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GENESIS, CHRONOLOGY AND TECTONICS OF THE QUATERNARY MARINE TERRACES OF THE TYRRHENIAN COAST OF NORTHERN CALABRIA (ITALY). THEIR CORRELATION WITH CLIMATIC VARIATIONS

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RIASSUNTO - *Genesi, cronologia e tettonica dei terrazzi marini pleistocenici della costa tirrenica della Calabria settentrionale e loro correlazione con le variazioni climatiche* - Il Quaternario, **3**(2), 1990, pp. 75-94 - Lungo la costa tirrenica della Calabria settentrionale, tra i fiumi Noce-Castrocucco e Lao, sono stati riconosciuti cinque ordini di terrazzi marini. Questa parte bassa della costa si differenzia, con grande contrasto, dai versanti a monte, che presentano invece forme molto evolute di ambiente continentale e dove le superfici terrazzate sono poco frequenti e mal conservate e la loro origine marina non è documentata.

Il terrazzo del 1° ordine è il più esteso (la larghezza supera anche i 3 km); esso è stato correlato alla sedimentazione delle argille di età emiliana. La corrispondente linea di riva (margine interno del terrazzo) è ben riconoscibile in base a depositi di spiaggia, a fori di litodomi, ecc. Per questo alto terrazzo viene proposto un modello genetico nuovo: l'estesa piattaforma di abrasione si sarebbe formata per la somma di trasgressioni, sempre più alte in quota, durante un lungo periodo di subsidenza, mentre l'emersione completa del terrazzo è avvenuta alla fine del Pleistocene inferiore sia per l'intenso sollevamento che ha interessato tutta la regione, sia per il forte ritiro del mare dovuto a glacioeustatismo.

La ricostruzione cronologica della successione dei terrazzi, controllata da datazioni Th^{230}/U^{234} su *Cladocora* (terrazzo del 4° ordine), ha permesso il confronto con le curve paleoclimatiche basate sugli isotopi dell'ossigeno e la correlazione con gli alti livelli del mare corrispondenti ai picchi interglaciali.

L'andamento altimetrico delle superfici terrazzate di ogni singolo ordine ha dato infine informazioni sui sollevamenti differenziali subiti dai vari settori costieri durante il Pleistocene medio e superiore.

I risultati conseguiti con la presente ricerca permettono di affermare che un terrazzo marino non deve essere visto come una semplice "morfologia marina", ma come il risultato di una complessa interazione tra eventi climatici, oscillazioni eustatiche del livello del mare e movimenti verticali della costa.

SUMMARY - *Genesis, chronology and tectonics of the Quaternary marine terraces of the Tyrrhenian coast of Northern Calabria (Italy). Their correlation with climatic variations* - Il Quaternario, **3**(2), 1990, pp. 75-94 - Five orders of marine terraces have been identified along the Tyrrhenian coast of Northern Calabria (Italy) between Noce-Castrocucco and Lao rivers. The terraced portion of the coast is markedly different from the portion uphill that displays a mature continental morphology with few poorly preserved terraces whose marine origin is not evidenced.

The 1st-order terrace is the most extensive (up to >3 km wide) and has been correlated with the clay sedimentation of Emilian age. The corresponding shoreline (inner edge of the terrace) is clearly indicated by beach deposits, *Lithodomus* holes, etc. A new genetic model is proposed for this terrace: i.e., the extensive wave-cut platform would have formed because of the cumulative effect of repeated transgressions each of which having reached an elevation greater than the preceding one owing to a long-lasting subsidence period. The complete emergence of the terrace would have occurred at the end of Lower Pleistocene due to the combined action of the uplift of the region, and the regression because of glacio-eustatic changes of sea level.

The chronological reconstruction of the sequence of terraces based on the morphological evidence was controlled with U-series age measurements on *Cladocora* from the 4th-order terrace. It was also compared with oxygen isotope palaeoclimatic curves and high sea stands corresponding to interglacial peaks. Variation in the elevation of each order of terraces has provided information concerning the differences in uplift that occurred along the coast during Middle and Upper Pleistocene.

The results of this study suggest that a marine terrace cannot be regarded as a simple "marine form", but must be thought of as the result of the complex interaction between climatic variations, sea level changes, and coastal vertical movements.

Parole chiave: Pleistocene, cronologia, variazioni climatiche, terrazzi marini, tettonica, Calabria, Italia
Key words: Pleistocene, chronology, climatic variations, marine terraces, tectonics, Calabria, Italy

1. INTRODUCTION

The Tyrrhenian coast of northern Calabria in southern Italy is characterized by two distinct morphological features: i.e., a series of marine terraces at various elevations, the highest of them being also the largest; and an evolved type of relief (e.g., Richter slopes) landwards above the terraces.

These two morphological features are well represented not only in the area located between Noce-Castrocucco River to the north and Lao River to the south where this study was carried out, but also elsewhere along the Tyrrhenian Italian coastline (Latium, Sicily, Basilicata). The question is thus which major climatic and tectonic events occurred and when have produced such great morphogenic changes.

Two paths have been followed to answer this question: to establish the chronological succession of the marine terraces (reference data are provided by U-series coral dates and the epimerization ratio of

LOCALITIES	TERRACE ORDERS								FAULT THROW
	Y	X	W	V					
				■	*	o	△	▼	
NOCE RIVER RIGHTHAND SIDE **1**	18 * o	~22 o	45 * o	110	105	105	130	125	-
NOCE RIVER LEFTHAND SIDE **2**	~20 △		60÷65 ■ *	130÷135	140	120	140÷150		+20 -
PRAIA A MARE (FIUM. TORTORA) **3**	~18 * o	30÷35 o	60÷65 ■ o	135	166	145	160÷170	150	+20 -
DINO ISLAND (FORESTA) **4**	17 — *	35 —	60 —	150÷160	180		180÷200	205	+30
S. NICOLA ARCELLA **5**	19 — *	32 — ■	60 —	160÷175	190	190	190÷200		
SCALEA **6**	19 * o	35 —	60÷65 — *	160 170			190		-
S. DOMENICA TALAO **7**		~30 ■	65 ■ *	190÷210	240	240	220÷240		+50
LAO RIVER (SUVARETA) **8**		~30 ■ *	65 ■	215					-
DIAMANTE – M.CARPINOSO **9**	30 ■ *	100 ■ △	220 ■ * △	510	500	550	550		+310

—	RELICS OF ABRASION PLATFORMS	o	BOREHOLES, SEA CAVES, NOTCHES
■	INNER MARGIN OF THE TERRACES	△	SCARP–FOOT
*	BEACH DEPOSITS	▼	EOLIAN SAND

L.C

Table 1 - Elevations (mean values, in m) of the morphological and sedimentological features used to determine the order of the terraces and old shorelines. The fault throws are referred to the 1st-order terraces. Numbers 1 to 9 show coast sectors in Plate 1
Altitudine (valore medio, in m) delle forme e dei depositi usati per determinare l'ordine dei terrazzi e delle antiche linee di costa. I rigetti delle faglia si riferiscono ai terrazzi del 1° ordine. I numeri da 1 a 9 si riferiscono a tratti di costa indicati nella Tavola 1

isoleucine in marine molluscs), and to study the fauna associations in the Lower Pleistocene marine deposits outcropping in the Fornaci San Nicola - Piano della Suvareta area (Plate 1). Very useful comparisons can be made with the coeval deposits in Sicily, which Ruggieri et al. (1984) have subdivided into the three sub-stages Santernian, Emilian and Sicilian shown in Figure 6. In their view, an initial transgression had occurred in Santernian which was followed by uplift and regression. A second transgression took place during upper Emilian (Ruggieri, 1978) and then uplift and eustatic regression would occur at the end of Sicilian (Buccheri, 1985; Sprovieri, 1986). In Sicily, all the recognized sections of Sicilian are truncated by an erosional surface (Ruggieri & Sprovieri, 1976). In the Fornaci San Nicola - Piano della Suvareta area, the erosional surface of the Sicilian cycle is clearly older than the first lower terrace of Middle Pleistocene age.

In order to correlate the upper marine terraces to the Lower Pleistocene stratigraphic sequence, the following question must be answered: is it possible to distinguish the shorelines of the Lower Pleistocene transgressions?

The clay deposit outcropping at Fornaci San Nicola (Fig. 1 and 2) is Emilian in age. On the basis of the bathymetric features of the fauna, Compagnoni et al. (1969) consider the deposit as "formed when the shoreline was 100 metres above the present one".

According to Damiani (1970) the 7th-order terrace of Plio-Calabrian age would correspond with this deposit on the south of Lao river (the terrace is at the elevation 180÷300 m a.s.l. at Serra Bonangelo, and 315÷540 m a.s.l. at Monte Carpinoso), whereas Piano della Suvareta would represent the 5th-order terrace (which is Sicilian in age).

The clay-sand sequence outcropping at Fornaci San Nicola, on the right of Sant'Angelo stream (Fig. 2), has therefore been reexamined in order to find a chronological reference for the reconstruction of the succession of terraces (and of the corresponding high stands of sea level)(1). According to Compagnoni et al. (1969) the clay and sand sequence (biocalcarenite) is "Calabrian" in age (*sensu* Ruggieri & Selli, 1949) and the overlying gravel deposits (with interbedded lacustrine clay) —that they regard as transgressive— are "Sicilian". On the basis of analyses we carried out on the microfauna in a new series of biocalcarenite samples with *Globorotalia truncatilinoides excelsa* (Conato, 1985, unpublished ENEA report), the clay-sand sequence is to be dated from Sicilian (*sensu* Ruggieri et al., 1984). Thus, the gravel of the 65 m 2nd-order terrace (W) (Table 1 and Plate 1), which is transgressive on the Emilian clay and Sicilian biocalcarenite (Fig. 1) should be dated from Middle Pleistocene.

The stratigraphic and morphological study of the most recent deposits outcropping near the coast, that included the measuring of the outcrops maximum elevation, and U-series age measurements on *Cladocora* (Carobene et al., 1986), have given a first evidence of differential uplift along the part of the coast between Noce-Castrocucco and Lao rivers in the latest 300,000 years.

Part of the area has been investigated also by Brancaccio & Vallario (1968), who distinguished three orders of terraces on the NW of Scalea.

The terraces described in this paper had already been studied by Damiani & Pannuzi (1979), who distinguished them into: a) Plio-Calabrian (6th order) terrace and Sicilian (5th order) terrace, which together may be identified with the Lower Pleistocene 1st-order terrace shown as V in Plate 1 and Table 1; b) Milazzian (4th-order)(2) terrace corresponding to the Middle Pleistocene first terrace (shown as W in Plate 1 and Table 1); c) Tyrrhenian I (3rd-order) terrace, which may be correlated to the Middle Pleistocene second terrace (shown as X in Plate 1 and Table 1); and, d) Tyrrhenian II (i.e., the Last Interglacial) 2nd-order terrace, which matches well our 300 kyr old terrace Y. It can thus be concluded that, although there are partial analogies in the two studies as far as the elevations of terraces are concerned, it is not so as to the respective chronological attributions.

