4th day

Late Quaternary deposits and archaeological remains along the Adriatic coast of Puglia

by

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Introduction

During the 4th day the geomorphological and archaeological features of the coastal area stretching at the foot of Ostuni scarp will be shown. The transfer from Taranto will run in the first tract in west-east direction along the Soglia Messapica, which divides the Murge plateau, to the north, from the Brindisi-Taranto plain, to the south. The second tract crosses the Murgia Plateau (cfr Cap 2) reaching the foot of the Ostuni scarp which separates the plateau from the low elevated coastal area.

Geological and geomorphological setting

The landscape of this part of the Adriatic coastal area is dominated by the presence of the Ostuni scarp, a large geomorphological feature linking the elevation between about 300 and 120 m a.m.s.l.. The scarp was previously considered to be formed by an important tectonic fault. However, a different origin has been recently proposed by some Authors (Guarnieri *et al.*, 1990; Laviano and Pieri, 1990; Luperto Sinni *et al.*, 1994; Laviano, 1999): the inner area of Murge Plateau and the local top of carbonate sequence would be a late Mesozoic back reef unit (Calcari di Altamura) whereas the Ostuni scarp is thought to be the eastern margin of the Apulia carbonate platform (Fig. 4.1).

Figure 4.1 - *The Ostuni scarp between Fasano and Ostuni.*

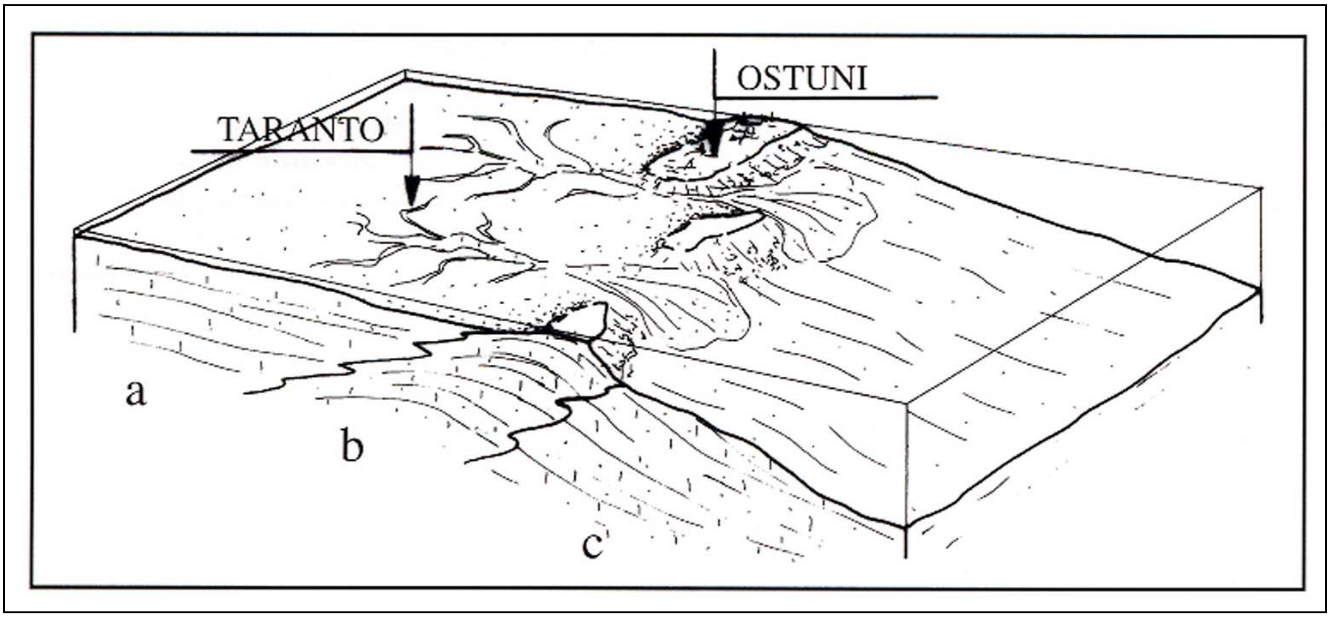


Figure 4.2 - *A schematic reconstruction of the carbonatic platform of Apulia during the late Mesozoic (from: Laviano, 1999).*

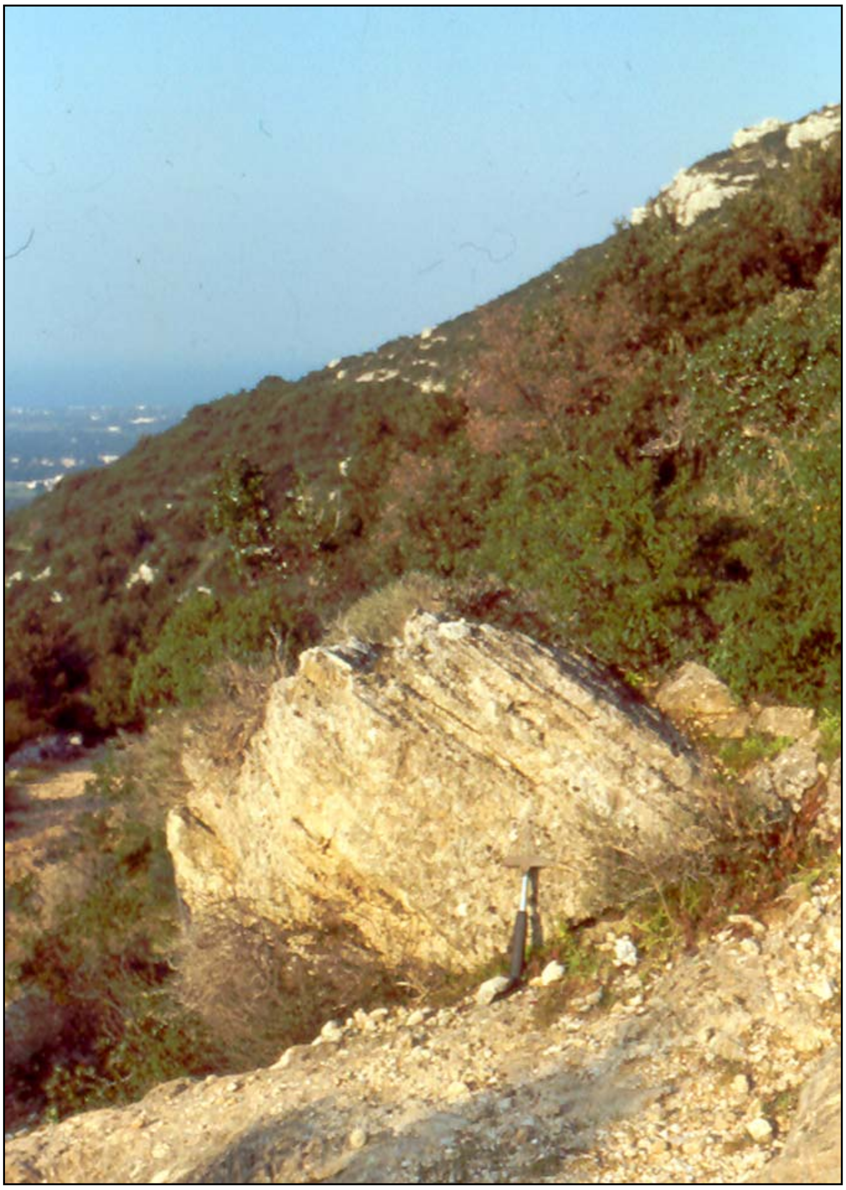


Figure 4.3 - *The Middle Pleistocene dune deposits recognised at the top of Ostuni scarp (about 280 m a.p.s.l.).*

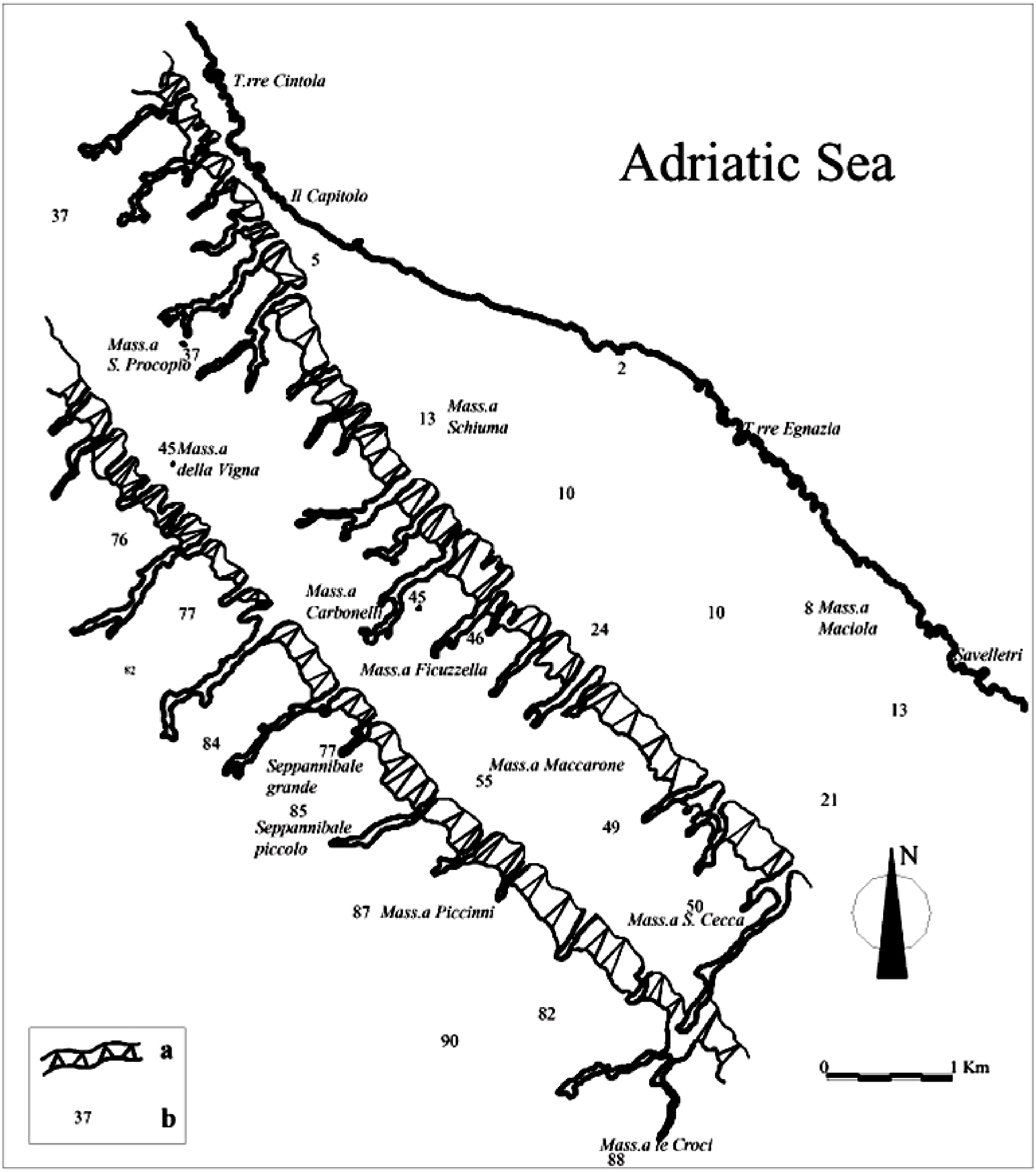


Figure 4.4 - *Geomorphological sketch of the coastal area stretching along the Adriatic coast to the southeast of Monopoli. a – relict coastline; b – elevation (m).*

In particular, near the Ostuni village a bioclastic calcareous unit named Calcari di Caranna, typical of the Y zone of the Selley (1976) model, crops out (Fig. 4.2) (Luperto Sinni *et al.*, 1994).

A well-cemented aeolian deposit has been recognised in the upper part of the Ostuni Scarp. It most likely developed during the first phase of marine terrace formation, in the Middle Pleistocene (Neboit, 1975) (Fig. 4.3).

The coastal plain stretching at the foot of Ostuni scarp is compound by five main terraces arranged in a staircase from about 65 m of altitude to sea level. They are mainly abrasion platforms shaped on the Plio-Pleistocene calcarenites (Calcarenite di Gravina) as only small patches of marine terraced deposits can be found in this area (Di Geronimo, 1970). The lowest of the marine terraces reaches the maximum altitude of about 4 m in correspondence of a relict coastline which is marked by a well cemented dune belt.

Figure 4.5 - *A view of the partly submerged sapping valley of Torre Encina near Monopoli (Bari).*

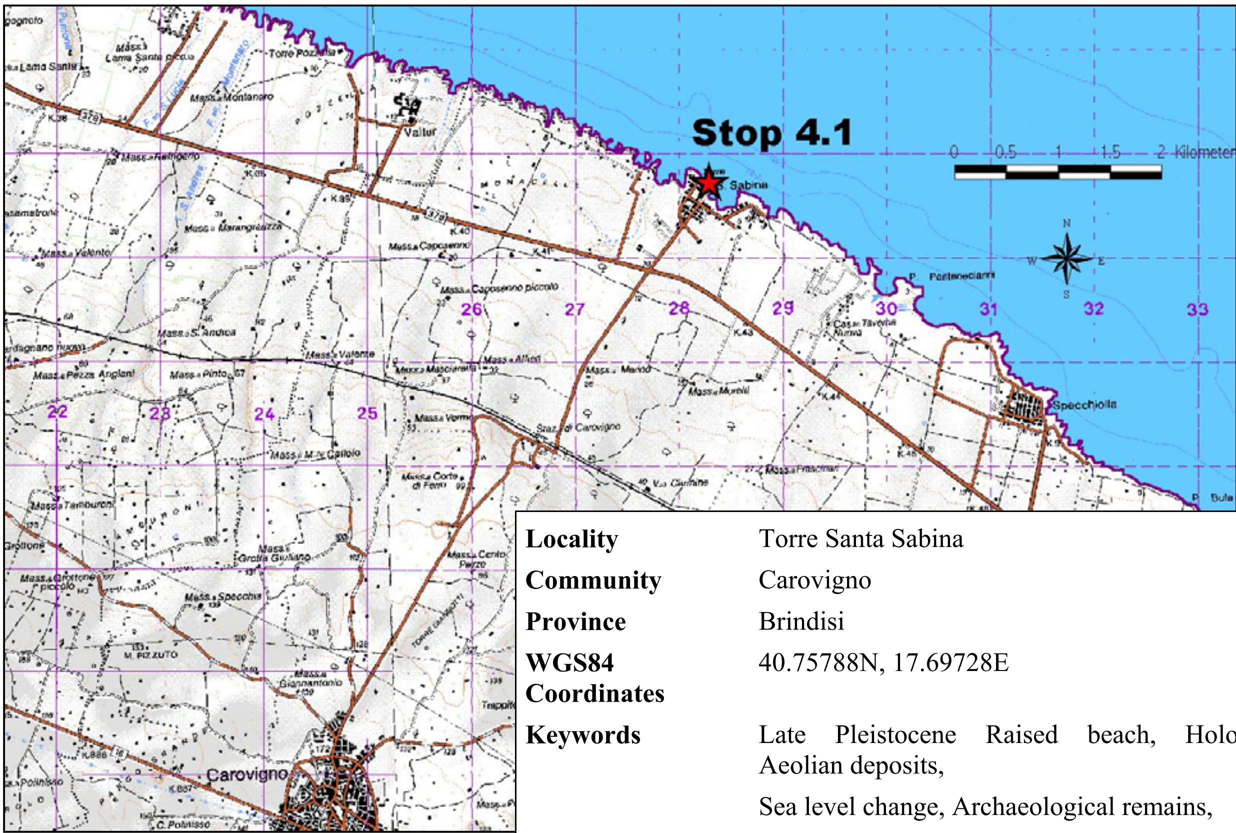
Four other surfaces can be recognised at higher altitude, showing their outer-inner margin at 10-13 m, 15-22 m, 25 - 40 and 45-65m, respectively (Fig. 4.4). Regional geomorphological evidences suggest that the formation of these terraces most likely occurred during Middle-Upper Pleistocene high sea level stands, even if no absolute age determinations are available yet.

