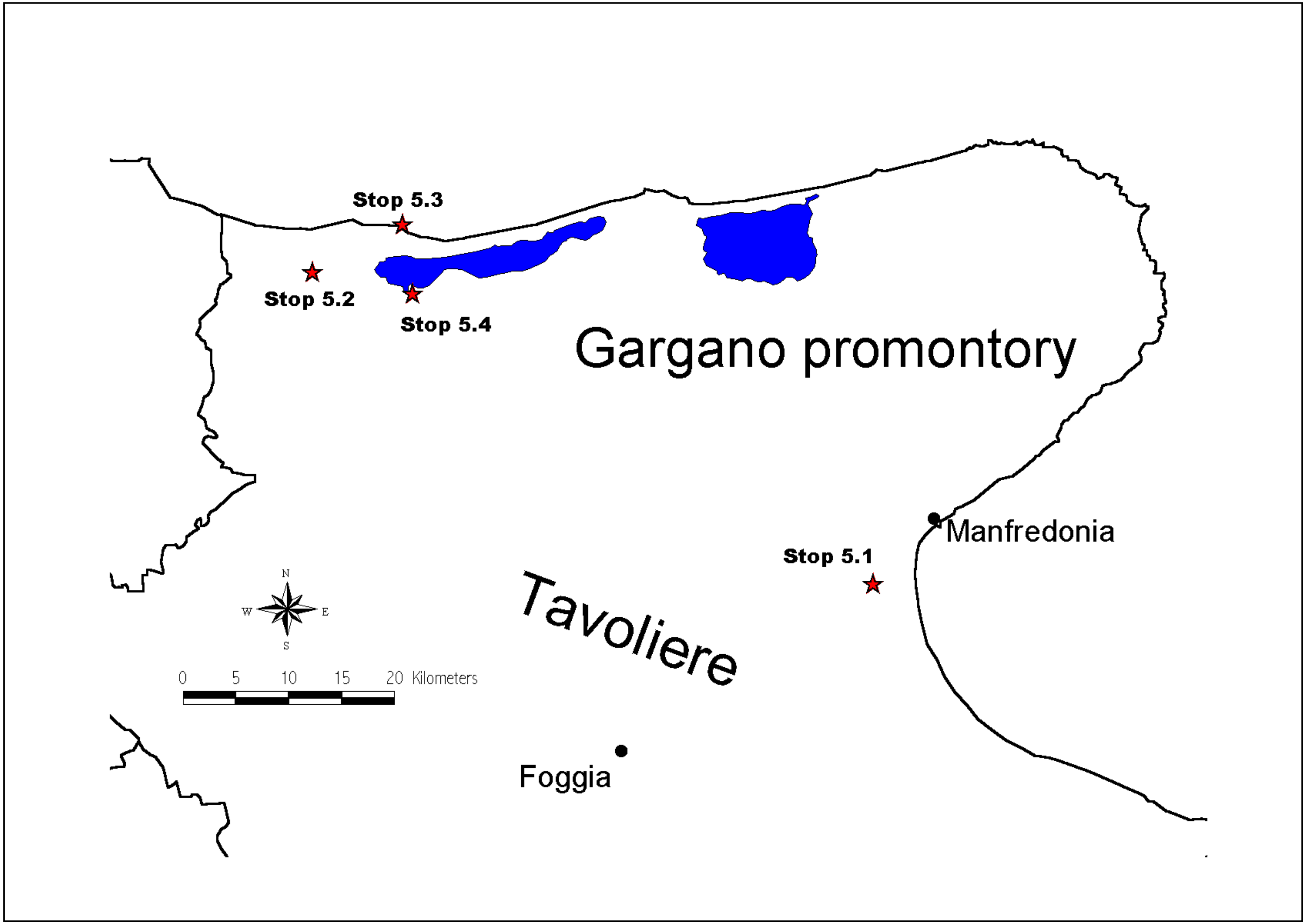
Stop 5.3
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Foggia

Puglia 2003 - Final Conference
Project IGCP 437

Coastal Environmental Change
During Sea-Level Highstands:
A Global Synthesis with implications
for management of future coastal change

Otranto / Taranto - Puglia (Italy) 22-28 September 2003
Quaternary coastal morphology and sea level changes

Project 437

5th day

The coastal plain of Tavoliere and of Fortore River

by

Caldara M., Cazzella A., Gianfreda F.,
Gravina A., Mastronuzzi G., Sansò P., Simone O.

Introduction

The fifth day of field trip run through the northern Puglia, crossing the alluvial plain of Tavoliere delle Puglie (cfr Cap. 1), which is the second costal plain in Italy as area (Fig. 5.1). It stretches at the foot of the Gargano promontory and of the Apulian part of Apennine chain, called Subappenino Dauno.

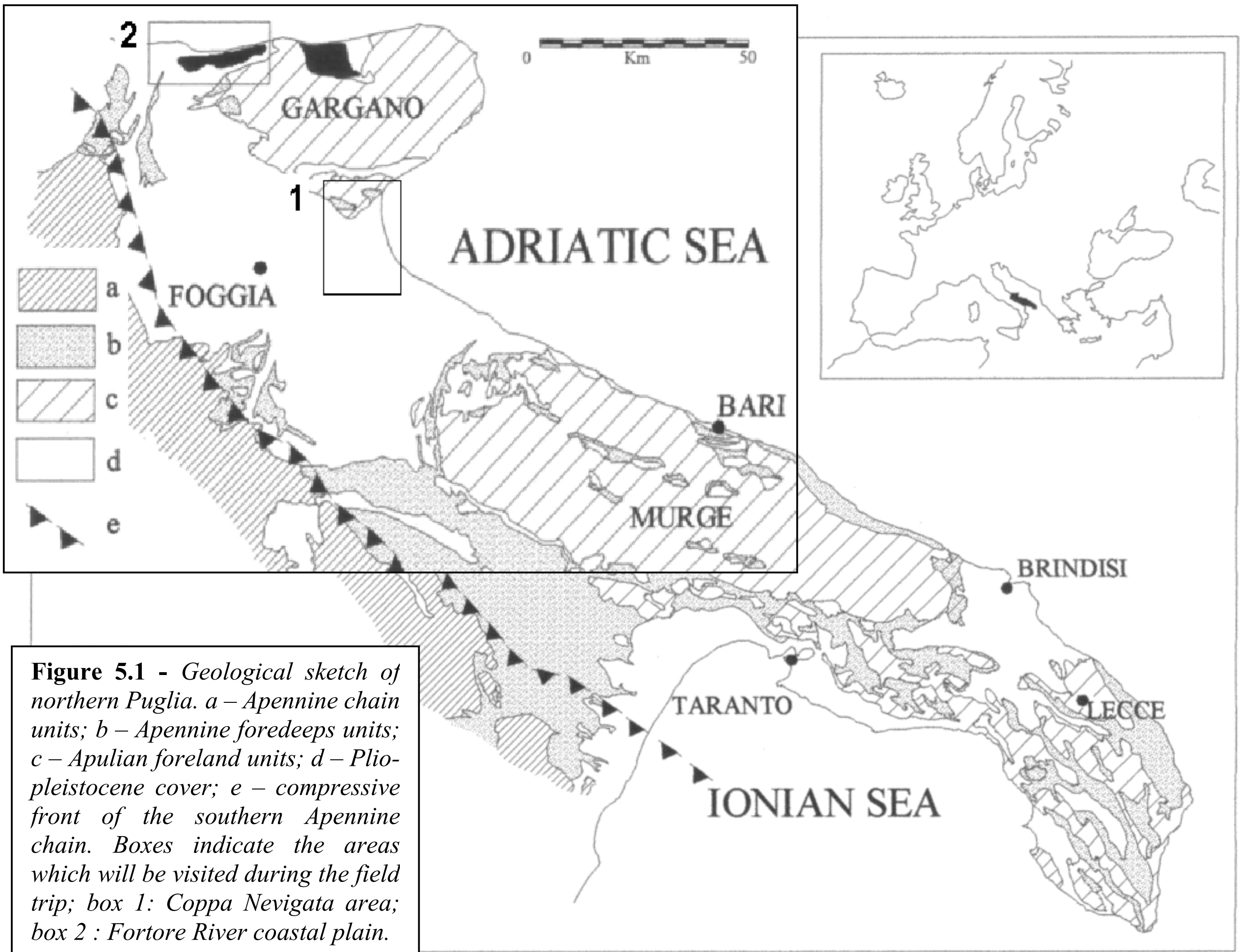


Figure 5.1 - *Geological sketch of northern Puglia. a – Apennine chain units; b – Apennine foredeeps units; c – Apulian foreland units; d – Plio-pleistocene cover; e – compressive front of the southern Apennine chain. Boxes indicate the areas which will be visited during the field trip; box 1: Coppa Nevigata area; box 2 : Fortore River coastal plain.*

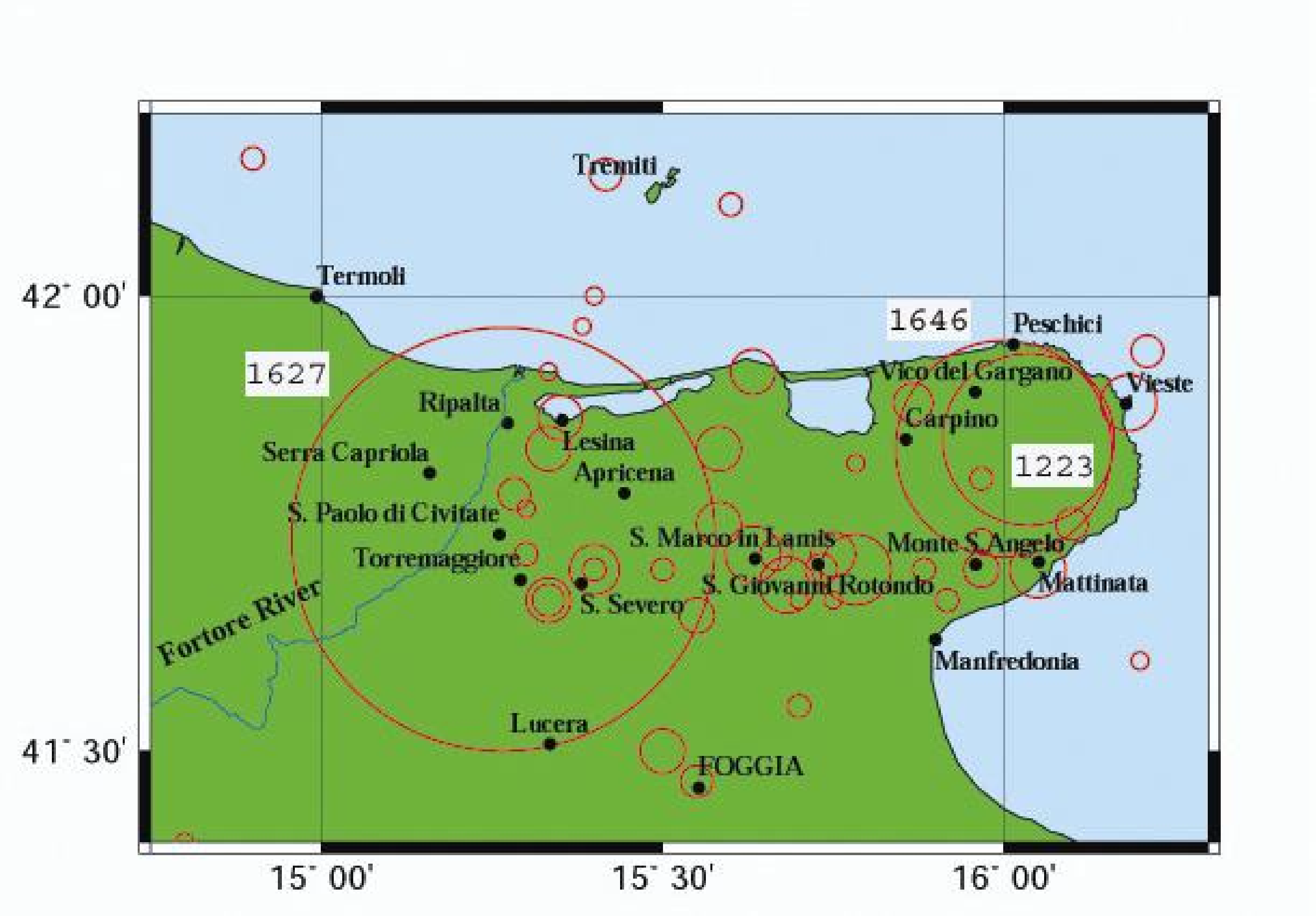


Figure 5.2 - *Spatial distribution of seismicity throughout the Gargano Promontory; black circles represent the focal volumes of damaging earthquakes documented from AD 1000 to 1980 (after Del Gaudio and Pierri, 2000)*

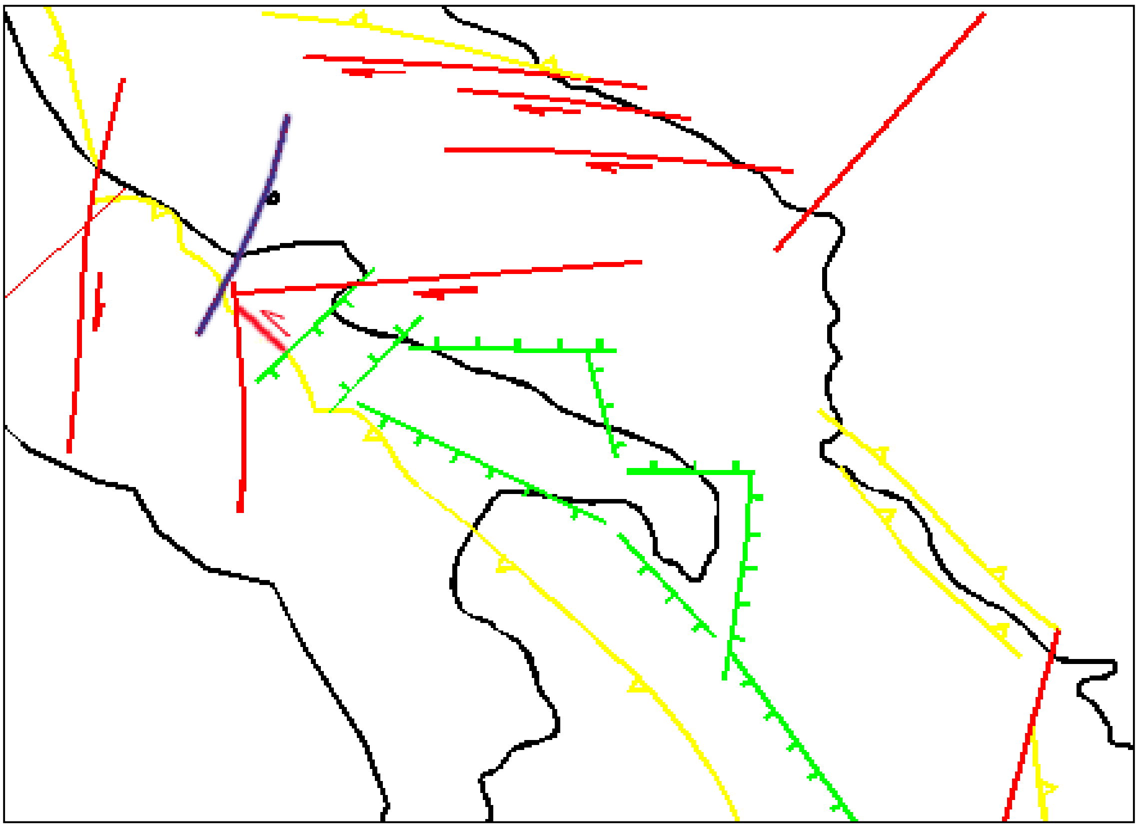


Figure 5.3 - *Main tectonic alignments recognised in northern Puglia.*

This last one is characterised by high relief landcape, reaching up to about 1000 m of altitude, affected by high geomorphological instability (slides and rapid erosion). The outer border of the chain is marked by the presence of the Monte Vulture volcanic complex (Ciccacci *et al.*, 1999). The area is affected by intense seismic activity; it has been interested by strong earthquakes whose epicenters are distributed along the Fortore river valley and along main apenninic structural alignment, NW-SE trending (Del Gaudio and Pierri, 2000; Del Gaudio *et al.*, 2002) (Fig.5.2).

