

LATE QUATERNARY SHORELINES IN SOUTHERN CILENTO (MT. BULGHERIA): MORPHOSTRATIGRAPHY AND CHRONOLOGY

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ABSTRACT

A detailed geological and geomorphological survey of shorelines and continental deposits, cropping out along the carbonate coast between the Mingardo river mouth and Cala degli Infreschi bay, was carried out. Several erosional indicators of paleo-sea level stands were collected such as notches, wave-cut terraces and upper limits of *Lithophaga* burrows. Littoral sediments are often present on with these erosional features and are made up of sands and conglomerates which locally contain mollusc shells, red algae and corals. These evidence have been preserved along paleo-sea cliffs or inside coastal caves of prevalent karstic origin.

The continental deposits, often associated with marine successions, are represented by eolian and colluvial deposits, paleosols and, inside the coastal caves, by speleothems and graviclastic breccias. In many localities these continental deposits contain lithic industries of palaeolithic age which can be considered as lower or upper chronological limits for the associated shorelines.

Geomorphological cut-cross relations, stratigraphic position and altimetric correlation among continental and marine deposits were analysed in order to recognise both their relative chronology and the phases of coastal morphogenesis, linked to the interaction between sea level fluctuations and tectonic uplift. Mineralogic analysis on paleosols was also carried out for paleoenvironmental reconstructions. Moreover, Th/U datings of speleothems, which directly cover or are buried by marine deposits, were carried out in order to give chronological constrains for the reconstruction.

At least six orders of Middle Pleistocene marine terraces are present between 75 and 15 m a.s.l.; the complete flight of these terraces is only well preserved along the western part of the Mt. Bulgheria coast. Between 10 e 3.5 m a.s.l. we recognised three other paleo-sea level stands, the youngest of which is represented by fossiliferous conglomerates and sands. The Th/U age of the speleothem (90 ka BP) which is buried by these marine deposits and the Th/U age of the speleothem which cover the marine sands (50 ka BP) allowed us to ascribe this shoreline to the OIS 5a. This correlation is supported by the mousterian age of the graviclastic breccia lying on them.

RIASSUNTO

E' stato eseguito un rilevamento geologico e geomorfologico di dettaglio delle linee di riva e dei depositi continentali affioranti lungo il settore di costa carbonatica compreso tra la foce del fiume Mingardo e Cala degli Infreschi. Sono stati individuati diversi indicatori erosionali di paleostazionamenti del livello marino, rappresentati da solchi bioerosivi, piattaforme d'abrasione e dal limite superiore orizzontale dei fori di litodomi. Spesso a queste forme erosionali si associano depositi marini, costituiti da sabbie e puddinghe che localmente contengono resti di molluschi, alghe rosse e coralli. Queste evidenze sono preservate lungo le paleofalesie o all'interno di grotte costiere, in molti casi di origine carsica. Deposit continentali sono a volte associati alle successioni marine; si tratta soprattutto di depositi eolici, colluvioni, paleosuoli e, all'interno delle grotte, di speleotemi e brecce graviclastiche. In molte località questi depositi contengono industrie paleolitiche che possono essere considerate come limite cronologico inferiore o superiore per le linee di riva ad esse associate.

L'analisi dei rapporti geomorfologici, le posizioni stratigrafiche e la correlazione altimetrica tra i depositi continentali e marini hanno permesso di ricostruire la loro cronologia relativa e le fasi di morfogenesi costiera legate all'interazione tra le variazioni del livello marino e i movimenti di sollevamento. Analisi mineralogiche sono state condotte sui paleosuoli allo scopo di ottenere delle ricostruzioni paleoambientali. Inoltre, sono state eseguite datazioni Th/U di alcuni speleotemi che poggiano su/ o sono coperti da depositi marini, al fine di ottenere dei vincoli cronologici per la ricostruzione degli eventi.

Tra 75 e 15 m s.l.m. sono stati riconosciuti almeno sei ordini di terrazzi marini medioplestocenici; questa gradinata di terrazzi si è preservata completamente solo lungo il settore costiero occidentale del Monte Bulgheria. Tra 10 e 3.5 m s.l.m. sono presenti altri tre paleostazionamenti marini, il più recente dei quali è rappresentato da una puddinga fossilifera che passa verso l'alto a sabbie. L'età Th/U dello speleotema (90 ka BP) su cui si rinvengono i suddetti depositi marini e quella dello speleotema che copre le sabbie (50 ka BP) permettono di ascrivere questa linea di riva al substage 5a della stratigrafia isotopica. Tale attribuzione è confermata dall'età mousteriana delle brecce graviclastiche poggianti sul deposito marino.

Keywords: Paleo-sea level stands, Late Quaternary, speleothem, paleosol, U-series dating, Cilento promontory, Southern Italy.

Parole chiave: Paleostazionamenti del livello marino, tardo Quaternario, speleotema, paleosuolo, datazioni con la serie dell'Uranio, Cilento, Italia meridionale.

1 INTRODUCTION

The Cilento promontory is a large structural high located between the Gulf of Salerno to the north and the Policastro gulf to the south (Fig.1). Its southern coasts are carved in high resistant rocks such as limestones

and cherty limestones (flintstones) of the Mt. Bulgheria Mesozoic– Caenozoic units. Due to the Pliocene–Quaternary tectonic history of the Mt Bulgheria massif, which was characterised by several phases of normal faulting mainly EW and NE SW trending (Ascione *et al.*, 1997), the coast of southern Cilento is constituted by

same structure-controlled bays, filled in some cases with sandy and gravelly beaches (Capo Grosso, Cala D'Arconte, La Calanca and Lentiscelle beaches), which alternate with active vertical sea cliffs from some metres to hundreds of metres high.

Karstic caves, more or less reworked and enlarged by marine abrasion (Esposito *et al.*, 2001), are present all along the carbonate active and inactive sea cliffs.

