Mem. Descr. Carta Geol. d'It.
LII (1994), pp. 237-260

Emerged and submerged quaternary marine terraces of Palinuro Cape (southern Italy)

Terrazzi marini quaternari emersi e sommersi presso Capo Palinuro

ANTONIOLI F. (*), CINQUE A. (**), FERRANTI L. (**), ROMANO P. (**)

ABSTRACT – Palinuro Cape, located in the southern part of Cilento region, Tyrrhenian Sea, is a carbonatic promontory characterized by sheer cliffs and surrounded landward by more gentle hills where terrigenous deposits outcrop. Evidences of ancient quaternary sea-level stands are widespread at Palinuro Cape and have been studied both in the emerged belt and in the underwater one down to − 50 m b.s.l.

In the emerged sector, seven orders of stepped marine terraces have been distinguished. Upper five terraces, located at + 170/180, + 130/140, + 100, + 70, + 50 m a.s. l., respectively, are represented by wave-cut platforms with occasional remnents of the marine deposits originally covering it. Most of them cut both the Mesozoic carbonates of Palinuro Cape and the upper Pliocene-lower Pleistocene continental deposits of the Centola Formation. Said terraces can be traced laterally with a fairly good continuity from Palinuro Cape to the southern flank of the nearby M. Bulgheria, where they have been attributed to the middle Pleistocene by ASCIONE *et alii* (1995). They were formed during the last phase of generalized uplift which affected the Cape and surrounding regions, and accompanied to the entranchment of the Lambro river, cessation of hydrologic continuity between the larger M. Bulgheria acquifer and Palinuro Cape, and endokarst development in the latter area.

The lower two orders are found at + 7/3.5 and + 2.2/1.5 m a.s.l., respectively, and are represented by wave-cut platforms and notches to which marine and continental deposits are associated. Younger marine deposits are found up to + 2.5/3 m a. s. l., and are attributed to the isotopic stage 5 on the base of the epimerization value of *Glycimeris glycimeris* shells found within the deposits (BRANCACCIO *et alii*, 1990) and of the finding of rare and poorly preserved specimens of *Strombus bubonius*. Said deposits are onlapping above an older generation of marine deposits found up to + 8 m a. s.l., which are tentatively attributed to the stage 7 or 9 of oxygen isotopic curve. The elevation a. s.l. of latter deposits indicate that the Cape acquired a substantial tectonic stability at the middle-late pleistocene boundary, with only a weak generalized subsidence at the end of Quaternary as indicated by the elevation of stage 5 deposits.

Evidences of paleo-sea level stands in the underwater belt are grouped in 4 orders (at − 44/46, − 18/24, − 12/14, − 7/8 m b.s.l., respectively), which are particularly well preserved in several submerged karstic caves.

The recurrent and laterally continuous wave-cut platform and other minor marks at -18/24 m b.s.l. are referred to multiple oscillations of the eustatic sea-level during the late part of the isotopic stage 3, which in the Tyrrhenian sea reached similar depths (ALESSIO *et alii*, 1992).

The paleo-sea level at − 44/46 m b.s.l. is represented by a notch and loose pebbles without evidences of subaereal exposure, which are attributed to the eustatic rise following the isotopic stage 2. A short-lived sea-level stand has left notches and levelled mouth of caves at − 7/8 m b.s.l., which are referred to either substage 5.1 or 5.3 of the oxygen isotopic record. Abrasional platforms at − -12/14 m b.s.l. are preserved at the entrance of caves and display features of subaereal reincision; they are considered not younger than the last interglacial, since subsequent sea-level rises never reached so high.

KEY WORDS: marine terraces, Quaternary, coastal and underwater geomorphology, submerged karstic caves, Southern Italy.

RIASSUNTO – Nell'area di Capo Palinuro (Cilento, Italia meridionale) è stato effettuato uno studio geologico e geomorfologico finalizzato al riconoscimento delle tracce di antichi stazionamenti del livello del mare e degli effetti che essi, interagendo con l'attività tettonica, hanno prodotto sulla evoluzione quaternaria del paesaggio. I dati sono stati raccolti sia nel settore costiero emerso che sommerso; quest'ultimo è stato indagato sino alla profondità di 50 m per mezzo di immersioni con ARA effettuate sia lungo la falesia che nelle numerose cavità carsiche sommerse presenti all'interno del promontorio calcareo.

Nella fascia costiera emersa è stata individuata una successione di 7 ordini di terrazzi marini compresi fra 180 e 2 m s.l.m. Essi tagliano sia le rocce carbonatiche mesozoiche

(*) Department of Environment, ENEA Casaccia. Via Anguillarese 301, I-00060 Rome, Italy.
(**) Department of Scienze della Terra, Università di Napoli "Federico II" , Italy.

che costituiscono l'ossatura del Capo Palinuro sia le formazioni terrigene meso-cenozoiche che affiorano nell'area a nord del Capo. I primi cinque ordini di terrazzi (rispettivamente posti a 180/170, 140/130, 100, 75/65 e 50 metri s.l.m.) sono rappresentati da ripiani di abrasione marina che solo localmente conservano resti di una originaria copertura sedimentaria. Il sesto (8/7 m s.l.m.) ed il settimo ordine (3/2 m s.l.m.) sono invece rappresentati sia da forme di abrasione marina (piattaforme e solchi di battigia) scolpiti lungo le falesie carbonatiche del Capo Palinuro che da depositi marini, passanti a formazioni eoliche e a depositi di versante, affioranti lungo la costa compresa fra l'abitato di Palinuro e Torre Caprioli. Il rinvenimento di alcuni frammenti di *Strombus bubonius* nei depositi marini associati alla linea di riva più recente (7° ordine) conferma la sua attribuzione all'Eutirreniano proposta da BRANCACCIO *et alii* (1990) in base a misure di racemizzazione eseguite su gusci di *Glycimeris glycimeris* rinvenuti nel medesimo livello fossilifero. I rapporti morfostratigrafici fra i depositi e le forme di erosione marina eutirreniani ed i depositi e le forme marine del sesto ordine di terrazzi riconosciuto consente di proporre per quest'ultimo una correlazione con l'high stand del mare relativo allo Stadio Isotopico 7. I cinque ordini di terrazzi più antichi risultano, infine, limitati cronologicamente all'inizio del Plesitocene medio in base alla loro continuità fisica con un'analoga successione di linee di riva affiorante poco più a sud (lungo il versante meridionale del Monte Bulgheria) e ascritta dalla letteratura (ASCIONE *et alii*, 1995) al Pleistocene medio. La loro genesi è contemporanea all'ultima fase di uplift che interessa il Cilento meridionale in toto e si verifica in periodi in cui il ritmo di sollevamento tettonico è eguagliato da quello della risalita eustatica del mare e/o durante periodi di stasi nel sollevamento tettonico della terraferma. Detta fase di sollevamento cessa verso la fine del Pleistocene medio, come indica sia la quota dei depositi ascritti in via tentativa allo Stadio Isotopico 7 o 9 (+7/8 m s.l.m.) sia correlazioni con l'area sud-cilentana. La quota di affioramento della linea di riva eutirreniana (+2/3 m s.l.m.) indica, viceversa, un ribassamento, seppure minimo, dell'area realizzatosi alla fine del Quaternario.

Le evidenze geomorfologiche relative a paleostazionamenti rinvenute nel settore sommerso dell'area studiata sono rappresentate principalmente da terrazzi di abrasione marina affioranti lungo la falesia, che spesso penetrano all'interno delle cavità carsiche fossili spianandone il fondo. Altre evidenze sono rappresentate da solchi di battigia e più raramente da conglomerati marini forati da organismi litofagi. Esse sono complessivamente raggruppabili in 4 ordini principali ubicati alle profondità di −44/46, −18/24, −12/14 e −7/8 m.

Le tracce delle linee di riva rinvenute tra −12/14 e −7/8 metri sotto il livello del mare sembrerebbero da ritenersi circa coeve, se non più antiche, dell'ultimo Interglaciale. Esse, infatti, mostrano indizi di rielaborazione in ambiente subaereo avvenute durante una fase regressiva del mare che, per le quote alle quali esse si rinvengono, non può che essersi realizzata poco prima o poco dopo il massimo trasgressivo dell'inizio del Pleistocene superiore, sicuramente non in tempi più recenti, durante i quali il mare ha stazionato a profondità maggiori. Tuttavia, il paleostazionamento rappresentato dai solchi e dalle piattaforme di abrasione situati tra −7/8 metri di profondità può essere tentativamente ascritto ad uno degli stazionamenti minori del livello del mare occorsi durante lo Stadio Isotopico 5 (sub-stadio 5.1) in base alla differenza di quota che esso presenta con i solchi e le piattaforme di abrasione eutirreniani affioranti fra +1,5/2 metri s.l.m. Di più sicura attribuzione cronologica risultano i due paleostazionamenti più profondi. Il terrazzo situato tra −18/24 metri può essere attribuito alla parte finale dello Stadio Isotopico 3 sulla base della correlazione altimetrica con le quote riportate nella curva delle oscillazioni del livello del mar Tirreno in ALESSIO *et alii* (1992). Le tracce di stazionamento del mare rinvenute alla profondità di −44/46 metri possono, infine, essere ascritte ad una sosta del mare occorsa durante l'ultima trasgressione marina post-glaciale, in base al loro buono stato di conservazione ed alla totale assenza di rimodellamento subaereo.

PAROLE CHIAVE: Antiche linee di riva, Quaternario, geomorfologia costiera e sommersa, cavità carsiche sommerse, Italia meridionale.

1. – INTRODUCTION

Palinuro Cape constitutes a minor east-west elongated promontory of the much wider headland of Cilento (Campania Region), with about two kilometres of lenght and a width that varies from 0.7 to 1.5 kilometres across. The promontory, formed by carbonate rocks, attains a maximum elevation of 203 metres a.s.l. and is bounded all round by high, sub-vertical sea-cliffs.

Many geomorphological and sedimentological evidences of Quaternary sea-level variations and the relative effects on the landscape morphoevolution are found in this area, where carbonate rocks provide a high preservation potential, which is enhanced by the substantial tectonic stability acquired at the onset of late Pleistocene. Moreover, a severe karstification affected the carbonate block creating even more conservative enviroments for the geomorphological record.

Notwithstanding such desirable conditions, detailed investigations in the submerged and even in the emerged belt of Palinuro Cape and surrounding areas are lacking. By integrating evidences from surface and underwater surveys the geomorphological evolution of the area is outlined in this paper, which results in a tentative chronological framework of ancient sea-level presently observed in both environments.

2. – GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

The Cilento is a short and wide, rectangular headland intervening between the Gulf of Salerno to the north-west and the Gulf of Policastro to the south-east. It corresponds to a morphostructural high with peaks as high as 1700 metres, that merges landward into the main carbonate relief of the Southern Apennines. Quaternary normal faults define both the frontal and lateral coasts of this headland (fig. 1).