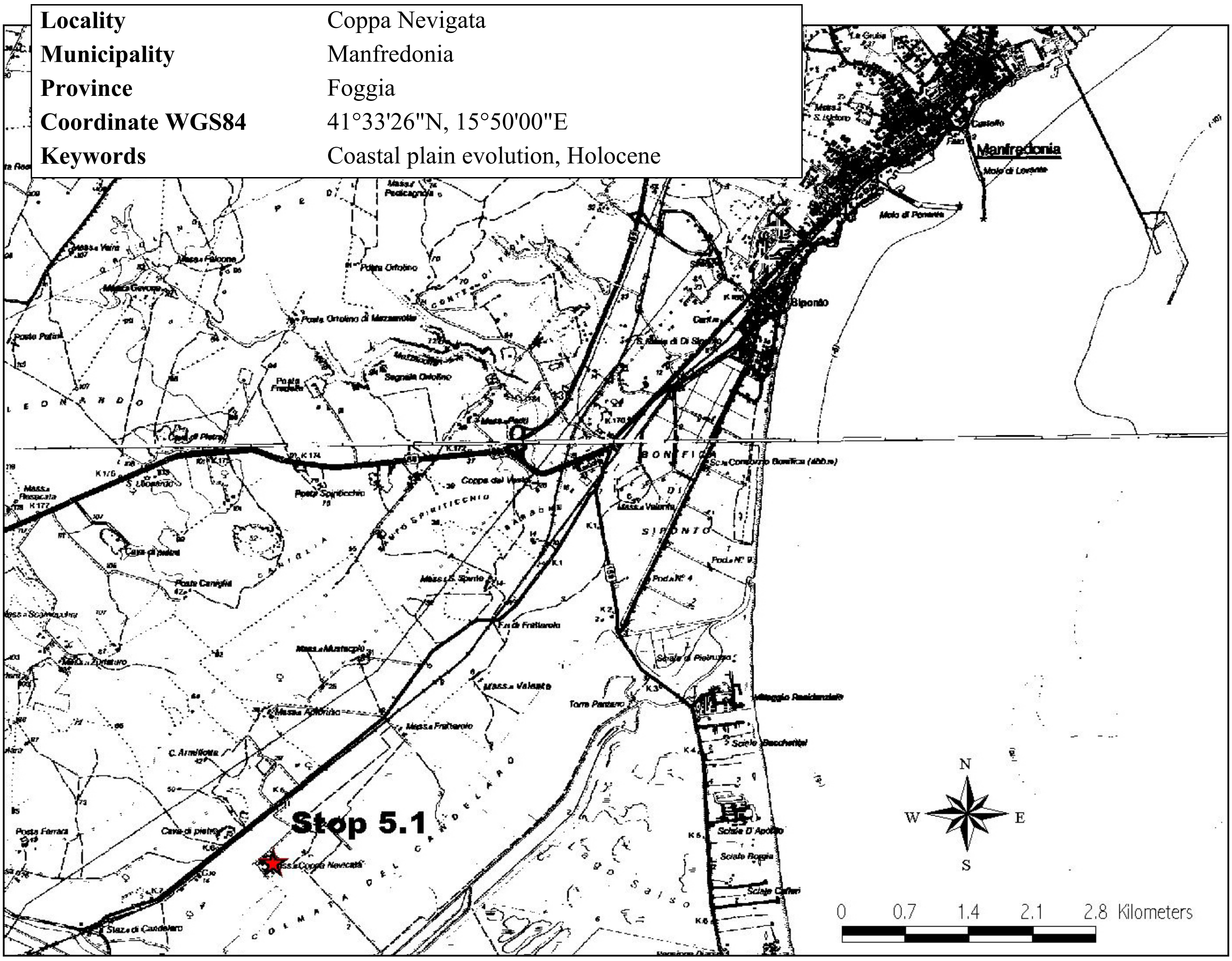
The Gargano promontory is the most uplifted part of the Adria plate and is constituted by a wide carbonatic anticline crossed by a number of strike-slip faults with E-W, WNW-ESE and NW-SE orientations.

The distribution of earthquake epicenters shows that the seismogenetic activity clusters along two main tectonic alignments: the E-W trending Mattinata fault (Billi and Salvini, 2000), and the tectonic alignment running in SSW-NNE direction along the right side of Fortore River valley which extends offshore up to the right-lateral transfer zone of the Tremiti Islands (Fig. 5.3).

According to Del Gaudio *et al.* (2002), the Fortore River tectonic structure is the most likely source for major historical earthquakes recorded in the area and for the generation of large tsunamis with struck the northern coast of Gargano promontory with a recurrence period of about one thousand years.

Site 5.1

Locality	Coppa Nevigata
Municipality	Manfredonia
Province	Foggia
Coordinate WGS84	41°33'26"N, 15°50'00"E
Keywords	Coastal plain evolution, Holocene



Stop 5.1.1 – The area of Coppa Nevigata settlement between history and environmental changes (M. Caldara, A. Cazzella, O. Simone)

Introduction

The Coppa Nevigata archaeological site is located between the edge of the Tavoliere Plain and the Gargano headland, about five kilometres from the modern coastline (Fig. 5.4). The Tavoliere, some 4500 km^2 wide, is the largest alluvial plain in the peninsular Italy, whose coastland consists of recent alluvial sediments overlaying Plio-Pleistocene marine sandy-gravelly deposits.

This area was among the first in Italy where the cereal cultivation (VI millennium BC) and stock rearing began (Barker *et al.*, 1987).

Studies carried out onto the eastern margin of the Tavoliere have demonstrated the existence, during the Holocene, of a lagoon. This basin, during periods of maximum extension, stretched approximately 40 km from the town of Siponto to the Ofanto River delta (Caldara and Pennetta, 1990, 1992; Caldara *et al.*, 2002b).

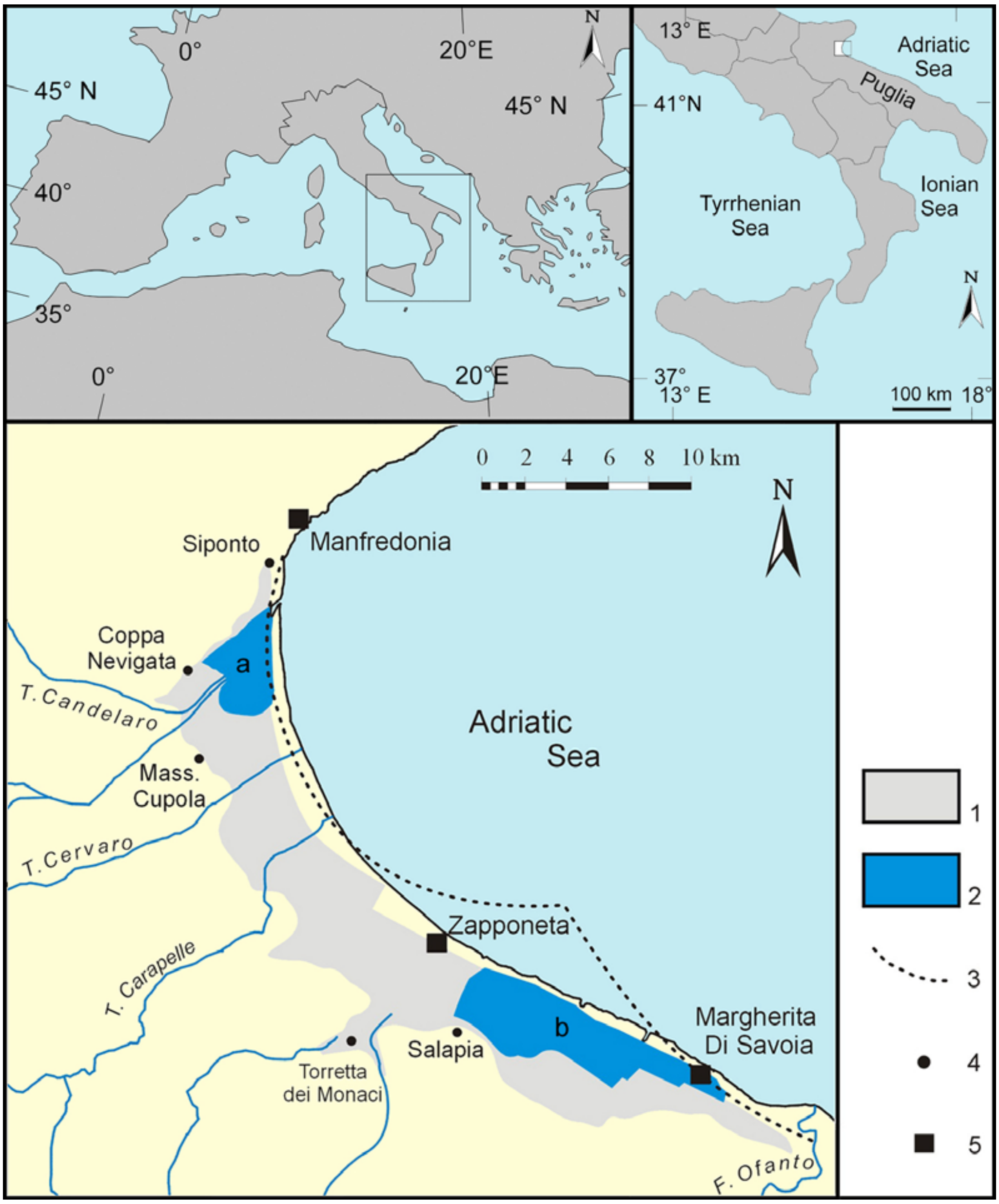


Figure 5.4 - *Geographic position of Coppa Nevigata and the Salpi Lagoon through the time. 1) maximum expansion of the lagoon during the Neolithic; 2) present day wetlands: a) Palude Frattarolo-Lago Salso, b) Saline di Margherita di Savoia - Lago di Salpi; 3) approximate position of the Neolithic coastline; 4) ancient settlements; 5) main present day settlements.*

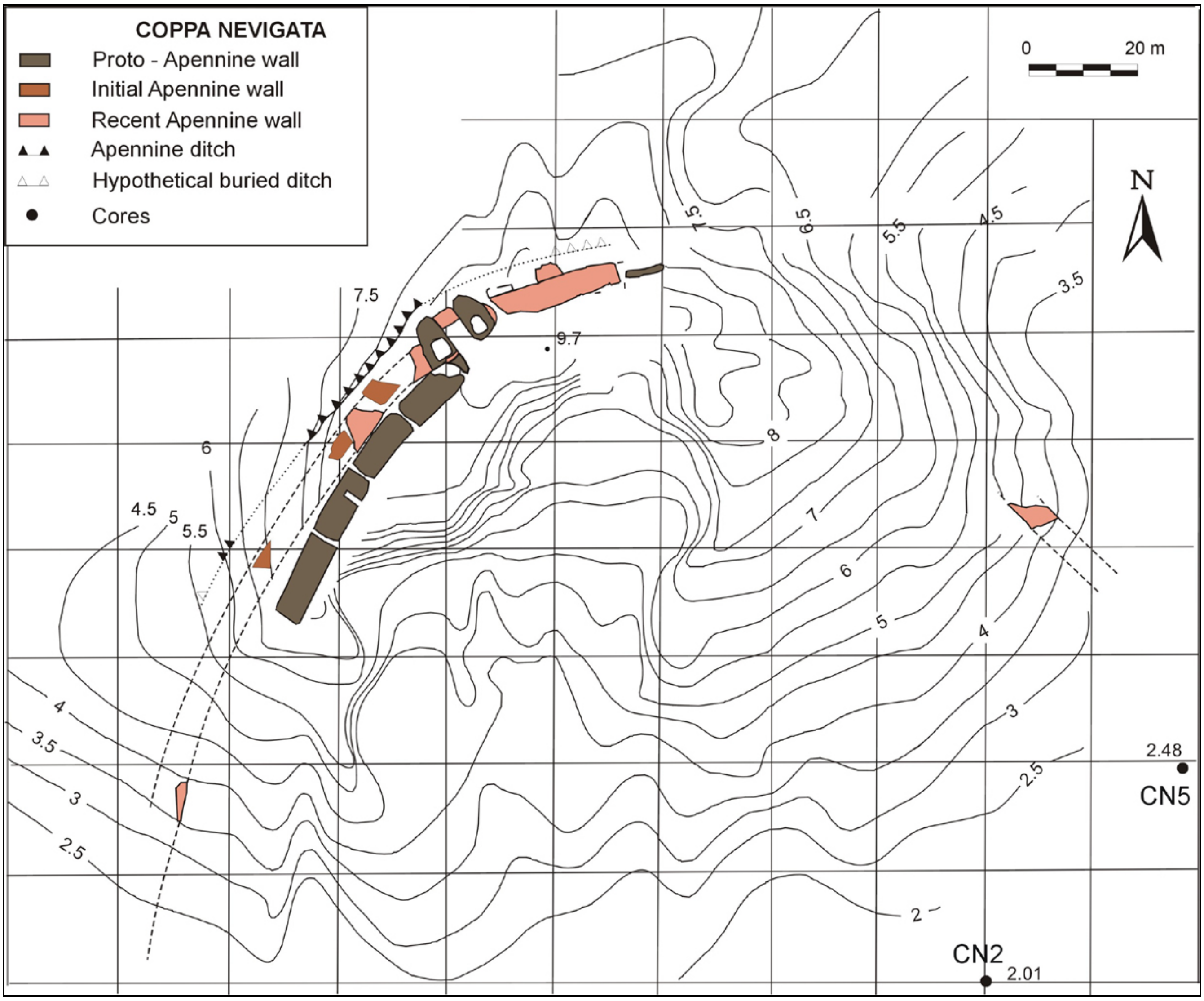


Figure 5.5 - *plan of the Coppa Nevigata excavations: Bronze Age wall structures and coring sites.*

In spite of the many palaeoenvironmental-geographical studies (Delano Smith and Morrison, 1974; Delano Smith, 1976; Ciaranfi, 1983; Caldara *et al.*, 1999, 2001, 2002b; Caldara and Pennetta, 1990, 1992) it is still not clear when the oldest lagoonal phases took place. By the archaeological investigations is evident that the lagoon already existed during the early Neolithic, when this area was densely settled.

The presence of the lagoon could be inferred by the abundance of flint microliths, interpreted as tools used to open the *Cerastoderma* shells, found in to the archaeological sites (Puglisi, 1955; Ronchitelli, 1988). For the lagoonal sites Deith (1987) documented an economy based on the gathering and exploitation of *Cerastoderma glaucum*. In addition, the typical "cardial pottery" was recovered in the many Neolithic sites. Decorations on this pottery were made using the shells of *C. glaucum*. Archaeological horizons characterized by the "cardial pottery" have been dated between 6850 ± 80 BP and 6880 ± 90 BP at Coppa Nevigata (Hedges *et al.*, 1989). The oldest radiocarbon dates obtained for archaeological beds are 8150 ± ? BP (Tongiorgi *et al.*, 1959), 7780 ± 320 BP uncal (Ambers *et al.*, 1989) and 7600 ± 100 BP at Santa Tecchia (Belluomini and Delitala, 1983). However, these dates are considered unreliable by some authors (e. g. Whitehouse, 1994).

Since the Neolithic, the configuration of the lagoon has changed many times. Probably the first significant change occurred during the late Neolithic (after the radiocarbon date 5470 ± 40 BP), when the lagoon turned into a sabkha (Boenzi *et al.*, 2001). This broad coastal basin was again occupied by a lagoon since the Early Bronze age (Caldara and Pennetta, 1990, 1992; Caldara *et al.*, 2002b). Another change in the configuration of the lagoon took place during the Roman period. In fact, after Titus Livius (*Ab Urbe Condita Libri*, XXXIX, 2), silting up of the Salpi Lake, by the sediments discharged by the Carapelle stream, produced two separate basins during the 2nd century BC. These changes were probably due to the large scale man-made clearance of forested areas (Caldara and Pennetta, 1990, 1992; Caldara *et al.*, 2002b). Notwithstanding the numerous transformations that occurred during the following centuries, due to natural and anthropogenic causes, several coastal basins still existed at the beginning of the XX century, when radical reclamation activities began.

Today two areas of the ancient Holocene lagoon still survive: the first is a swamp in the Palude Frattarolo area, the latter is a saltworks area, called "Saline di Margherita di Savoia" (Fig. 5.4). The Coppa Nevigata settlement is situated on a low hill, about 10 m in height above sea level, along the border of the Palude Frattarolo.

Phases of occupation at Coppa Nevigata

The archaeological area at Coppa Nevigata was first investigated at the beginning of the last century (Mosso 1909), but it was not until the 1950s that it began to be studied by archaeologists (Puglisi, 1955, 1975; 1982). Systematic excavations started again in 1983 (Cazzella and Moscoloni, 1988; 1990).

