We tell these tales, which are strictest true,
Just by way of convincing you
How very little, since things was made,
Anything alters in any one's trade!

A truthful song

.....

Once on a time, the ancient legends tell,
Truth, rising from the bottom of her well,
Looked on the world, but, hearing how it lied,
Returned to her seclusion horrified.
Meantime, her kindlier sister, whom men call
Fiction, did all her work and more than all,
With so much zeal, devotion, tact, and care,
That no one noticed Truth was otherwhere.

A Legend of Truth

(R. Kipling)

Project IGCP 437

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

Puglia 2003 - Final Conference

Quaternary coastal morphology and sea level changes

Otranto / Taranto - Puglia (Italy)
22-28 September 2003

Field Guide

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Foreword

Puglia 2003 is the final meeting of IGCP 437 Project: "Coastal Environmental Change during sea Level Highstands: a global synthesis with implications for Management of Future Coastal Change". It is the occasion to summarise the results of this project as prosecution of the past IGCP 61, IGCP 274 and 367 projects and to launch a project for the next future.

This field guide comprises results of about 20 years of research carried out along the coast of Puglia region by researchers belonging to different universities and nationalities. Most of researches have been supported by Italian Research Minister (Ministero dell'Università e della Ricerca Scientifica e Tecnologica). They have been coordinated by Prof. Giovanni Palmentola and by Prof. Federico Boenzi of Bari University.

The field guide includes seven chapters.
The first one yields a general overview of the climate, geology and geomorphology of Puglia region, comprising the geodynamic contest of this area in the Mediterranean basin as well as the evolution of its landscape.
In the Chapter 2, the main features of Puglia coast and its dynamics are described and the effects induced by human activity stressed.
The following five chapters describe the five days of field trip.
The Chapter "1st day" is devoted to the description of the field trip which will be held during the afternoon of the second day of the Conference. It will deal with the policyclic coastal landscape which marks the southearnmost part of Puglia, between Otranto ("the easternmost point" of Italy) and Capo Santa Maria di Leuca (the heel of the boot).
The Chapter "2ndday" describes several sites placed along the Adriatic and the Ionian coasts of Salento peninsula, an area stretching to the south of Taranto – Brindisi alignment. This alignment, named by Strabone as "soglia messapica", divide ancient mid-southern Puglia in two part: the Messapia to the southeast from the Peucetia to the northwest. Among other things, the effects of tsunami on rocky coast and an indication of Holocene relative high sea level will be shown.
The Chapter "3thday" has its focus on the Taranto area which is very famous for the intense colonization during the Neolithic, Phoenician, Greek and Roman age. It preserves some of the most famous outcrops of Tyrrhenian (OIS 5) deposits and fauna in Italy.
The Chapter "4th day" is devoted to the description of Last Interglacial and Holocene landforms which mark the Adriatic coastal area stretching at the Ostuni (the "white town") scarp. The visit of the archaeological site of Egnatia, often used for the reconstruction of historical sea level change, closes the day.
The Chapter "5th day" closes the field trip. A long transfer to the Coppa Nevigata area and to the Fortore river coastal plain allows the description of recent modifications of the coastal landscape and its influence on human colonisation.

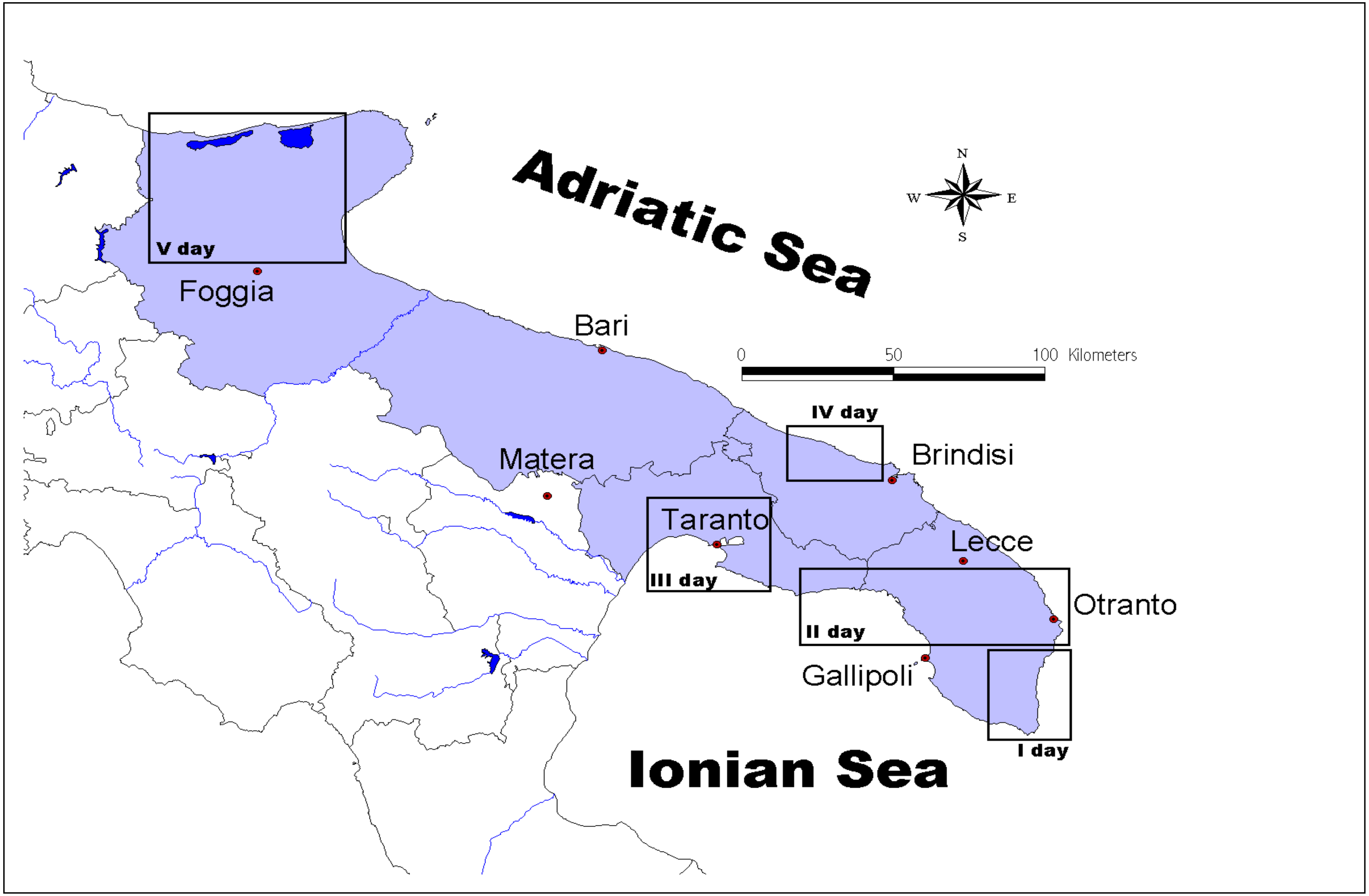
Data and results reported in this field guide are not definitive. Some of them are only the starting point of future research which will surely benefit of fruitful discussions and suggestions made on the field.

We warmly thank all the contributors which made the realisation of this field guide possible.

We wish all participants a great time in Puglia.

The organizers of the Conference

Giuseppe Mastronuzzi and Paolo Sansò


Adriatic Sea
N
W
E
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V day
Foggia
Bari
0
50
100 Kilometers
IV day
Brindisi
Matera
Taranto
III day
Lecce
Otranto
II day
Gallipoli
I day
Ionian Sea

Geological and geomorphological setting

by

G. Mastronuzzi, C. Pignatelli, P. Sansò

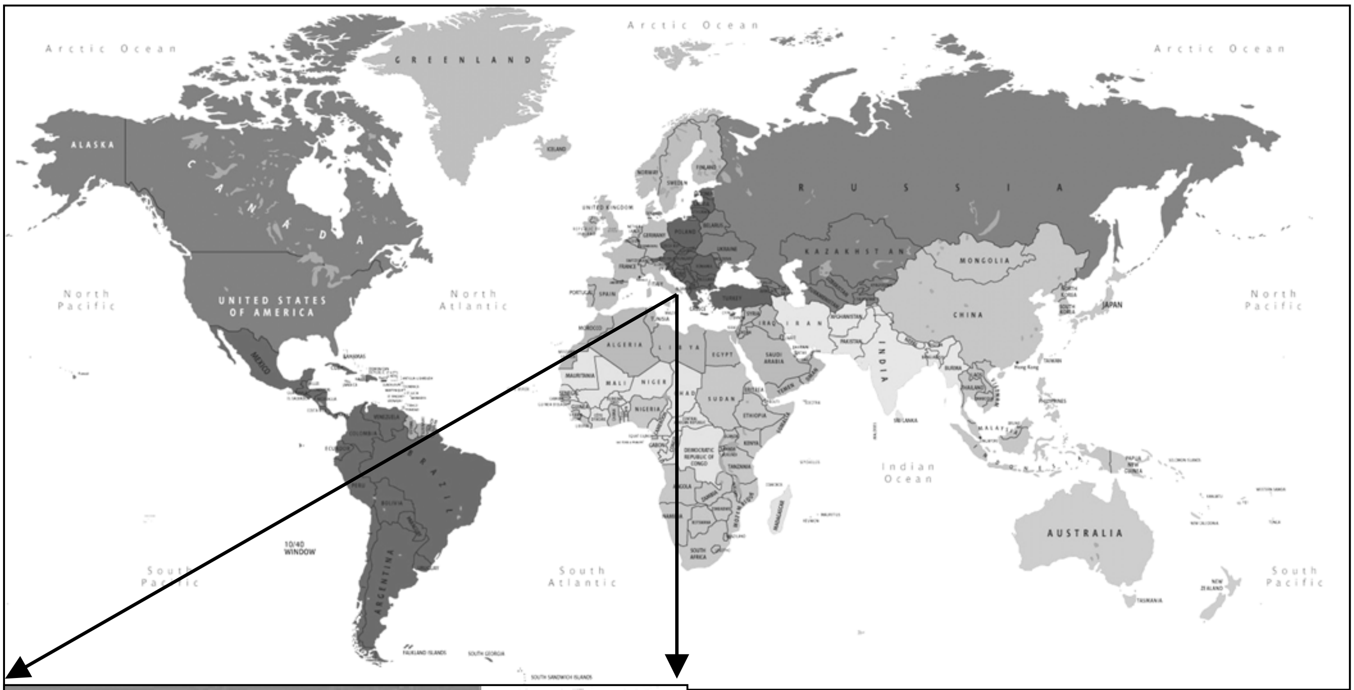


Figure 1 – *Geographic position of Puglia region*

Introduction

Puglia region stretches for 350 kilometers in the southeastern most part of Italy, between the Adriatic and Ionian Seas. Puglia region is bordered by Molise, Campania and Basilicata regions. The name "Puglia" (in latin "Apulia") comes from the ancient population of Apuli which settled before the Roman Age in mid-northern area of the modern Puglia region. Puglia region is at present divided in five administrative provinces: Foggia, Bari, Taranto, Brindisi and Lecce (Fig. 1).

Puglia region shows a typical Mediterranean climate characterised by mild winters and dry, warm summers. The mean annual values of rainfall range from about 1100-1200 mm at the Gargano Promontory to below 400 mm at Tavoliere plain. The mean value of the entire region is about 600 mm.

Climatic group	Minimum temperature (°C)	Mean temperature (°C)	Maximum temperature (°C)	Rainy days	Mean rainfall (mm)	Potential evapotran-spiration (mm)	Real evapotran-spiration (mm)	Water surplus (mm)	Water deficit (mm)
I	8.9	17.3	26.6	59.0	567	907	552	114	454
II	6.6	15.3	24.6	69.3	614	806	601	124	327
III	7.8	16.1	25.2	65.9	605	845	585	136	376
IV	8.5	16.5	25.4	63.3	659	863	616	213	403
V	7.3	15.9	25.4	62.8	499	841	525	58	392
VI	3.6	12.3	21.3	92.0	827	691	735	320	184
VII	4.2	12.9	22.3	87.0	894	726	749	365	197
VIII	6.1	14.0	22.9	71.4	699	754	653	204	260
IX	6.0	14.6	24.1	86.8	798	788	686	277	266
X	8.7	16.5	25.5	65.4	834	859	694	347	372
XI	2.7	11.5	20.7	103.0	1269	682	823	692	104

Table 1 - *Distinctive features of each climatic group recognisable in Puglia region (from Zito et al., 1988).*

Mean temperature values are comprised between 11 and 12 °C recorded at the most elevated areas of Subappenino Dauno and Gargano Promontory and more than 17 °C along the Ionian coastal area. In summary, 11 climatic groups can be recognised in Puglia region (Zito et al., 1988) (Table 1). Their distribution is influenced mainly by the altitude whereas it is quite indipendent by the distance from the sea (Fig. 2).

Moreover, the exposition to the most frequent winds does not affect the Puglia region climate: the Adriatic coast, exposed to the dry, cold northern winds shows the same climate of the Ionian coast which is interested by the warm, moist southern winds blowing from Africa.

Geology

Puglia region belongs to the complex structural environment of the Central Mediterranean region (i.e.: Channel and Horvart, 1976; Channel *et al.*, 1979; D'Argenio *et al.*, 1980; Auroux *et al.*, 1985; Slejko *et al.*, 1999) (Fig. 3). Here African and Eurasian plates collide, giving rise to some seismically active belts.

The Padan-Adriatic region is currently interpreted as a rigid microplate bordered, on the eastern, northern and western margins, by a mobile mountain belt which includes the Albanides, the Dinarides, the Alps and the Apennines. The southern margin of the plate, that is the Africa-Adria boundary, is still undefined although geological and geodetical evidence points to a significance divergence between Southern Sicily and Puglia. The relative motion of Adria versus Europe during the Neogene-Quaternary period is marked out by a counter-clockwise rotation around a pole located in western Liguria (RP in Fig. 3).

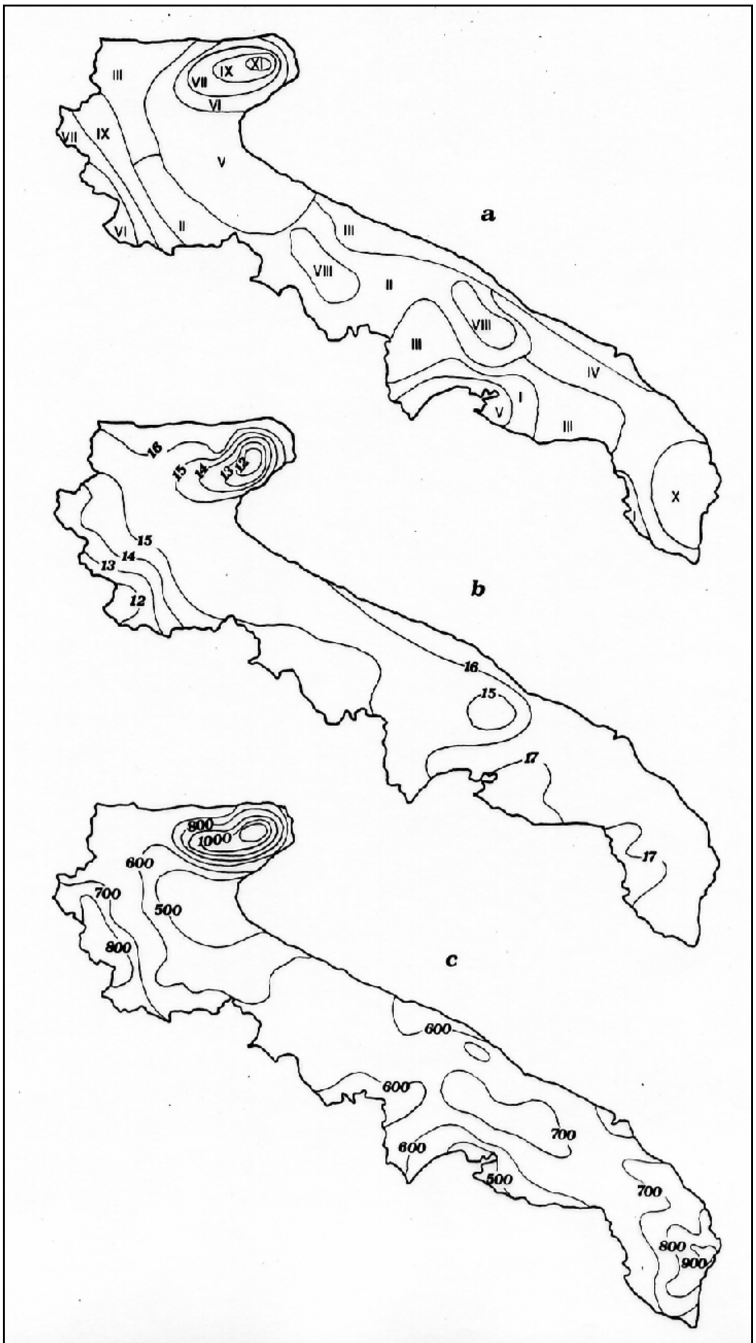


Figure 2 - *Climatic group (a), temperature (b) and rainfall (c) distribution in Puglia region (from Zito et al., 1988).*

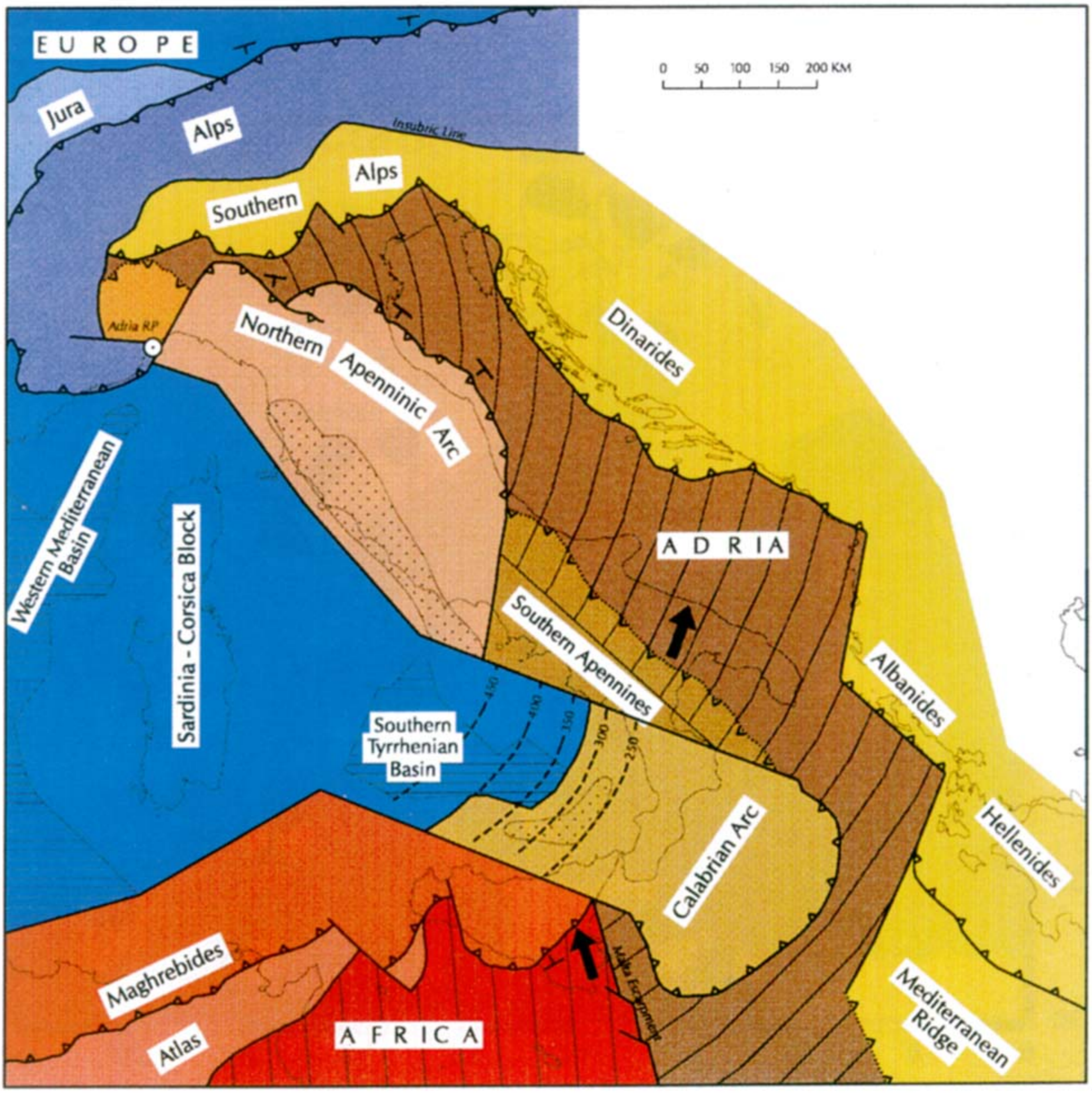


Figure 3 - *Geodynamic sketch of Adria plate and surrounding areas (from Slejko et al., 1999).*

In particular, Puglia region is the emerged part of the Adria plate which constitutes the foreland of both Apenninic and Dinaric orogens. It comprises a Variscan basement covered by a 3-5 km thick Mesozoic carbonate sequence – the *Calcari delle Murge* unit -, and overlain by thin deposits of Neogene and Quaternary age (Ricchetti, 1980; Ricchetti *et al.*, 1988) (Fig. 4). The Apulian foreland is weakly deformed and affected by Apenninic (NW-SE) and anti-Apenninic (NE-SW) trending faults which subdivide it into five main structural blocks characterized by different landscapes and uplift rates – Gargano, Tavoliere, Murge, Taranto-Brindisi plain and Salento peninsula.