Apart from the limited exceptions represented by the Palinuro Cape, the Mt. Bulgheria and few other outcrops, the mountains and hills of the Cilento headland are made of terrigenous rocks that

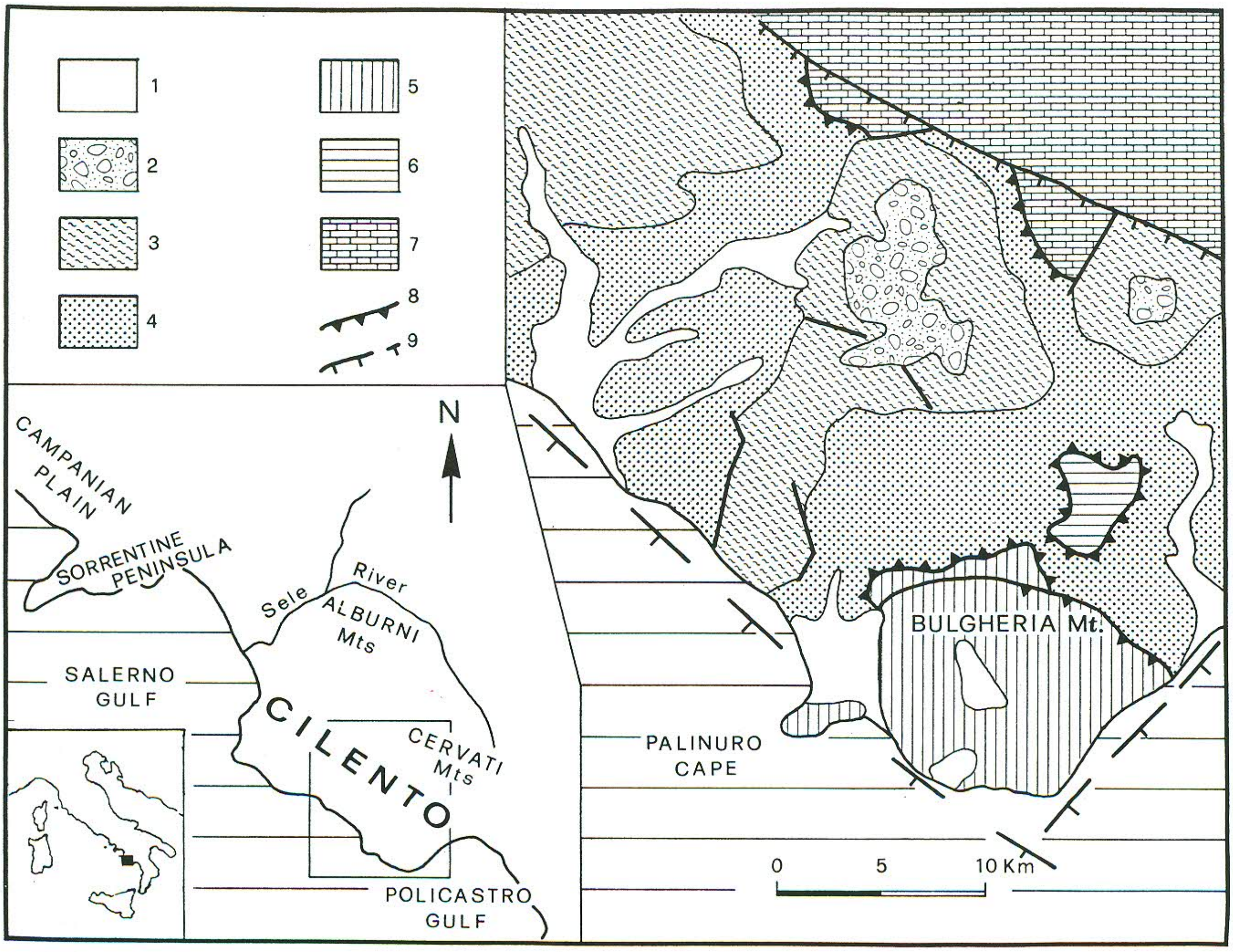

Fig 1 – Schematic Geological map of Southern Cilento. Post-orogenic formations: 1) Undifferentiated marine and continental formations (Pliocene-Quaternary). Main synorogenic formations (Cilento Group); 2) Monte Sacro Formation (Middle-Upper Miocene); 3) San Mauro and Pollica Formations. (Lower-Middle Miocene). Tectonic units of the thrust belt; 4) Nord-Calabrese Unit; 5) Monte Bulgheria Unit 6) Roccagloriosa Unit; 7) Alburno-Cervati Unit; 8) thrust; 9) main fault.

Carta geologica schematica del Cilento meridionale. Formazioni post-orogene: 1) Formazioni marine e continentali (Pliocene-Quaternario). Principali formazioni sin-orogene (Gruppo del Cilento); 2) Formazione di Monte Sacro (Miocene medio-superiore); 3) Formazioni di Pollica e S. Mauro (Miocene inferiore-medio). Unità tettoniche della catena; 4) Unità Nord-Calabresi; 5) Unità di Monte Bulgheria; 6) Unità di Roccagloriosa; 7) Unità Alburno-Cervati; 8) sovrascorrimenti; 9) faglie principali.

accumulated into deep marine basins from late Mesozoic to Miocene times. The oldest among these formations belong to the Nord Calabrese Unit (BONARDI *et alii*, 1988a), which is the highest structural unit in this sector of the Southern Apennines thrust belt. In the Cilento area, it is represented by a Malm-Oligocene succession of dark clay, shales and marly limestones, which attains a thickness of 1,000-1,300 metres. The Nord Calabrese unit is covered by early Miocene synorogenic rocks, which show a lesser degree of deformation than the underlying thrust assemblage. The Miocene flysch (known as Cilento Group) includes, from the base upward, the Pollica, the San Mauro and the Monte Sacro Formations, with a total thickness of 1,500 to 1,700 metres (BONARDI *et alii*, 1988a; GUERRERA *et alii*, 1993).

The mesozoic carbonatic sequences exposed at Palinuro Cape and in the Mount Bulgheria massif belong to a slope-to-basin paleosedimentary domain, and show different facies characteristics relative to the neritic carbonates which outcrop around the nord-east side of the Cilento area, in the Alburno-Cervati massifs (BONARDI *et alii*, 1988b).

During the Miocene, the Mt. Bulgheria Unit was overridden by the Nord Calabrese Unit and overlying Cilento Group. But nowaday the M. Bulgheria terrains are widely exposed and even prominent above the surrounding outcrops of their original cover. This inversion was mostly due to a later (late Miocene or early Pliocene in age) rise of Mt. Bulgheria - Palinuro Cape area and to the consequent fast denudation of the terrigenous units, which are much more erodible than the underlying carbonatic unit. The M.te Bulgheria uplift was accomodated by the northward folding of the carbonatic sequences (well visible along the northern escarpment of the massif) and by their thrusting above the Nord Calabrese unit on a south-dipping reverse fault, clearly exposed only along the souteastern border of Cilento (BONARDI *et alii*, 1988b).

Similarly to the whole inner sector of Southern Apennines, contractional tectonics was ceased also in the Cilento area by the end of Miocene or, at the latest, by the first part of Pliocene. Afterward, as thrusting migrated further to the east, the Cilento area became part of the inner portion of the chain, which was dominated by uplift and extension (DOGLIONI, 1991; CINQUE *et alii*, 1993; AMATO & CINQUE, 1995; FERRANTI *et alii*, 1995).

The formation and deepening of the already mentioned transversal depressions of Salerno and Policastro Gulf are included among the events that affected the inner sector of the chain after the end of contractional tectonics. During Pliocene and early Pleistocene times, a more generalised tectonic retreat of the Tyrrhenian coast of Southern Apennines took place. Morphostructural reshaping of this part of the tectonic belt was due to the collapse of coastal *tranches* along north-west trending normal faults which dip towards the Tyrrhenian Sea, like those ones that finally defined the present outline of the Cilento headland frontal coast (fig. 1).

As documented by the occurrence of raised marine terraces, the landmass of Cilento was subject to an uplift of up to four hundred metres that followed the just mentioned coastal truncations (i.e. during the late early Pleistocene and part of middle Pleistocene). Absolute estimates of uplift can be obtained by the vertical distribution of Pleistocene marine terraces along the Cilento coasts. In the northern Cilento area, the oldest marine terraces, middle Pleistocene in age, are found at a maximum elevation of 60 m a.s.l. (CINQUE *et alii*, 1994b). At M. Bulgheria (Southern Cilento), the upper Pliocene-lower Pleistocene marine terraces are uplifted at 450 m a.s.l., the Emilian ones are found at a maximum elevation of 350 m a.s.l. (CIAMPO, 1976; BAGGIONI *et alii*, 1981; LIPPMAN-PROVANSAL, 1987; BORRELLI *et alii*, 1988) and the middle Pleistocene ones starting from 200 m a.s.l. downward (ASCIONE *et alii*, 1995). On the contrary, the Eutyrrhenian paleo-sea level marks are found at a fairly constant eustatic elevation all along the Cilento coast (ROMANO, 1992), and document that the region had acquired a substantial tectonic stability at the end of middle Pleistocene.

In the area immediately north-west of Mt. Bulgheria and Palinuro carbonatic blocks large outcrops of a continental formation named Conglomerati di Centola (SGROSSO & CIAMPO, 1966; BAGGIONI, 1975; GUIDA *et alii*, 1979) are found. Between Palinuro and Centola villages, the base of the continental formation dips below the present sea-level (see enclosed Geological Map, Tab. 1). The lower half of its whole thickness (200 m) is represented by fluvial muddy, silty and sandy deposits, with subordinate conglomeratic lenses, while upwards it passes to fanglomerates that are dominated by very coarse debris flow facies, with rounded boulders of some cubic metres.

Since the Centola conglomerates seals the high-angle reverse faults that accomodated the late Miocene - early Pliocene uplift of the Mt. Bulgheria block, they are considered not older than the Pliocene (ASCIONE *et alii*, 1995). A much younger age (late Pliocene?) for the lower limit is suggested by the evidence that this formation accumulated when the block of Mt. Bulgheria had already been noticeably exhumed from beneath its original terrigenous cover. The upper chronological limit to the Centola formation is provided by middle Pleistocene terraces of the southern coastal slope of M. Bulgheria massif (ASCIONE *et alii*, 1995), which are perfectly correlated to the terraces which cut the Centola formation in the surroundings of Palinuro village.

3. – MIDDLE AND UPPER PLEISTOCENE EMERGED MARINE TERRACES OF PALINURO CAPE AREA

In the area including Palinuro Cape and its near hinterland (see tab. 1) several orders of ancient marine terraces and other palaeo-sea level marks occur between sea-level and about 180 metres a.s.l.. Although discontinous, such paleo sea-level marks cut at almost constant elevations through different stratigraphic units (Mt. Bulgheria Unit, Nord Calabrese Unit and Centola Formation) and different tectonic blocks. Each abrasional platform was modelled during pauses in the uplift and/or whenever the rate of uplift was equal to the rate of eustatic rise (CINQUE *et alii*, 1994a). Moreover, some morphological features of the marine terraces suggest that they could have had a polycyclic origin, each of them representing more than one period of relative sea level stability.

Our field investigations did not provide elements for absolute dating single episodes of sea-level stand. The terraces have been consequently ordered according to a relative chronology starting from the lowermost and youngest paleo sea-level at 2-3 m a. s.l., referred to the sea-level highstand which occurred during the Isotopic Stage 5 (BRANCACCIO *et alii*, 1990).

Notwithstanding the lack of absolute dating, it is also possible to establish a lower chronological limit for the modelling of the steeped terraces, based on morphostratigraphic correlation with the nearby M. Bulgheria massif. As mentioned before, a similar sequence of steeped marine terraces has been recognized on the southern flank of M. Bulgheria massif by ASCIONE *et alii* (1995), who refer them to the middle Pleistocene when last phase of generalized uplift of the region started to take place. Such terraces can be traced without lateral discontinuity for about 10 km all along the coast of southern Cilento between M. Bulgheria and Palinuro Cape (fig. 1), thus allowing to refer the marine terraces older than the Eutyrrhenian ones that we found in the our studied area to the middle Pleistocene.

3.1. – GEOMORPHOLOGICAL MARKS OF ANCIENT SEA-LEVEL

The highest and oldest order of marine terraces is represented by few, small and scattered abrasional surfaces that locally preserve sparse rounded cobbles as a residual of their original littoral cover. They occurr at 170/180 metrs a.s.l. near the summit of Palinuro Cape (fig. 2), on the north-south trending ridge that separates the Lambro river valley from the coast, and on the limestone reliefs of the western flank of M. Bulgheria, to the left of Mingardo river (tab. 1).

Presumably, only the peaks of westernmost blocks of the present Palinuro Cape (namely the Faro and Monte d'Oro blocks with elevation of up to 200 m a.s.l.) were exposed when the 170/180 m platforms were being modelled. The remaining portion of the ridge was, on the contrary, still buried under the Centola Formation and was reexhumed only during successive phases of uplift and dissection.

The first one of said phases ended up with the modelling of another series of marine abrasional forms, which are nowaday found at an elevation of 130/140 m a.s.l. on all blocks of Palinuro Cape (fig. 3) and on the coastal hills made of Centola Conglomerates. Remnants of the second order of abrasional terraces can be also found on the carbonatic reliefs to the left of Lambro river mouth (fig. 2); here the marine terrace is covered by a 15/20 m thick sequence of marine pebbles and silt (tab. 1).