The monotony of the coastal landscape is interrupted by a relict drainage network made of deep sapping valleys, locally named lame, which dissect the entire terrace sequence (Fig. 4.5) (Mastronuzzi and Sansò, 2002b; cfr Stop 3.2.2).

The coast is made of three main morphological types: gently sloping rocky coasts, low cliffs and beaches. Gently sloping rocky coasts are formed by a gently sloping flat surface, cut through cemented Plio-Pleistocene calcarenites or Mesozoic limestones. Cliffs characterise several coastal tracts (Maracchione *et al.*, 2001): near Monopoli and north to Torre Guaceto they are shaped in Plio-Pleistocene calcarenites, near Polignano they cut the Mesozoic limestones whereas in the Brindisi area they are generally composed of clays at the base and calcarenites at the top.

Beaches are less than 40 m wide and up to 8 km long; they are generally placed inside small inlets limited by calcarenitic headlands. Beaches are bordered landward by a dune belt of historical age, which often covers a early/mid-Holocene cemented dune core (Dini *et al.*, 2000; 2001; Mastronuzzi *et al.*, 2001; Mastronuzzi and Sansò, 2002c). The presence of the Early/Middle and Late Holocene dune belts produced a number of coastal swamps supplied by fresh water springs (Mastronuzzi and Sansò, 2002c). Many of these backdune areas have been reclaimed and urbanised.

Site 4.1 - Torre Santa Sabina



Locality	Torre Santa Sabina
Community	Carovigno
Province	Brindisi
WGS84 Coordinates	40.75788N, 17.69728E
Keywords	Late Pleistocene Raised beach, Holocene Aeolian deposits, Sea level change, Archaeological remains, catastrophic waves deposits

Stop 4.1.1 - The Ancient Harbour
(R. Auriemma, G. Mastronuzzi, P. Sansò)

Human activity and settlements developed along the coast of southern Puglia since the Neolithic promoted by the presence of coastal lagoons for hunting/fishery activities and coastal plains for agricultural practices. At Torre Santa Sabina, human presence could be ascribed to the Palaeolithic time. In particular, during the second millennium b.C., the southern Adriatic and Ionian coast was interested by the rising of numerous settlements and by the Greek colonization. During Roman times, the major towns of Puglia - *Tarentum*, *Brundisium, Hydruntum* and *Callipolis* - were connected to Rome by a network of roads. Some of these roads, as Via Traiana and Via Appia, running along the coast, were studded by small villages, the *mantiones* as *Karbina*, placed near Torre Santa Sabina.

On the contrary, the coastal area was deserted during the Middle Ages, because of malaria desease with the exception of major towns. The coastal area was marked by small fishery harbours and, because of the presence of calcarenitic outcroppings, studded by large quarries. They supplied the building material for a defensive network of castles and towers built along the coast against pirates fleets.

The area of Torre Santa Sabina played an important role during the Roman and Middle ages as testified by the presence of an important harbour and by large quarries.

Figure 4.6 – *The submerged medieval quarry of Santa Sabina. The bottom is up to 1.4 m b.p.s.l.*

Figure 4.7 - *Torre Santa Sabina. Roman drainage channel at present partially below present sea level.*

Detailed underwater geomorphological and archaeological surveys put in evidence the presence of three wrecks of Roman age in the second inlet placed to the south of the tower.

More important for the reconstruction of sea-level change is the presence of a wide submerged medieval quarry at the headland which separates the two inlets placed few meters to the southeast of the tower (Fig. 4.6). Moreover, the northern side of the Mezzaluna pocket beach, north of the tower, is cut by a sewer channel of Roman age. It have the outlet at 0.8±0.10 m below the biological sea-level (Fig. 4.7).

Stop 4.1.2 - The Late Pleistocene raised beach deposits (G. Mastronuzzi, B. Mauz, P. Sansò)

The local stratigraphical sequence can be observed along the coast few meters to the west of the Torre Santa Sabina. Locally the gently sloping rocky coast is shaped on the following stratigraphic sequence (Fig. 4.8):

a. bioclastic calcarenites marked by large bivalves, echinoids and algal pellets related to the Calcarenite di Gravina formation of Plio-Pleistocene age; few km to the NW of Torre Santa Sabina area, near Monopoli, the sequence was ascribed to the Early Pleistocene (D'Alessandro and Iannone, 1982; 1984);
b. colluvial deposits made of continental reddish clayey sands with numerous small pebbles of quartz, pedogenetic pisolites and coatings. A flint shred was found in this deposits; it could be referred to a not well defined Late Paleolithic – Mousterian on the base of the general scheme of the human presence on the Murgia Plateau reconstructed so far;
c. brownish fine and well sorted calcarenites with intense bioturbation mainly due to worms and crustaceans activity (Fig. 4.9). This shoreface deposit could be referred to the last interglacial period on the base of elevation and stratigraphic relationships.

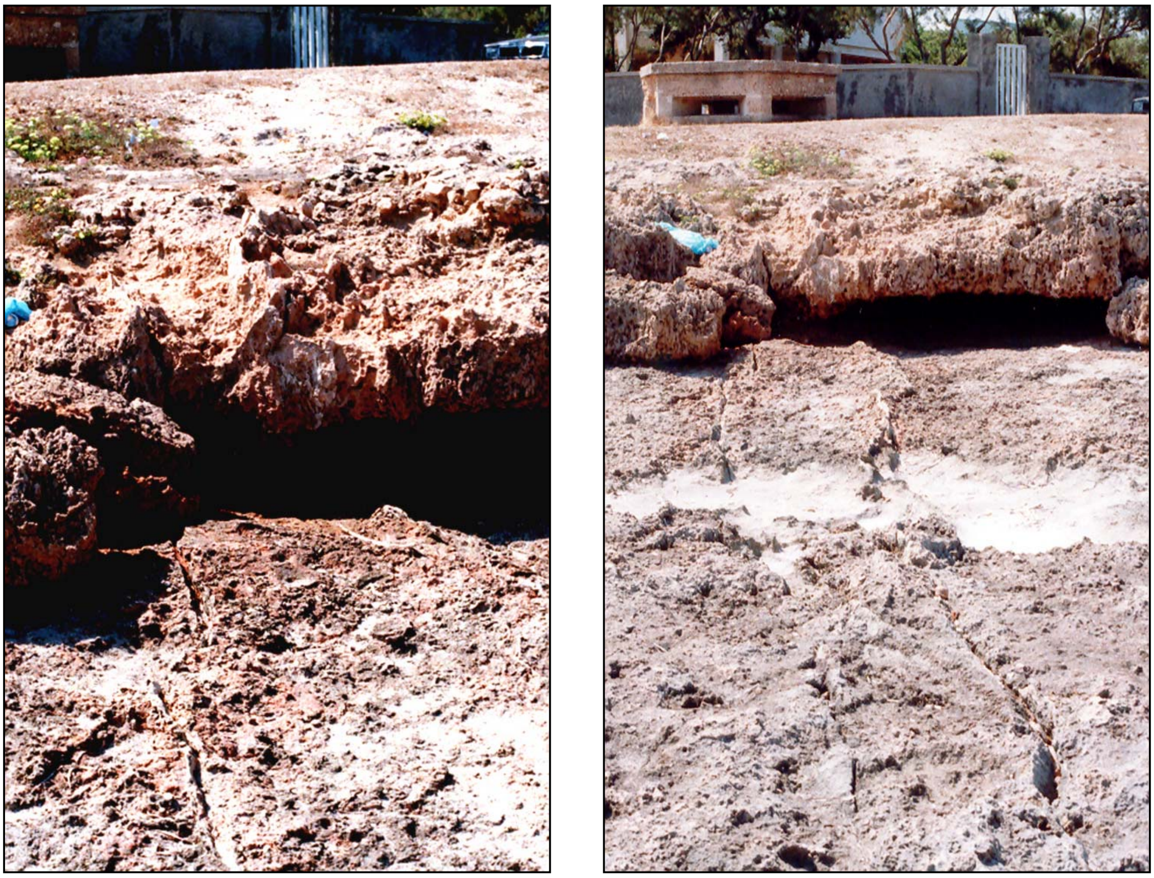


Figure 4.8 - *A view of the network of fractures which cuts the Plio-Pleistocene Calcarenite di Gravina and the Pleistocene marine terraced deposits in the surroundings of Santa Sabina. These fractures can be frequently found in other localities along the Adriatic coast.*

Both calcarenites are affected by irregular fractures sealed by calcitic filling showing a well defined lamination (Fig. 4.8). The filling is about 5-15 cm thick, vertically laminated and more resistant to weathering and erosion than the bedrock. According to Magagnosc (1980) similar structures form in semi-arid regions in response to local earthquakes.

In northern Africa, the strong 1980 earthquake produced numerous fractures marked by different width and depth which affected either the soil and the bedrock. Detailed analysis of fractures shows that they often developed along former joints and that they were rapidly cemented by crystallisation of sparitic calcite (Fig. 4.10).

At Torre Santa Sabina, some fractures are not sealed by sparitic calcite suggesting a very recent activity. Moreover, seismogenic sedimentary structures have been found in marine sediments of Last Interglacial age cropping out in this coastal area north of Bari and south of Brindisi (Moretti and Tropeano, 1996; Moretti, 2000). Their presence would confirm that this region has been affected by active tectonics during recent times.

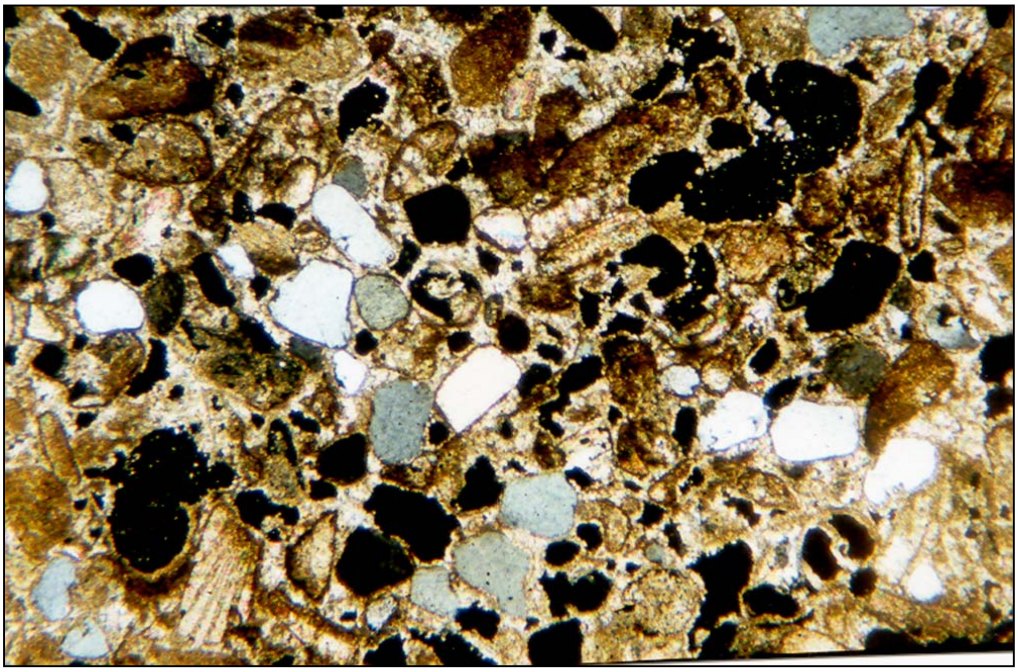


Figure 4.9 - *Views of the shoreface deposits belonging to the raised beach of Santa Sabina*

Stop 4.1.3 - The boulders accumulation
(G. Mastronuzzi, P. Sansò)

At the Torre Santa Sabina site an accumulation of about 80 boulders were found. A detailed topographical survey of this boulders accumulation and of the surrounding coastal area was carried out to obtain data concerning the direction and the strength of waves responsible for boulders transportation and deposition.

The coast is locally composed of a rocky platform gently sloping seaward, placed between 0.5 and 2 m above m.s.l. and shows a mean slope lower than 4°. In greater details, the platform surface is affected by weathering micro- and meso-landforms in correspondence with its seaward limit. Wave erosion has shaped in its easternmost part a short, wide channel open to the NNE direction. The detailed submerged profile of the coast was reconstructed by direct scuba surveying. It is marked by an irregular, steep surface which joins the low tide platform, up to 8 m wide, to a sandy plain placed at a depth of approximately 4.5 m. This surface shows variable length (from 12 to 22 m) and mean slope (from about 14% to 25%); it is also marked at several points by deep potholes and to a greater extent it has been colonized by brown algae. Some boulders, with major axis up to 4 m in length, rest on this surface; many of them moved recently as can be ascertained from the lack of colonization or by the presence of white, unweathered rock on some parts of their surface.

A total station was used to survey the position, altitude, size and a-axis direction of each boulder, as well as the detailed topography of the emerged rocky platform itself. Boulders are scattered along a strip stretching from the coastline to the maximum altitude of 2 m; however, the largest boulders are to be found concentrated along a narrow belt WSW-ENE oriented, between 0.5 and 1.5 meters above m.s.l..

The largest boulders are slabs of calcareous sandstones (a-axis>b-axis>>c-axis) with size up to 2.9x2.4x0.7 m and weighing up to 8 tonnes (Fig. 4.11). They are generally arranged in small groups of three or four elements, often imbricated and disposed in lines. The surface of some boulders was colonized by marine organisms living in the mid-infra littoral zone as *Dendropoma* sp. and bored by *Lithophaga* shells. In a few cases, biogenic encrustations can be observed at the lower face of boulders, indicating that they must have overturned during their transportation. Boulder 72 covers man-made features (most likely small salt pools) which most probably date back to the late Middle Ages (Fig. 4.12).

