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COASTAL CHANGES AND THE ENVIRONMENTAL EVOLUTION OF THE ARCHAEOLOGICAL SITE OF SYBARIS (SOUTHERN ITALY)

ABSTRACT: PAGLIARULO R., *Coastal changes and the environmental evolution of the archaeological site of Sybaris (Southern Italy)*. (IT ISSN 1724-4757, 2006).

In order to investigate the geological and geotechnical incidences in the disappearance of the archaeological site of Sybaris (Southern Italy) and to define the causes of the relative land subsidence affecting the area since ancient times a research project has been carried out in the past few years. An interdisciplinary approach which includes history, archaeology, geomorphology and soil mechanics, has been used to ascertain the nature of the morphological changes. In particular, this paper represents a portion and a work in progress of the whole research after new data concerning the regional uplift and the eustatic sea level rise. Previous papers showed that the land subsidence was the result of three main components: neotectonic, sea level changes and the compression of sediments comprising the plain, while the present paper infers that the major contribution to the settlements is due to the compression of sediments. The rates of both the tectonic uplift and the subsidence are of the same size. Furthermore, the characteristics of the sediments are described, reconstructing their depositional environments and the evolutionary history. Numerous boreholes with continuous coring allowed a detailed examination of the litho-stratigraphic profiles along with bio-stratigraphic and chrono-stratigraphic ones, contributing to the geomorphological reconstruction of the area. The results obtained from the different analyses are in agreement and confirm each other.

KEY WORDS: Land subsidence, Alluvial plain, Eustatic changes, Tectonics, Sybaris, Calabria.

RIASSUNTO: PAGLIARULO R., *Variazioni dell'ambiente costiero ed evoluzione del sito archeologico di Sibari (Italia meridionale)*. (IT ISSN 1724-4757, 2006).

Negli ultimi anni sono stati condotti studi interdisciplinari per riconoscere e valutare l'incidenza dei condizionamenti geologici e geotecnici nella scomparsa della città di Sibari e per definire le cause che determinano la subsidenza dell'area sin da tempi remoti. Così, per accertare la natura dei cambiamenti dell'ambiente costiero, sono stati condotti studi multidisciplinari che spaziano dalla geomorfologia e dalla meccanica delle terre, alla archeologia ed alla storia. Di seguito sono esposti ed analizzati dati che riguardano le relazioni fra il comportamento tettonico locale e le variazioni eustatiche del livello del mare. Sino ad ora si è sostenuto che la subsidenza dell'area costiera era connessa alla coesistenza di una componente neotettonica, di variazioni positive del livello del mare e della compattazione dei sedimenti. Il presente lavoro dimostra che questa ultima è quella che determina il maggiore contributo mentre i ratei di subsidenza e del sollevamento tettonico sono della stessa entità.

La ricostruzione geomorfologica del sistema costiero è stata possibile attraverso l'analisi delle caratteristiche dei sedimenti campionati in numerosi sondaggi ed attraverso la correlazione dei profili litostratigrafici, biostratigrafici e cronostratigrafici

TERMINI CHIAVE: Subsidenza, Piane alluvionali, Variazioni eustatiche, Tettonica, Sibari, Calabria.

INTRODUCTION

The case history of the ancient Sybaris shows how relevant may be the studies on the archaeological sites both to the understanding of the events determining the present setting of the area and to the definition of the phases of the environmental evolution. The archaic site of Sybaris, once a flourishing Greek colony, lies on the Ionian coast of Calabria, (fig. 1), within the alluvial plain of the same name, which is crossed by the low valley of Crati River and its tributaries. The archaeological finds, concentrated in some areas, Parco del Cavallo and Casa Bianca along the actual course of the Crati River, and Stombi (fig. 2), show three superimposed towns, indicative of continuous habitation of the site since VIII-VII century BC. According to the historians Herodotus (484-425 BC), Strabo (64 BC-21 AD), Diodorus Siculus (1st century AD) and Livy (59 BC-17 AD), the old town founded by the Acheans in 720 BC, was destroyed by the Crotonians in 510 BC. The following was the Hellenistic town of Thurii (444/443-285 BC) and later, in the first century BC the Roman town of Copia (193 BC), (fig. 3). At present, the three towns are at a depth between 7 and 3.5 m below present ground level, (Fondazione Lerici, 1967). Actually the archaeological le-

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FIG. 1 - Location map of the studied area.

vels are affected by the shallow watertable and a well point system drains the waters in those areas.

The research, supported by the Italian Research Council (CNR) was carried out in the field and in the laboratory on samples obtained by several boreholes. The results and the discussions about the geotechnical aspects of the research are not described in this paper.