Towards the end of the modelling of the 130/140 m a.s.l. platforms, the Lambro river started its entrenchment into the limestones of the Palinuro ridge. A canyon formed with a well developed meandering path, which documents the existence of a substantially flat topography in the area before the entranchment took place. Moreover, the depression that is nowaday found upstream of the dissected block had not yet appeared. Such observations indicate that the eastern part of Palinuro Cape structure was still buried and levelled by the Centola Conglomerates and presumably by an overlying cover of younger coastal alluvial deposits, whose small remnants outcrop on the 130/140 m a.s.l. marine terrace located southward of Centola village.

A third -probably short-lived- event of relative sea level stand is witnessed by weak evidences of coastal abrasion that occur at about 100 m a.s.l. on the promontory (tab. 1).

The fourth period of marine terracing is recorded by small abrasion platforms that occur at elevations of 65 to 75 m a.s.l. along the southern slope of Palinuro Cape and the western slope of the north-south trending ridge that separates the Lambro valley from the coast of Torre di Caprioli. Near Palinuro village, these terraces are locally associated with yellowish sands with cross-stratification related to eolian transport (fig. 4). In the slope behind Cala del Buon Dormire the sands attain a thickness of about 30 metres, while eastward of Palinuro village they mantle the slope up to an elevation of about 125 metres and mask higher and older abrasional forms cut into the calcareous substratum.

The fifth order of marine terraces is represented by few and small abrasion terraces which occur at about 50 m a.s.l. at Palinuro Cape. The best evidence of this order is visible on the southern flank of the promontory, immediately west of the Lambro River mouth (tab. 1).

The sixth and the seventh orders of marine terraces recognized in the area are well testified either by marine deposits, which outcrop near Palinuro village (see next section), and by notches and small wave-cut platforms, which are well preserved along the sea-cliff of Palinuro Cape and on the western

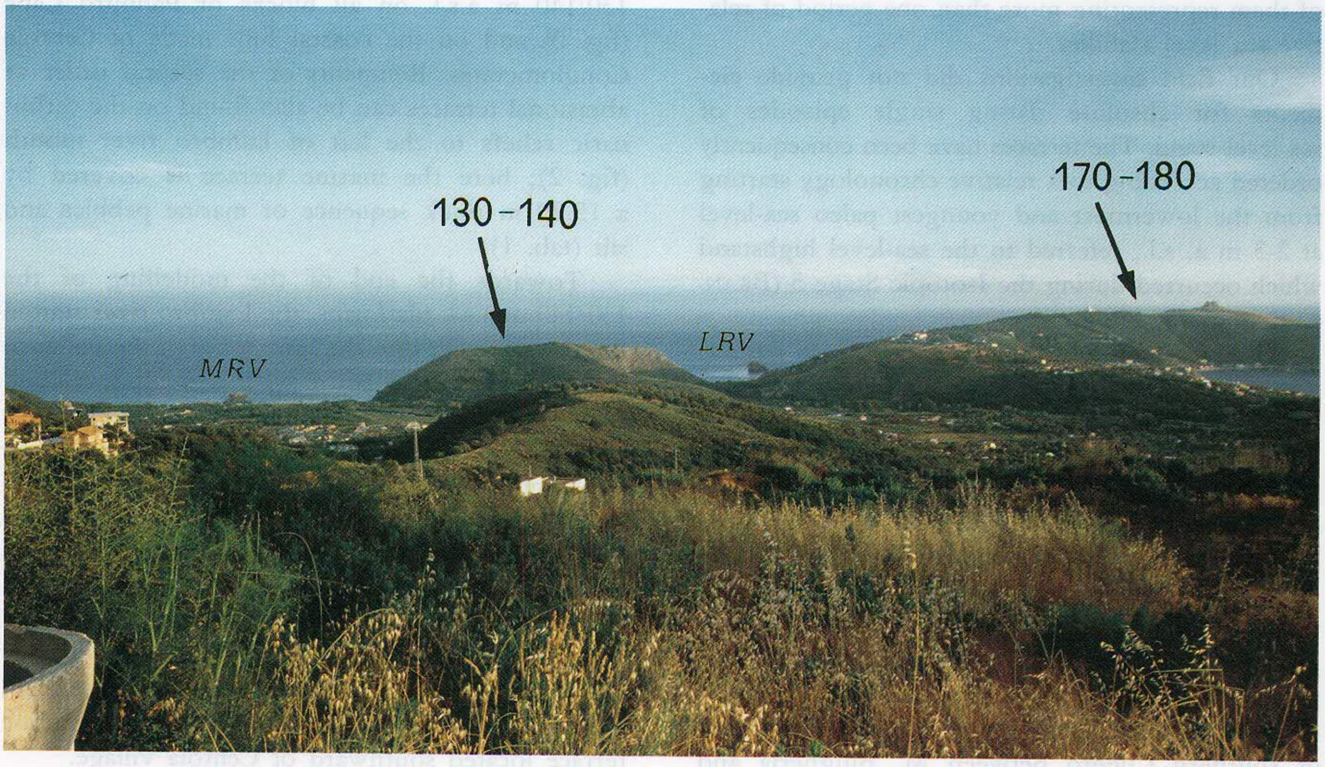

Fig. 2 – Panoramic view of Palinuro Cape area. The terraces at 180/170 (I order) and 130/140 (III order) m a. s.l. are indicated by the arrows. It is also shown the Lambro River valley (LRV) and the Mingardo River valley (MRV).
Panoramica dell'area di Capo Palinuro. Le frecce indicano il primo ed il terzo ordine di terrazzi marini, rispettivamente posti a 178/180 e 130/140 metri s.l.m. Sono inoltre visibili le valli dei fiumi Lambro (LRV) e Mingardo (MRV).

Fig. 3 – Foreground: 130 m a.s.l. marine terrace (III order) at Torre dell'Architiello, southern side of Palinuro Cape. Background: the coastal belt of M. Bulgheria, displaying the wide Paleosuperficie at 700 m a.s.l. and the underlying tectonic stair of Early Pleistocene marine terraces.
Terrazzo marino del III ordine (130/140 m s.l.m.) presso Torre dell'Architiello (versante meridionale di Capo Palinuro). Sullo sfondo è visibile il versante meridionale del Monte Bulgheria lungo il quale affiora la gradinata tettonica dei terrazzi marini del Plesitocene inferiore.

flank of M. Bulgheria. The spatial distribution of these paleo-sea level marks of abrasional origin appears largely controlled by lateral variations in the stability of the rocky walls, which is generally lower in the zones of denser fracturation. The fractures and the faults are mostly SSW-NNE trending and are often marked by small bays due to differential erosion.

The small abrasional platforms belong to two distinct groups, which occurr at elevations of about 5 to 3.5 metres and 2 to 1.5 metres a.s.l. respectively (tab. 1). The platforms of both the above groups are often veneered by well cemented beach conglomerates rich in big boulders (*sea-cliff base deposits*). The latter are in turn covered by breccias which represents the talus debris that accumulated at the cliff base during the sea-level falls.

Also the corrosion notches (tab. 1) can be grouped into two orders: the higher one -at about 7/8 m a.s.l.- is scarcerly present and not well preserved; the lower one occurs at 2.2 m a.s.l. and is more recurrent and well developed (fig. 5).

Both groups of marine abrasional morphologies (wave-cut platforms and notches) are nicely exposed in the northwestern (Grotta Azzurra inlet) and southeastern (Cala del Buon Dormire) side of Palinuro Cape, where their relative chronology can be fairly well established.

In the Grotta Azzurra inlet, the remnant of a coastal cave is filled with a strongly cemented marine conglomerate, formed by large-sized, rounded carbonate blocks, that outcrops up to 8 m a.s.l.. A massive carbonate talus breccia mantles the conglomerate, and is in turn cut by a notch at 2.2 m a.s.l. (fig. 6). The stratigraphic relationships between the sedimentary bodies and the marine abrasional marks indicate that during a period of relative sea-level stand following the deposition of the conglomerates, a regression occurred that allowed the deposition of talus breccia. A new marine trasgression followed which modelled the notch at 2.2 m a.s.l.

On the southern side of Cala del Buon Dormire (southeast side of Palinuro Cape) a notch at 2.1 m a.s.l. is associated with a large wave-cut platform at 1.5 m. a. s.l. In a rock shelter behind the terrace, a marine conglomerate is found up to 3 m a.s.l.

Fig. 4 – Cross-bedded eolian sands associated to the +70 m marine terrace (IV order). Southern side of Palinuro Cape.
Sabbie eoliche a stratificazione incrociata associate al terrazzo di abrasione marina ubicato a 70 m s.l.m. (IV ordine) sul versante meridionale di Capo Palinuro.

Fig. 5 – Corrosion notch at 2.2 m a.s.l. at Cala del Presepe, southern sea-cliff of Palinuro Cape.
Solco di battigia a 2.2 m s.l.m. presso Cala del Presepe (versante meridionale di Capo Palinuro).

The conglomerate is formed by well rounded and cemented carbonate elements with mollusc shells (*Glycimeris, Arca, Pecten*). A talus breccia with small clasts overlies the conglomerate, and both are covered by calcite concretions. *Lithophaga* holes affect the carbonate bedrock up to 7 m a.s.l. (fig. 7). In the central sector of the bay, two orders of small marine abrasional platforms are cut on a small projecting head at 1.5 and 3.5 m a.s.l.

Two different episodes of relative sea-level stands can be identified also in the latter outcrop. Earlier stand attained a relative elevation of 7/8 m a. s.l., as documented by the upper limit of *Lithophaga* holes in the bedrock. During or slightly before this stand, short wave-cut platforms were carved at 3.5 m a. s.l. and covered by a fossiliferous marine conglomerate. The following regression was accompained by the retreat of the projecting sea-cliffs and by the deposition of talus breccia above the littoral sediments. Similarly to the northwest sector of Palinuro Cape, a second transgressive episode is documented also in this area, which resulted in the modelling of a corrosion notch at 2.2 m a. s.l. and a small wave-cut platform at 1.5 m a.s.l.

To sum up, the sixth and seventh order of marine terracing and the episode of continental morphogenesis which occured in between are documented in several localities along the sea-cliffs of Palinuro Cape. The notches at 7/8 m a.s.l. and the platforms at 3.5/5 m a.s.l. can be related to minor oscillations during a single episode of relative highstand. A later relative sea-level high stand is responsible for the modelling of notches and wave-cut platforms which outcrop at 2.2 m and 1.5 m a.s.l., respectively.

3.2. – Quaternary deposits and their correlation with the geomorphological marks

In the northern coast of Palinuro area, the last two orders of paleo-sea levels (VI and VII orders) are better represented by deposits rather than by terraced landforms, because of the masking effect of the thick eolian sands that close up the sequence associated with this palaeo-shorelines.

The active cliff of Lido Ficocelle (near Palinuro village) offers a nice natural section across the sedi-

Fig. 6 – Schematic section of Grotta Azzurra inlet. 1) limestones; 2) marine conglomerates; 3) talus breccia; 4) corrosion notch.
Sezione schematica presso la cala della Grotta Azzurra. 1) calcari; 2) puddinghe marine; 3) brecce di versante; 4) solco di battigia.

mentary sequence associated with the VI order of marine terraces. The sequence (hereinafter referred to as Ficocella Unit) shows a lower marine portion (from the sea level to about 8 m a. s.l.) and an upper eolian one which is more than twenty metres thick and mantles the slopes behind up to 70 m a.s.l.. The total thickness of the Ficocella Unit can not be established, since its base lies below the sea-level and is covered by actual marine sands.

The lower two metres of the sequence are made of coarse grained, beach conglomerates that have a sandy matrix and are poorly stratified and slightly dipping toward the sea (interval A of fig. 8). The larger boulders are up to a couple of metres across and come from different formations of the Miocene Cilento Group. Since no river could have carried the boulders down to this outcrop from the far Cilento mountains where the Cilento formations are exposed, and the Lambro river had already assumed its present course when the Ficocella Unit deposited, we believe that they were extracted from a near outcrop of the Centola Conglomerates into which the sea cliff of the time was cut. This palaeo-sea cliff cannot be seen today because it is covered by the same beach and eolian deposits of the Ficocella Unit. However, some other residual outcrops of Centola Conglomerates are still present in the vicinity (see enclosed Geologic Map and section in tab. 1).