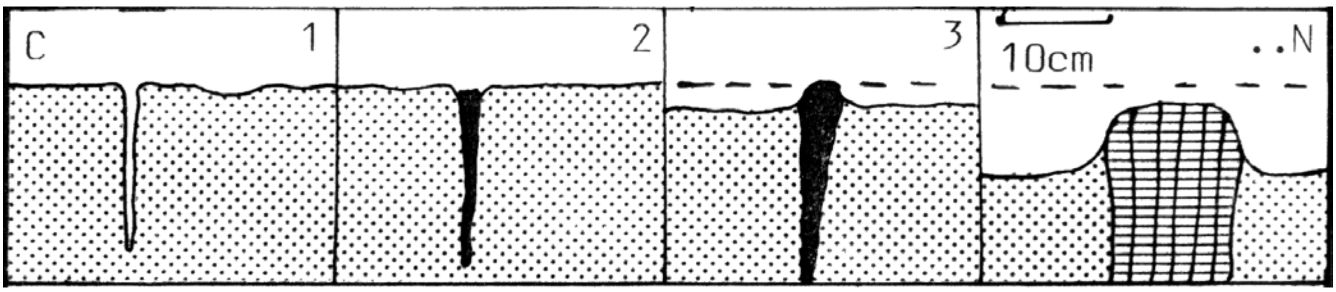


Figure 4.10 - *Model of coseismic fractures genesis and laminated sparitic calcite development (after Magagnosc, 1984).*

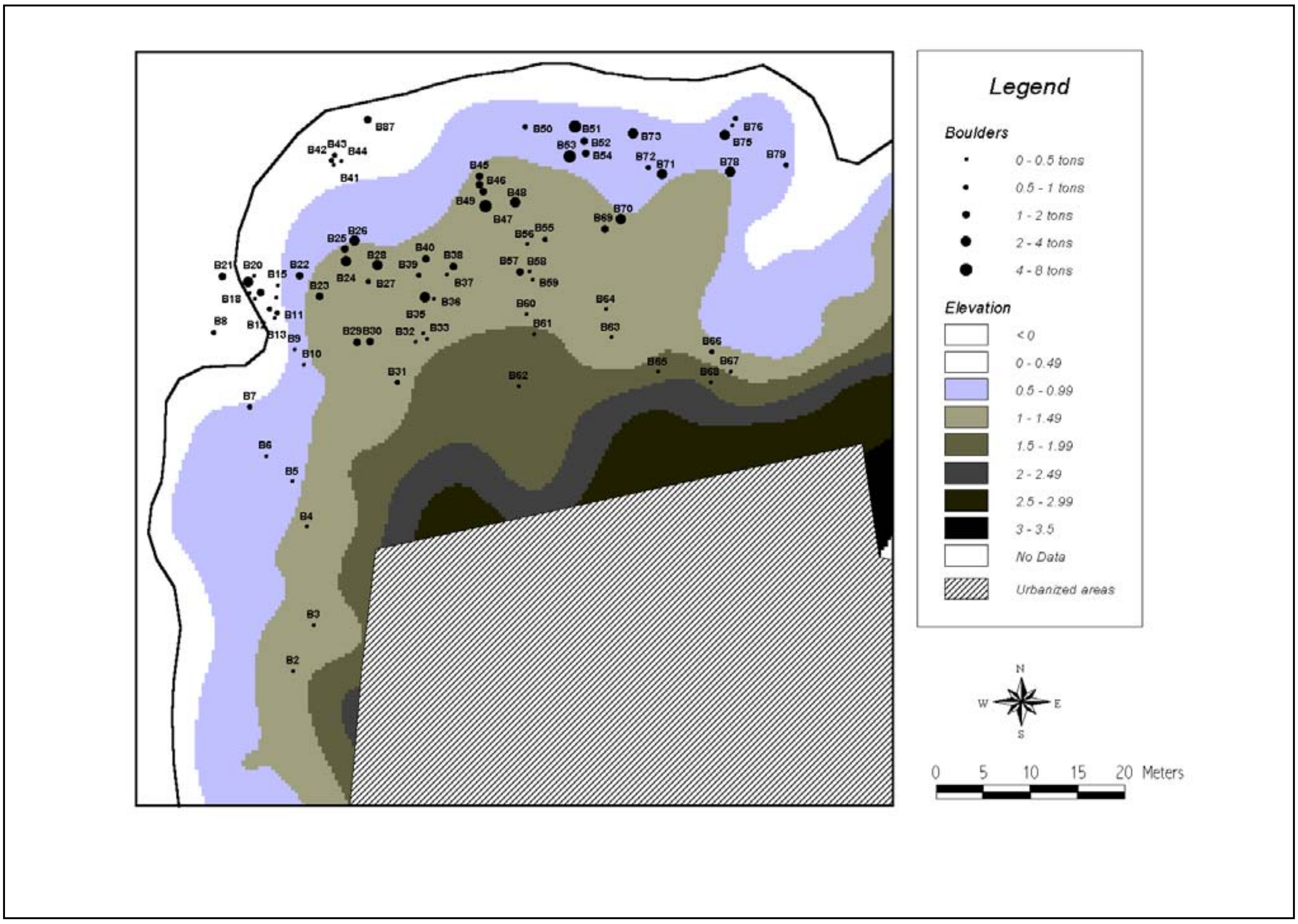


Figure 4.11 - *Boulders position and weight distribution at Torre Santa Sabina locality.*

Samples of Vermetids were gathered from the surface of four imbricated elements (B47, B46, B49, B45) (Fig. 4.13; Fig. 4.14) and their age established by using radiocarbon dating techniques. With the exception of B47, the other boulders are overturned. The conventional age of the samples is 610+/-60, 540+/-60, 1200+/-80 and modern age respectively (Table 4.1). We expect that the age of B45 and B49 boulders, the youngest elements of imbricated row, should be younger or very similar to B47 and B46 age.

The obtained conventional age for B49 boulder can be explained either taking into account boulder reworking, pollution coming from older fossil remains or particles of Plio-Pleistocene bedrock included within the *Dendropoma* encrustation.

Figure 4.12 - *The B72 boulder cover a manmade features, probably a small salt pool which date back the late Middle Age.*

The modern age of B45 sample, performed with AMS techniques on a shell of Vermetid, indicate a very recent deposition of this boulder. The calibration of radiocarbon age determinations, carried out using CALIBRA 4.3 software and adopting a deltaR value of 43±48 (Stuiver *et al.*, 1998), yielded the calibrated age range from 1667 to 1843 for boulder number 47 and from 1797 to 1904 for boulder number 46.

The 4th of January 2002, shortly after the detailed topographical survey, a severe sea storm was produced by strong NE winds whose velocity exceeded 30 knots. The National Wave Measuring Service (*Servizio Ondametrico Nazionale*) buoy at Monopoli, which is stationed few kilometers to the NW of T.S. Sabina area, recorded waves marked by significant height up to 4.8 m and peak period of 8.3 seconds propagating with N43E direction. These wave statistics indicate this extreme event as among the most severe storms at sea recorded along this coastal area since the ninenties (fig. 4.15).

Figure 4.13 - *A view of Dendropoma encrustations on B49 boulder.*

During the sea storm one single boulder was detached, transported landward for about 1.6 m and eventually deposited at 0.5 m of altitude. The boulder has triangular shape (2.2 m at its base, 1.3 m in height and about 0.7 m thick) and weighs 1.4 tonnes. The biogenic colonization present at the base of the boulder indicates that it was carved out from the midlittoral-sublittoral zone, and that it overturned during transportation. The place where the boulder was detached from has been identified by means of scuba survey.

During another storm at sea occurred on the 12th of January 2003 the boulder was moved once again by storm waves with a significant wave height of 4 m and peak period of 9.1 seconds propagating in N49E direction (data from Monopoli buoy, RON - Rete Ondametrica Nazionale/National Wave Measuring Service). The boulder was transported for about 20 m in NE-SW direction, colliding at first with the B42 and B43 imbricated boulders before stopping against the B15-16-17-18-19-20 imbricated boulders group, where it is now established as a new imbricated element with its upper face dipping parallel to the direction of transportation (Fig. 4.16).

An attempt to determine the approach direction of the actual waves responsible for the boulders accumulation has been made by measuring the spatial distribution of elongated boulders' major axis (a-axis) (49 elements), and assuming the a-axis to be parallel to the crest of waves responsible for depositing the boulders, and while considering as of no great relevance any disturbance due to a few irregularities in the surface of the rocky platform. Boulders a-axis (Fig. 4.17) shows a bimodal distribution marked by two frequency peaks at N80E and at N110E orientations which should indicate directions of wave approach of N350E and N20E, respectively. Furthermore, notwithstanding the spatial distribution is of a complicated pattern, it does clearly indicate that boulders with different a-axis orientation intersect with each other at several points and that some groups of imbricated boulders are made up of elements belonging to both sets. In details, boulders transported by waves approaching the coast with N350E direction are in several cases much heavier than those ones transported by N20E wave trains.

The large boulders accumulations studied in our survey are seen to share features with others which have been commonly described in other coastal regions of the world. These latter accumulations have been often related to catastrophic waves but it has generally proven difficult to make any distinction between the action of storms waves and that of tsunami.

At Torre Santa Sabina locality, field data point out that the observed large boulders accumulation is the cumulative effect of several storm waves events. The effect of each event is superimposed on the effect of the preceding effect or of one or two tsunami run-up events.

Furthermore, some features of boulder accumulations such as imbrication, arrangement in groups or rows, etc., are not specific for tsunami run-up, but can also be ascribed to storm wave action.

A hydrodynamic approach was adopted by Nott (1997) to determine whether tsunami- or cyclone-generated waves were responsible for the deposition of fields of well-imbricated boulders (up to 290 tonnes in weight) along the coast of Cairns inside the Great Barrier Reef, Australia. This Authors defined two equations which take into account the forces necessary to overturn boulders in the surf zone; the means permit to calculate the minimum height required by tsunamis or breaking waves to render them capable of initiating the transportation of boulders.

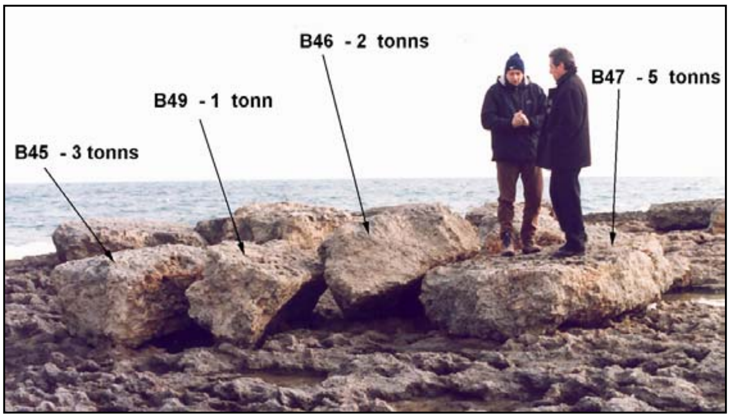


Figure 4.14 - *The boulders line which has been dated by 14C analyses (cfr. Table 4.1).*

Applying these proposed equations to the boulders at Torre Santa Sabina, one can calculate a maximum breaking wave heigth of about 24 m and a tsunami height of 1.5 m (Tab. 4.2) (Mastronuzzi and Sansò, 2003). Breaking wind waves with this characteristics can be produced by deep water waves which should have a significant height of 11 m and a peak period of about 22 seconds. It is very unlikely that waves with such characteristics could be generated in the semi-enclosed Adriatic Sea. A significant height of about 6.5 m has been calculated from Monopoli buoy data for storm waves in the southern Apulia area for a return period of 100 years (Corsini *et al.*, 2002). This figure corresponds to a breaking wave height of about 12 m, capable to overturn a boulder weighing about 2.5 tons.

Taking all these considerations into account, it can be surmised that the detaching and depositing of very large boulders (weight>2.5 tons), could be the effect of the run-up of unreported tsunamis, occurred during the last three centuries.

However, no tsunamis have been reported as having struck the Adriatic coast of southern Apulia in the course of the last five centuries, and this notwithstanding the fact that numerous tsunami-generative earthquakes have taken place in the southern Adriatic and northern Ionian regions during last millennium.

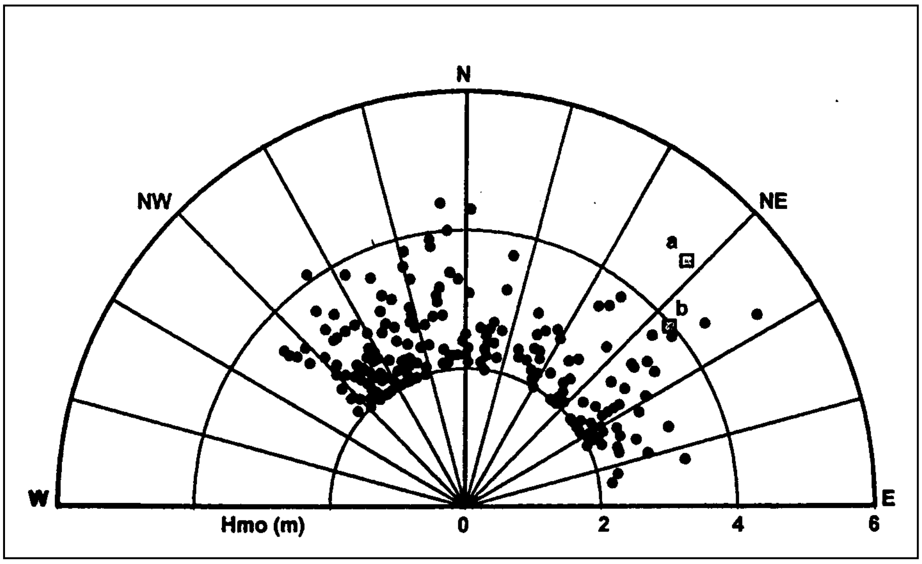


Figure 4.15 - *Azimuth distribution of waves higher than 2 m recorded since 1990. Grey boxes indicate the storm waves characteristics of 4th of January, 2002 (a) and of 12 January, 2003 (b).*

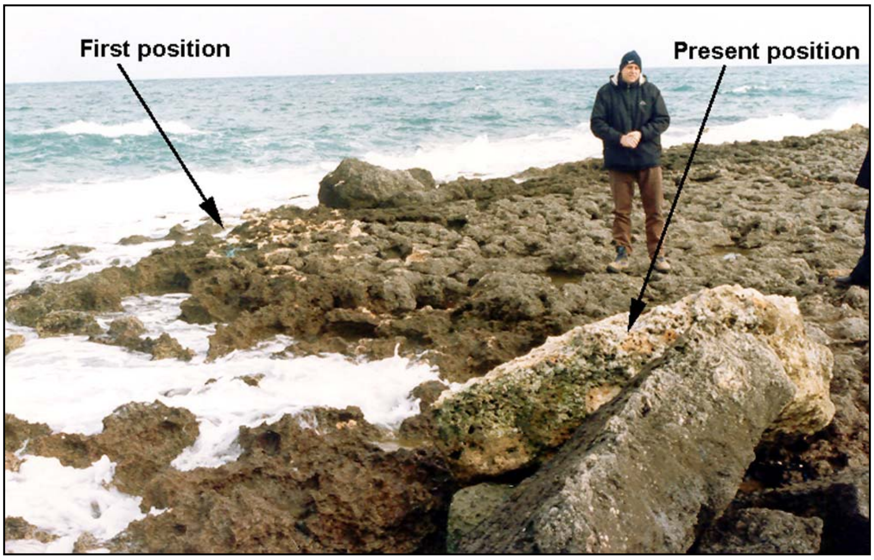


Figure 4.16 - *A view of the B87 boulder on B15-16-17-18-19-20 imbricated group.*

A sea withdrawal was observed at Brindisi harbour during the strong earthquake occurred the 20th February, 1743, however there was no inundation following it (Tinti and Maramai,1996).

Perhaps, the lack of historical chronicles concerning these events may be due to the low height of seismic sea waves and to the absence of settlements in these coastal areas until very recent times. A further enigma is posed by the presence of the stone-walled coastal tower of Santa Sabina.

This tower, which was built very close to the coastline during the XVI century, would almost certainly have been affected by a tsunami run-up and it is likely that news of any damage would be mentioned in the local chronicles. According to the chronological and morphological data at our disposal, two distinct tsunamis may have struck the Adriatic coasts of southern Apulia. The first to take place would be linked to the strong earthquake which struck Ragusa (modern day Dubrovnik) on the 6th April 1667. The epicentre of the earthquake, which was accompanied by a destructive tsunami, was located a few kilometers offshore the Dalmatian coast, about 190 kilometer to the NNE of southern Apulia coast (Guidoboni and Margottini, 1988). Very probably the second tsunami to take place was produced by the strong earthquake which hit southern Apulia on the 20th February 1743. The actual epicentre of this earthquake remains unknown, though it is generally indicated as having been somewhere to the south of the island of Corfù. However, the areas most severely affected by this earthquake are to be found at the southeastern border of studied area. A strip of land stretching from Taranto to Brindisi was affected by an "increase of intensity" (Margottini, 1981), and the already mentioned sea withdrawal in the harbour of Brindisi could support the hypothesis of the generation in the area of a small tsunami. While bearing in mind all of the uncertain factors cited here above, a model possibly capable of providing an explanation for the formation of large boulders accumulation observed at Torre Santa Sabina could be formulated as follows. In an initial phase, boulders would have been carved out during major sea storms, from the midlittoral zone for the most part, capsized and deposited on the seaward limit of the rocky platform.