GEOLOGICAL AND STRUCTURAL SETTTING

In the Northern and Northwestern part of the research area, the Sibari Plain is bordered by the Mesozoic carbonate rocks of Pollino massif, while to the South and Southwest, it is bounded by the crystalline mountains of Sila, (Parotto & Praturlon, 2004) (fig. 4). The Sibari Plain is a graben with a ENE-WSW trend. The upper part is filled up by alluvial sediments, whose thickness increases from the North to the Southwest, e.g. it increases from 103 to 478 m respectively to the South of the Crati river. This is ascertained by deep boreholes drilled in this area and offshore during oil-exploratory campaigns in the '50. (Patacca & Scandone, 2004). A series of dune ridges runs parallel to the coastline between the alluvial plain and the present beach. Close to the Crati river mouth there are swamps elongated in a direction perpendicular to the coast, separated by thin sand bars.

From the structural point of view the graben is bounded by some fault systems with different strikes, the most important being NE-SW. This regional tectonic line borders on the plain to the North while a fault belt with strikes ranging from E-W to ESE-WSW bounds the plain along the Ionian coast, separating it from Sila massif (Tortorici, 1983). The neotectonic activity has given rise, in the graben, to a lowering relative to the rest of the region, which is generally rising along with the Apennine chain. Therefore the uplift rate in the graben is lower than in the surrounding area.

Marine terrace studies provide basic contributions in active tectonics. The reconstructions of this section of the Ionian Coast, from Pleistocene to the present, have been made studying four marine terraces, related to the correspondent paleo-sea level highstands (Bordoni & Valensise, 1998), (Cucci & Cinti, 1998; Cucci, 2002).

The elevation of the terrace correlated to the Marine Isotope Stage (MIS 5.5), located in-land, at 115 m, above

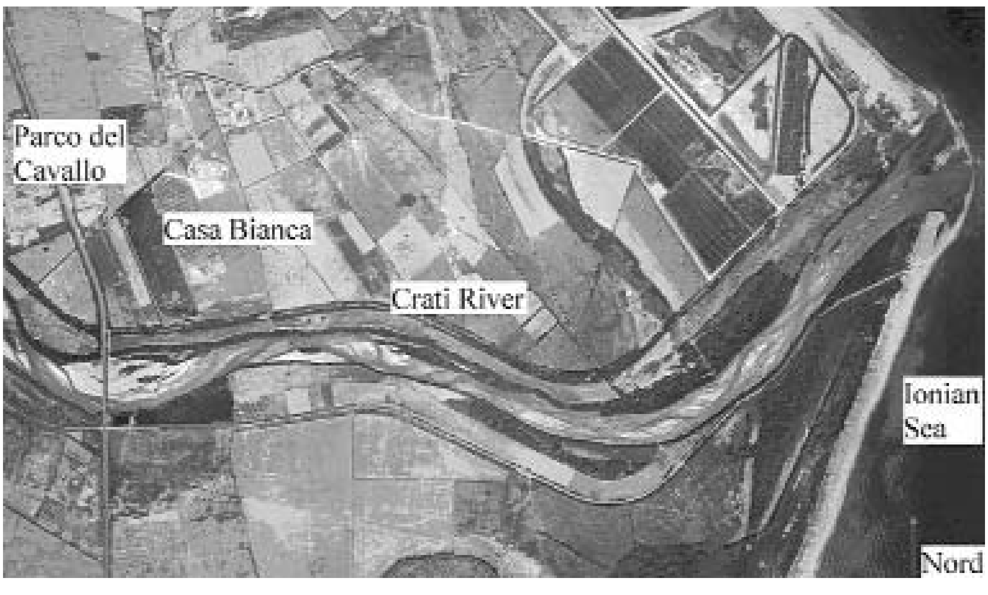

FIG. 2 - Aerial photo of the Crati river delta with the location of two archaeological areas of the site of Sybaris.