The top of the basal conglomerates of Ficocella Unit is cut by an abrasional surface that witnesses a regression of the sea level long enough to allow the cementation of the conglomerates. The remaining portion of the marine sequence was deposited during the following transgression. It is composed, from the base upward, of 1 to 2 metres of cross-laminated sands and conglomerates (interval B) followed by about 2.5 to 3 metres of planar sets of cross laminated sands (interval C), other 3 metres of sands with wedge shaped sets of parallel laminations (interval D) and a last meter of massive backshore sands that are rich in concretioned root tur-

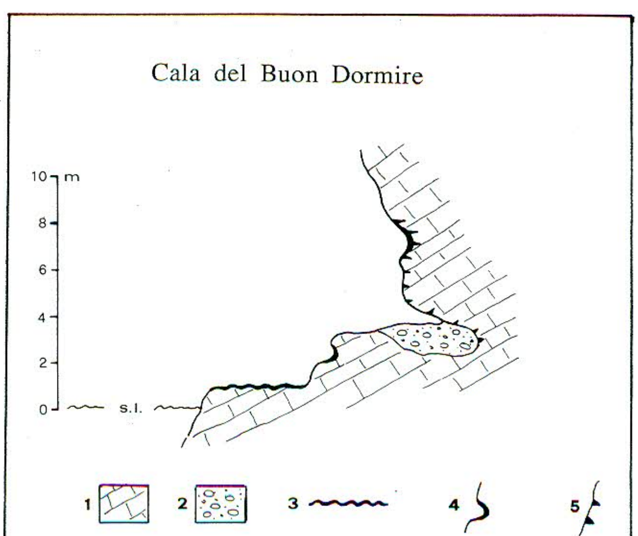

Fig. 7 – Schematic section of Cala del Buon Dormire. 1) limestones; 2) fossiliferous marine conglomerates; 3) wave-cut plataform; 4) corrosion notch; 5) Litophaga holes.
Sezione schematica presso la Cala del Buon Dormire. 1) calcari; 2) puddinghe marine fossilifere; 3) piattaforma di abrasione marina; 4) solco di battigia; 5) fori di Litodomi.

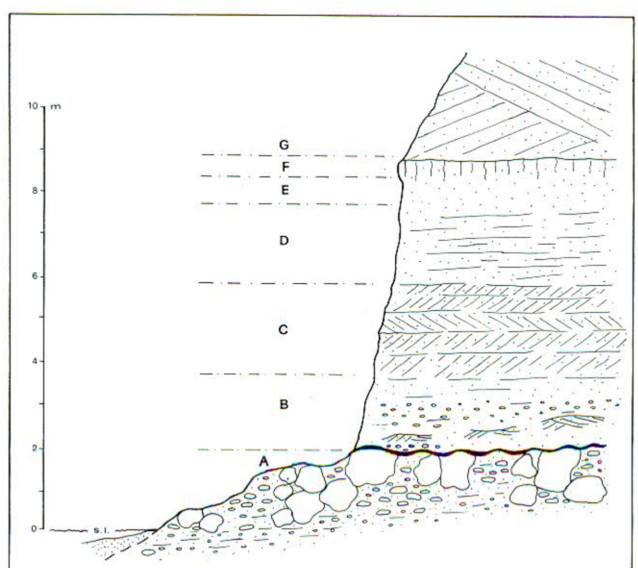

Fig. 8 – Type stratigraphic section of the Ficocella Unit. See the text for explanation.
Colonna stratigrafica tipo dell'Unità di Ficocelle. Per la spiegazione degli intervalli fare riferimento al testo.

Fig. 9 – Sea-cliff base deposits lying on a wave-cut platform carved into the carbonatic bedrock (eastern side of Palinuro harbour bay). The inner rim of the wave-cut plataform is 3.5 m a.s.l. high.
Depositi di piede di falesia in appoggio su una piattaforma di abrasione marina tagliata nel substrato carbonatico (versante orientale della baia del Porto di Palinuro). L'orlo interno della piattaforma di abrasione si trova alla quota di 3.5 m s.l.m.

bations (interval E). This transgressive-regressive portion of the sequence is topped by a brown paleosoil (interval F) which is in turn buried by a thick eolian complex (interval G). The eolianites are made of gray-yellowish sands with high-angle cross stratification and interveining brownish soils sometimes topped by a *caliche* up to one decimeter thick.

Downslope the east face of Palinuro bay, the Ficocelle Unit is represented by a marine conglomerate with large-sized, rounded carbonatic block which were supplied by the paleo-sea cliff behind. The conglomerate lies on a wave-cut platform carved in the carbonatic bedrock, whose inner rim is found at 3.5 m a. s.l. (fig. 9), and is in turn carved by a notch at 2 m a.s.l. To the west, the conglomerate grades either upwards and laterally to a few metres thick, thinly stratified calcarenite which is found up to 8 m a. s.l. and dips slightly seaward.

Notwithstanding tha lack of absolute datation, also the abrasional platforms and beach deposits at 3.5/5 m as well as the notches at 7/8 m a.s.l. found along the sea-cliff of Palinuro Cape (see previous section), can be considered coeval to the deposition of Ficocelle Unit. This attribution is based on the outcrop elevation and the relationships between the marine deposits and the abrasional morphologies observed on the eastern side of Palinuro harbour bay.

The Ficocelle unit can be tentatively related to the Stage 7 of the oxygen isotopic record (SHACKLETON & OPDYKE, 1973) on the base of the elevation a.s.l. and the relationships with the overlying deposits referred to the Last Interglacial transgression. The latter deposits are represented by a thin, cemented calcarenitic sequence (hereinafter called Eutyrrhenian Unit) that is well exposed along the coast between Palinuro and Caprioli up to a maximum elevation of 2.5/3 m a.s.l., and disappears under the actual beach sands after Torre Caprioli (tab. 1). The epimerization value of some fossil shells of *Glycimeris glycimeris* sampled in the calcarenites indicates that they belong to the Stage 5 of the oxygen isotopic record (BRANCACCIO *et alii*, 1990). This attribution is confirmed by the presence in the sediments of some shells of *Strombus bubonius*. Since the well cemented beach deposits of the Eutyrrhenian Unit form a resistent, wedge-shaped sedimentary body that reaches locally up to the base of the cliff that cuts the older Ficocelle Unit (fig.10), latter deposits had already been cut by a sea cliff during the eustatic transgression of the Last Interglacial

Four different intervals can be distinguished within the three metres thick Eutyrrhenian Unit. The lowest one (interval A of fig. 11) is a beach conglomerate with a sandy matrix and clasts derived from both the Centola Formation and the Ficocella Unit. This conglomerate is cut by an abrasional surface and covered by a few decimetres thick and discontinous organic limestone rich of algal concretions and with some *Cladocora coespitosa* corals in growth position (interval B). Also this interval is truncated by a smooth surface of marine abrasion that is followed by 1.5 to 2 metres of plane laminated sands gently dipping towards the sea (interval C, fig. 11). The basal decimetres of this last unit are sometimes very rich in fossils shells, particularly of *Glycimeris glycimeris* (fig. 12). It contains also the rare specimens of *Strombus bubonius* that confirm the Eutyrrhenian age of these deposits. The sequence continues upward with one of two metres of weakly cemented, massive sands of emerged shore environment, whose top part is rich in concretioned roots and whose elevation a.s.l. is not more than 2.5/3 metres (interval D in fig. 11).

The last (VII) order of abrasional paleo-sea level marks (notches and wave-cut platforms) recognized along the sea-cliff of the Palinuro Cape can be correlated to the Eutyrrhenian Unit. In fact, said marks are found at an elevation a. s.l. which is broadly comparable to the top of the Eutyrrhenian beach

Fig. 10 – Lido Ficocelle coastal section, showing the morpho-stratigraphic relationships between the cliff-forming Ficocelle Unit (FU, right), and the platform-forming Eutyrrhenian Unit (EU, left).

Località Lido Ficocelle. Sono ben visibili i rapporti morfostratigrafici fra l'Unità di Ficocelle (affiorante lungo la falesia costiera ed indicata con la sigla FU) ed i depositi marini dell'Unità Eutirreniana (EU), che si sovrappongono ai precedenti formando corpi tipo "chevron" resi evidenti dalla morfoselezione che insiste al contatto fra le due unità.

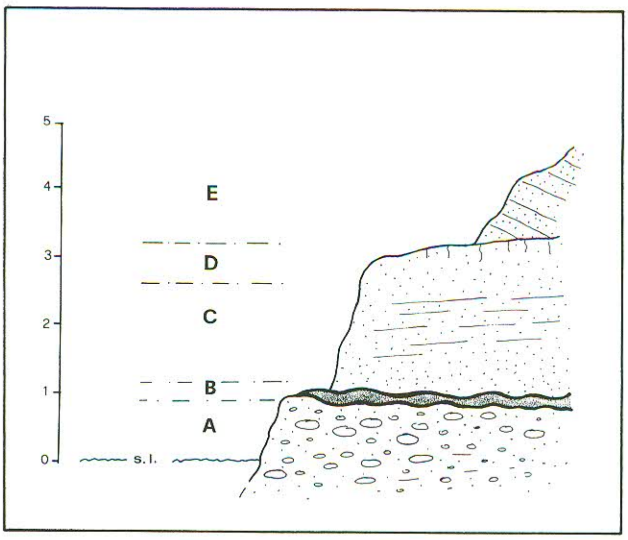

Fig. 11 – Type stratigraphic section of the Eutyrrhenian Unit. See text for explanation.
Colonna stratigrafica tipo dell'Unità Eutirreniana. Per la spiegazione degli intervalli fare riferimento al testo.

deposits (respectively 2.1 m a.s.l. for the notches, 1.5 m a.s.l. for the abrasion platforms and 2.5/3 m a.s.l. for the Eutyrrhenian beach deposits). Moreover they show the same chronological relationships with the Ficocelle unit, as documented on the eastern side of Palinuro harbour bay where a 2 m a.s.l. notches cuts the basal cliff conglomerates of the Ficocelle Unit.

Northward of Palinuro village, the marine Eutyrrhenian sequence is overlain by about 10 metres of eolian sands and by some tens of metres of slope deposits. The continental top of the Eutyrrhenian Unit is well exposed along the sides of many deep gullies which dissect the hillslope west of the ridge that separates the Lambro R. valley from the coast (fig. 13, tab. 1).

The eolian sands, which are grey in color and cross laminated, were probably accumulated during the regression that followed the Last Interglacial sea level maximum. They form dunes of moderate height (possibly lower than 10/15 m) near the coast

Fig. 12 – Detail of the Eutyrrhenian Unit. Thick line indicate the erosional contact between the Cladocora-bearing algal concretion (interval B in fig. 11) and overlying fossiliferous level (interval C in fig.11).
Dettaglio dell'Unità Eutirreniana, dove è visibile il contatto erosivo (evidenziato con la linea spessa) tra la biocostruzione contente cespi di Cladocora coespitosa (intervallo B nella fig.11) e la sovrastante calcarenite fossilifera (intervallo C nella fig.11).

Fig. 13 – Alternance of alluvial and colluvial deposits overlying the Eutyrrhenain Unit, affected by intense gully erosion.
Alternanze di alluvioni e colluvioni poggianti sui depositi eolici e marini dell'Unità Eutirreniana.

and thick veneers on the sea-facing hillside. The base of the dunar sands is exposed on the road cut (fig. 14). They rest on reddish, loamy sands with sparse pebbles, which can be interpreted as the colluviated and weathered top of the Ficocella Unit. Their top is weathered into a brown soil and covered by thinly laminated clayey silts which represent the infilling of a small inter-dune or back-dune lacustrine basin. The soil at the top of the dune and the lack of coarse materials in the infilling of the basin witness a period of coastal hillslopes stability.

The sequence continues upwards with crudely stratified light-yellowish colluvial and alluvial deposits. Their abundant matrix derives partly from the erosion of the Centola Conglomerates (which is exposed on the upper reach of the hillslope) and partly from the reworking of the eolian sediment that had veneered the same hillslope during the post-Eutyrrhenian regression. These deposits witness the onset of a phase of accelerated soil erosion on the hillslope that was probably due to the disappearance of the woody vegetation during a peak of the Last Glacial (Stage 4?). Afterwards, the concave basal bevel that had been previously created by the light-yellowish deposits underwent a severe linear erosion by big gullies, later filled almost completely by a new series of colluvial deposits (fig. 14) which can be distinguished from the older ones based on their reddish colour. The younger colluvial unit is generally characterised by a steeper stratification and contains a pyroclastic layer (up to half a meter thick) that has been referred to the about 35 ky old Ignimbrite Campana Auct. by LIRER *et alii* (1967).