Samples	Laboratory No	Approx. Weight (tonns)	Overturned	Specimen	Method	Conventional 14C age (yr BP ± 1σ)	$\delta^{13}C_{PDB}$ ‰	Calibrated Age AD
B47	GX-28869	5	N	*Dendropoma* sp.	^{14}C	610 ± 60	+0.4	1667 – 1843
B46	GX-28868	2	Y	*Dendropoma* sp.	^{14}C	540 ± 60	-0.1	1797 – 1904
B49	GX-29669	1	Y	*Dendropoma* sp.	^{14}C	1200 ± 80	+0.4	-
B45	GX-29790	3	Y	*Dendropoma* sp.	AMS ^{14}C	103 ± 0,43 % of modern ^{14}C activity 1950	+0.4	-

Table 4.1 – *Samples dated by ^{14}C at Torre Santa Sabina; age calibration for marine samples was performed by mean of CALIB 4.3 software and adopting ΔR values of 43±48 (Stuiver and Reimer, 1998). Analyses were performed at Geochron Laboratoires Krueger Enterprises Inc. (Cambridge, Massachusets, U.S.A.).*

Boulder	A-axis (m)	B-axis (m)	C-axis (m)	Volume (m^3)	Weigth (tonnes)	Storm wave heigth (m)	Tsunami heigth (m)
B87	2.2	1.3	0.6	0.9	1.4	9.3 (7.5)	-
B24	2.4	1.8	0.5	1.9	3.1	19.5	1.2
B51	2.9	2.4	0.7	4.9	7.9	22.7	1.4
B79	3.3	2.2	0.5	2.6	4.3	23.8	1.5
B78	1.7	2.7	0.6	1.9	3.1	24.1	1.5

Table 4.2 - *Largest boulder sizes and wave (tsunami and storm) heights required to their transport. B87 boulder was detached from sublittoral zone and transported by a breaking wave 7.5 m high during the storm of 4th January, 2002; during the storm of 12th January 2003 it was transported farther inland for about 20 m (cfr. photo 5) and imbricated on a larger boulder.*

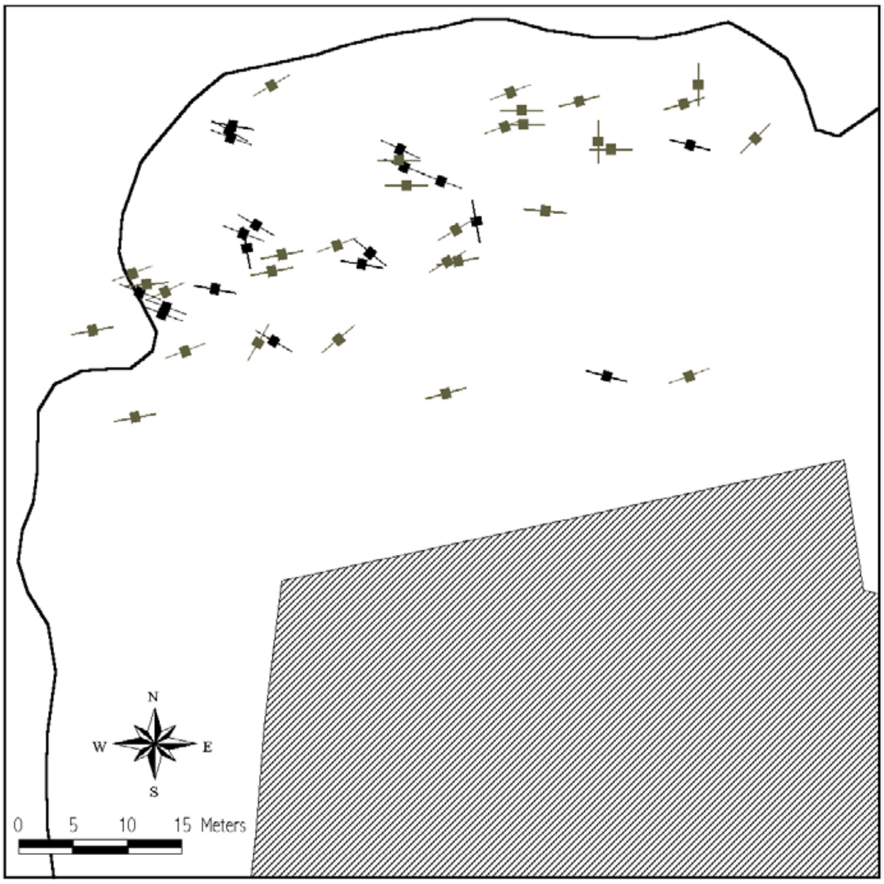


Figure 4.17 - *Long axis distribution of elongated boulders in Torre Santa Sabina locality.*

Unreported tsunamis would have been responsible for the detachment of the largest boulders. Some time there after further severe storms would have caused the sliding of the same boulders along the even surface of the rocky platform. This latter process would have required less energy that than unleashed in the initial phase, and would have determined the development of "packed" assemblages of boulders made of rows or group of imbricated elements and this would also account for the particular distribution of the a-axis of elongated bouders, as observed in our survey.

Stop 4.1.4 - The solution pipes
(A. Marsico, G. Selleri)

Puglia region is characterized by a complex karst landscape shaped on Mesozoic, Miocene and Plio-Pleistocene carbonatic rocks and developed in response of several morphogenetic phases which took place since the late Mesozoic under different climatic and tectonic contexts. In particular, numerous localities placed along the Adriatic coast show a particular type of karstic landforms, the solution pipes, which developed on Plio-Pleistocene calcarenites during the late Pleistocene. The pipes of Torre Santa Sabina (Fig. 4.18) are nearly cylindrical and concave-bottomed; the section changes from circular to slightly elliptical, with diameter ranging from few centimeters to around 40-50 cm, decreasing in depth. Pipes diameter increases where they intersect bedding planes. The maximum depth is about 2 meters, but some forms are few decimetres deep.

Sandy silty clay or clayey sandy silt fill the pipes. Clay rate increases toward the pipes bottom most likely because of the dissolution of the carbonatic bedrock and to the insoluble residue concentration inside pipes and on their walls. The carbonatic fraction is nearly absent.

Figure 4.18 - *A view of Torre Santa Sabina solution pipes.*

Pipes walls are covered by a brownish concretion, from a centimeter to more than a 10 centimeters thick. Brownish carbonatic nodules of different sizes can be found frequently inside the pipes, near the walls and at the bottom. The concretion also covers with discountinity the Plio-pleistocene calcarenitic bedrock. Some pipes are longitudinally cut by joints and diffusely tapered by whitish calcite (Fig. 4.19). A small shift of about 1 centimeter has been measured between the two edges of a pipes. Root traces represented by vertical, tubular and twisted calcitic concretions, with thickness of 2-5 mm and convex endings, have been recognized inside the crust (Fig. 4.20). Roots traces are constituted by cryptocrystalline calcite and show a concentric structure in cross section. These data would suggest that the calcium carbonate has not gradually replaced the vegetable structures but that it precipitated in the void originated by roots degradation.

Pipes cluster in groups of numerous elements of different sizes, separated by large areas where pipes are almost absent. It is not possible to put in evidence a relationships between pipes distribution and geometry and frequency, geometry and position of the joints affecting the bedrock.

T.S. Sabina pipes can be interpreted as cryptokarst forms (Nicod, 1976). According to Fabre and Nicod (1982), during the Pliocene and the Quaternary this type of corrosion played an important role in the evolution of the Murge karst landscapes and in other regions at the same latitudes in the Mediterranean area.

Several theories exist on the formation of cryptokarst surfaces. In literature different importance is given to the presence of perched groundwater, to the seepage chemical characters, to the role of the vegetation (p.e. Fabre et Nicod, 1986; Jennings, 1987; Nicod, 1992; Walsh & Morawiecka-Zacharz, 2001). According to Quinif (1998) this type of corrosion is connected exclusively to the structural context of the region. The cryptokarst landforms developed by dissolution of the carbonatic bedrock beneath a permeable and not karstifiable cover. The permeable rock allows slow infiltration and it can hold perched groundwater which feeds seepage (Bonte, 1963).

The resulting forms consist in depressions, pipes, pinnacles, ruinforms, crypto-dolines and crypto-kluftkarren. During the cryptokarst evolution, the permeable cover sinks in the voids of the bedrock created by dissolution. This process produces on the topographical surface closed depressions which could be subsequently filled with palustrine and alluvial sediments Along pipe walls, crypto-dolines, etc. walls a concretion constituted by insoluble minerals originated by carbonatic bedrock dissolution forms (Bonte, 1963).

The erosion of the soil cover exposes a landscape characterised by cryptokarst.

At Torre Santa Sabina the cover, which promoted pipes formation, is still preserved since it has been fossilized by a calcarenitic beach deposit. The cover is made of reddish sandy clayey silt or continental silty clayey sands, up to 1.5 meter thick. The silty and sandy fractions are constituted almost exclusively by sub-spherical and well rounded grains of quartz in the coarse fraction. Subangular granules with smoothed edges have been found in the fine fraction as well as small quantities of pyroxenes and opaque minerals; grains surface is covered by thin layer of reddish oxides.

The carbonatic fraction is almost exclusively constituted by fragments and shells of continental Gastropods; they are scattered in the sediment or disposed in discontinuous and thin layers. The deposit is also marked by lithoclasts and bioclasts coming from calcarenites as well as by little pebbles and clasts of Mesozoic micritic limestone. Rare Foraminifera and reddish or dark rounded aggregates of oxides can be recognized. Thin layers or lens of sands made of well rounded quartz grains and, subordinately, of limestone mark the lowermost levels of the cover.

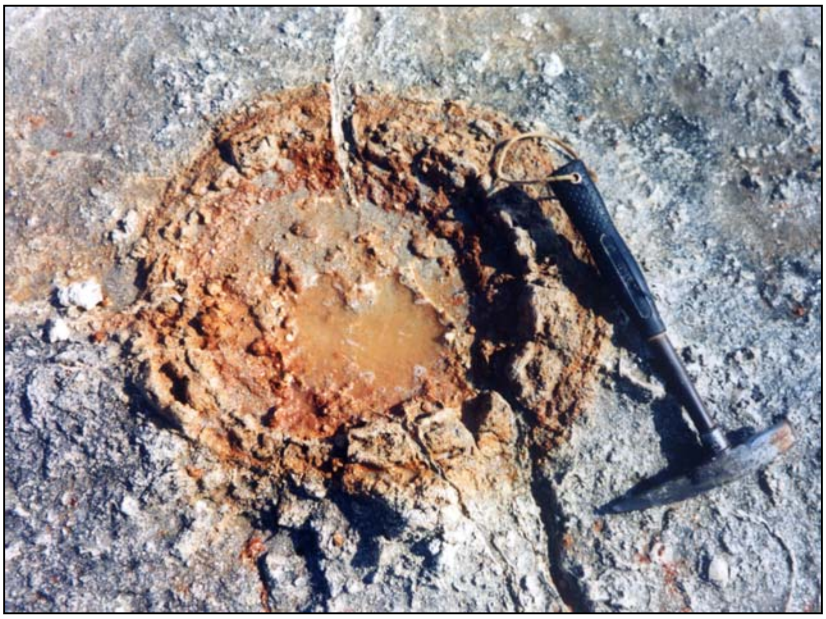


Figure 4.19 - *A pipe dislocated along a fracture.*

Figure 4.20 - *A root trace in the crust which coats the Torre Santa Sabina pipes (photo by Raffaele Puce).*

This cover formed most likely from the erosion of the soil which developed on marine terraces surface and its following deposition as colluvial deposit. The stratigraphic relationship and the presence of a flint shred in the deposit indicate that this event should occurred during the Middle Pleistocene.

Landscape evolution

The field data collected at Torre Sabina locality allow the reconstruction of the geomorphological evolution of this coastal area since Middle Pleistocene (Fig. 4.21).

At the end of Middle Pleistocene a colluvial cover deposited on a wave cut platform shaped on the Plio-Pleistocene bedrock (steps A and B). Solution pipes formed beneath this cover in response to a significant dissolution of the carbonatic bedrock (step C). Pipes distribution was affected by the permeability of the colluvial cover; during this phase, vegetation colonized the cover surface.

A period marked by semi-arid climatic condition stopped cryptocorrosion processes promoting the precipitation of calcium carbonate with the development of a crust on the contact surface between cover and bedrock. Many traces of roots of the vegetable that colonized the cover surface were preserved in this way (step D). The colluvial cover and the cryptokarst forms have been fossilized during the last interglacial period by the deposition of marine calcarenitic deposits (step E). Finally, solution pipes have been exposed during the late Holocene by wave action which eroded the last interglacial marine deposits and the colluvial cover.

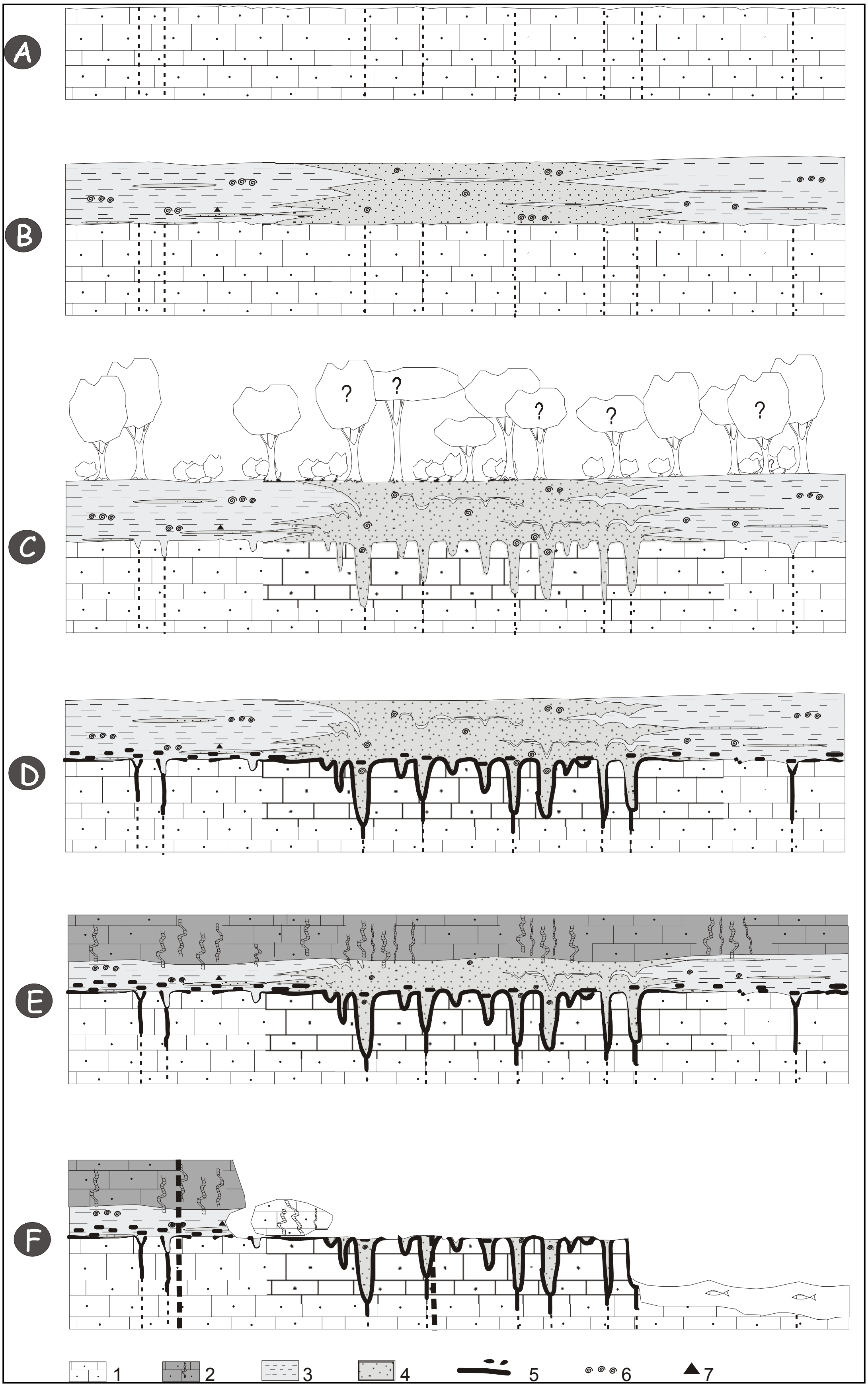


Figura 4.21 - *Model of the solution pipes evolution along the Adriatic coasts of Puglia region. 1 – Plio-pleistocene calcarenites; 2 – last interglacial calcarenites (?); 3 – colluvial sandy-silts; 4 – colluvial silty-sands with small pebbles; 5 – carbonatic crust and nodules; 6 – pulmonate gastropods; 7 – flint sherd.*

Stop 4.1.5 - The Late Holocene aeolian deposits
(G. Mastronuzzi, B. Mauz, P. Sansò)

Westward to the Torre Santa Sabina, a large relict dunefield can be recognised on the southern slope of a small inlet formed where the shoreline intersects a relict river valley. The aeolian deposit is made of weakly cemented well sorted grey sands and up to about 6 m thick. Its composition is characterised by prevalent terrigenous components (carbonate and silicoclasic grains = 60%). The deposit retains rare remains of gastropods pulmonate and is characterised by high angle cross lamination. South-dipping stratification and the aeolian deposits distribution indicate a prevailing of the most frequent and strongest winds which, as at present, blow from the N-NE.