Uplift rates

The general subsidence of the Apulia foreland, occurred after the early Miocene, was followed by the uplift of the entire area. According to Doglioni *et al.* (1994) the reversal of the general tectonic behaviour of the Puglia region started in the Middle Pleistocene when the thick continental lithosphere of the Apulian swell reached the Apenninic subduction hinge, offering larger resistance to the flexure. The subsequent slowing down of the eastward rollback of the subduction hinge and the penetration of the slab induced the buckling of the foreland which is responsible for the uplift of this region (Fig. 5).

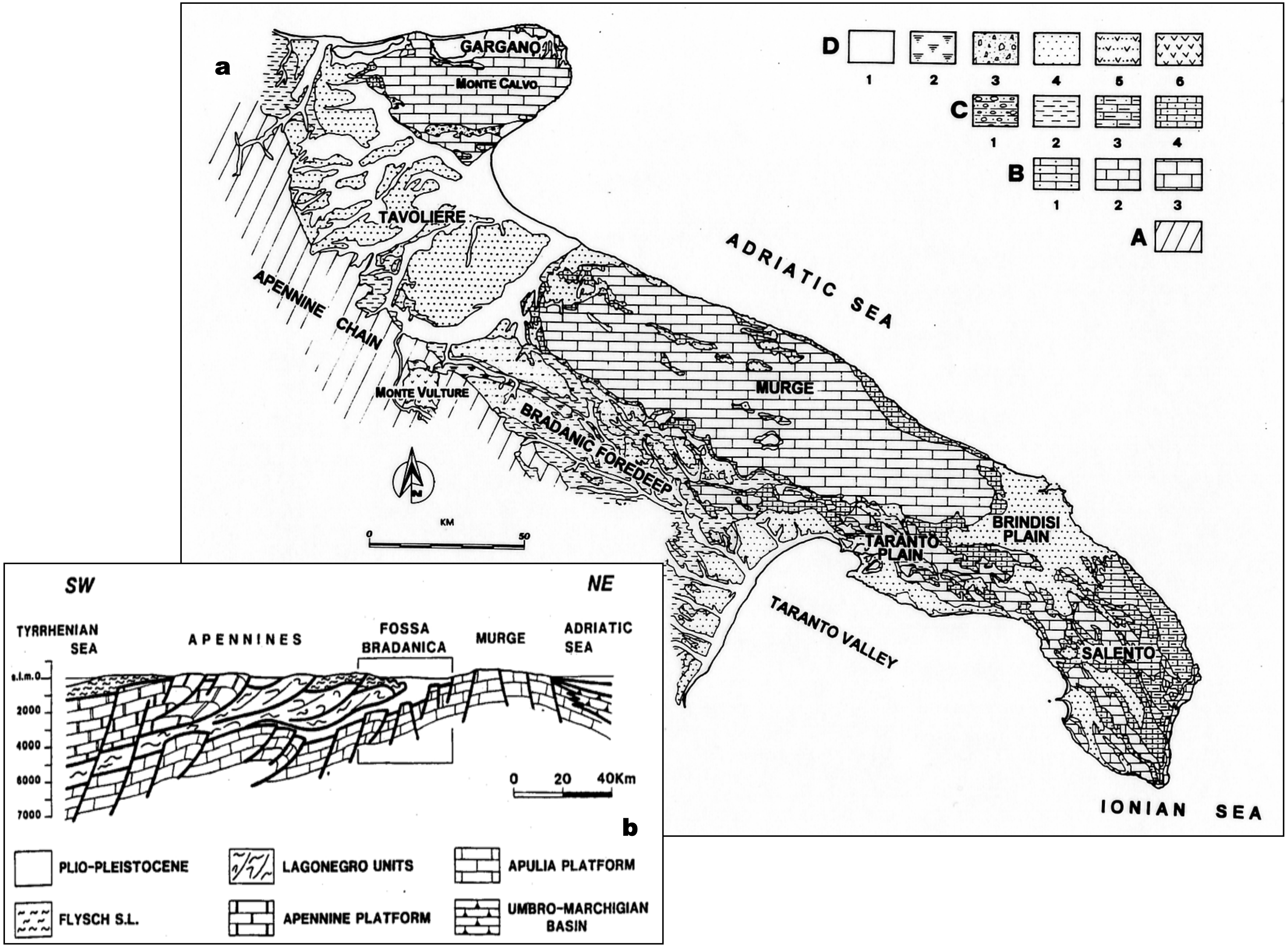


Figure 4 - *Geological map and geological cross section of Puglia region.* ***A. Apenninic Units****; B. Apulian Foreland: 1 - Open shelf carbonate sequences. Miocene. 2 - Calcarenites and calcilutites. Paleocene - Oligocene. 3 - Limestones and dolomites. Cretaceous.* ***C. Foredeep:*** *1 - Sands and conglomerates. Lower Pleistocene. 2 - Clay. Lower Pleistocene. 3 - Calcarenites and calcilutites. Pliocene. 4 - Calcarenites. Middle Pliocene - Lower Pleistocene.* ***D. Quaternary:*** *1 - Alluvial, beaches and coastal dune deposits. Upper Pleistocene - Holocene. 2 - Lacustrine terraces deposits. Lower - Middle Pleistocene. 3 - Slope deposits. Late Pleistocene. 4 - Marine terraced deposits. Middle-Upper Pleistocene. 5 - Volcano-sedimentary deposits. 6 - Volcanic deposits.(from Caldara et al., 1998; Sella et al., 1988)*

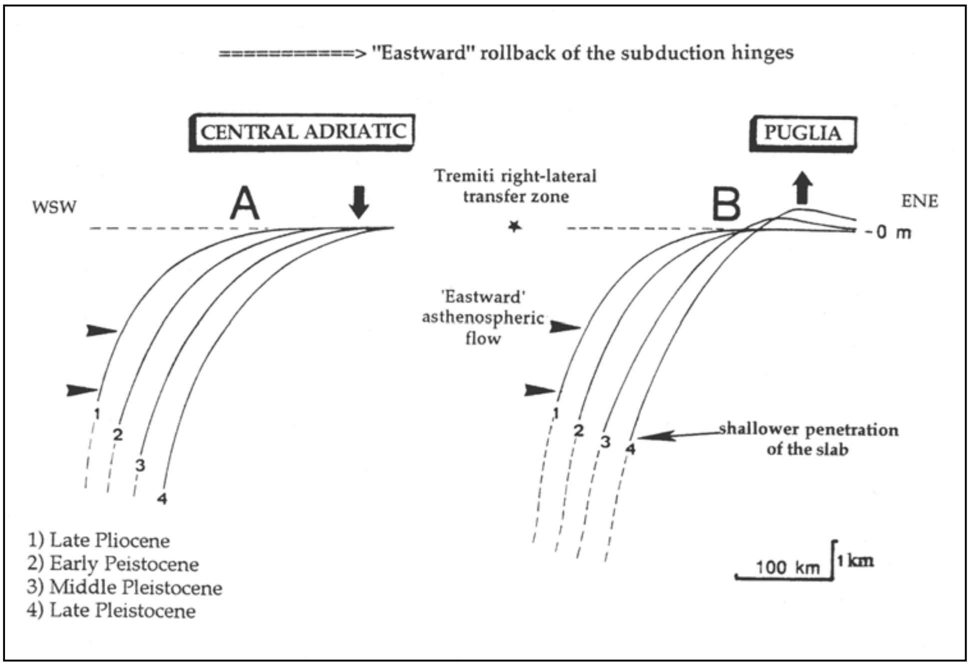


Figure 5 - *Comparison of the different evolutions of the subduction hinge rollback of the central Adriatic and Puglia region (from Doglioni et al., 1994).*

Locality	Elevation OIS5e shoreline	Dating method	Mean uplift rate (m/ka)
Ponte del Re	45	Palaeontology and aminostratigraphy	0.31
Santa Teresiola di Galbe	28	U-Th	0.18
M.S.Pietro	28	Palaeontology and aminostratigraphy	0.18
Torre Castelluccia	28	Palaeontology and aminostratigraphy	0.18
Torre Colimena	20	Geomorphological correlation	0.11
Torre Castiglione	2	Palaentology and U-Th	-0.03
Gallipoli	10	Palaeontology and aminostratigraphy	0.03
Torre S. Giovanni	8	Palaeontology and aminostratigraphy	0.02

Table 1 – *Uplift rates during last 125 ka along the coast of southern Puglia (from Bordoni and Valensise, 1998; modified).*

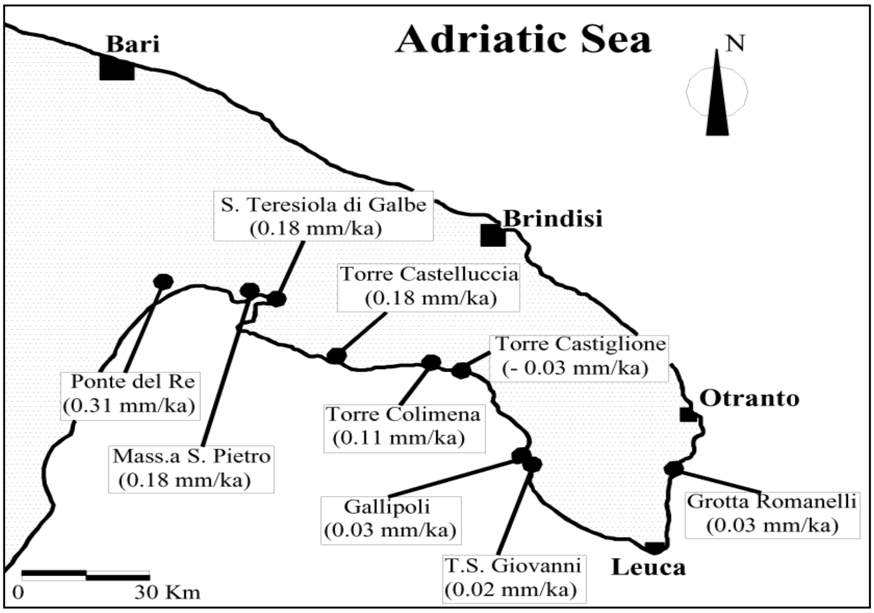


Figure 6 - *Uplift rates along the coast of southern Puglia (from Bordoni and Valensise, 1998; modified).*

In particular, uplift rates of the Puglia region have been estimated by means of the last interglacial (oxygen isotope substage 5e) marine terrace elevation (Cosentino and Gliozzi, 1988; Westaway, 1993; Bordoni and Valensise, 1998). This terrace is marked along the Ionian coast by a distinctive faunal assemblage containing the index fossil *Strombus bubonius* Lamarck. Taking into account an average eustatic elevation of 6 m above p.s.l. and an age of 125 ka for the Tyrrhenian (substage 5e) sea level highstand (i.e.: Ku *et al.*, 1974; Neumann and Hearty, 1996), Bordoni and Valensise (1998) point out a decreasing uplift rate from north-west to south-east along the Ionian side of Puglia region. Rates range, in fact, from 0.31 m/ka at the north-west of Taranto (Ponte del Re locality), to 0.18 m/ka in the surroundings of Taranto (Santa Teresiola di Galbe and Masseria San Pietro localities) and to the southwest (Torre Castelluccia locality), to 0.11 m/ka at Torre Colimena, to –0.03 m/ka at Torre Castiglione, to 0.03 m/ka at Gallipoli, and to 0.02 m/ka at T.S. Giovanni (Table 1; Fig. 6).

Uplift rates along the eastern side of Puglia are more difficult to determine as it was most likely never colonised by Senegalensis fauna during the last interglacial. In literature, uplit rates are often calculated from data collected at Grotta Romanelli, near Castro, where a notch and an abrasion platform covered by a coarse marine deposit are placed between 8 – 10 m above present sea level (Blanc, 1921). However, *S. bubonius* was never be found in this deposit (as in some case erroneuosly reported) nor valid radiometric data exist so far.

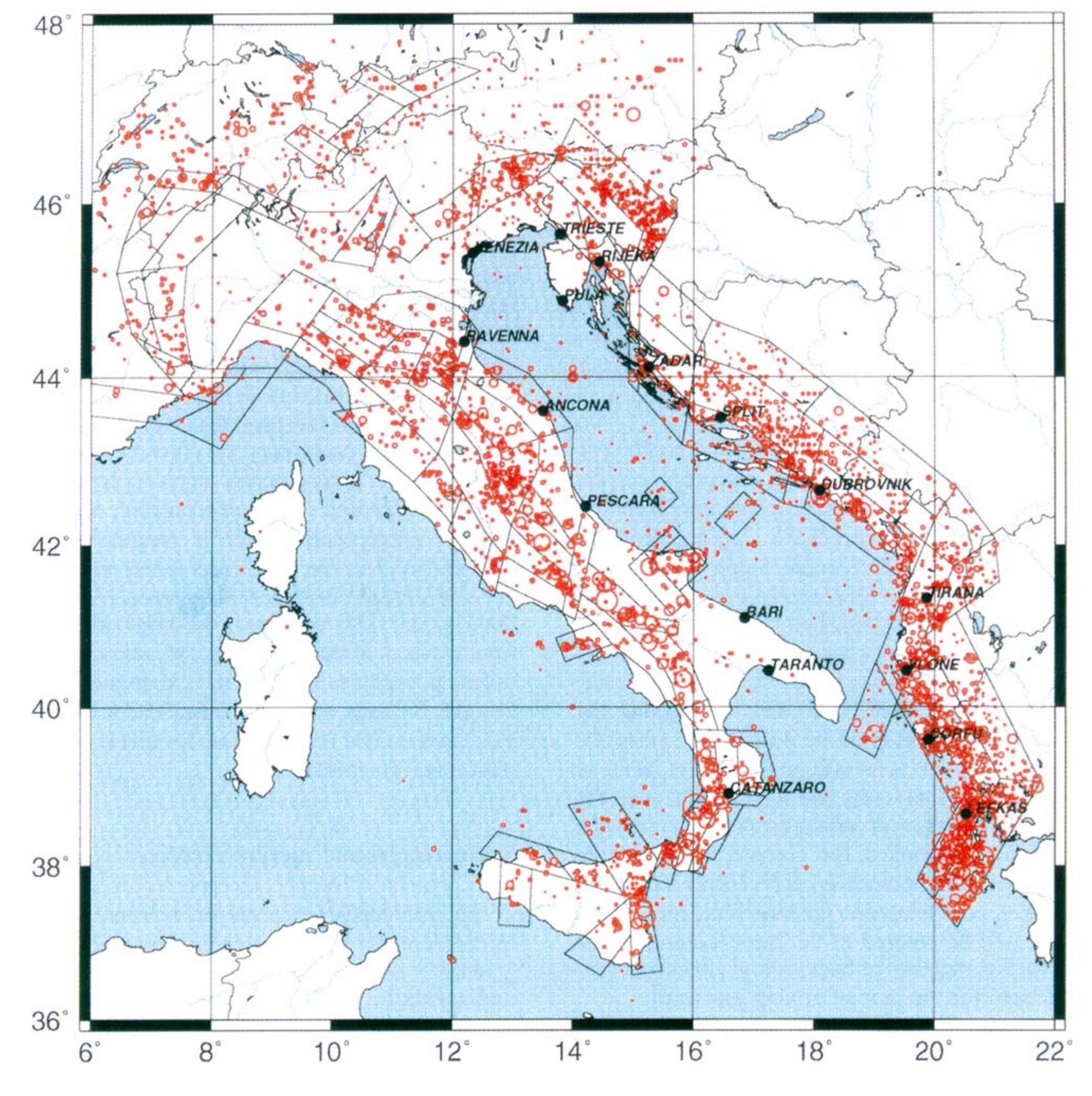


Figure 7 - *Selected epicentres of earthquakes in Adria plate and surroundings area (from Slejko, 1999).*

Code	Year	Latit.	Long.	Subregion	Reliab.	M_Earthq	Tsun_In	Ref.
1	-57	41.3	19.5	Albanian coasts	2.0	6.6	3	a
2	1273	41.3	19.7	Albanian coasts	2.0	6.5	3	a
3	1622	37.6	21.0	Ionian islands	1.5	6.6	-	a
4	1627	41.8	15.3	Gargano	4.0	6.3	5	b
5	1633	37.5	21.0	Zante island	3.0	6.9	3	a
6	1667	42.5	18.2	Dubrovnik	3.0	-	4	a
7	1723	38.5	20.5	Leukada	3.0	-	3	a
8	1731	41.5	15.6	Gargano	2.0	6.3	-	b
9	1732	39.5	20.0	Ionian islands	2.0	-	2	a
10	1743	39.0	19.3	Apulia	2.0	7.3	-	b
11	1784	38.3	16.4	Ionian Calabria	2.0	4.1	-	b
12	1791	37.8	21.0	Ionian islands	2.0	7.0	3	a
13	1821	37.8	21.2	Ionian islands	2.0	6.5	4	a
14	1821	37.8	21.3	Ionian islands	3.0	6.5	-	a
15	1825	38.8	20.7	Ionian islands	3.0	6.8	3	a
16	1832	39.0	17.0	Ionian Calabria	4.0	6.7	2	b
17	1833	40.4	19.9	Albanian coasts	3.0	6.4	4	a
18	1836	39.6	16.7	Ionian Calabria	4.0	6.2	3	b
19	1851	40.7	19.7	Vlona	2.0	6.6	3	a
20	1866	40.3	19.4	Vlona	2.0	6.5	4	a
21	1883	39.5	20.0	Corfù	2.0	-	3	a
22	1889	42.1	15.5	Gargano	2.0	-	-	b
23	1898	37.8	21.0	Zakynthos	2.0	-	2	a
24	1907	38.0	16.0	Ionian Calabria	4.0	5.9	3	b
25	1914	38.8	20.6	Levkas	2.0	6.3	4	a
26	1920	40.3	20.0	Vlona	2.0	6.1	4	a
27	1948	38.7	20.5	Levkas	3.0	6.5	4	a
28	1953	38.0	20.1	Itaka	2.0	-	6	a
29	1979	41.9	19.0	Boka_Kotorska	4.0	7.0	1	a

Table 2 - *Tsunamis with known epicentres occurred in southern Adriatic and Ionian seas during last two millennia according to Soloviev (1990) (a) and Tinti and Maramai (1996) (b).* ***Latit. and Longit.****: position of the epicenter of tsunami-generative earthquakes;* ***Reliab.****: Reliability; 0 - very improbable tsunami, 1 - improbable tsunami , 2 - questionable tsunami, 3 - probable tsunami, 4 - definite tsunami;* ***M_Earth.:*** *Magnitude of tsunami-generative earthquake;* ***Tsun_In****: Intensity of tsunami: 1 - very light, 2 - light, 3 - rather strong, 4 - strong, 5 -very strong, 6 - disastrous.*

Recently, Mastronuzzi and Sansò (2002c) using a combination of geomorphological and radiometric data from the northern coast of the Gargano promontory (comprising the Fortore River coastal plain and Punta delle Pietre Nere) estimate the uplift rate of about 1.5 mm/yr in this area during the Holocene.