This paper aims at giving a first estimate of the height of the shoreline at the time of the maximum transgression of the sea during Emilian times as inferred from new field data, and a genetic interpretation of the highest terrace (surface V in Plate 1 and Table 1).

The paper gives also some information on the tectonics affecting this part of the Calabria coast during Pleistocene including the identification of zones with uplift rates decreasing from south to north, as based on the correlation of the marine tarraces in the area.

2. DESCRIPTION OF THE TERRACES

Description of the terraces (Plate 1) is based on both new field data and information from the literature.

There is usually a narrow "junction surface" (average slope = 10÷15°) between terrace (average slope = 4÷5°) and escarpment uphill (average slope = 30÷35°). A distinction has thus to be made between the inner margin of a terrace (i.e., the upper limit of the terrace surface) and the foot of the upward escarpment (i.e., the upper limit of the junction surface). The elevation of the escarpment foot, which is often evidenced by marine deposits or by a typical coastal morphology (Table1), corresponds fairly well with the old raised shoreline when the junction surface is not hidden by continental deposits (talus debris and/or colluvium). Therefore, where possible, two levels have been distinguished: 1) the inner margin (i.m.) of the terrace, and 2) the scarp-foot (s.f.).

2.1 The 1st-order terrace (V)

The width and elevation of the 1st-order terrace decrease from south to north (Plate 1; Table 1). Besides its morphological features, the marine origin of the terrace is demostrated also by the presence of beach deposits, *Lithodomus* holes, caves and

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(1) This zone has recently been examined by Malatesta & Zarlenga (1988a, b) and Carboni et al. (1988). Their papers are unfortunately unclear because of gaps and inaccuracies in the collection and interpretation of the data.

(2) The Milazzian stage was established in 1918 by Déperet on the basis of a terrace deposit located at the elevation of 40÷50 m a.s.l.on the promontory of Milazzo (Sicily). The term was used to indicate a pre-Tyrrhenian and post-Sicilian period of temperate climate during Middle Pleistocene, defined by a transgression on the margin of the northern Apennines (Ruggieri & Selli, 1949). Later on, however, Ruggieri et al. (1976) concluded that in the type locality "Milazzian" corresponds with Tyrrhenian (last interglacial period) and suggested to substitute the term "Milazzian" with the term "Crotonian" on the basis of the results obtained from the investigation carried out on the large terrace of the peninsula of Crotone (Calabria) extending from 140 to 230 m above sea l.evel and previously defined as Milazzian by Selli (1962).

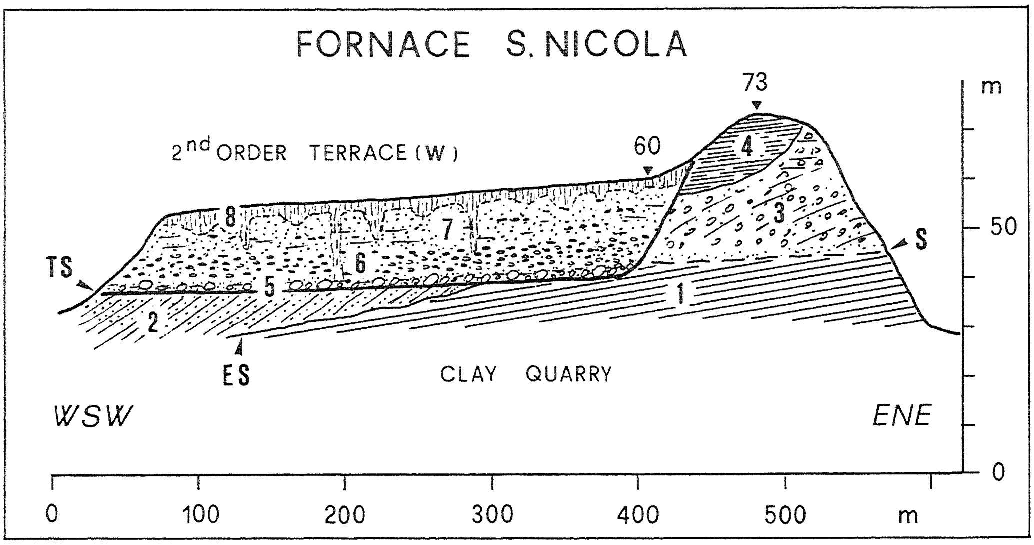

Fig. 1 - Geological cross-section at Fornace San Nicola. 1) grey-blue clay with *Hyalinea balthica* of Lower Pleistocene (Emilian) dipping 5÷6° westwards; 2) cemented biocalcarenite with *Globorotalia truncatulinoides excelsa* of Lower Pleistocene (Sicilian) dipping 10÷20° to the NW and forming foresets resting on a 7° dipping erosion surface (ES); 3) cemented gravel with rounded pebbles dipping 20÷25° to the WSW and forming foresets resting on an indistinct surface S. In the upper part, predominance of poorly sorted rudites with sub-rounded pebbles; 4) yellowish lacustrine clay marking the end of the Sicilian regression (see also Fig. 9) and dipping 4÷5° to the W; 5) conglomerate with *Lithodomus* holes, and Middle Pleistocene transgressive marine sand referred to the 60 m terrace (2nd-order, W). The transgression surface (TS) has a 2÷3° dip. The thickness varies from 2 to 3 m. Some boulders are as much as 1.5 m in diameter; 6) poorly cemented alluvial fan gravel, with imbrication and erosional channels, and aboundant matrix, dipping 4÷7° to the NW, and passing (above) to 7; 7) coarse sand with gravel horizons; 8) "pockets" of altered, rubified sand (colours 2.5 YR 3/6; 10 R-3/4) descending several meters into the unalterated gravel

Sezione geologica schematica in località Fornace San Nicola (Scalea). 1) Argille grigio-azzurre ad Hyalinea balthica *(Emiliano) inclinate di 5÷6° verso W. 2) Biocalcareniti cementate a* Globorotalia truncatulinoides excelsa *(Siciliano) inclinate di 10÷20° verso NW. Costituiscono foreset poggianti su una superficie erosionale (ES) inclinata di 7°. 3) Ghiaie cementate, con ciottoli sfericizzati, inclinate di 20÷25° verso WSW. Costituiscono foreset poggianti su una superficie S non ben definita; verso l'alto prevalgono ruditi mal classate con ciottoli poco arrotondati. 4) Argille lacustri giallastre che indicano la fine della regressione del Siciliano (v. anche Fig.1); sono inclinate di 4÷5° verso W. 5) Conglomerati con ciottoli forati dai litodomi e sabbie marine della trasgressione del Pleistocene medio, alla quale viene riferito il terrazzo di 60 m (2° ordine). La superficie di trasgressione (TS) è inclinata di 2÷3°. Lo spessore è di 2÷3 m; alcuni massi raggiungono 1,5 m di diametro. 6) Ghiaie di alluvial fan, poco cementate, con imbriciatura, canali di erosione, molta matrice sabbiosa, inclinate di 4÷7° verso NW. 7) Sabbie grossolane con livelli di ghiaie. 8) Sabbie alterate e rubefatte (colore 2,5 YR 3/6; 10 R 3/4). Presentano "sacche" che sprofondano per parecchi metri entro le ghiaie non alterate*

wave-cut surfaces.

On the **right of Noce river** (Plate I, sector 1), a relic of wave-cut surface extends from 68 to 105÷110 m a.s.l. (inner margin = 110 m). Rounded pebbles and *Lithodomus* holes are visible in the bedrock limestone. A deposit of cross-bedded eolian sand covered by slope breccias extends up to 125 m a.s.l. Cemented gravel, sand and *Lithodomus* holes in the bedrock limestone have been found along the State Road no.18 (km 243) to Maratea. The scarp foot is 130 m a.s.l.

On the **left of Noce river** (Table 1, sector 2; Fig. 3 I), bedded sand and gravel with marine molluscs *(Ostrea)* and *Lithodomus* holes overlying a calcareous bedrock have been found up to 135 m a.s.l. (Fig. 4). The terrace is more clearly visibile farther to the south at Rosaneto, San Brancato and Castiglione, where it extends from 100 to 135 m a.s.l. (inner margin = 135 m) (Fig. 5).

Bulgarelli (1973) refers us to a surface between 90 and 100 m a.s.l. with *Lithodomus* holes. Damiani & Pannuzi (1979) attribute the surface between 90 and 135 m a.s.l. to the 5th-order ("Sicilian") terrace. A red-coloured deposit composed of sand and gravel here and there cemented into a puddingstone, is described by Segre (1984) near Rosaneto. This deposit belongs to a terrace from 60 to 100 m high a.s.l.; lithic artifacts on its surface have been attributed by Segre (1984) to the end of the Italian Acheulean.

This very terrace is less evident at **Praia a Mare** (i.m. about 130 m a.s.l.). Sand, gravel and large pebbles with *Lithodomus* holes have been found at elevation140 m a.s.l. (right side of the Fiumarolo stream valley). On the left of Fiumarella Tortora, the shoreline can be located at about 170 m a.s.l. on the basis of morphological evidence only, as sedimentary deposits are lacking. A loose mostly non-carbonatic gravel deposit has also been found at 166 m a.s.l. on the top of an isolated calcareous hill at Castiglione, where a terrace at 130 m a.s.l. was described by Cortese (1886).

The 1st-order terrace is well recognizable at **Dino Island** (Table 1, sector 4; Figg. 3, 11 and 6) where a portion of it coincides with the surface of the

Fig. 2 - Fornaci San Nicola (sector 8). A: clay of Lower Pleistocene (Emilian); B: biocalcarenite of Lower Pleistocene (Sicilian). The contact between A and B is irregular. The elevation of the site is 31 m a.s.l.
Fornaci San Nicola (settore 8). A: argille del Pleistocene inferiore (Emiliano); B: biocalcareniti del Pleistocene inferiore (Siciliano). Il contatto fra A e B è irregolare. La quota del piano di cava è 31 m

island itself (70÷99 m a.s.l.). The landward portion of the terrace on the mainland coincides with the locality Foresta, where the surface extends from 100 to 160 m a.s.l. (inner margin = 160 m); the scarp foot is at 180 m a.s.l. and correspond to an old shoreline. On the right side of the Fiuzzi river valley a beach deposit composed of conglomerate with calcareous pebbles bored by *Lithodomus* overlies the Mesozoic dolomitic substratum (Fig. 7). A well-sorted eolian carbonatic sand, covered by slope breccias has been recognised at elevation 208 m a.s.l.

The 1st-order terrace was already described by Brancaccio & Vallario (1968) and Damiani & Pannuzi (1979) as developing from 100 to 140 m a.s.l. and from 90 to 170 m a.s.l., respectively.

At **San Nicola Arcella** (Table 1, sector 5), the 1st-order terrace is mentioned in De Fiore (1937). Brancaccio & Vallario (1968) locate it at elevations from 120 to 140 m a.s.l., and Damiani & Pannuzi (1979) from 110 to 170 m. Actually, it extends from 80 to 175 m a.s.l. and the scarp foot is at about 200 m a.s.l.