The slope developing over the sea cliff is characterised by a flight of marine terraces, from 400 to 10 m above the present sea level, cut by subsequent and consequent stream valleys.

According to the last researches carried out on the marine terraces of southern Cilento (Ascione & Romano, 1999; Russo, 1994), the Eutyrrhenian shoreline (*i.e.* the one correlated with the Oxygen Isotope sub-Stage 5e) can be found at almost the same elevation along the coast of Mt. Bulgheria; *i.e.* it was recognised at Cala Bianca bay at 6 m a.s.l. by means of racemization on *Astraliium* shells (Russo, 1994). These findings testify a late Quaternary tectonic stability for the area. Moving southward of the Mt. Bulgheria coasts, a moderate Upper Pleistocene-Holocene tectonic uplift was highlighted near Sapri, where Brancaccio *et al.* (1990) recognised, at 15 m a.s.l., fossiliferous marine conglomerates dated to the eutyrrhenian transgression. Finally, evidence of post-eutyrrhenian subsidence was pointed out at Capo Palinuro, the carbonate promontory that bounds Mt. Bulgheria to the north, where a + 2 m high marine notch was correlated to the OlsS 5e sea level highstand (Antonoli *et al.*, 1994).

In this paper the results of a detailed survey carried out on the late Quaternary shorelines along the coast of Mt. Bulgheria are presented. The collected data refer to all the erosional and depositional indicators of fossil shorelines which are preserved along the active and inactive sea cliffs as well as inside the coastal caves. As erosional indicators we considered the point of maximum concavity of bioerosive notches (*sensu* Pirazzoli, 1996), the inner rim of wave-cut terraces and the upper limit of burrows (the latter only when straight, horizontal and laterally continuous for some metres).

Along the fossil shorelines, a detailed survey was also carried out on the continental deposits associated with the erosional and depositional marks of strandlines, such as alluvial and colluvial deposits, paleosols, tephra layers and speleothems.

2 GEOLOGICAL AND GEOMORPHOLOGICAL SETTING OF THE SOUTHERN CILENTO

Starting from the sixties, several geological, structural and geomorphological studies have been carried out in order to reconstruct the Mt. Bulgheria long and short term geological history (Scandone *et al.*, 1964; Ciampo, 1976; Lippmann-Provansal, 1987; Borrelli *et al.*, 1988; Tozzi *et al.*, 1996; Ascione A., 1997; Ascione *et al.*, 1997; Ascione & Romano, 1999).

The massif is a topographic high made up of a carbonate succession Upper Triassic to Lower Miocene in age which is unconformably covered by Pliocene-Quaternary continental, transitional and marine deposits.

The Pliocene-Quaternary geomorphological and tectonic evolution of Mt. Bulgheria is testified by fluvial and lacustrine terraces, wave-cut and wave-built marine terraces, structure controlled forms (such as fault scarps, subsequent fluvial valleys, etc.), as well as by the above quoted successions of different sedimentary environments.

In particular, the early Pleistocene depositional events were recorded by marine successions: the S. Vito Formation, Santernian in age (Ascione, 1997), the Lentiscosa Formation (Sgrosso & Ciampo, 1966; Lippmann Provansal, 1987; Borrelli *et al.*, 1988), the Cala Bianca Frms Emilian in age (Sgrosso & Ciampo, 1966; Ciampo, 1976) and Torre dell'Isola Frms, Emilian in age (Ascione, 1997). All these Formations are unconformably lying on the Caenozoic and Mesozoic

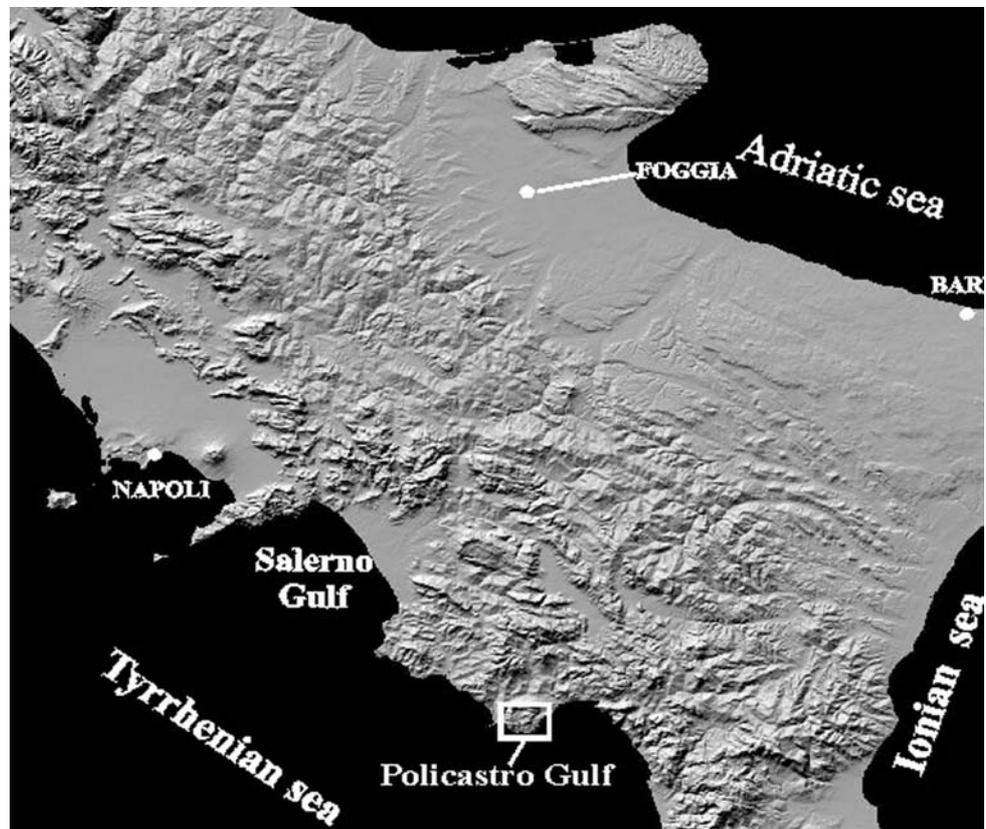


Fig. 1 - Location of the studied area.
Ubicazione dell'area studiata.

dell'Isola conglomerates (Emilian stage).