The archaeological investigations (Fig. 5.5) revealed a complex stratigraphy with phases of human settlement from the Early Neolithic, throughout the Bronze Age and into the Iron Age (Cazzella, 1996a; Cazzella and Moscoloni, 1999a; 1999b). During the Neolithic, there was a village with a surrounding ditch. Apart from the traces of a settlement from the Eneolithic and Early Bronze Age, in later phases, between the Middle and Late Bronze Age, the Coppa Nevigata settlement was characterised by a sophisticated management of space and by the presence of an imposing defensive wall.

Recent studies into the settlement have led the archaeologists to distinguish, for the Middle Bronze Age, different cultural phases. These are: the Proto-Apennine (1800-1500 BC cal) and the Apennine. The Apennine is subdivided in Early (1500-1450 BC cal) and Late (1450-1300 BC cal). For the Late Bronze Age the archaeologists have identified a Sub-Apennine phase, divided into Early and Late (respectively 1300-1200 and 1200-1100 BC cal). The Final Bronze Age has been documented by the proto-geometric pottery (1100-1000 BC cal; Calderoni *et alii* 1994; Cazzella and Moscoloni, 1994). Traces of Early Iron Age occupation have been found in a marginal area of the settlement, at the feet of the hill (Boccuccia, 1997). This is the youngest record of human occupation at this site.

The palaeoenvironmental studies in the Palude Frattarolo area

The first palaeoenvironmental studies in this area, based on sedimentological and palaeontological analyses as well as archaeological and documentary evidence, were published by Delano Smith and Morrison (1974), and Delano Smith (1976). These authors found that, in the first century AD, immediately south of Siponto a short-lived water body, spanning a few km^2, was separated from the open sea by a sandy barrier. This small basin was apparently disconnected from the Palude Frattarolo, thought to be an embayment rather than a lagoon (Delano Smith, 1976). No further detailed palaeoecological studies were made in this area until 1997, when five cores were drilled in vicinity of Coppa Nevigata (Caldara *et al.*, 1999; 2001; in press; Fig. 5.5), one of the best known ancient sites in this area, inhabited from the Early Neolithic to the Iron Age. The drillings were carried out to establish the relationship between the settlement and the adjacent basin. To date have been studied only two of the five cores drilled. These are the CN2 and CN5 cores, the nearest to the site (Caldara *et al.*, 1999; 2001, 2002a; in press).

An hydraulic corer was used to drill the clayey sediments. The diameter of the core is of 80 mm. Not the whole successions were studied, since the first centimetres of each core were disturbed by ploughing. Great attention was paid to the analysis of environmental indicators that could give information on both natural processes and anthropogenic activities. Plant (pollen, wood charcoals, seeds) and animal remains (foraminifers, molluscs, polychaeta, vertebrates and insects) have been studied by a team of specialists (Caldara *et al.*, 1999, 2001, in press). These associations have allowed us to formulate some hypotheses on the palaeoenvironments. When possible, the stratigraphic data were integrated with the chronological indications obtained from archaeological artefacts and radiometric dating.

History and environmental changes at Coppa Nevigata

The comparison between the results of the analysis of the two cores nearest to the site and the archaeological data obtained from the excavation at the settlement allowed the reconstruction of the phases of human occupation and the changes of the surrounding lagoon environment. The span of time investigated ranges from the Early Bronze Age to recent times.

Early Bronze Age (until 1800 BC cal)

The CN2 core has reached a lagoon deposit, at the depth of 4.39 m below the present day mean sea level, probably dating back to the Early Bronze Age. Given the most common taxa found in these levels, we named this environment "Hydrobiidae spp. and *Cerastoderma* Lagoon".

The molluscan association is composed by three stocks of species. The most important group is constituted by "characteristic exclusive" or "accompanying" taxa in Euryhaline and Eurytherm Lagoons (Pérès and Picard 1964, Picard 1965, Pérès 1967), such as Hydrobiidae spp., *Cerastoderma glaucum*, *Abra segmentum* and *Cyclope neritea*. The second stock is represented by taxa commonly found in lagoons and are prolific in sheltered coastal environments. In addition a few marine molluscs were found. The oligotypic populations of brackish and marine fauna, including foraminifers and ostracods, indicate a degree of confinement corresponding to zone IV (a zone with strictly paralic species) tending to the zone III (dominated by mixed species) according to Guelorget and Perthuisot (1983).

A tephra layer, several centimetres thick, has been found in the lagoon sediments. Geochemical analyses indicate that this bed contains products related to different explosive eruptions of the Campanian volcanoes, which most probably occurred within a few centuries of each other (Caldara *et al.*, 2001; in press). Among these eruptions, the most recent one is the "Avellino eruption" of the Vesuvius. In the literature, this Plinian event is dated at about 3500 ÷ 3600 BP (Terrasi *et al.*, 1999; Albore Livadie *et al.*, 1998; Rolandi *et al.*, 1998; Andronico *et al.*, 1995).

However, these pyroclastic products are not in a primary position. Assuming that the reworking and accumulation of the volcanoclastic material took place over a relatively short period of time, it is possible to hypothesise that this level was deposited around the time of the Avellino eruption or immediately afterwards. This finding, is a confirmation of the hypothesis that the fallout of this volcanic event took place in areas situated to the east of the Vesuvius (Lirer *et al.*, 1973; Rolandi *et al.*, 1993; Cioni *et al.*, 1999; 2000) and enables us to extend the interested areas to the Adriatic coast, at a distance of at least 140 km far from the emission point (Caldara *et al.*, 2001).

Sporadic pottery remains recovered at the site indicate that, during the Early Bronze Age, the hill was probably inhabited. However there is no further reliable information on the settlement characteristics. In addition, the only human indicators found in these levels are a few tiny shards of flint, this suggest that the settled area was small, or distant to the drilling site.

Middle Bronze Age Proto-Apennine phase (1800-1500 BC cal)

The analysis of the cores, CN2 and CN5, indicates a continuing presence of the "Hydrobiidae spp. and *Cerastoderma* lagoon" (Caldara *et al.*, in press). The amount of material attributed to anthropogenic sources increases in this horizon. In fact, high levels of charred plant remains and other organic material related to the activities of the settlement were found in

Figure 5.6 - *Aerial view of the Coppa Nevigata excavations (1996). The large defensive wall structures are visible.*

the sediment. Pottery fragments dating back to this period and containing pyroclastic material were found at the site. During this period This kind of clay was commonly used to produce pottery (Levi *et al.* 1999). The presence of this material in the lagoon bottom sediments suggests that the clay used to shape the earthenware was obtained locally. In this phase, the settlement at Coppa Nevigata was expanding fast. The remains of a number of constructions, including passageways and walls have been found. The evidence suggests two different phases of development. Initially, 1700-1600 BC cal, there was the construction of several large walls (Fig. 5.6). In the second phase, 1600-1500 BC cal, the settlement expanded outside the original walls. The layout of the settlement is sophisticated, and quite complex (Cazzella and Moscoloni 1998). Since this phase the interaction between the settlement and the lagoon becomes increasingly apparent in the record.

Apennine phase (1500-1300 BC cal)

During this period the sedimentary sequences of the cores record a horizon characterised by a greater quantity of organic remains connected to the activities carried on in the settlement.

This includes the burnt remains of secondary woody tissue, the charred remains of cultivated cereals and the mummified residues of herbaceous vegetation. Scattered pottery fragments, molluscs and fragments of domestic animal bones also occur (Fig. 5.7). There is an abundance of fragments of *Phyllonotus trunculus* shells. This species was used both for extracting purple dye and as a source of food, as documented by Minniti (1999). Within this horizon the exoskeletons of several species of insect, which are known to live in granaries, and the pupae of diptera Cyclorrapha have been found. These larvae generally feed on rotting meat. In other words, this area acted as a dumping ground for waste products from the nearby settlement or a wash-off zone from the village (Caldara *et al.*, in press). The lateral continuity of this layer has not yet been clarified, although it appears to involve at least the area around cores CN2 and CN5. After the anthracological analysis, very few rounded charcoal remains were found, while the angular ones prevailed. The low mechanical resistance of charcoal suggests a low energy depositional environment. In addition, the excellent state of preservation shown by the organic remains leads us to propose two transport hypotheses. The first is that the site was used as an intentional dumping ground; in this case the deposit could be described as a midden. The second hypothesis is that the material originated after short, none-turbulent, sheet wash processes resulting in a rapid accumulation; in this case this horizon could be compared to a colluvial deposit. We will be able to say more about the nature of this deposit only after further investigations. In fact, new drillings will give us the possibility to reconstruct the extension, the geometry and eventually the nature of this organic accumulation. This deposit appears to have been developed before 3195±80 BP, and was accumulated during at least two centuries, until 3000±80 BP (Caldara *et al.*, 2001).

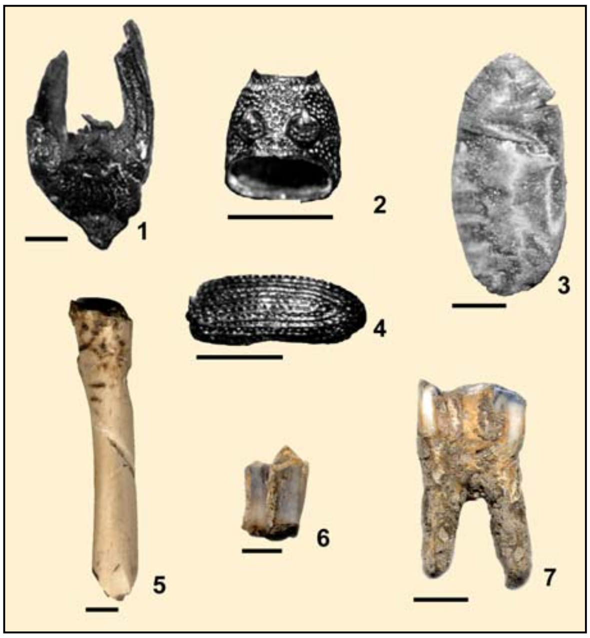


Figure 5.7 - *Some examples of material found in the lagoonal sediments and connected to anthropic activities. 1) charred cereal remain (Triticum spelta); 2) fragment of a curculionid head; 3) pupae of diptera Cyclorrapha; 4) Coleoptera remain; 5) bone fragment of a sheep; 6) deciduous teeth of a young sheep; 7) cow teeth. The bar scales are 1 mm for pictures 1 - 4, 1 cm for 5 - 7.*

During the time period represented by this horizon, changes occurred in the surrounding woodland (Fiorentino and Magri, 1999; Caldara *et al.*, 1999). The environment was originally characterised before this time by an open woodland dominated by deciduous species, including *Quercus*, *Carpinus betulus*, *Carpinus orientalis*/*Ostrya*, *Ulmus*, *Fagus*. This environment evolved into a woodland where the deciduous species diminished in favour of evergreen taxa such as *Quercus ilex* type, *Olea* and *Pistacia*.

Figure 5.8 - *View of part of the late Appennine wall (September 2002).*

The on-site evidence suggests that at the beginning of the Apennine phase a new defensive wall was built. Subsequently, this has been obliterated by later constructions. There are clear indications that the Proto-Apennine wall fell into disuse at this time. This is shown both by evidence of burials in a few secondary passageways and by a series of structures that appear to have been used for combustion. These structures occur within a small area near the disused walls (Cazzella and Moscoloni, 1999c). Immediately later, during the Late Apennine, the fortifications were renewed, especially near the main gateway (Fig. 5.8). This included the addition of rectangular towers and a wide ditch on the outside. Near the walls there are traces of various circular structures, which may be linked to a form of collective storage (Cazzella and Moscoloni, 1999c; Cazzella *et al.,* 2001).

Late Bronze Age Sub-Apennine phase (1300-1100 BC cal)

The cores from the early Sub-Appennine show a phase of infilling and a lagoon retreat. The deposition of the high organic content layer continued during the retreat of the lagoon and the subsequent sub-aerial phase. This transformation may have been simply the result of the volume of the material being deposited in this area at this time. Given the data collected so far, even in this case we cannot say whether or not the accumulation has been favoured by natural processes and/or anthropogenic activities. However, the deposition of this material would have produced a very localised infilling of the lagoon. Once this area of the lagoon became dry, the settlement expanded to incorporate it. Evidence of this expansion is supported by the sedimentary record. Rock fragments and clayey *concotto* materials were found in the core sediments in this section. This type of deposit can be indicative of ancient walls (Caldara *et al.*, 1999). The change from the lagoon to the terrestrial environment is recorded at circa 2 m below the present day mean sea level.

There is no clear evidence of new defensive walls having been built between the Early and the Late Sub-Apennine period. However, the ditch appears to have been in use. The evidence suggests that the ditch was re-dug several times and was only filled in at the beginning of the Iron Age. New structural features associated with pathways within the settlement have been discovered in these later phases. In conjunction with these remains, are the foundations associated with new rectangular-plan houses. Pottery artefacts recovered show an increase in Mycenean-type wheeled and painted earthenware items. The first evidence of the presence of donkeys on the site was found contemporaneous to this archaeological context. Donkeys were introduced as pack animals from the Eastern Mediterranean (Cazzella 1996b).

Final Bronze Age to historical times

The sedimentary evidence shows that the time span in which the area near the settlement was dry was relatively short, and lasted perhaps no more than two centuries. This is supported by the ^{14}C dating on the material on CN2 (Fig. 5.9). Subsequently the lagoon submerged this area. The date obtained for this period is 2870 ± 40 BP. The name given to the sediments corresponding to this new lagoonal phase, "*Cerastoderma* lagoon", is due to the molluscan species occurring more frequently.

Artefacts (proto-geometric painted ware) coming from horizons dating back to this period have been found only in a few limited areas of the settlement (Boccuccia, 1996, 1997). However, at this time the archaeologists cannot reconstruct the layout of the settlement and its interaction with the surrounding area with any certainty.

During the Final Bronze Age, around 1 m below the present day sea level (Caldara *et al.*, 1999), the lagoon retreated. This phase of retreat was named the "Salt marsh I". The scarcity of materials associated with the settlement in these horizons indicates that this environmental change operated independent from anthropogenic activity.

From the end of Final Bronze Age the evolution of the environment around the Coppa Nevigata seems to have been driven essentially by natural factors. In addition, the several changes that the wetland was subjected to, occurred in a still not clear chronological frame. In particular, we found paralic deposits indicating a slight connection to the open sea ("Hydrobiidae and *Abra segmentum* lagoon"), followed, around the present day sea level, by a new episode during which part of the lagoon near the settlement fell dry ("Terrestrial phase II"). The successions continue with a new wet phase, the "Salt marsh II", whose deposits are cut at the top by an erosional surface. This terrestrial phase, is characterised by carbonatic crusts and evaporitic lumps. The presence and the thickness of such deposits suggests long lasting arid or sub-arid conditions.

Modern Age

The sediments directly above the erosive surface were first deposited in a basin characterised by low salinity waters ("*Ovatella myosotis* wetland"), subsequently the wetland became fresh ("*Bithynia leachi* wetland"). The radiocarbon date obtained from the lower part of this section (CN 5 core) is 370±50 BP (Caldara *et al.* 2001). The studied successions end with the "Terrestrial phase III" lasted until the present days.

Final remarks

The presence of a lagoon near the Coppa Nevigata settlement is documented back to the Early-Middle Bronze Age, at a depth between 4,39 m and 2 m below the present sea level. The documented age of this lagoonal sediments is between the dates 3600 ÷ 3500 BP (the "Avellino eruption") and 3090±40 BP. If during the Early Bronze Age Coppa Nevigata was probably inhabited, throughout the Middle Bronze Age the layout of the settlement was well developed and sophisticated. Clear traces of human activities were found in the lagoonal sediments referred to this period. Subsequently the lagoon fell dry ("Terrestrial phase I") and in the area surrounding the inhabited site the sedimentation was strongly controlled by anthropogenic activities. A short lagoonal episode occurred around 2870±40 BP ("*Cerastoderma* lagoon"). During the Final Bronze Age the wet area near the settlement took up the character of a salt marsh ("Salt marsh I").