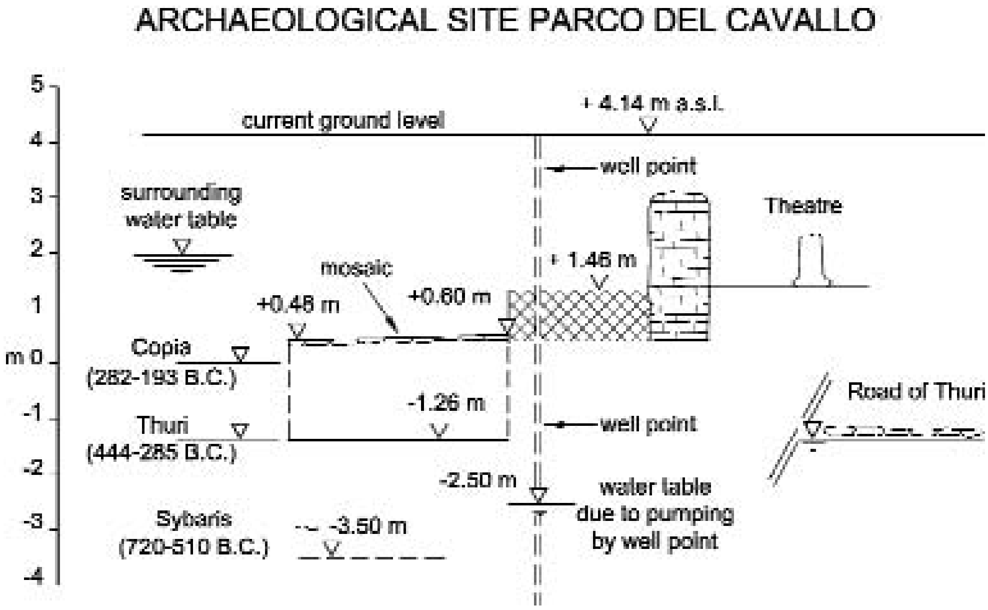

FIG. 3 - Actual depths of the ancient towns in the archaeological area Parco del Cavallo and the watertable levels (after Pagliarulo & Cotecchia F., 2000).

sea level at present, shows that the average tectonic uplift rate is about 0,7 mm/yr, while the uplift rates for the surrounding areas are about 1,0-1,1 mm/yr. The uplift occurred since Middle Pliocene and is still active during Holocene as reported for an adjacent area of the Taranto Gulf, (Bentivenga & *alii*, 2004).

CHARACTERISTICS OF THE SEDIMENTS

In order to reconstruct the geology and the sediments of the alluvial plain, during the research, more than 20 boreholes were drilled with a variable depth from 10 to 120 meters from the actual ground level, (fig. 4: circle). The studied alluvial deposits consist of sands, clays, sandy clays and gravels frequently in heteropic facies. Peat levels are often found interbedded at various depths, (fig. 5). From the borehole cores drilled during the research numerous samples have been obtained for mineralogical, litho-stratigraphic, bio-stratigraphic and chrono-stratigraphic analyses. Figure 6 shows the textural classification of 14 samples obtained from the borehole S1. The sediments have been sampled every fourth meter of the core in the range 15÷70 m u.s.l. The samples were classified both on the basis of Shepard's diagram (1954) and Pejrup's one (1988). While the first diagram defines them only from the textural point of view, the second one, using the percentage of the clay fraction and the sand content of the coarse-grained part, gives information about the hydrodynamic conditions of the environment at the time of deposition. Most of the samples show silts and clays deposited in a hydrodinamic environment of low energy.

Mineralogical analyses were run on two groups of samples, one includes samples obtained from the borehole S1, while the other group comes from the faces of excavations of the archaeological digs, extended to a depth of six meters below ground level in the Parco del Cavallo area. The two groups give different analytical results (fig. 7). The most evident features of the samples coming from the faces of excavations are: a) the prevalence of phyllosilicates over other components due to the weathering of illite; b) the carbonates are more common than quarz and felspars; c) the absence of fossil traces. While, in the samples coming from the borehole S1, quarz and felspars prevail. Flakes and packets of phyllosilicates are present, as well as fragments of schistose rocks and künzigites.

ANALISYS OF THE STRATIGRAPHIC LOGS AND ^{14}C DATINGS

a - Methods

During the execution of the boreholes numerous samples were taken also for ^{14}C datings. The conventional age of the carbon frustules and the remains of fossils was obtained by means of analyses with the Accelerator Mass Spectrometer (AMS), considering the small amount of organic substances. The analyses were partly carried out in the Australian National Tandem for Applied Research of Sidney and partly in the Department of Physics and Atmospheric Sciences at the University of Tucson, Arizona. The conventional, the calibrated ages as well as the kind and the depths of samples are described in table 1.

b - Discussion on data

The following remarks can be made observing the sediments in the boreholes. The upper part of the stratigraphic columns shows lithologic characteristics which