The stratigraphical constraints for this order of terraces are well exposed at Cala d'Arconte and Capo Grosso bays where two different generations of paleosols, developed on colluvial deposits, cover the wave-cut terraces. The oldest one (2.5÷3 m thick) is reddish, contains manganese nodules and some *stone-lines*; several artifacts of Acheulean age were reported by Palma di Cesnola (1982). The youngest paleosol (6 m thick), discordant on the other, is brownish-red and does not contain gravels; Mousterian artifacts were found in it (Palma di Cesnola, 1982). A lens of grey, weathering pyroclastic sand is present at the top of the youngest paleosol.

In the Cilento area the mousterian lithic industries are dated between 130 and 40 ka B.P. (Gambassini & Ronchitelli, 1998). This means that the oldest colluvium, which only contains Acheulean artifacts, was settled before 130 ka B.P.; consequently the age of the 12÷10 m terrace, over which the paleosol is located, is pre-Tyrrhenian.

Another evidence of this shoreline is represented by the inner edge of the wave-cut terrace located at 10 m a.s.l. and covered by marine grey sandstones along the Cala d'Arconte promontory, and by a bioerosive notch, clearly visible on the right side of Grotta della Serratura cave, in the Cala Lentiscelle bay.

Evidence at 8.5÷8 m a.s.l.– This shoreline is represented by a wave-cut terrace in the west side of Calanca bay, by horizontal upper limits of *Lithophagus* burrows, between Monte di Luna and Cala Bianca and in *Riparo Infreschi* cave, and by two bioerosive notches in Cala Bianca bay and in the *Infreschi* cave.

Evidence between 7.5 and 5 m a.s.l.– Between Torre Fenosa and Marina di Camerota wave-cut terraces and bioerosive notches, located at 6÷5 m a.s.l., represent the evidence of an ancient shoreline. Remains of grey marine sandstones are associated with some of these terraces.

On the Torre dell'Isola promontory a bioerosive notch located at 7.5 m a.s.l. may be the evidence of another paleo-sea level, but no similar evidence was found along the coastal sector.

In particular, on this promontory between 7.5 and 5 m a.s.l. at least three relative paleo-sea levels can be recognised, respectively at + 7.5 , + 5 m. and + 7 m (Fig.4). At 5 m a.s.l., in fact, a wave-cut terrace with polygenic well rounded beach conglomerates is present. The conglomerates are unconformably covered by a fossiliferous marine deposit (1.5 m thick), which laterally passes to a clinostatified grey sandstone (2 m thick). The latter is cut at 7 m a.s.l. by a sub-horizontal surface that looks like another wave-cut terrace. A reddish continental deposit covers this terrace and fills the bioerosive



Fig. 3 - The 10 m a.s.l. wave-cut terrace of Cala d'Arconte promontory.

Terrazzo d'abrasione dei 10 m s.l.m. sul promontorio di Cala d'Arconte.

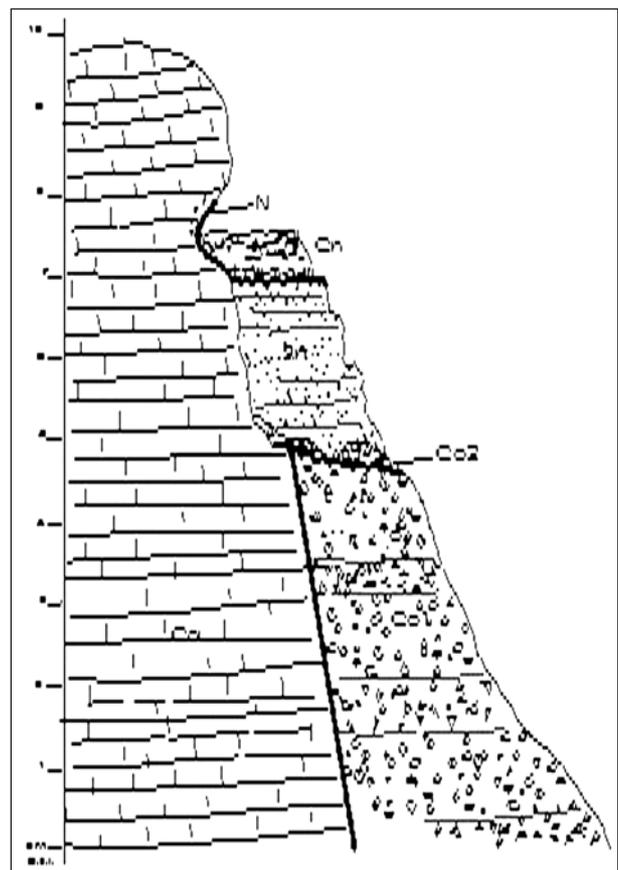


Fig. 4 - Schematic profile of Torre dell'Isola sector. Ca-mesozoic limestone; Co1- marine monogenic conglomerates and breccias of Torre dell'Isola succession; Co2- marine polygenic conglomerates; Sn- marine sands; Cn-continental deposits with breccias and flowstone; N-bioerosive notch *Lithophaga* burrows.

Profilo schematico del settore di Torre dell'Isola. Ca- calcari mesozoici; Co1-puddinghe monogeniche e brecce della successione di Torre dell'Isola; Co2- puddinghe poligeniche; Sn- sabbie marine; Cn- depositi continentali con brecce e concrezioni; N- solco bioerosivo; fori di Litodomi.

notch at 7.5 m a.s.l., too.