In conclusion, the area around Palinuro retains good evidence of at least seven different generations of paleo-sea level marks. They all formed after the end of the latest relevant phase of block-faulting which affected the region, and all but the last one (Eutyrrhenian in age) have been tectonically raised.

Only the youngest order of marks can be safely traced to the Last Interglacial on the base of the fossil content and epimerization value. Its maximum elevation is of some 3/4 m lower than the eustatic elevation (MOORE, 1982) therefore indicating a weak subsidence of the Palinuro Cape block during late Quaternary.

The older orders of marine terraces are supposed to represent different moments of Middle Pleistocene (and possibly of the end of Early Pleistoce-

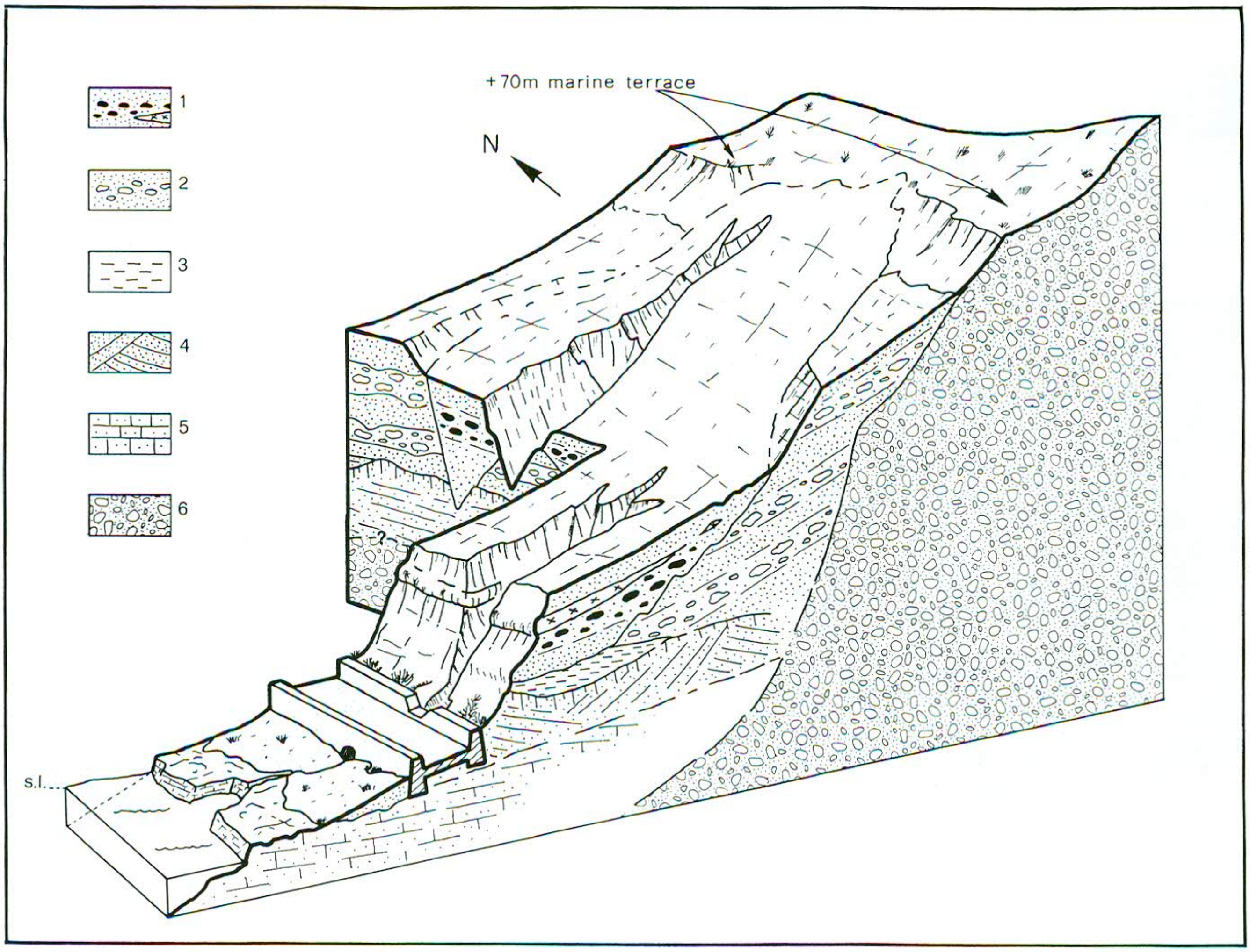

Fig. 14 – Block-diagram scheme of the Le Saline outcrop, showing the relationships between the Eutyrrhenian Unit, the regressive eolianites and overlying two generations of colluvial and alluvial deposits. 1) second generation of slope deposits with an interbebbed pyroclastic layer; 2) first generation of slope deposits; 3) laminated clayey silts; 4) cross laminated aeolian sands; 5) marine deposits of the Eutyrrhenian Unit; 6) conglomerates of the Centola Formation.

Block-diagram illustrante i rapporti fra l'Unità Eutirreniana ed i sovrastanti depositi eolici e di versante del Pleistocene superiore - Olocene. 1) seconda generazione di depositi di versante (alternanze di alluvioni e colluvioni con intercalato il livello piroclastico correlato all'Ignimbrite Campana in LIRER *et alii, 1967); 2) prima generazione di depositi di versante (alternanze di alluvioni e colluvioni); 3) argille siltose laminate; 4) sabbie eoliche a stratificazione incrociata; 5) depositi marini dell'Unità Eutirreniana; 6) Formazione di Centola.*

ne) coastal morphogenesis as documented by the correlation of said orders with similar paleo sea-level marks found in the nearby area of M. Bulgheria massif and attributed to the Middle Pleistocene (ASCIONE *et alii*, 1995).

4. – MIDDLE AND UPPER PLEISTOCENE SUBMERGED PALEO-SEA LEVEL MARKS

The steep coastal cliffs of Palinuro Cape extend also in the underwater belt down to depths of 50 m b. s.l. Steeper coastal profiles are found on the western side of the promontory, while the northern and southern ones are partly covered with sediments supplied by northward longshore currents and by the Lambro river, respectively. At depth greater than 50 m, the paleomorphologies are everywhere hidden under the recent sedimentary prism of the continental platform.

The Cilento platform stretches NW-SE parallel to the coastline, and in Palinuro Cape area the shelf break is less than 10 km offshore. South of Palinuro Cape and offshore Punta Licosa, NW Cilento, the pre-Holocene basement is at places exposed at the sea-bottom (BONIFACIO *et alii*, 1994), and shows an irregular top related to subaerial erosion during late Quaternary negative sea-level stands.

Our observations on the submerged paleo-sea level marks have been carried out along several sections across the Palinuro cliff down to about 50 m b. s.l. Some of the sections intersect caves where we concentrated most invstigations. In fact, the underwater caves represent an ideal natural laboratory to investigate the effects of sea-level variations at Palinuro Cape, since they have better preserved evidences of paleo-sea level stands (such as notches, beaches, submerged speleothems with marine overgrowth) due to the lower marine energy produced inside them.

4.1. – Some remarks on the karst of Palinuro Cape

Notwithstanding its small areal extent, the endokarst phenomena are well developed at Palinuro Cape. At present, about 50 subaerial (Muscio & Sello, 1993) and more than 30 submerged caves (Alvisi *et alii*, 1994; Ferranti & Antonioli, in press) are known.

Caves were formed generally in the continental enviroment by karst processes, but many of them experienced subsequent submersion and emersion. During sea-level stands, reshaping of cave entrance occurred mostly at the coastline where both marine abrasion and mixing of fresh-/ and sea-water are able to enlarge former karst morphologies.

Neither ponors nor springs of some importance are known at Palinuro Cape, and the present circulation is best concealed with a dense network of little fractures. Different waters ‹cold and "warm" (about 27°) fresh-water, and sulphureous waters› are found within the first metres depth, and are thought to have different sources and circuits (Muscio & Sello, 1993). Warm and sulphureous waters have been related to the activity of Pliocene-Quaternary volcanic centers located less than 100 km offshore Palinuro, and are considered as the main cause of cave formation in this area (Alvisi *et alii*, 1994). However, we believe that sulphureous waters alone are not able to justify the dimension and morphology of most caves, which are best referred to "normal" karst processes. Sulphureous waters require preexisting open spaces to be active and can cause locally important but second-order effects on speleogenesis.

Two main groups have been distinguished among submarine caves on the base of morphology, depth and effects of secondary marine processes (Ferranti & Antonioli, in press).

First group includes relatively short galleries which lead to subcircular rooms, and are globally distributed within the first 20 m depth. In many cases galleries display a triangular or trapezoidal section, that is related to later marine abrasion. Rounded morphologies of rooms and anastomosing channels departing from the central room can be related to water mixing with increasing dissolution effects ("mixing hyperkarst", Forti, 1991). The narrow dimensions of most entrance tunnels indicate that they could have been very close to their natural emergence, and suggest that they could have been formed when the promontory had grossly acquired its present configuration. Consequently, this speleogenetic phase can be tentatively considered not older than Middle Pleistocene, i.e. after last episodes of block-faulting which affected the area. Consequently, resheping of the related endokarstic forms occurred during the last glacial-interglacial cycle.

Second group of caves includes larger systems of galleries and rooms with longitudinal dimensions of some hundreds of metres and vertical relief of several tens of metres. The concourse of karst and hyperkarst dissolution, fresh-water erosion, marine abrasion and biocorrosion is at places very complex, as in the case of the Grotta Azzurra and Grotta Sulfurea di Cala Fetente. These caves are concentrated in the W/SW side of Palinuro Cape where a transition from vertical shafts to subhorizontal galleries is observed between – 45 and – 60 m depth. The wideness and areal extent of horizontal segments, that might have formed at the vadose-phreatic boundary, suggest the existence of an ancient groundwater level at quoted depths. Dimensions and morphologies of such caves are best related to hydrological conditions characterized by a greater water supply than what can be provided by the present Palinuro Cape block, which is nowadays isolated from the most relevant carbonate aquifer of Mt. Bulgheria (Guida *et alii*, 1979). The paleophysiographic connection between Palinuro Cape and the larger Mt. Bulgheria massif was truncated by the downcutting of the Mingardo and Lambro gorges during regressions that followed the modelling of the +130/140 m marine terrace. The creation and deepening of the karst system in object could be ascribed to lowstands occurring when the above mentioned marine terrace had already been uplifted of some tens of metres, and the river gorges had not yet attained a great depth. Consequently, the deeper karst system would be referred to th earlier part of Middle Pleistocene.