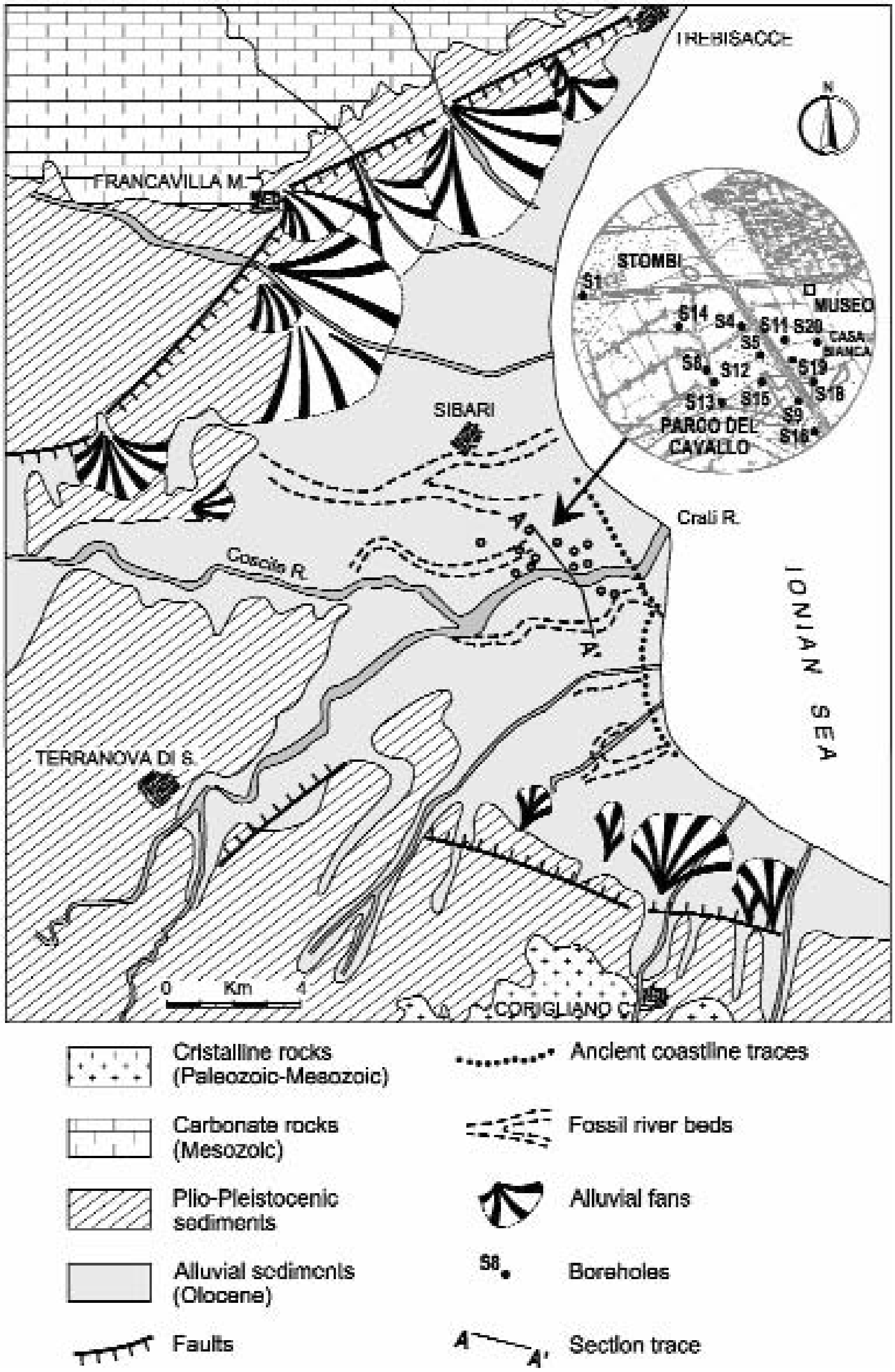

FIG. 4 - Schematic geological map. In the circle there is the location of the boreholes drilled during the research project supported by CNR.

are typical of reworked soils resulting from the presence of layers with traces of human settlements. Generally, until a depth of about –5.00 m below the ground level the remains of buildings and various parts of ceramics were found (fig. 8). Below this depth the sediment variability becomes more frequent, changing quickly from the clayey silts to fine quartz sands with large quantities of mica and from these to sandy silts between –35 and –45 metres from the ground level. Then, down to a depth of –75 metres the sediments show more uniform lithologic

TABLE 1 - Conventional and calibrated ^{14}C ages of samples obtained from the boreholes