At the foot of the slope made up of Mesozoic limestone, a 2÷4 m thick marine deposit, composed of conglomerates at the base and cemented sands at the top, has been found between 190 and 195 m a.s.l. at Fontanile del Salice (terrace to the north of San Nicola Arcella). It is associated with a small cave of possible marine origin. Other caves with alabaster deposits are visible to the south of San Nicola Arcella from elevation 180÷190 m a.s.l. The junction surface extends from 160 to 190 m a.s.l. and has a silty colluvial cover. Palaeosol (MCC colours: 2.5 YR 3/4 and 5 YR 4/6). has a local thickness of several metres.

On **Scalea promontory** (Table 1, sector 6; Fig. 3, III), the wave-cut platform is very extensive (up to 2,000 m) and varies in elevation from 100 m (at the outer edge) to 170 m a.s.l. (at the inner margin). The deposits covering it are poorly preserved, but a palaeosol (2.5 YR-4/6) can be observed. The terrace surface has a "step" at about 140 m a.s.l. and the s.f. is at about 190 m a.s.l.

Pata (1956) attributed this terrace to "Sicilian" owing to the presence of *Pecten jacobaeus* and *maximus* L., *Clamys septemradiatus* Mull., etc. in cemented sands.

At **Santa Domenica Talao** (Table 1, sector 7), the 1st-order terrace has the greatest extent (3,600 m) and varies in elevation from 80 m (at the outer edge) to 220 m a.s.l. (at the inner margin); the scarp foot on the southern slope of Serra Ummara varies in elevation from 210 to 240 m a.s.l. On the W of Santa Domenica Talao (Fig. 8), 1÷2 m thick beds of cemented sand with rare pebbles and large *Spondylus* shells associated with *Lithodomus* holes in the carbonatic substratum mark the location of the shoreline at elevation 240 m a.s.l. The deposit is locally covered by breccias and alabastrine flowstones probably from the collapse of sea caves.

At **Piano della Suvareta** (Table 1, sector 8), the terrace surface lies between 80 and 215 m a.s.l. It has the maximum width of about 3,400 m and an average slope of 2÷3°. Its continuity is broken by small faint steps at 130 and 170 m a.s.l. (Fig. 9). In contrast with the thinness of the other deposits, Piano della Suvareta deposit forms the upper surface of a gravel and sand alluvial fan as much as 100 m thick blanketing the Emilian clays (Fig. 10). The occurrence of an alluvial fan deposit is linked to the abundant contribution of debris from Lao river in resistasy morphoclimatic conditions, during a regression stage which took place at the end of Lower Pleistocene. As a matter of fact, a sandy clay specimen (LB164) collected at the elevation of 80 m a.s.l. (Fig. 9) would be Sicilian in age from its Foraminifera association (pers. comm., Colalongo, 1990). Damiani & Pannuzi (1979) attribute this terrace (from 60 to 230 m a.s.l. in elevation) to the 5th-order ("Sicilian").

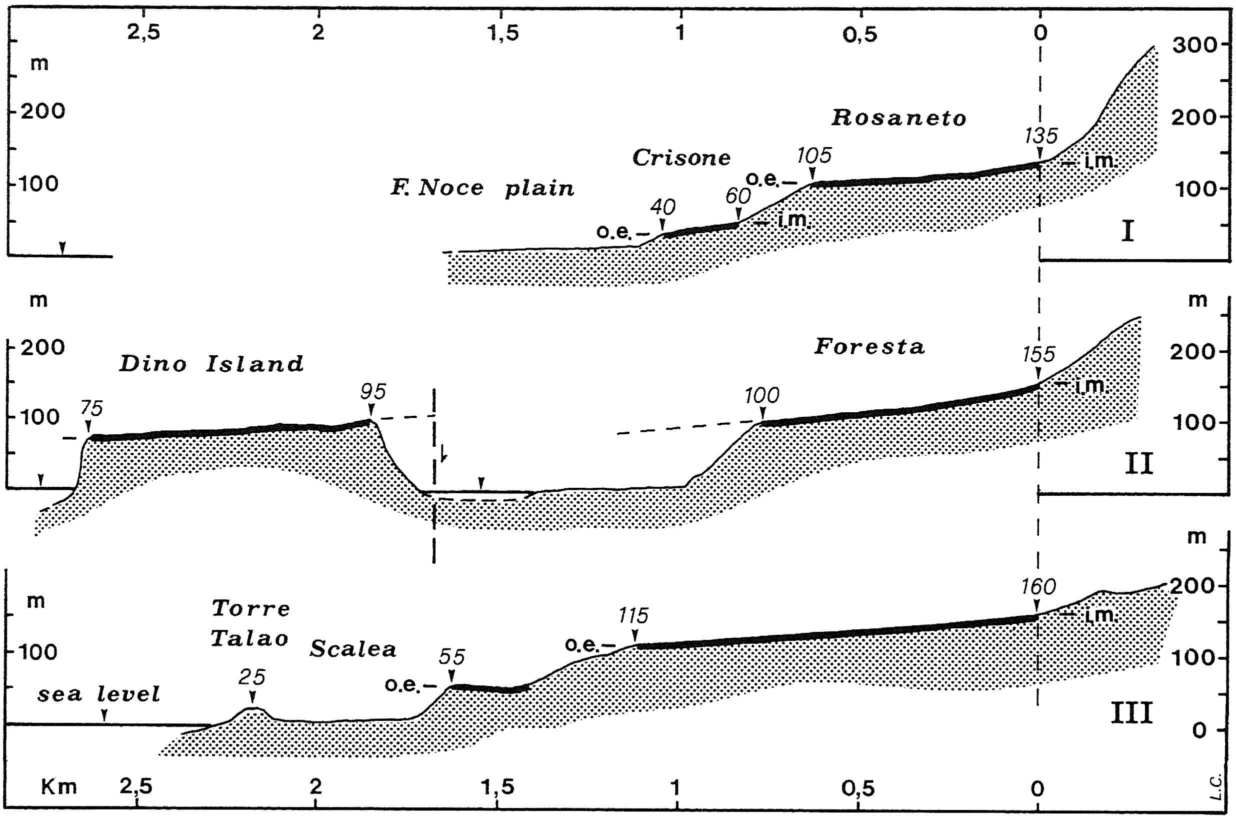

Fig. 3 - Topographic profiles taken from the 1:10,000 maps (for locations, see Plate 1). The 1st-order terrace (V) is clearly represented. Its inner margin (i.m.) becomes higher from north to south. In section II, a fault interrupts the continuity of the terrace resulting in a slight tilting of the eastern part. The 2nd-order terrace (W) is well visible in profiles II and III. At Torre Talao (profile III), the 4th-order (Y) shoreline at 20 m a.s.l. is documented by *Cladocora coespitosa* deposits (U-series age: 252,000 years) and a small cave with *Lithodomus* holes

Profili topografici ricavati dalle carte in scala 1:10.000 (per l'ubicazione dei profili vedi Tav. 1). E' ben rappresentato il terrazzo del 1° ordine (V); la quota del suo margine interno (i.m.) cresce da nord a sud. Nella sezione II una faglia interrompe la continuità della superficie terrazzata provocando un leggero basculamento della parte orientale. Il terrazzo del 2° ordine è ben visibile nelle sezioni I e III. A Torre Talao (sez. III) depositi a Cladocora coespitosa (età Th^{230}-U^{234}*: 252.000 anni) ed una grotticella con fori di litodomi documentano la linea di riva del 4° ordine (Y) a 20 m di quota*

Since it is the highest and best represented terrace, and because of its morphology, it has been correlated with the large terrace lying between Monte Carpinoso (km 16 SE of Scalea) and the sea (Carobene, 1987) which extends from 270 to 535 m a.s.l. (Tab. 1) and whose maximum width is 3300 m. Its inclination is 2° at the lower end and 6° at the upper end.

These high surfaces form the 1st order terrace (shown as V in Plate 1) nearly always displaying a very evolved soil, that can be classified as a "plintite" truncated at the top by erosion.

2.2 The terrace of the 2nd-order (Middle Pleistocene)

The terrace immediately below the 1st order terrace just described, is found at a generally

Fig. 4 - Partial view of the beach deposits at 135 m a.s.l. near Rosaneto (1st-order terrace, sector 2). The calcareous bedrock with *Lithodomus* holes is clearly visible in the photo
Particolare dei depositi di spiaggia a 135 m di quota nei pressi di Rosaneto (1° ordine, settore 2). Si può osservare il basamento calcareo con fori di litodomi

Fig. 5 - Partial view of the 1st-order terrace located on the rightside of Fiumarella Tortora (sector 2). The inner margin is at 135 m a.s.l. A dolomite of Lower Lias forms the substratum of the terrace
Particolare del terrazzo di 1° ordine in sponda destra della Fiumarella di Tortora (settore 2). Il margine interno è a 135 m. Il substrato è rappresentato da dolomie del Lias inferiore

Fig. 6 - View of Dino Island (on the right) and the Terrace of Scalea (in the background)
Veduta dell'Isola di Dino, sullo sfondo il terrazzo di Scalea

Fig. 7 - Beach deposits at 170 m a.s.l. on the right of Fiuzzi river, at Foresta. The deposits cover the wave-cut surface carved into the Upper Trias-Lower Lias dolomite
Depositi di spiaggia a 170 m di quota in destra del torrente Fiuzzi, a Foresta. I depositi sono soprastanti alla superficie di abrasione nelle dolomie del Trias superiore-Lias inferiore

constant elevation (40÷65 m a.s.l.) between the rivers Noce to the N and Lao to the S. It is slightly lower (30÷45 m) on the north of Noce, whereas it is much higher on the S of Lao (170÷220 m; Table 1, sector 9). It has the maximum width (650 m) on the SE of Scalea. This 2nd-order terrace (W on Plate I) has been dated: at Fornaci San Nicola (4 km SE of Scalea), Emilian-Sicilian clays and biocalcarenites (*sensu* Ruggieri et al.,1984) are cut by a wave-cut platform which is overlain unconformably by sand and gravel which are marine in the lower portion and fluvial in the upper part up to 65 m a.s.l. Consequently, the clastic deposit represents the first great eustatic transgression of Middle Pleistocene (probably the stage 21) occurred after a long period of sea level lowering (probably the stages 24 and 22; see Fig. 15, col. g).

Because this terrace of Middle Pleistocene age can be correlated with certainty, it may be considered as a key surface for dating the other terraces along the coast. Sand and clay deposits, caves and notches, relics of platform and palaeosols (Table 1) are distinctive features of the terrace.

In particular, it is worth mentioning a) the conglomerate deposit at 45 m a.s.l. including pebbles with *Lithodomus* holes that outcrops on km 243 of the State Road no.18 to Maratea. (Table 1, section 1), which Carboni et al. (1988) have attributed to the 1st-order terrace; b) the layered polygenic sand and gravel at 60 m a.s.l. near San Brancato (Table 1, sector 2); c) the "Grotta della Madonna" cave at Praia a Mare (Table 1, sector, 3) which is indicative of a sea level at 64 m above the present sea level (Carobene, 1987); and, eventually, d) the sand and gravel deposits with rounded clasts covering the metamorphic bedrock that outcrop on the NW of Scalea (Fig. 11).