Central and southern Puglia are low seismic regions surrounded by highly seismic zones which constitute the borders of Adria plate (Fig. 7): the coast of Albania and Ionian Islands (western Greece) to the east, the Calabrian arc and southern Apennines to the west, and the Gargano promontory to the north.

Seismic activity has been responsible for the recording of numerous earthquakes in this region during the last millennium and can explain the historical tsunamis which have struck the southern Adriatic and Ionian coasts (Soloviev, 1990; Tinti *et al.*, 1995;Tinti and Maramai, 1996; Mastronuzzi and Sansò, 2000; 2002d; 2003; Gianfreda *et al.*, 2001) (Table 2, Fig. 8).

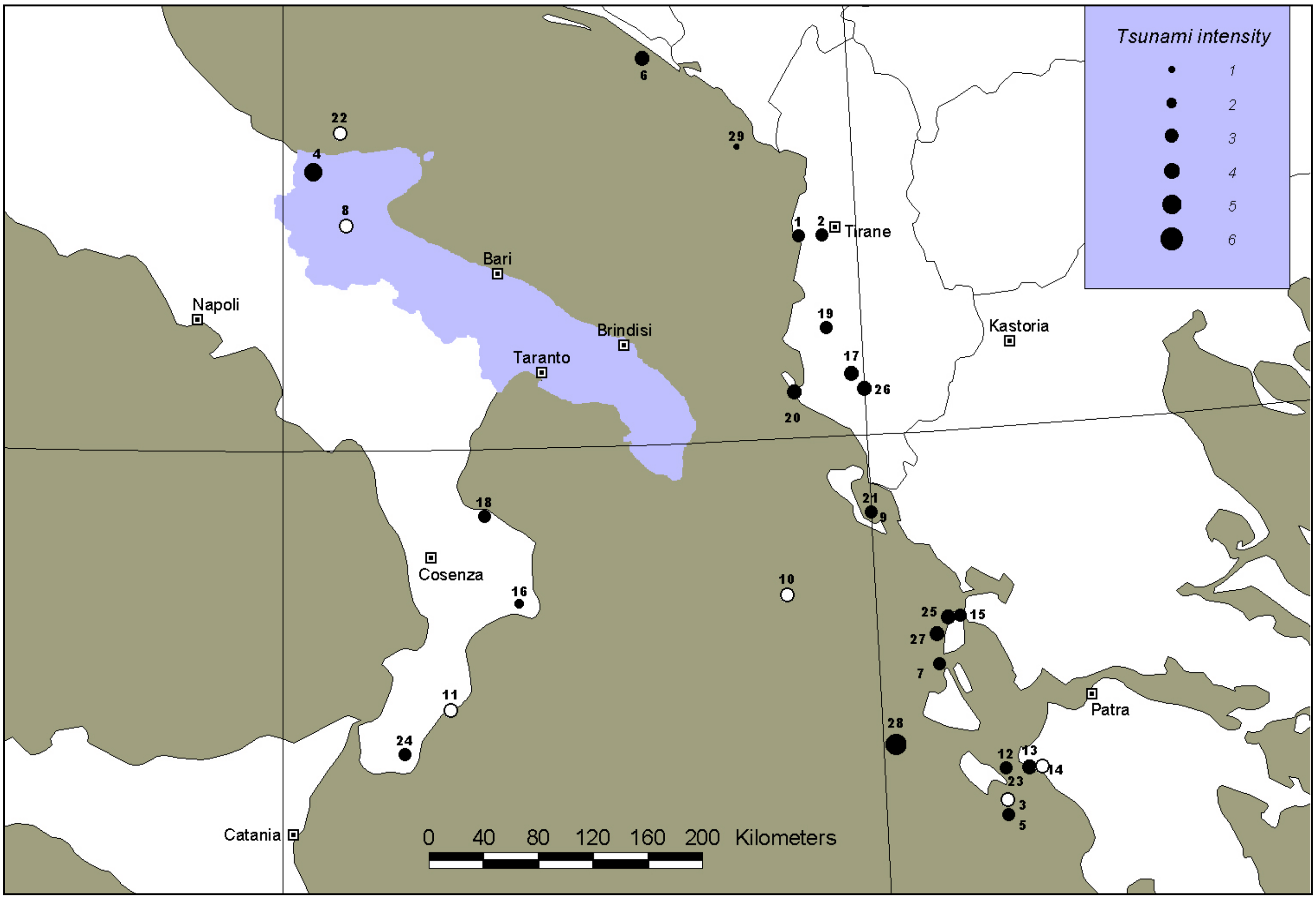


Figure 8 - *Geographical distribution of tsunami-generative earthquake epicenters in southern Adriatic and Ionian seas. Legend: Tsunami intensity: 1 - very light, 2 - light, 3 - rather strong, 4 - strong, 5 -very strong, 6 - disastrous. White dots mark the epicentres of earthquakes which produced tsunamis of unknown intensity.*

The Puglia landscape

Puglia region shows six different landscapes in response to the geological evolution: the Subappenino Dauno, the Tavoliere plain, the Gargano promontory, the Murge plateau, the Brindisi-Taranto plain, the Salento peninsula, the Metaponto plain (see Fig. 4).

The Subappenino Dauno is a small part of southern Apennines. The highly dissecated landscape is here dominated by mass-movements and intense fluvial erosion. The Tavoliere plain is a wide alluvial plain stretching from the Apennine Chain front to the west down to the Manfredonia Gulf to the east. It is crossed by the Ofanto, Carapelle, Cervaro and Candelaro rivers which at present are marked by a very low solid load because of the construction of numerous dams in their drainage basins (Caldara *et al.*, 1998).

The Gargano promontory is a carbonatic horst widely affected by karstic landforms and by the development of a relict drainage network. Active tectonic structures are responsible for the development of numerous tectonic landforms and for the historical seismicity of the area.

The Murge plateau is marked by a rolling surface constituted by an etchplain of Tertiary age, partly modified by more recent karstic landforms (Sansò and Triggiani, 2001).

The Taranto-Brindisi plain is a Middle Pleistocene wide sediplain placed between the Murge plateau to the NW and the Salento peninsula to the SE. This last one is marked by a landscape composed of narrow and low-elevated carbonatic ridges which separate small plains shaped on Pliocene and Quaternary sediments. The peninsula is drained by an endorheic drainage network which flows in the underground circuits through karstic sinkholes; an esorheic relict drainage con be recognised along the coastal area.

The Metaponto plain is a coastal alluvial plain formed in the Apennine foredeep (Fossa Bradanica region) by the Bradano, Basento, Agri and Sinni rivers. It is bordered landward by a well defined staircase of middle-late Pleistocene marine terraces (Boenzi *et al.*, 1976; Brückner, 1980; Boenzi, 1984).

The coastal landscape

The coastal landscape of Puglia region is generally characterized by a number of marine terraces produced by the superimposition of regional uplift and glacio-eustatic sea level changes which have occurred since the Middle Pleistocene (i.e.: Ciaranfi *et al.*1988; 1994; Palmentola, 1987; D'alessandro *et al.*, 1994). Terraces are arranged in a stair-case and stretch from an elevation of about 450 m to present mean sea level. Some of them display a thin sedimentary body composed of calcareous sandstones (*panchina*), in some places accompanied by dune deposits, whereas others are only represented by abrasion platforms. The higher terraces are generally shaped on Mesozoic limestones whereas the lower ones are cut on the overlying calcareous sandstones of Upper Pliocene – Lower Pleistocene age (*Calcarenite di Gravina* unit) or more recent units.

Middle Pleistocene terraces have been poorly defined because of the difficulty to properly date them. These terraces show in fact a low grade of preservation and lack of characteristic macrofauna assemblages which makes the recognition of related sediments difficult. On the contrary, the last interglacial marine terraces are marked by deposits containing a rich Senegalese fauna. In particular, the occurrence of *S. bubonius* marks out the oldest deposits of the Last Interglacial, which should locally deposited only during the OIS 5e, about 125 ka (i.e. Hearty and Dai Pra, 1992).

However, marine terraces marked by deposits with Senegalese fauna lack along the western and eastern coasts of the Adriatic Sea, notwithstanding marine terrace deposits in the region of Bari (Iannone and Pieri, 1976) are at about the same altitude of Tyrrhenian marine terrace deposits occurring along the Ionian coast. The absence of *S.bubonius* specimens is probably due to the cold marine current pattern in the eastern Mediterranean Sea, which impeded the diffusion of this species in the Adriatic Sea (Malatesta, 1985). For this reason, the occurrence of the last interglacial deposits has been hypothetically suggested by Di Geronimo (1969; 1970; 1979) and by Iannone and Pieri (1979) but never validated by chronological or paleontological data.

The monotony of Puglia coastal landscape is broken by a relict drainage network characterised by deep valleys, locally named *gravine* or *lame*, which dissect the sequence of marine terraces. These valleys belong to different generations, each one of them related to a high sea level stand as their mouths are constantly located at the inner margin of a marine terrace, i.e. - in correspondence of an ancient coastline.

The high permeability of the Mesozoic and Plio-Pleistocenic successions cropping out in the central part of the Puglia region and the low local relief cause the lack of overland flow. Rain-water rapidly infiltrates feeding a wide, deep aquifer which rests on sea-water intruded from the nearby coastal area (Ghyben-Herzberg principle) (Fig. 9). At present, in the Murge plateau, the piezometric surface reaches the maximum altitude of about 200 m above m.s.l. in its innermost area. This surface slopes about 0.2-0.8‰ towards the coastline (Cotecchia, 1977) which is studded by a number of coastal springs.

Morphological features of valleys along with the hydrogeological characteristics of the area mark the leading role of the sapping processes in the genesis of these landforms. These processes were enhanced by groundwater flow and produced a network of narrow, straight valleys showing a box transverse profile whose growth has been affected in several localities by joints (Mastronuzzi and Sansò, 2002a).

Sapping processes were strongly influenced by Pleistocene sea level changes in consequence of the aquifer resting on sea water, intruding from the nearby coastal area. Highly favourable conditions for the development of sapping valleys occurred several times during the Middle-Upper Pleistocene sea level highstands as each relict shoreline shows its own generation of sapping valleys. However, at Ionian side the longest and deepest valleys formed during the OIS 7 sea level highstand probably in response to the combined effect of high rainfalls and rapid sea level rise, which increased the hydraulic head at springs and the intensity of the sapping processes (Fig. 10).

At the Adriatic side, the longest valleys are linked to the +13 and +4 m relict shorelines which have been not dated yet (Fig. 11). However, the occurrence of sapping valleys partly submerged along the Adriatic coastal area suggests the presence of relict coastlines below the present sea level and a slight subsidence of this area.

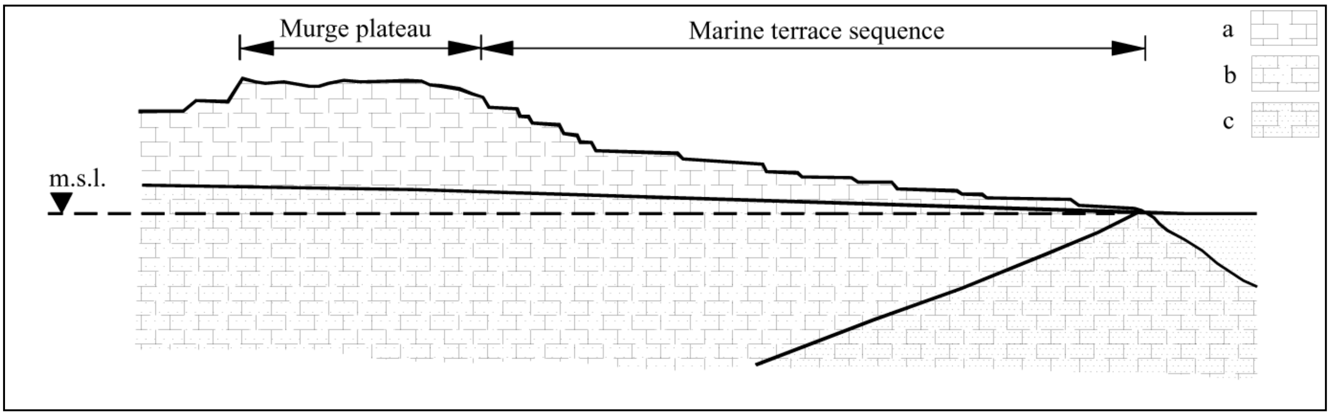


Figure 9 - *Hydrogeological sketch of Puglia coastal aquifer. Legend: a - Mesozoic limestones; b - fresh groundwater; c - intruding seawater.*

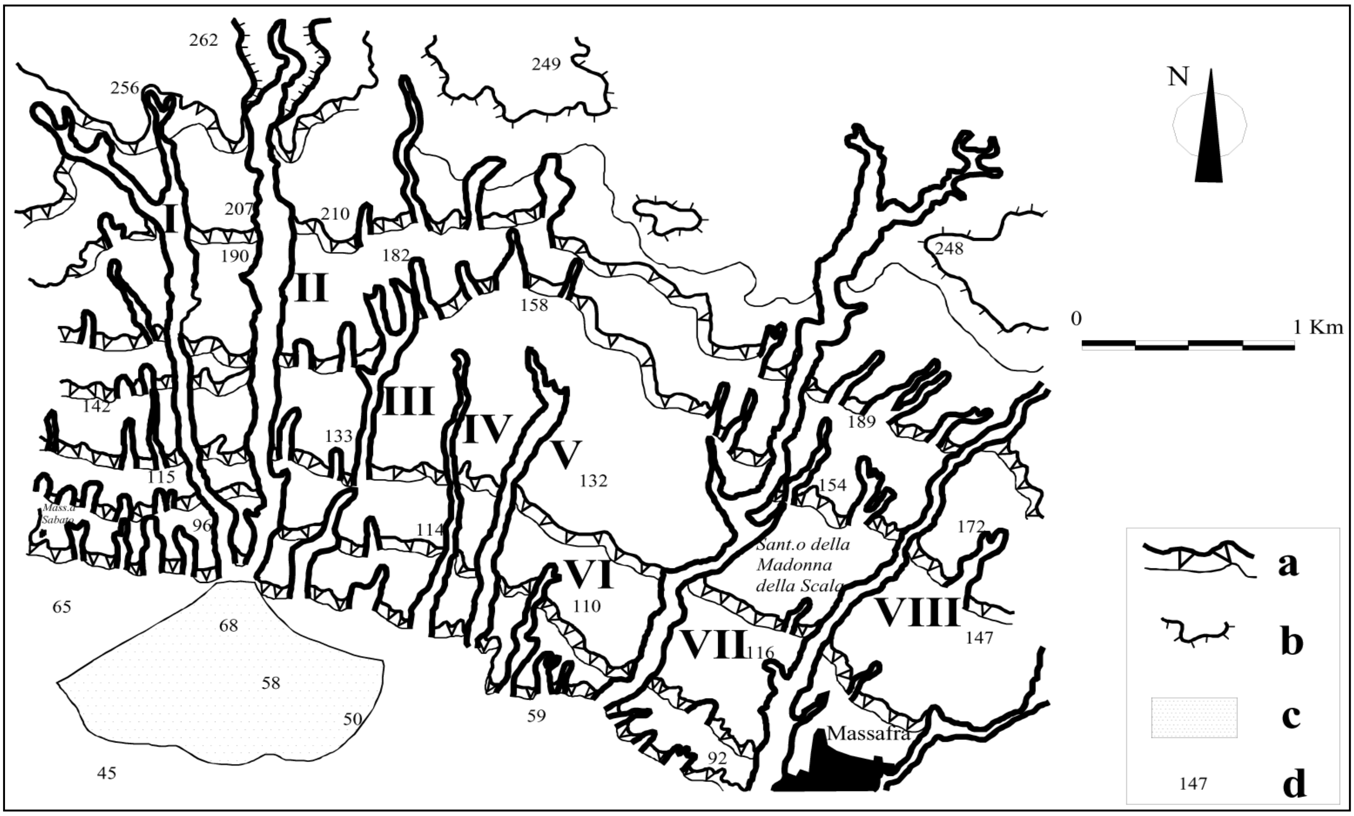


Figure 10 - *Geomorphological sketch of Taranto-Mottola area (Ionian coastal area). Legend: a - relict cliff; b - denudational scarp; c - alluvial fan; d - elevation (m). I - Gravina Petruscio; II - Gravina Capo di Gavito; III - Gravina Canale Lungo; IV - Gravina Giulieno; V - Gravina Portico del Ladro; VI - Gravina Palombaro; VII - Gravina Colombato; VIII - Gravina Madonna della Scala.*