Cores	Elevation (m)	Sample Material	Conventional ^{14}C age (yr BP)	Age error (± yr)	Calibrated age (yr BP)
S1	6.00				
	3.00	Peat	4685	69	5416
	38.00	Peat	8410	70	9362
	55.00	Peat	9835	142	11129
S15	4.40				
	0.10	Organic	1940	60	1877
	40.40	Organics + fossils	6310	70	6723
S16	5.10				
	6.75	Peat	3140	50	3375
	-57.40	Organic	6540	70	7399
	-59.80	Organics + fossils	7100	110	7629
	-63.40	Fossils	9250	130	9838
S18	3.00				
	-0.20	Organics	1840	40	1298
	-1.30	Organics	2930	40	3068
	-6.10	Peat	3265	50	3361
	-17.10	Organics	4470	65	5053
	-21.10	Organics	4945	50	5626
	-38.90	Organics	5775	55	6575
	-40.90	Organics	6610	55	7567
	-51.00	Organics	8900	70	10015
	-68.70	Organics	11980	80	14012
	-90.70	Organics	29850	300	31805
	-97.10	Organics	31790	660	36711
	-97.10	Organics	29850	770	33340

features and the particle size becomes extremely fine. The core of S 18 shows almost uniform lithology from a depth of –71,3 m, whose calibrated age is 14012±80 yr BP, down to the bottom of the borehole and consists of fine sands with large quantities of mica and organic substances, giving it its dark grey colour. The uniform sandy levels are interrupted by some gravel layers with large blocks of granitic and gneissic rocks. The largest layer is located at approximately –75 m and it is probably an ancient riverbed. In the S1 and S15 boreholes, located further inland, a larger particle size was found more or less at the same depth. The core-logging of the borehole S1, located inland versus the present-day shoreline, shows more heterogeneous sediments. Observation the age of sediments is to note that the rate of sedimentation was not constant. For example in the borehole S 16 the small range of depth, 57,40÷63,40 u.s.l., has been slowly filled in by fine materials and the ages increased from 7399±70 yr to 9838±130 yr BP.

DEPOSITIONAL ENVIRONMENTS AND SEA LEVEL CHANGES

On the basis of the lithological and chrono-stratigraphical features of the samples it is possible to define the

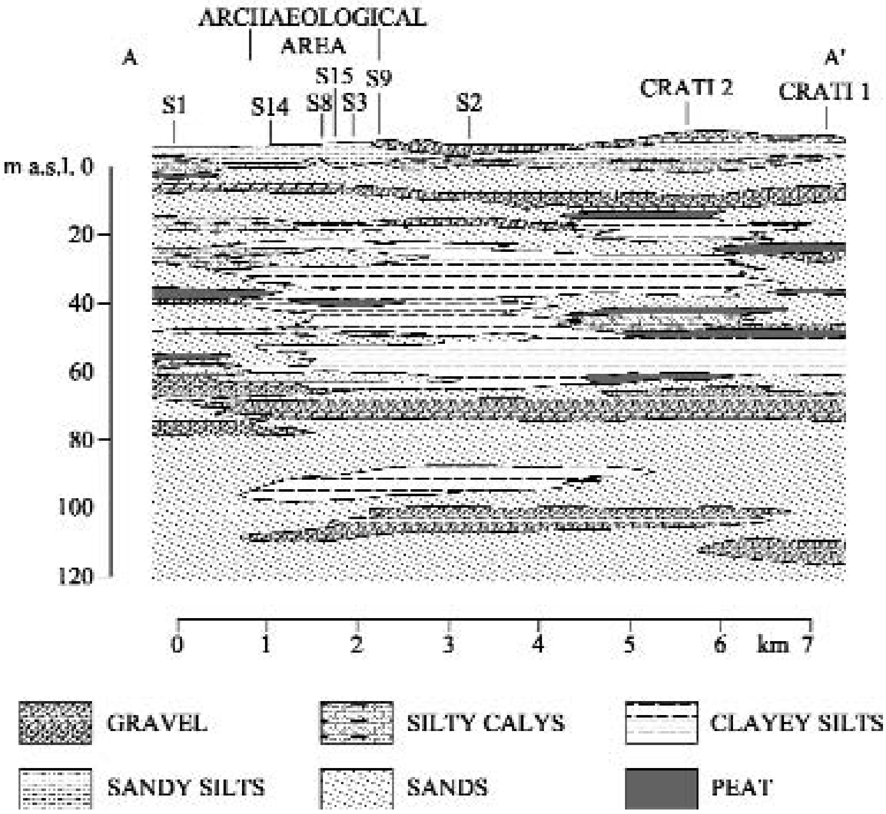

FIG. 5 - Geological section of the alluvial sediments.