Stratigraphic relations between erosional features and deposits suggest the following relative chronology of events: the + 7.5 m notch represents a first paleo-sea level stand, the + 5 m wave-cut terrace and the grey marine sandstones indicate a subsequent sea level stand and a relative trasgression, finally the sea level stand rises again, as the + 7 m wave-cut terrace testifies. After this marine phase, the deposition of continental deposit occurs.

Evidence at 4.5-4 m a.s.l.- Between Torre Zancale and Cala degli Infreschi, bioerosive notches and wave-cut terraces are clearly visible at 4.5÷4 m a.s.l.. These erosional morphologies are rather continuous and sometimes remains of grey marine sandstones (similar to the sandstone cropping out on the + 5 m terrace located W of Marina di Camerota, see precedent paragraph) are visible on the terrace. In the Cala Bianca and Cala degli Infreschi bays a *Cladocora*-bearing biocalcarenitic is present on the 4.5 m wave-cut terrace.

Evidence at 3.5-3 m a.s.l.- Evidence of this shoreline was mainly observed in the eastern coastal sector and along the western promontory of the Calanca bay (Fig.5) where a continuous (ca. 200 m) and well-marked wave-cut terrace with marine sandstones (max 2 m thick) is present.



Fig. 5 - The 3.5 m a.s.l. wave-cut terrace of Calanca bay.
La piattaforma d'abrasione di 3,5 m s.l.m. della baia della Calanca.

3.1 The case of Cala degli Infreschi.

In the sub-circular bay of Cala degli Infreschi a lot of different erosional indicators of paleo-sea level stands together with marine and continental deposits were collected; the stratigraphical record is well preserved in two little caves located in the western sector of the bay: the *Infreschi* cave and the *Riparo Infreschi* cave (Fig. 2).

The *Infreschi* cave

This cave represents a remnant of an ancient karstic phreatic level (Esposito et al., 2001) connected with the basal water table of Mt. Bulgheria, that nowadays flows into the sea through karstic channels located along the western rim of the bay.

The oldest evidence of a paleo-sea level stand is represented by a well-marked bioerosive notch located at 8 m a.s.l. on the right side of the cave (Fig 6, 7A); this notch is cut by a wide strip of *Lithophaga* burrows, whose upper limit is horizontal and located at 8.5 m

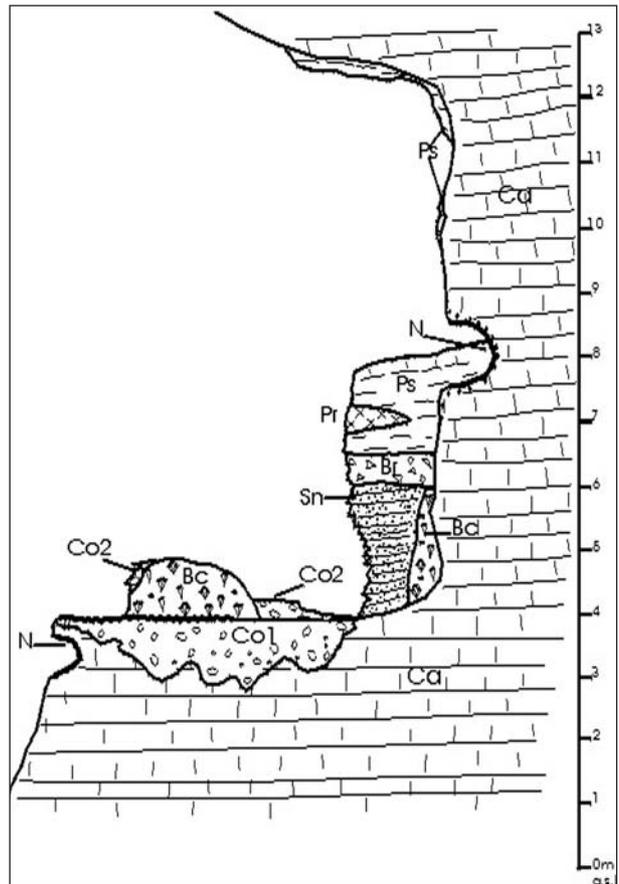


Fig. 6 - Schematic profile of Infreschi cave.
Ca-mesozoic limestone; Co1-marine conglomerates; Bc- biolimestonenite with Cladocora; Co2-marine conglomerates; Sn-marine sands; Br- graviclastic breccias; Ps-paleosol; Pr-pyroclastic layer; N-bioerosive notch; Lithophaga burrows.

Profilo schematico di Grotta degli Infreschi.

Ca- calcari mesozoici; Co1- puddinghe; Bc- biolimestonenite a Cladocora; Co2- puddinghe; Sn- sabbie marine; Br- breccie graviclastiche; Ps-paleosuolo; Pr- piroclastite; N- solco bioerosivo; fori di Litodomi.

a.s.l..

At the entrance of the cave a wave-cut terrace is present at 4.5 m a.s.l. (Fig.6, 7B) cut in the carbonate succession of Mt. Bulgheria as well as in a monogenic carbonate beach conglomerate. The external rim of this terrace is covered by a *Cladocora*-bearing biocalcareni- te which is also visible in remains on the wall of the cave up to 6 m a.s.l..

This biocalcareni- te is covered by a polygenic beach conglomerate (ca.1 m thick) passing upward to plano-parallel stratified sands, clearly trasgressive and unconformable on the *Cladocora*-bearing biocalcareni- te; the top of these sands reaches the altitude of 6 m.

Along the scarp of the + 4.5 m wave-cut terrace a bioerosive notch, located at about 3.5 m a.s.l., is present and continuously well preserved also in the area surrounding the cave.

At the back of the cave a continental succession covering the sands is preserved; it is made up of gravi- clastic carbonate breccias almost without matrix, passing upward to a brownish paleosol with manganese nodules (see p.5). Two strongly altered yellowish pyro- clastic levels are included in the paleosol.