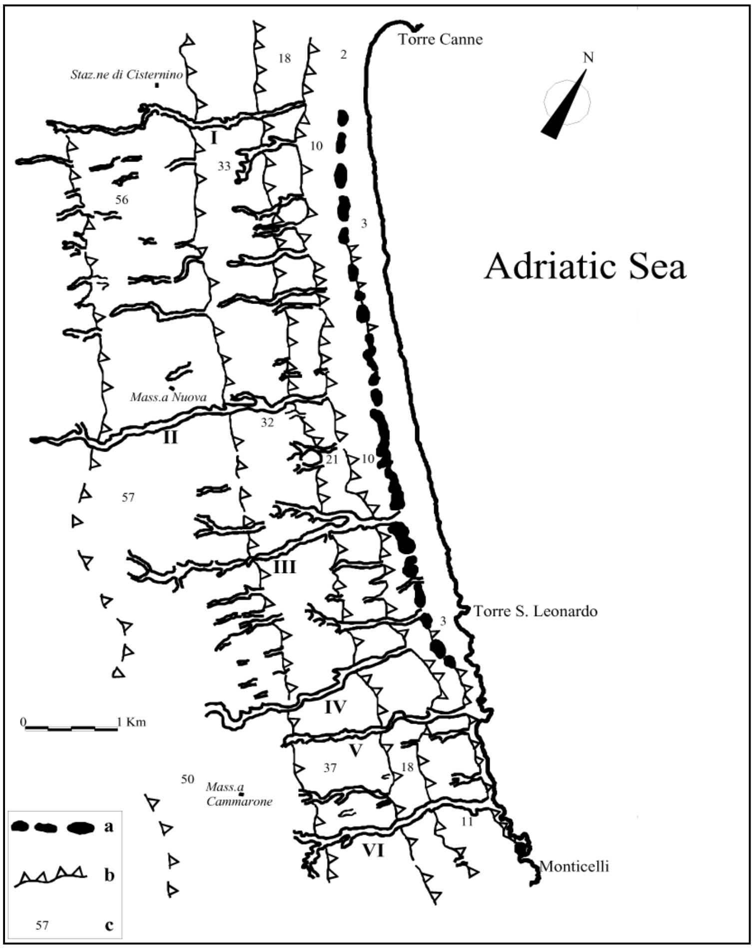


Figure 11 - *Geomorfological sketch of T. Canne – Monticelli area (Adriatic coastal area). Arrows mark the position of relic cliffs; black areas represent last interglacial dune belt. I – Lama di Torrebassa; II – Vallone Difesa di Malta, III – il Fiume, IV - Lamacornola, V – Vallone del Pilone; VI – Fiume di Rosa Marina.*

Holocene sea level change recorded along the Puglia coast

The general trend in "eustatic" sea level is reasonably well-constrained (Fairbanks, 1989), with a sea level rising rapidly in the early Holocene but decelerating sharply around 6500 years BP, after which there was a slight sea level rise. Although many "far-field" sites (those distant to the former ice sheets) record a mid Holocene highstand, Miyauchi *et al.* (1994) report no evidences of a Holocene high stand around the Italian peninsula. Emerged Holocene marine deposits here only occur where net tectonic uplift has exceeded the rise in "eustatic" sea-level. Good examples of Holocene sea-level highstands occur in northeastern Sicilia and Ionian Calabria, which are two of the most uplifted Italian areas since OIS 5e (Firth *et al.*, 1996; Pirazzoli *et al.*, 1997; Stewart *et al.*, 1997; Rust and Kershaw, 2000).

There are few Holocene sea-level curves for the Mediterranean Sea, those that exist are from the coast of the Tyrrhenian Sea (Antonioli *et al.*, 2000).

Alessio *et al.* (1994) reconstruct a sea level curve for the last 22000 years derived from the study of Vermetid encrustations on speleothems preserved in coastal caves on the stable coasts of the Tyrrhenian Sea. They suggest that following the rapid rise in sea-level during the early Holocene, sea level stabilised at about 3.5-3.0 m below the present position between 6500 and 2500 years BP.

A similar but smoother Holocene sea level curve has been proposed by De Muro and Orrù (1998) based on an analysis of beach rock data from the northeastern coast of Sardinia.

Laborel *et al.* (1994) reconstruct the sea-level curve for the last 4500 years along the Mediterranean rocky coasts of France and Corsica. Sea level rise here was estimated to be about 0.4 mm/year between 4500 and 1500 years BP, falling to 0.2 mm/year from 1500 years BP to the present time.

According to Lambeck and Bard (2000), sea level along the French Mediterranean coast has risen continuously since the time of the last glacial maximum with no Holocene highstands. They suggest that sea level was about 3 m below present at 6000 years and at about - 0.5 m at 3000 years BP.

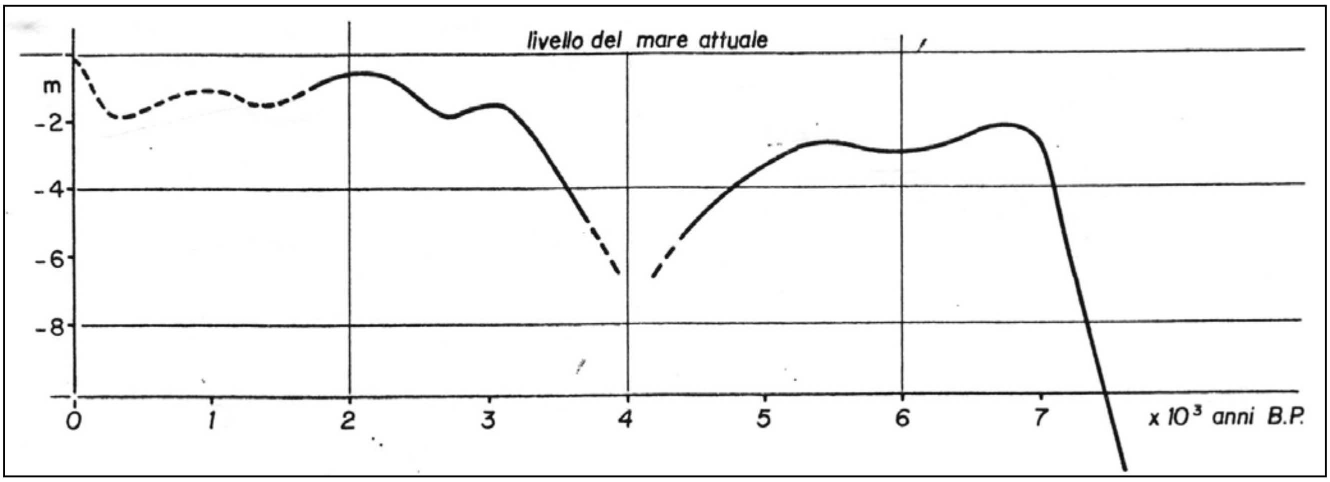


Figure 12 - *Relative sea level changes reconstructed along the Ionian coast of Puglia region during the last 7 ka (from Dai Pra and Hearty, 1988).*

Lastly, Morhange *et al.* (2001) report a 1.5 m steady rise in relative sea level from 5000 to 1500 years BP from their analysis of the ancient harbour of Marseilles. This was followed by a near stable level close to present until the start of the last century.

Few data about Holocene sea level change have been published for the Adriatic and Ionian coast of Italy. However, several studies suggest that there is evidence in this area for a mid Holocene sea-level highstand.

Along the Ionian coast of Puglia, Dai Pra and Hearty (1989) identify a sea level highstand around 7000-5000 years BP (conventional ^{14}C ages) at about 2.5 m below present, followed by a low stand around 4000 years BP and then by a sea level rise up to the present (Fig. 12).

Using data collected along the Ionian coast of Basilicata, Westaway (1993) suggests for southern Italy that the Holocene relative sea level peaked at about + 2 m between 7000 and 6000 years BP before falling to present about 4000 years BP.

Finally, along the Adriatic coast of Puglia Dini *et al.* (2000) suggest a relative high sea level stand at about 6000 years BP (conventional ^{14}C ages) 1 m above p.s.l. followed by a low stand at about -2 m during historical time (Fig. 13).

More recently, Auriemma *et al.* (2003) suggest on tha base of available geomorphological, archaeological and radiometric data collected on the coast of Puglia (Fig. 14) the occurrence of a Mid Holocene sea level stand slight higher than present position followed by a deep low stand during the Bronze Age first and by a fast rise of sea level during Greek-Roman times (Fig. 15).

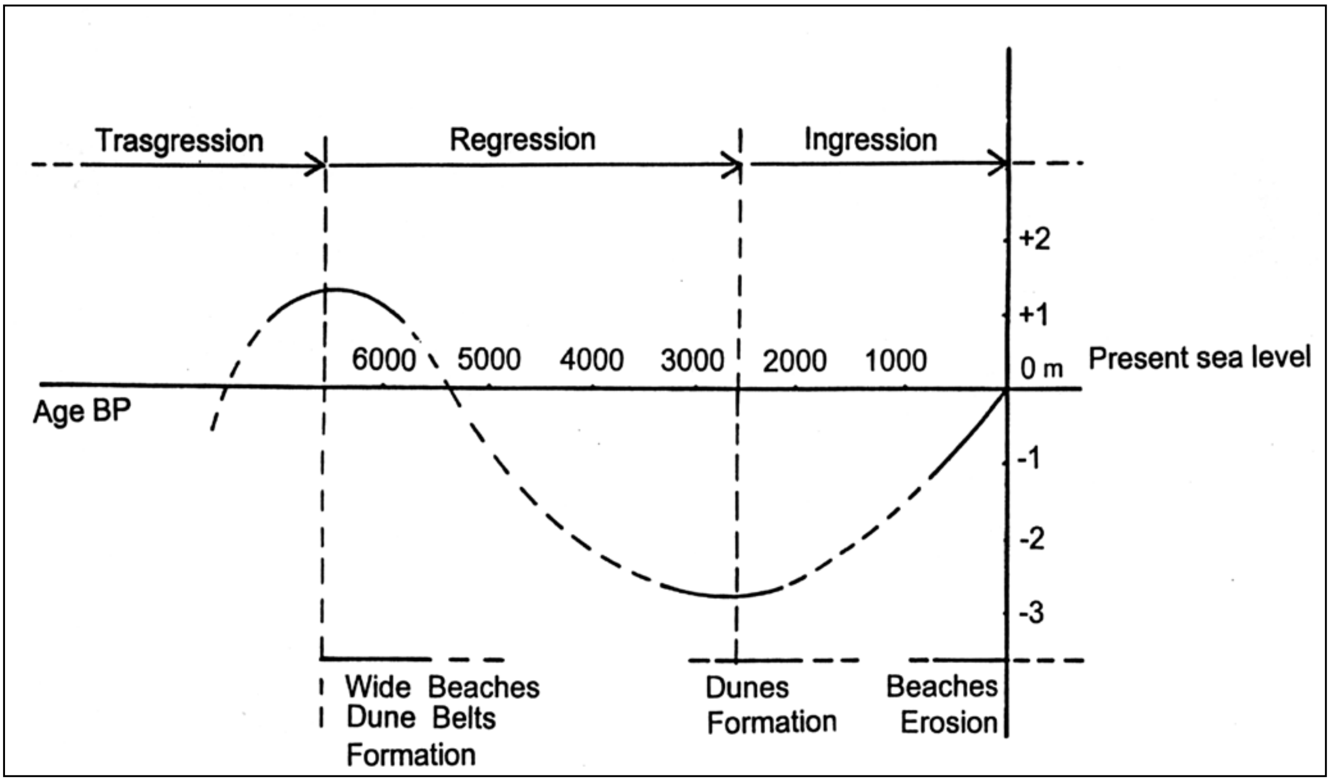


Figure 13 - *Relative sea level changes and morphogenetic phases recognized along the Adriatic coast of Puglia region (FROM Dini et al., 2000).*

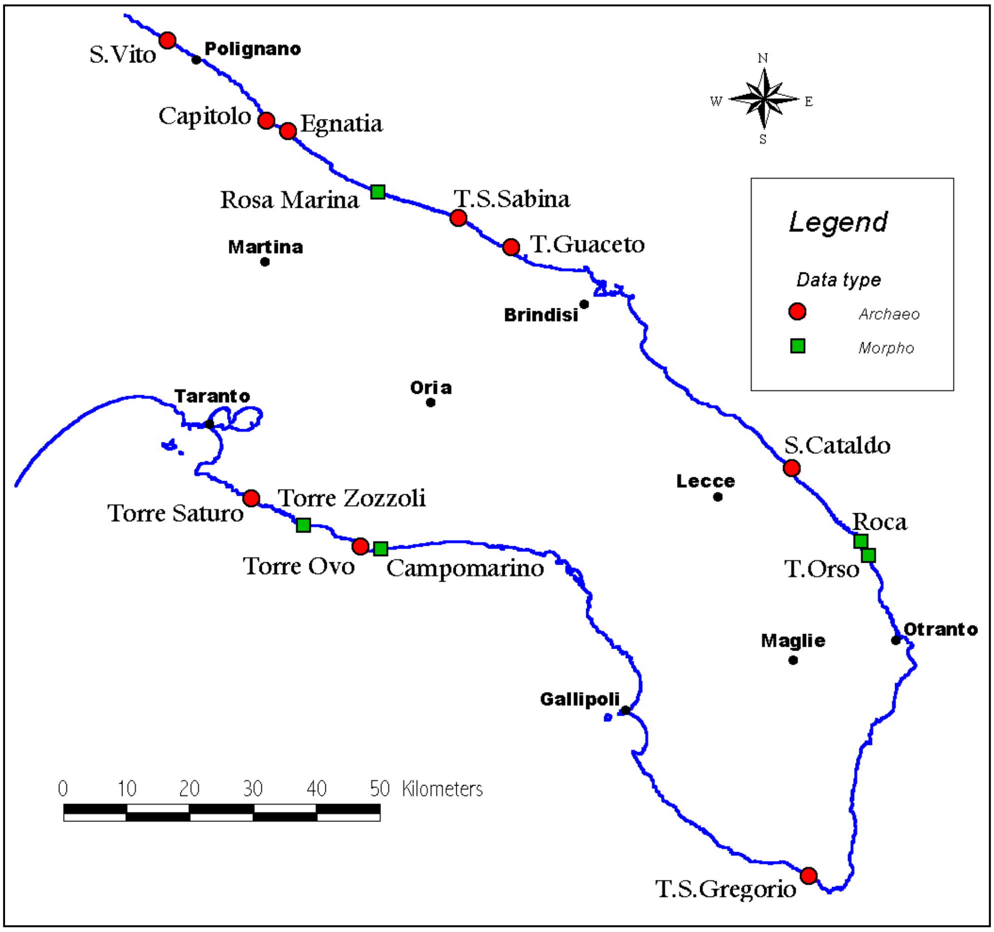


Figure 14 - *Geographical position of sites which provide data useful for relative sea level reconstruction along the southern coast of Puglia region.*

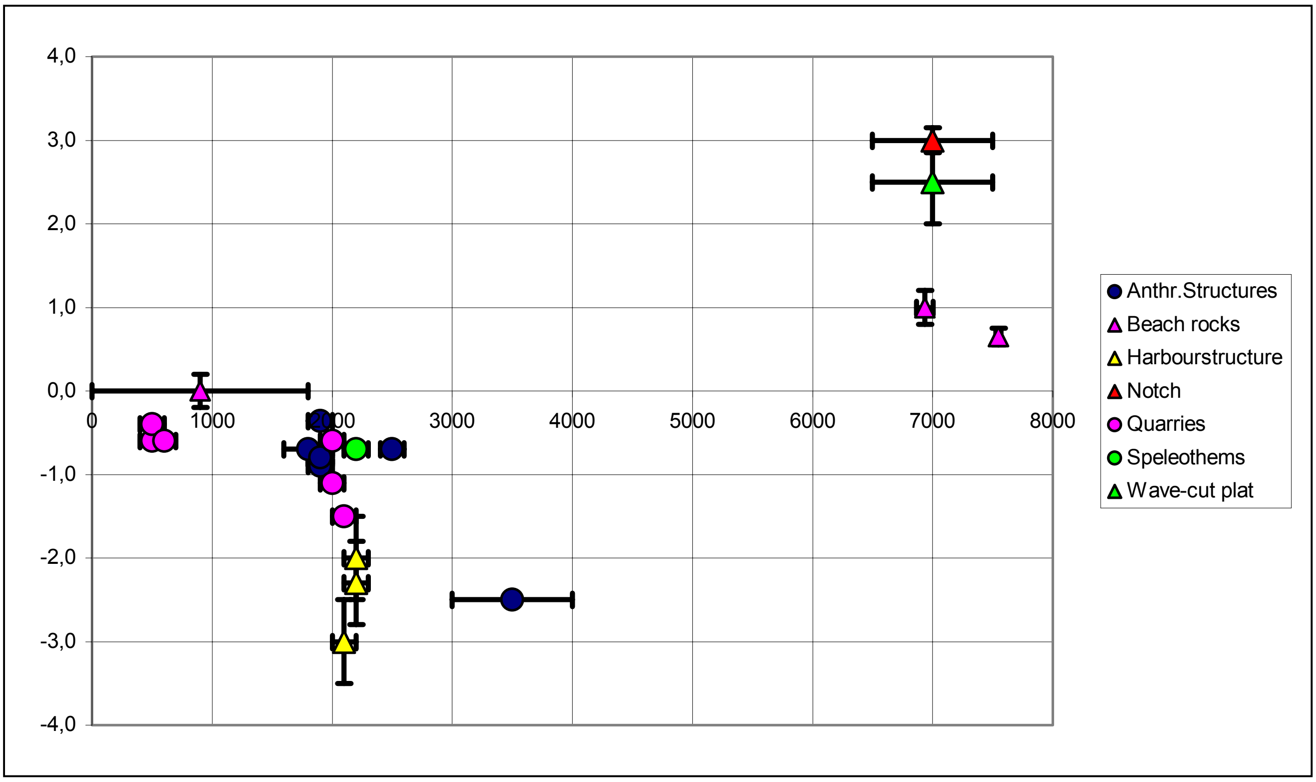


Figura 15 - *Altitude versus age of sea-level (▲ triangles) and land (● circles) indicators. The Mid – Holocene high sea-level stand and the low position during the Bronze – Roman age are pointed out.*

Interestingly, these field observations do not match with Holocene sea level curve reconstruct on the Tyrrhenian coast of Italy and contradict rebound model predictions for the southern Adriatic and Ionian Seas. Thus, according to Lambeck and Johnston (1995) sea level along the coast of Puglia was at c. -6 m around 6000 years BP and at -1.5 around 2000 years BP (Fig. 16).