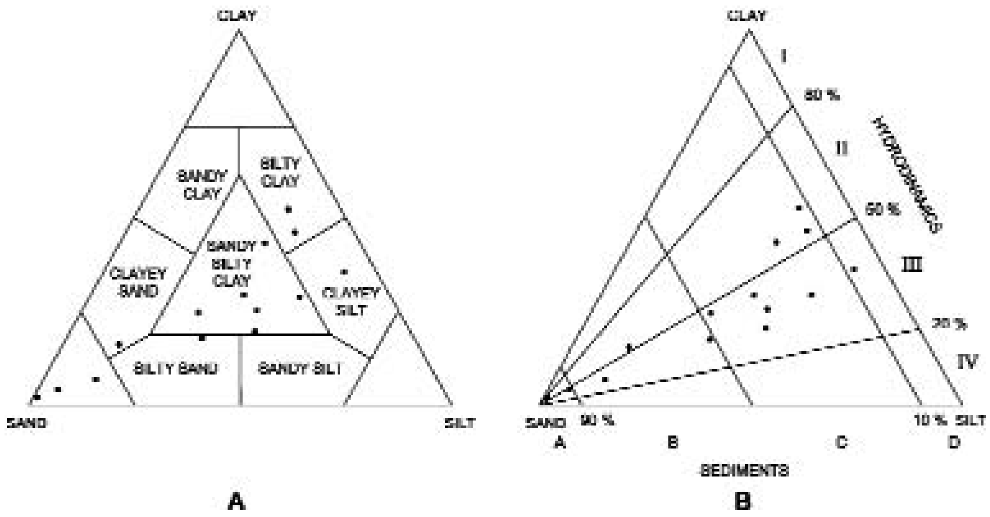

FIG. 6 - Textural classification of sediments according A) Shepard's diagram; B) Pejrup's diagram.

depositional environments of these sediments. The palaeontological analyses performed on 10 fossilliferous samples obtained from the core of S 15 are not completely representative and the fossils recognized cannot be environmental markers as they are mostly derived. The main fossil content consists of small benthic *Foraminifera* sometimes associated with *Globigerinoides*, different species of *Ostracoda*, remnants of T*urritelids* and *Echinocardia*. The age of this faunal assemblage is to refer to Middle-Upper Pleistocene (Pagliarulo & *alii*, 1995).

The great variability in the gain size of the sediments is typical of an alluvial plain sedimentary regimes where the land surface is repeatedly flooded and submerged. The peat levels, above all the three consistent horizons found in the borehole S 1, suggest the presence of swamps along the river floodplain, at time of deposition, with a different distribution of water. The morphological changes in the course of the rivers favoured that sediments flowing with the river water, remained in channels and bends, creating the condition for wetlands and consequently the formation of peat. Moreover, the actual presence of hydrogen sulfide and methane is detected in boreholes drilled since the fifties. This indicates the chemical reduction of organic materials by the brackish fossil water confined in the deepest layers.

However, peat levels become less thick and rarer moving toward SE. Given the presence of clays and some rare planktonic fossils, from a depth of –42,60 m, the sediment deposition may be related to an enclosed brackish basin, with relatively shallow waters. This indicates that, being the same age, the sedimentation environment changed from NW to SE, more precisely, from the inland typical alluvial plain, to marshy episodes enabling peat sedimentation, to a mixed coastal environment.

The coastline of the Ionian sea has undergone great changes since the end of Pleistocene period and these have deeply influenced the sedimentation area, triggering shifts in the river baselevels (Cotecchia & *alii*, 1971). If the ages of the three peat levels of the borehole S 1 are plotted on the Relative Sea Level curve for the Ionian Sea, the sea lev-

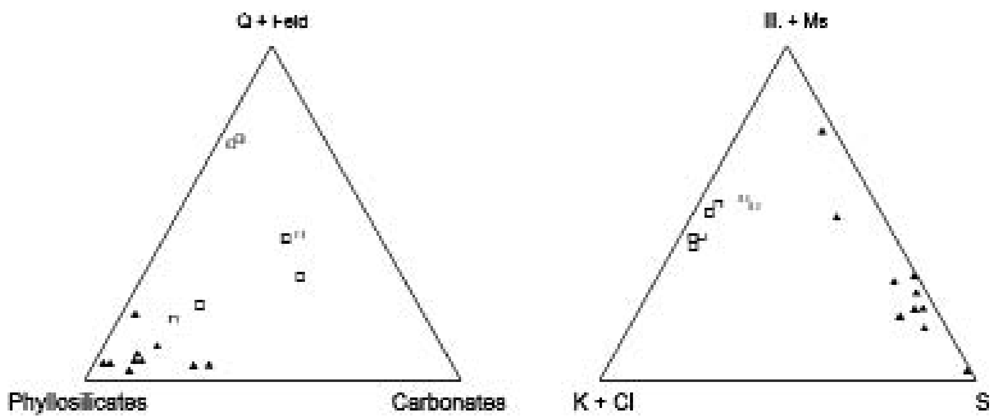

FIG. 7 - Trend of distribution of quartz + feldspars (Q+Feld), phyllosilicates and carbonates and illite + muscovite (Ill+Ms), kaolonite + chlorite (K+Cl), and smectite. The triangles indicate the mineral composition of the first six meters below ground level; the squares indicate borehole samples.