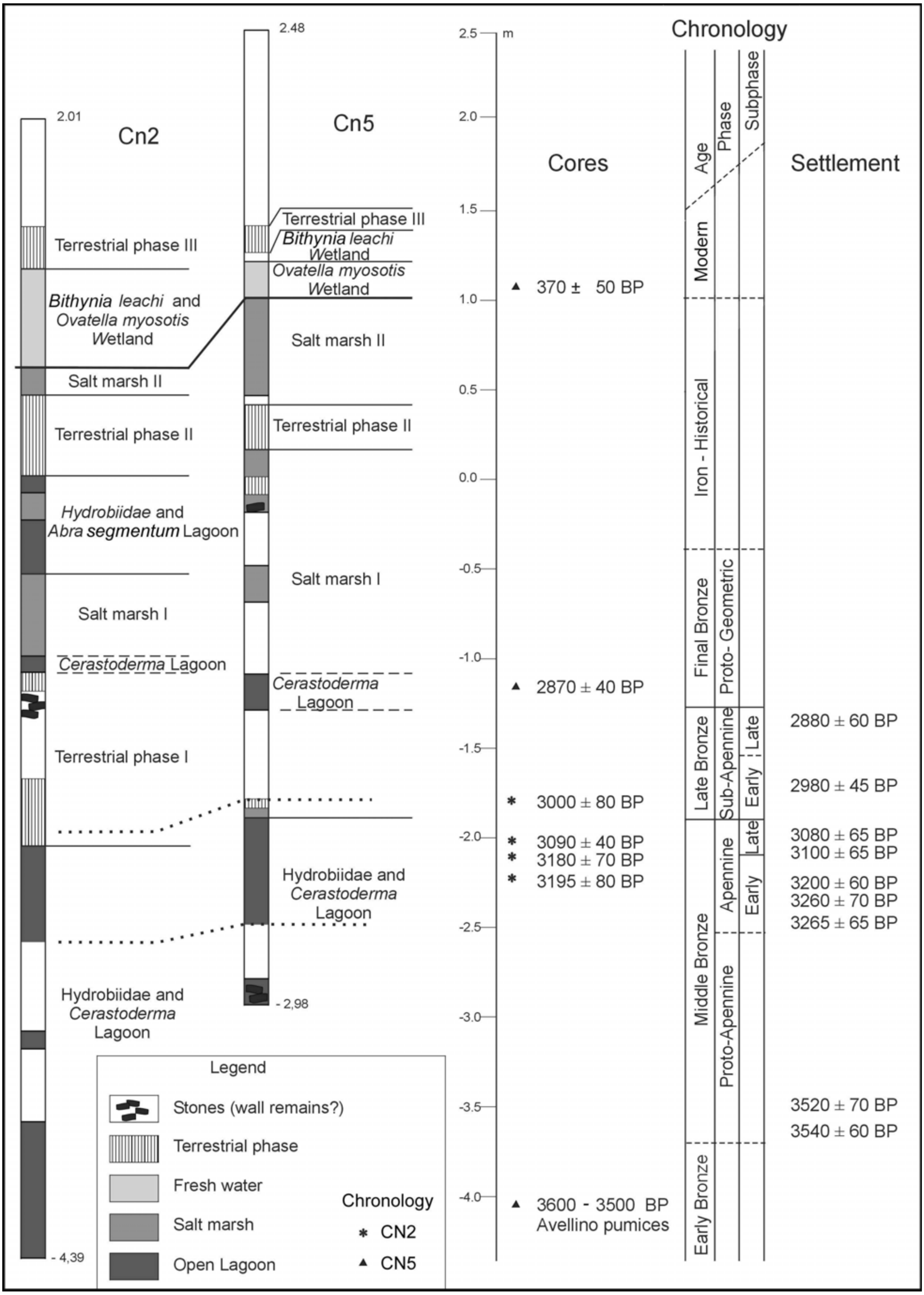
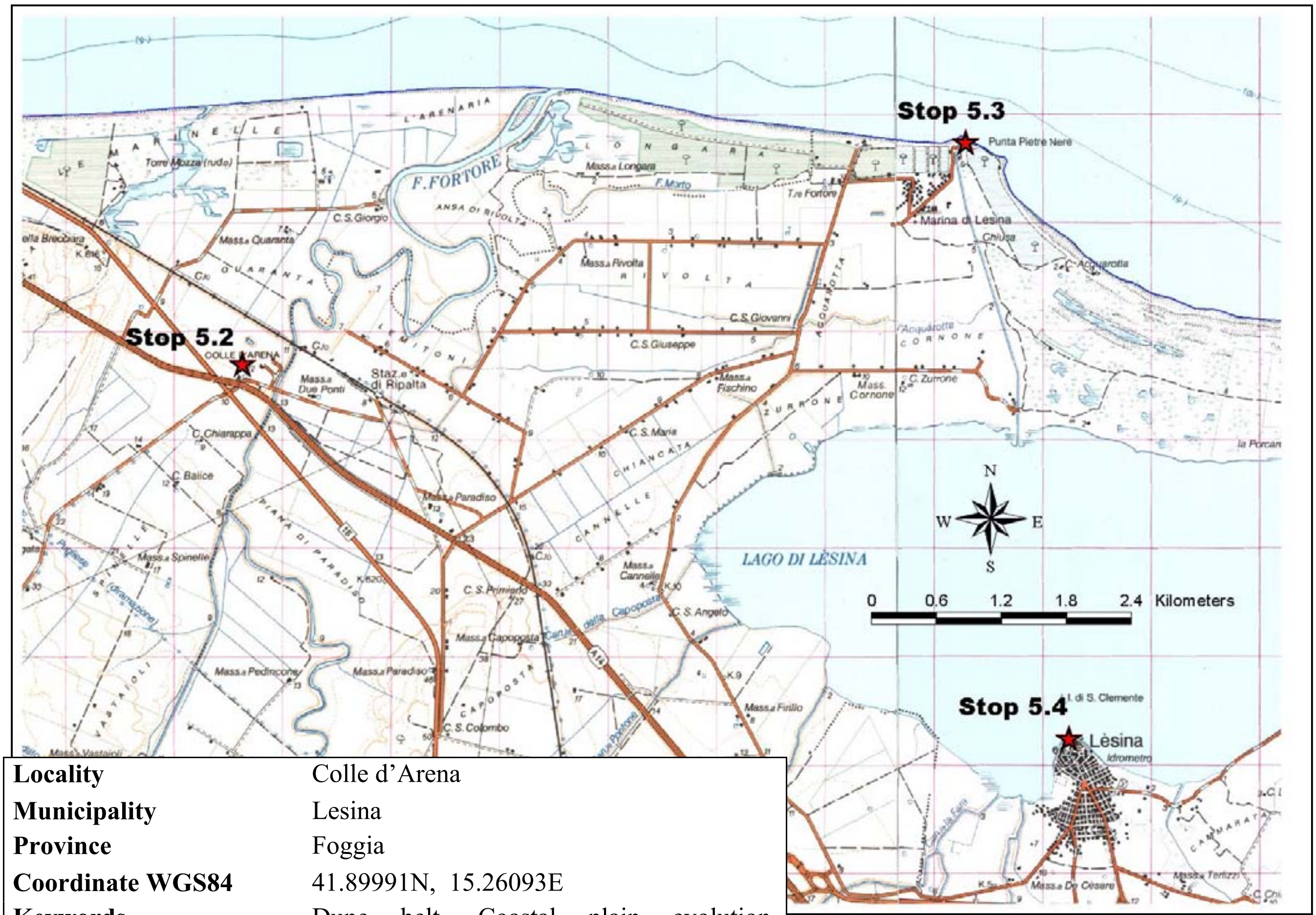


Figure 5.9 - *Schematic representation of the reconstructed environments and chronological data (from Caldara et al., in press, modified.)*

The last recorded lagoonal environment (across the boundary between the Final Bronze and the Iron Ages) is the "Hydrobiidae and *Abra segmentum* lagoon". The closure of this brackish episode lies around the present day sea level. The upper part of the two cores continue with a sub-aerial environment (the "Terrestrial phase II") followed by a new salt marsh phase (the "Salt marsh II"). The "Salt marsh II" deposits are cut by an erosional surface.

At this time we are not able to estimate how long lasted the sub-aerial period during which the erosive processes occurred. Nonetheless a radiocarbon date obtained from the lower part of the subsequent wet phase ("*Ovatella myosotis* wetland", CN 5 core) gave the age 370±50 BP. The studied successions end with the "Terrestrial phase III" lasted until the present days.

Site 5.2



Locality	Colle d'Arena
Municipality	Lesina
Province	Foggia
Coordinate WGS84	41.89991N, 15.26093E
Keywords	Dune belt, Coastal plain evolution, archaeological remains, uplift, Holocene

Stop 5.2.1 - The Fortore River coastal plain (A. Gravina, G. Mastronuzzi, P. Sansò)

The Fortore River coastal plain has an elevation between +6 m and present sea level. The inner margin of this plain is defined by a cliff whose top constitutes the outer border of the lowest marine terrace, locally placed between +25 and +10 m (Fig. 5.10). The coastal plain of the Fortore River formed because of rapid beach progradation, and is marked by a number of low dune ridges with irregular spacing. Beach sediments are laminated sands gently sloping seawards alternated to thin layers of small pebbles and bivalves shells. The innermost dune belt, which reaches a maximum elevation of about +22 m (Colle d'Arena dune belt), formed at the foot of the relict cliff. Radiocarbon datings performed on *Helix* sp. specimens (Arena 1 sample in Fig. 5.10) collected from basal levels of this inner dune belt yielded a conventional ^{14}C age of 4340±80 yr BP. A small morphological step runs roughly parallel to the present shoreline and divides the coastal plain in two sub-horizontal surfaces. The higher and inner surface stretches between +6 m and +3 m whereas the lower, outer surface is found between +2 m and present sea level. An association of marine bivalve shells and cuttlebones in these beach deposits provides an excellent supralittoral-floatsam deposit (Laborel pers. comm.). Samples of these were collected near the seaward edge of the higher surface of Fortore River coastal plain, just below the contact between beach deposits and related aeolian sands, at about +2 m (Arena 2 sample in Fig. 5.10; Fig. 5.11).

Samples	Laboratory No	Specimen	Method	Elevation n	Conventional 14C age (yr BP ± 1σ)	δ^{13} C_{PDB} ‰	Calibrated age BP - atmospheric - ΔR 118 ± 60	Calibrated Age AD/BC -atmospheric -ΔR 118 ± 60
				Fortore River Coastal Plain				
Foce Vecchia	GX-27752	*Helix sp.*	^{14}C	1.5	1590 ± 190	-7.3	**1470 ± 165** -	**AD 480 ± 165** -
Arena 2	GX-27751	*Lima sp.*	^{14}C	2	3030 ± 190	-2.4	- **2613 ± 45**	- **664 ± 245 BC**
Arena 1	GX-27750	*Helix sp.*	^{14}C	7	4340 ± 80	-8.0	**4912 ± 81** -	**2963 ± 81 BC** -

Table 5.1 – *Samples dated by ^{14}C on the Fortore river coastal plain. Radiocarbon age determinations were performed on coral and shell samples at Geochron Laboratories, Krueger Enterprises Inc., Cambridge, Massachussets, USA. Samples were cleaned throughly in an ultrasonic cleaner and then leached with diluite HCl to remove additional surficial material which may have been altered to be sure only fresh carbonate material was used. The cleaned samples were then hydrolyzed with HCl, under vacuum, and the carbon dioxide was recovered for analysis. The ages obtained are based on the Libby half-life (5570 yr) for ^{14}C. The error is 1 sigma as judged by the analytical data alone. The modern standard is 95% of the activity of N.B.S. Oxalic Acid. The age is referenced to the year AD 1950. The conventional radiocarbon ages have been calibrated using the CALIB 4.3 software (Stuiver et al., 1998).*

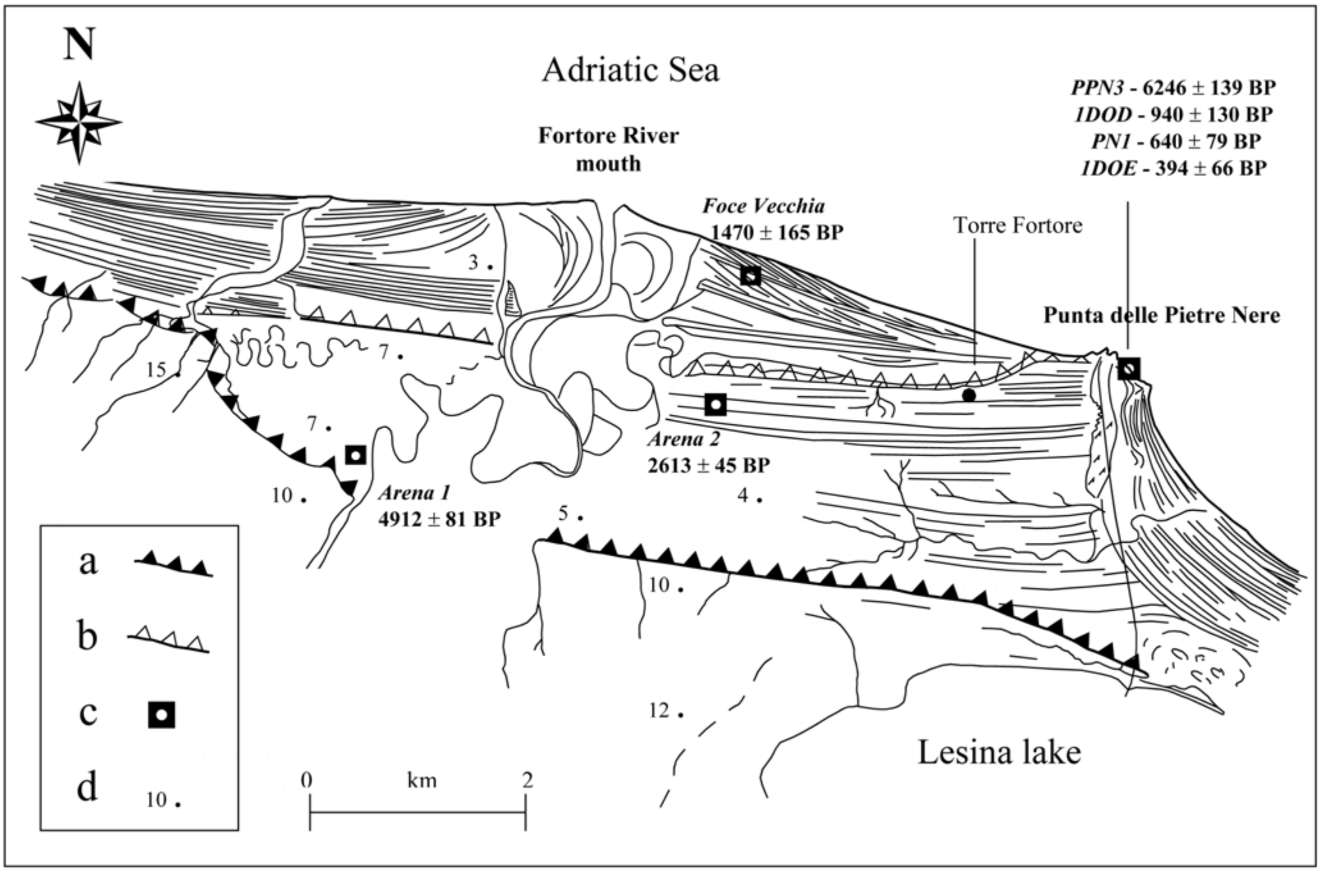


Figure 5.10 - *Geomorphological sketch of Fortore River coastal plain - Punta delle Pietre Nere area. a -Mid-Holocene cliff; b - Medieval cliff; c - position of samples and calibrated ages BP; d - elevation (m).*

Figure 5.11 - *A view of Arena 2 locality. The hammer indicate the transition between marine and dune sediments where Arena 2 sample has been collected.*

Figure 5.12 - *The present cliff is shaped on dune deposits dated at about 1470 cal years BP.*

Radiocarbon dating on *Lima* sp., a marine bivalve, yielded the conventional ^{14}C age of 3030±190 yr BP.

The lower surface of coastal plain has been actively eroded by waves during last fifty years, which shaped a cliff into face of the coastal dune deposits. *Helix* sp. specimens were collected from this cliff at Foce Vecchia (Foce Vecchia sample in Fig. 5.10; Fig. 5.12) and yielded a conventional ^{14}C age of 1590±190 yr BP by means of radiocarbon method.

The Colle d'Arena relict cliff marks the maximum position reached locally by the Holocene transgression at the end of the rapid postglacial eustatic sea level rise dated to 6500 cal. yr BP in the sea-level curve of Alessio *et al.* (1994). The foot of the cliff, at about 6 m above m.s.l., was buried by the development of the Colle d'Arena dune belt during the following phase of coastal plain progradation. Assuming this cliff of Holocene age and taking into account an eustatic sea level rise of c. -3.5 m since 6000 yr, a net uplift since mid Holocene of about 3.5 m at a mean rate of 1.5 mm/yr can be calculated.

