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CONTRIBUTION FROM THE STUDY OF ANCIENT SHORELINES TO UNDERSTANDING THE RECENT VERTICAL MOTIONS. FIELD TRIP ACROSS THE MESSINA STRAITS.

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NEW DATA ON LATE HOLOCENE UPLIFT RATES IN THE MESSINA STRAIT AREA, ITALY

keywords: tectonic uplift, Holocene, relative sea-level change, Messina Strait, Calabria, Sicily

1. INTRODUCTION

In this study the results of recent geomorphological and stratigraphical surveys, new radiocarbon dating, palaeontological and sedimentological analysis and previous archaeological findings (Bidditu et al. 1979) are presented in order to highlight Holocene movements and estimate present uplift rates of the coastal areas along the northern part of the Messina Strait (M.S.) (Fig. 1).

The M.S. is located along a normal fault system that divides the Southern Calabrian block from the Northeastern Sicilian block within a dynamic crustal sector where destructive earthquakes, often associated with tsunamis, have occurred in recent and in historical times.

Pleistocene marine deposits and terraces together with active terrestrial and submarine normal fault systems in the Southern Calabria coast, in the northeastern part of Sicilian coast and in the M.S. have been the subject of detailed research (Ascenzi, Segre 1971; Bonfiglio 1972, 1983, 1991; Ghisetti et al. 1981, 1984, 1992; Barrier et al. 1986; Hearty et al. 1986; IGAL 1987; Fontes et al. 1987; Dumas et al. 1987, 1988, 1999; Valensise, Pantosti 1992; Westaway 1993; Miyauchi et al. 1994; Monaco et al. 1996; Balescu et al. 1997; Monaco, Tortorici 2000; Galli, Bosi 2002).

Marine deposits containing *Arctica islandica* (Lower Pleistocene) were found along the slopes of the Aspromonte Massif at 1,000 m above present sea level and beach remains of Late Pliocene were found at 1,250 m in the Peloritani Mts (Bonfiglio 1970). The MIS 5.5 terrace of 125 kyr, named "Tyrrhenian" in

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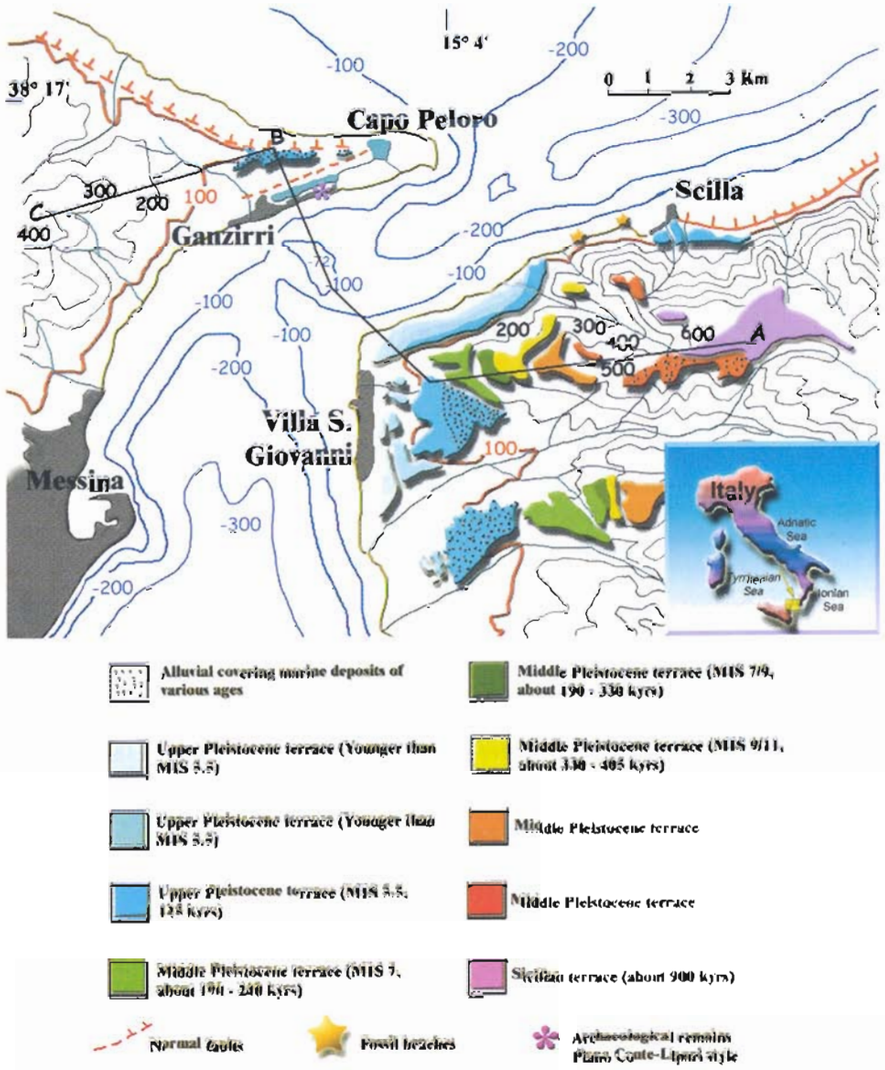

Fig. 1: Investigated area: topo-bathimetrical and terraces map, marine fossils and archaeological sites (redrawn after Bonfiglio, Violanti 1983 – sicilian side; Miyauchi et al. 1994 – calabrian side).

Mediterranean sea and marked by the presence of *Strombus bubonius*, is well carved and uplifted along the Tyrrhenian coast of Calabria (Bonfiglio 1972; Dai Pra et al. 1993; Miyauchi et al. 1994). The inner margin altitude above present sea level ranges between 160 m at Nocella (South of Reggio Calabria) and 160-125 m in the area of Villa S.Giovanni-Scilla (Miyauchi et al. 1994; Dumas et al.

1999). In the Northeastern part of the Sicilian coast the uplifted *Tyrrhenian* terrace is preserved in the Capo Peloro and Milazzo peninsulas. *Strombus bubonius* was found in the deposits of Capo Peloro at 85 m and the top of this marine depositional sequence is at about 95-100 m above sea level (Bonfiglio, Violanti 1983).

Holocene marine deposits and notches were found in Eastern Sicily, at Taormina, Capo St. Alessio, and Capo Milazzo (Bonfiglio 1981; Firth et al. 1996; Stewart et al. 1997; Rust, Kershaw 2001; Antonioli et al. 2003), and near Crotone in the Ionian side of the Calabrian coast (Pirazzoli et al. 1997). No Holocene dated deposits are reported up to now in the study area. Only within the littoral dune of Ganzirri ceramic tools of Holocene age have been discovered (Bidditu et al. 1979).