The Riparo Infreschi cave

This site represents the remains of an ancient coa- stal cave, like that of *Infreschi*, now destroyed by roof



A



B

Fig.7 - Infreschi bay. A- the 8 m a.s.l. bioerosive notch; B-the 4 m a.s.l. wave-cut terrace.

Cala degli Infreschi. A- solco bioerosivo a quota 8 m s.l.m.; B- piattaforma d'abrasione dei 4 m s.l.m.

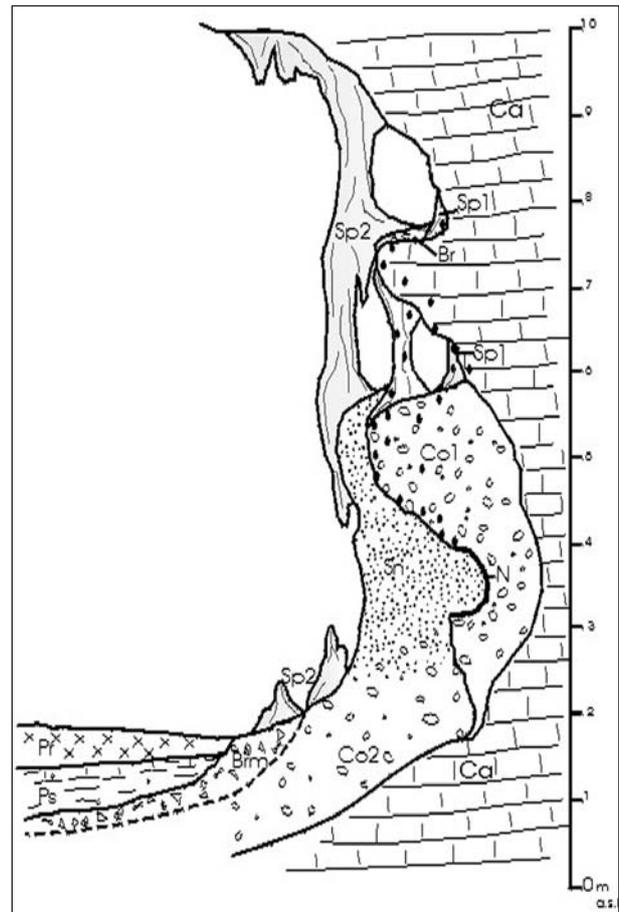


Fig. 8 - Schematic profile of Riparo degli Infreschi. Ca-mesozoic limestone; Co1-marine conglomerates; Sp1- speleothem; Lithophaga burrows; Br- gravilastic breccias; N-bioerosive notch; Co2-marine conglomerates; Sn-marine sands; Brm- mousterian gravilastic breccias; Sp2- speleothem; Ps-paleosol; Pr-pyroclastic layer.

Profilo schematico del Riparo degli Infreschi. Ca- calcari mesozoici; Co1- puddinghe; Sp1- speleotema; fori di Litodomi; Br- breccie gravilastiche; N- solco bioerosivo; Co2- puddinghe; Sn- sabbie marine; Brm- breccia gravilastica di età musteriana; Sp2- speleotema; Ps-paleosuolo; Pr- piroclastite.

falls. Also in this case a well preserved record of marine and continental deposits is present (Fig.8, 9). Mousterian lithic industries were found in the continental part of the succession (Guide Archeologiche, 1996).

All deposits are preserved on the left side and in the central part of the paleo-cave together with erosional evidence of paleo-sea level stands. In particular, the highest evidence is represented by a wide strip of burrows whose horizontal upper limit rests at 8.5 m a.s.l.. At about 8 m a.s.l., a flowstone drapping the wall of the cave was found, which was cut by the burrows and then sampled for U-series dating (**Sp1-RI 7**).

At about 6 m a.s.l. carbonate marine conglomerates are covered by a speleothem; as the carbonate substratum, both of them are cut by burrows (Fig.10). This speleothem was sampled for U-series dating. (**Sp1-RI 5**).

Over the carbonate marine conglomerates and over the speleothem, marine sands are present, which

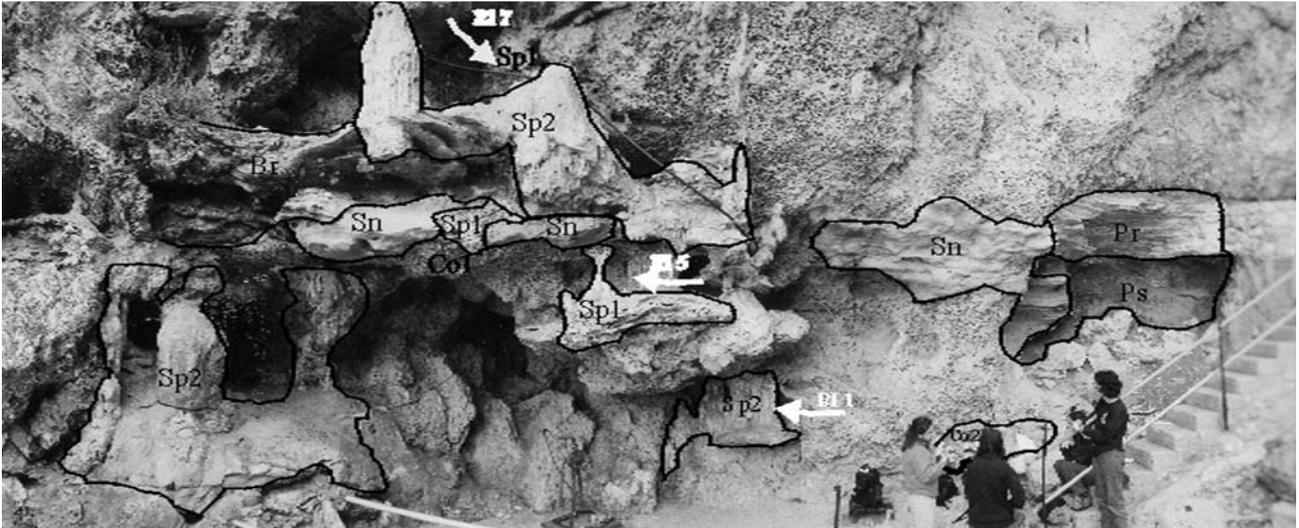


Fig. 9 - Riparo degli Infreschi cave.
Co1- marine conglomerates; Sp1- speleothem; Br- graviclastic breccias; Co2-marine conglomerates; Sn- marine sands; Sp2- speleothem; Ps- paleosol; Pr- pyroclastic layer; RI 7- sample of Sp1 at 8 m a.s.l.; RI 5- sample of Sp1 at 6 m a.s.l.; RI 1- sample of Sp2.

