

# Integrated stratigraphic approach to the study of the Neogene-Quaternary sedimentation and volcanism in the northern Hyblean Plateau (Sicily)

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## ABSTRACT

The area investigated lies along the northern margins of the Hyblean Plateau (SE Sicily). The main purpose of this work is to apply the sequence stratigraphy concepts to the well exposed Plio-Quaternary succession stored up in subaerial to deep sea environments. All rock outcrops are mapped at 1:10,000 scale paying particular attention to all contacts which might be eustatically controlled. In particular, we sought to recognise and trace first-order sequence boundaries (s.b. I on the map). The term s.b. I is used to define a sea-level fall below the offlap break which may result in erosion of the bank margin, with the development of deep erosional incisions of the shelf. Our highstand systems tracts generally commenced with a flooding surface and catch-up system, slowly leading to keep-up carbonate production. Finally the development of progradational clinoform beds commenced and a carbonate ramp scenario became established. Moreover, we use the term s.b. II to indicate a sea-level fall which does not fall beyond the offlap break and remains above or at the bank margin level. Consequently, all sediment bodies with wedge-shaped profiles (esp. those with internal, basinward facing clinoform beds) and truncated tops or erosional bases were mapped as potential s.b. II indicators. Significant outcrops were field logged paying attention to positions of maximum flooding surfaces (deduced from bio- and lithofacies shifts). Laboratory work involved field sections plotting for correlation purposes. Petrological studies were carried out on the igneous rocks as many of the extrusives provided time synchronous horizons of value in distance correlation. Carbonate facies were also petrologically analysed as facies shifts were found to be an efficient way of predicting eustatic event timing and directional trends.

## AIMS

The prime aim of the research was to apply current concepts and methods of sequence stratigraphy to a well exposed varied succession deposited in environments ranging from subaerial to deep submarine. In particular, the extrusive igneous suites provided erosion resistant topographies around which highstand carbonates could develop.