Geological and geophysical data show that the rapid uplift of North-Eastern Sicily and Southern Calabria and the subsidence of the M.S. during Quaternary time are related to an extensional stress field (Fig. 2) that coexists with a compressional stress field in the Ionian Sea, offshore from the Calabrian peninsula. These phenomena, associated with an intense seismic activity, are the result of the collision of African and Eurasian plates and of upper mantle doming (Ghisetti et al. 1984, 1992; Locardi, Nicolich 1988; Westaway 1993; Miyauchi et al. 1994; Tortorici et al. 1995; Jacques et al. 2001; Gvirtzman, Nur 2001, Doglioni et al. 2001, Oldow et al. 2002).

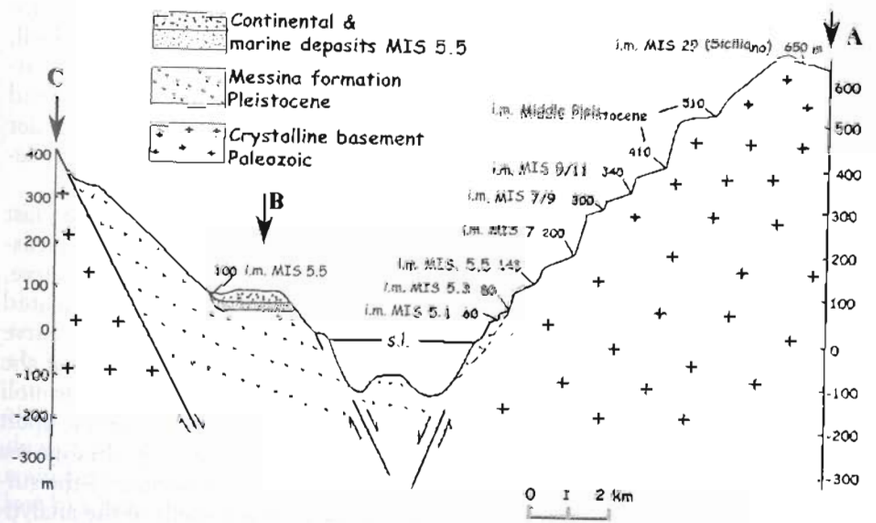

Fig. 2: Schematic geomorphological section across the Northern part of the M.S. (see Fig. 1 for location; redrawn after Bonfiglio, Violanti 1983 – sicilian side; Miyauchi et al. 1994 – calabrian side). The altitude of the terraces inner margins (i.m.) is shown.

2. METHODOLOGY

As mentioned above, several studies focused on deposits and morphology related to the last interglacial and older MIS were performed in North-Eastern Sicily and in South Calabria. The situation is different for Holocene deposits: no data have been reported up to now in the investigated area, the Sicilian and Calabrian coasts along the Northern part of M.S. (Ganzirri-Capo Peloro, Scilla-S.Giovanni; Fig. 1), with the exception of the archaeological discovery in the Ganzirri littoral dune. It is important to stress that the Southern coast of Calabria and the northeastern coast of Sicily are easily eroded as a consequence of the outcropping lithologies and of the steep sea cliffs. Moreover, the Capo Peloro peninsula has a very high density of houses on the littoral dunes that border the two lagoons. These situations are not favourable to the preservation of marine fossils and archaeological remains and therefore to the geological research on Holocene deposits. So, we have focused our attention on some particular conservative and low energy coastal areas as caves and gulfs along the coast south-westward of Scilla (Calabrian side). All surveyed sites have been investigated also underwater; sea-floor features were mapped with the aim of providing an outline of the depth and morphology of the seafloor. Besides the data collected in the Calabrian coast, new geomorphological and stratigraphic data together with previous archaeological findings in the Capo Peloro Peninsula are analysed with the aim of determining the recent geodynamical evolution of this part of the Sicilian coast (Figs. 1, 2).

Any sea-level marker indicates a relative level, which can be somewhat different from the global eustatic sea-level, the difference being linked to glacio-hydro-isostatic re-adjustments and tectonic movements (Lambeck and Chappell, 2001). However, at mid and low latitude sites (so-called intermediate and far-field sites relative to the glacial ice sheets), the difference between global and local sea-level is relatively small, on the order of some metres. These second-order effects can be evaluated using geophysical models as published from central Mediterranean sea by Lambeck, Jhonston (1995) and Lambeck, Bard (2000).

In order to relate the study area to the eustatic sea level change during last 5 ka cal BP, we have used the sea level curve of Morhange et al. (2001), measured for the North Tyrrenian sea - Cote d'Azur, Marseille (Fig. 3). This curve, obtained by radiocarbon age of observed data (biological indicators), as stated by the Authors, is in good agreement with the Lambeck predicted sea level curve calculated for Marsiglia. Fig. 10 of Lambeck and Bard (2000) shows that the palaeoisobaths are constant from Marsiglia down to Calabria. Again, Antonioli et al. (2003) have successfully used this curve to produce Holocenic tectonic uplift ratea on the eastern coast of Sicily. In synthesis, we think that the Mohrange sea level curve can be applied with confidence to Southern Italy because: *i* the surveying methodologies are similar, employing dated marine shells; *ii* the analytical techniques and calibrations are the same (^{14}C program by Stuiver et al. 1998); *iii* the glacio-hydro-isostasy corrections are similar in the tectonically stable Cote d'Azur and in the dynamic Messina Strait area.

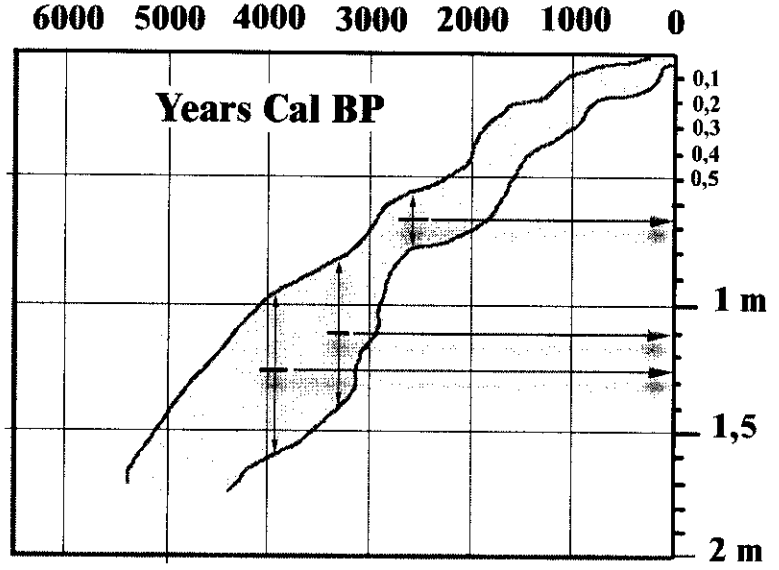

Fig 3: Sea-level curve showing data produced by Morhange et al. (2001). The Authors used marine fauna fixed upon archaeological structures as well as bio-sedimentary units in the ancient harbour of Marseilles, Southern France; the black lines enclose 31 data with error bars. Horizontal bars indicate Scilla site 2 ^{14}C datings that are related to the palaeo sea level (the arrows indicate the error margins of the paleosealevel). Data on palaeo sea level are used to calculate the effective uplift of Scilla marine fossils.