Site 5.3

Locality	Punta Pietre Nere
Municipality	Lesina
Province	Foggia
Coordinate WGS84	41.91817N, 15.34141E
Keywords	crustal uplift, coseismic movements, sea-level bioindicator, sea level change, Holocene,

Stop 5.3.1 - The Punta delle Pietre Nere
(G. Mastronuzzi, P. Sansò)

At Punta delle Pietre Nere, igneous rocks, Upper Triassic black limestones and deformed gypsum deposits crop out in a small area. According to Cotecchia and Canitano (1954) these rocks rose through the Jurassic-Cretaceous sedimentary sequence as a result of diapirism; however, other interpretations suggest a genetic process of tectonic squeezing (Guerricchio, 1983) and wedge expulsion by tectonic compression (Ortolani and Pagliuca, 1987).

In the Mediterranean basin, sea levels indicators are derived from lithological and biological sources (e.g. Laborel, 1986; 1987; Laborel *et al.*, 1994a; 1994b; Laborel and Laborel Deguen, 1994; Pirazzoli *et al.*, 1994a; Pirazzoli *et al.*, 1996; Pirazzoli, 1996b), as well as from archaeological data (e.g. Flemming, Webb, 1986; Erol and Pirazzoli, 1992; Stiros and Pirazzoli, 1995; Pirazzoli *et al.*, 1994b). Some *in situ* bioconstructions are the most valuable indicators of sea-level changes in this region. Past sea-level stands can be inferred by their presence (e.g. the corniche of *Lithophyllum lichenoides*, or reefs of the *Dendropoma* sp.) or by the coexistence of erosional landforms and biological indicators (notches and Vermetids, or notches and algal rims) that are representative of the midlittoral zone or of the uppermost limit of sublittoral zone.

Rapid and recent uplift of a coastal area is indicated by the presence of small and fragile sublittoral fossils above present-day sea level. In the supralittoral zone, in the swash area, small biological indicators such as isolated briozoa or Vermetids are easily erased in few years by wave action (Laborel and Laborel-Deguen, 1994). Where waves do not arrive directly, subaerial processes can also erode biological indicators. In active tectonic coasts, the preservation of fragile biological indicators of sea level is determined by the rapidity and amplitude of tectonic movements in relation to the tidal range and by operation of subaerial processes (Pirazzoli *et al.*, 1997; Pirazzoli *et al.*, 1999).

Figure 5.13 - *A general view of the bioherm made of calcified worms, calcareous algae, Vermetids and Cladocora caespitosa (L.), cropping out at Punta delle Pietre Nere locality; near the hammer a large globular colony of Cladocora coespitosa - 0.60 m of diameter - is recognisable.*

Holocene biogenic deposits also occur at Punta delle Pietre Nere. They have been surveyed in detail, with altitudes expressed relative to the biological mean sea-level as defined by the upper level of living algae (Laborel and Laborel-Deguen, 1994). The Vieste tidal gauge, c. 60 km to the east of the study area, recorded in the period 1998-2001 a mean tidal range of about 30 cm; however, the record shows sea level fluctuations with maximum amplitude of about 1.09 metres in response to change in atmosperic pressure, wind and wave climate and surficial currents influence.

A bioherm outcrops at Punta delle Pietre Nere with an upper surface reaching an elevation of 1.15 m above the biological mean sea level. It comprises low pillars showing irregular section and variable diameter, and extends up to 1.7 m in height above the sea bed (Fig. 5.13; Fig. 5.14). The bioherm surface is very irregular because of abrasion and solution processes as well as of bioerosion.

The inner structure of bioherm is exposed where it has been eroded by wave action. The bioherm is mostly made of calcareous tubes of polychet annelids, supplemented with Vermetids and coralline algae which are represented by small, platy encrustations and by coralline algal thallus cemented onto bedrock. Globular colonies of *Cladocora caespitosa* (Linneo) in living position, up to 0.8 m large (Fig. 5.15) mark the base of bioherm. Smaller colonies occur frequently close to the top of bioherm. *C. caespitosa* colonies represent not more then 10% of the bioherm. Also included within the bioherm are well-rounded pebbles and small boulders - up to 1.0 m of diameter - composed of limestone and basalt.

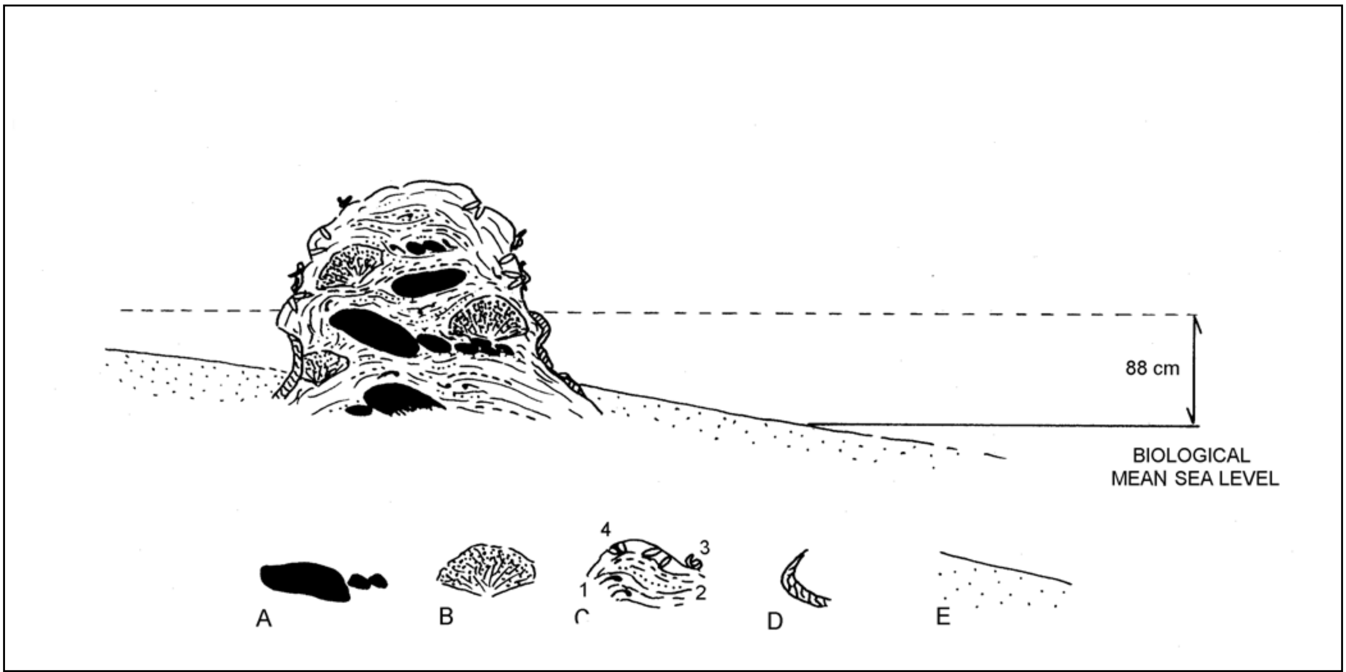


Figure 5.14 - *A scheme of Punta Pietre Nere bioherm and of the 2 cm-thick biogenic encrustation and their relationship with the present sea level. A - limestones and igneous blocks and pebbles; B - globular colonies of Cladocora caespitosa (max diameter 0.80 m); C - algal and Vermetids encrustations: C1 - reworked bivalves and gastropods shells, C2 - bioclastic sand and clay levels, C3 - Vermetids encrustations, C4 - Lithophaga sp.; D - Dendropoma sp. encrustation; E - present beach.*

Traces of activity of *Lithophaga* and clionid sponges as well as the presence of sea-urchins and of sessile organisms (i.e. *Arca* sp.) are apparent. The bioherm does not show any particular spatial variations in the distribution of constructor organisms or accessory biota.

Samples analysed under a light microscope confirm the presence of calcified Serpulid worms and coralline algae (*Lithophyllum* and *Tenarea* sp.). The inner interstices are filled by partially cemented bioclastic sands and clays; the superficial interstices show a second generation filling made by modern sands and clays.

The presence of Serpulid worms, algae, sponges, Vermetids, *Lithophaga* and other sessil bivalves in the inner part of bioherm points out that its growth occurred without emergence episodes; in fact they lived on the bioherm surface and were included in the bioconstruction ("coralligenous") during its development (Fig. 5.16).

In the Mediterranean Sea some similar Holocene fossil bioconstructions (algal-dominated reefs) but without large colonies of *C. caespitosa* and developed on a rocky substrate, have been recognised by Firth *et al.* (1996) and Kershaw (2000) along the northeastern coast of Sicily. These reefs are composed mainly of coralline algae and calcified worms and show a complex structure and composition which reflect variations in substrate morphology and local tectonic history. The altitude of these reefs has been used to infer that the northeastern coast of Sicily was uplifted as a series of sub-blocks with different uplift rates.

Montcharmont - Zei (1954, 1955) suggested on the basis of micropaleontological data that the development of Punta delle Pietre Nere bioherm occurred in shallow water in temperate climatic conditions, most likely during the last integlacial period.

Figure 5.15 - *A view of the large colonies of Cladocora caespitosa occurring inside the Punta delle Pietre Nere bioherm.*

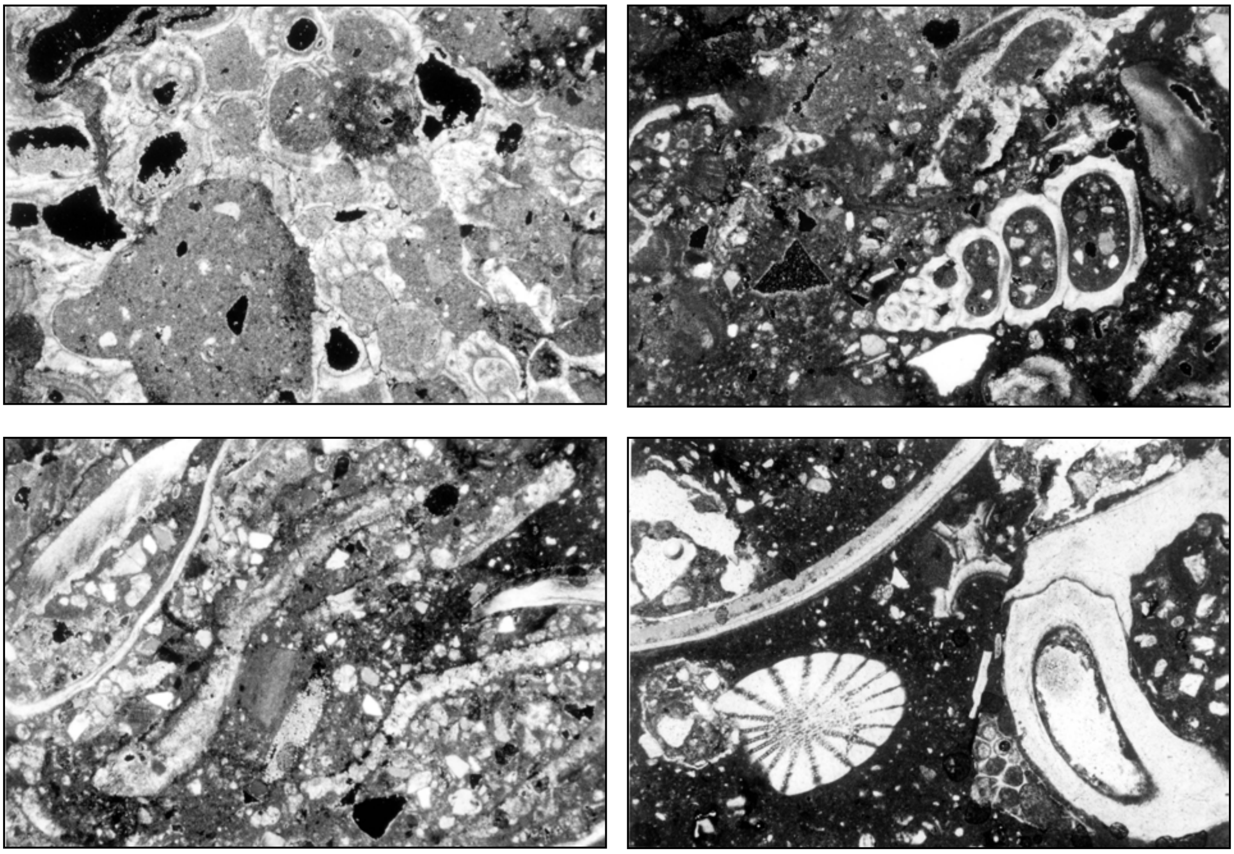


Figure 5.16 - *Particulars of Punta delle Pietre Nere bioherm.*

Figure 5.17 - *A general view of Punta delle Pietre Nere bioherm and of Dendropoma sp. encrustation upper limit placed at 0.88 m above biological mean sea level.*

Sample (No – Lab)	% Aragonite	$[U]_{ppm}$	$^{234}U/^{238}U$	$^{230}Th/^{234}U$	$^{230}Th/^{232}Th$	$[^{234}U/^{238}U]_{t=0}$	Age (ka)
PPN1 (6166)	95%	1,899±0,043	1,135±,021	0,106±0,003	1,47±0,04	1,140	12,1 [+0,3/-0,4]
PPN2 (6507)	97%	1,958±0,015	1,067±0,007	0,523±0,020	1,06±0,04	1,084	79,5 [+4,6/-4,5]
PPN 3 (6661)	99%	2,263±0,013	1,140±0,005	0,071±0,002	1,45±0,05	1,143	8,0 [+0,1/-0,2]

Table 5.2 – *Report of $^{230}Th/^{234}U$ age determinations on Cladocora caespitosa samples collected at Punta delle Pietre Nere. Th/U radiometric datings were performed on C. caespitosa samples at CERAK (Centre d'Etudes et des Recherches Appliqués au Karst), Faculté Polytechnique de Mons, Belgique (Table 1). Samples were subjected to the following procedures: a) the samples underwent diffrattometer analysis to define the Calcite/Aragonite ratio according to the method proposed by Griffin (1971). Since the C. caespitosa skeleton is composed of aragonite, the presence of signicant amount of calcite can indicate the opening of the geochemical system; b) the uranium concentration should be close to that of modern corals (about 2.7+/-0.5 ppm) (Smart and Frances, 1991); c) the ratio $^{234}U/^{238}U$ corrected for decay should be 1.15+/-0.02, that of modern sea water (Smart and Frances, 1991).*

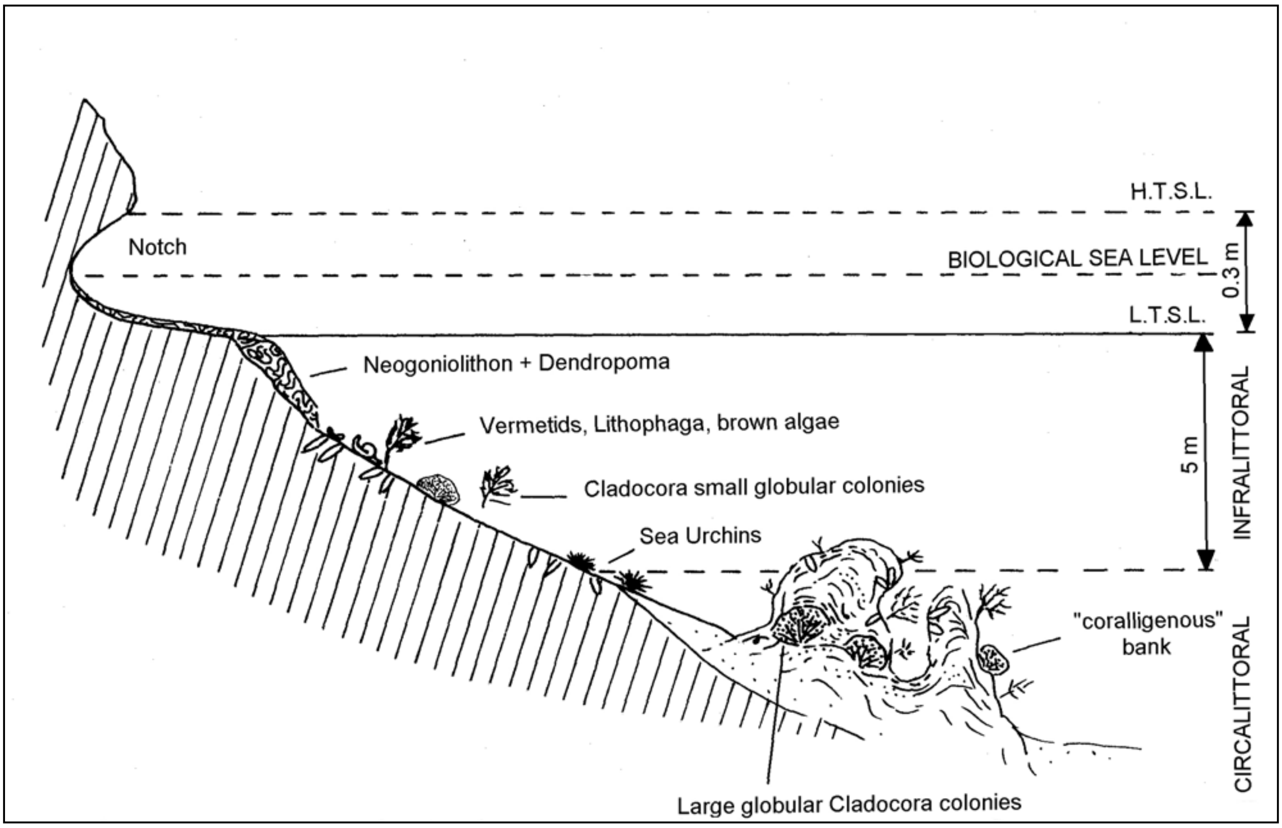


Figure 5.18 - *Distribution of erosion and bioconstruction at the Northern coast of Gargano reconstructed by bibliographic data and underwater survey; dotted lines indicate variable levels. At Punta delle Pietre Nere locality the limit between infralittoral and circalittoral zone is placed at about 5 - 15 m below sea level and marked by “coralligene - like” bio-constructed formations.*

This was despite the absence of the Senegalese fauna and the low elevation of the biogenic construction, which may suggest a more recent age may be Holocene (Caldara, 1993). The bioherm has also been referred to the last interglacial period in more recent papers (Boni *et al.*, 1969; Ricchetti *et al.*, 1999). We collected three samples of *C. caespitosa* which were dated using Th/U dating at CERAK - Faculté Polytechique de Mons, Belgique- in order to determine the age of this important bioherm (Tab. 5.2).