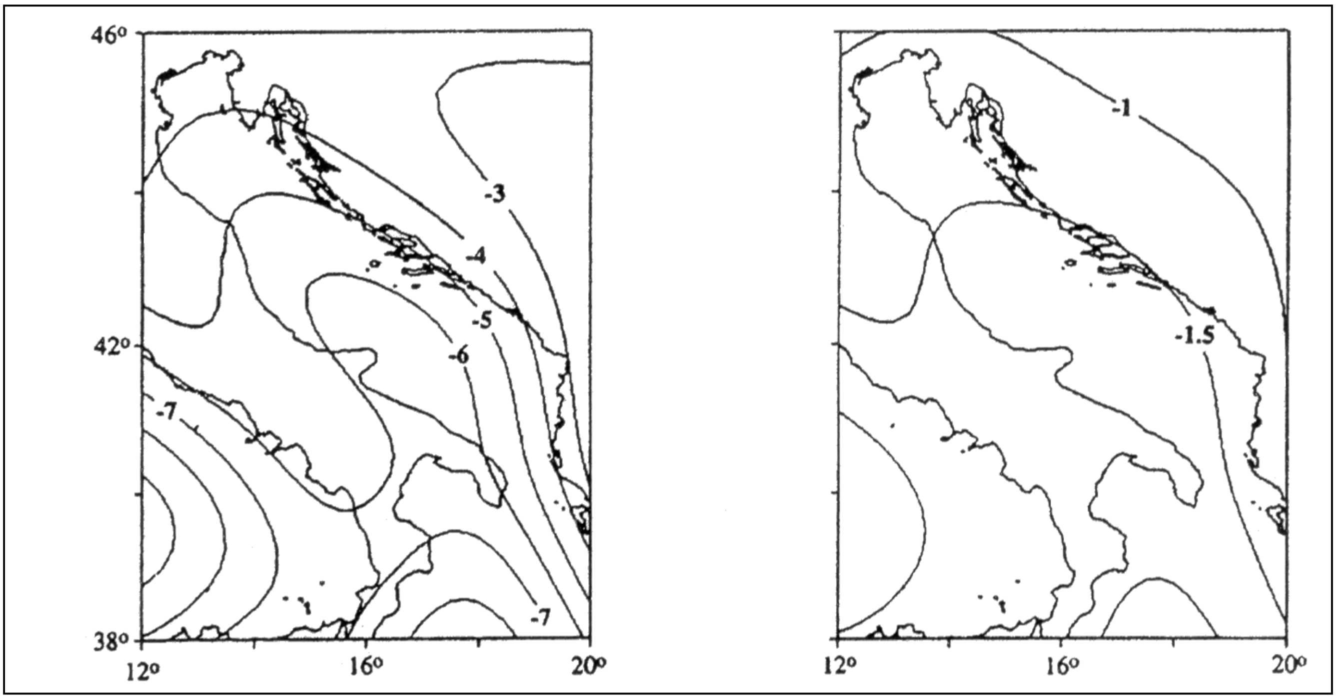


Figure 16 - *Spatial pattern of predicted sea level changes at 6000 (on the left) and 2000 years BP (on the right) for the Adriatic region. Contour lines (in metres) specify the position of sea level relative to the present value (from Pirazzoli, 1998 mod.)*

According to the M2 model of Peltier (Pirazzoli, 1998), at Bari sea level rose rapidly until -0.5 at 5000 years BP (calibrated age) before slowing to increase gradually to its present position (Fig.17). These discrepancies could rise from the limited number and inaccuracy of field data and/or by the complex geodynamic structure of Adria plate most likely neglected during the model construction.

The costal dunes of Puglia region

Pleistocene aeolian deposits are very often associated to terraced marine deposits. The oldest are represented by small remnants because of erosion as those ones occurring along the Adriatic coast near Ostuni at 280 m of altitude. The most recent and lowest aeolian deposits still constitute well-preserved dune belts; they can be found along the Apulian Ionian coast (Cotecchia *et al.*, 1969; Palmentola, 1989) and in the surroundings of San Giorgio Jonico, along the Adriatic coast near Bari (Pieri, 1988) and between Monopoli and Brindisi (Di Geronimo, 1969; 1970). In this last case, the aeolianite, up to 17 m high, is formed by a well cemented, light brown, fine bioclastic calcarenite with high angle cross-lamination, marked by cemented fractures. It retains minor quantity of quarts and silicates; levels rich in pyroxenes and garnets coming from the Monte Vulture volcanic complex have been found at its base. Red continental clayey sands are often recognisable behind the dune belt. They are up to 4 m thick, and generally massive and rich in pedogenic pisolites and manganese coatings. These deposits partly fill the backdune depression and are easily recognisable where the present coastline has overcame the older one.

In particular, the coastal area is characterised by the presence of widespread Holocene aeolian deposits, cropping out mainly along the present main beaches (Fig. 18); three Holocene aeolian units are recognisable.

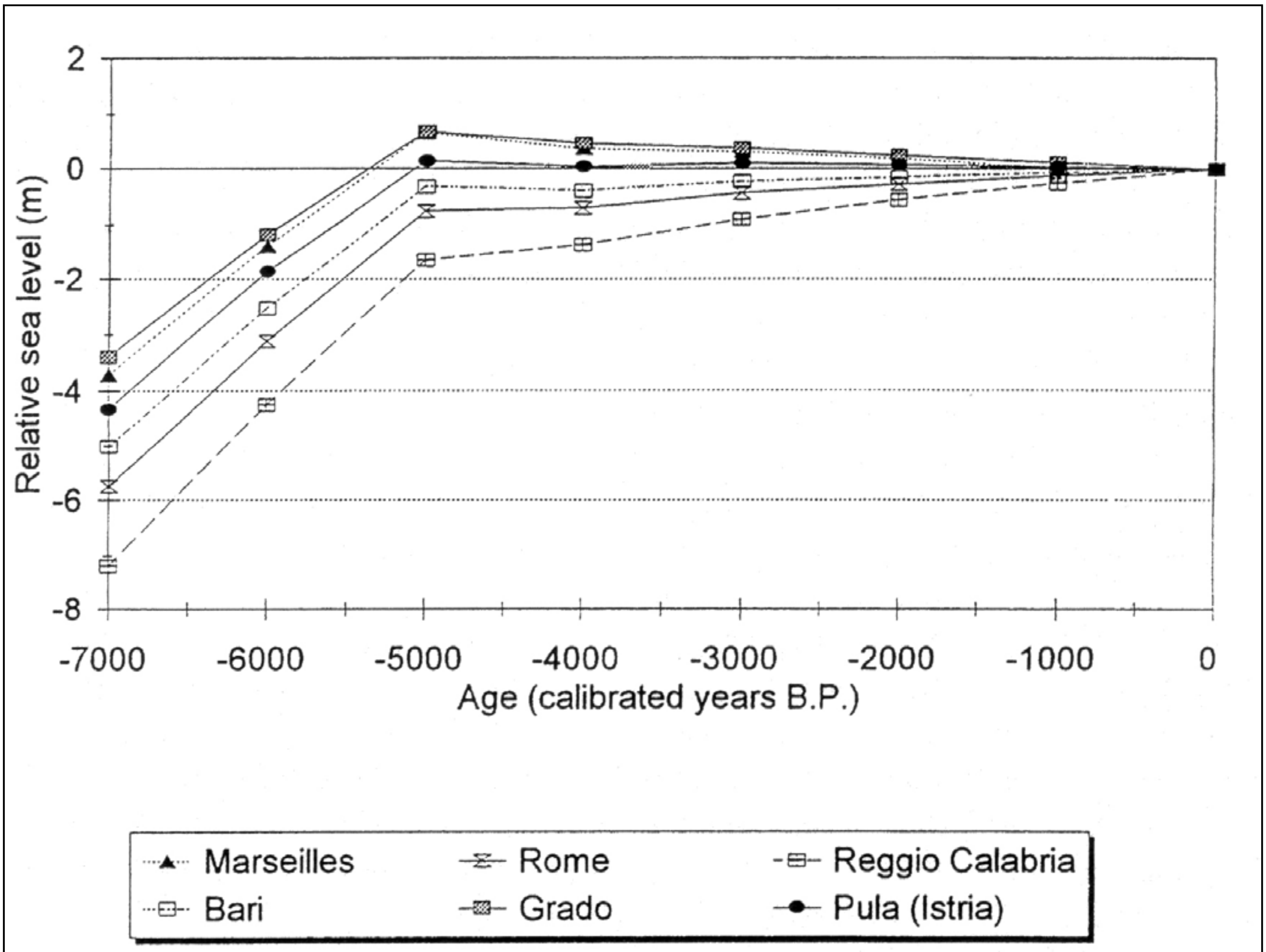


Figure 17 - *Prediction of relative sea level changes during the last 7000 years by model M2 at selected sites of Mediterranean coasts (from Pirazzoli, 1998 mod.).*

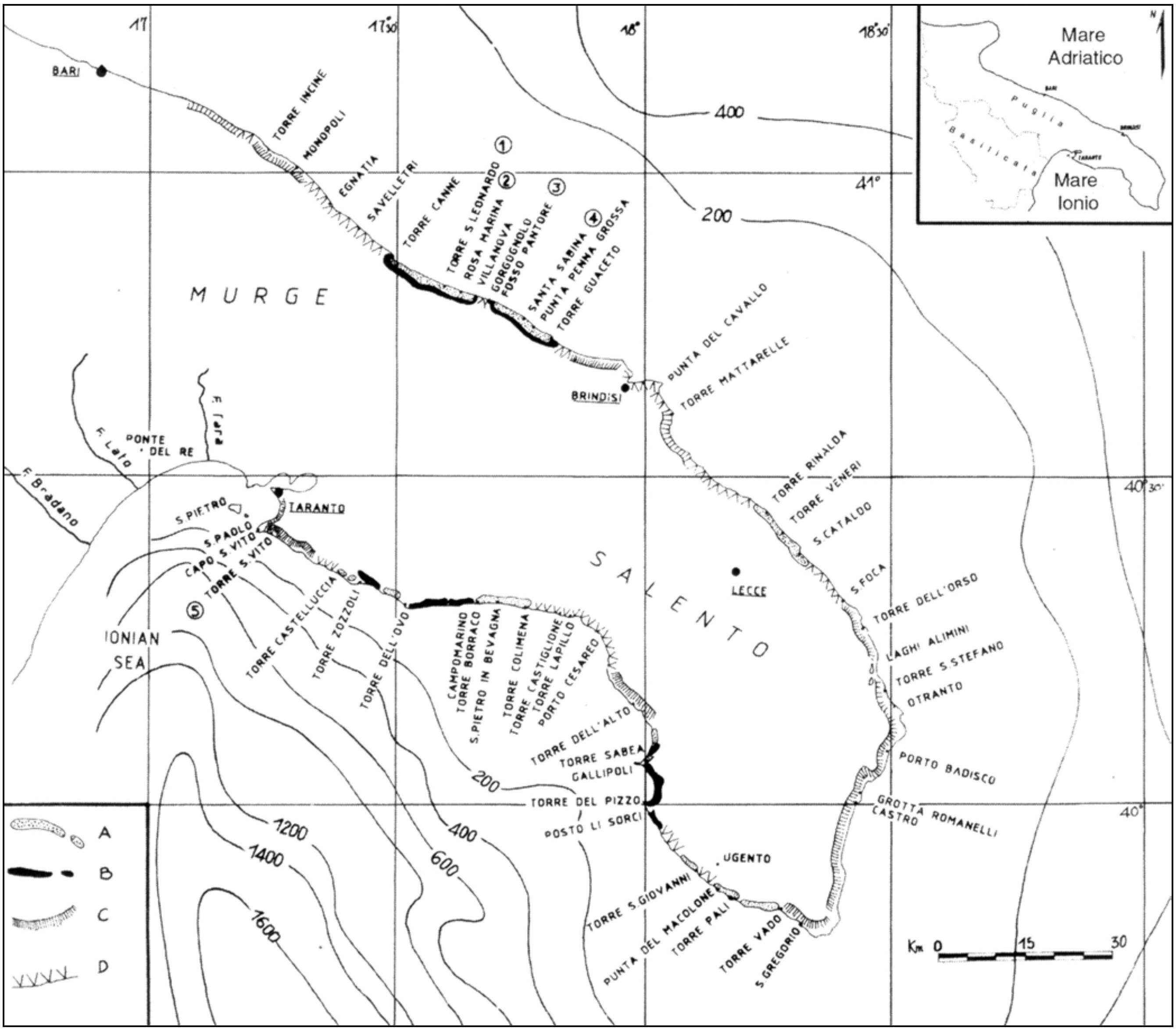


Figure 18 - *Distribution of Holocene aeolian deposits recognised along the coast of southern Puglia. Legend: A - Greek-Roman aeolian deposits; B - Mid-Holocene aeolian deposits; C - cliffs; d - sloping rocky coasts.*

The Mid-Holocene dune belt

The oldest aeolian unit forms a dune belt lengthened about parallel to the present coastline; its remains crop out along the Ionian coast from Lido Checca to Porto Cesareo and from Gallipoli to Torre San Giovanni whereas along the Adriatic one at main beaches from Monopoli to Torre Guaceto. This unit is constituted by grey sands partly cemented and characterised by high angle cross-lamination.

This aeolian unit formed along numerous coastal tracts of Puglia region in a relatively short span of time ranging from 6780 BP to about 5290 conventional years BP, corresponding to 7651 - 6062 cal years BP (Mastronuzzi and Sansò, 2002b) (Table 3; Fig. 19). In this period stable, well-nourished beaches fed dune belts which formed without significative breaks as marked out by the lack of soil levels. The development of mid-Holocene dune belts was most likely promoted by a sea level stand. In fact, the Holocene relative sea level curves reconstructed from data collected along the coasts of southern Puglia (Dai Pra and Hearty, 1989; Dini *et al.*, 2000) show that the last glacial low stand, placed at about 120 below present sea level, was followed by a rapid sea level rise which ended roughly 6000 years BP, when an high sea level stand occurred.

This last period was characterised by the warmest and wettest climatic conditions of the Holocene and it is known in literature as *Climatic Optimum* (i.e. Bertolani-Marchetti, 1985; Rossignol-Strick *et al.*, 1992; Yan and Petit-Maire, 1994) (Fig. 20). Warmer sea water probably increased the amount of bioclastic material available for beach nourishment. Dune belts referred to the Holocene *Climatic Optimum* are wide spread in several Countries belonging to different climatic zones, i.e. England (Pye and Neal, 1993) and Spain (Zazo *et al.*, 1993).

The "Greek-Roman" dune belt

The second aeolian deposit is made by loose, light brownish sands, up to 10 m thick, characterised by numerous dark brown soil levels and very rich in *Helix spp.* remains. This deposit is widely diffuse along the entire coastal perimeter of Puglia region. It deposited mainly from 3910 to about 2000 conventional years BP, corresponding to 3019 - 1961 calibrated years BP (Fig. 19).

This unit is the most widespread aeolian cover in the Apulian coastal area since it borders all the present beaches and it is present along several coastal tracts which are at present constituted by rocky coasts. Its formation occurred during the historical low sea level which followed the mid-Holocene high stand.

During this period, dune development was most likely promoted by the rapid progadation of main coastal plains which surround Puglia region. To the North, the Fortore River formed in this period a cuspidate delta and its materials moving eastward by littoral drift fed the spits which closed in Roman times the Lesina lake first and the Varano lake then.

To the West, the Ionian coastal plain, placed in the Taranto Gulf and formed by Bradano, Basento, Sinni and Agri rivers, was affected during the Greek period by frequent floods which brought to the filling of main valleys (Boenzi, 1984; Boenzi *et al.*, 2001a) and, most likely, to the rapid progradation of shoreline. This last process was accompanied by the development of several dune belts and of wide coastal swamps infested by malaria which induced the decline of the Greek colonies settled in this area around the VI century b.C..

To the southeasternmost part of Puglia, the Salento peninsula, dune belts and coastal swamps formed along numerous coastal tracts (Casalabate, Alimini coastal tracts on the Adriatic side, Punta Prosciutto, Padule Bianco, etc. on the Ionian one).

This phase of major solid load of main rivers has been related to the pressure of Greek and Roman activities on landscape (Neboit, 1975; Brückner, 1980). The diffuse agricultural use of plains and the deforestation of Apenninic slopes would have brought to a significative increase of soil erosion and then to the filling of main valleys. However, the effects on the coastal area of the anthropic pressure could be overestimated especially as regards Greek age, suggested by dune age as the period of shoreline main phase of shoreline progradation. Greek colonies were small settlements which studded and exploited the coastal area and it is most unlikely that their limited activities could have effects of regional importance.

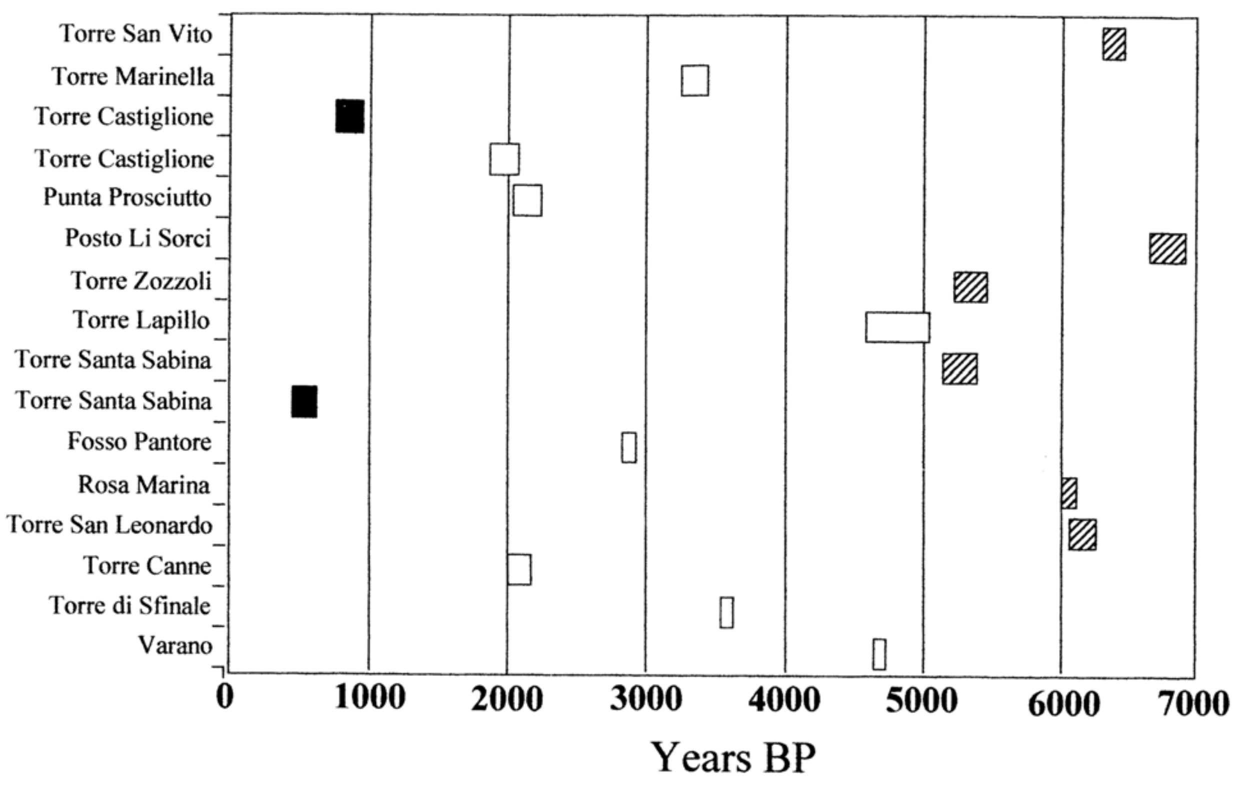


Figure 19 - *Age distribution of pulmonate Gastropods collected at several localities of Puglia region. Lined bars: partly cemented grey aeolian sands; white bars: loose, light brownish sands marked by numerous levels of brownish soil; black bars: loose, yellow-grey aeolian sands.*