3. SCILLA LOCALITIES AND DATED MATERIALS

In the coastal area south-west of Scilla three sites showing uplifted marine deposits with shells between 2 and 4 metres above present sea level were found (Fig. 4).

Site 1. A well cemented sandy deposit at the foot of a steep slope marked by the presence of boulders has been surveyed (Fig 5). The deposit containing abundant fossil shells is located inside a little cave surrounded by large boulders at an altitude between 2 and 4 m above present sea level and has a variable thickness of 4-6 cm. The sedimentological features, the palaeontological content of the encrusting fauna and the good preservation of the morphology of shells (Fig. 6), often with coloured pigmentation, suggest that the fossils are an "in situ sediment" deposited in a medium energy infralittoral environment not deeper than -5\-10 m (Fig. 7). Such hypothesis excludes an external fringing deposit transported by sea-waves. In detail, the relevant number of centimetric, rounded pebbles often associated with unrounded continental debris flows with low bioclastic debris (Fig. 8) indicate that the sedimentation occurred nearby the coastline. The ^{14}C dated shells were collected between 3-3.4 m above present sea level and the following species have been identified: *Glycymeris violacescens, Triarca lactea, Spondylus sp., Hexaplex trunculus, Arca noae* (Fig. 6).

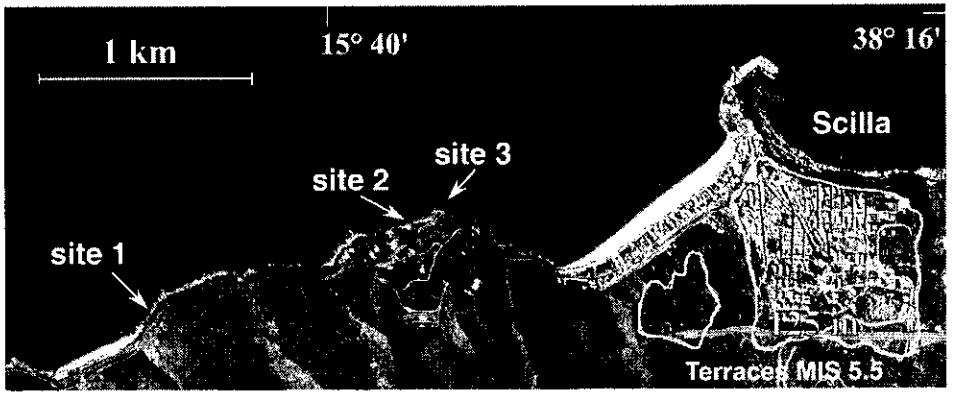

Fig. 4: Site 1,2,3. Locations of the sites where ^{14}C dated marine fossils were found. The Tyrrhenian terrace (MIS 5.5) showing an inner margin at an altitude between 120 and 125 m near Scilla is mapped.

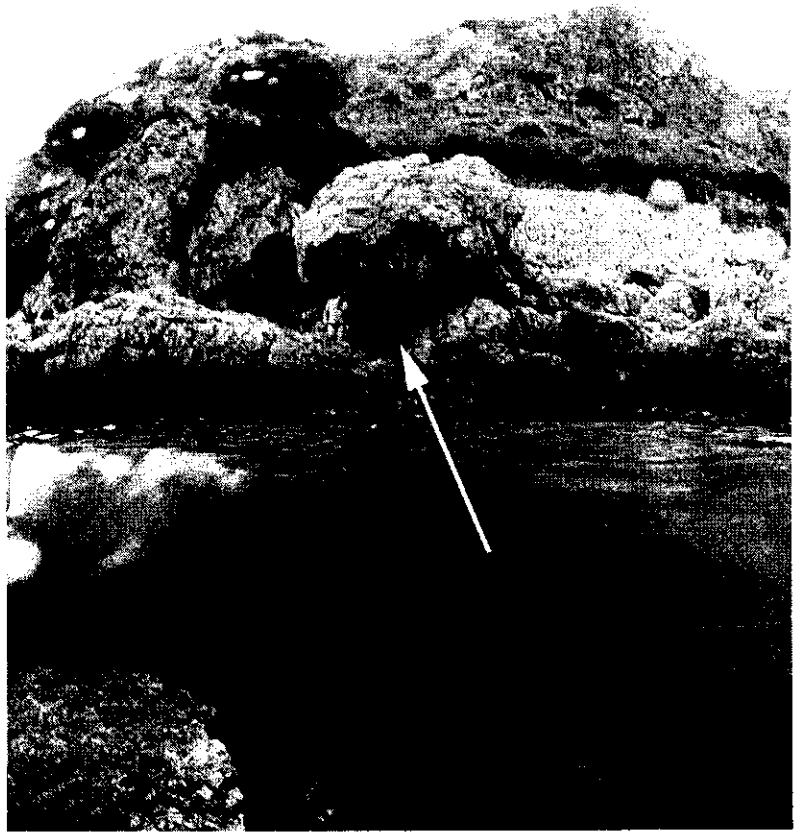

Fig. 5: The photograph shows the location (arrow) of the fossiliferous outcrop of site 1, that is protected by a big boulder of pre-holocene landslide origin. The submarine part of the photo shows how big boulders lie on the sea floor and protect the coast from sea storms.

Fig. 6: Detail of the outcrop of fig. 5: an *Arca noae* shell covered by the flowstone deposit that allowed the conservation of the entire fossil beach.

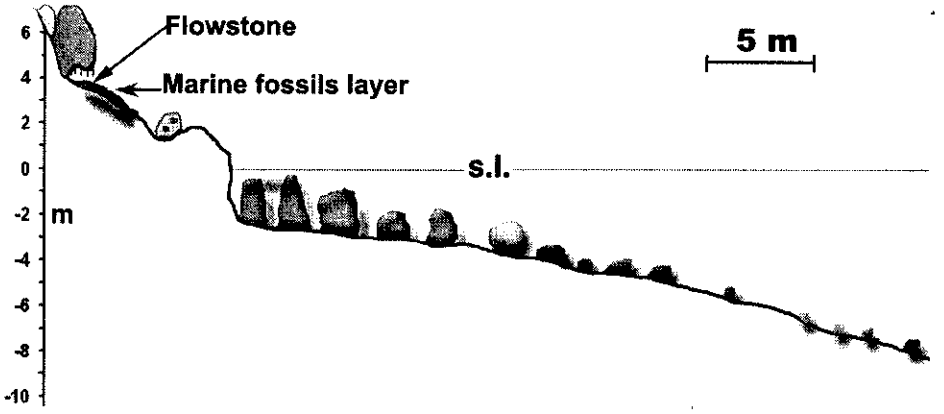

Fig. 7: Section of site 1: some particular stratigraphical and morphological features are pointed out.