Riparo degli Infreschi.

Co1- puddinghe; Sp1- speleotema; Br- breccie graviclastiche; Co2- puddinghe; Sn- sabbie marine; Sp2- speleotema; Ps- paleosuolo; Pr- piroclastite; RI 7- campione di Sp1 a 8 m s.l.m.; RI 5- campione di Sp1 a 6 m s.l.m.; RI 1- campione di Sp2.



A



B

Fig. 10 - Riparo degli Infreschi cave.
A- speleotema tagliato da fori di *Lithophaga* burrows; B- speleotemi e marine conglomerates cut by *Lithophaga* burrows.

Riparo degli Infreschi.

A- speleotema tagliato da fori di *Litodomi*; B- speleotemi e puddinghe tagliati dai fori di *Litodomi*.

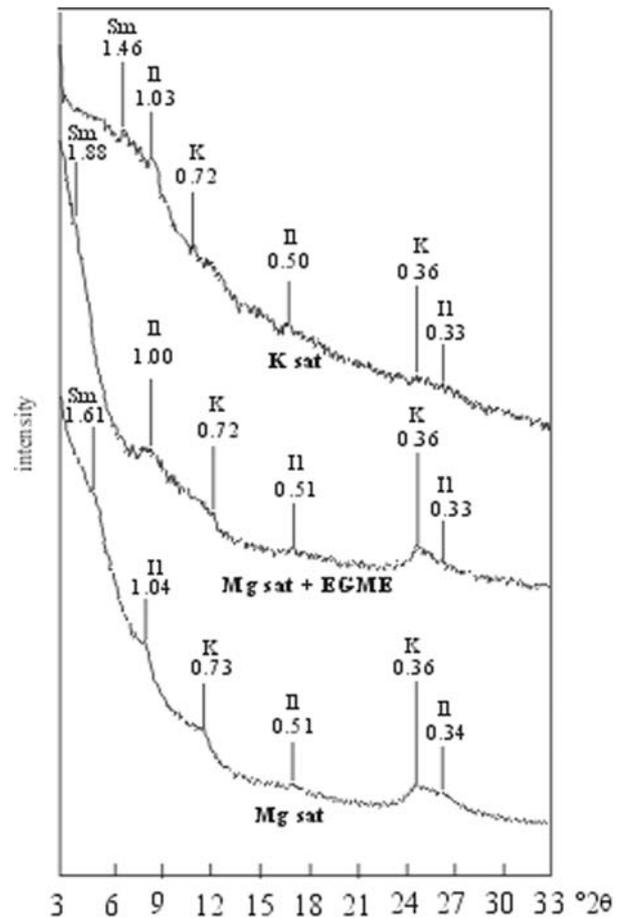


Fig. 11 - Infreschi cave paleosol. XRD patterns for fine clay (< 0.2 mm) fractions after different treatments in horizon B3. Il = illite; K = kaolinite; Sm = smectite; d is expressed in nm.
Paleosuolo di Grotta degli Infreschi. Diffratogrammi ai raggi X delle argille fini (< 0.2 mm) con differenti trattamenti nell'orizzonte B3. Il = illite; K = caolinite; Sm = smectite; d è espressa in nm.

reach 6 m a.s.l. and clearly cover the burrows. These marine sands also cover a bioerosive notch located at 3.5 m a.s.l., which cuts the flank of the cave.

The sands pass downward to carbonate marine conglomerates with abundant matrix and gasteropod shells with spines. In the central part of the paleo-cave at 4 m a.s.l., this conglomerate clearly covers a flowstone which is cut by several burrows. This speleothem was also dated using U-series (**Sp1-RI 4**).

A graviclastic breccia containing remains of Mousterian age is present over the above mentioned conglomerate, testifying human frequenting of the cave at the end of Upper Pleistocene.

Over the breccia deposit a pyroclastic level, which passes upward to a brownish paleosol, is preserved in a corner of the paleo cave. This pyroclastic level is strongly weathered and for this reason its petrochemical analysis didn't give any significant result.

Further flowstones, laying on the sands and on the breccia deposits and never cut by burrows *Lithophaga*, were sampled (**Sp2-RI 1**) in order to give upper chronological constraints to the reconstruction.

4 U-SERIES DATA

Four speleothems interbedded with marine deposits were sampled in *Riparo Infreschi* cave and analysed by U-series disequilibria. Samples were accurately field-selected in order to exclude all materials with macroscopic signs of weathering and further examined under a binocular microscope to refine the selection. Fragments with no trace of secondary alteration were analysed according to standard procedures (Bischoff *et al.*, 1988).

Three to six gram samples were spiked with a $^{228}\text{Th} + ^{232}\text{U}$ tracer (in secular equilibrium) and activity ratios were counted in an EG&G ORTEC 920-8 alpha spectrometer system. The ages and the initial $^{234}\text{U}/^{238}\text{U}$ activity ratios were calculated by means of ISOPLOT, a plotting and regression program designed by Ludwig (1994) for radiogenic-isotope data. The uranium contents, the activity ratios and the calculated ^{230}Th ages are listed in Tab.1; all errors are reported as 1 sigma.