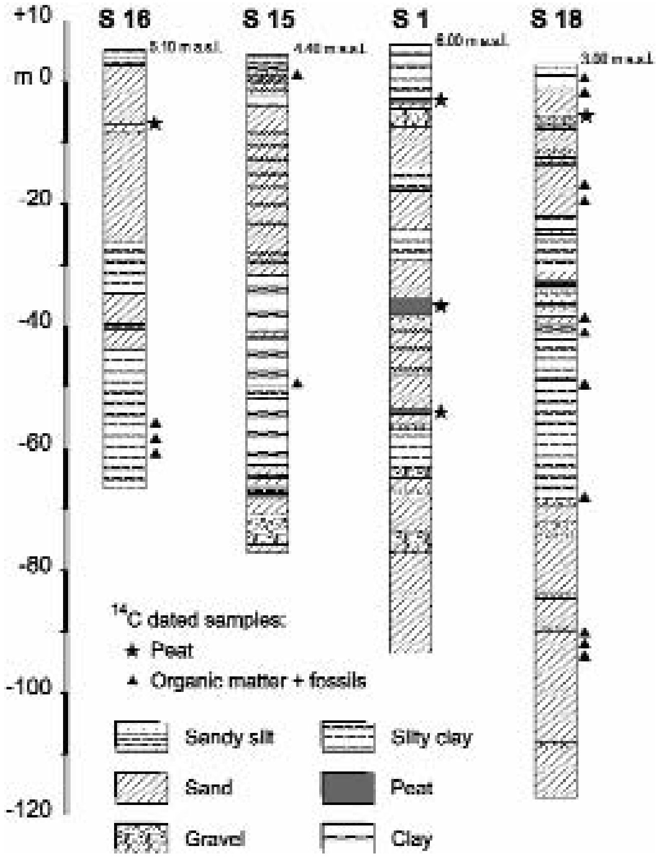

FIG. 8 - Soil profiles along the deepest four boreholes.

el at the time of their deposition can be deduced. The rate of the total (apparent) subsidence has been calculated (fig. 9). The rate of subsidence referred to the depth of –55 m u.s.l. obtained on ^{14}C peat level cal dating 11129±142 yr BP is 5,4 mm/yr while it decreases upward to the ground level to a value of 1,6 mm/yr.

The RSL curve has been reconstructed on the basis of the Lambeck's predictive model for the Late Pleistocene and Holocene changes in relative sea level and estimate rates of vertical movements (Lambeck & *alii*, 2004). Palaeogeographic reconstructions obtained for the Last Glacial Maximum (22±2 ky cal BP) indicate that the sea level in the Ionian sea was about –140 lower than the present one and at the Holocene Climatic Optimum (8±1 ky BP) the shoreline, in the same area, was about –20 m (Antonioli & *alii*, 2004). Later on, the sea level rose further to reach present-day value (Waelbroek & *alii*, 2002).

LAND SUBSIDENCE AND CONCLUSIVE REMARKS

During the first stages of this research project, the causes responsible for the land subsidence of the area were due to three main components: a) neotectonics; b) glacio-eustatic changes; c) compression of sediments. (Cotecchia & *alii*, 1994; Cherubini & *alii*, 1994; 2000; Cotecchia & Pagliarulo, 1996; 2001; Pagliarulo, 2002).

The tectonic subsidence was considered to be equivalent to the change in elevation caused by the Pleistocenic