The fossil sandy deposit extinguishes inside the cave and is partially covered by a flowstone originated by small speleothems located on the top of the small cave (Fig. 7). This flowstone allowed the preservation of the beach. Considering the mineralogical composition of the metamorphic rocks, the carbonate was directly precipitated by meteoric water. The radiocarbon age of this flowstone (1.9 ka BP) is younger than the marine shells age that show ^{14}C ages ranging between 2.7 and 3.9 ka +/- 150 cal BP.

In the same site some boulders of the dimension of about 6-10 m^3 with many shells of *Vermetids, Serpulids* and corals (*Parazoanthus*) encrusted on the whole boulder surface, were detected in living position immediately below the fossil deposit at an altitude of about 1-2m above present sea-level.

Site 2. A wave cut platform developed on the metamorphic basement located between 1.8 and 2.7 m above present sea level has been surveyed. The surface of this platform is often carved by fossil cobbles with a maximum depth of 50 cm filled of sandy fossiliferous sediments (Fig. 9). In the inner portion of one of the reworked cobbles, at 2 metres of height, a well cemented sandy deposit with fossil shells - *Cyprea*, *Arca*, and *Spondylus* was discovered. A sandy deposit without fossils, of the same colour and granulometry of that above mentioned, was found in thin lenses, about 1 cm thick, up to the height of 2.3 metres (Fig. 10). A ^{14}C dated shell (2.4 ka cal BP) of *Spondylus sp.,* was collected at 2 m above present sea level.

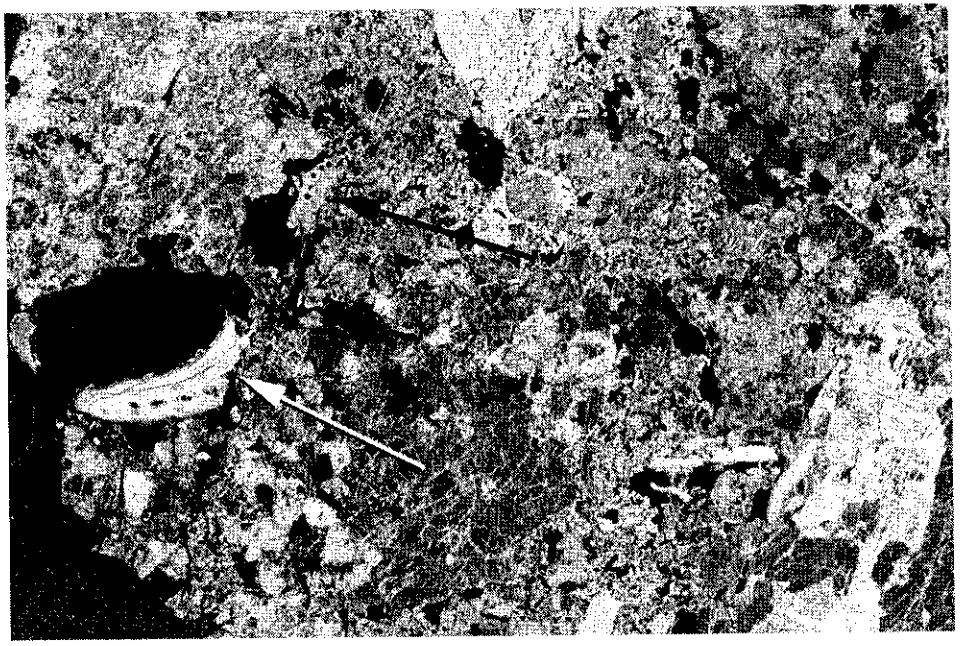

Fig. 8: Thin section sampled at Site 1. The arrows show marine fossils.

Fig. 9: Site 2, uplifted marine reworked cobbless.

Two boulders with marine fossils lye on the cemented sandy deposit. The boulders, that reach a maximum volume of about 20 m^3 and – considering a density of 2.7 g/cm^2 – a weight of about 50 tons, are covered by fissile shells as *Vermetids, Serpulids,* and corals (*Parazoanthus*) showing a fresh appearance, suggesting that they were completely submerged and subsequently were transported and deposited above the sea level.

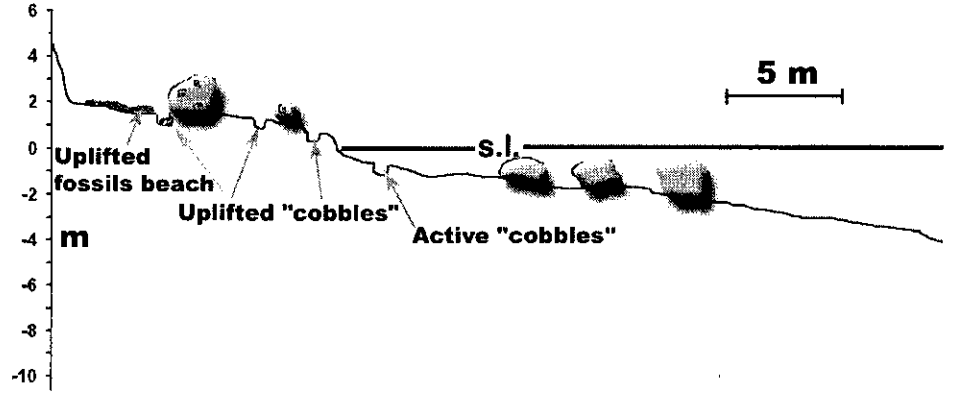

Fig. 10: Section of site 2, some particular stratigraphic and morphological features are pointed out.

Site 3. This is located on the western slope that delimits the wide gulf of Scilla in a very steep portion of the coast with a deep sea-floor. Here a small cave was investigated. Inside the cave at 1.4 metres above present sea level a white silty deposit with *Ostrea* and Foraminifera related to a deep environment was detected. A reworked *Ostrea* sampled at Site 3 reached an age near to the limit of dating methodology. The microscopic analysis of the sediment containing such *Ostrea* shows the presence of foraminifera, that indicate a deep water deposition (50-100 m), together with pebbles and fossils (like the *Ostrea*), that are related to input of debris from the surrounding steep slopes. Therefore, this sediment is considered to be older than Holocene. Similar sequences – without *Ostree* but with several marine fossils (corals) – outcrop in some fractures of the metamorphic bedrock in sites 1 and 2 up to 50 m of altitude.

4. Ganzirri localities and dated materials

The coastal area of Ganzirri is located in the Capo Peloro Peninsula, which is composed of three main physiographic units: 1. the Hills; 2. Faro Lake-Ganzirri Lagoon area that includes the ancient Margi saline; 3. Capo Peloro sand tongue (Fig. 11).