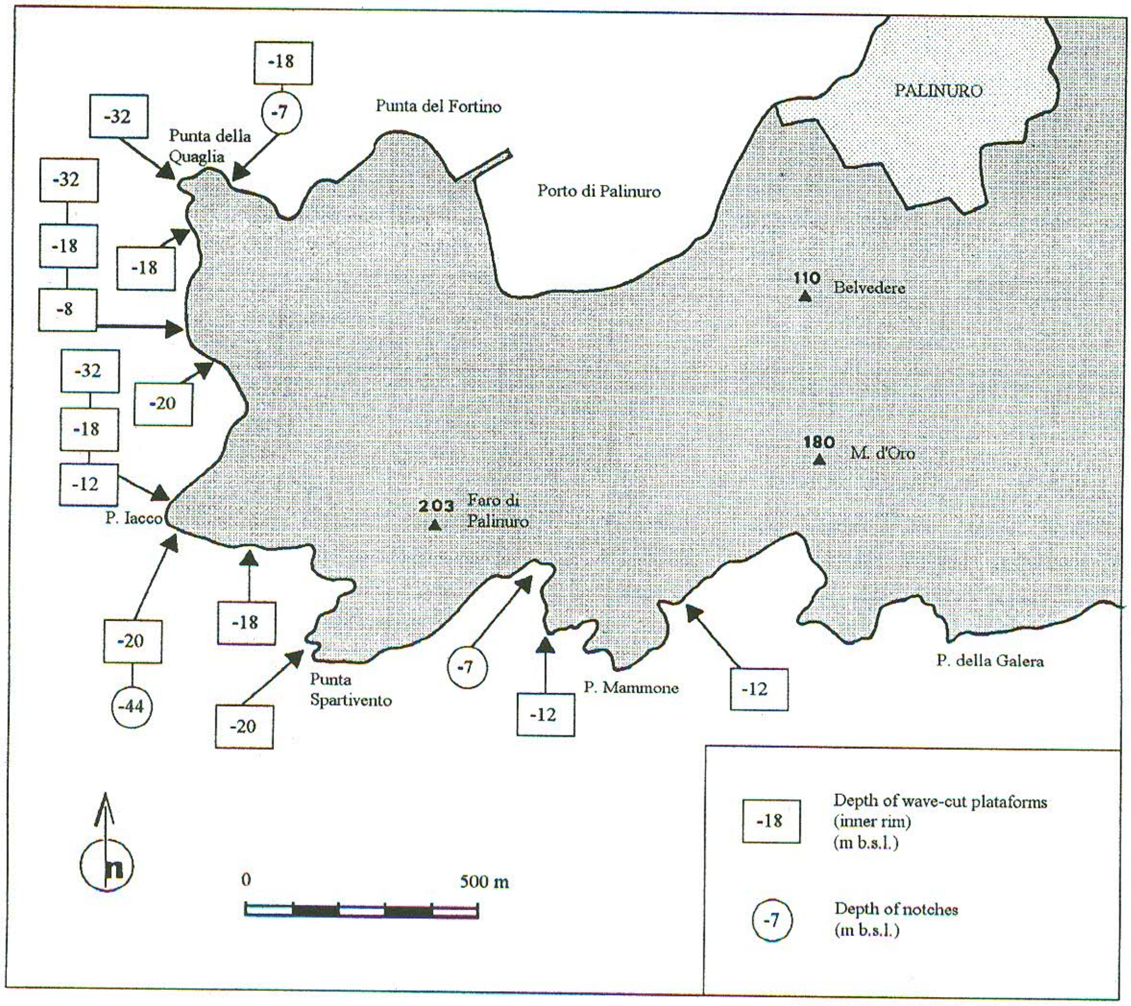

Fig. 15 – Location and depth of the submerged paleo-sea level marks at Palinuro Cape.
Ubicazione e profondità delle evidenze morfologiche di paleostazionamenti marini rinvenute al di sotto del livello del mare lungo la falesia e le grotte sommerse del Capo Palinuro.

However, we can not exclude that said karstification is much older, i.e. predates the last significant phase of blockfaulting, which occurred between the late Early Pleistocene and the early Middle Pleistocene.

4.2. – Geomorphological marks of ancient sea-levels

The geomorphological features of selected underwater profiles and caves are described in this section starting counterclockwise from Palinuro harbour (see fig. 15 for location and depth of recognized paleo-sea level marks).

In the Punta della Quaglia sector many paleo-sea levels can be evidenced within the Grotta Azzurra, which is formed by a complex system of galleries and a submerged central room with two large entrances averaging dimensions of 25x25 m, as well as on the outside cliff (fig. 16). Said evidences are represented by the levelled floor of the entrances at two different depths (respectively –18/20 and –32/33 m b.s.l.), to which accompany sea-enlarged vaulted roof. A notch is associated to the levelled bottom of the shallower entrance. At a shallower depth, a subcircular horizontal conduit and a notch are found respectively at –5/9 m and –8 m b.s.l.

The Grotta Azzurra formed in a vadose/phreatic environment during multiple karstification stages related to progressively deepening base levels. Subsequent episodes of marine ingression reshaped the deeper entrances, and modelled terraced bottoms presently found at – 18/20 and – 32/33 m depth.

The shallower levelled floor correlates to the flat top of a submerged butte found at about – 20 m b.s.l. few tens of metres eastward of the entrance (fig. 16).

A 5-8 m large terrace at – 18 m b.s.l. stretches more than 50 m along the submerged cliff south of Punta della Quaglia (fig. 15), and can be traced also near the Grotta della Cattedrale 2 where it is connected to the deeper entrance of this cave. Also a less well preserved terraced bottom is found outside the deeper entrance of said cave at about – 30 m depth.

To the south, close to Punta Iacco, the Scaletta-Punta Iacco cave system is found, which consists of 60 m high vertical shafts and deep networks of meandering galleries formed through the progressive mixing of individual fusoids (fig. 17). In this sector, marine abrasion has formed terraces presently found at – 12 and – 18/20 m depth. The latter terrace is particularly well developed outside the Grotta delle Corvine (fig. 18), where it is associated to pot-holes and to a notch. At a greater depth, a notch (fig. 19a) and loose rounded pebbles (fig. 19b) are found respectively on the wall and on the floor of the Grotta di Punta Iacco entrance (– 44/46 m b. s.l.), which is located at the edge of a steep cliff. The position of the pebbles and the presence of *lithophaga* holes affecting them suggest that they were deposited and rounded *in situ*, during a sea-level stand at relative depth.

In the sector between Capo Spartivento and Punta Mammone the underwater cliff is interrupted by a recurrent marine terrace between – 18 and – 22 m b. s.l., which is characterized by a width of nearly 15 m The inner rim of the terrace is well preserved at a costant depth of – 18 m b. s.l., while it is more irregular between – 18 and – 22/24 m, toward the terrace edge. This indicate a polycyclic origin of the terrace, which could be linked to minor oscillations of the sea-level stand during which the terrace was cut. During subsequent sea-level falls, the terrace has suffered subaereal linear erosion, as documented by metre-large gullies incised on the terrace and on the cliff behind. The terrace found on the cliff is connected to the flat top of submerged buttes few tens metres off, which lie at a broadly similar depth and were likely levelled during the same sea-level stands. Both the cliffs and the buttes have the toe between – 40 and – 50 m depth, where they merge into the offshore sedimentary prism.

At Cala Fetente, hyperkarst processes developed along major NNE-SSW trending tectonic lines have led to the enlargment of caves hosting relevant sulphureous springs (Grotta Sulfurea, Grotta del Lago, Grotta Viola, etc.). To the east of Cala Fetente, the underwater belt does not display interesting erosional or depositional features related to ancient sea-level stands, since any of these features are buried under recent sands supplied by currents or by the Lambro river.

4.3. – Chronological order of paleo sea-levels

The correlation of geomorphological marks found at similar depth throughout the Palinuro Cape has allowed to distinguish a number of ancient sea-levels, which have been chronologically ordered on the ground of depth and other geomorphological observations. Most of the paleo sea-levels have been attributed, with a variable degree of confidence, to well defined episodes of sea-level stand. The attribution criteria are discussed in the following, starting from the youngest paleo sea-level.

Evidences of a paleo-sea level at – 44/– 46 m b. s.l. have only been found at Punta Iacco, and are represented by a notch associated to *lithofaga-* bored pebbles preserved at the mouth of a cave. Our observations suggest that the site has never underwent subaereal exposition. In fact, if the site would have been crossed by a falling sea level, the increasing wave energy had certainly removed the loose pebbles from their very unstable position, and the deposit as well as its bedrock would have been affected by subaereal reworking and likely buried by continental deposits like calcite concretions or rockfall debris. Therefore we refer these evidence to a minor stand during the post-Stage 2 rise.

At depth greater than – 45 m, the submerged cliffs terminate beneath the recent offshore sediments. The sedimentary prism could insist on a major abrsion platform at imprecisable depth.

The most recurrent paleo-sea level in the underwater belt of Palinuro Cape is represented by a terrace found at – 18/– 24 m b. s.l. which forms a sharp break on the submerged cliffs. We suppose a polycyclic origin for the terrace, which is subhorizontal and well preserved close to the inner rim at – 18 m b. s.l., where it associates with notches and pot-holes, while it is gently inclined outward between – 22 and – 24 m, where it is karstified and cut by gullies.

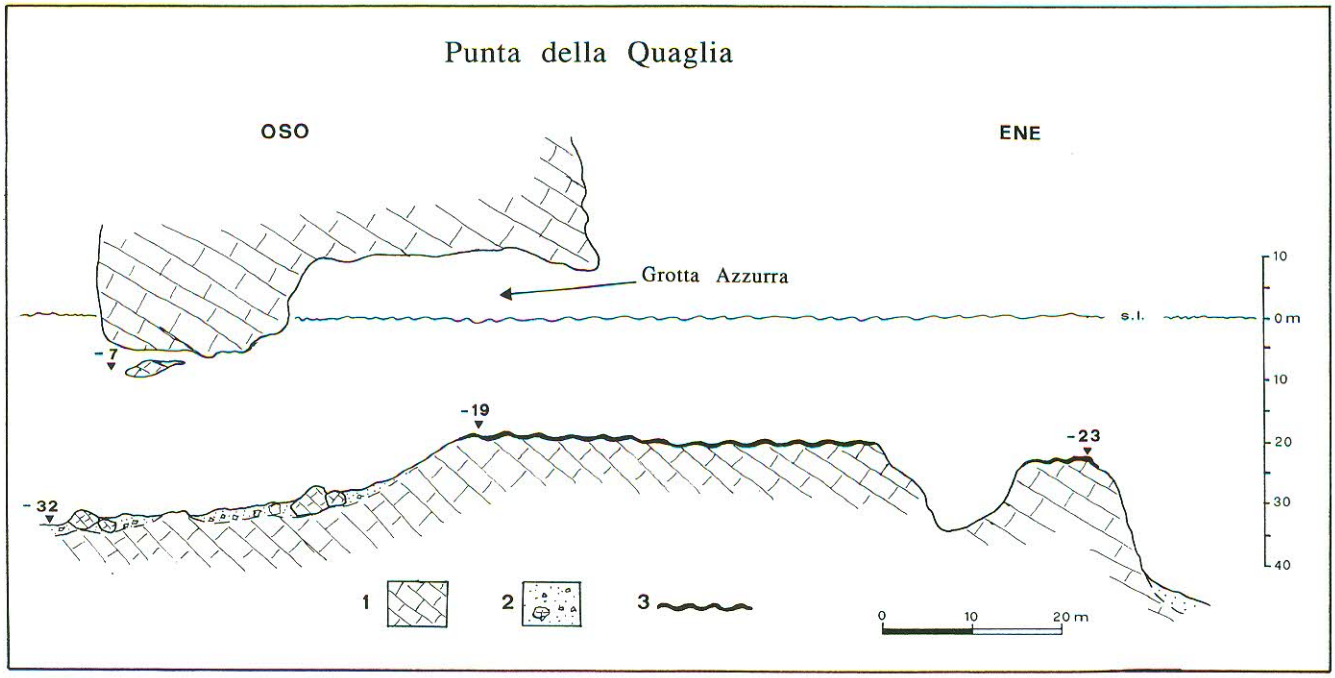

Fig. 16 – Schematic section of Punta della Quaglia submerged sea-cliff and caves. 1) limestones; 2) rock fall deposits and actual marine sands; 3) wave-cut platform.
Sezione schematica della falesia e delle cavità carsiche sommerse presso Punta della Quaglia. 1) calcari; 2) depositi da crollo e sabbie marine attuali; 3) piattaforma di abrasione marina.