A deep pedogenesis (colour:10 YR 3/4) has affected the upper portion (up to 2÷3 m in depth) of the sand and gravel deposit at Fornaci San Nicola (Fig. 1). The presence of large (1÷2 m in diameter) reversed cones formed of reddish reworked gravel that penetrate for 5÷10 m from the surface into the unaltered fluvial gravel is the subject of a current study.

2.3 The lower shorelines

The best recognisable lower shoreline has been dated with the U-series method on *Cladocora coespitosa* (Carobene et al., 1986) (Fig. 12). The age ranges from 250 to >360 kyr, and the episode has thus been referred to the stage 9 of the oxygen isotope curve, though the influence of high stand sea levels in the stages 7 and 11 cannot be ruled out (Fig. 15). The shoreline is located between 14 and 20 m a.s.l. and is characterised by *Cladocora*-bearing biocalcarenitic deposits, marine caves (Fig. 13), small wave-cut platforms and bands rich in *Lithodomus* holes. The inner margin (i.m.) increases in elevation on the South of river Lao only. This shoreline (4th-order) is shown as Y on Plate 1.

The series of narrow platforms (Praia a Mare, Scalea, Santa Domenica Talao), small caves and *Lithodomus* holes (Praia a Mare), and deposits that are present along the coast between 20 and 35 m a.s.l. (Table 1) and not all of which mappable at the scale of Plate 1, can chronologically be attributed to the time span between the first post-Sicilian terrace and the about 330 kyr old *Cladocora* shoreline (letter X in Fig. 15; 3th-order terrace).

Another high sea level stand is marked by a wave-cut platform of limited extent and beach deposits that overlie the *Cladocora*-bearing biocalcarenites which outcrop at 4÷8 m a.s.l. Age measurements with the isoleucine epimerization method on *Arca* (D/L = 0.32) and *Astralium* (D/L = 0.41) shells(3) (Carobene & Dai Pra, in press), confirm that this high sea stand dates from stage 5 (letter Z in Fig. 15; 5th-order terrace).

3. ORIGIN OF THE 1ST-ORDER TERRACE (V)

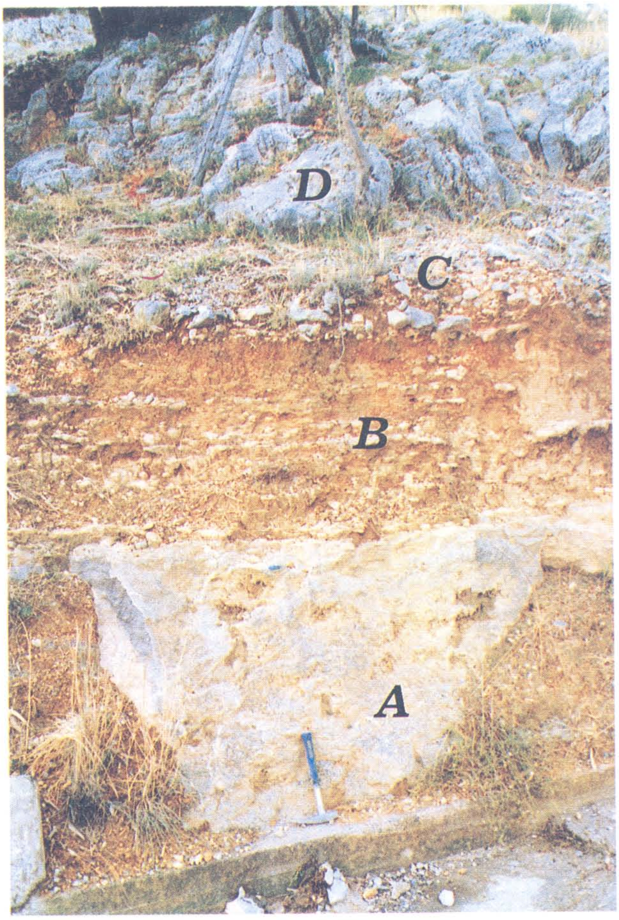

Fig. 8 - Old shoreline at 240 m a.s.l. on the west of Santa Domenica Talao (1st-order terrace, sector 2). A: marine sandstone with bivalve shells; B: continental mud with thin sandstone horizons; C: debris cover with angular clasts; D: Jurassic dolomitic limestone
Antica linea di costa a 240 m di quota ad ovest di Santa Domenica Talao (1° ordine, settore 2). A: arenarie con Lammellibranchi; B: limi continentali con sottili orizzonti di arenarie; C: detriti con clasti a spigoli vivi; D: calcari dolomitici del Giura

The morphology of the highest terrace (Carobene, 1987) is much the same along the coastline between Scalea and Diamante: 1) marked extension (up to about 3,300 m); 2) great difference in elevation between inner and outer margins (up to a maximum of 260 m on the Monte Carpinoso terrace); 3) gentle slopes (less than 5°). It may thus be assumed that it formed in almost constant environmental conditions. A very long tectonic standstill, or better, a slow-rate subsidence produced a progressive transgression of the sea and hence the formation of a very extensive wave-cut platform. Under these conditions, the "numerous", probably slight(4) glacioeustatic fluctuations which occurred during this very long period of time, always transgressed beyond the previous shoreline (Fig. 14 A) by

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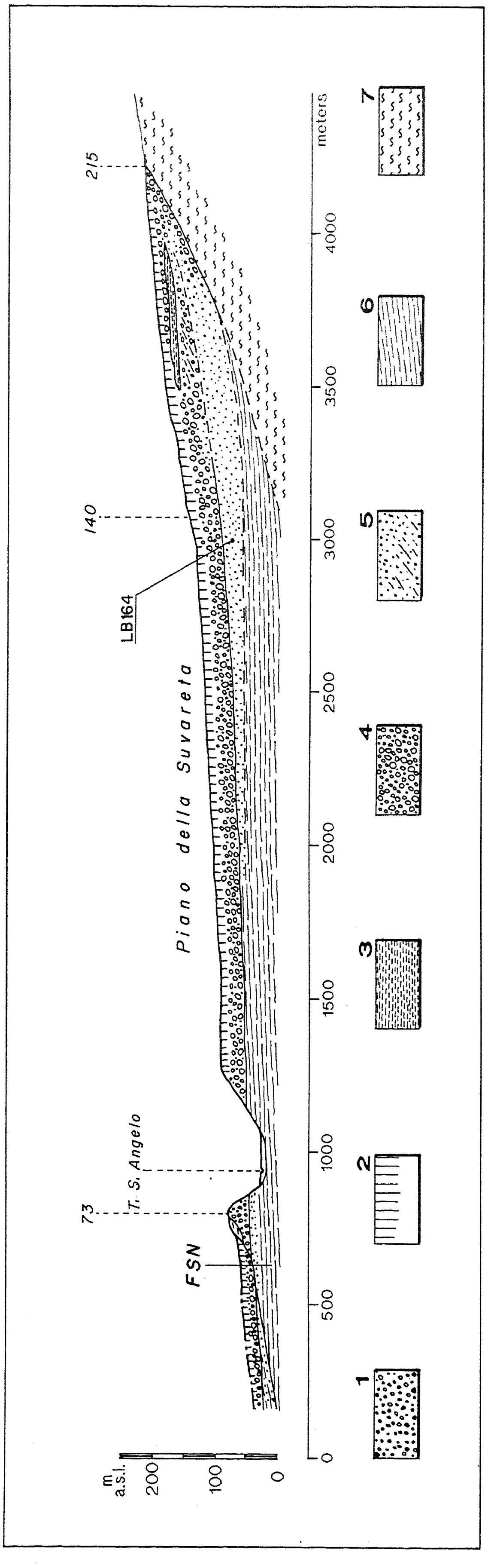
(3) The analyses were carried out by the Amino Acid Geochronology Laboratory (Director: Dr. G.H. Miller, INSTAAR, Colorado University, Boulder).

(4) Oxygen isotope palaeoclimatic records emphasize that interglacial periods occurred with a frequency of 45,000 years during Lower Pleistocene (Shackleton & Opdyke, 1976; Shackleton & Hall, 1984). In particular, it has clearly been shown (Williams et al.,1988) that the amplitude of climatic changes during Lower Pleistocene is 30% less than those of Middle and Upper Pleistocene. Eustatic changes were accordingly similar.



gradually widening the wave-cut platform. The genesis of the platform is, thus, polyphasic and its surface diachronous. When the uplift of the area began, the shoreline corresponding to the last interglacial period (no. 6 in Fig. 14 A) emerged and could no more be reached by the subsequent high sea levels (e.g. no. 7, 8 and 9 in Fig. 14 B). In our model the sea level during the interglacial period no. 7 is assumed to be 25 m lower than that during the interglacial period no. 6, if we take an uplift rate of 0.5 mm/yr and a "return time" of interglacial periods of 50,000 yr. During the rapid regression of the sea consequent to the tectonic uplift, steps lower and lower in elevation might form during interglacial high stands of the sea, or in correspondence of normal faults following episodes of extensive tectonics.

According to this model, the highest sea level stand was attained at the time of the maximum deepening of the sea before the resuming of tectonic activity (uplift). The long subsidence period when tectonic activity was relatively quiescent, favoured the deposition of thick clay deposits. In Calabria, the clay deposits are everywhere of Emilian age (*sensu* Ruggieri, Buccheri et al., 1976), a substage between 1.1 and 1.4 Myr (Ruggieri et al., 1984). Shoreline should have attained the highest elevation at the end of this period.

3.1 The Emilian transgression

The hypothesis of the formation of the extensive wave-cut platform of the 1st-order terrace (see Fig.14) following the tectonic uplift of the area during Emilian (Fig. 15, col. e) is supported by the fact that in many places there is a hiatus in early Emilian as demonstrated by Ruggieri (1978, 1988) and Ruggieri et al. (1981) which would be the result of the tectonic uplifting causing the emersion of the deposits of Lower Pleistocene (former "Calabrian" acc. to Gignoux, 1913, or "Santernian" acc. to Ruggieri & Sprovieri, 1976). It is unlikely that emersion of the deposits was caused by a very big glacioeustatic decrease of sea level (see Ch. 4 and Fig. 15, col. g).

Fig. 9 - Geological cross-section on the right of Lao river:
1) sand and gravel (W terrace); 2) very evolved red soil ("plintite"); 3) lacustrine clay; 4) concordant bedding in locally cemented gravel; in the upper portion, rudites with poorly rounded pebbles; 5) biocalcarenite and sand with *Globorotalia truncatulinoides excelsa* (Lower Pleistocene - Sicilian); 6) grey-blue clay (Lower Pleistocene - Emilian); 7) bedrock; FSN = Fornace San Nicola
Sezione geologica in destra fiume Lao. 1) sabbie e ghiaie (terrazzo w); 2) suoli molto evoluti ("plintiti"); 3) argille lacustri; 4) ghiaie, talora cementate e clinostratificate, verso l'alto ruditi e ciottoli mal arrotondati; 5) biocalcareniti e sabbie a Globorotalia truncatulinoides excelsa *(Siciliano), 6) argille grigio-azzurre (Emiliano); 7) substrato metamorfico. FSN = Fornace San Nicola*

Clay deposition indicates again deep sea conditions during Emilian. This "transgressive period" was characterised by numerous interglacial peaks, and the corresponding wave-cut platform was, thus, modelled during numerous high sea level stands (Fig.15, col. g).