A sample for radiocarbon dating was also carried out on the PPN3 sample which yielded a conventional ^{14}C age of 5950±110 BP (Table 5.3) and confirmed a Holocene age of the *C. caespitosa* bioherm of Punta delle Pietre Nere locality.

At the Punta delle Pietre Nere locality, the Holocene uplift rate can be estimated using the altitude and age of the Holocene bioherm. This bioherm is characterised by calcareous algae, Serpulid worms, Vermetids and *C. caespitosa*, which lived at the limit of the infralittoral and circalittoral zones (Pérès, 1967; Bellan -Santini *et al.*, 1994). However, the depth of this limit can differ considerably depending on ecological and physical parameters (light, turbidity, waves, currents, etc.). At present along the Apulian coast, coralligenous biocoenoses occur on flat sandy sea floor at a depth of 4 -10 m, where they are indistinguishable from the concretions living at 10 or 20 meters depth (Sarà, 1968; Sarà and Pulitzer-Finali, 1970; Sarà, 1971).

At present, *C. caespitosa* lives in warm - temperate waters in the infralittoral and circalittoral zone, from a few centimeters below sea surface up to 50 m of depth, although it is rarely found below 30 m (Peirano *et al.* 1996; 1999). The presence of large pebbles and small boulders within the bioherm suggests that it formed close to the coastline, although large globular colonies of *C. caespitosa* can grow only below the mean wave breaking depth (Fig. 5.18). These observations suggest that the bioherm grew at a water depth between 5 and 15 m below present sea level. Indeed, in the northern Apulia coastal area the large amount of fluvially derived suspended sediment load reduces the depth of the photic zone. Similar living bioherms, characterised by presence of calcareous worms and coralline algae (but with no corals) have been recognised in the Adriatic Sea, near Pescara, between 5 and 10 meters depth (Corriero, pers. comm.). Presently no similar living bioherm have been found in the study area. This is probably due to the recent progradation of Fortore River coastal plain and to the large amount of fluvial sediment brought to the coastal zone.

Th/U and ^{14}C datings of *C. caespitosa* specimens do not match exactly. Systematic differences in age between Th/U and ^{14}C determinations have been observed by Edward *et al.* (1993) on corals of New Guinea. Holocene samples show a ^{14}C age about 1000 yr younger than Th/U age; in our case the difference is of about 1800 yr. Nevertheless, the combined analyses allow us to reject the previous attribution of the bioherm to the last interglacial period and to refer its development to the mid Holocene (6246 ± 139 cal. yr BP). This chronological attribution suggests that the shoreline linked to the bioherm development should be the Colle d'Arena relict cliff. Its foot marks the relative sea level position at the end of postglacial transgression at about 6 m a.p.s.l.. If this correlation is valid, the Punta delle Pietre Nere bioherm developed in a water depth of 5 m.

The broad indication of relative sea level suggested by the bioherm does not allow any precise determination of uplift rate. However, taking into account a depth of 5-15 m for bioherm development and a "eustatic" sea level of about -3.5 at 6200 cal. yr BP, an uplift rate ranging from 1.5 to 3.0 mm/yr can be calculated. A similar uplift rate is obtained based on the present altitude - about 2 m above p.s.l.- of the raised beach sediments dated at 2613 ± 45 cal. yr BP (Arena 2 sample).

Rapid sea level changes indicators

Samples	Laboratory No	Specimen	Method	Elevation n	Conventional 14C age (yr BP ± 1σ)	δ^{13} C_{PDB} ‰	Calibrated age BP	Calibrated Age AD/BC
				Punta Pietre Nere				
PPN3	GX-28709-PRI	*Cladocora caespitosa*	^{14}C	0.5	5950 ± 110	-3.6	6246 ± 139	4297±139 BC
1DOD	*GX-26368*	*Vermetid sp.*	^{14}C	0.95	1520 ± 110	-0.2	940 ± 130	AD 1009 ± 130
PN1	GX-27061	*Dendropoma sp.*	^{14}C	0.77 – 0.88	1210 ± 70	-3.3	640 ± 79	AD 1310 ± 79
1DOE	GX-26369-AMS	*Lithophaga sp.*	AMS ^{14}C	0.93	880 ± 40	-2.9	394 ± 66	AD 1557 ± 66

Table 5.3 – *Samples dated by AMS ^{14} C and by ^{14} C at Punta delle Pietre Nere. Radiocarbon age determinations were performed on coral and shell samples at Geochron Laboratories, Krueger Enterprises Inc., Cambridge, Massachussets, USA. Samples were cleaned throughly in an ultrasonic cleaner and then leached with diluite HCl to remove additional surficial material which may have been altered to be sure only fresh carbonate material was used. The cleaned samples were then hydrolyzed with HCl, under vacuum, and the carbon dioxide was recovered for analysis. The ages obtained are based on the Libby half-life (5570 yr) for ^{14}C. The error is 1 sigma as judged by the analytical data alone. The modern standard is 95% of the activity of N.B.S. Oxalic Acid. The age is referenced to the year AD 1950. The conventional radiocarbon ages have been calibrated using the CALIB 4.3 software (Stuiver et al., 1998). The marine reservoir correction for marine samples (1DOD, 1DOE, PN1, PPN3 samples) has been made using the ΔR values of 118 ± 60, obtained from the nearest sample to Gargano promontory, a specimen of Chlamys varia coming from Barletta, South Adriatic (Taviani and Correggiari, pers. comm.) (Stuiver et al., 1998).*

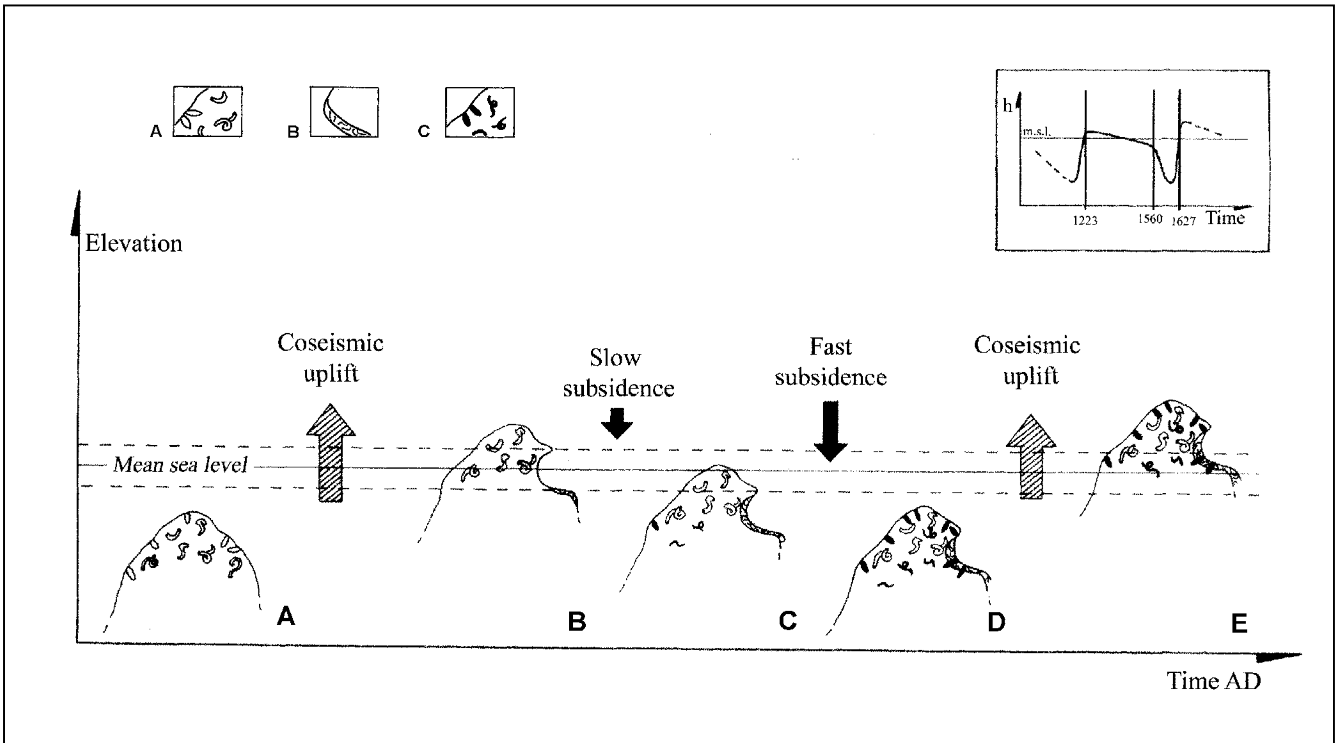


Figure 5.19 - *Model of the vertical movements occurred during historical times in response of major hearthquakes recorded at the locality of Punta delle Pietre Nere. In the box window is schematically reported a relative sea level curve for northern Gargano coast during last millennium. A - Vermetids and Lithophaga sp. (first colonization); B - Dendropoma sp. encrustation; C - Vermetids and Lithophaga sp. (second colonization).*

At the Punta delle Pietre Nere locality well preserved fragile and small sublittoral fossils have been found *in situ* in the supralittoral zone on the bioherm surface. In particular, there are remains of sparse Vermetids (*Vermetus* cf. *granulatus* Grav. and *Vermetus* cf *triqueter* Biv.) and articulated valves of *Lithophaga* sp. in bored holes scattered across the bioherm surface.

These shells are easily distinguished from those included in the inner structure of bioherm since they are not filled by fine sands or clays, are sparse on the bioherm surface, and are light in colour. In some cases, at the top of bioherm, Vermetid gastropods cover older *Lithophaga* boreholes which are sealed by fine sands. Evidence for a palaeosea-level is recorded by the presence of a discontinuous notch about 40 cm high and 30 cm deep shaped directly on the bioherm. It is occurs at about 77 cm above biological mean sea level. The entire notch surface is covered by a 2 cm-thick biogenic encrustation made by *Dendropoma* sp., which colonizes a continuous belt with an upper limit of 88 cm above biological mean sea level (Fig. 5.17). *Dendropoma* encrustation cover the older *Lithophaga* boreholes whereas is on its turn bored by recent *Lithophaga*..

- The error range of the performed height determinations depends on several factors linked to the possibility to identify the biological mean sea level (b.m.s.l.) as a reference datum (Laborel, 1986; Laborel *et al.*, 1994b). Where possible, these errors can be best estimated by comparing the upper limit of fossil formations and living populations. Unfortunately, the presence of beach sand deposits and the effectiveness of abrasion processes mean we were unable to determine the growth of living bioconstructions of *Dendropoma* at this site. However, a local determination of the biological mean sea level is provided by brown sea weeds which grow on the bioherm surface and from which a maximum error range of ±10 cm can be estimated (Blanc and Faure, 1990).

- Radiocarbon dating of Vermetid (1DOD sample) collected at about 95 cm a.b.s.l. yielded the conventional ^{14}C age of 1520±110 yr BP. Shells of *Lithophaga* collected at about the same altitude (1DOE sample) gave by means of an AMS determination a conventional ^{14}C age of 880±40 yr BP. The encrustation of *Dendropoma* (PN1 sample) yelded a conventional ^{14} C age of 1210±70 yr BP (Tab. 5.3). These data suggest that Vermetids colonized the mid Holocene bioherm surface during a period when it was completely submerged (phase A - Fig.5.19). This phase terminated at about 940±130 cal. yr BP (cal AD 1009±130) when subaerial exposure produced the death of Vermetids (phase B - Fig. 5.19). Subsequentely, a small notch formed, presently at 0.77±0.10 m above biological mean sea level, during a short-lived sea level stand. Simultaneously, the development of *Dendropoma* encrustation commenced near the low tide level (phase C - Fig. 5.19). *Dendropoma* is a good indicator of the upper infralittoral limit, growing always few centimeters underwater (Morhange *et al.*, 1998).

Dendropoma encrustation migrated slowly up the bioherm in response of a gradual, slow rise of relative sea level covering the entire notch and a slightly higher to a maximum of 0.88±0.10 m above present biological mean sea level. *Dendropoma* colonization ended at 640±79 cal. yr BP (cal. AD 1310±79) because of the rapid subsidence of the entire bioherm below the midlittoral zone (phase D- Fig.5.19) where *Dendropoma* can not survive.

During this phase *Lithophaga* bored the entire bioherm surface and the *Dendropoma* encrustation. A final emersion of the bioherm is dated at 394±66 cal. yr BP (cal. AD 1557±66) (phase E - Fig. 5.19) and caused the end of *Lithophaga* colonization.

The present altitude of notch (0.77±0.10 m a.b.m.s.l.) and of the mid-Holocene bioherm top surface (1.15 m), became entirely colonized by Vermetids in the phase A and by *Lithophaga* in the phase D. This indicates that emergence/submergence movements in the area probably exceeded 0.5 m.

Within the study area, the identification of recent sea-level positions is possible thanks to the presence of *in situ* bioconstructions and shells of boring bivalves associated to erosional marks. The remains of the mid Holocene bioherm in the locality of Punta delle Pietre Nere were part of a tiny island situated close to the shoreline up the eighteenth century, as shown by historical maps. Only during last two centuries it has been joined to the main land and become partly drowned by beach sands associated with the progradation of the Fortore River coastal plain. Marine organisms colonized the bioherm several times during historical times, and their remains provide evidence for relative sea level changes during the last millennium at this location. However, some uncertainties still exist due to the restricted number of radiometric age determinations and to the presence of markers as *Lithophaga* and Vermetids that occupy a wide depth range within the infralittoral zone.

Field evidence would suggest that these emergence episodes may represent coseismic uplift events. According to Laborel and Laborel Deguen (1994) and to Pirazzoli (1996) the preservation of fragile bioconstructions or shells, would have been impossible under conditions of slow, gradual emergence, because they would have been destroyed rapidly by midlittoral erosion. In our case the preservation of Vermetids shells, *Dendropoma* bioconcretion and articulated valves of *Lithophaga* would not been possible if gradual change in sea level had occurred. If our interpretation is valid coseismic rapid uplift in the area of Punta delle Pietre Nere would be preceded by local subsidence (Fig. 5.19), whose rate seems to increase shortly before a strong earthquake. A detailed study of historical sources provides a complete record of earthquakes during last millenium in northen Puglia (Boschi *et al.* 2000; Del Gaudio and Pierri, 2001) (Table 5.3). The strongest one occurred in the 1627 when four earthquakes of IX-XI intensity (MCS scale) hit the area between the Gargano Promontory and the Apenninic Chain (Molin and Margottini, 1981). This earthquake produced a number of ground effects in the lower valley of Fortore River (cracks, sand liquefaction, landslides etc.). It is likely that coseimic vertical movements also affected the Lesina lake area. Chronicles report that the earthquake raised the lake bottom whereas Lesina village, on the landward bank of the lake, underwent coseimic subsidence (*"... per il che si diceva che il furore del terremoto havesse alzato due volte il fondo del lago; altri scrivono che con voragine abbia assorbito la città di Lesina contigue ad esso lago..."* De Poardi, 1627) (Fig. 5.20).