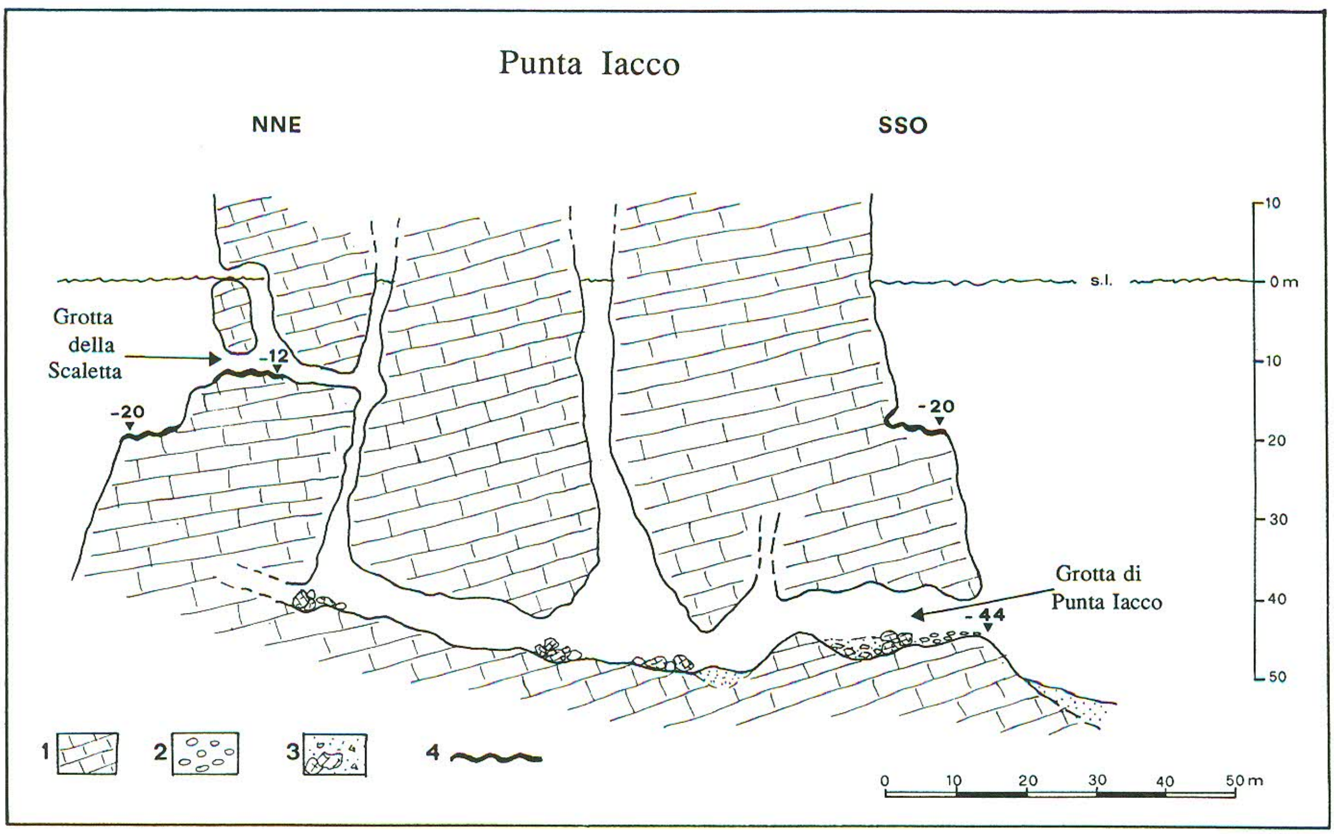

Fig. 17 – Schematic cross section of Punta Iacco submerged sea-cliff and caves. 1) limestones; 2) marine conglomerates; 3) rock fall deposits and actual marine sands; 4) wave-cut platform.
Sezione schematica della falesia e delle cavità carsiche sommerse presso Punta della Quaglia. 1) calcari; 2) puddinghe marine; 3) depositi da crollo e sabbie marine attuali; 4) piattaforma di abrasione marina.

Fig. 18 – Terrace at -18 near Corvine cave.
Terrazzo ubicato a -18 m nei pressi della grotta delle Corvine.

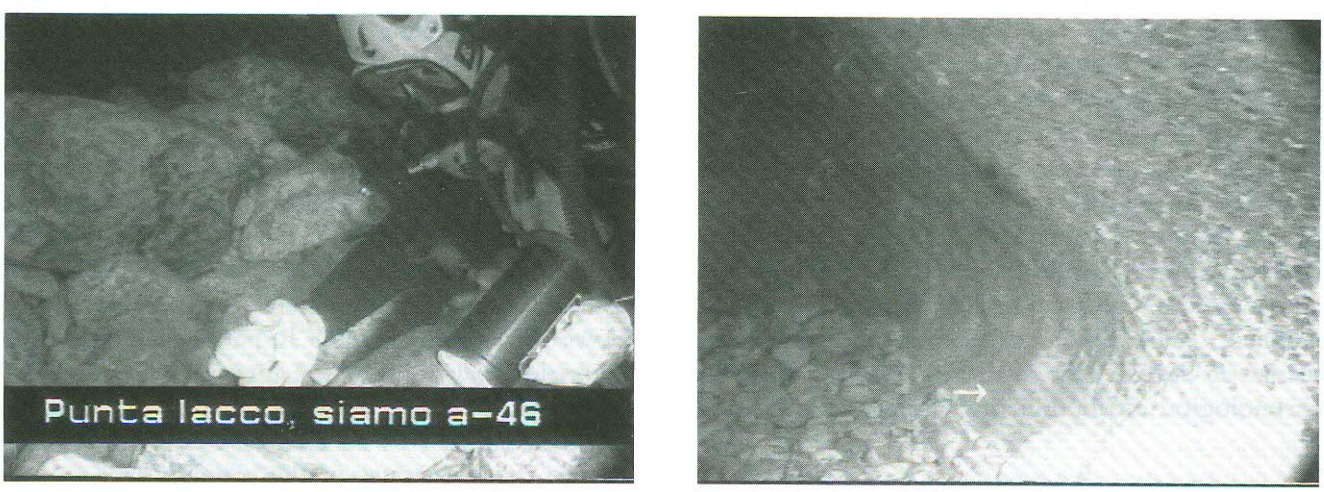

Fig. 19 – Corrosion notch and loose pebbles at -46 m b. s.l., Punta Iacco, which are attributed to the Versilian sea-level rise.
Solco di battente a -46 m b. s.l., associato ad una puddinga sciolta presso Punta Iacco, attribuito alla risalita del mare olocenica.

A paleo-sea level at similar depths has been described in several carbonatic areas within the Tyrrhenian coastal belt, such as Gaeta, Latium (ANTONIOLI & ROSSI, 1991), Argentario, Tuscany (ALESSIO *et alii*, 1992), Capri island, Campania (ANTONIOLI & FERRANTI, 1992), and Capo Zafferano, Sicily (ANTONIOLI *et alii*, 1994), where substantial tectonic stability was gained at the beginning of the late Pleistocene. The sea-level curve for the Tyrrhenian basin of ALESSIO *et alii*, (1992) indicates the occurrence of repeated relatively minor sea-level stands at −18/−21 m below the present sea-level at the end of the Stage 3. Therefore, the paleo sea-level in object is referred to the Stage 3 of the oxygen isotopic curve, in agreement with ANTONIOLI & FERRANTI, 1992, ANTONIOLI *et ali*, 1994.

The bottom of few caves (Grotta della Scaletta and Grotta Viola) is levelled by abrasion near their entrance, at −12/14 m b.s.l. A weak reincision by channelized water proves that said terraced bottoms underwent subaereal conditions during a subsequent sea-level fall, and constrains their formation before the Stage 2 of the oxygen isotopic curve. Moreover, they could be Eutyrrhenian or older, since during Stage 4 and 3 the sea level never reached so high.

Notches, wave-enlarged gallery-mouths, poorly levelled cave bottoms and large pot-holes are found at −7/8 m b. s.l. in some caves (Grotta Azzurra, Grotta del Sangue etc.). The difference in height with the notch found at about +2 m a.s.l. in the same area, which is referred to the stage 5.5 (see section 3.2), equals to about 10 m; such difference is broadly comparable to the one which exists between stages 5.1/5.3 and 5.5 in the sea-level curve of CHAPPEL & SHACKLETON, 1986. We tentatively assign the geomorphological marks at −7/8 m to either the 5.1 or the 5.3 substages.

Finally, we have poor evidences of a paleo-sea level few metres below −30 m b. s.l., represented by the bottom of some caves (Grotta Trombetta, Tunnel Azzurro, Grotta Azzurra) which is enlarged and levelled by marine abrasion, in particular in the entrance sector. Since no other geomorphological marks or deposits are available at this depth, no chronological attribution can be inferred.

5. – GEOMOPRHOLOGICAL EVOLUTION OF PALINURO CAPE FROM LAND AND SEA EVIDENCES

In this section we give a chronologically ordered synthesis of the main morphogenetic episodes that shaped the landscape of Palinuro area, integrating both on-land and underwater evidence.

In its essential lines, the relief of Palinuro Cape is a structural high formed by Mesozoic carbonatic rocks of the Mt. Bulgheria Unit. This morphostructure appeared to the surface during Upper Pliocene-Lower Pleistocene times, when erosion removed the thick terrigenous units (Nord Calabrese thrust sheet and Cilento Group flysch formations) that had buried the Mt. Bulgheria Unit during the Miocene.

In the Lower Pleistocene the carbonatic blocks forming the Cape were resting at an higher elevation than today. At that time the faults that nowaday separate the structure of the Capo from the massif of Mt. Bulgheria had not yet moved and, moreover, the deep gorge of the Mingardo River had not been cut yet. These circumstances allowed a hydrogeological continuity between Mt.Bulgheria and Palinuro Cape blocks, so as to permit a cospicous underground circulation of water in the rocks of Palinuro promontory where big karstic galleries were modelled (Grotta Scaletta and Grotta Punta Iacco).

During the last part of Early Pleistocene or, at the latest, at the beginning of Middle Pleistocene the area of Palinuro was affected by a last phase of block-faulting and subsidence. The carbonatic block forming the Cape went then completely submerged under the sea along with the overlying fluvial formation of the Centola Conglomerates.

During the Middle Pleistocene the area was uplifted again of at least 180 metres. Several orders of marine terraces were modelled during pauses in this uplift and/or whenever the rate of uplift was equaled by the rate of eustatic rise. The marine terraces of Palinuro Cape are groupable into at least six orders, respectively found at about 170, 130, 100, 75, 50 and 8 m a.s.l. (fig. 20).

The phases of fluvial dissection and denudation that alternated with the phases of marine modelling caused a progressive, new exhumation of the promontory blocks, wich had been previously covered by the Centola Conglomerates (Upper Pliocene or Lower Pleistocene in age). In particular, during the regression that followed the abrasion of the II order of marine terraces (+130/140 m terrace) the Lambro River entrenched its inherited meandering course into the limestones of the promontory.

During the late Middle Pleistocene the cape had substantially attained its present morphology and elevation. Beach sediments (Ficocella Unit) to be likely assigned to the Isotopic Stage 7 are indeed found at an elevation of few metres and mark an

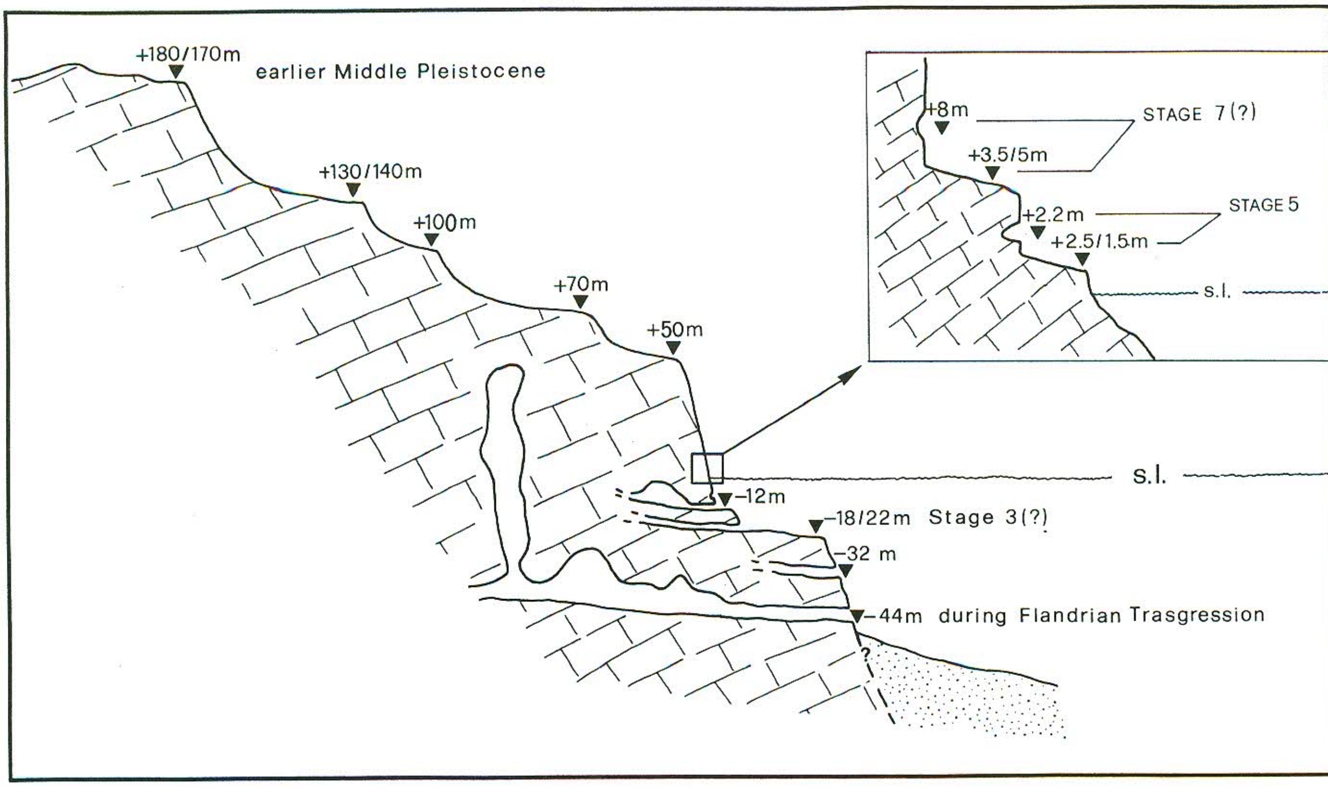

Fig. 20 – Schematic cross section summarizing the evidence of paleo-sea level stands recognized in the subaereal and submarine sectors of Palinuro Cape.
Sezione schematica che sintetizza le evidenze dei paleostazionamenti del livello del mare (per i quali dove possibile è stata indicata la presunta o certa attribuzione cronologica) rinvenuti nel settore emerso e sommerso del'area di Capo Palinuro.

ancient coast line that does not differ substantially from the present one. Also the plan outline of the Cape have not changed much since the late Middle Pleistocene as long portion of its modern sea cliff are marked by notches and abrasion platforms at +7/8 and +3.5 to +5 m respectively, that we tentatively attribute to the Isotopic Stage 7 or 9.