N°	Sample	Locality	Remain	$\delta^{13}C_{PDB}$ (‰)	$\delta^{18}O$ (‰)	Uncalibrated Age (years BP)	Calibrated Age (years BP)	Lab.	Reference
1	SSB3	Dune deposit - Torre Santa Sabina	Pomatia sp.	-8,27	-0,84	565±80	615 ± 31	A	Dini *et al*, 2000
2	-	Torre Castiglione	Helix sp.	-	-	865 ± 90	745 ± 51	-	Cotecchia *et al*., 1969
3	-	Torre Castiglione	Helix sp.	-	-	1995 ± 95	1961 ± 102	-	Cotecchia *et al*., 1969
4	Torre Canne 1	Soil –Torre Canne	Helix sp.	-	-	2110±90	2071 ± 86	-	Magri and Zezza, 1970
5	-	Punta Prosciutto	Helix sp.	-	-	2160 ± 100	2113 ± 72	-	Dai Pra and Hearty, 1989
6	P17	Dune belt - Fosso Pantore	Helix sp.	-7,09	-2,15	2910±50	3019 ± 62	A	Dini *et al*, 2000
7	P8 (GX-26736)	Soil - Lido Morelli	Pomatia sp.	-5,5	-	4330±40 AMS	4860 ± 20	B	Auriemma *et al*., 2003
8	SSB2	Dune belt -Torre Santa Sabina	Helix sp.	-5,95	-1,31	5290±120	6062 ± 130	A	Dini *et al*, 2000
9	-	Torre Zozzoli	Helix sp.			5360 ± 115	6038 ± 44	-	Cotecchia *et al*., 1969
10	RM1	Dune belt – Rosa Marina	Helix sp.	-6,53	-0,89	5796±70	6595 ± 71	A	Auriemma *et al*., 2003
11	RMD (GX-18124)	Dune belt – Rosa Marina	Helix sp.	-7,4	-	6084±52 AMS	6934 ± 70	B	Dini *et al*, 2000
12	TSL6	Dune belt – Torre San Leonardo	Helix sp.	-7,48	-1,41	6185±90	7187 ± 23	A	Dini *et al*, 2000
13	LB 1	Torre San Vito	Helix sp.	-7,68	-	6386 ± 70	7294 ± 41	A	Dini *et al*., 2000 Iannone *et al*., 2003
14	CAMPO 1 (Gx 29910)	Dune belt – Campomarino	Helix sp	-6.8	-	6600 +/- 40 AMS	7546 ± 21	B	Auriemma *et al*., 2003
15	-	Posto Li Sorci	Helix sp.	-	-	6780 ± 125	7651 ± 92	-	Cotecchia *et al*., 1969

Table 3 - *Review of the ^{14}C conventional and calibrated age of coastal dunes ($\pm 1\sigma$) in southern Puglia. Calibration was performed by Calibra 4.3 software by Stuiver et al., 1998. A - Laboratorio di Geochimica Isotopica, Università degli Studi, Trieste (Italia); B - Geochron Laboratoires Krueger Enterprises Inc. (Cambridge, Massachusets, U.S.A.).*

On the other hand, valleys filling and shoreline progadation could be the combined effect of the rise of sea level from the historical low stand and the humid climatic phase which affected Europe between X and the IV century b.C.(Lamb, 1977; Pinna, 1996) and in particularly for southern Italy, between the V and the III century b.C. (Boenzi, 1984; Boenzi *et al*., 2001a) (Fig. 20).

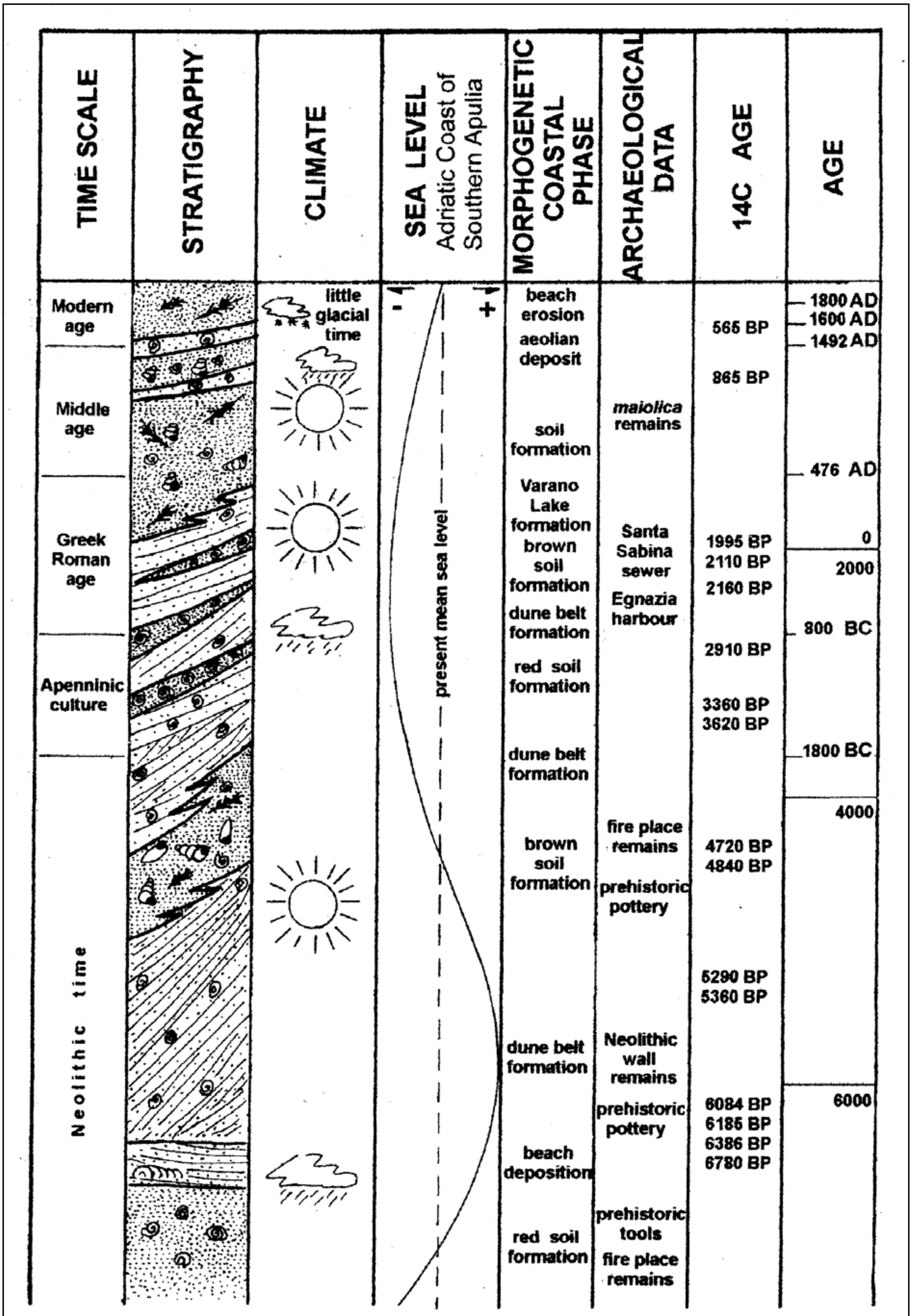


Figure 20 - *Chronological framework of stratigraphy, climate fluctuations, morphogenetic coastal phases, radiocarbon data, and sea-level changes occurred during the last 7ka in Puglia region.*

The Middle Age aeolian deposits

Younger aeolian deposits, made by discontinuous yellow - grey sands, crop out locally along the coast. They have been recognised on the top of the cliff occurring along the northern coast of San Pietro island, near Taranto; they, about 1 m thick, cover the remains of Late Roman farms, about IV – VI century a.C. (D'Andria and Mastronuzzi, 1999). Along the Adriatic coast, *Pomatia* spp. collected at Santa Sabina from these deposits yielded an ^{14}C uncalibrated age of 565± 80 years BP (745 cal years BP) (Dini *et al.*, 2000; 2001). On the Ionian side, Cotecchia *et al.* (1969) point out an aeolian loose deposits near Torre Castiglione dated at 865±90 years BP (615 cal years BP) by means of radiocarbon age determination on *Helix* spp. specimens.

The last eolian unit is surely of a minor importance as regard the geographical extent. The few available radiometric age determinations mark out a medieval phase of dune development. However, further data need to recognize the significance of this event and to relate it to sea level changes, climatic fluctuations or human activities.

At present, the Holocene dune belts are under severe erosion because of natural and human factors. The first ones are mainly represented by the present sea level rise, which according to data of Trieste tide-gauge is of about 1.33-1.61 mm/yr (Mosetti and Purga, 1991), that forces the coastal system to modify towards new , stable configurations. The latter are mainly constituted by the lack of sediment input to the coastal zone due to human activity during last fifty years, which have brought to the damming of main rivers and to the construction of harbours and coastal defence structures which dramatically reduce the sediment input and impede the longshore transport of sediment.

The coastal features of Puglia region

by

De Santis V., Maracchione M.I., Caldara M., Centenaro E., Mastronuzzi G., Palmentola G., Sansò P., Sergio A.

Introduction

The dynamics of the coast of Puglia is the result of complex interactions between emerged and submerged morphological elements, hydrologic and oceanographic factors, climatic and sea-weather conditions. Human impact has to be added to these interactions, at least since the Greek – Roman age. Particularly in the last decades, anthopic pressure has strongly altered the dynamics of the coastal environment. Hydraulic works have affected all the drainage basins reducing the contribution of alluvial deposits to the coast and inducing a negative sedimentary budget. Harbour facilities and coast defence works modify and impede the longshore transport of sediments. This situation amplify the effects of the world-wide rise of sea-level (Nicholls e Leathermenn,1995; Nichols *et al.*, 1995) due to eustatic and steric worldwide factors and amplified by local factors; it can be estimated in some mm per year (Pirazzoli, 1996; Douglas, 2001). Data provided by satellites ERS-1 and Topex-poseidon have shown the same trend for the eustatic sea level with an increase of about 0,5 mm per year (Pirazzoli, 1998; Pirazzoli and Tomasin, 1999). As a consequence of this, several tracts of Apulian coast are interested by severe erosion and environmental problems, rendering them vulnerable even to small environmental changes.

Continental shelf

The continental shelf of Puglia region shows very variable width (Fig. 21). Along the Adriatic coast the shelf width ranges from 18 km near Otranto up to 60 km at the Manfredonia Gulf, sloping about 1.5%. On the Ionian side the shelf is very narrow reaching the maximum width of 20 km between Porto Cesareo and S. Maria di Leuca where it is characterised by three submerged terraces. The shelf shows its minimum width of about 5 km in front of Bradano River mouth.

The shelf break is placed at about 100-110 m along the lonian side and at about 160-200 m of depth along the Adriatic one. It is affected by the heads of numerous canyons running along the continental slope; these heads are in some cases placed at about 1 km from the shoreline convoying the gravitative movement of sediments beyond the continental shelf.

The continental shelf is covered by coastal sands (down to 10-15 m of depth), by silt and clay (down to 125 m of depth) and by sands again from 125 m of depth to the shelf break. These last sediments are relict sands marked by littoral (D'Onofrio, 1972; Taviani, 1978) or lagoonal fauna (Fabbri and Gallignani, 1972), partly reworked by postglacial transgression (Hesse *et al.*, 1971). Their deposition has been related to the Middle Pleistocene (Aiello *et al.*, 1995) or to the last glacial low sea level stand (Colantoni *et al.*, 1975; Colantoni and Gallignani, 1978).

The composition of sediments placed on the Adriatic continental shelf mirrors the lithology of the influent drainage basins; it is marked out by heavy minerals coming from the Monte Vulture, a Pleistocene volcano placed in the drainage basin of Fortore River. The present sedimentation rate in the inner part of shelf has been estimated about 4mm/yr (Van Straatten, 1985).

Along the Ionian side, shelf sediments are constituted mainly by bioclastic material to the south of Taranto whereas in front of Metaponto plain silty-sands have been detected by Pennetta (1985).

Posidonia oceanica meadows form large patches on the inner shelf, generally where fine sands occurred (surroundings of Gallipoli, Torre Canne-Brindisi coastal tract); it is replaced off-shore by coralligenous (Fig. 22). These biocoenoses play a key role in the nourishment of beaches since they are the main source of bioclastic sands, overall in the present situation because of the scarce sediment input of main rivers.

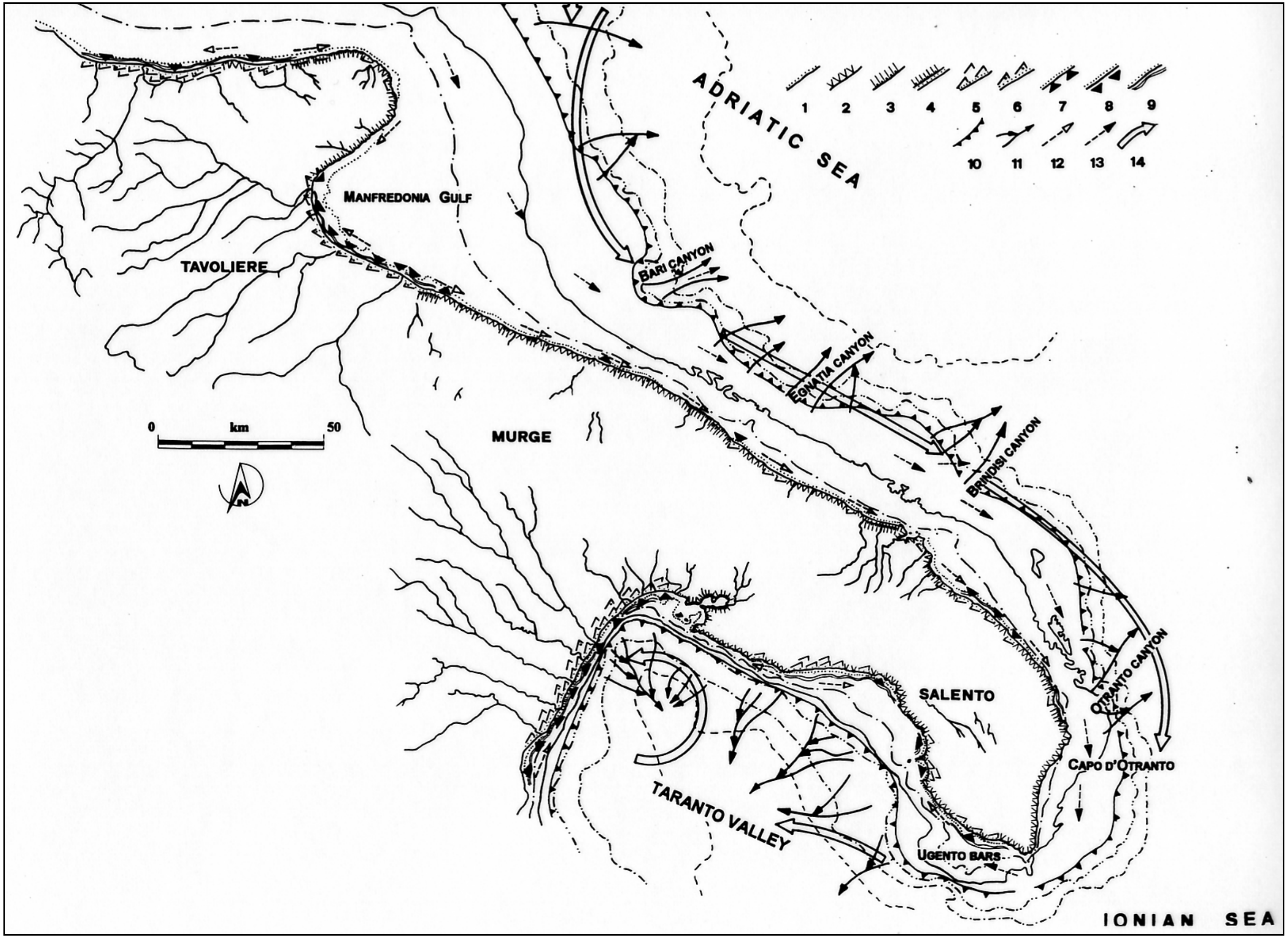


Figure 21 - *Nearshore features and submarines morphology of coastal area of Puglia. 1 – sand/pebble beach; 2 – sloping rocky coast; 3 – cliff; 4 – cliff with beach at the foot; 5 – dune belts; 6 – dune belts affected by human activity; 7 – shoreline recession; 8 – shoreline progradation; 9 bars; 10 – shelf break; 11 – submarine canyon; 12 – inshore sediment drift direction; 13 – offshore sediment drift direction; 14 – marine surface current (from Caldara et al., 1998).*

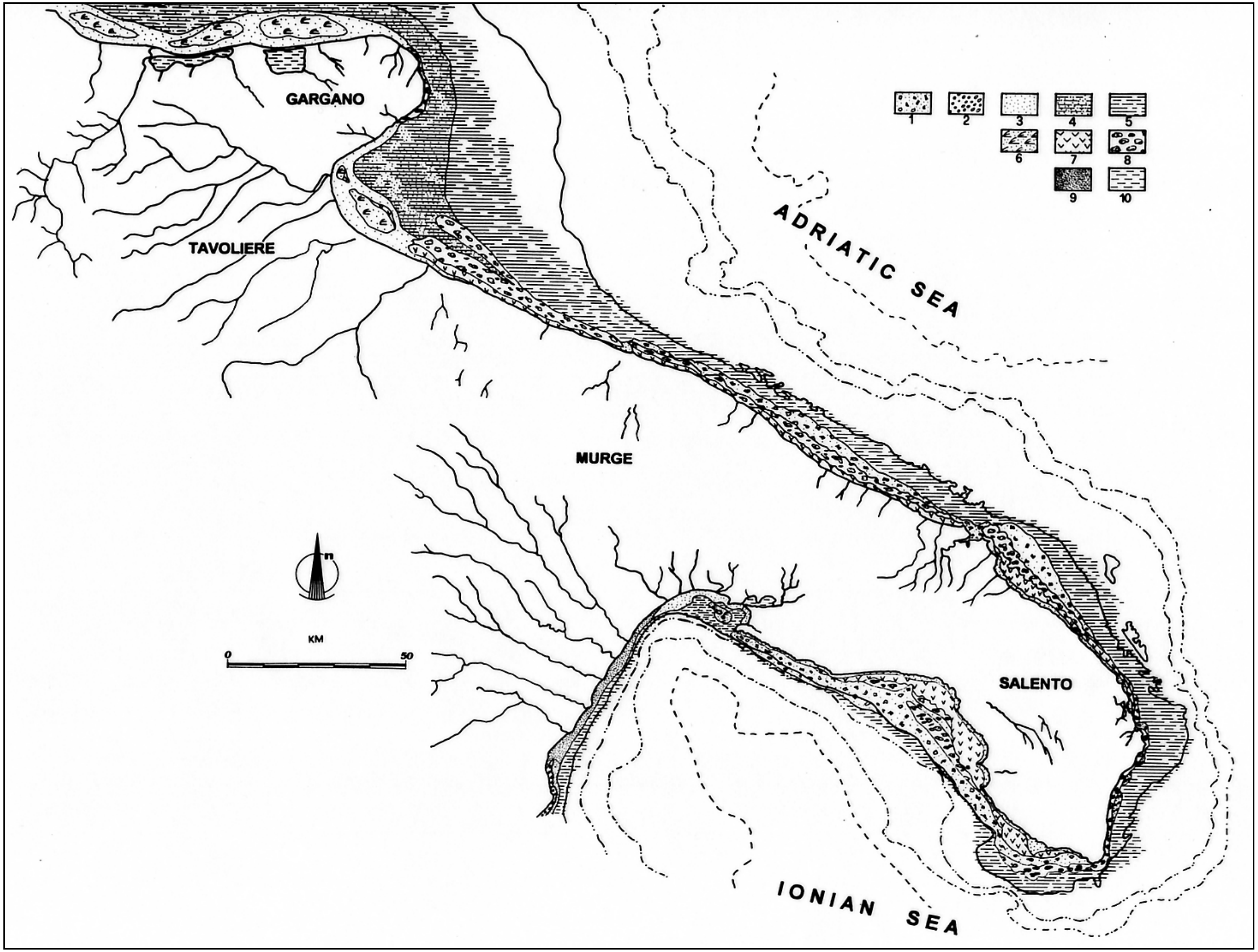


Figure 22 - *Benthic sedimentary characteristics and biological assemblage along the shelf of Puglia. Biocoenosis terminology from Pérès (1967) and from Pérès and Picard (1964). 1 – coastal detritic bottoms (DC); 2 – pebbles beach sediments; 3 – fine well-sorted sands (SFBC); 4 – transition between SFBC and VTC; 5 – terrigenous mud (VTC); 6 – Cymodocea nodosa meadows; 7 – Posidonia oceanica meadows (HP); 8 – coralligenous; 9 – coarse terrigenous sands; 10 – superficial muddy sands in sheltered areas (SVMC); eurhyaline and eurythermal in brachish waters (LEE) (from Caldara et al., 1998).*

Hydrological Features

The Puglia coastal area receives alluvial sediments from drainage basins extending over areas with different geological characteristics (Fig. 21).