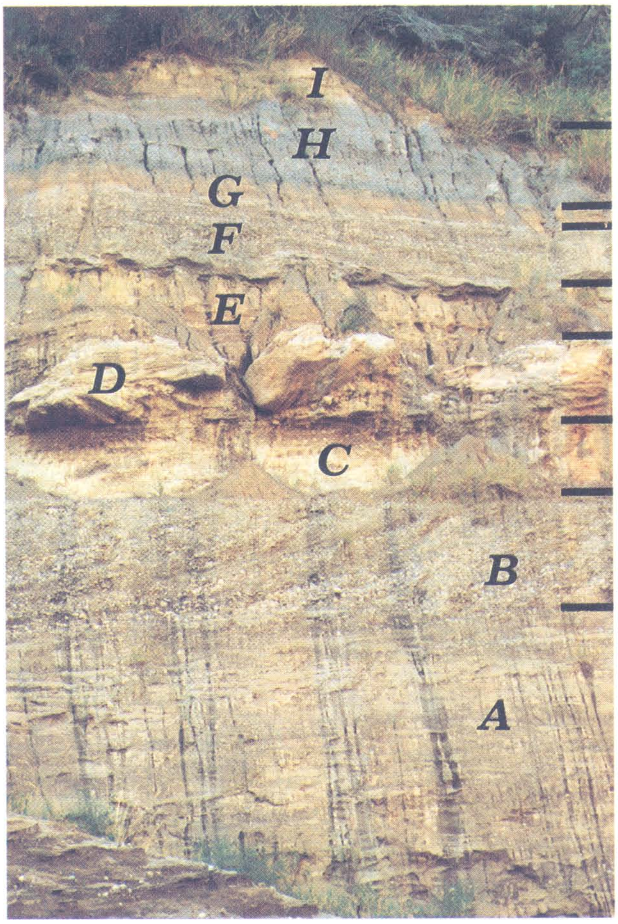


Fig. 10 - Stratigraphic sequence of Lower Pleistocene at Suvareta (sector 8), between 110 and 165 m a.s.l. A) marine sand with cross laminations (Emilian ?); B) regressive gravel showing concordant bedding (Sicilian ?); C) sand; D) cemented conglomerate; E) marine sand; F) flat-lying (fluvial?) gravel; G. yellowish mud; H. lacustrine blue clay; I) yellowish mud; vegetation conceal a paleosol
Successione del Pleistocene inferiore in località Suvareta (settore 8), tra le quote di 110 e 165 m. A) sabbie marine con laminazione incrociata (Emiliano ?); B) ghiaie regressive con strati originariamente inclinati (Siciliano ?); C) sabbie; D) conglomerati cementati; E) sabbie marine; F) ghiaie (fluviali?); G) limi giallastri; H) argille bluastre lacustri. I) siltite giallastra; la soprastante vegetazione nasconde il paleosuolo

3.2 The Sicilian regression

Because the Sicilian biocalcarenites outcropping at Fornaci San Nicola overlie unconformably the lower Emilian clays (Fig. 1), uplift must have started at the end of Emilian, resulting in the rapid ending of clay sedimentation and the subsequent deposition of coarse regressive sediments.

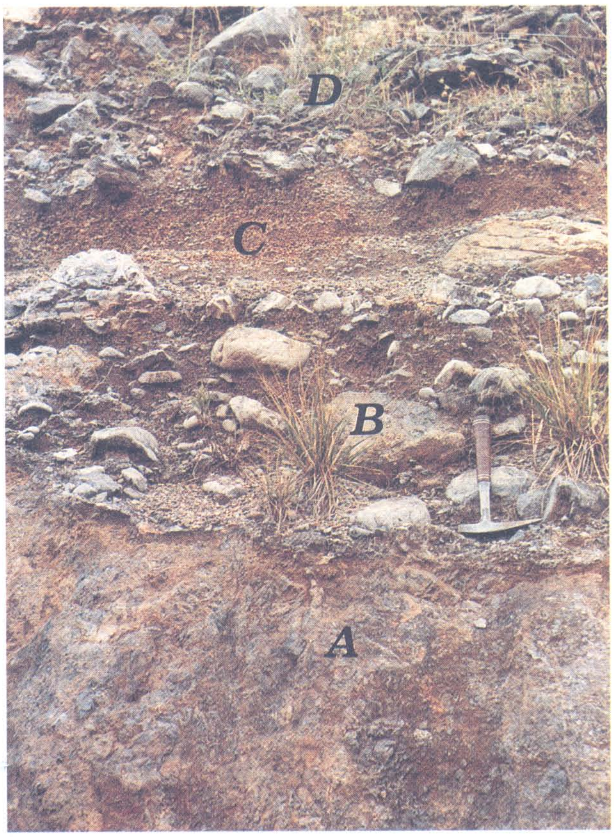


Fig. 11 - Wave-cut surface carved into the dolomite (A) of the substratum at 60 m a.s.l. (2nd-order terrace, sector 6 of Table 1) on the northwest of Scalea. B) conglomerate with predominant *Lithodomus* holes in few places; C) puddingstone with rounded clasts 1 to 2 cm in diameter; D) mixed continental breccias with rare rounded clasts
Superficie di abrasione sulle dolomie (A) del basamento a 60 m di quota a nord ovest di Scalea (terrazzo del 2° ordine, settore 6 di Tab.1). B. conglomerati con ciottoli prevalentemente forati dai litodomi; C. puddinghe con clasti arrotondati di diametro da 1 a 2 cm; D. breccia con rari clasti arrotondati

Our opinion is in good agreement with synthesis data which give an age of about 1 Myr for the beginning of the uplift in Calabria (Ciaranfi et al, 1983). According to Ciaranfi et al. the Southern Apennines started to form in Miocene mainly as the outcome of compressive tectonic stresses. From 1 Myr ago up to present extensive tectonic deformations have taken place causing the great isostatic uplift of the area . Ciaranfi et al. (1983) give an uplift rate of about 0.5 mm/yr for the area between the rivers Noce-Castrocucco and Lao and of about 1 mm/yr for the area farther south along "Catena Costiera". Contemporaneously, the Tyrrhenian area in front of the Calabrian coast was rapidly subsiding.

Based on all these data the formation of the wave-cut platform of the 1st-order terrace (V) started about 1.3 Myr B.P. when the area was still subsiding. The highest shoreline —that which corresponds with the platform inner margin— would mark the sea level elevation when the tectonic uplift started about 1.1 Myr ago (stage 33 or 35 in Williams et al., 1988).

4. CORRELATION BETWEEN MORPHO-STRATIGRAPHIC SEQUENCE AND PALAEOCLIMATIC CURVE

In Figure 15 the orders of the coastal terraces (Plate I) are related to the Pleistocene chronostratigraphic scale and the palaeoclimatic curve of Williams et al. (1988). The first interval of the curve (zone A: 1.66÷0.8 Myr B.P.) shows slight oscillations with average frequency of 45 kyr (stages 57÷25). The second interval (zone B: 0.8÷0.45 Myr B.P.) is marked by irregular oscillations whose amplitude is about 1/3 greater which are characterized by three very marked glacial peaks (stages 22, 16 and 12). At last, there is a third interval (zone C: from 0.45 Myr until present) with more marked interglacial stages with average frequency of 100 kyr and lower glacial peaks than in zone B. Because climatic and eustatic fluctuations are highly interdependent (Shackleton & Opdyke, 1976), the above mentioned features could also be related to marine terraces which are known to form during interglacial high sea stands.

Moreover, another factor governing the formation of the terraces was tectonics. The Santernian deposits on the Tyrrhenian coast of Calabria are often transgressive and unconformable on the Middle Pliocene clay deposits or older sediments, which is suggestive of an uplifting phase during Upper Pliocene (the same that would have caused a stratigraphic hiatus, well documented in Sicily), followed by local lowering during Lower Pleistocene (Fig. 15, col. e). On the other hand, on Crotone Peninsula in eastern Calabria, there is no solution of continuity between Upper and Lower Pleistocene clay deposits (Vrica section, Colalongo et al., 1982).

Subsidence during Emilian (Fig. 15, col. e) led to the deposition of clay found in all "Calabrian" sedimentary basins (Ogniben, 1974). Clay deposition was followed by regressive Sicilian deposits indicative of the marked uplift which has affected the entire region since then (Ghisetti et al., 1983). The Eutyrrhenian deposits with *Strombus bubonius* (stage 5e) have been risen up to 100÷130 m a. s.l. at Ravagnese and Bovetto (southernmost Calabria) (Gignoux, 1913; Bonfiglio, 1973) and 157 m a.s.l. near Pellaro (Dumas et al., 1987).

The regression of Sicilian age is well documented in the Lao valley. The geological section of Figure 9 shows the transition from Emilian clay at the bottom to marine sand, followed by continental sand and gravel with lenses of lacustrine clay on the top (Fig.10). This regression was caused by both tectonic uplift and marked eustatic fall of sea level. The relatively sharp temperature decrease is well documented by the Sicilian type-section of Ficarazzi near Palermo in Sicily (Ruggieri et al., 1984).

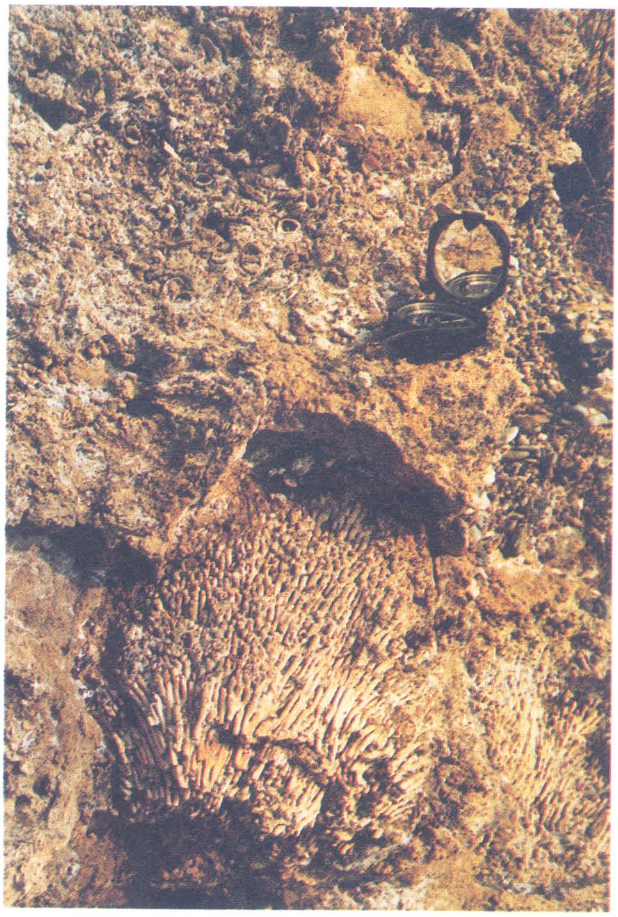


Fig. 12 - Biocalcarenite with *Cladocora coespitosa* outcropping at Grotta del Prete (15 m a.s.l.; sector 5, Plate 1). The U-series age of the deposits is 329 (+196-64) kyr (M. Gewelt, 1989). The deposit can be ascribed to the Y terrace (4th-order)

Biocalcarenite a Cladocora coespitosa *affiorante a Grotta del Prete (15 m s.l.m.; settore 5, Tav. 1). L'età* Th^{230}/U^{234} *su* Cladocora *è risultata di 329 (+196 - 64) kyr (M. Gewelt, 1989). Il deposito può essere ascritto alla linea di costa Y (4° ordine)*

As mentioned earlier (para. 2.2.), Emilian clay and Sicilian biocalcarenite are truncated at Fornaci San Nicola by a transgression surface at an elevation of about 30 m a.s.l. The lowermost 1÷2 m of the deposit overlying this surface are composed of marine sand and large pebbles with *Lithodomus* holes indicative of the first major transgressional event younger than Sicilian (W terrace in Plate 1 and Fig. 15). The formation of this marine terrace can thus be ascribed with good approximation to the stage 21, i.e. to a sharp increase in temperature (Fig. 15, col. g).