The littoral sand-dune associated with Ganzirri Lagoon has been dated by the presence of ceramics discovered during an excavation carried out in the 1970s under the direction of one of the Authors (A.G. Segre) (Figs. 12, 13, 14). The archaeological deposits are located at 3 m above present sea level, have lenses of charcoal and lie on a volcanic pumice layer. Unfortunately, the charcoal fragments were not sampled at the time of the excavation, and no ^{14}C dating is available, but the ceramics are identical with the well studied and ^{14}C dated Piano Conte style Lipari island ceramics, characteristic of the Eneolithical period (5.0 - 4.2 ka BP; see Alessio et al. 1966, 1980), and allow a determination of a reliable age of the containing deposits of 4,600 +/- 400 yr BP (Bidditu et al. 1979). The pumiceous layer just below the archaeological deposits is very thin – 5-10 cm of thick – has no particular sedimentary structure and is composed of sorted grey trachitical pebbles of 2-4 cm of diameter with scattered microsanidine crystals of Aeolian islands volcanic provenance. The stratigraphic position and geometry of the layer – a single horizontal layer lying directly on the marine sand just below the base of the continental sequence - and the absence of strong Aeolian volcanic eruptions with pyroclastic fallings that have destroyed human settlements in the Capo Peloro Peninsula during the Late Holocene (see Pichler 1980; Fagnani 1985), indicate that the pumice pebbles are not a primary pyroclastic deposit. The pumice pebbles were eroded from their primary depositional location, were transported by marine currents and were deposited by the sea-waves on the beach, just above the marine sand. These considerations suggest that the pumice layer marks a coastal zone located between the ancient palaeoshoreline and the limit of storm waves run up (due to the particular geographical location of this part of the Strait (Fig. 1) the limit is not higher than 1/1.5 m). The age - Eneolithical period - and the stratigraphic position of the ceramic fragments - at the base of the aeolian sand sequence, just above the pumiceous layer - supports the hypothesis that human settlement of the littoral dune took place after 5 ka BP when the continental sand was in the initial stage of accumulation and Ganzirri Lagoon was setting up.

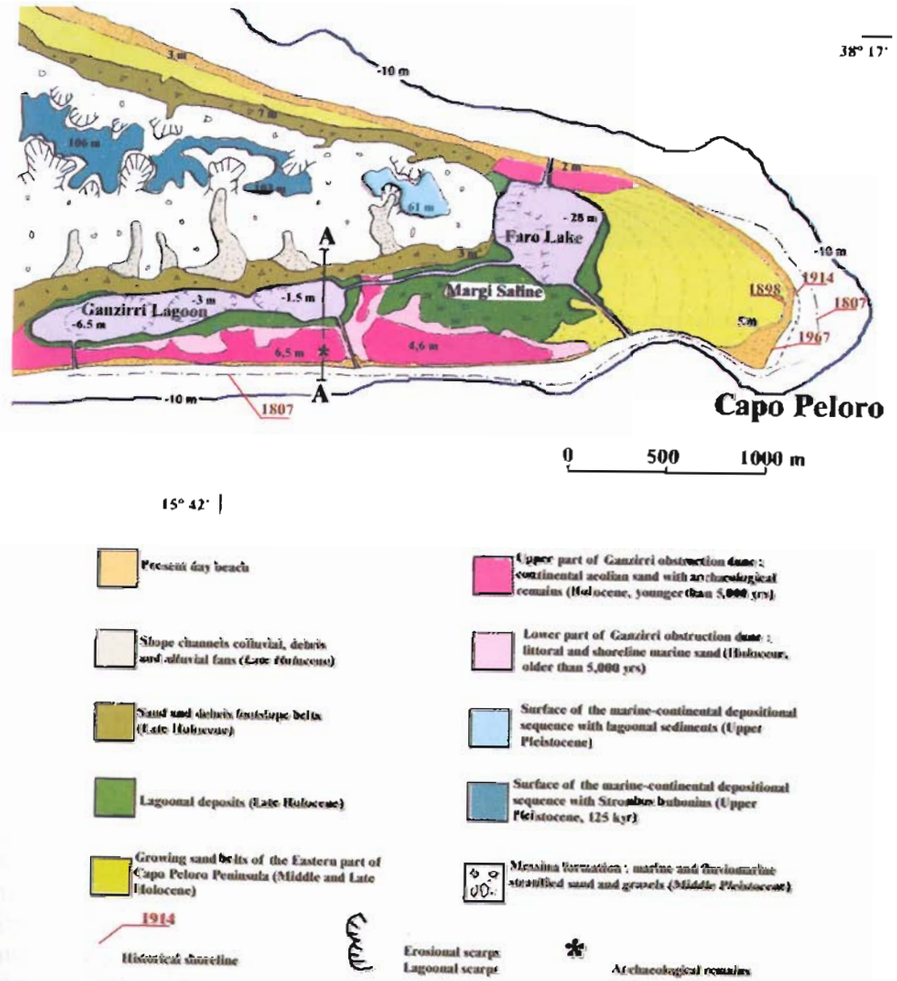

Fig 11: Geomorphological map of Capo Peloro Peninsula.
Note. The depositional sequences of the High Tyrrhenian and the Low Post-Tyrrhenian terraces evolve from marine (bottom) to continental (top) sediments, separated by an unconformity surface. The upper part of the Holocene littoral dune that borders Faro Lake in the eastern side is buried by Late Holocene growing sand belts. The archaeological fragments – ceramics of the *Piano Conte* style Lipari island (Eneolithical period 4,600 +/- 400) - are contained at the base of the continental sand dune - 3m of altitude – just above a pumice stones thin layer that lies on the marine sequence.

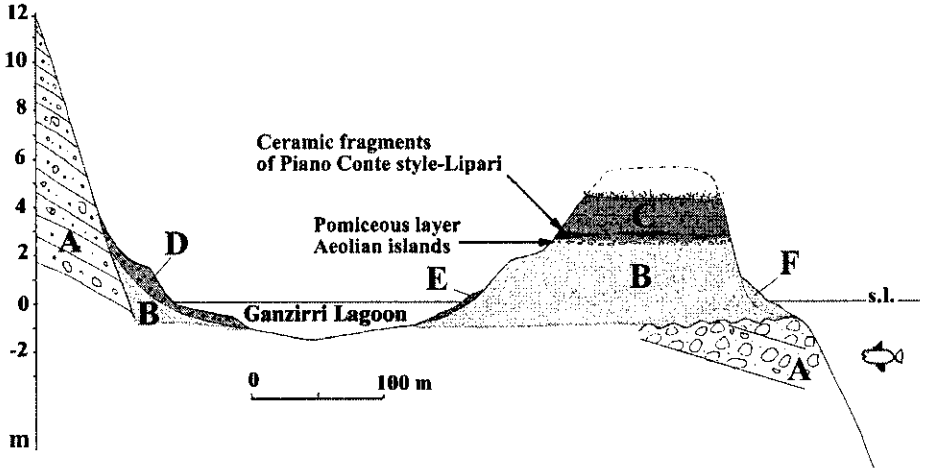

Fig. 12: Perpendicular section N-S of Capo Peloro Peninsula. A = Gravel and sand of the Messina formation (Middle Pleistocene); B = Marine sand (Holocene, older than 5,000 yr BP); C = Continental sand (Holocene, younger than 5,000 yr BP); D = Debris; E = Lagoonal deposits; F = present beach. The pumice layer is stylized, it does not cover the whole littoral dune.