Very permeable limestones crop out on Gargano, Murge and Salento areas; the drainage network is there poor developed as rain water rapidly infiltrates underground through joints and sink-holes feeding a karstic aquifer. Phreatic waters reach the sea through the numerous coastal springs, someones submerged.

Rivers flowing on Tavoliere and Ionian areas crosses very impermeable, erodible rocks. As a consequence, they are characterised by well-developed drainage basins and by important discharge and load. However, the natural discharge has been dramatically reduced both by the intense exploitation of rivers for agricultural, civil and hydroelectrical uses, as well as by land reclaimation and hydraulic works carried out mainly along the coastal area stretching from Manfredonia to Barletta and near Metaponto (Fig. 23).

Currents, Winds and Tides

Puglia stretches between two marine basins, the Ionian and the Adriatic basins, each one characterised by peculiar morphological features. The former is deeper, reaching the maximum depth of about 2000 m, whereas the latter is about 1000 m deep.

The current pattern is influenced by the interaction between waters belonging to the Ionian and Adriatic basins. The effect of earth's rotation forces waters entering in the Adriatic Sea from the south to flow northward along the western coast of Canale d'Otranto (Fig. 21).

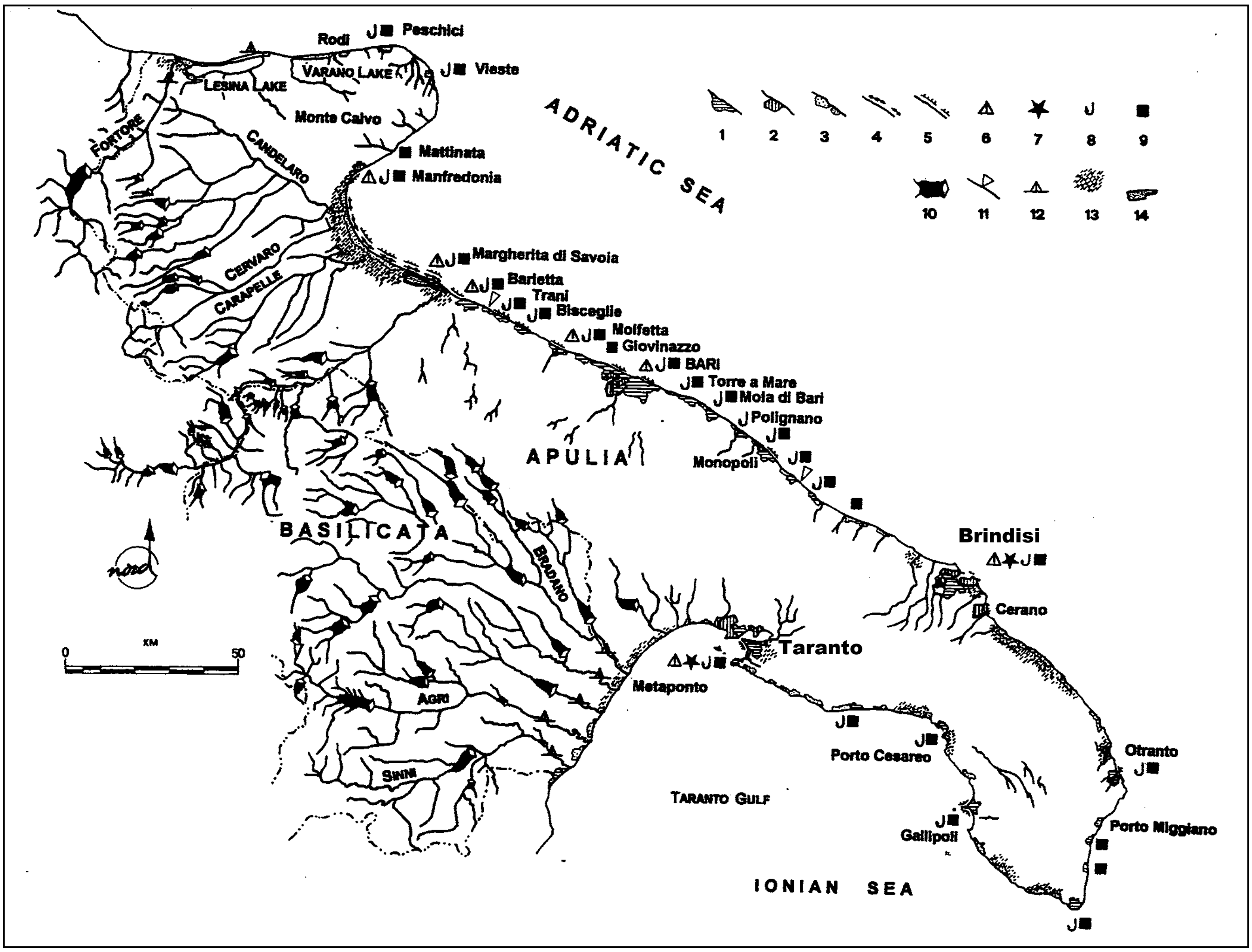


Figure 23 - *Human activities influencing the coastal area of Puglia. 1 – urbanised coastal area; 2 – large industrial facilities; 3 – touristic coastal area; 4 - coastal defence works on land; 5 – coastal defence works at sea; 6 – industrial harbour; 7 – military harbour; 8 - fishing harbour; 9 – touristic harbour; 10 – dams and relative catchments; 11 – quarry waste materials dumps; 12 - quarries in river bed and on beach; 13 – reclaimed land; 14 – salina (from Caldara et al., 1998).*

After having received the waters coming from Po River, the current bends to the south-east flowing along the eastern Italian coasts. The current detaches from the coastline only in correspondence of Manfredonia Gulf because of the effect of E-W elongated Gargano Promontory which forces the current to describe a wide bend before reaching the coast again near Bari. A northwestward flowing counter-current forms in the Manfredonia Gulf. To the south of Bari the current flows toward the Canale d'Otranto where reaches the speed of 4 knots (Hydrographer of the Navy, 1957).

The amount and the speed of waters which enter in the Ionian sea depend on meteorological conditions, mainly to the atmospheric pressure of eastern Mediterranean Sea. The current, once overcome Capo S.Maria di Leuca, enters in the Taranto Gulf flowing northward along the western coast of Salento peninsula, giving pIace to a counterclockwise flow strongly influenced by smaller seasonally currents.

In the Adriatic Sea winds blow mainly from NW and subordinately from S-SE. They induced a similar pattern in the wave climate with the most frequent waves coming from the N-NW and , at lesser extent, from the S-SE. According to Simeoni (1992) more than 61% of waves show height smaller than 0.5 m whereas only 0.9% of them are higher than 2.5 m. The long shore drift of sediment occurs from the NW to the SE, with the exception of Margherita di Savoia-Barletta coastal tract where the drift is oriented toward the NW.

The lonian coast is exposed to the scirocco wind, blowing from the SE, which is locally the most frequent and the strongest one. It induces a long shore drift of beach sediment from the SW to the NE.

The coast of Puglia region is affected by a maximum annual tide range of 1 m along the Adriatic coast at Vieste and of 0,6 m along the Ionian coast at Taranto; the maximum day tides are 0.7 m and 0.5 m, respectively.

Morphological types of coast and coastal erosion

The coast of Puglia is characterised by the alternation of cliffs, rocky sloping coasts and beaches (Fig. 21). Cliffs constitute several coastal tracts of the Gargano promontory, where they are cut on Mesozoic limestones and on sediments of late Pleistocene. Cliffs can be also found on fractured limestones between the towns of Barletta and Bisceglie, on calcareous sandstones between Bisceglie and Monopoli, where they are the result of the considerable erosion of a sloping, rocky coast (Maracchione *et al.*, 2001). The limestone cliffs of Polignano are stable, even if the urban load increases the risks of collapse. The cliffed coast of Cerano, south of Brindisi, is shaped on sandy clayey deposits and is marked by a backing rate estimated to 1-1.5 m per year over the last century (Gentile and Monterisi, 1994).

The cliffs placed to north of Otranto and at Porto Miggiano are cut through calcareous sandstones, with a backing rate of about 0.2 m per year (Mastronuzzi *et al.*, 1992; Sergio, 1999). Finally, a backing rate of about 0.8 m per year has been estimated (Mastronuzzi and Sansò, 1998) for cliffs bordering the Mar Grande of Taranto.

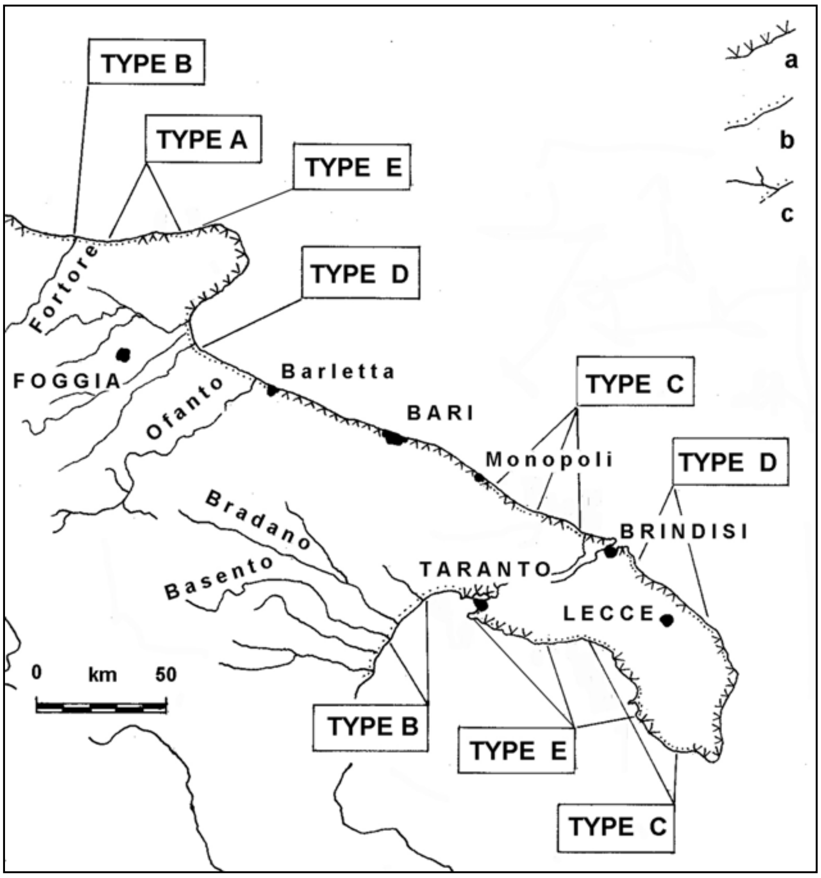


Figure 24 - *Geographical distribution of wave-dominated sedimentary coasts. A – rocky coasts; b – beaches.*

The sloping coasts, flat and convex, are the most widespread morphological type in the region. The coast with convex profile are constituted by a steep subaerial slope, in some places mantled by slope deposits as in Otranto – Capo S. M. Di Leuca coastal tract. The flat sloping coast are made up of a low, gently platform cut through terraces calcareous sandstones, on Plio-pleistocene calcareous sandstones as well as on Mesozoic limestones. The retreat rate of this type of coast is generally low; in the zone of Taranto it has been estimated at about 0.06 m per year (Mastronuzzi and Sansò, 1998).

Several types of waves dominated sedimentary coasts occurring in Puglia region as showed in Fig 24 and Fig. 25.

Long beaches border wide alluvial coastal plains near the mouth of the river Fortore, between Manfredonia and Barletta and in the Metaponto area in the gulf of Taranto.

The Fortore river formed a cuspidate delta which produced the closing of Lesina and Varano coastal lakes during Roman age (Mastronuzzi and Sansò, 2002c). During the last decades, the delta area underwent to a severe coastal erosion so that beaches have been replaced by cliffs shaped on dune deposits (Fig. 26).

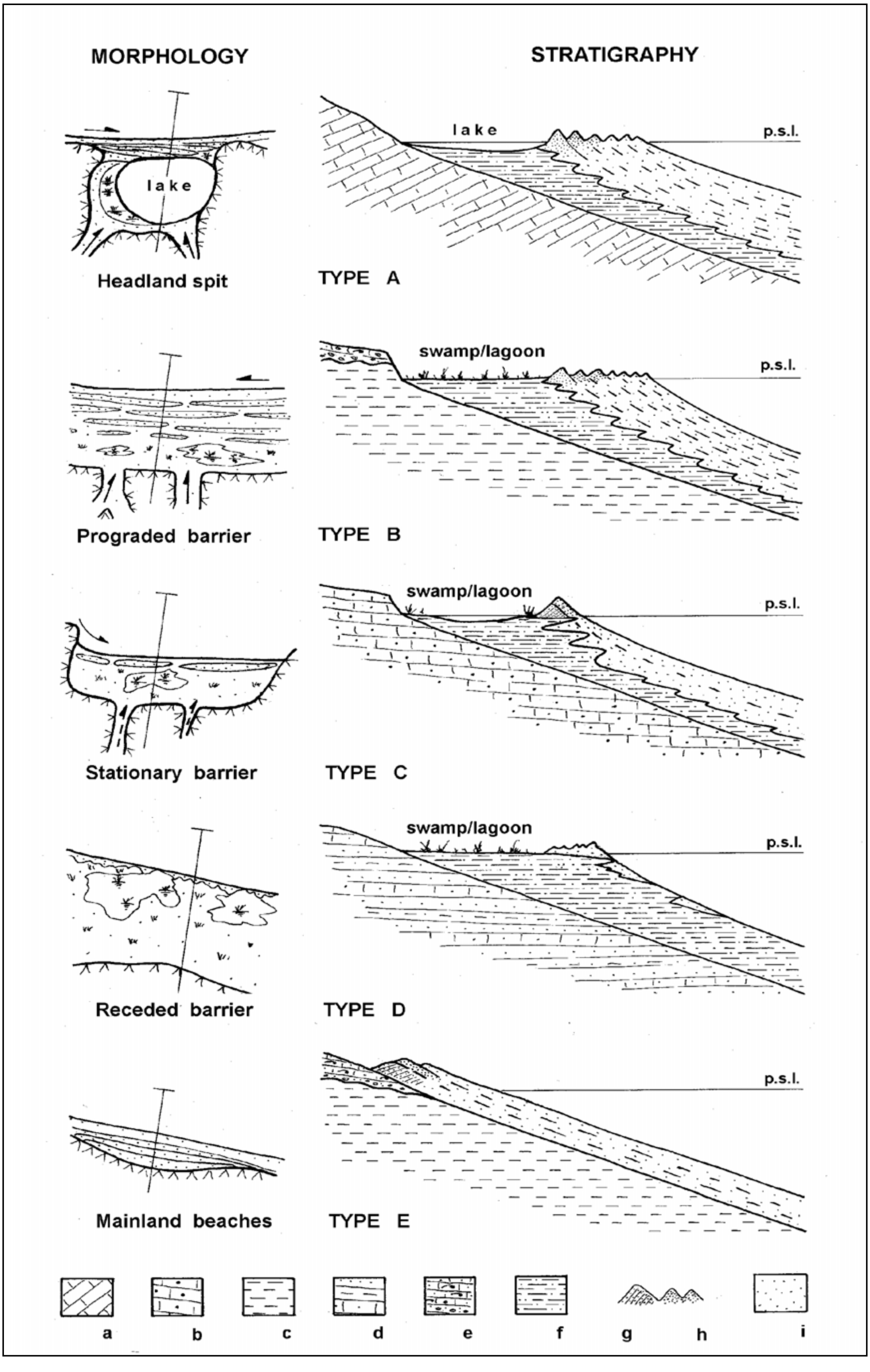


Figure 25 - *Types of wave dominated sedimentary coasts occurring along in Apulian region. a – limestones; b – calcareous sandstones; c – clay; d – sands interbedded with clays and arenites; e – raised beach deposits; f – back dune deposits; g – Mid – Holocene and h – Greek dune belts; i – beach sediments.*

