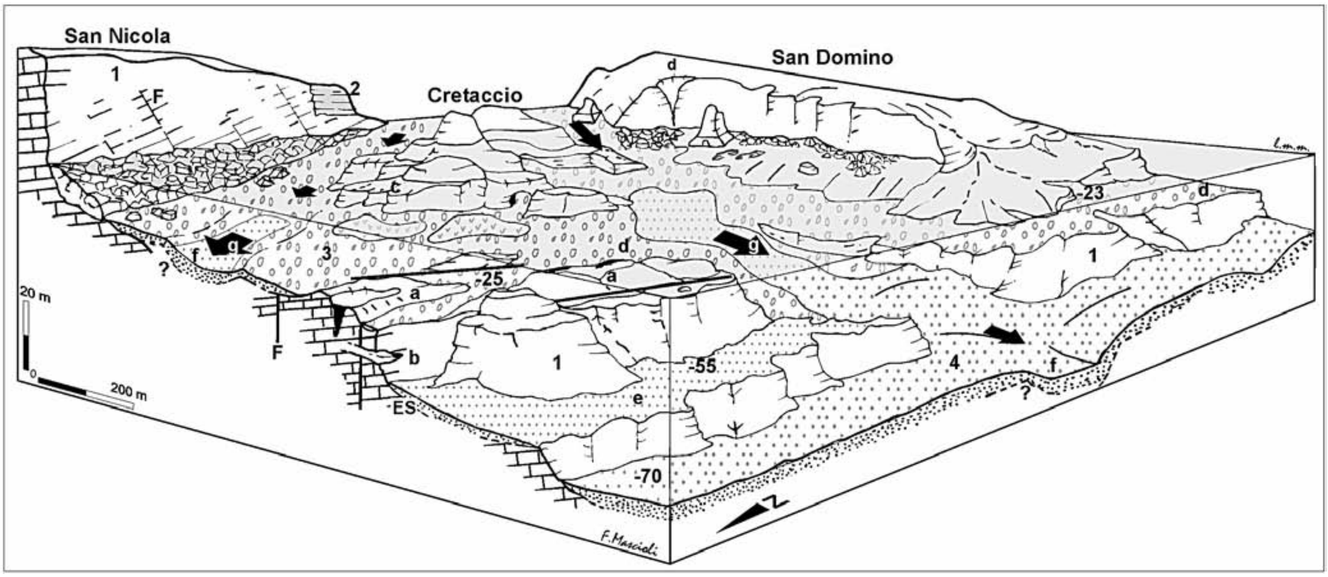

FIG. 8 - Block diagram of the area between San Domino and Capraia islands. *Lithology*: 1-Carbonate bedrock (Paleocene-Pliocene); 2-Conglomerates and paleosoils (Late Middle Pleistocene, Miccadei & *alii*, 2011); 3-Gravel deposits (Holocene); 4-Sand deposits (Holocene); ES-Erosive surface. *Tectonics*: F-Faults. *Landscape*: a-Karst dissolution landforms, dolines and minor depressions (Eocene-Upper Pleistocene); b-Karst littoral submerged caves (Eocene-Upper Pleistocene); c-Marine surface at 8-10 m b.s.l. (Holocene); d-Marine surface at 25-25 m b.s.l. (Upper Pleistocene); e-Marine surface at 50-55 m b.s.l. (Holocene); f-Incisions (Upper Pleistocene-Holocene); g-Paleodrainage (late Middle Pleistocene).

continental shelf in marine environment during Holocene sea-level rise.

CONCLUSIONS

The study of inner continental shelf point out a great spatial and temporal variability of marine, coastal, and continental (fluvial, karst, slope) geomorphological processes during Late Quaternary driven by tectonic and sea level fluctuations, and gives a contribution to reconstruct the Late Pleistocene landscape.

The widespread subaerial, coastal, and marine processes are due to alternate morphogenic phases driven by sea-level changes. Older subaerial phases consist of fluvial processes, generating a SE-NW paleodrainage network also controlled by pre-existing tectonic elements. Up to late Middle Pleistocene, this paleodrainage is related with a paleolandscape characterized by emerged areas extending towards SE, morphologically similar to calcareous and marly-calcarous hills, and connecting the Tremiti area to the Gargano area (Miccadei & *alii*, 2011). In the surrounding continental shelf, this phase is well documented by the erosive surfaces in the stratigraphic sequences of central-southern Adriatic structural high areas (Ridente & Trincardi, 2002).

A more recent fluvial phase is active during late Upper Pleistocene, according with other Italian areas (Orrù & Ulzega, 1987; Orrù & Pasquini, 1992; Mastronuzzi & Sansò, 1998). This causes the partial reactivation of late Middle Pleistocene pre-existing landforms and is testified by incisions extending from present sea-level to over 50 m below present sea-level and alluvial fans developed on the flat surface at 20-25 m below present sea-level. The paleolandscape at this time is characterized by a greater extent of emerged areas, with a hilly paleogeography; the paleoshoreline is located towards the NW, due to a paleo sea-level ~140 m lower than the actual one (Waelbroeck & *alii*, 2002). The hilly landscape is affected by several major and minor karst landforms and by a E-W, SE-NW and S-N drainage system (fig. 9).