Finally, during Late Holocene period, a concentric multiphase accumulation of littoral and aeolian sand around the eastern border of Faro Lake determined the development of the Capo Peloro tongue. In historical times the Capo Peloro shoreline has been subject to some variations (Fig. 11).

Fig. 13: Photograph of the section in the Ganzirri littoral dune, where the Lipari-Piano Conte ceramics was found in 1977. The top of the dune was erased before the excavation and nowadays is completely covered by houses.

Fig 14: Representative fragments of the Piano Conte – style Lipari island ceramics discovered within Ganzirri littoral dune.

5. MIS 5.5 HIGSTAND ALTITUDE

The overhanging hills Peloro head are marked by two well developed terraces: the High Terrace that reaches an altitude of about 110 m above present sea level and the Low Terrace at 60-65 m (Figs. 1, 2, 11). The High Terrace is attributed to MIS 5.5 (Tyrrhenian) for the presence of *Strombus bubonius* found at 86 m; marine deposits – littoral sand and gravels – are reported up to about 100 m and are covered by alluvial and colluvial red gravels (Bonfiglio, Violanti 1983). The age of the Post-Tyrrhenian low terrace, that is composed by marine and lagoonal deposits with *Ostrea-Tapes* shells association covered by red alluvial gravels, is not yet unequivocally known. Both Tyrrhenian and Post-Tyrrhenian stratigraphic sequences lie on an unconformity surface carved within Middle Pleistocene stratified marine-fluvial sand and gravels – the "Messina Formation" - S-SE dipping and delimited by E-W normal faults (Figs. 1, 2).

On the Calabrian side of the Messina Strait an impressive terrace aged MIS 5.5 by Miyauchi et al. 1994, is clearly visible at Scilla; the inner margin of this terrace has an altitude of 125 m (Figs. 1, 4).

6. Discussion

6.1 *Scilla uplift rates*

The beach fossil shells of the of Site 1 uplifted at about 3-3.4m of altitude above present sea-level have ages ranging between 2.7 and 3.9 ka cal BP. The fossil beach of Site 2 uplifted at 2.0 m have an age of 2.4 ka cal BP. The observed altitude of marine shells was corrected by use of Stuiver et al. (1998) calibration program. The maximum range of the semidiurnal tide at Reggio Calabria is 0.4 m. The depth of all submerged features and samples collected is measured relatively to present sea-level (BMSL), determined with a digital depth gauge (typical error ± 0.1 m). The relative sea level change was obtained by the Morhange et al. curve (2001) (Fig. 3, section 2).

If we assume that the ^{14}C dated shells were living in the proximity of the ancient shoreline we obtain uplift rates ranging between 1.2 and 1.4 mm a^{-1} (Tab. 1). This assumption is supported by a recent finding of impressive intertidal Balanids lines (*Balanus stellatus,* Ferranti et al. in progress) in Sites 1 and 2 and allows us to restrict the error bars related to the fact that the fossil shells are of infralittoral environment (living between 0 and -10m). The Balanids coastlines, that are located between 1.7 e 2.1 m of altitude and have ^{14}C ages of 1.8 and 2.3 ka cal BP, give uplift rates between 1.1 and 1.4 mm a^{-1} and confirm that the ^{14}C dated shells of Site 1 and Site 2 represent a precise coastline with low error bars.

SITE & Lab N°	Species	Elevation m	^{14}C Age	Calibrated ^{14}C ages 1σ	Relative sea level change m	Corrected Elevation m	Uplift rate mm\yrs
SITE 1 28045	*Spondylus*	3	2930±60	2668±164	0.7	3.7	1.4
SITE 1 28332	*Spondylus*	3.4	3450±40	3318±103	1.1	4.5	1.4
SITE 1 28331	*Hesaplex*	3.4	3930±40	3901±125	1.3	4.7	1.2
SITE 1 R2626	Flowstone	3.6-2	1936±56	1947±121	-	-	-
SITE 2 2625	*Spondylus*	2.0	2683±450	2370±105	0.6	2.6	1.2
SITE 3 R3521	*Ostrea*	-	39000 ±2000	over cal. limit	-	-	-

Table 1: Fossils species, observed elevation of fossils, ^{14}C and ^{14}C CAL age of Scilla fossils, corrected elevation, Scilla coast uplift rates. The GX sample are all AMS ^{14}C; the age determinations were provided by Geochron Laboratories, USA. The R3521 age was provided by Physics Dept. of Univ. of Rome. All samples were ^{13}C corrected. A reservoir age of 400 years was added taking into consideration the paper by Siani et al. (2000) that reported values for southern Italy. Observed elevation is relative to present sea level. Relative sea level change is referred to the age of the living shells and includes eustatic and isostasy components, see Morhange et al. sea level curve (Fig. 3).

In the three investigated coastal sites westward of Scilla a great number of boulders lye on the sea floor and several boulders outcrop above present sea level and are completely covered by fissile marine shells - *Vermetids, Serpulids, Parazoanthus* corals. The existence of marine organisms which are typical of an infra-littoral environment (1-10 m of depth) encrusted on the sub-aerial boulders and their extremely recent radiocarbon calibrated ages - between present day (1950) and 813 yr BP (Tab.2), together with their position (10 m far and 2,3 m above present shoreline) and their dimension (20 m^3) and weight (50 tons), suggest that the boulders were transported by huge marine waves (or tsunamis) and were deposited above the present shoreline. For these reasons the ^{14}C dated shells encrusted on the boulders cannot be used for calculating the uplift rates of this part of the Calabrian coast.

SITE Lab N° GX	Species	Elevation m	^{14}C AMS Age	Calibrated ^{14}C ages 1σ	$\delta^{13}C_{PDB}$
SITE3 28041	*Parazoanthus*	1.2	106.63+/-0.53 pmc	Modern	-8.7
SITE2 28042	*Chthamalus*	2.0	1340+/-40	813±65	+0.8
SITE2 28043	*Vermetids*	1.5	420+/-40	160±50	-0.5
SITE2 28044	*Vermetids*	2.1	106.63+/-0.53 pmc	Modern	-1.1

Table 2: Ages and species of fossils sampled on the *not in situ* boulders.