Coral samples from *Infreschi* cave in Cala degli Infreschi were not analysed because of recrystallization problems, testified by high proportion of calcite. Also red algae samples contained in the calcarenite from the same cave were not suitable for the dating because of the high content of secondary carbonate cement,

making the obtained age too young and not consistent with the overall evolution of the area.

5 PEDOLOGICAL DATA

The soil profile of the *Infreschi* cave is characterised by morphological description and bulk sampling for mineralogical analyses (XRD of the fine clay and the sand fractions).

The main morphological features are reported in Tab. 2. On the basis of the reddish to brownish colours determined with the Munsell Soil Color Charts (Munsell, 1994), also the *Redness rate* (Torrent *et al.*, 1980) was evaluated and applied to estimate hematite content according to Ferrari & Magaldi (1983): the former values range from 3 to about 12 allowing to predict up to 1.4 % Hm (data not shown), approximately accordant with the method proposed by Torrent *et al.* (1983). The weak to null effervescence reaction given by the HCl test (10% solution) allows to estimate no more than 2 % of carbonate in the soil.

X-ray diffractometry of the sand fraction indicates the dominance of quartz among the mineral grains, with the presence of feldspars and micas in suborder (data not shown). Also calcite was recognised, presumably related to the secondary calcium carbonate precipitations observed. XRD analysis of fine clays shows a mineralogy mainly formed by kaolinite, illite and smectite (Fig 11). Halloysitic components, possibly deriving from the weathering of the pyroclastic material, cannot be excluded, although no specific treatment was performed to discriminate them from kaolinite.

The examined paleosol can be regarded as *Terrae Rossae*-like (*Rhodoxeralfs*, *sensu* USDA, 1998), largely widespread in southern Italy and other low- and mid-latitude areas, and widely studied by several Authors (e.g. Colombo & Terribile, 1994; Bellanca *et al.*, 1996; Bronger & Bruhn-Lobin, 1997; Yaalon *et al.*, 1997; Yassoglou *et al.*, 1997; Durn *et al.*, 1999).

CONCLUSION

Along the southern sector of the Mt. Bulgheria, between 12÷10 e 0 m a.s.l. several paleo-sea level evidence was identified and gathered in five range of altitude. The oldest one (12÷10 m a.s.l.) is pre-Tyrrhenian in age. The lower evidence develop not continuously along

Tab.1- U-series data of speleothems from Riparo Infreschi, (Italy). Quoted ratios are activity ratios and errors are expressed as 1 sigma. ($^{234}\text{U}/^{238}\text{U}$)_{init.} represents the initial uranium activity ratio.

Datazioni U-series degli speleotemi del Riparo degli Infreschi, (Italia). I rapporti riportati sono rapporti di attività e gli errori sono espressi come 1 sigma. ($^{234}\text{U}/^{238}\text{U}$)_{init.} rappresenta il rapporto di attività iniziale dell'uranio.

Sample	ppb U	($^{234}\text{U}/^{238}\text{U}$)	($^{230}\text{Th}/^{234}\text{U}$)	($^{230}\text{Th}/^{232}\text{Th}$)	($^{234}\text{U}/^{238}\text{U}$) _{init.}	Age (ka)
RI 1	827 ± 17	1.032 ± 0.023	0.373 ± 0.011	40 ± 2	1.037 ± 0.027	50.6 ± 1.9
RI 4	608 ± 42	1.049 ± 0.029	0.565 ± 0.022	38 ± 2	1.063 ± 0.037	89.8 ± 5.4
RI 5	102 ± 4	1.364 ± 0.071	0.588 ± 0.035	infinite	1.472 ± 0.092	91.7 ± 8.2
RI 7	141 ± 5	1.086 ± 0.053	0.650 ± 0.038	infinite	1.118 ± 0.072	111.9 ± 11.0

the coastal belt, so it's difficult to correlate them. Moreover, continental and marine deposits associated with these erosional features not provide chronological constraints, with the exception of the deposits surveyed in the *Infreschi bay*.

The stratigraphical data collected in the *Infreschi* and *Riparo Infreschi* caves were tentatively correlated (Tab. 3).

The Th/U ages of the speleothems Sp2-RI1, Sp1-RI4 and Sp1RI5 represent good chronological constraints for the marine sands and conglomerates of the *Riparo Infreschi* cave (Sn and Co2 in Figg. 7 and 9) suggesting their attribution to the OlsS 5a (>50 ka BP and <89 ka BP). We correlated them to the marine con-

glomerates and sands that partly fill the nearby *Infreschi* cave and which have the same stratigraphical (are covered by similar graviclastic breccia and paleosol) and altitudinal (in both cases the top of the sands is located at 6 m a.s.l..) position. Therefore, these deposits testify a distinct marine ingression in both caves, occurring between two episodes of continental deposition, the last of which is represented by graviclastic breccias and paleosols.

In particular, the *Infreschi* cave paleosol shows an intense degree of weathering, probably partly inherited. In fact, it consists of reworked soil sediments with much allochthonous windblown material, previously weathered under interglacial climatic conditions, clearly warmer

Tab. 2- Description of the *Infreschi* cave's paleosol.
Descrizione del paleosuolo di grotta degli *Infreschi*.