The dune buried a small prehistoric settlement of Neolithic age represented by a wall made with limestone blocks (Coppola, 1977); an uncalibrated ^{14}C age determination carried out on some *Helix* spp. specimens collected from the aeolian unit just above a Neolithic wall yielded an age of 5290 ±120 years BP (calibrated age 6062 ± 130) (Table 4.3; Fig. 4.22).

Sample	Deposit	Locality	Age (a)	$\delta^{13}C_{PDB}$(‰)	$\delta^{18}O$ (‰)	^{14}C Age (cal a BP)	Material	Lab.	Reference
SSB3	Aeolian	TorreSanta Sabina	565±80	-8,27	-0,84	615±31	*Pomatia* sp.	A	Dini *et al.*, 2000
-	Aeolian	Torre Canne	2110±90	-	-	2071 ± 86	*Helix sp*	-	Magri and Zezza, 1970
P17	Aeolian	Fosso Pantore	2910±50	-7,09	-2,15	3019±62	*Helix* sp.	A	Dini *et al.*, 2000
P8 (GX-26736)	Soil -	Lido Morelli	4330±40 AMS	- 5,5	-	4860 ± 20	*Pomatia* sp.	B	Auriemma *et al.*, 2003
SSB2	Aeolian	Torre Santa Sabina	5290±120	-5,95	-1,31	6062±130	*Helix* sp.	A	Dini *et al.*, 2000
BN 113	Aeolian	Torre San Leonardo	5400±300	-	-	n.d.	Quartz	C	this paper
RM1	Aeolian	Rosa Marina	5796±70	-6,53	-0,89	6595±71	*Helix* sp.	A	Auriemma *et al.*, 2003
RMD (GX-18124)	Aeolian	Rosa Marina	6084±52 AMS	-7,4	-	6934±70	*Helix* sp.	B	Dini *et al.*, 2000
-	Aeolian	Torre Canne	6900±90	-	-		Fireplace remain	-	Coppola and Costantini, 1987
TSL6	Aeolian	Torre San Leonardo	6185±90	-7,48	-1,41	7187±23	*Helix* sp.	A	Dini *et al.*, 2000

Table 4.3 - *Radiocarbon (±1σ) and OSL ages of samples deriving from the lower unit of the dune belt situated next to the modern shoreline (Adriatic coast of Puglia). Calibration of radiocarbon ages was performed following Stuiver et al. (1998a and 1998b). A - Laboratorio di Geochimica Isotopica, University of Trieste (Italy); B - Geochron Laboratoires Krueger Enterprises Inc. (Cambridge, Massachusetts, U.S.A.); C – Luminescence Dating Laboratory, University of Bonn (Germany); n.d. – not determinable.*

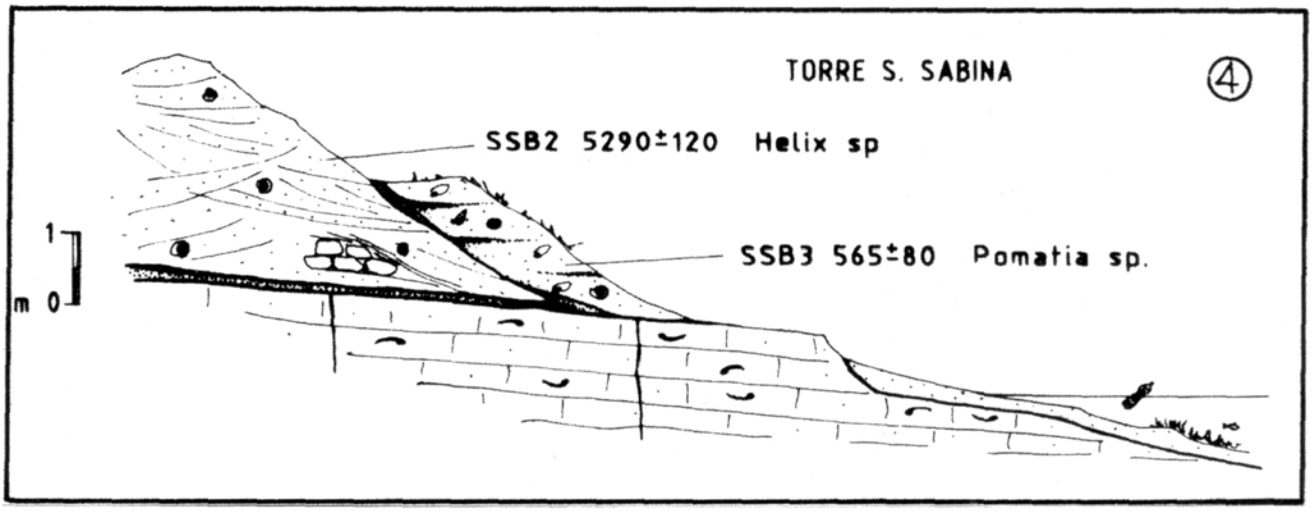


Figure 4.22 - *Schematic stratigraphic sequence of Santa Sabina dune deposits. a – Plio-pleistocene calcarenites (Calcarenite di Gravina); b – brownish bioturbated calcarenite (Last Interglacial Time ?); c – aeolianite (Last Interglacial Time?); d – reddish colluvial clays; e – beach calcarenites (Early-Middle Holocene); f – aeolianite with pulmonate gastropods (Middle Holocene); g – aeolianite with discontinuous level of brownish soil (Late Holocene); h – paleosol; i – soil.*

Stop 4.1.6 - Archaeological area
(D. Coppola)

Figure 4.23 - *The "fiume della mezza-luna" on its final tract facing North*

Today 'Torre Santa Sabina' is a hamlet located in the Carovigno area (Brindisi) along the Adriatic coast.

The geological environment is typical of the low-lying coasts of Salento (a part of Apulia) with yellowish white detrital organogenic layers of calcarenite (Vezzani, 1968; Di Geronimo, 1969; 1970). From a morphological point of view, the territory is characterized by two big sapping valleys (locally named "*lama*") running perpendicular to the shoreline (Coppola, 1977). These flow into two inlets full of contemporary sand deposits: the eastern valley, at about 400 metres from the coastline, divides into two forks. The western fork fastens onto the terrace outside Masseria Caposenno n.3 forming a pincer-like closing.

Figure 4.24 - *The "Isoletta" and the coast with stratified deposits and artificial excavations dating back to Bronze Age settlement*

In particular the 'lama' named "fiume della mezza luna" (half-moon river), which has aquifer water leaks on its final tract (Fig. 4.23), shows steep and high cliffs and large top terraces with calcarenite outcrops on which one finds fossilized dunes. On the contrary the low-lying coast rich in inlets covered by sand is dramatically eroded by the sea which has caused the fall of huge relict rocks, such as the 'isoletta' (little island) (Fig. 4.24) (Magri and Zezza, 1970).

In the Morelli district a burial ground dating back to the Bronze Age was discovered in 1957 and explored later (Lo Porto, 1963). Some years later a repeated topographic survey highlighted the existence of different frequentation phases until the Roman Empire period; this site was actually used as a *mansio* (from Latin "place where someone stays") and the harbour of Santa Sabina was still functioning in the sixteenth century as reported (Fig. 4.25a).

A late-Neolithic site, which a community of growers inhabited in the sixth millennium, occupied a calcarenite plane which outcropped from the southern part of a ridge made of fossil dunes and from the eastern part of the "fiume della mezza luna". In the same area a lithic work was found confirming the existence of "Romanellian" presence (Coppola, 1977). In the Bronze Age high-density settlements developed on the terraces around the valley, occupying a substantial part of the calcarenite platform. The coastal area stands out for the presence of thousands of holes into the ground; here piles were vertically driven in to support the structure of huts, fences were erected and composite structures – which are difficult to interpret – were built up. There is a strong correlation between the excavation areas and the distribution of the archaeological materials emerging from the almost intact slab of layered deposits (Coppola, 1977) (Fig. 4.25b). Several graves sited in Masseria Caposenno n.3 are worthy of attention: they are dug into calcarenite on the margins of the lama and on the southern side of the Bronze-Age village. Tools, such as a miniature sword and a small bronze dagger, have not been unearthed during regular excavations, but they already belonged to the necropolis. These items have been attributed to a Mycenaean influence of the half of the thirteenth century BC.

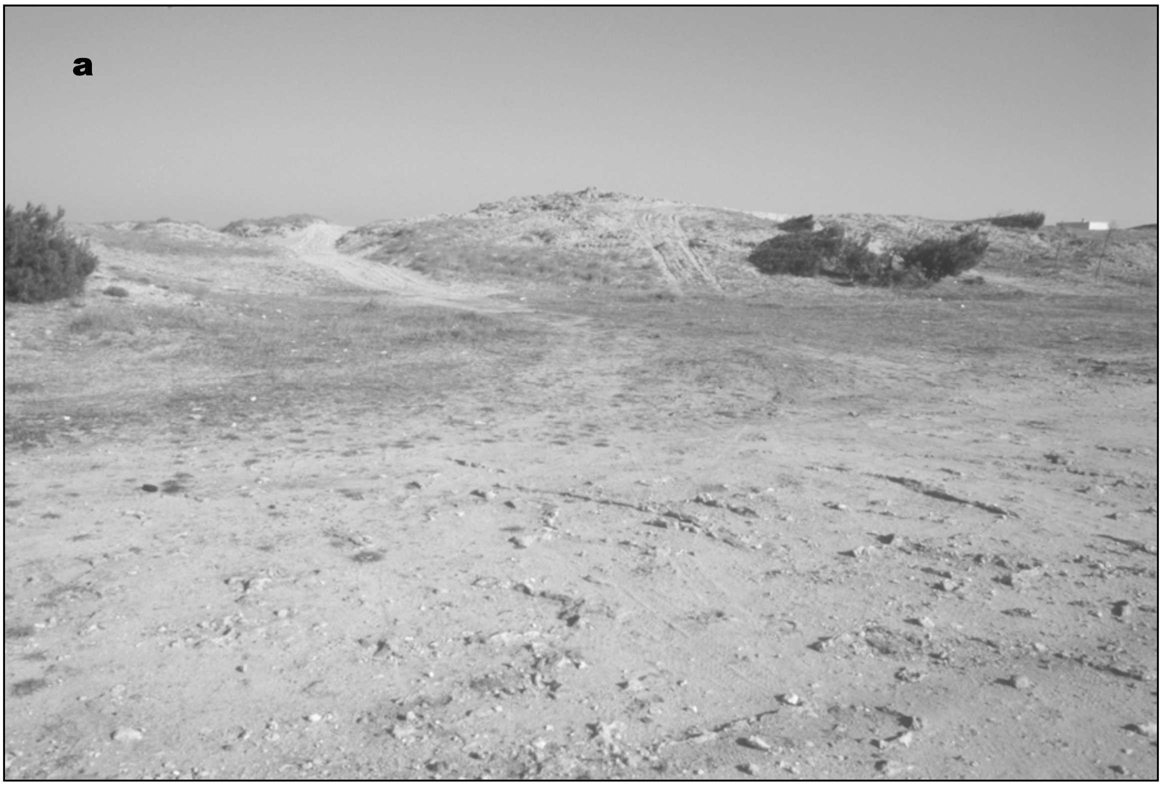


Figure 4.25 - (a) *The calcarenite platform after the removal of the fossil dunes, with paleo-epipaleolhitic remains and the ancient neolithic (sixth millennium). In-site fossil dunes are visible northwards. (b) The calcarenite platform on the western side of the "fiume della mezza-luna" with pile holes, outcropping blackish archaeological soil (13^{th} – 12^{th} century BC) and sand dunes covering the remains*

Figure 4.26 - *Beach deposits at the mouth of the "fiume della mezza-luna" with calcarenite walls eastwards. Here are artificial little caves dating back to the Bronze Age and partially covered by recent sand deposits*

Figure 4.27 - *1978 – Same area with rests of the wall partially covered by sand, the visible part is destroyed at the present*

The distribution of these tombs recalls that discovered at the burial ground in the Morelli district.

In 1990 works were carried out to lay the foundations of a villa on the calcarenite bank on the western side of the “fiume della mezza luna”, behind the relict rock named “isoletta”. During these works two semipogeic structures flanking each other were identified (Coppola and Raimondi, 1995; Coppola and Cinquepalmi, 1998). These structures, facing South-North, were surrounded by holes of piles formerly driven into the ground and had narrow hallways with stairs which led into sub-rectangular rooms. In addition to the local ceramic elements, the presence of ceramic objects of the Mycenaean period (LH IIIC) suggests that the structures have a second frequentation phase (level b) between the thirteenth – possibly the fourteenth century according to some elements – and the twelfth century BC.

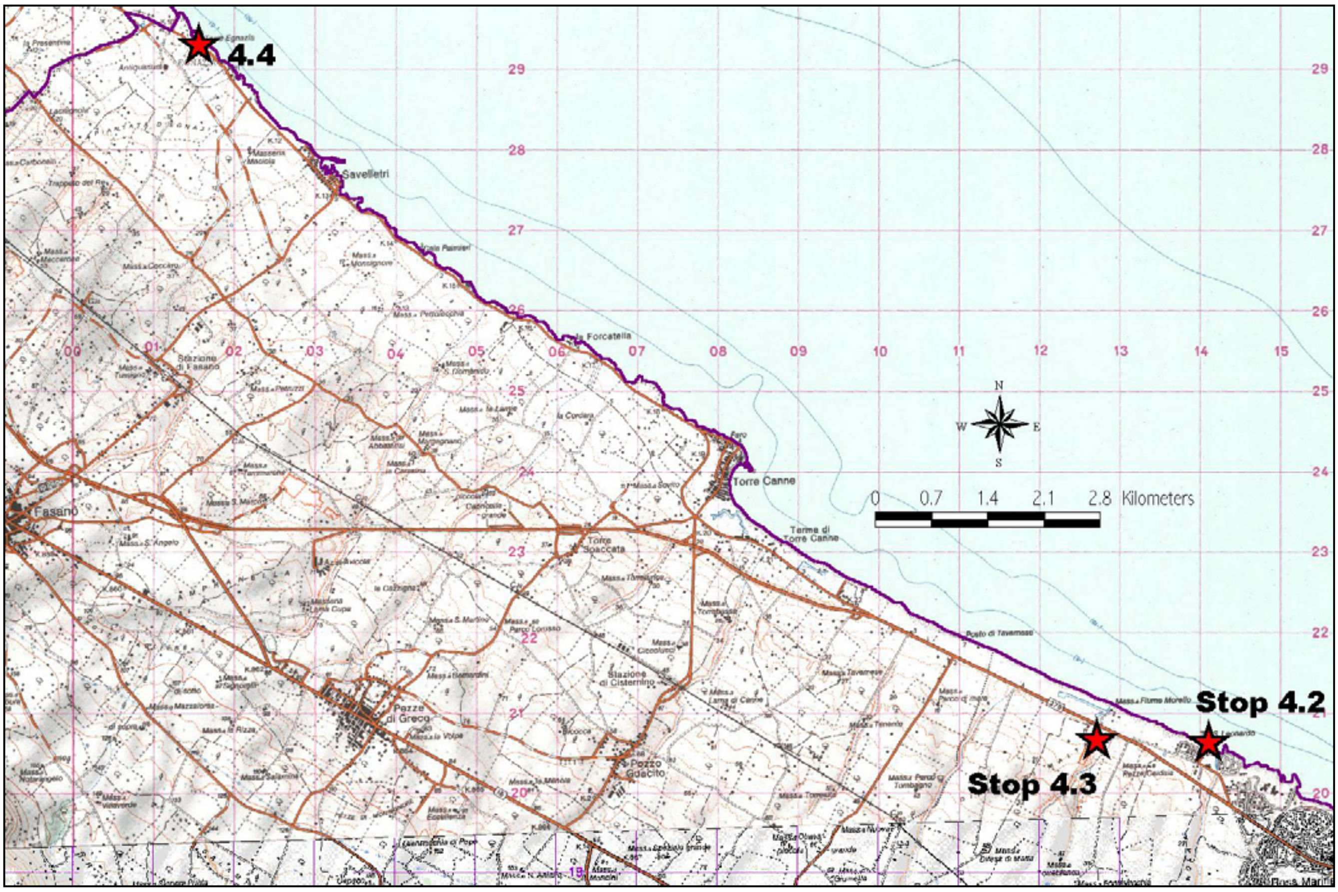
The studies on the settlement of Torre Santa Sabina provide information about an area with a Mycenaean presence reported as phase III A (burial ground) and III C (structures 1 and 2).