During the regressive phase that followed the deposition of the Ficocelle Unit beach sediments, thick dunal deposits accumulated near the coast and on the calcareous slopes of the promontory, up to an elevation of about 50 metres. Along the sea cliffs that bound Palinuro Cape, the same regression is witnessed by cemented breccias covering the abrasion forms at +3.5/5 m a.s.l.. These small outcrops of detrital material represent the remnants of the originally wider and thicker debris cones and talus that formed at the base of the sea cliffs during a period of cold climate (enhancing the physical degradation of the cliff) and low sea level (possibly related to the Stage 6 of the oxygen isotopic record).

During the glacial-eustatic trasgression of Stage 5 the waves dismantled the debris cones and cut new abrasion platforms (at +1.5 to +2 m a.s.l.) and notches (at +2.2 metres a.s.l.) at the base of the sea cliffs. On the coast between Lido Ficocelle and Caprioli the same transgression cut a sea cliff into the beach deposits of the Stage 7/9 and left at its base few metres of beach conglomerates and sands (Eutyrrhenian Unit) that reach up to 2.5 metres a.s.l.. We assume that both this beach complex and the abrasion/corrasion forms occurring between 1.5 and 2.2 metres belong to the first and highest peak of the Last Interglacial transgression (Sub-Stage 5.5) and that the marks eventually left by the other peaks of the same interglacial (Sub-Stages 5.3 and 5.1) are under the present sea level. The corrosion notch that occur at about 7 metres b.s.l. along the plunging sea cliff of Palinuro Cape is tentatively assigned to one of said minor peaks of Stage 5.

During the regression due to the Last Glacial cold period (that resulted in more than three km of coastline advance) the Eutyrrhenian beach deposits of Lido Ficocelle-Torre di Caprioli area went covered by thick eolian sands and colluvial deposits. At the base of Palinuro Cape sea cliffs new debris talus where formed that covered the platforms and notches of the sub-Stage 5.5.

The submerged marine terrace of – 18/22 metres (fig. 20) was probably abraded during one or more stands of Stage 3 and then dissected during a subsequent fall of the sea level (Stage 2).

The corrosion notch and the associate rounded pebbles found at −46 metres near Punta Iacco do probably represent a short-lived stand during the Post Glacial (or Flandrian) transgression.

We have no evidence of other sea level stands at shallower depths that could be referred to the Flandrian transgression (which was indeed too fast and lacked pauses long enough to leave erosional marks on hard rocks). However it is evident onshore that this trasgression has progressively dismantled the debris talus that covered the base of the coastal cliffs during the Last Glacial , thus allowing once again the re-activation of these hundred thousand years old coastal features.

Acnowledgments

This work has been supported by ENEA dep. of Environmental; grants MURST 60%, 1993-94 awarded to A. Cinque.; L. Ferranti acknowledges support from Geomare-sud CNR; we thank you Luigi Ghelia and the Diving Center "Il Pesciolino sub" for the assistance.

REFERENCES

Alessio M., Allegri F., Antonioli F., Belluomini G., Ferranti L., Improta S., Manfra L. & Proposito A. (1992) - *Risultati preliminari relativi alla datazione di speleotemi sommersi nelle fasce costiere del Tirreno centrale.* Giornale di Geologia, ser. 3, **54** (2): 165-193.

Alvisi M., Barbieri F., Bruni R., Cinelli F., Colantoni P., Grandi G. & Maltoni P. (1990) - *Le Grotte Marine di Capo Palinuro.* Mem. Ist. It. Speleologia, **6**, ser. 2, 143-181.

Amato A. & Cinque A. (1995) - *The evolution of erosional landsurfaces in the Southern Apennine chain and its geodynamic implication.* Tectonophysics (in press).

Antonioli F. & Ferranti L. (1992) - *Evidenze geomorfologiche sommerse relative ad oscillazioni del livello del mare: l'esempio di capri (Grotta Azzurra e Grotta di Tragara).* Boll. Soc. Geogr. It., Proceedings of the 26 Congr. Geogr. It. (in press).

Antonioli F. & Rossi L. (1991) - *Geomorfologia subacquea e costiera del litorale compreso tra Punta Styendardo e Torre S. Agostino (Gaeta). Un esempio di collaborazione tra informatica e geologia.* ENEA, internal report, pp. 51

Antonioli F., Belluomini G., Ferranti L., Improta S. & Reitano G. (1994) - *Il sito preistorico dell'Arco Naturale di Capo Zafferano (Sicilia). Aspetti geomorfologici e relazioni con le variazioni del livello marino olocenico.* Il Quaternario, **7** (1): 109-118

Ascione A., Cinque A. & Romano P. (1995) - *Movimenti verticali al margine tirrenico dell'Appennino meridionale: nuovi dati dal Monte Bulgheria (Cilento, Campania). Conv. Scient.: «Geodinamica e tettonica attiva del sistema Tirreno-Appennino».* Abstract Volume, Camerino, 9-10 febbraio 1995.

Baggioni M. (1975) - *L'evolution quaternaire des versants calcaires dans le Massif du Mont Bulgheria (Italie meridionale).* Actes de Symposium sur les Versants en Pays Méditerranéens, Aix-en-Provence, C.E.G.E.R.M., **5**.

Baggioni M., Suc J.P. & Vernet J.L. (1981) - *Le Plio-Pleistocene de Camerota (Italie Meridionale): Geomorphologie e paleoflores.* Geobios, **14** (2): 229-237.

Bonardi G., Amore O., Ciampo G., De Capoa P., Miconnet P. & Perrone V. (1988a) - *Il Complesso Liguride Auct.: stato delle conoscenze, problemi aperti sulla sua evoluzione pre-appenninica e suoi rapporti con l'Arco Calabro.* Mem. Soc. Geol. It., **41**: 17-35.

Bonardi G., D'Argenio B. & Perrone V. (1988b) - *Carta Geologica dell'Appennino meridionale alla scala 1:250.000.* Mem. Soc. Geol. It., **41**.

Bonifacio D., Ferraro L., Pescatore T. & Senatore M. R. (1994). *Studi di geologia marina del margine tirrenico: la piattaforma continentale tra Punta Licosa e Palinuro Cape. Carta Geomorfologica.* Dipartimento di Scienze della Terra, Napoli

Borrelli A., Ciampo G., De Falco M., Guida D. & Guida M. (1988) - *La morfogenesi del Monte Bulgheria (Campania) durante il Pleistocene inferiore e medio.* Mem. Soc. Geol. It., 41: 667-672.

Brancaccio L., Cinque A., Russo F., Belluomini G., Branca M. & Delitala L. (1990) - *Segnalazione e datazione di depositi marini tirreniani sulla costa campana. Boll. Soc. Geol. It.,* **109**: 259-265.

Chappel J.& Shackleton N. J. (1986) - *Oxygen isotopes and sea level.* Nature, **324**: 137-140.

Ciampo G. (1976) - *Ostracodi pleistocenici di Cala Bianca (Marina di Camerota, Salerno).* Boll. Soc. Paleont. It., **15**: 3-6.

Cinque A., Patacca E., Scandone P. & Tozzi M. (1993) - *Quaternary kinematic evolution of the Southern Apennines. Relationships between surface geological features and deep lithospheric structures.* Annali di Geofisica, **36**, n. 2: 249-259.

Cinque A., De Pippo T. & Romano P. (1994a) - *Coastal slope terracing and relative sea level changes: deduction based on computer simulations.* Earth Surf. Proc. and Landf., **20**: 87-103.

Cinque A., Romano P., Rosskopf C., Santangelo N. & Santo A. (1994b) - *Morfologie costiere e depositi quaternari fra Agropoli e Ogliastro Marina (Cilento, Italia meridionale).* Il Quaternario, **7** (1) (in press).

Doglioni C. (1991) - *A proposal for the kinematic modeling of the W-dipping subductions. Possible applications to the Tyrrhenian-Apennines system.* Terra Nova, **3**: 423-434.

Ferranti L. & Antonioli F. (1995) - *Le grotte sottomarine di Capo Palinuro. Aspetti geomorfologici e implicazioni speleogenetiche.* Le Grotte d'Italia, Atti XVII Congr. Naz. di Speleologia, sept. 1990-Lucca (in press).

Ferranti L., Oldow J. S. & Sacchi M. (1995) - *Pre-Quaternary orogen-parallel extension in the Southern Apennine belt, Italy.* Tectonophysics (in press).

FORTI P. (1991) - *Processi ipercarsici e speleogenesi. Speleologia*, 24: 42-46.

GUERRERA F., MARTIN-ALGARRA A. & PERRONE V. (1993) - *Late Oligocene - Miocene syn - / - late - orogenic successions in Western and Central Mediterranean Chains from the Betic Cordillera to the Southern Apennines.* Terra Nova, **5**: 525-544.

GUIDA D., GUIDA M., IACCARINO G., METCALF G., VALLARIO A., VECCHIO V. & ZICARI G. (1979). *Il bacino del Mingardo (Cilento). Evoluzione geomorfologica, fenomeni franosi e rischio a franare.* Geol. Appl. e Idrogeol., **14** (2): 119-198.

LIPPMAN-PROVANSAL M. (1987) - *L'Apennin Campanien meridional (Italia). Etude geomorphologique.* Thése de Doctorat d'Etat en Geographie Physique, Universite d'Aix-Marseille, Aix-en-Provence.

LIRER L., PESCATORE T. & SCANDONE P. (1967) - *Livello di piroclastiti nei depositi continentali post-Tirreniani del litorale sud-tirrenico.* Atti Accad. Gioenia Sci. Nat. Catania, ser.6, **18**: 85-115.

MOORE W. S. (1982) - *Late Pleistocene sea-level history. In: Ivanovich M. and Harmon* R. *S. (Eds.). Uranium series disequilibrium. Applications to environmrntal problems.* Claredon Press, Oxford, pp. 481-494.

MUSCIO G. & SELLO U. (1993). *Le grotte di Palinuro Cape (SA). Le Grotte d'Italia.* Atti XVI Congr.Naz. Spel., **16** (1992-1993), (4): 69-82.

ROMANO P. (1992) - *La distribuzione dei depositi marini pleistocenici lungo le coste della Campania. Stato delle conoscenze e prospettive di ricerca.* Studi Geologici Camerti, Spec. Vol. (1992), (1): 265-269.

SHACKLETON N. J. & OPDYKE N. D. (1973) - *Oxygen isotope and paleomagnetic stratigraphy of equatorial Pacific core V28-238: oxygen isotopes temperatures and ice volume on a* 10^{87}*-*10^{87} *years scale. Quat. Res.,* **3**: 39-55.

SGROSSO I. & CIAMPO G. (1966) - *Sulla presenza di terreni calabriani nei dintorni di Camerota.* Boll. Soc. Natur. in Napoli, **75**: 561-587.