After the stage 12 glaciation there are two very

Fig. 13 - Paleocliff and marine cave near Praia a Mare. Marine deposits, *Lithodomus* holes and morphology of the cave indicate the high sea level stand at 18÷20 m above present sea level (4th-order terrace, sector 3)
Paleofalesia e grotta marina nei pressi di Praia a Mare. I depositi marini, i fori di litodomi e la morfologia della grotta indicano il livello marino a 18÷20 m (4° ordine, settore 3)

pronounced warm peaks (No. 11 and No. 9). Stage 9 deposits that have been dated with various methods (Dai Pra & Stearns, 1978; Carobene et al., 1986; Hearty et al., 1986), suggest a situation of high sea level which, in Apulia and Calabria is characterized by a 330 kyr old *Cladocora*-bearing biocalcarenite. Apart from a single evidence at Carelli near Taranto (Hearty & Dai Pra, 1985), neither forms nor deposits to refer to stage 7 have been seen in the field. This may be due to the fact that stage 7 deposits have been covered by the subsequent stage 5 transgression deposits, which outcrop throughout the Mediterranean area, where they can clearly be distinguished because of their typical Senegalese fauna, and on the basis of numerous age measurements.

5. TERRACES AND PLEISTOCENE TECTONICS

The results of the analysis of the terraces in the studied area of Calabria, i.e.: a) identification of four orders of marine terraces (beside the Tyrrhenian *s.l.* terrace, which is not shown on Plate 1) along the stretch of coast examined; b) correlation and grouping of the highest surfaces into a single order (1st-order terrace, V) based on morphological and stratigraphic evidence, and on the localization of the corresponding shoreline in particular (Table 1); c) correlation between the four orders of terraces and the palaeoclimatic curve, and hence chronological distribution of the terraces, also on the basis of U-series age measurements and palaeontological findings as far as Lower Pleistocene is concerned (see Introduction), can be used for an interpretation of the tectonic stresses that acted in the area.

Three groups of faults and lineaments can be distinguished from aerial photos (scale 1:33,000; 1954) and field observations:

a) Westward-dipping N-S trending faults;
b) NW-dipping NE-SW trending faults and fractures;
c) SW-dipping NW-SE trending faults and fractures.

5.1 Vertical movements in time

In agreement with the above mentioned data, the tectonic, morphological and sedimentological evolution of the area would be as follows:

1) Weak and extended lowering of the coast during Lower Pleistocene (Emilian chronozone) causing a slow transgression which formed extensive wave-cut platforms along the coast. The formation of the platforms is the product of numerous high sea stands (see the scheme shown in Fig. 14), while clay sediments containing *Hyalinea balthica* were being deposited offshore (Fornaci San Nicola).
2) Strong and rapid uplift causing major environmental changes such as a) emersion of extensive coastal areas; b) marked increase in the sedimentation rate in the basins; c) termination of clay sedimentation and onset of environmental conditions favouring the formation of clastic deposits. The deposits containing *Globorotalia*

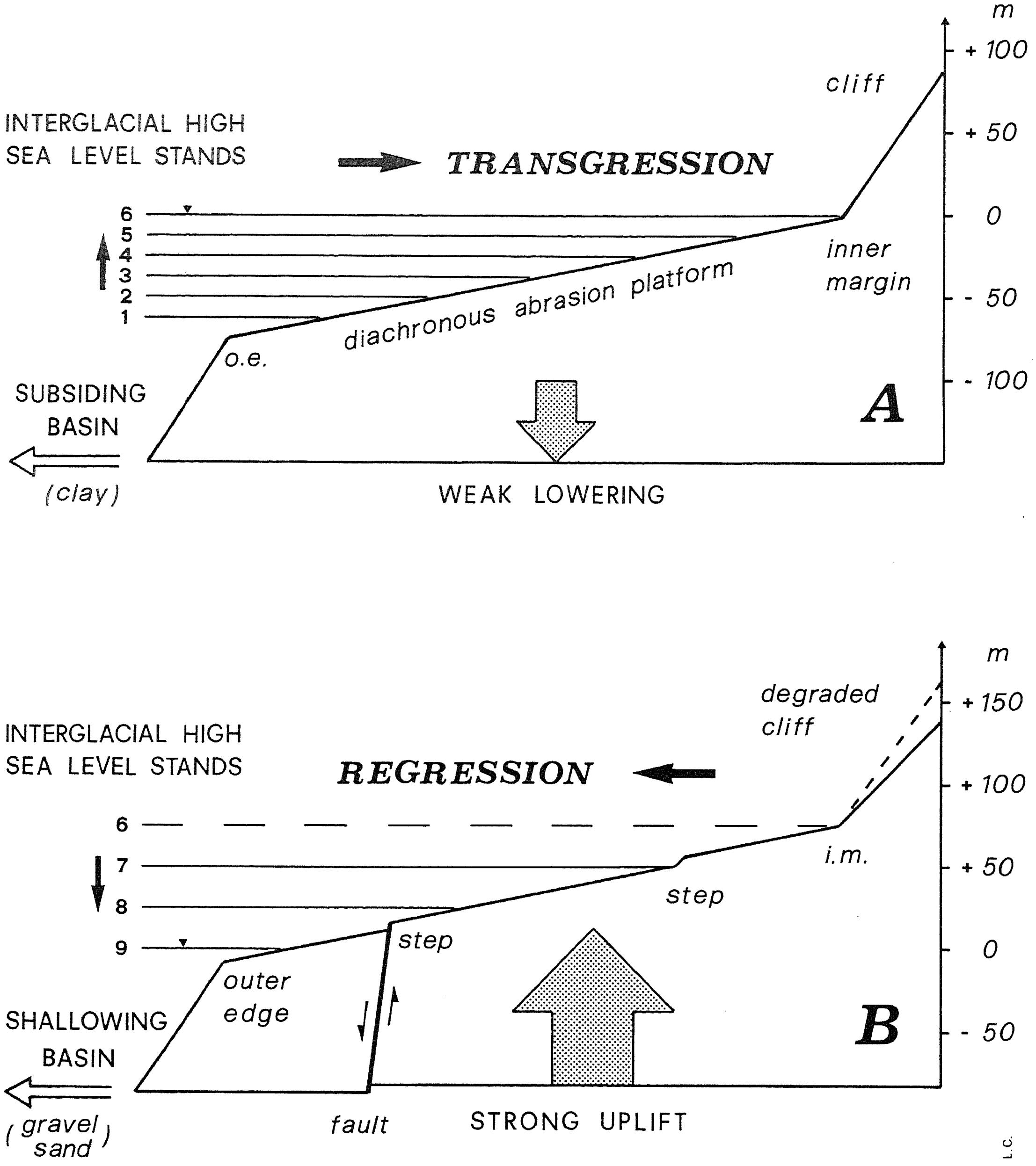


Fig. 14 - Genetic model of the 1st-order terrace.
A) The wave-cut platform has been formed in a long period of time corresponding to the deposition of Lower Pleistocene (Emilian) clay during the numerous high sea stands corresponding with interglacial peaks in the assumption of a long-lasting, slow subsidence (mean rate of subsidence: 0.25 mm/yr, that might be greater offshore), and eustatic fluctuations of equal amplitude occurring every 50,000 years. This model explains both the great width of the 1st-order terrace and the marked difference in elevation between its outer and inner edge. B) The wave-cut platform emerged at the end of Lower Pleistocene (Sicilian) due to an areal rapid uplift involving the entire region. The duration of this "regression period" was, thus, shorter than the preceding "transgression period". Steps on the platform may have formed as a result of high sea stands or faults. The assumptions in B model are: 1) strong uplift (mean uplifting rate of 0.5 mm/yr); 2). eustatic fluctuations as in A; 3). enhanced erosion of emerged areas and greater transport of sand and gravel debris into the sea.
Note: The sedimentary cover is not shown. The drawing is not on scale (the width of the terrace is more than 3 km in places)
Schema di formazione del terrazzo alto.
A) La piattaforma di abrasione si forma in un lungo intervallo di tempo, corrispondente alla deposizione di argille del Pleistocene inferiore (Emiliano), per opera di numerosi alti livelli di stazionamento del mare, corrispondenti a picchi interglaciali. Ipotesi: 1) leggera e lunga subsidenza, mediamente pari a 0,75 m/kyr, maggiore al largo; 2) oscillazioni eustatiche di uguale ampiezza, con periodo costante di 50.000 anni. Questo meccanismo spiega sia la grande ampiezza del terrazzo, sia il forte dislivello esistente tra l'orlo esterno ed il margine interno. B) La piattaforma di abrasione emerge alla fine del Pleistocene inferiore (Siciliano) in conseguenza di un forte sollevamento dell'area. Per questo motivo la durata del "periodo regressivo" è minore di quella del "periodo trasgressivo" precedente. "Gradini" possono formarsi in corrispondenza di stazionamenti marini o di faglie. Ipotesi: 1) sollevamento forte, mediamente pari a 0,5 m/kyr; 2) oscillazioni, come in A; 3) aumento dell'erosione nelle aree emerse con maggiore trasporto di detriti (sabbie e ghiaie) al mare
Nota. La copertura sedimentaria non è segnata. Il disegno non è in scala (l'ampiezza del terrazzo può infatti superare i 3 km)

truncatulinoides excelsa of Sicilian age (Fig. 15) date the beginning of the uplift back to 1.1 Myr. Uplifting of the Southern Apennines (and of Catena Costiera and Sila in Calabria, as well) can be explained with an isostatic compensation in an extensional stress field (Ciaranfi et al., 1983).