Ceramic elements found on the seabed of the present harbour of Santa Sabina had been imported from Greece since the seventh century BC (e.g. Corinthian amphorae used for trade purposes, Laconia vases, East-Greece ceramics decorated with stripes, etc.). This is the evidence that the site has been an important landfall along the southern Adriatic sea since the Bronze Age.

Future research areas are the numerous artificially burrowed caves located on the western wall of the “fiume della mezza luna”, where ceramics of the Bronze Age have been detected after a preliminary survey. A big wall made of lines of stones probably dates back to the Eneolithic – the Middle Bronze Age (Fig. 4.26); it is entirely covered by a strongly concreted sand dune deposit (D2) and located between the sloping bank of the lama (where the little caves are) and the bed of the present “fiume della mezza luna”, best viewed in a 1978-picture (Fig. 4.27).

Site 4.2

Locality	Torre San Leonardo – Il Pilone
Community	Ostuni
Province	Brindisi
WGS84 Coordinates	40.75788N, 017.69728E
Keywords	Early Holocene beach sequence, Sea level change



Stop 4.2 - The Early Holocene beach sequence of Torre San Leonardo
(G. Mastronuzzi, B. Mauz, P. Sansò)

At Torre San Leonardo, the Early/Middle Holocene sediments beach sequence recognizable also in other localities along the Adriatic coast of Puglia can be observed. (i.e . Rosa Marina site)

The beach sequence covers a discontinuous level of reddish continental clays that in the surrounding of Torre Canne contains ancient Neolithic pottery and fireplace remains. These last ones yielded an uncalibrated ^{14}C age of 6900 ± 90 years BP (Coppola and Costantini, 1987).

The lower part of the beach sequence is made of a coarse bioclastic calcarenite with small pebbles, partly cemented, showing a well developed low angle cross lamination locally destroyed by bioturbation (Fig. 4.28). Beach deposits ends at about 1 m above m.s.l. passing rapidly upward to an aeolian deposit. This is characterised by well sorted fine calcarenite, partly cemented, with high angle cross stratification and abundant remains of pulmonate gastropods. Helix sp. collected at its base yielded a ^{14}C uncalibrated age of 6185 ± 90 years BP corresponding to 7123 ± 23 cal years BP (Dini *et al.*, 2000).

The observed foreshore/backshore sequence suggest a Holocene sea level at about the same position or slight higher than present sea-level.

Other age determinations have been performed on dune sediment and fossils. An AMS uncalibrated ^{14}C age determination performed on some specimens of Helix spp. collected at the base of the aeolianite at Rosa Marina locality, about 0.5 km to the SE, yielded an age of 6084 ±52 years BP. Moreover, an OSL age determination performed on a sediment sample coming from the upper part of the dune near Torre San Leonardo suggest an age of about 5350 years.

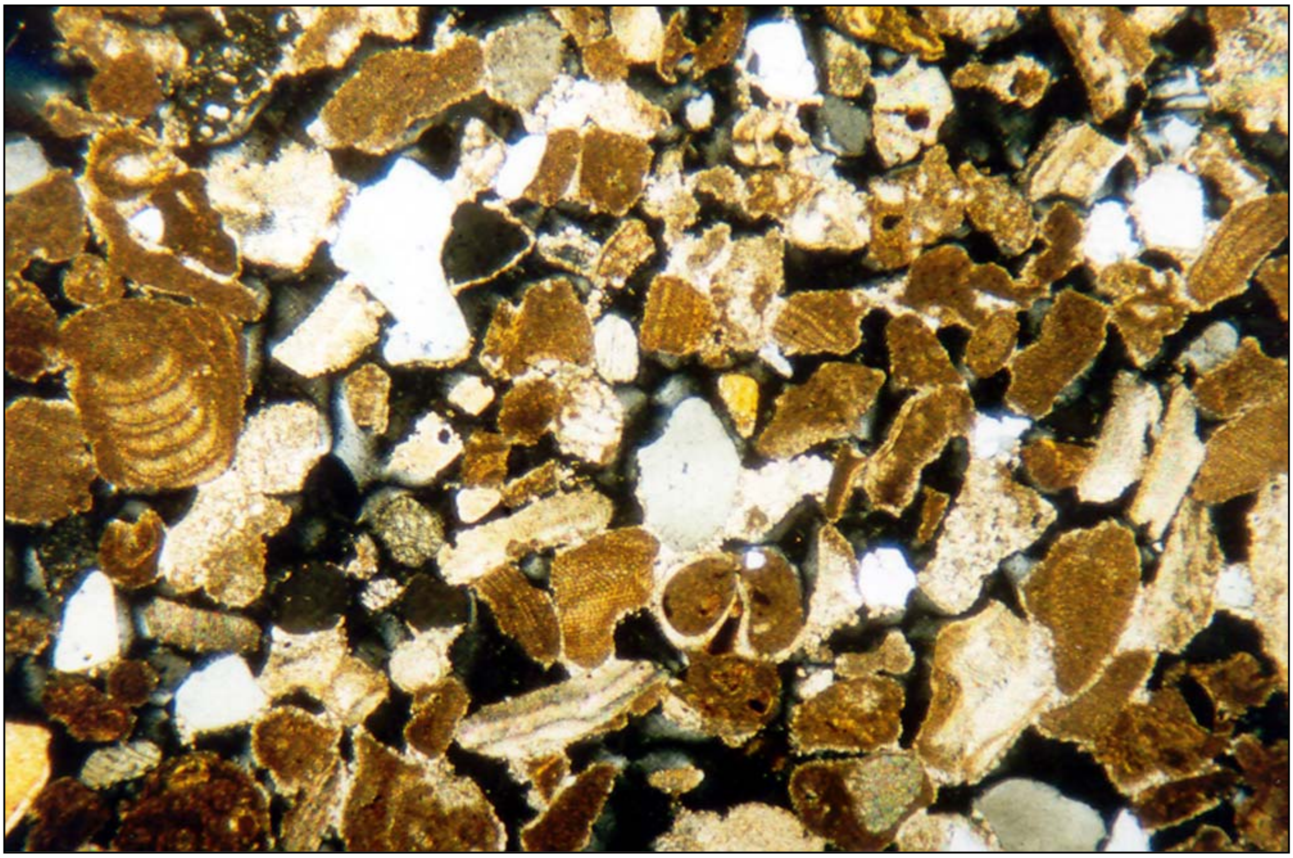


Figure 4.28 - *A view of the Early – Middle Holocene backshore deposit of Torre San Leonardo*

The Early/Middle Holocene dune is covered by loose dune deposits made of fine loose light brown sands with numerous discontinuous, thin layers of brownish soil and remains of pulmonate Gastropods (Helix, Pomatia, Rumina spp).

This last unit is the most widespread aeolian cover in the Apulian coastal region as it borders all the present beaches and is present along several coastal tracts which are, at present, rocky . A number of radiocarbon age determinations and the presence of Greek and Roman archaeological remains allow to refer its deposition to the time interval spanning from 3360 to 2000 years BP (conventional age).

Sample Code	Field Reference	Water Content	U (µg g^{-1})	Th (µg g^{-1})	K (wt %)	$\dot{D}_{cosm}$ (Gy ka^{-1})	$\dot{D}_{effective}$ (Gy ka^{-1})	Age (±1σ, ka)
BN 113	Pilone	1.16±0.15	1.73±0.05	2.48±0.89	0.50±0.00	0.19±0.01	1.18±0.06	5.35 ± 0.29

Table 4.4 - *Analytical data and OSL dating results. Water content is the measured field moisture normalised to the dry mass and corrected for fluctuation of water content; U-, Th-, and K-concentrations are determined by α-spectrometry and used to calculate the total dose rate;* $\dot{D}_{cosm}$ *is the cosmic dose rate determined from the mean burial depth of the sample;* $\dot{D}_{effective}$ *is the total dose rate corrected for water absorption; OSL-ages are given with 1σ error limits. n.d. = not determinable*

Sample Code	Grain Size (µm)	D_e (Gy)	N	Skewness	Kurtosis
BN 113		6.09±0.16	10	-0.22	1.71

Table 4.5 - *Analytical data of equivalent dose (D_e) determination. Grain size indicates the quartz grain size used for OSL-dating; D_e is given as arithmetic mean of n number of single-aliquot D_e determinations, n indicates the number of measured aliquots; D_e distribution is indicated by means of its shape.*

Sample Code	Recuperation (%)	Recycling Ratio	Dose Recovery	D_e(t) (s)	IR sensitivity
BN 113	0.03±0.01	-	-	0-4	0.06±0.01

Table 4.6 - *Analytical data of equivalent dose (D_e) determination. Recuperated OSL-signal is given in % of the natural OSL signal, recycling ratio is the ratio of the first regenerated dose and the repeated first regenerated dose at the end of the SAR protocol; D_e(t) indicates the stimulation time range (s), where D_e is constant (1σ); IR sensitivity indicates a feldspar component based on the IR OSL signal.*

Site 4.3

Locality	Lido Morelli
Comunity	Ostuni
Province	Brindisi
Coordinate WGS84	40.80836N, 017.52042E
Keywords	late Pleistocene? dune belt

Stop 4.3 - The Late Pleistocene dune belt of Lido Morelli (G. Mastronuzzi, B. Mauz, P. Sansò)

This stop aims to show the coastal landscape between Torre Canne and T.S. Leonardo (Fig. 4.29) which is dominated by a relict dune belt running about parallel to the modern coast line in NW-SE direction Its top reaches the altitude of 17 m and it is marked by increasing width in NW-SE direction from about 50 m to about 200 m. A thin layer of loose sands rich of piroxenes and garnets originating from the Monte Vulture volcano mark the base of the aeolianite. This volcano, situated about 200 km to the north, on the eastern border of the Apenninic Chain, was active from the Middle Pleistocene (about 700 ka) to the late Pleistocene (about 132 ka; Ciccacci *et al.*, 1999). The volcanic cone is placed inside the catchment area of the Ofanto river and its tributaries which carry the volcanic material to the Adriatic shoreline, north of the study area. The fluvial material is transported to the south by the longshore drift induced by prevailing northerly winds (Mastronuzzi & Sansò, 1993).

The dune belt developed against the cliff which borders landward a marine terrace easily recognizable at an altitude of 4 m. Terrace sediments, about 2 m thick, are compound by bioclasts and terrigenous grains, lacking of macrofossils and in some places diffusely bioturbated. They show a low-angle cross lamination and cover a discontinous soil level retaining clasts of the bedrock or directly an abrasion platform (Fig. 4.30).

The dune belt formation caused the obstruction of small river mouths which break in several points cliff continuity and the development of backdune depressions, subsequently filled by red continental sands.

Regional geomorphological evidences would refer the terrace placed at +4 m to the Last Interglacial period, even if no absolute age determinations are available yet. In fact, radiocarbon determination on Pomatia sp. yielded an age of 21750 ± 365 years BP, close to the time limit of the method whereas an OSL age determination on the aeolian sediment did not supplied any result.

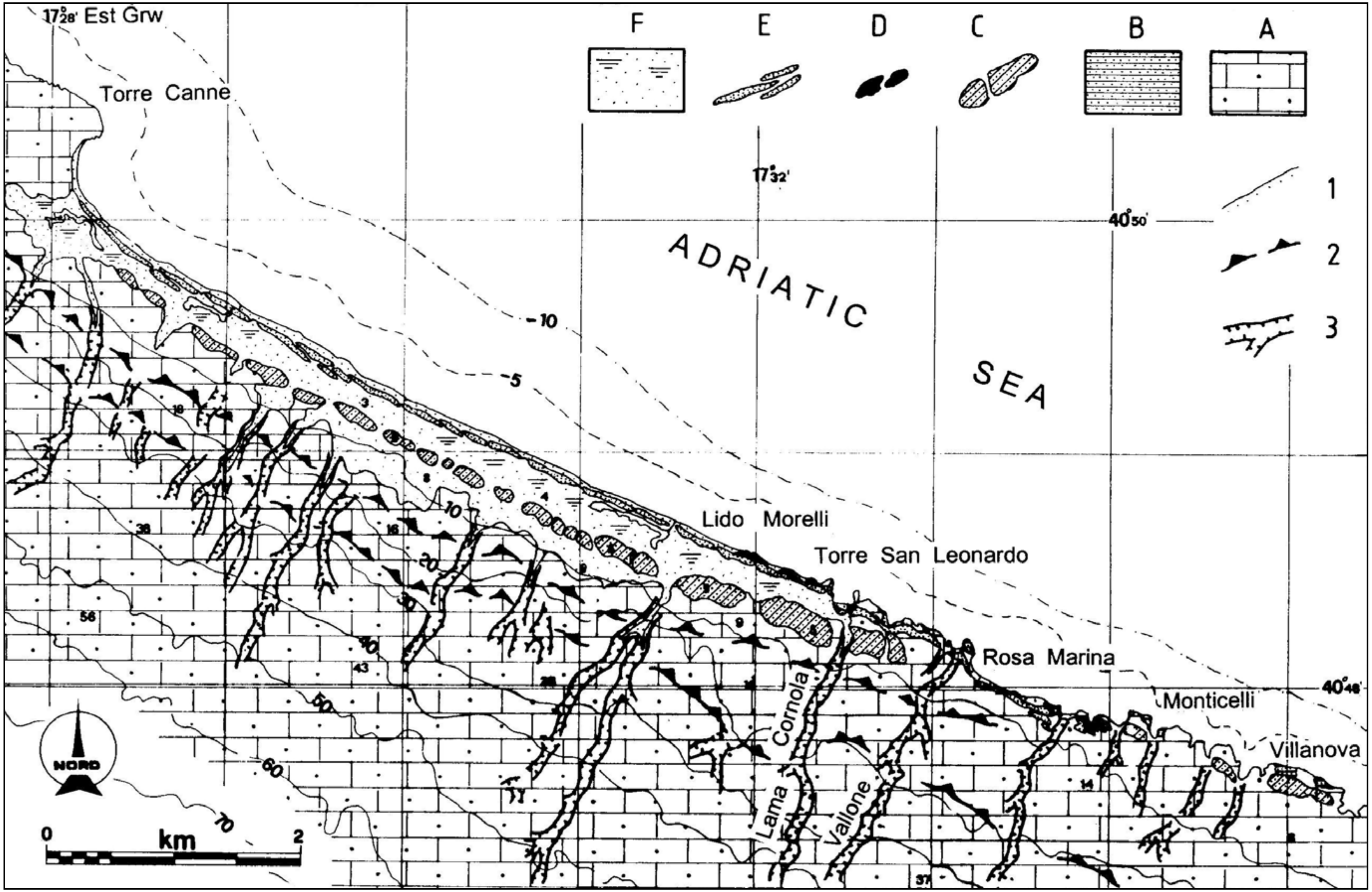


Figure 4.29 - *Geomorphological sketch of the coastal area between Torre Canne and Villanova. Legend: A) Calcarenite di Gravina; B) Last Interglacial beach; C) Last interglacial aeolianites; D) Mid - Holocene aeolianites; E) Roman Age aeolianites; F) backdune deposits; 1) sandy beaches; 2) relict cliffs; 3) river valleys (lame).*

Figure 4.30 *- Block diagram showing the coastal landscape evolution between Torre Canne e Torre San Leonardo. Legend: A) Calcare di Bari; B) Calcarenite di Gravina; C) Paleosol; D) Last Interglacial calcarenites, soil and aeolianites; E) Red paleosols; F) Middle Holocene beach and aeolianites; G) Greek-roman Age aeolianites; H) backdune deposits.*

Site 4.4

Locality	Egnatia
Community	Fasano
Provincia	Brindisi
WGS84 Coordinates	40.75788N, 017.69728E
Keywords	Sea level change, Archaeological remains, catastrophic waves deposits

Stop 4.4 - Archaeological site and sea-level changes (R. Auriemma, G. Mastronuzzi, P. Sansò)

The archaeological site of Egnazia, north of Brindisi, proves incontrovertibly a rise in sea level and changes in coast profile, thanks to the attitude of substantial evidence. This site experienced various occupation phases, from the protohistoric period to the late ancient and medieval times.