Finally the landscape evolution of the Tremiti Islands archipelago can be summarized in the following steps, taking into account the geomorphological features of the inner continental shelf analysed in this work and the geomorphology of above sea level areas:

– hilly landscape connecting the Tremiti area to the Gargano promontory area during the late Middle Pleistocene sea-level lowstand; SW-NE fluvial incisions and karst processes affecting this landscape, controlled by pre-existing tectonic elements, testified by landforms on the modern inner continental shelf area;
– marine and coastal landscape after the last interglacial sea-level highstand (Late Pleistocene); coastal processes forming the shore platform now at 20-25 m b.s.l. and local landslides; tectonics also affects the area along SW-NE and E-W fault systems; this process has downthrown the SE areas between Tremiti Islands and Gargano area (Miccadei & *alii*, 2011);
– hilly landscape during the Late Pleistocene sea-level lowstand, with elevation up to 250 m a.s.l. and again connection to the Gargano area (fig. 9); new fluvial processes development with local reactivation of the previous

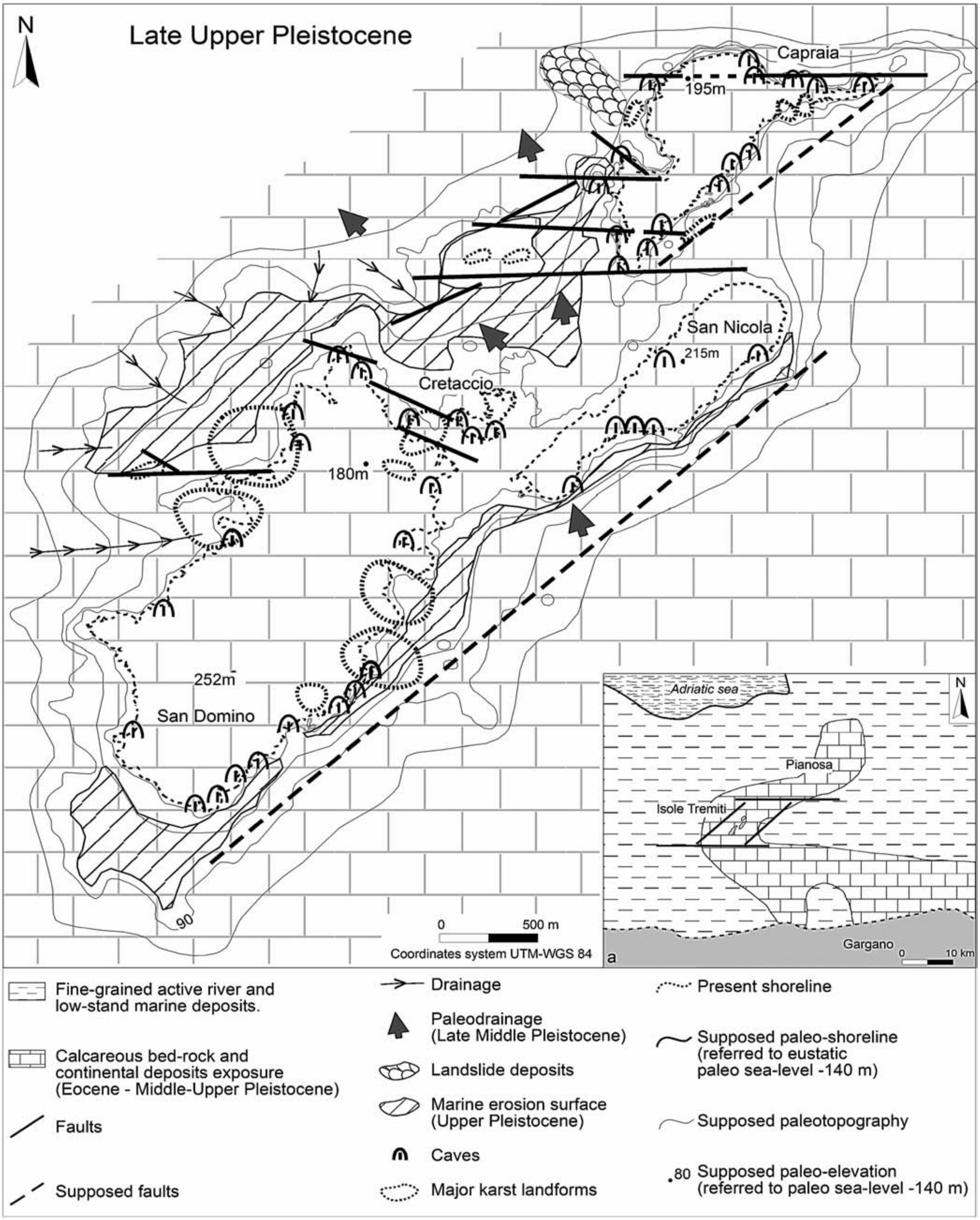

FIG. 9 - Reconstruction of Tremiti Islands paleolandscape during late Upper Pleistocene. a-Paleolandscape of northern Gargano area (from Antonioli & Vai, 2004).

incisions and development of alluvial fans on the shore platform now at 20-25 m b.s.l.; partial filling of karst landforms;
– coastal and marine landscape during the Late Pleistocene sea-level rise; incision of shore platform at 50-55 m b.s.l. and at 8-10 m b.s.l.; sealing of karst landforms with coastal and marine deposits;
– modern landscape mostly affected by coastal and slope processes inducing incision and collapsing of previous fluvial and karst landforms, cliffs retreat, and formation pocket beaches.

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(Ms. received 31 December 2010; accepted 30 June 2011)