3) Uplift and emergence of the 1st-order terrace (V) accompanied by the extensional tectonics .responsible for an uplift greater in the southern areas than in the northern ones (Table 1 and Fig. 16). Uplift might also be the cause of a slight seaward tilting as the slope of the terraces ranging between 2° and 3° with a maximum of 6° for the Monte Carpinoso terrace(5) (Table 1, sector 9) would suggest.
4) The 1st-order terrace that had been broken up into several platforms more or less covered by transgressive-regressive deposits, finally emerged at all during the first major climatic cooling period, which can be related to the stage 22 dating back to about 800 kyr (Shackleton & Opdyke, 1976). This well-documented event (Ruggieri et al., 1984) caused a pronounced eustatic lowering of sea level favouring the emplacement of wide alluvial fans at the mouth of the Lao valley and of other large valleys.
5) The next high stand sea level (corresponding to the stage 21) was much lower than the elevation of the 1st-order terrace (V), both because the coast continued uprise, and sea levels appear to have been lower in the stages 13-21 (Fig. 15, col. g) than the preceding ones. Another wave-cut platform formed (the 2nd-order terrace W), probably also with the contribution of the stage 19 and 17 lower high stand levels (Fig. 15, col g). The corresponding shoreline is everywhere recognizable at the elevation 60-65 m a.s.l. (Fig. 1 and Fig. 3), and it is lower (45 m a.s.l.) only on the right of Noce-Castrocucco river northward, whereas it raises up to 220 m a.s.l. on the south of Lao river (near Diamante, see Table 1).
6) A subsequent great glaciation (the stage 16), that is perhaps the most important glaciation in Pleistocene times, caused the emersion of also this terrace which would no more be reached by the next high sea level (stage 15). It can be explained if the uplift rate in the area and the time interval between the formation of the two shorelines are taken into consideration(6). The high sea level corresponding to the stage 13 may also have contributed to the construction of this wave-cut platform.
7) The stage 12 glaciation (450 kyr old) changed the climatic regime once again. Interglacial lows became more marked with "return time" of 100,000 years on the average (Fig. 15, col. g), and the corresponding high sea level stands coincided with the formation of the 4th-order terrace (Y). Morphological evidence of its shoreline is well visible at about 19 m a.s.l. where a *Cladocora*-bearing deposit has a U-series age ranging between 250 and > 350 kyr (see para. 2.2).
8) On the basis of morphological and sedimentological information it has been possible to localize also the stage 5 shoreline (Carobene et al., 1986) at the maximum elevation of 8÷9 m a.s.l. in this area, which is suggestive of a decrease in the uplift rate during Upper Pleistocene.

5.2 Further considerations on local tectonics

Damiani & Pannuzi (1979) distinguished: a) a severe, Pre-Sicilian tectonic phase bringing about the major differential uplift; b) a second, post-Sicilian tectonic phase following a Sicilian marine ingression, causing a further differential uplift and a north-northwestward tilting, and eventually c) a third, post-Milazzian tectonic phase that was much weaker than the preceding ones. This scheme of tectonic evolution contrasts with our hypothesis as above summarised.

In particular, according to the results of our study, the Middle Pleistocene uplift would be weaker and more uniform: in fact, shoreline W is at a constant elevation of 60÷65 m a.s.l. between the rivers Noce and Lao, whereas it is more than 65 m high a.s.l. on the south of Lao. If the sectors 8 and 9 in Fig. 16 are compared with one another, we see that the difference in elevation can be explained as the effect of faulting with total throw of 155 m. The same comparison for the uppermost V shoreline gives a difference of 310 m, which clearly demonstrates that the most pronounced uplifting and faulting took place before the formation of the W shoreline which is the first in Middle Pleistocene.

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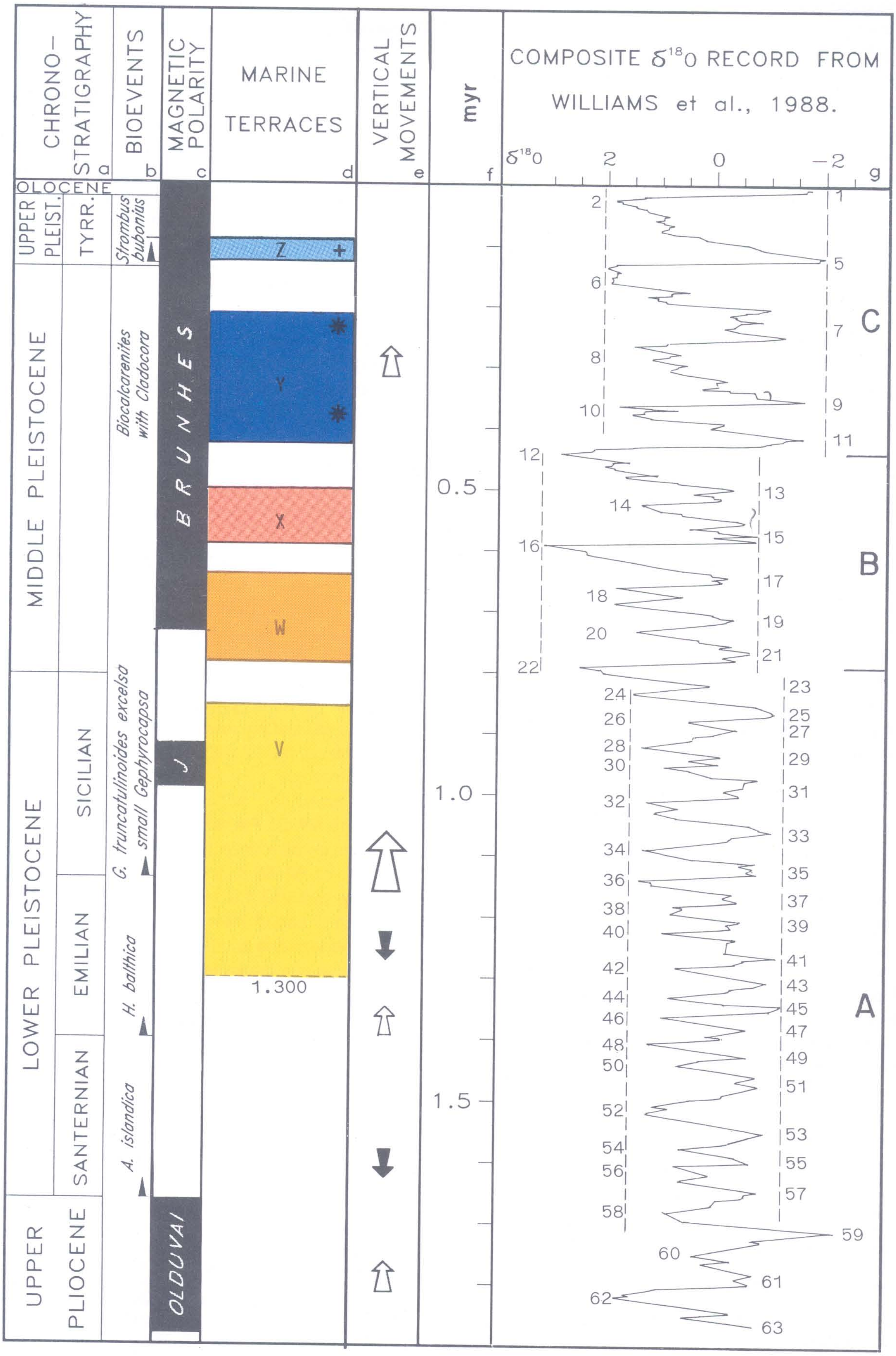
(5) Bradley & Griggs (1976) reported slope values generally less than 2-3° for wave-cut platforms in California. An interesting comparison can be made with their highest platforms: Quarry and Blackrock terraces (dated 900-1200 kyr) may correspond with our V-terrace; Wilder terrace (dated 750 kyr) with our W-terrace, and Western terrace (dated 450 kyr) with our Y-terrace. The Santa Cruz terrace, that is the lowest in elevation is classed as Tyrrhenian (namely, the age of our Z-terrace).

(6) If the 2nd-order (stage 21) and the 3rd-order (stage 15) shorelines are dated 760 kyr and 580 kyr respectively, the rate is the same for both: 0.13 mm/yr, taking into account the original differences in elevation with regard to the present sea level (about-35 m). This would give a theoretical difference in sea level of 24 m for the 180 kyr time interval between the two shorelines. This figure is very close to the 25-30 m observed in the field (see the heights of the two terraces in Plate 1).


CHRONO- STRATIGRAPHY
a
BIOEVENTS
b
MAGNETIC POLARITY
c
MARINE TERRACES
d
VERTICAL MOVEMENTS
e
myr
f
COMPOSITE δ18O RECORD FROM WILLIAMS et al., 1988.
g
δ18O
2
0
−2
OLOCENE
UPPER PLEIST.
TYRR.
MIDDLE PLEISTOCENE
LOWER PLEISTOCENE
SICILIAN
EMILIAN
SANTERNIAN
UPPER PLIOCENE
Strombus bubonius
Biocalcarenites with Cladocora
G. truncatulinoides excelsa
small Gephyrocapsa
H. balthica
A. islandica
BRUNHES
J
OLDUVAI
Z
Y
X
W
V
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0.5
1.0
1.5
A
B
C
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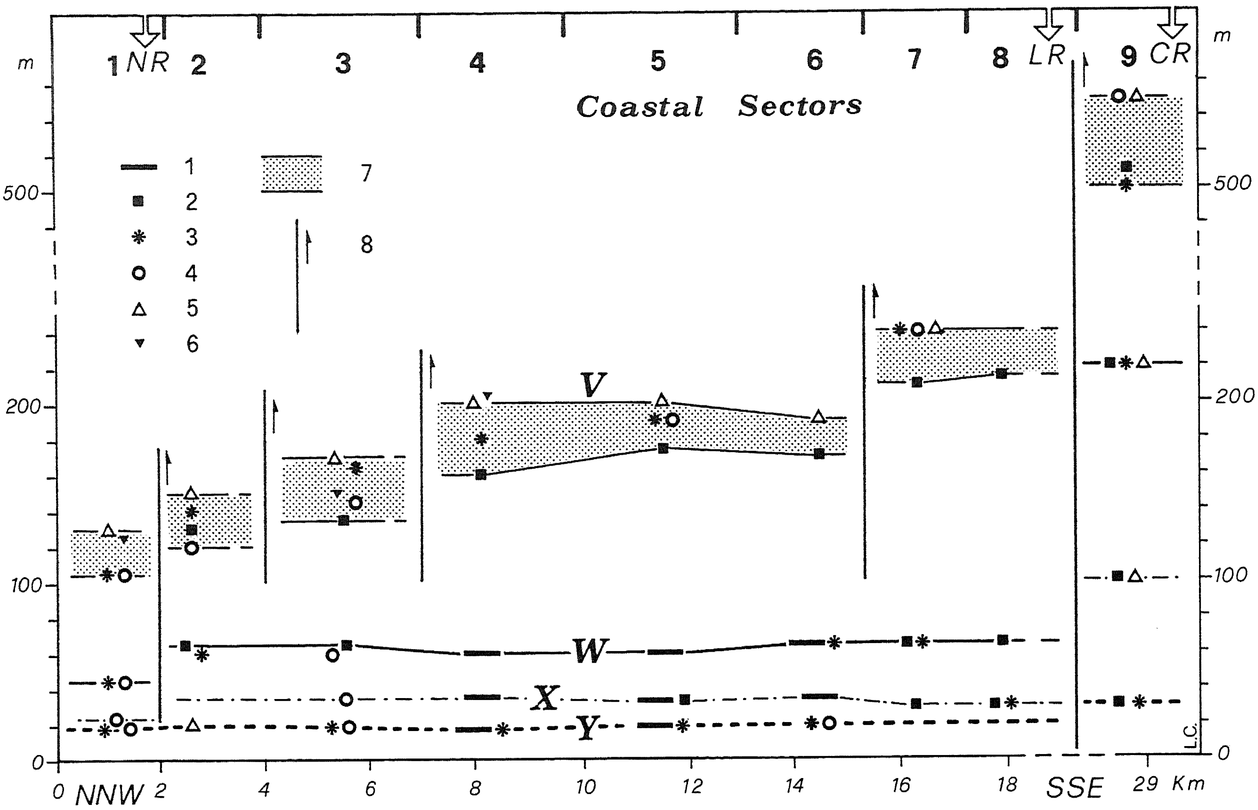