The Hellenistic and Roman phases, which offered important remains of the urban fabric, are particularly well documented. The submerged structures in the inlet to the north of the acropolis and belonging to the ancient Roman port are extremely important for the assessment of the abovementioned phenomena (Diceglie 1981a, 1981b, Freschi 1980, 1995; Freschi – Alloa 1979-80; Sciarra – Bardaro - Andreassi 1982; Andreassi *et al.* 2000), as was unquestionably confirmed by the most recent researches (Auriemma 2003).

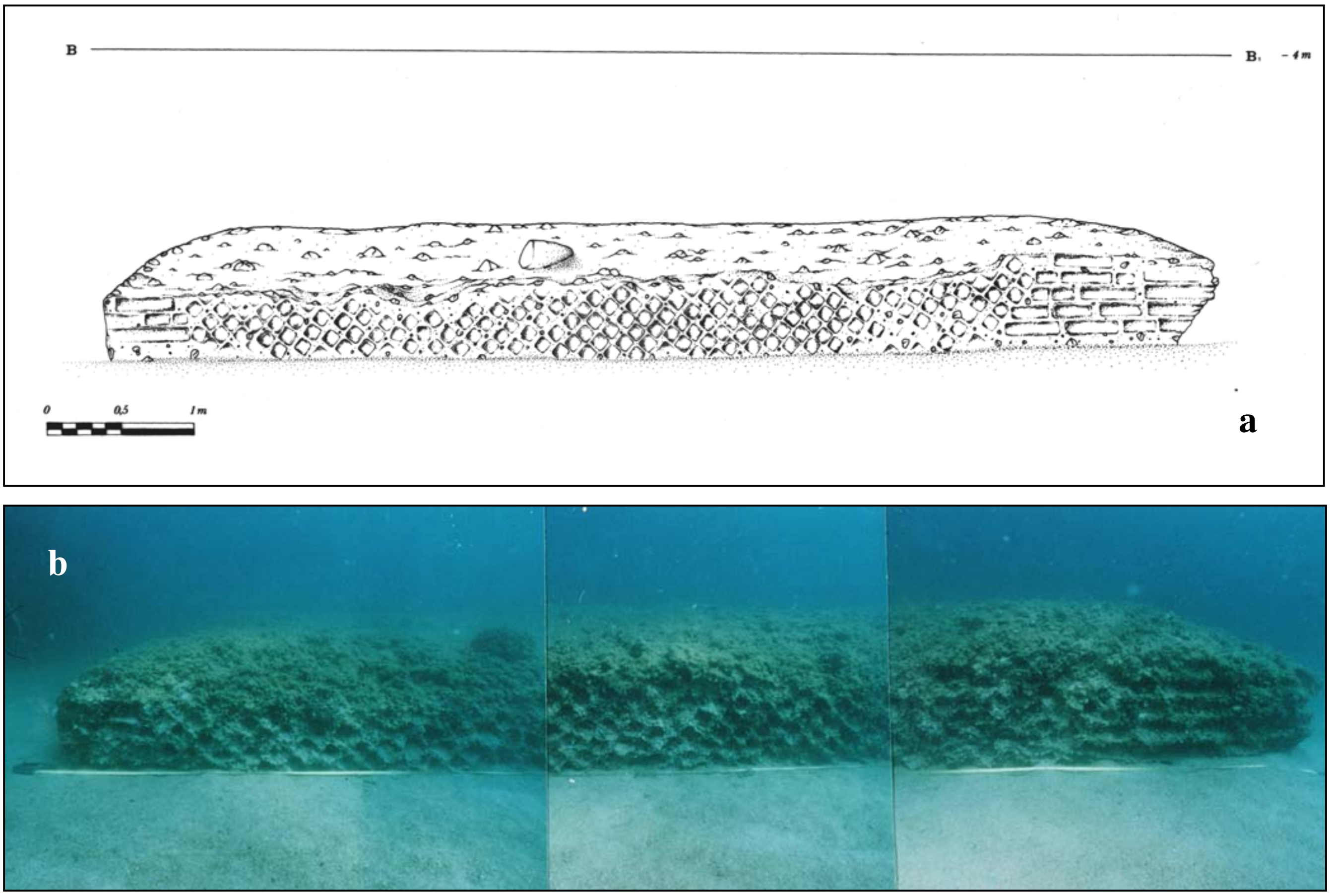


Figure 4.31 - *Photomosaic of the north-western pier of Egnatia harbour.*

They are remains of two defensive works of the port basin (Fig. 4.31; Fig.4.32). The northern one begins at the most advanced point of the northern part of the coast, with a rectangular, shaped outcrop of a layer of rock (ca. 6 x 4 m) with the base very much eroded by wave action at 1.2 – 1.5 m of depth.

A bit less than 100 metres far from this structure, 45° to the North, two huge parallelepiped blocks emerge from the sand at a depth of 6.2 metres. They are inclined, staggered and 3 metres far from each other. They both seem to be placed in a cutoff of the submerged coast. The step at the bottom of the rock was likely to serve as housing for the wooden formwork used during the construction of these '*pilae*'. They were made of Roman hydraulic cement, i.e. using pozzolana for a faster solidification. In the Roman times this technique was well known for the construction of port infrastructures.

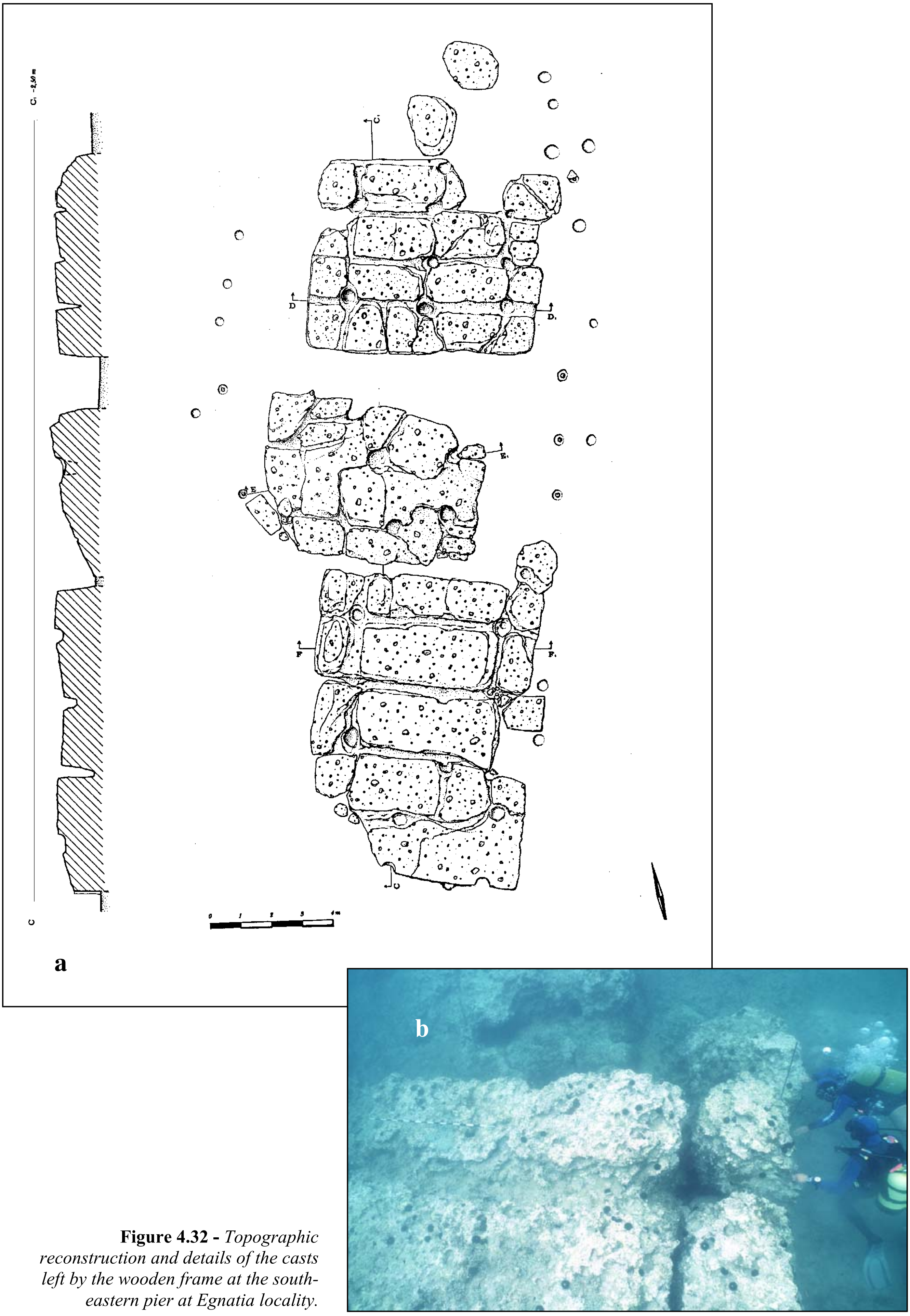


Figure 4.32 - *Topographic reconstruction and details of the casts left by the wooden frame at the south-eastern pier at Egnatia locality.*

It envisaged, like in this case, that cement had to be covered with small blocks of stone (*opus reticulatum*). The internal plinth, the closest to the coast ('a') is the tallest: it emerges from 2.40 to 3.1 metres; its upper face is irregular and its highest point reaches– 3 metres. The external plinth ('b') is ca. 0.60 metres tall (Fig. 4.33).

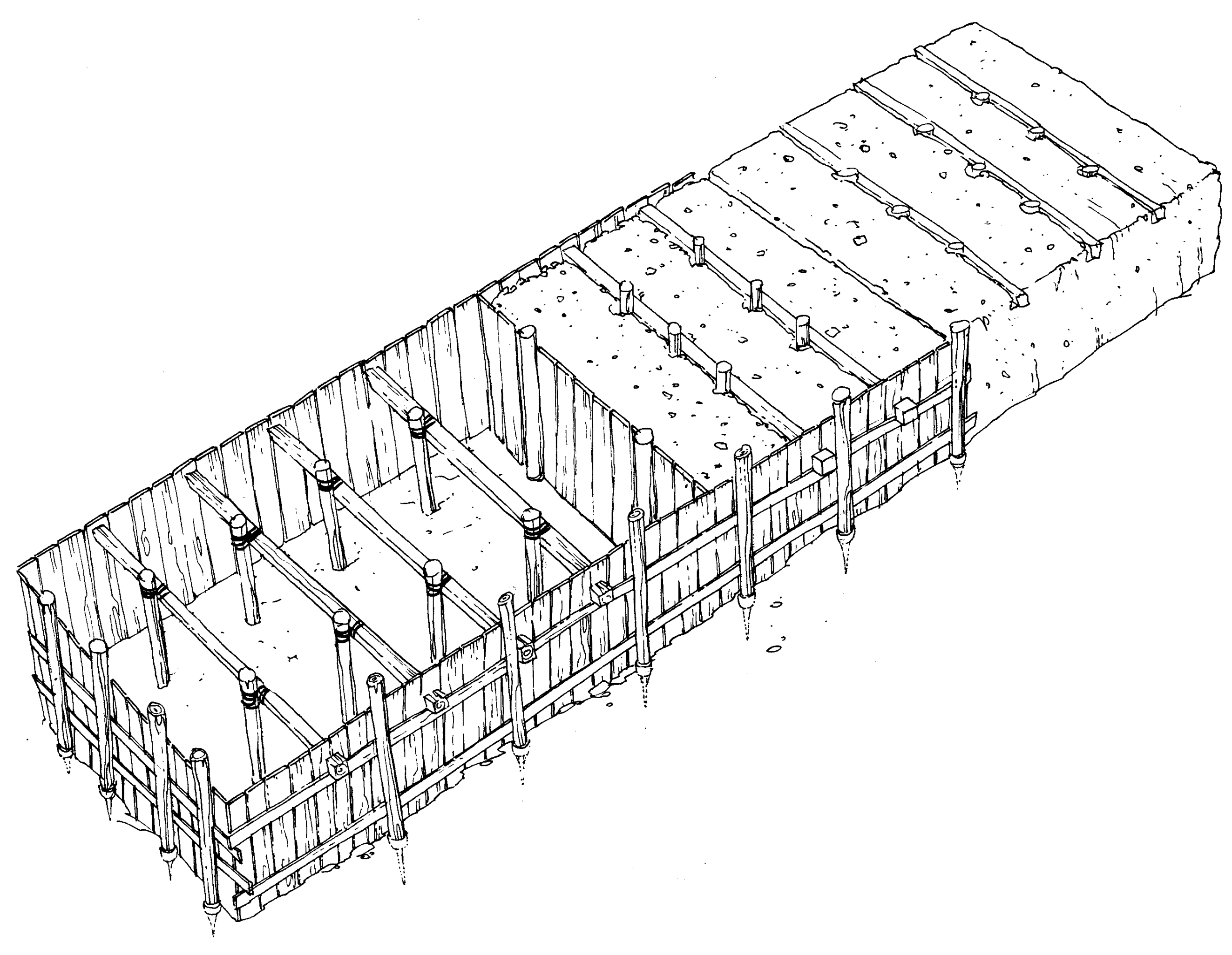


Figure 4.33 - *Scheme of phases and methods of construction of the south-eastern pier.*

Along the line connecting the shaped rock block to the remaining plinths, i.e. along the alleged course of the northern "pier", fragments of cement, some of them very big, sometimes with the negative of *opus reticulatum*, can be noticed. They are indications of the existence of structures similar to those discovered.

The remaining part of the southern pier is impressive. It faces SSW – NNE and is made of cement, with successive castings into wooden formworks. The surrounding rocky area is at 4.60 metres, while the structure top is at a depth of a bit more than 3 metres. The total length of the visible segment is 23 metres, but three segments or 'blocks' of different size can be distinguished clearly (Fig. 4.32). These show the negatives of the elements constituting the wooden frame, the internal frame of the formwork in which the structure was constructed; the loss of the posts, of the vertical poles (*destinae*) and of the horizontal beams for connecting and supporting the starlings (*catenae*) led to the appearance of holes, sometimes deep, and parallel tracks. Originally the structure had to be uninterrupted, made of modules and advances; wave action and streams 'worked' on the most yielding lines of the nucleus, weakened by the loss of the wooden frame. The formwork had external perimeter poles, whose metal pins were sometimes found, turned to ferrous concretions with traces of wood, fixed in holes made in the rocky seabed.

As regards the remaining plinths of the northern pier, this can be said to be a pillar work (*opus pilarum*) made with the support of a 'sealed' formwork, which was almost waterproofed and emptied with pumps, in order to work inside in a dry environment, as is proved by the presence of the stone lining. Obviously, the non-alignment and the substantial difference in height exclude the fact that they might be arcade pillars of a continuous pier. Instead, they appear as elements built separately, whose function may be hypothesised considering that they are only few remaining elements of an originally more complex structure, as is suggested by other fragments.