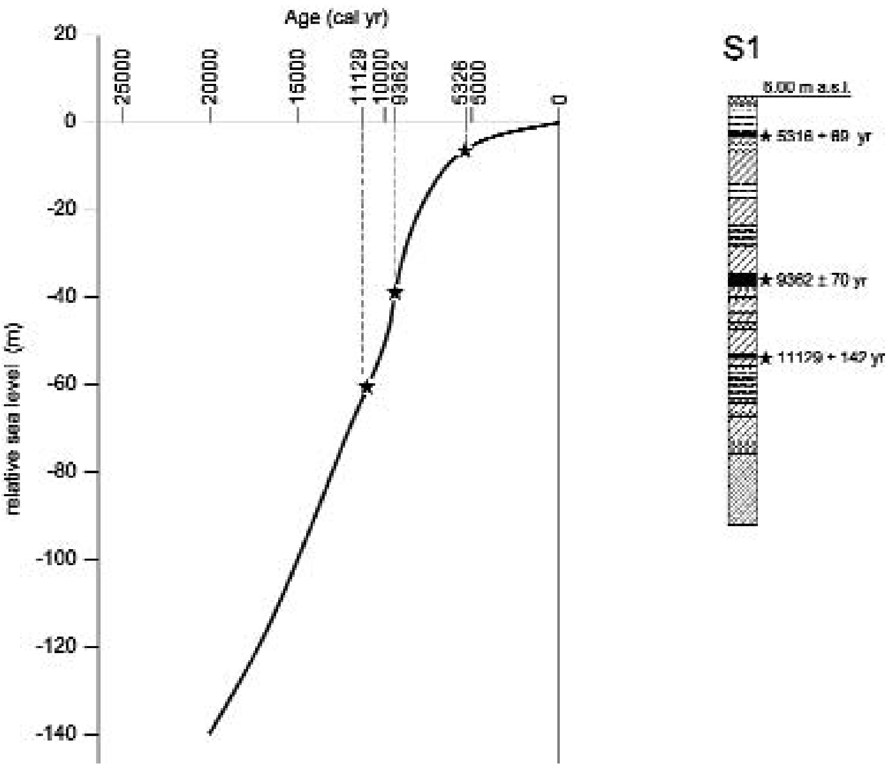

FIG. 9 - Relative sea level curve for the Ionian sea and the soil profile of the borehole S1 with the three ^{14}C dated peat levels.

activity of the fault systems bordering the graben, while the rate of tectonic uplift, measured since MIS 5.5, is 0.7 mm/yr. The apparent subsidence is the component relative to the eustatic increase in sea level. This value is 5,4 mm/yr, for the deep strata of the alluvial deposits. With regard to the geotechnical subsidence, a natural component is the effect of the slow and progressive process of the primary consolidation of highly compressible clayey soils present at –35 to –50 m depth and the peat levels. An anthropic component has been also observed, due to the recent excessive and uncontrolled withdrawal of the underground water. Since 1950 about 20 cm soil subsidence has been measured with respect to the IGM bench mark located on the bridge of the Crati River. The rates of the tectonic uplift and the subsidence are almost of the same size, consequently, it is possible to conclude that the tectonic component is negligible, since the plain is generally uplifting, although it is a graben, with a lowering trend. The rate of subsidence has decreased with time.

The coastal changes are the result of the balance between the sea levels and the overfloodings of the Crati river. The evolution of the Sibari Plain in the last 20 ka yr has been reconstructed, interpreting the sequence of deposits and their links to the climatic conditions, as well. During the LGM the cold and dry climatic phase involved also the Mediterranean areas, followed by another cold period, the Younger Dryas, about 11 ka yr BP (Orombelli & Ravazzi, 1996). In this period the sedimentation of coarse-grained deposits can be assumed. Later on, the climatic conditions changed, the temperature became milder as well as the rise in the sea level. The sedimentation environment varied from a typical sedimentary alluvial regime inland from the coastline, with marshy areas and the sedimentation of the peaty levels to a mixed coastal environment.

As far as evolution during the Holocene is concerned, it can be seen that the ^{14}C age values are in line with the archaeological dating of the inhabited layers. The archaeological area Casa Bianca (fig. 2), belonging to the Hellenistic town of Thurii, now located at approximately 2,5 km from the sea, was originally on the coastline, it was the harbour. The morphological evolution resulting from the changes in the Crati and Coscile river courses must also be taken into account. Historical sources indicate that the ancient town of Sybaris was located between the two rivers Crathis and Sybaris (now called Coscile). While the two rivers now have one single outlet which has moved towards the sea since IV-III century BC, they flow together a few kilometres upstream from the archaeological area of Parco del Cavallo. The catchment of the river Coscile by the river Crati cannot have influenced the historical evolution of the ancient inhabited layers of Sybaris, Thurii and Copia, since the two rivers still had separate courses as it is showed by some geographical maps by Rizzi Zannoni Zotti of 1714, 1759 and 1783. The maps are displayed in the Sibaritide Museum at Sibari.

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LIVY (59 BC- 17 AD) - *Histories* IX. 19.4; X. 2; XXV. 7.11; XXV. 15.7-17; XXVII. 1.14.

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