Fig. 16 - Relationship of raised shorelines between one another (terrace order: V, W, X and Y). Symbols: 1. relics of wave-cut platform; 2. inner margin; 3. beach deposit; 4. holes, caves, notches; 5. scarp-foot; 6. eolian sand; 7. altitude range of the 1st-order shoreline; 8. active faults during Pleistocene times; NR. Noce river; LR. Lao river; CR. Corvino river. Names of sectors and elevations a.s.l., as in Table 1. Distances (in km) are the projection of coastline measurements on a NNW-SSE straight line (see Plate I)
Correlazione dei dati relativi alle linee di riva sollevate (ordine di terrazzi V, W, X e Y). Simboli: 1. relitti di piattaforma di abrasione; 2. margine interno; 3 depositi di spiaggia; 4. fori di litodomi, grotte, solchi di battigia; 5. piede della scarpata; 6. sabbie eoliche; 7. banda di oscillazione della quota del terrazzo del 1° ordine; 8. faglie attive durante il Pleistocene ; NR. fiume Noce; LR. fiume Lao; CR fiume Corvino. Per la denominazione delle sezioni e per le quote vedi Tab. 1. Le distanze in km sono riferite ad una retta NNW-SSE parallela all'andamento della costa (vedi Tav. 1)

6. DISCUSSION

Morphostratigraphy of marine terraces in uplifted areas when compared and correlated with chronostratigraphic scale, climatic and eustatic curves, and local tectonic features is a particularly interesting subject. Some of these topics have been considered in this paper, others however require further investigation. As an example, correlation between coastal areas is of particular concern, as well as tectonics is a subject requiring great caution in sketching out conclusions even within a single region. The correlations proposed by Parea (1988) appear, therefore, to be speculative and not well proved.

However, detailed studies of terraces in Sicily, Latium and Southern Calabria enable us to make some comparisons. The series of terraces at Marsala, in western Sicily, are regarded by Ruggieri, Unti et al. (1976) as definitely younger than Sicilian, and Decima (1963) concludes that the highest terraces, previously dated as "Calabrian", are in fact post-Sicilian or contemporaneous with the final stage of the Sicilian cycle because they are separated from the "Montallegro Formation" (southwestern Sicily).

For an identical situation in northern Latium, Conato and Dai Pra (1981) attribute the "Macchia della Turchina series" to Lower Pleistocene and conclude that the terraces of "Casale Pisciarello" and Piana del Termine" represent the first transgressive event in

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Fig. 15 - Relationship between marine terraces, palaeotemperatures and coastal vertical movements.
+ Isoleucina epimerization age; * U-series age dating on *Cladocora coespitosa*
Correlazione fra i terrazzi marini, la curva delle paleotemperature ed i movimenti verticali della costa.
+ Datazioni col metodo dell'epimerizzazione dell'isoleucina;
** Datazioni Th^{230}/U^{234} su* Cladocora coespitosa

Middle Pleistocene.

As to Pleistocene, Di Grande & Raimondo (1984) recognized five orders of terraces in Syracuse (Sicily): the oldest (maximum elevation: 475 m a.s.l.) is associated with the deposition of Lower Pleistocene blue clay; two orders are regarded as Middle Pleistocene, and the two lowermost orders are referred to a generic "Tyrrhenian" time. Elevation of old shorelines varies considerably as a result of the tectonic deformations following the uplift of the area. It is, thus, very likely that the uplift took place in five successive main pulses. According to Di Grande & Raimondo (1984), it is likely that the uplift took place in five successive main pulses.

The highest terrace in Di Grande & Raimondo (1984) would reasonably correspond with our highest terrace (V).

In Aspromonte (southern Calabria), the extensive terraces ("Pianalti") described by Cortese (1909) are found at elevations of over 1000 m. Barrier et al. (1986) identified a shoreline at about 1100 m a.s.l., and described the marine sediments locally covering the wave-cut platform. This shoreline marks the maximum ingression of the sea during Lower Pleistocene, which corresponds to the sedimentation of grey bathyal clay offshore. Uplift at the end of Lower Pleistocene resulted in the deposition of thick layers of gravel ("Ghiaie di Messina") which represent a deltaic, regressive, diachronous formation. Also in this case, the broad analogies between ours and the Aspromonte situation suggest that there is a correlation between the Aspromonte terrace of elevation 1100 m a.s.l. and the "1st-order terrace" described in this paper; as well as the Messina and the Suvareta terrace gravels seem to be homologous.

Another interesting morphological feature is the various extension of the terraces of the northern Calabrian coast (Plate 1). The genetic mechanism of the wave-cut platform as proposed in this paper explains in part such varied extension. In fact, it is likely that numerous high sea level stands over a long time period contributed to the formation of the V terrace (max width 3300 m); whereas three high sea level stands to the formation of terrace W (max width 650 m) and two high sea level stands to that of terrace X (max width 200 m).

Obviously, the width of a terrace depends also upon other factors such as: more or less marked subsequent interglacial high sea stands; succession of high sea stands of equal value; type of bedrock; rate of coastal uplift, etc. The tectonic-eustatic model proposed by Bradley & Griggs (1976) for the development of marine terraces gives a good indication of the moment of marine erosion during a single interglacial high stand of the sea. On the other hand, it does not explain convincingly the great width of some wave-cut platforms.

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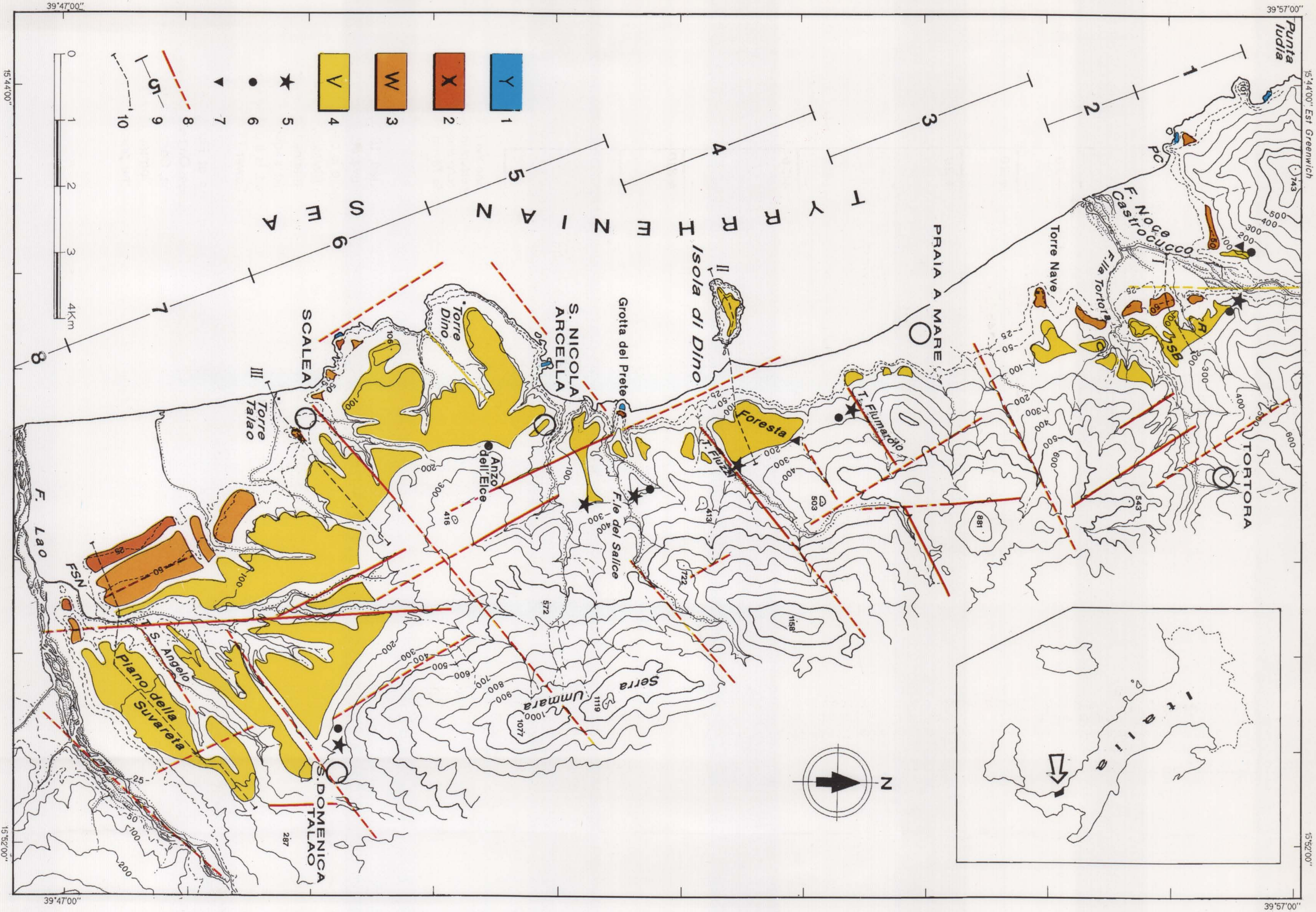

Plate 1 - Schematic geomorphic map. 1) Y terrace; 2) X terrace; 3) W terrace; 4) V terrace; 5) beach deposits; 6) holes of *Lithodomus;* 7) eolian sand; 8) tectonic lineaments, and faults (solid line: certain; dashed line: uncertain); 9) sections of Table 1; 10) morphological profile; PC = Porticello di Castrocucco; R = Rosaneto; SB = San Brancato; C = Castiglione; FSN = Fornace San Nicola.

Carta geomorfologica schematica. 1) terrazzo Y; 2) terrazzo X; 3) terrazzo W; 4) terrazzo V; 5) depositi di spiaggia; 6) fori di litodomi; 7) sabbie eoliche; 8) faglie; 9) sezioni di Tab.1; 10) sezioni morfologiche; PC = Porticello di Castrocucco; R = Rosaneto; SB = San Brancato; C = Castiglione; FSN = Fornace San Nicola.

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