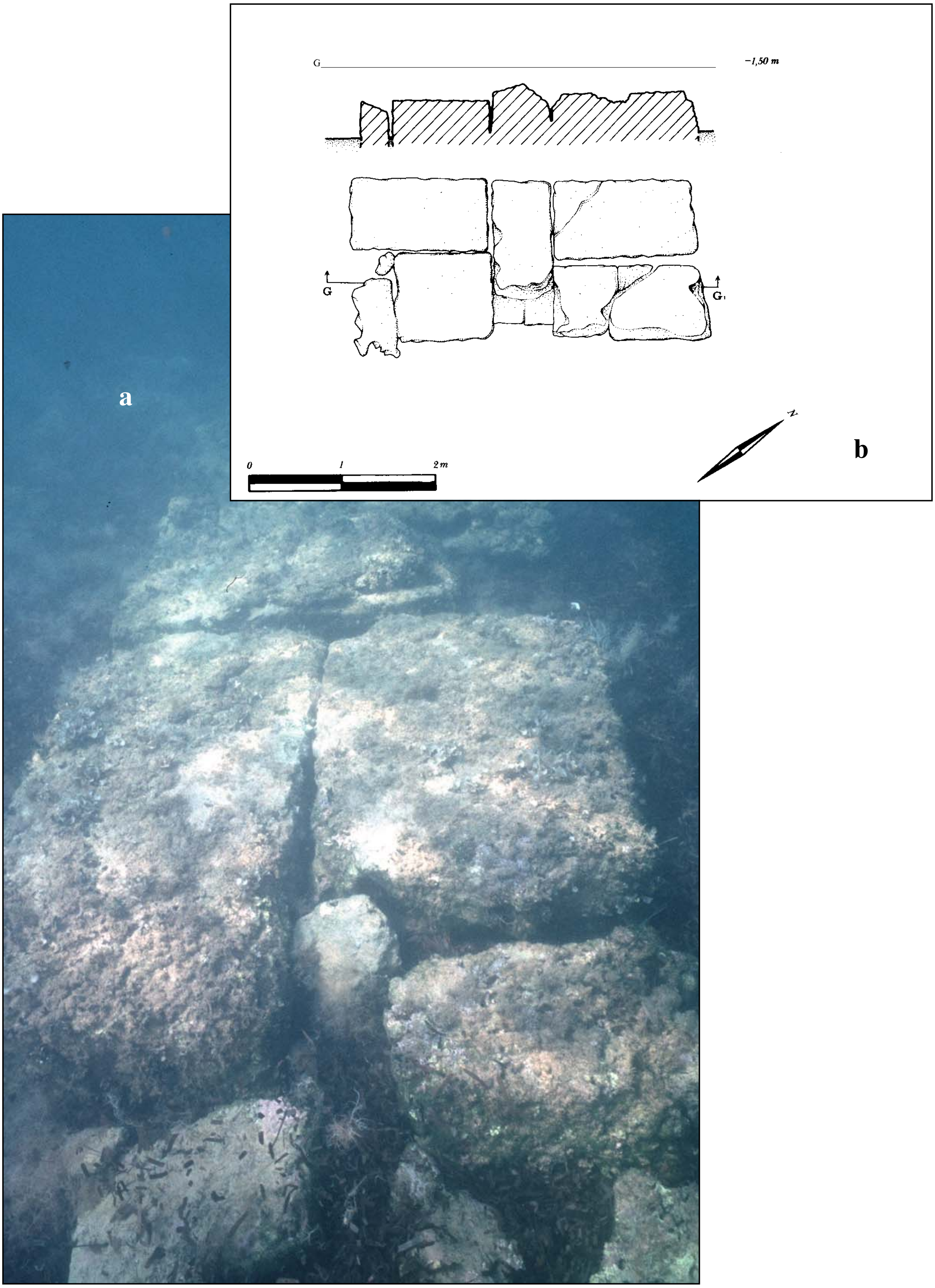


Figure 4.34 - *View and planimetry/section of the block structure in the southern inlet.*

Figure 4.35 - *A view of a Roman cistern showing the bottom below present sea level.*

The reason for the distance and the staggering of the two plinths may lie in the need of resisting wave action (by breaking waves better) thanks to a less extended surface and of avoiding the sanding of the basin, thus guaranteeing water movement. In the light of the construction commitment, the destination of use as a breakwater does not seem to convince completely, because a simple riprap structure would have been sufficient, even if, considering the prevailing winds and the streams, this part of the coast had to be protected with particular care. The upper part is clearly missing; it could have also been made of different material, which might have been in part perishable, like wood. In this case, they would hypothetically be no-longer-visible bases of structures and rises (for signalling the entrance of the port with fires?).

As regards dating, a series of elements, among which the construction technique, date back to the time of Augustus, when many ports were strengthened both in the Adriatic and in the Tyrrhenian, in particular along the coasts of Campania. The port of Egnazia is not as complex as the ports discovered by underwater archaeologists in the Gulf of Naples, but a military destination of the dock between 40 and 32/31 B.C. is not unlikely. The very construction materials, like the pozzolana and the tufelli (tuff) of the *reticulatum*, suggest a common plan and that it may be a product of the same workers.

Indeed, they are underwater works built under sea level. The systems, the techniques and the construction materials correspond perfectly to the text of Vitruvius, *De Architectura*, and are similar to well known sites of the Tyrrhenian, North African and Israeli coasts.

At the centre of the southern inlet, a bit more than 50 metres from its bottom, a ‘structure’ made of dry-placed limestone blocks was discovered (Fig. 4.34). The maximum size is 3.65 metres (longitudinal extension along NE-SW direction) x 1.64. A bit more than 2 metres in depth, two rows of blocks, the lower barely visible, emerge from the mud and the sand covering the base rock. They are ca. 30 cm tall. No certain data is available on the function and the dating of this ‘structure’. Most likely it is a short segment of a wall. However, excavations would be decisive.

Other useful evidence for geomorphologic considerations can be found in the area included within the boundary wall of Hellenistic period: tombs of the coastal necropolis, excavated in the rock, quarries, drainage canals, cisterns (Fig. 4.35), seats for wall lines, today in part or completely submerged or at sea level. The quarries are open and worked with the benching method. The ‘negatives’ of the removed blocks are evident. However, blocks prepared but not yet detached are often kept *in situ*. A good instance can be seen on the extremity closing the southern cove (Fig. 4.36) or in the area to the north of the acropolis. Here, close to the big quarry next to the remaining part of the boundary wall, very regular cuts can be noticed underwater, up to 1 metre in depth. The area used for these quarries is at present between - 0.5 metres and – 0.80/1.00 metres. The dating is not yet certain, but the presence of tombs with pseudosarcophagus, i.e. with lowered edge to install cover slabs, which date back to the 5th and 4th centuries B.C. and were cut from the bottom of the very quarries, is a useful *terminus ante quem* for the exploitation of the bed of rock. The blocks removed or abandoned before being detached are, moreover, of considerable size, which is further evidence that they date back to very ancient times.

Figure 4.36 - *Quarry with blocks in situ. The bottom of the cave is up to 1.1 m below present sea level.*

The canal oriented at NE – SW, parallel and little far from the northern basin limit is noteworthy. It is likely to have been used to discharge rainwater from the town to the port, also to avoid its sanding. It is excavated in the bed of rock and shows the offset for the bearing of the slabs. At present the bottom is at 0.70/0.80 metres under sea level. Similar canals, proving the level rise like this in Egnazia, can be found in Torre S. Sabina (Br), in the inlet of Mezzaluna (cfr Fig. 4.7), and in S. Vito di Polignano (Bari). In the latter, even some cover slabs can be found.

Obviously, these descriptions find their place in a geomorphologic framework which differs from the present one. The submerged structures in the northern cove create an entrance which is 40 metres wide, reaching 6 – 6.5 metres in depth today.

A lower sea level by 1 – 1.5 metres (Vlora, 1975; Caldara and Pennetta, 1995) at the time of the structure construction would not have affected port accessibility. These data would correspond to the depth of the erosion signs due to wave action that can be noticed along the coast (for instance, at the base of the alleged beginning of the northern 'pier').

The present upper part of the south-eastern pier or better of its remaining segment is slightly deeper than 3 metres, its base is at – 4.30 / - 4.60. The original height cannot be established with certainty, but, if sea level was 1.50 metres lower, the disappearance of 1.5 metres of the structure can be hypothesised, that is to say the remaining part is almost half of the original construction. Collapsed material can be seen around the structure. It is also made of huge blocks, which do not however correspond in size and quantity to the disappeared volume. Wave action may have scattered and dispersed the cement fragments, but the limited quantity of fragments remained around is unusual. On the other hand, the presence of traces of *catenae* on the upper face usually identifies this part as the original surface, corresponding to the coeval sea level. For instance, in the similar pier of S. Marco di Castellabate, for which no relevant changes are reported from the ancient times until today, the tracks constituting the traces of the *catenae* are at water level or emergent (Felici, 1993; Benini, 2002). This consideration may lead to the assumption that sea level was lower than the current 3 metre level, corresponding to the level geologists postulate for much more ancient phases (between the Bronze Age and the Iron Age) as regard the examined part of the coast. The depth of 3 metres at the entrance was however sufficient. For the landing of small-tonnage boats or warships, a structure 1.6 metre tall, without considering the emerging part, guaranteed a still reasonable draft. The top of the tallest of the two plinths of the alleged northern pier is – 3 metres deep, too, but this did not have to emerge necessarily.

Elements supporting one or the other hypothesis may come from the continuation of the works in this area, in the framework of a project which will involve underwater archaeologists and geomorphologists. Indeed, along the coast of Salento, a lot of other archaeological evidence was found, which, together with Egnazia evidence, is an important indicator of geomorphologic phenomena interesting the coast profile in the ancient times (Auriemma *et al.*, 2003).

Discussion of OSL age data

Optically stimulated luminescence determines the time since sediments were last exposed to light as such exposure removes the geologically acquired latent luminescence signal. The OSL data presented here were obtained using a dating protocol called single-aliquot regenerative dose protocol (SAR), which is designed for quartz grains ranging from 80µm to 300 µm in size. This dating approach has several advantages and disadvantages caused by luminescence properties of natural quartz. Likewise, luminescence properties of the individual quartz sample used for dating plays and important role.

With the exception of the Holocene dune sample BN 113(cfr. Tab. 4.4, Tab. 4.5, Tab. 4.6), all OSL samples presented here showed signs of saturation and some samples even showed radiation quenching (Table 4.7-4.10). Saturation means that no electrons can be added to the electron population already being trapped in the finite number of light-sensitive traps. Hence, no further energy coming from environmental ionising radiation can be accumulated in the crystal. By saturation of electron traps the physical limit of the dating technique is reached. In terms of age, the saturation level depends on the luminescence properties of the individual quartz grain and on the annual dose of energy from environmental ionising radiation affecting the quartz grain. Radiation quenching means lost of energy dose during the dating procedure in the laboratory. It is an artificially induced physical process in the quartz crystal, which must be linked to saturated electron traps, but is currently not well understood. The phenomenon of radiation quenching turns a sample undatable (see table) whereas saturation usually allows to estimate a minimum age of the sample.

In the case of the Puglian quartz samples the conditions mentioned above mean that all OSL samples should be older than 75 ka. Unfortunately, no further age information is available.

Sample	Deposit	Locality	Age (a)	$\delta^{13}C_{PDB}$ (‰)	$\delta^{18}O$ (‰)	Material	Lab.	Reference
P16	Aeolian	Lido Morelli	21750±365	-7,55	-4,42	*Pomatia* sp.	A	Mastronuzzi *et al.*, 2001
P15	Aeolian	Torre Rossa	32.000±1125	-3,98	-1,58	*Pomatia* sp.	A	Mastronuzzi *et al.*, 2001
BN 102	Beach-foreshore	Monticelli	n.d.	-	-	Quartz	B	This paper
BN 101	Aeolian	Lido Morelli	n.d.	-	-	Quartz	B	This paper
BN 103	Beach-shoreface	Apani	n.d.	-	-	Quartz	B	This paper
BN 106	Beach-shoreface	Torre Rossa	n.d.			Quartz	B	This paper

Table 4.7 - *Radiocarbon and OSL ages (±1σ) of samples deriving from the pre-Holocene costal deposits of the Adriatic coast of Puglia. A - Laboratorio di Geochimica Isotopica, University of Trieste (Italy); B – Luminescence Dating Laboratory, University of Bonn (Germany); n.d. – not determinable.*

Sample Code (BN)	Field Reference	Water Content	U (µg g^{-1})	Th (µg g^{-1})	K (wt %)	$\dot{D}_{cosm}$ (Gy ka^{-1})	$\dot{D}_{effective}$ (Gy ka^{-1})	Age (±1σ, ka)
BN 101	Morelli	1.25±0.20	3.02±0.07	2.59±0.03	0.170±0.009	0.181±0.009	1.09±0.05	n.d.
BN 102	Monticelli	1.10±0.10				0.171±0.009		> 75
BN 103	Apani	1.15±0.15	1.27±0.03	11.39±0.36	1.69±0.05	0.161±0.008	2.56±0.51	n.d.
BN 106	Torre Rossa	1.06±0.06	0.83±0.03	1.80±0.11	0.56±0.03	0.15±0.00	1.32±0.4	n.d.

Table 4.8 - *Analytical data and OSL dating results. Water content is the measured field moisture normalised to the dry mass and corrected for fluctuation of water content; U-, Th-, and K-concentrations are determined by γ-spectrometry and used to calculate the total dose rate;* $\dot{D}_{cosm}$ *is the cosmic dose rate determined from the mean burial depth of the sample;* $\dot{D}_{effective}$ *is the total dose rate corrected for water absorption; OSL-ages are given with 1σ error limits. n.d. = not determinable*

Sample Code	Grain Size (µm)	D_e (Gy)	N	Skewness	Kurtosis
BN 101	160-200		15	-	-
BN 102	160-200	≥204	15	-0.3	2.2
BN 103	200-315	> 200	15	-	-
BN 106			10		

Table 4.9 - *Analytical data of equivalent dose (D_e) determination. Grain size indicates the quartz grain size used for OSL-dating; D_e is given as arithmetic mean of n number of single-aliquot D_e determinations, n indicates the number of measured aliquots; D_e distribution is indicated by means of its shape.*

Sample code	Recuperation (%)	Recycling Ratio	Dose Recovery	D_e(t) (s)	IR sensitivity
BN 101	0.04±0.02	1.05±0.02	-	-	-
BN 102	6.8±4.2	-	-	-	0.2±0.1
BN 103			0.806±0.02		0.09±0.01
BN 106	0.00±0.00	-	-	-	-

Table 4.10 - *Analytical data of equivalent dose (D_e) determination. Recuperated OSL-signal is given in % of the natural OSL signal, recycling ratio is the ratio of the first regenerated dose and the repeated first regenerated dose at the end of the SAR protocol; D_e(t) indicates the stimulation time range (s), where D_e is constant (1σ); IR sensitivity indicates a feldspar component based on the IR OSL signal.*

Conclusion

The geomorphological, radiometric and archaeological data collected along the Adriatic coast of southern Puglia allow us to define the coastal landscape evolution during last interglacial/glacial cycle. In fact, despite the inaccuracy of the geological and chronological record, and the incompleteness of historical reports, the following scheme of events can be outlined:

a) during last interglacial period a wide marine terrace, at presently placed at about 4 m above p.s.l. formed. At its inner margin a continuous dune belt, up to 17 m high, developed;

b) after the last glacial low stand, sea-level rose quickly until about 7000 years BP when it reached the maximum position at about 0.5 m above the present one; this high stand induced the first important phase of beach-dune belt formation;

c) sea level dropped to about 2.5 m below present position at about 3500 years BP;

c) from Bronze Age sea-level rose up to the present position with a minimum rate of 0.7 mm/year. This phase was accompanied by the discountinous accumulation of aeolian sands on the older Holocene dune belt.