Moreover, this event produced a large tsunami (Tinti *et al.*, 1995) that struck the northern coast of Gargano Promontory. A numerical simulation performed by Tinti and Platanesi (1996) suggests that a fault located inland caused the uplift of the sea block facing the Lesina lake.

Minor earthquakes (IX-X MCS) are reported for the area surrounding the Fortore River coastal plain even if for the oldest events epicentral area and earthquake effects are largely unknown (Tab. 5.4). Indeed, chronicles and documents report other evidence of probable vertical movements in the area. Thus, Lesina village was so severely damaged during the middle of the XVI century that it was abandoned. Tria (1744) refers the damage of the village caused by the flooding of the Adriatic Sea. This inundation was, given the absence of description of loss of life, likely to have been a gradual rather than a catastrophic event. Furthermore, strong earthquakes did not occur in this period in the area and nor have historical reports or morphological evidence been found of tsunamis during the XVI century (Gianfreda *et al.*, 2001). The relative sea level record reconstructed at Punta delle Pietre Nere would suggest that the diffuse damage of the Lesina village during the XVI century could be the associated with a relatively rapid pre-seismic subsidence preceding the strong 1627 earthquake.

Year	Month/Day	Epicentral area	Io	Imax	Me
1087	09/-	Apulia	6.5	7.5	5.0
1223	-/-	Gargano	8.5	9.0	5.7
1414	-/-	Vieste	8.5	8.5	5.7
1627	07/30	Gargano	10.0	10.0	6.8
1627	07/08	Gargano	9.0	9.0	6.0
1627	09/06	Gargano	8.5	8.5	5.7
1646	05/31	Gargano	9.5	9.5	6.2
1731	03/20	Foggia	9.0	9.0	6.6
1893	08/10	Gargano	8.0	8.5	5.4
1894	25/03	Lesina	7.0	7.0	5.0
1948	08/18	North Apulia	7.5	7.5	6.0
1948	08/21	North Apulia	-	-	-
1948	08/22	North Apulia	-	-	-

Table 5.4 – *Major earthquakes occurred in northern Apulia from 1000 AD (after Monachesi and Stucchi, 1998; Boschi et al., 2000). Earthquakes with unknown epicenter are pointed out in italics. Io, Imax and Me are the epicentral intensity (degrees, MCS scale), maximum intensity (degrees, MCS scale), equivalent magnitude, respectively.*

Figure 5.20 - *San Clemente island. The island, settled since the Bronze age, retains the ruins of a convent, whose last phase of construction is dated back to the XII century, just below mean sea-level.*

In summary, notwithstanding the inaccuracy of the geological and chronological record, and the incompleteness of historical reports, the comparison of geomorphological and historical data allows the following scheme of events to be outlined. The mid Holocene bioherm underwent coseismic uplift in response of a strong earthquake which occurred at the beginning of the last millennium, most probably the AD 1027 or AD 1223 event. As a consequence of this, the bioherm became a little island and the development of a notch started at mean sea level. At the same time the upper fringe of the sublittoral zone was colonized by *Dendropoma*. This association migrated then upward to colonize the entire notch in response of slow subsidence. Shortly before 1560 AD, *Dendropoma* colonization stopped in response to an increasing rate of subsidence which caused the submergence of the entire bioherm that was diffusely affected by the boring activity of *Lithophaga*. Finally, the strong 1627 earthquake caused the rapid uplift of bioherm to about 1 m above the biological m.s.l..

Site 5.4

Locality	Lesina Sandy Barrier
Municipality	Lesina
Province	Foggia
Coordinate WGS84	41.86857N, 15.35262E
Keywords	Coastal morphology, sandy barrier, coastal lake, tsunami washover.

Stop 5.4.1 - The Lesina coastal lake
(F. Gianfreda, A. Gravina, G. Mastronuzzi, P. Sansò)

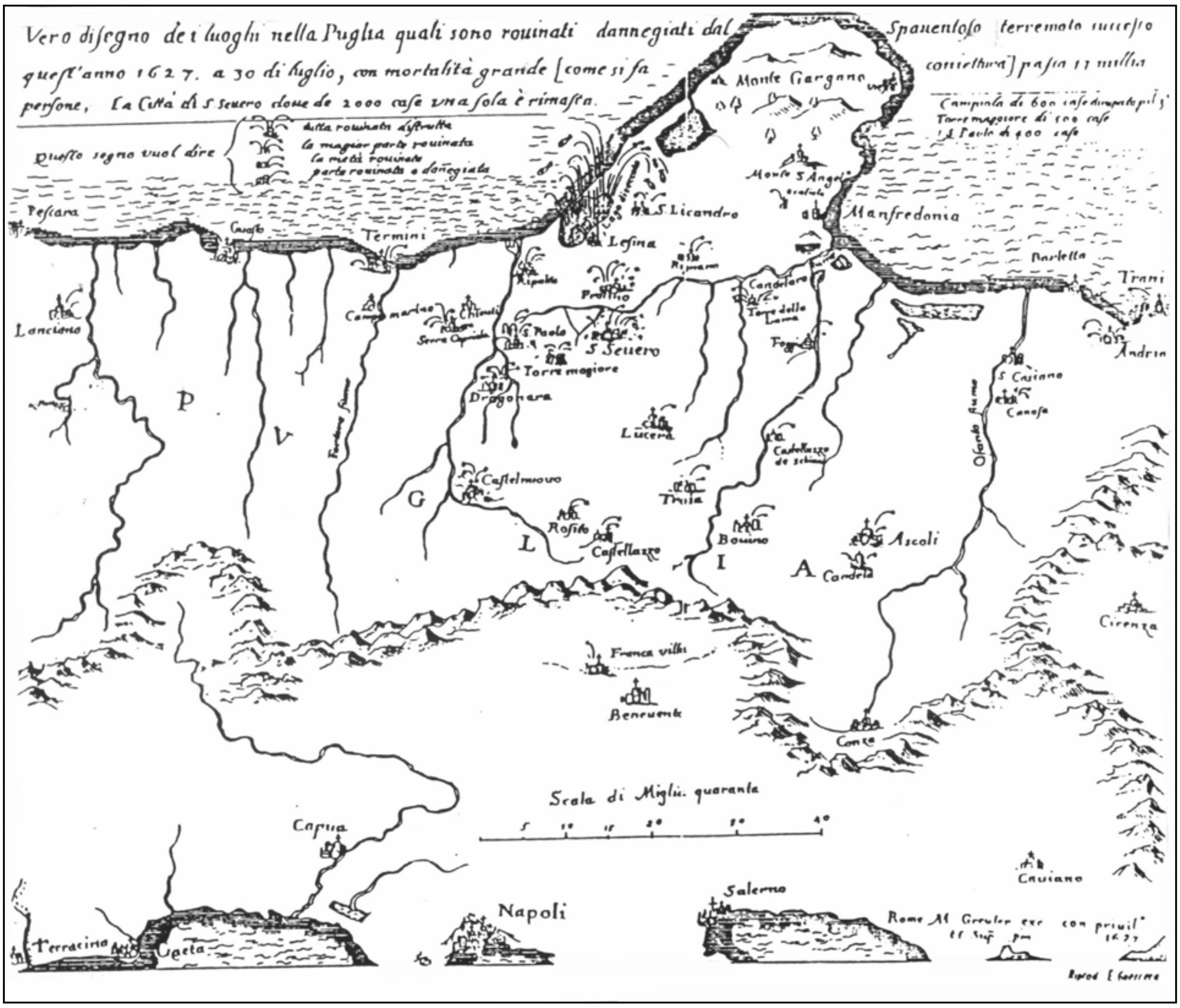


Figure 5.21 - *The effects of the 30th July 1627 earthquake and tsunami described in the Magini's map (1627).*

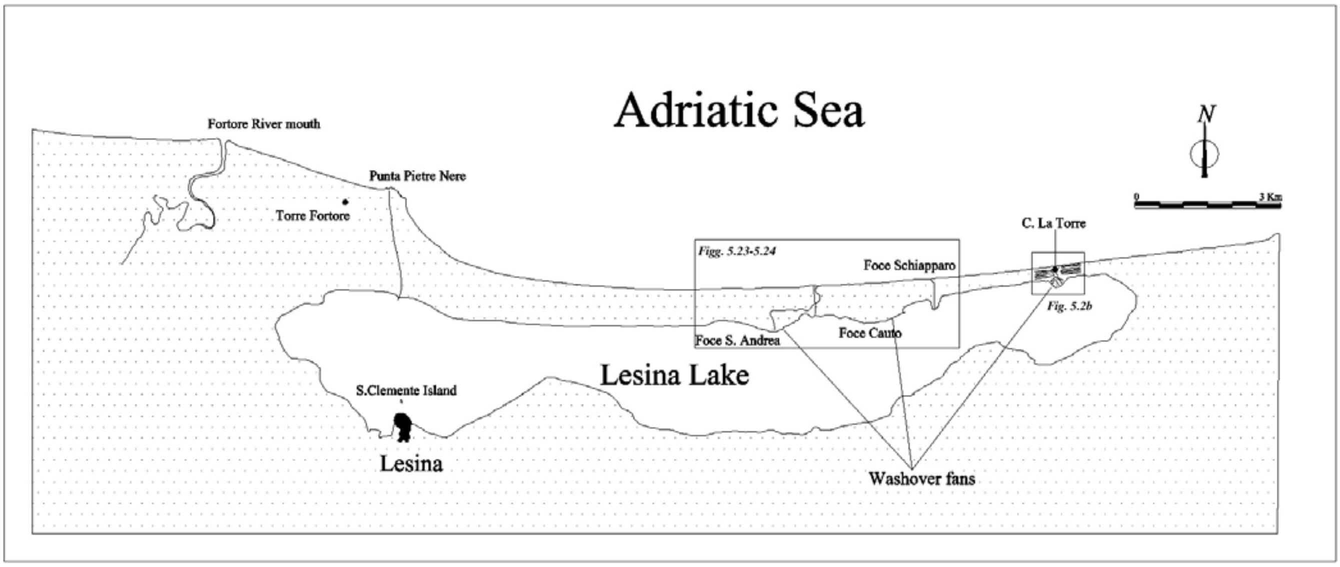


Figure 5.22 - *Geographic position of the Lesina coastal barrier and washover fans.*

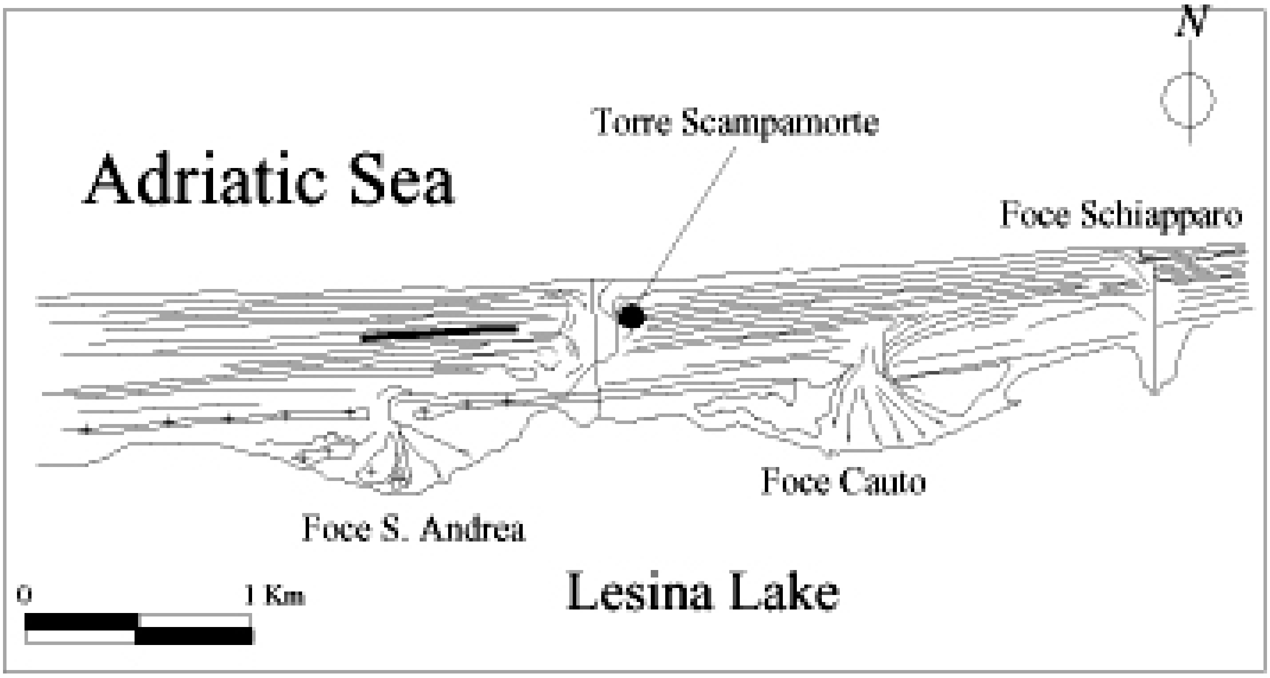


Figure 5.23 - *Dune ridges and washover fans on the Lesina coastal barrier in the area of Sant'Andrea and Foce Cauto.*

The Gargano Promontory is known to have been affected by several violent earthquakes during historical times, with epicenters localised both in inland and offshore areas. A detailed study of historical sources provides a complete record of recent earthquakes, some of which were accompanied by devastating tsunamis (Tinti *et al.*, 1995). The largest one occurred on the 30th of July, 1627 (Fig. 5.21). It was generated by an intensity-XI earthquake that caused severe damage and many victims (Molin and Margottini, 1981; Guidoboni and Tinti, 1987). A numerical simulation performed by Tinti and Platanesi (1996) suggests a generative fault located inland that caused the uplift of the sea block facing the Lesina lake. Historical sources (Molin and Margottini, 1981) report that the coastal waters withdrew as much as 3 km first and then overflowed into the lake. Minor tsunami events were reported on the 31st of May, 1646, the 20th of March, 1731, the 22nd of October, 1756, the 8th of December, 1889 and the 10th of August, 1893 (Tinti *et al.*, 1995).

Figure 5.24 - *The Foce Cauto washover fan.*

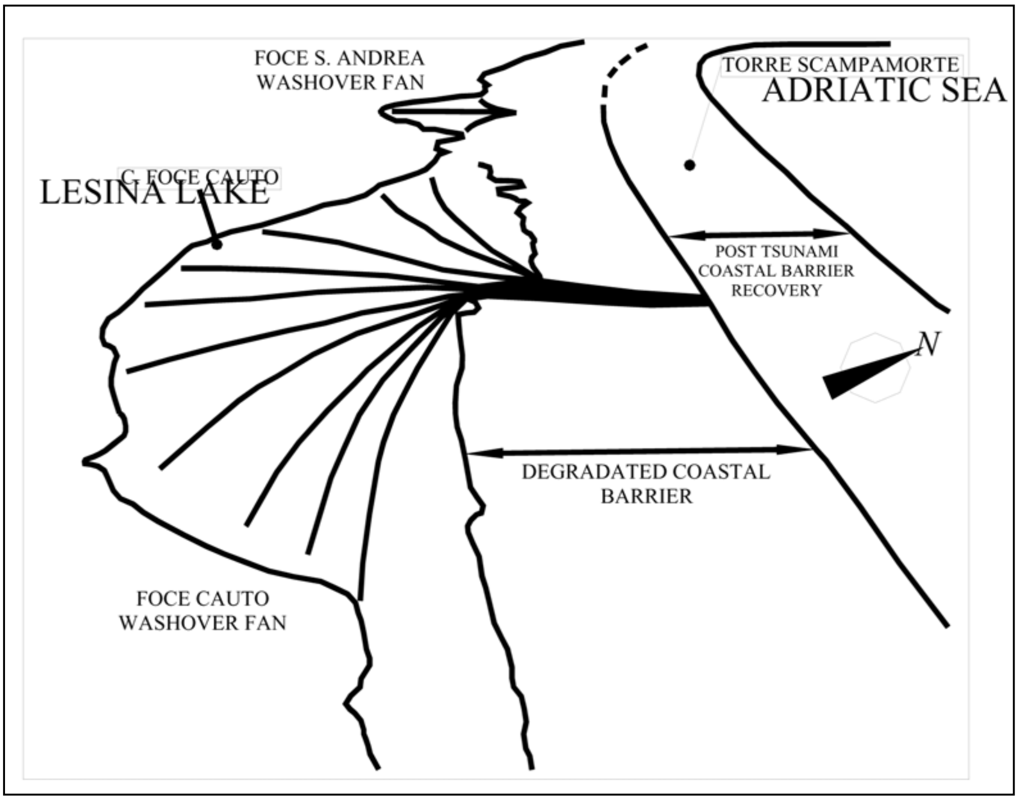


Figure 5.25 - *The geomorphological interpretation of the Lesina coastal barrier in the area of Foce Cauto from Fig. 5.24.*

Figure 5.26 - *A view of Casino La Torre washover fan and the growing urbanisation of the coastal barrier.*

The Lesina and Varano coastal barriers and lakes display favourable geomorphological setting to preserve a record of the effects related to tsunamis which struck the northern coast of Apulia during the last three thousands years (Fig. 5.22).