Horizon	Depth	Boundary	Colour (moist)	Texture	Structure	Carbonate reaction (10% HCl)	Gravel	Other features
B1	0-15	Clear, linear	2.5YR 4/6	Clay	Fine angular blocky	Weak	Rare, < 2cm	-
B2	15-70		5YR 4/4	Clay	Coarse to fine angular blocky	Weak	Occasional, < 1cm	Slightly decalcified calcareous clasts
BC1	70-72	Abrupt, linear	7.5YR 5/6	Sandy Loam	-	Null	-	Intensely weathered tephra layer: ash
B3	72-130		5YR 4/4	Clay	Coarse to fine angular blocky	Weak	Occasional, < 1cm	-
BC2	130-150	Gradual, linear	7.5YR 5/6	Sandy Clay Loam	Coarse to medium angular blocky	Null	Rare, < 10cm	Intensely weathered tephra layer: ash + white pumices (< 0.5 cm)
2C/R	150-180	Abrupt, linear	5YR 4/4	Gravelly (clast-supported), Sandy (matrix)	Fine angular blocky	Weak	Dominant, < 10cm	-
3Bb	180-230	Clear, wavy	5YR 4/4	Clay	Medium prismatic to medium angular blocky	Weak	Rare, < 10cm	-
	230	Abrupt, wavy						

LEGEND

	Vertical and horizontal rhizoliths		Fe-Mn coatings
	Gravel: coarse angular calcareous clasts (often karst-shaped)		Fe-Mn soft concentrations
	Tephra layer		CaCO ₃ coatings and soft concentrations

and wetter than today's. Soil reworking should have occurred after the deposition of the marine sands, followed by pedogenesis in the cave, which homogenised this parent material and led to the horizon differentiation and soil aggregation observed in the profile. Soil features related to in situ pedogenesis appear compatible with the succession of the Last Glacial and Holocene environments, alternating drier and moister phases at different time scales (10^3 - 10^2 years to yearly and seasonal cycles) and with very different temperature ranges in a "protected" site such as the *Infreschi* cave.

The Th/U age of the speleothem Sp1-RI 7 gives a lower chronological constraint (younger than 111 ka BP) for the evidence of paleo-sea level stands represented by the upper limit of *Lithophaga*. Because this limit is located at the same altitude in the *Infreschi* caves we ascribed both evidence to OIsS 5c.

Because of their relative chronological position, other evidence of ancient shorelines collected in the bay can also be ascribed to OIsS 5c or to OIsS 5a, but it is not clear if they represent complex oscillations within a single stage (substages) or pauses of the same transgressive event. Other stages, such as the OIsS 5e, have shown to be composed by complex, secondary fluctuations of the paleo-sea level (Hearty & Kindler, 1995; Neumann & Hearty, 1996; Zazo, 1999).

Other important considerations have to be made about the altitude of the collected evidence. The top of the marine sands reach in fact 6 m a.s.l. and the upper limit of the burrows is located at 8.5 m a.s.l.; both these altitudes are too high, if compared to the paleo-eustatic level quoted for the OIsS 5a and 5c. In fact, even if no agreement has been achieved in the scientific literature about the relative altitude of the sea during these stands, the suggested values are always around or below the present day elevation. In particular, Ku *et al.* (1990) and Richards *et al.* (1994) affirmed that both during the OIsS 5c and 5a the sea level was much lower than the present one. In contrast, other Authors, stated that during the OIsS 5a the sea level was close to the present one both in extramediterranean (Hearty & Kindler, 1995; Ludwig *et al.*, 1996) and Mediterranean areas (Hearty, 1986). For this reason we hypothesise a tectonic uplift of this sector of the coast after the isotopic sub-stage 5a, although we have no elements for estimating the rates and values of this movement.

These considerations

made us prudent in correlating the other evidence of paleo-sea level stands collected along the coast of Mt. Bulgheria. However, the evidence collected at 4.5÷4 m a.s.l., which, in most cases, is associated with depositional sand bodies, could probably be correlated to the marine sands and conglomerates of the Cala degli Infreschi bay and ascribed to OIsS 5a.

The reconstruction could be complicated by the possibility of hydroisostatic rebounds for each highstand, as proposed in literature for the last highstand (OIS 1) (Fleming *et al.*, 1998; Lambeck & Bard, 2000). This model could probably explain the complex fluctuations we found in the *Infreschi* bay but in other sites along the campanian coast the evidence of OIsS 5c and 5a are located at different altitudes: 4 m a.s.l. and 1.5 m a.s.l. respectively along the Punta Licosa promontory (Iannace *et al.*, 2001); around 13 m a.s.l. in the Sele river plain (Brancaccio *et al.*, 1986) and around 2 m a.s.l. in the Sorrento Peninsula. (Riccio *et al.*, 2001), thus testifying the existence of recent tectonic activity along the campanian coast.

Tab. 3 - Stratigraphic correlation between the Infreschi cave and Riparo degli Infreschi cave
Correlazione stratigrafica tra la Grotta degli Infreschi ed il Riparo degli Infreschi.

Infreschi cave	Infreschi Riparo	Isotopic stages
Graviclastic breccia covered by paleosol with pyroclastic layer	Graviclastic breccia containing remains of Mousterian age (130 - 40 ka BP) covered by pyroclastic layer and flowstones (Sp2-RI 1, 50 ka BP)	
Marine conglomerates and sands (sands top at 6 m a.s.l.) that covered a bioconstruction with <i>Cladocora coespitosa</i> .	Marine conglomerates and sands that are covered by Sp2-RI 1 (>50 ka BP) and lay on a flowstone with <i>Lithophaga</i> burrows (Sp1-RI 4, RI 5 89 e 91 ka BP, OIS 5b). The sands reach an altitude of 6m a.s.l. and they also cover a notch at 3,5 m a.s.l.	OIS 5a
Notch at 3,5 m a.s.l.	Notch at + 3,5 m	
Bioconstruction with <i>Cladocora coespitosa</i>	<i>Lithophaga</i> burrows between 4/6 m < 89 e 91 ka BP	
	Flowstone (Sp1-RI 4, RI 5) 89 e 91 ka BP	OIS 5b
Wave-cut terrace at + 4,5m. a.s.l. Notch at + 8 m	Marine conglomerates covered by Sp1-RI 4, RI 5 sand cut by <i>Lithophaga</i> burrows	
Upper limit of <i>Lithophaga</i> burrows at + 8,5 m that cut the notch	Upper limit of <i>Lithophaga</i> burrows at 8,5 m a.s.l. that cut Sp1-RI 7 < 111 ka BP	OIS 5c
	Flowstone Sp1-RI 7 111 ka BP	OIS 5d

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