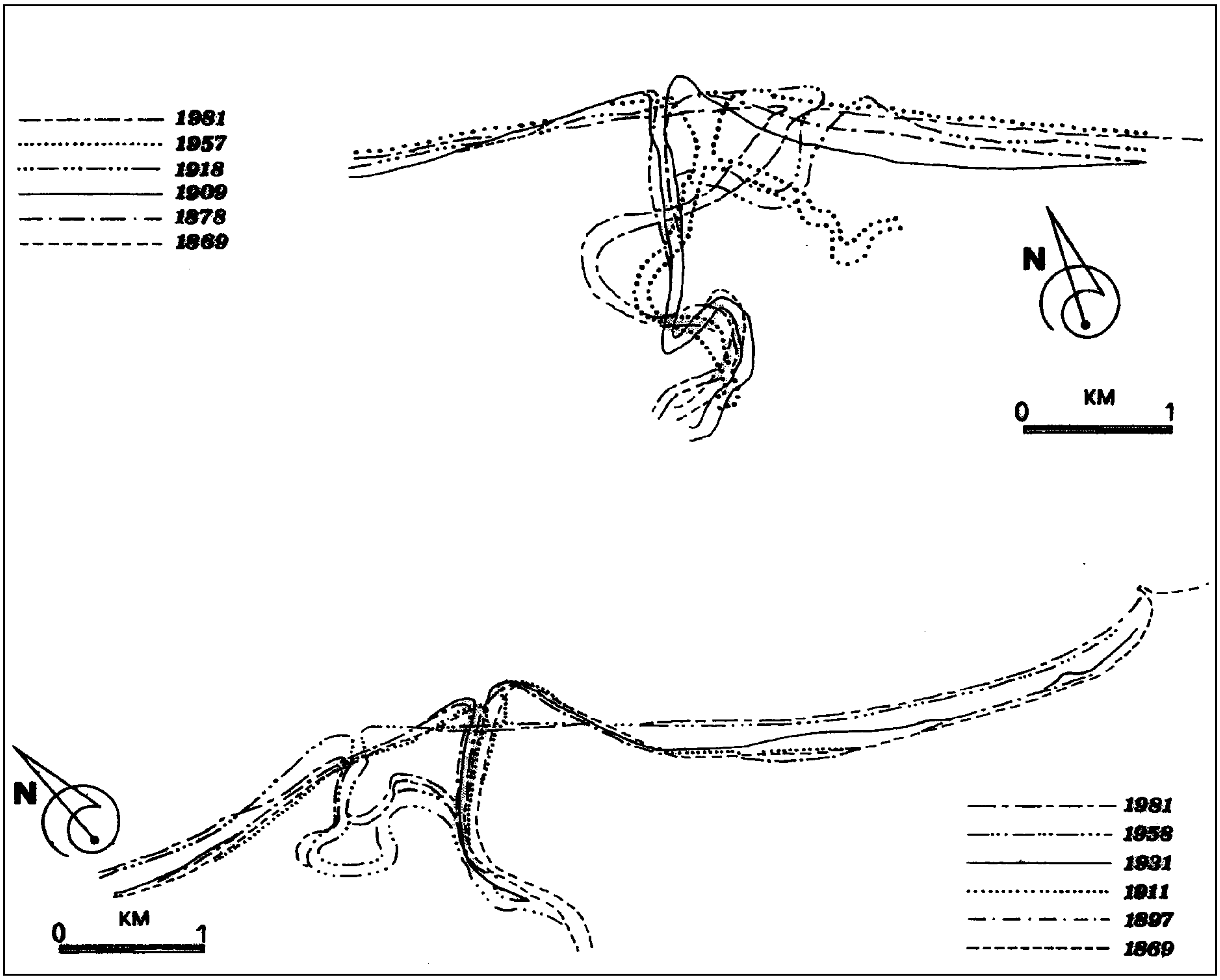


Figure 26 - *Recent modifications of shoreline in the surroundings of Fortore River mouth (a) and Ofanto River mouth (from Caldara et al., 1998).*

Beaches placed at the south of Gargano promontory, between Manfredonia and Barletta, are about 60 Km long and nourished by materials carried by the Ofanto, Carapelle, Cervaro and Candelaro rivers. In the past they were bordered by coastal dunes which have been completely removed by erosion or levelled by man and in some cases replaced by small artificial dunes aiming to protect the back dune areas. These beaches progradated until the end of the last century. However, since the 60s of the last century they have been affected by severe erosion with average retreat rate in the Ofanto mouth area of about 2 m per year (Pennetta, 1988).

Beaches in the Metaponto area (Gulf of Taranto) stretch for about 90 km (25 km of them in Puglia region) and are fed mainly by the solid load of Bradano, Basento, Sinni and Agri rivers. They were in accretion until about 40 years ago and bordered landward by a 2 km-wide strip of dune belts, up to 15 m high, which limited to the back large swamps. The entire area was interested by land reclamations works, extensive and intensive agriculture and by urbanization. At present, beaches are very narrow and border small cliffs shapedin dune or backdune deposits. The mean retreat rate for the last 40 years has been estimated in about 3-4 m per year (Amore *et al.*,1988)

Pocket beaches characterize the coasts of Gargano, Murge and Salento areas. They are placed in the numerous small bays which indent the general rocky and straight coastline. Along the Adriatic coast they are fed by relict sediment of Holocene age and by biogenic material. Ionian beaches are supplied by bioclasts coming from Posidonia meadows and coralligenous covering the sea bottom in front of them.

Causes or Beach Erosion

Erosion affects several tracts of Puglia coastline, both on rocky coasts and beaches. However, while the former represents a severe problem only on some spots, the latter have raised very diffuse problems during last fourty years (Fig. 27). Beaches, especially in the surroundings of main river deltas, after a secular history of progradation have reversed their trend and are at present retreating with a rate of some meters per year (Tab. 4) (Caputo *et al.*, 1991; Min. Ambiente, 1992; Caldara *et al.*, 1998; Mastronuzzi *et al.*, 2002).

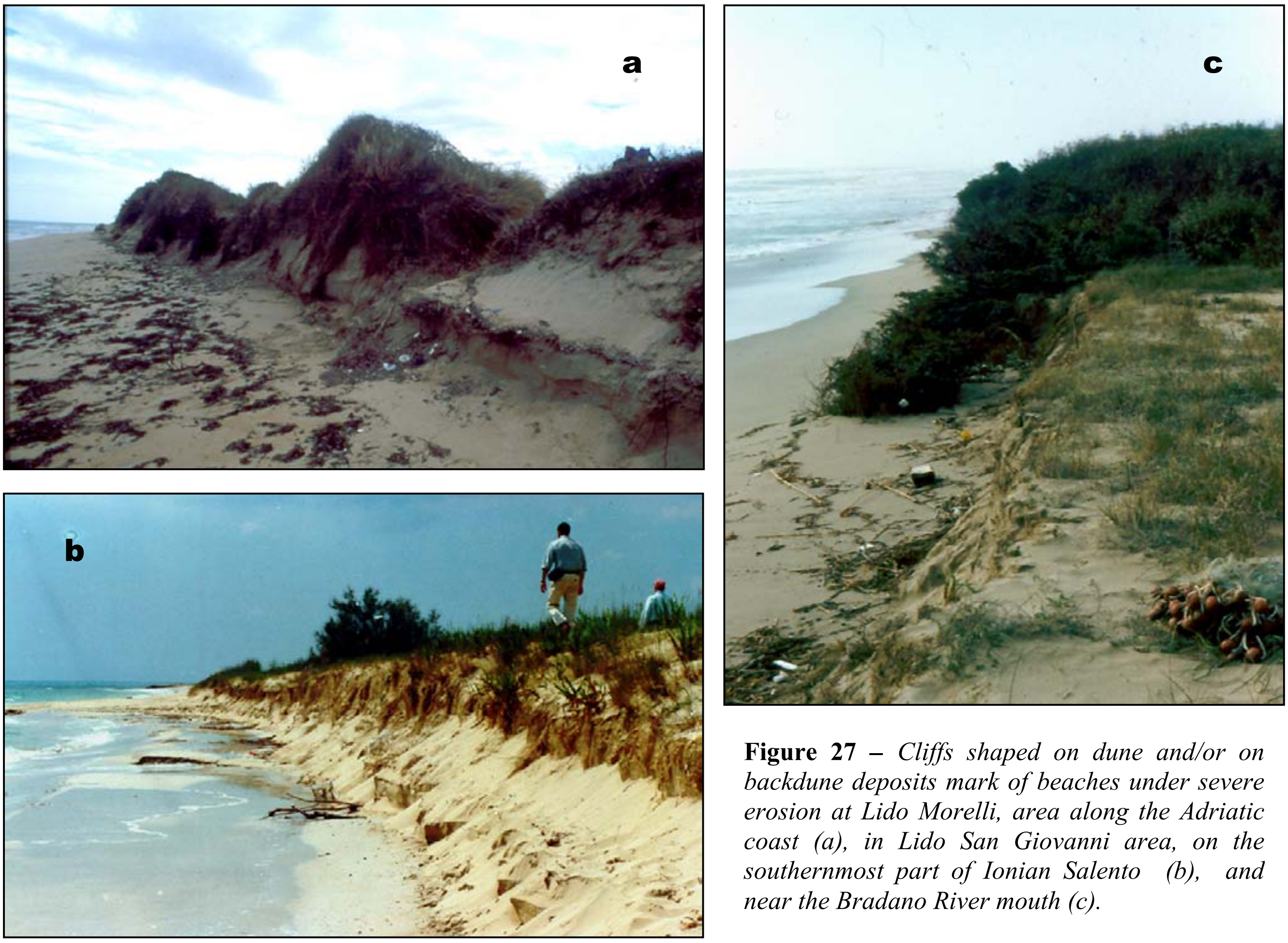


Figure 27 – *Cliffs shaped on dune and/or on backdune deposits mark of beaches under severe erosion at Lido Morelli, area along the Adriatic coast (a), in Lido San Giovanni area, on the southernmost part of Ionian Salento (b), and near the Bradano River mouth (c).*

This new evolutive trend is to be referred mainly to the numerous hydraulic works carried out on the drainage basins influent on the Apulian coast, on the construction of defence works and harbour structures, on numerous quarries in river bed and to the growing urbanization of the coastal area (Fig. 23).

The drainage basins which influence the Apulian coast stretch mainly in the Tavoliere (Fortore, Candelaro. Cervaro, Carapelle and Ofanto) and in the Ionian (Bradano, Basento, Agri, Sinni) areas, most of them having their head on the Apennine chain.

These rivers are characterized by variable discharge linked to the great difference between the maximum and rninimum values of annual mean rainfalls. Nevertheless, the load is high because of the high rates of denudation which characterize the drainage basins of these rivers, mostly shaped in the very erodible rocks of Apennine Chain and foredeep.

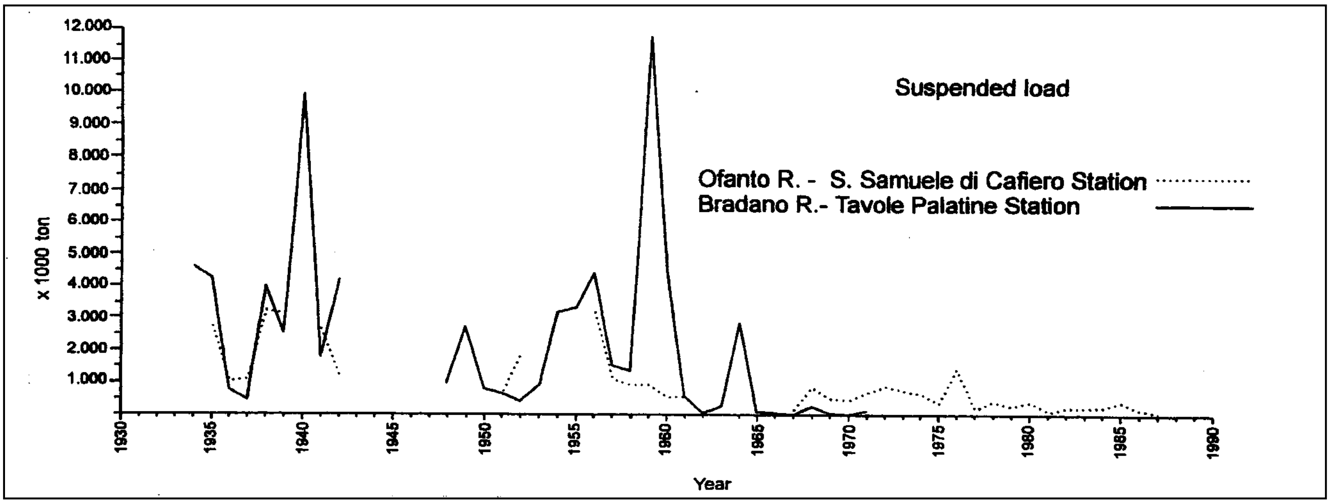


Figure 28 - *Suspended load trend of main rivers of Puglia (from Caldara et al., 1998).*

During last fourty years a sensible decrease of load of these rivers has been recorded (Fig. 28). This decrease is partly due to climatic variations but above all to the numerous dams built in their drainage basins (Mastronuzzi *et al.*, 1997).

The construction of these dams started in the fifties and continue until present days.The Ofanto river, the first Apulian river about 134 km long with a basin about 2898 km^2 wide, has been interested by about 20 dams with great capacity, some of them still under construction (Locone basin, 105 Mm^3; Capaciotti basin, 46 Mm^3; Rendina basin, 21 Mm^3; Conza basin, 54 Mm^3). They can store the maximum volume of about 250 Mm^3 complexively. In response to these hydraulic works, the Ofanto has reduced its load at the mouth from about $2 \cdot 10^6$ ton/yr during the period 1935 - 1961, to $0.6 \cdot 10^6$ ton/yr in the period 1967-76 and to about $0.2 \cdot 10^6$ ton/yr during last twenty years (Caldara, 1996).

Figure 28 - *The cleaning of the beach to remove the Posidonia oceanica leaves contribute to determine a negative sedimentary budget. In this photo one of more than 80 heaps illegaly damped in an olive plantation is shown. 2.5 Kg of this matirial is made of only 400 gr of leaves and algae. 2.1 Kg is beach sand.*

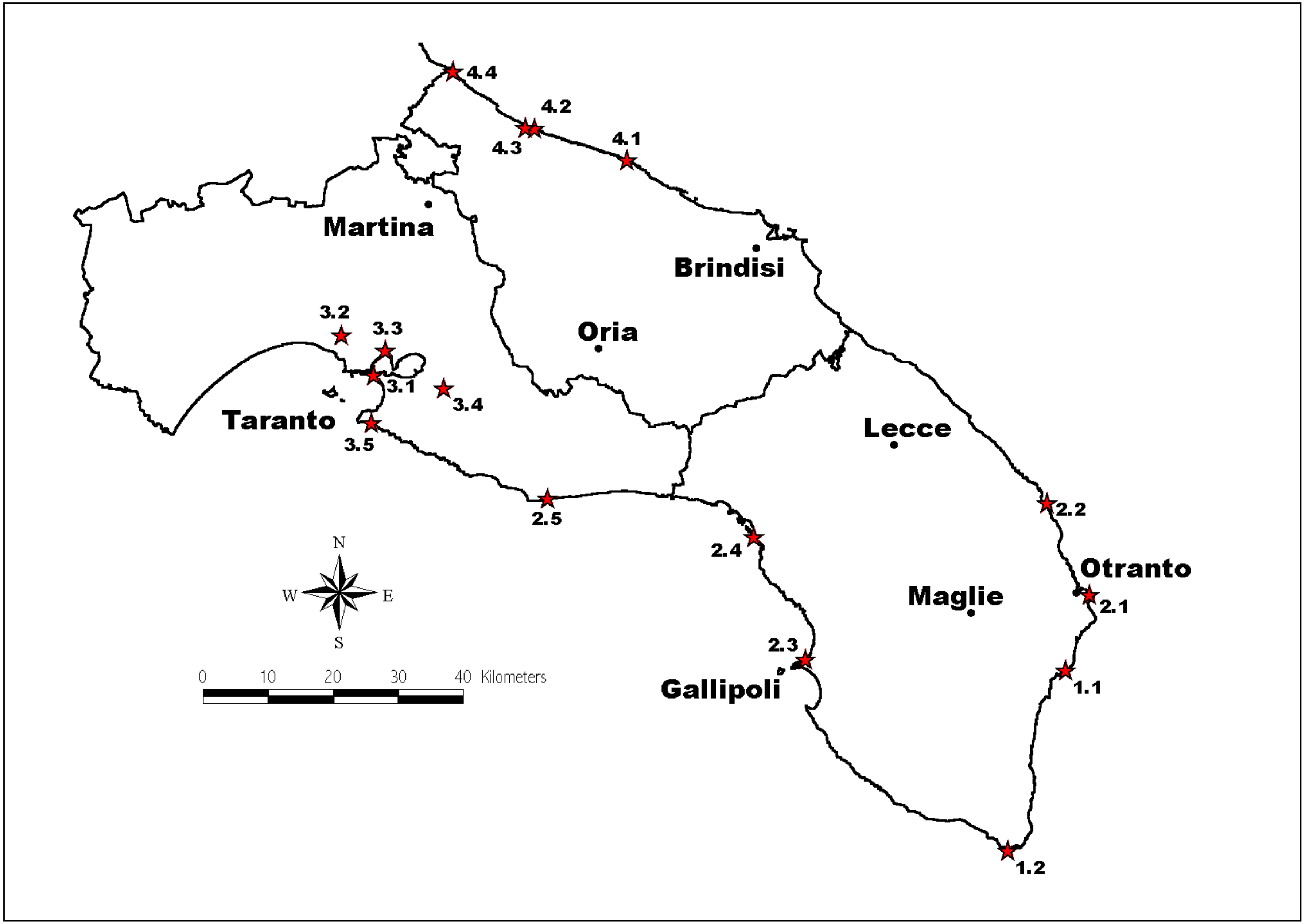
Similar situation occurs on the Ionian coast. The Bradano river, about 120 km long and with a drainage basin of about 2760 km^2 shaped on a Plio-Pleistocene sandy-clayey sequence, was characterized by a suspended load of about $3.5\text{-}4 \cdot 10^6$ ton/yr at the mouth. The construction of S. Giuliano dam ($107 \cdot 10^6$ m^3 of basin) in the 1958 has reduced the solid load at less than 10% (Cotecchia *et al.*, 1971). The same happens for the other rivers which flows in the Taranto Gulf whose drainage basins have been interested by numerous dams (Fig. 23).

Furthermore, the presence of numerous harbour structures, which interest about the 5% of the whole coastal perimeter, and of diffuse coastal defence works impede the long shore drift of materials and the natural nourishment of beaches far from sediment input points. During the last years the incorrect management of the beaches as touristic resource has increased the deficit of sedimentary budget of most of them (Fig. 29).

Finally, the growing urbanisation of coastal area gives to the coastal system an extreme rigidity so that it can not modify its morphological features in response to environmental changes (wind climate, short-term climatic changes, sea level changes and so on) becoming a very fragile system.

	Coasts in Erosion *		**Coasts in progradation**		**Stable Coasts****		**Coastal defences and harbour structures**		**Total**	
	Km	**%**	**Km**	**%**	**Km**	**%**	**Km**	**%**	**Km**	**%**
Cliff	- **124**	- **16**	- -	- -	- -	- -	- -	- -	*450* **124**	*57* **16**
Gently sloping rocky coast	- -	- -	- -	- -	- 296	- 38	- -	- -	- **296**	- **38**
Beaches	*89* **194**	*11(30)* **25** *(70)*	*1* **8**	*0* **1***(3)*	*212* **74**	*27(70)* **10***(27)*	-	-	*302* **276**	*38* **36**
Coastal defences and harbour structures	-	-	-	-	-	-	*41* **78**	*5* **10**	*41* **78**	*5* **10**
									793 **774**	

Table 4 – *Situation of Puglia coast. In italic are data from Ministero dell'Ambiente (1992). Data in bold have been obtained by Italian official cartography from Istituto Geografico Militare and from Atlante delle Spiagge (AA.VV, 1995). Difference between total length of shoreline is due to the difference of scale of the cartography employed. * included beaches protected; ** referred to beaches without anthropic protections; ( ) value respect the total of beaches (from Mastronuzzi et al., 2002).*


4.4
4.2
4.3
4.1
Martina
Brindisi
Oria
3.2
3.3
3.1
3.4
Taranto
3.5
Lecce
2.5
2.2
2.4
Otranto
Maglie
2.1
N
W
E
S
0
10
20
30
40 Kilometers
2.3
Gallipoli
1.1
1.2