Archaeological and historical data allow the age of Lesina and Varano coastal barriers to be estimated.

The Lesina lake barrier is the older of the two barriers since it was most likely developing during the Bronze Age and completing its formation during Roman times (Gravina, 1995). The Varano lake barrier was open during Roman times, but closed between the V and VII centuries AD (Alvisi, 1970).

The Lesina lake is elongated parallel to the shoreline with a length of 22 km and a width of 1.8 to 3.0 km. The lake salty waters reach the maximum depth of about 1.9 m. The Lesina lake is divided from the Adriatic Sea by a continuous sandy coastal barrier characterized by mean elevation of about 3 m above m.s.l., reaching the maximum height of about 8 m at Gravaglione locality. It measures 1400 m in width at its western end to a minimum of 350 m to the east (Fig. 5.23). Two artificial channels connect the lake with the Adriatic Sea.

The Lesina coastal barrier can be morphologically subdivided into three parallel strips. The oldest is represented by the remnants of a high dune belt marking the landward border of the coastal barrier near Gravaglione locality. A washover fan at Foce S. Andrea breaks the lateral continuity of this ridge. The fan spreads over a radius of 500 m with its throat closed seaward by a more recent dune belt. On the surface of the fan, structures from the Roman age have been found. The second strip is about 300 m wide and is characterized by widely-spaced, degraded dunes punctuated by shallow grooves without preferential spatial orientation. This last zone is broken by the Foce Cauto washover fan which has a mean radius of 700 m (Fig. 5.24; Fig. 5.25). The fan apex passes seaward into a narrow, deep trench which is closed by the third, youngest part of Lesina coastal barrier. The latter strip is about 400 m wide and marked by a close sequence of straight, sharp dunes. The remarkable continuity of this strip is broken only by a small washover fan at C. La Torre with a radius of 250 m. The fan opens to the present shoreline through a narrow trench (Fig. 5.26).

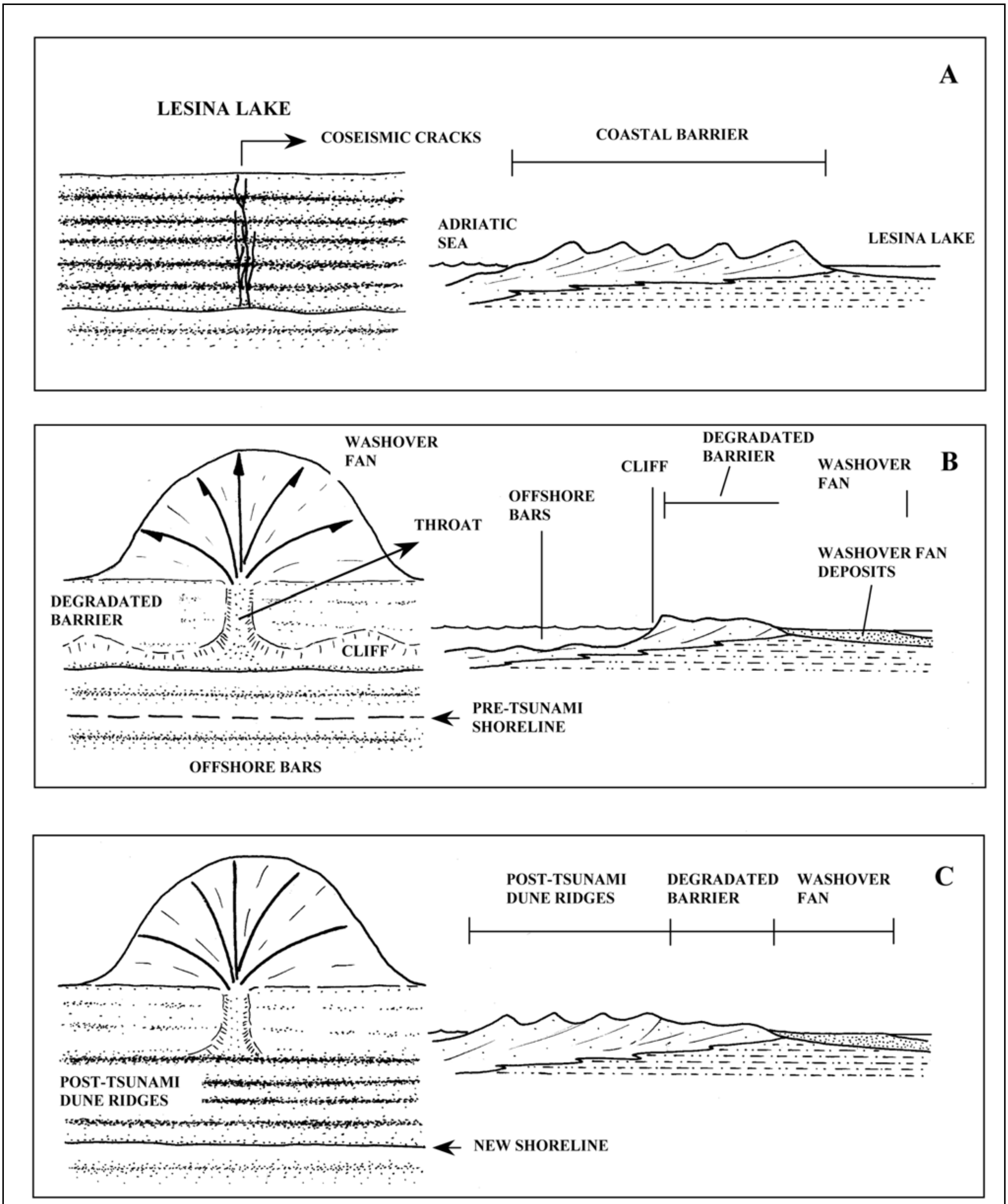


Figure 5.27 - *Geomorphological model of tsunami impact on the Lesina coastal barrier. A - coseismic cracks formed in the coastal barrier dune ridges during an earthquakes; B – tsunami waves flatten the coastal barrier ridges. Sea water running through the cracks shapes a narrow throat and a wide washover fan at the inner edge of the coastal barrier. At the same time, a cliff is cut at the seaward edge of the coastal barrier and significant amounts of barrier sediments are moved offshore forming submarine bars; C – normal waves are the final factor responsible for the transport of submarine bars sediments onshore, causing the recovery of the coastal barrier with new dune ridges forming and closing the washover throat.*

Discussion

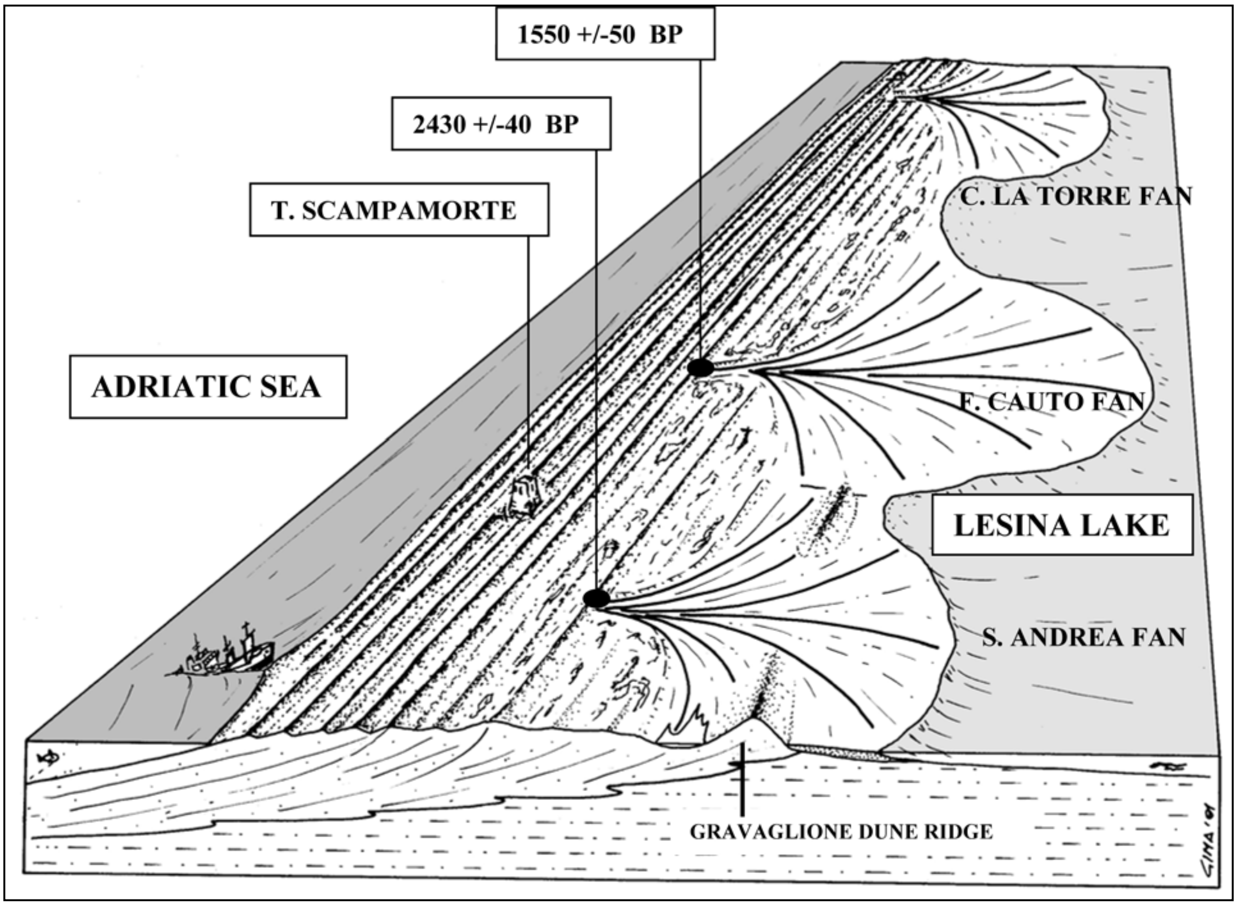


Figure 5.28 - *Geomorphological sketch of the Lesina coastal barrier. The position of samples dated by means of AMS radiocarbon age determinations is also reported.*

Washover fans form on a sandy coastal barrier when wave-swash overcame dune crest in correspondence of breaches or throats forming distintictive fans. They are made of a wedge-shaped body with the maximum thickness of the washover sediment at the barrier crest. With major surge volume the crest is often relocated landwards by sluicing overwash, and near continuous washover fans merge laterally into a washover flat (Orford and Carter, 1982).

The morphology of the Lesina coastal barrier indicates that at least three tsunamis struck the northern coast of Gargano Promontory in historical times. Each one deposited a washover fan 100.000 to 750.000 m^2 in area that excludes the action of storm waves restricted by the small, semi-enclosed state of the Adriatic Sea and by the small tidal range (about 1 m).

The washover fans were formed by catastrophic tsunami waves focused at distinct points of coseismic cracking that developed into narrow, long breaches through coastal barrier ridges (Fig. 5.27A).

The formation of cracks was noted during the earthquake of the year 1627 at several localities near the epicentre, affecting the alluvial deposits and sands of the Fortore River lower valley and coastal plain (Molin and Margottini, 1981). These marks are similar to those reported following the Japan Sea Earthquake and Tsunami of the 26th of May, 1983 (Minoura and Nakaya, 1991). Here, cracks that formed in the beaches and dunes separating Lake Jusan from the Japan Sea, allowed tsunami to rush into the back barrier area. At the Lesina coastal barrrier, during the second event, tsunami waves overtopped the coastal barrier leveling ridges and scouring a number of erosive grooves, similar to those reported by Sato *et al.* (1995) and McSaveney et al (2000) during tsunami events. Sea water ran through cracks forming a narrow throat and a wide washover fan at the inner edge of the coastal barrier. At the same time, the seaward edge of the coastal barrier was most likely cliffed and a signicant amount of barrier sediment was moved offshore forming submarine bars (Fig. 5.27B). This is similar to processes observed by Maramai and Tinti (1997) during the 3rd of June 1994 Java tsunami, and by Minoura and Nakaya (1991) in the offshore area soon after the Japan Sea Earthquake and Tsunami of 26th of May 1983. Normal wave climate was the final factor responsible for the transport of submarine bars onshore, causing the recovery of the coastal barrier and the formation of new dune ridges. These closed the washover throat and buried the cliff (Fig. 5.27C)

Morphological, archaeological and historical data allow a chronology of the tsunamis to be defined. The oldest tsunami and the first washover fan (S. Andrea fan) formation occurred before Roman times. It produced a gap in the coastal barrier which was exploited by the Romans to construct a waterway between the lake and the sea.

The same waterway was still in use during medieval times with the name of *Fuci Vetere* (Di Perna, 1998) and during the XVI century as shown by Gambacorta portolano drawings (1594). During this last period the waterway was protected by Torre Foce, built in 1568 and later named Torre Scampamorte (meaning “tower of avoided death”).

The Foce Cauto washover fan developed subsequentely. Its throat cuts across the dune ridges which closed the apex of the S. Andrea fan. Moreover it should be older than Torre Scampamorte construction which is placed at the third and youngest part of the coastal barrier and that could not have survived such a catastrophic event. The small washover fan of C. La Torre was formed in very recent times since its throat cuts through the coastal barrier.

Two AMS radiocarbon age determinations have been performed at Geochron Laboratories on pulmonate gastropods with the aim of dating this sequence. Samples of *Helix* sp. and *Pomatia* sp. were collected on the crest of the dune ridges closing the washover throats of the S.Andrea (S.Andrea - 1 sample) and Foce Cauto (Cauto –1 sample) fans. Results indicate an age of 2430 ± 40 years BP for the event responsible for S. Andrea washover fan development and 1550 ± 50 years BP for the formation of the Foce Cauto fan, confirming the reconstructed chronological framework. The relative calibrated ages of 736 ± 20 cal BC and 488 ± 55 cal AD, respectively, have been calculated using the CALIB 4.3 software (Stuiver and Reimer, 1998) (Fig. 5.28, Tab. 5.5)

Both the events are not documented in the historical chronicles and do not fit with none of the events reported by the most recent and updated catalogue of Italian strong earthquakes (Boschi *et al.*, 2000). Nonetheless, a strong earthquake in the Gargano area is described in one of the most important medieval sacred legends and traditionally dated at the 493 AD. It was enclosed on this basis in the older earthquake catalogues (*e.g.* Bonito, 1691; Mercalli, 1883; Baratta, 1901).

Samples	**Laboratory No**	**Specimen**	**Method**	**Conventional 14C age (yr BP ± 1σ)**	**δ^{13} C_{PDB} ‰**	**Calibrated age**
Cauto 1	GX 28021 AMS	*Pomatia sp*	AMS^{14} C	1550 ± 50	-8.6	**488 ±55 AD**
S.Andrea	*GX 28020* AMS	*Pomatia sp*	AMS ^{14} C	2430 ± 40	-7.4	**736 ±20 BC**

Table 5.5 – *Samples dated by AMS ^{14} C along the Lesina Barrier. The conventional radiocarbon ages have been calibrated using the CALIB 4.3 software (Stuiver et al., 1998).*

Figure 5.29 - *A view of the growing urbanisation on the Lesina coastal barrier.*

Recent structural data (Piccardi, 1998) suggest for this earthquake a magnitude between 6 and 7 in the southern area of the Gargano Promontory. The present study supplies the first convincing evidence that the 493 AD strong earthquake really occurred. It caused the tsunami which struck the Lesina coastal barrier forming the Foce Cauto washover fan.

Finally, the Casino La Torre washover fan formed during an event of minor intensity, most likely caused by the tsunami that struck the coast of northern Gargano on the 30th of July, 1627.