6.2 *Ganzirri uplift rates*

The ceramic fragments and the stratigraphic sequence reported in the Ganzirri littoral dune (Figs. 12, 13, 14) allow to define a maximum value to the uplift rate of this part of Sicilian coastal area during Late Holocene. As mentioned (section 4), the ceramic has an archaeological age of 4,600 +/- 400 yr BP and is located at the base of the continental sand at an altitude of 3m, just above a pumiceous layer that marks a coastal zone located between the ancient palaeoshoreline and the limit of storm waves run up (0 + 1/1.5m). Such stratigraphy supports the hypothesis that early human settlements began to frequent the littoral dune when the continental sand was in the initial stage of accumulation and Ganzirri Lagoon was setting up and that these prehistoric men settled down in the proximity of the palaeoshoreline at a minimum altitude of 1m above the ancient sea level. By using these data and taking into account the sea level rise curve in the last 5 ka BP (about 2m, see Fig. 3), we obtain a maximum uplift of the coastal area of 4 m, which is the sum of the present + 3m altitude of the ceramics and of the sea level correction in the last 5 ka BP (1m, Fig. 15). Therefore, the maximum uplift rate is of 0.8 mm a^{-1}. This rate is comparable to the average sea level rise rate, 0.4 mm a^{-1} during the last 5 ka, which is considered the minimum uplift rate otherwise the area would have been submerged, and allows us to explain the formation and persistence of the lagoons, that implies a dynamic equilibrium with the sea level. In fact, if the uplift rate of the coastal

areas was much higher than the sea level rise rate, the brackish lagoons would have been filled up and extinguished or would have become fresh-water lakes.

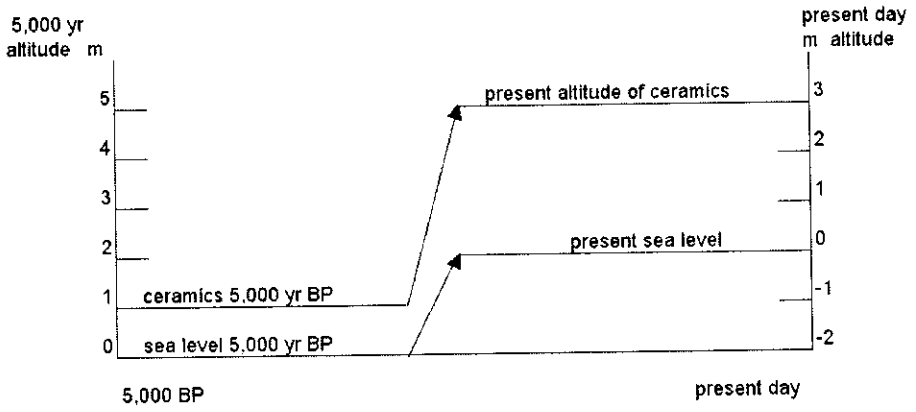

Fig 15: Sketch of the hypothesis of the sea level rise and tectonic movements during the last 5,000 yrs in the Ganzirri coastline. The altitude scales are referred to the 5,000 yr sea level (left) and present-day sea level (right). Sea level correction includes eustatic and isostatic components, see Morhange et al. sea level curve (Fig.3). The effective tectonic uplift (4m) is the sum of the altitude of the ceramics above present sea level (3m) and sea level correction in the last 5,000 yr BP (1m). The location of ceramics at + 1m at 5,000 yr BP is based on logical deduction that human settlement would not be lower than + 1m; see text for discussion.

6.3 *Tectonic uplift in the investigated area*

Our Calabrian Holocene uplift ratea are similar with the data of Balescu et al. (1997), who obtained a thermoluminescence age of 64 kyr on a sample from aeolian sand at 48 m of altitude near Villa S. Giovanni. Considering that 64 kyr ago the sea level was about -50\60 m below the present one (Lambeck et al. 2002) their uplift rate is of about 1.6 mm a^{-1}. On the contrary, the ^{14}C dates of 25 and 33 kyr (MIS 2 and 3) calculated by Fontes et al. (1987) on bivalves collected at Archi, Capo d'Armi and Bocale, near Reggio Calabria, at altitudes between 70 and 80 m above present sea level are doubtful, because if we were in presence of deposits related to MIS 2 at 70 m of altitude - in the MIS 2 the sea level was about 120 m below the present one - the uplift rate of the area would have been of about 6 mm a^{-1}, which is much higher than the regional uplift rate.

The Scilla average uplift rate of 1.2-1.4 mm a^{-1} in the last 4 ka BP likely represents the highest uplift rate operating over recent times in the Scilla coast if we consider that here the MIS 5.5 inner margin has been located at altitudes of 125 m Miyauchi et al. (1994), therefore the average uplift rate since the last interglacial has been estimated of about 1 mm a^{-1} (Figs. 1 and 2). On the contrary, in the Capo Peloro Peninsula the uplift rate seems to be quite constant during the last 125 kyr. In fact, the inner margin of the marine Tyrrhenian deposits with *Strombus bubonius* is located at about 100m of altitude and, therefore, the average uplift rate in the last 125 kyr is of 0.8 mm a^{-1}. The Holocene deposits, that contain ceramic fragments of 4,600 +/- 400 yr BP at an altitude of 3 m above present sea level, show a maximum uplift rate of 0.8 mm a^{-1} (the minimum rate during Holocene is assumed to be equal to the sea level rise: 2 m in the last 5 kyr - 0.4 mm a^{-1}).

The acceleration of the uplift rate in the Late Holocene has been documented also in the area of Taormina, 60 km south of Capo Peloro Peninsula, where Antonioli et al. (2003) pointed out that the uplift over the past 6 ka has been proceeding at an average of 1.3-1.4 mm a^{-1}, while, over a longer time period, from the MIS 5.5 to present day, the uplift rate has been slower, about 1 mm a^{-1}.

In the Calabrian coast south west of Scilla (Site 1) the dated marine shells at 2-3.4 m (2.4-3.9 ka cal BP) and the fossil beach extending between 2 and 4 m above present sea-level suggest the absence of rapid co-seismic uplift, because granulometry, species characteristic - lower mesolittoral biocenosis - and sedimentary structure gradually developed during a slow and continuous uplifting phase.

The regional a-seismic uplift is associated with normal faulting that induces a remarkable local subsidence often of a co-seismic type. Valensise and Pantosti (1992) considered the ground deformations that occurred during the 1908 Messina earthquake as the effects of a co-seismic subsidence related to normal faulting activity.

Triangulation measurements (Caputo et al. 1981) and precision levelings (Mulargia et al. 1984), as well as seismological models (Amoruso et al. 2002), have demonstrated that a slow (a-seismic) subsidence of about 1 mm a^{-1} along the submarine axis of the Strait is taking place in recent times and is predicted in the near future. These observations support the hypothesis that Messina Strait comprises a discontinuity of the regional uplift dynamics and can be considered a subsiding graben.

7. Conclusions

The main result of this investigation is the discovering of Holocene uplifted marine deposits in the calabrian coast south-westward of Scilla. Three sites with uplifted marine shells were surveyed and dated by radiocarbon. In two fossil beaches between 2 and 4 m above present sea-level, marine shells collected at 2-3.4 m have ages ranging between 2.4 and 3.9 ka cal BP. The new Holocene data on the coast between Villa S.Giovanni and Scilla, together with Mohrange et al. (2001) sea level curve, demonstrate that the tectonic uplift over the past 2.4 – 3.9 ka has proceeded at an average rate of 1.2-1.4 mm a^{-1}. This rate, calculated assuming that the uplifted fossil shells represented a precise coastline, has been confirmed by the uplift rates obtained on ^{14}C dated intertidal balanids

lines. The comparison of the new Holocene uplift rates with the long term MIS 5.5 higstand (1.0 mm a^{-1}) shows that the uplift of this part of the Calabrian coast has been subject to an acceleration during the last 4 ka.

In the Ganzirri littoral dune (Sicily), ceramics fragments of Piano Conte style-Lipari island of the Eneolithical period - 4,600 +/- 400 yr BP - were found at the base of the continental sand sequence, 3.0 m, just above a pumice layer related to an ancient shoreline. Archaeological and stratigraphic data are used to calculate a maximum tectonic uplift rate of the Ganzirri coastal area of 0.8 mm a^{-1} , being the minimum rate equal to the sea level rise - 0.4 mm a^{-1} - in the last 5 ka BP.

Ganzirri Holocene maximum uplift rate is comparable to the MIS 5.5 average rate (0.8 mm a^{-1}) of Capo Peloro Peninsula but is lower than the uplift rates of Scilla coast during the last 4 ka (1.2-1.4 mm a^{-1}) and in the last 125 ka (about 1 mm a^{-1}).

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ABSTRACT

In the Scilla coast (Calabria), two uplifted fossil beaches between 2 and 4 m above present sea-level have been discovered. Radiocarbon dating of marine shells collected at 2-3.4 m gives ages ranging between 2.4 and 3.9 ka BP. The new ^{14}C dates and amended sea-level curve are used to show that in the coast of Scilla the tectonic uplift over the past 4 ka has been proceeding at an average rate of 1.2-1.4-mm a^{-1}. In the Ganzirri littoral dune (Sicily), ceramics fragments of Piano Conte style (Lipari island) of the Eneolithical period - 5.0 – 4.2 ka BP - were found at the base of the continental sand sequence at 3.0 m of altitude just above a pumice layer related to an ancient shoreline. Archaeological and stratigraphic data are used to calculate a maximum tectonic uplift rate of the Ganzirri coastal area of 0.8 mm a^{-1} , being the minimum rate equal to the sea level rise - 0.4 mm a^{-1} - in the last 5 ka.

The marine fossil shells of Punta Paci near Scilla and the archaeological remains of Ganzirri are the first evidence of Holocene uplift ever reported in the coasts along the Northern part of the Messina Strait. These data suggest that non-uniform (differential) uplift has affected Capo Peloro Peninsula (Sicily) and Scilla-Villa S. Giovanni coast (Calabria) in recent times.

RIASSUNTO

In questo lavoro vengono presentati i primi dati che dimostrano l'esistenza di un sollevamento tardo-olocenico che ha interessato la costa calabrese a SW di Scilla e la costa siciliana di Ganzirri, lungo la parte settentrionale dello Stretto di Messina. Il sollevamento non è uniforme ma è di natura differenziale poiché la sponda calabrese sembra mostrare un tasso maggiore (1,2-1,4 mm a^{-1}) rispetto a quello della sponda siciliana (0,4-0,8 mm a^{-1}) .

Nella costa calabrese nei dintorni di Punta Paci sono stati rilevati due siti caratterizzati da forme e da depositi di spiaggia ricchi di conchiglie fossili che testimoniano la presenza di livelli marini di età olocenica sollevati ad un'altezza di circa 2-3 m al di sopra del livello del mare attuale. In entrambi i siti sono state campionate e datate con il ^{14}C conchiglie fossili di ambiente infralittorale (viventi sino a profondità di circa 5-10 m). Le età ottenute con il radiocarbonio sono comprese tra 2,4 e 3,9 ka. Assumendo che le conchiglie vivessero in prossimità dell'antica linea di riva ed utilizzando la curva di risalita del livello del mare di Morhange et al. (2001) sono stati calcolati dei tassi di sollevamento pari a 1,2-1,4 mm a^{-1}. Questi tassi sono in accordo con quelli ricavati tramite due linee a balani (*Balanus stellatus*) recentemente rinvenute nei siti 1 e 2 ad altezze di 1,7 e 2,1 m e di età al ^{14}C di 1,8 e 2,3 ka (Ferranti et al., in progress). In entrambi i siti è stata rilevata anche la presenza di massi di grosse dimensioni con numerose conchiglie marine incrostate, la cui età al ^{14}C è risultata molto recente. I massi sono stati messi in relazione con grandi tempeste marine e per questo motivo non sono stati considerati rappresentativi della dinamica di questo settore crostale.

Nella costa siciliana non lontano dalla cittadina di Ganzirri, l'analisi della ceramica Eneolitica e della stratigrafia della duna litoranea, già messa in luce negli anni '70 durante una campagna di scavo coordinata da uno degli Autori, A.G. Segre, ha permesso di ricostruire l'evoluzione geodinamica di questo settore costiero negli ultimi 5.000 anni BP. L'esistenza dei depositi di sabbia continentale con ceramica attribuibile all'Eneolitico di facies Piano Conte (Isola di Lipari) a 3 m di altezza subito al di sopra di un livello di pomici riferibili ad un'antica linea di costa ha permesso di calcolare un tasso di sollevamento massimo per la fascia costiera di Ganzirri. Considerando che: *i.* gli uomini preistorici certamente non si potevano essere insediati ad un'altezza inferiore ad 1 m rispetto al livello del mare dell'epoca; *ii.* la ceramica oggi si trova ad un'altezza di 3m; *iii* negli ultimi 5.000 la risalita del livello del mare è stata di circa 2 m - si ottiene un sollevamento di 4m e quindi un tasso massimo di sollevamento di 0,8 mm a^{-1}. Il tasso minimo di sollevamento è pari al tasso di risalita del livello del mare: 0,4 mm a^{-1}.

L'analisi della geologia e della dinamica olocenica è stata accompagnata da un riesame della geomorfologia quaternaria e dell'assetto tettonico-strutturale della parte settentrionale dello Stretto di Messina al fine di poter meglio valutare i risultati scaturiti dai rilevamenti sui depositi recenti. Appare chiaro così che i movimenti differenziali tra le sponde siciliane e calabresi hanno avuto luogo anche negli ultimi 125 ka (MIS 5.5) e che il blocco siciliano ha un tasso di sollevamento inferiore ed è svincolato dal blocco calabrese tramite un sistema di faglie dirette lungo cui è impostato lo Stretto di Messina.