## KEY WORDS

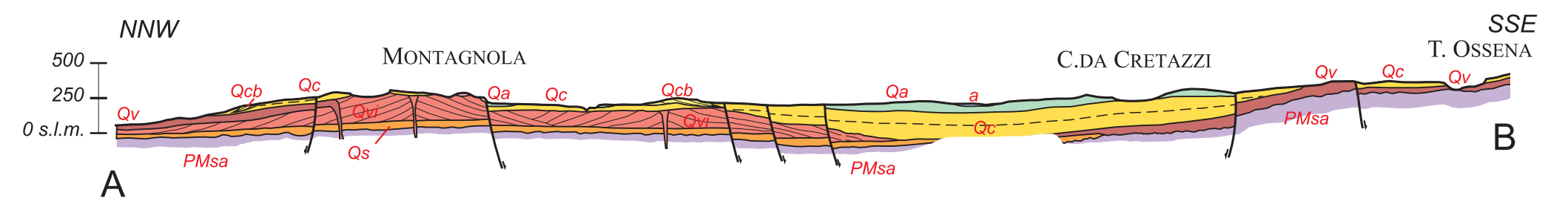
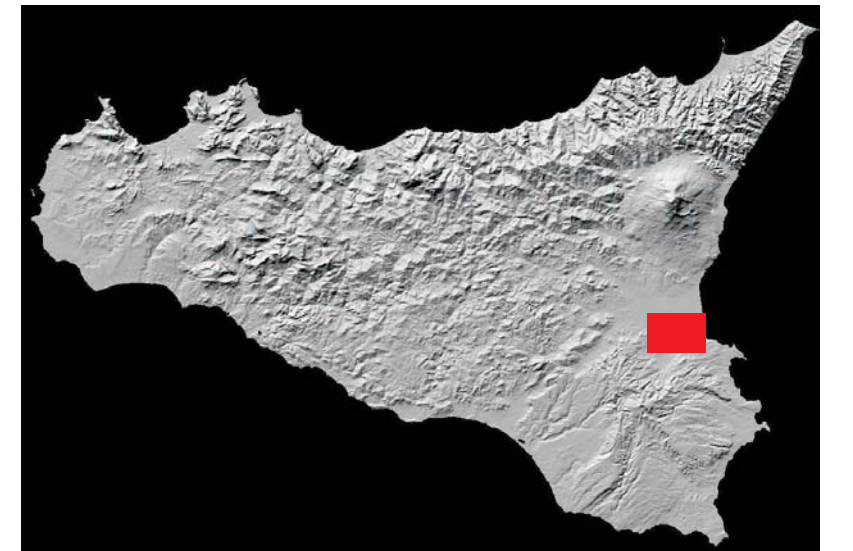
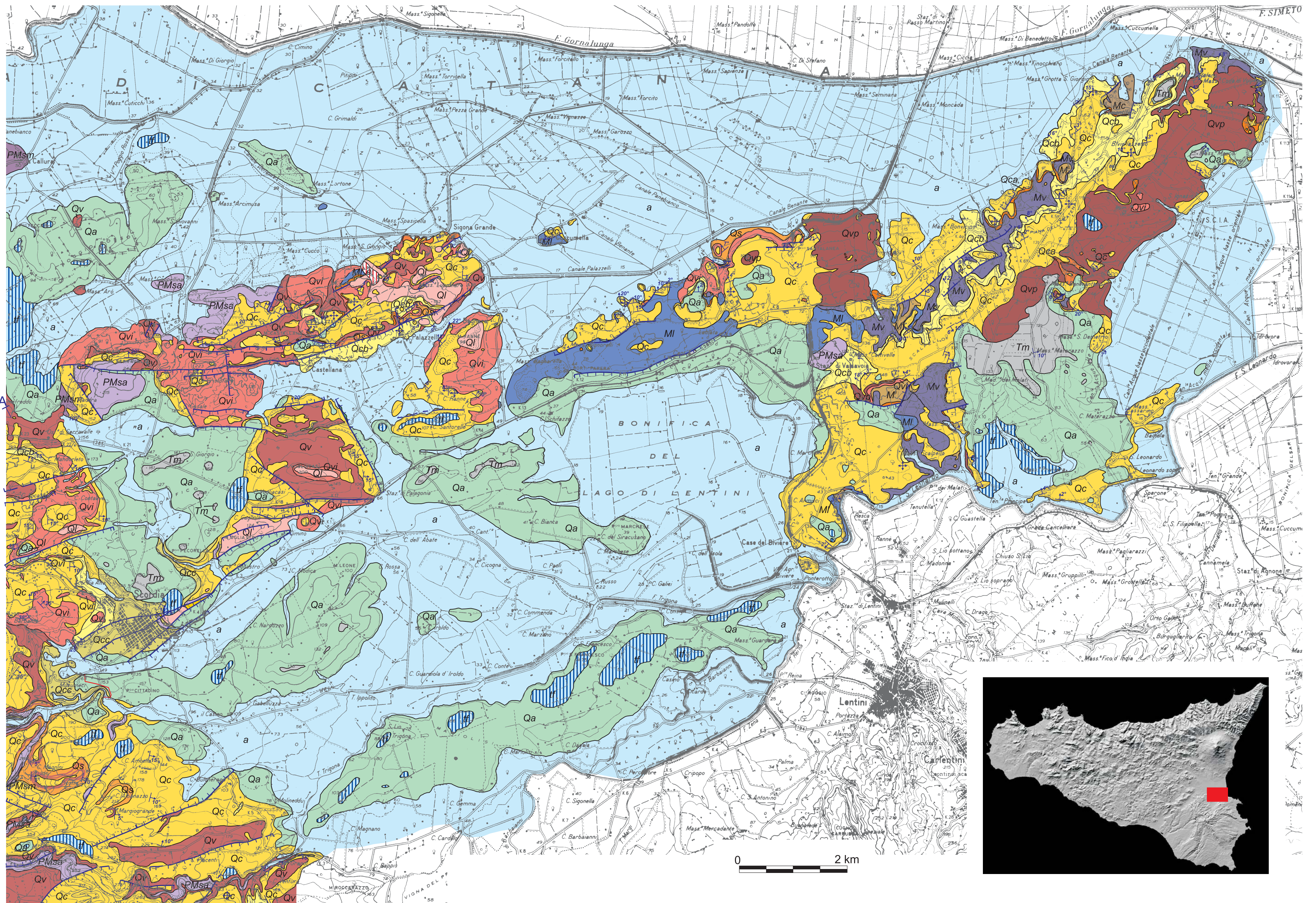
Hyblean Plateau, Plio-Pleistocene, volcanics, carbonate rocks, depositional sequences, sequence boundaries.

## RIASSUNTO

L'area studiata si trova presso il margine settentrionale del Plateau ibleo, dove sono stati applicati i concetti della stratigrafia sequenziale a una successione stratigrafica plio-quaternaria depositatasi in condizioni da subaeree a pelagiche. La cartografia geologica è stata effettuata alla scala 1:10.000, con particolare accuratezza per tutti quei contatti che potrebbero essere controllati da movimenti eustatici. In particolare si è curato di riconoscere e tracciare i limiti di sequenza di I ordine (s.b. I nella carta). Quest'ultima sigla è stata usata per definire un abbassamento del livello marino al di sotto della rottura di pendenza del margine della piattaforma, con sviluppo di profonde incisioni erosive. Nella stessa. I livelli di stazionamento alto iniziano generalmente con una superficie di annegamento e un sistema di cattura, che permettono lentamente l'instaurarsi della produzione carbonatica. Infine inizia la progradazione di strati clinoformi e si instaura una vera e propria rampa carbonatica. Inoltre si indica col termine s.b. II una caduta del livello del mare che comunque rimane sopra o allo stesso livello del banco carbonatico. Di conseguenza tutti i corpi sedimentari aventi un profilo cuneiforme (ad es. quelli con strati clinoformi rivolti verso il bacino) e troncati al tetto o con basi erosionali sono stati cartografati come potenziali indicatori del s.b. II. Gli affioramenti significativi sono stati rilevati con particolare attenzione alle posizioni delle superfici di massimo annegamento dedotto dai cambiamenti nelle bio- e litofacies. Il lavoro di laboratorio ha riguardato le correlazioni tra le sezioni misurate. È stato inoltre condotto lo studio petrologico sulle rocce ignee poiché molti dei corpi estrusivi costituiscono orizzonti sincroni utilizzabili per correlazioni a distanza. Anche le facies carbonatiche sono state analizzate petrologicamente poiché si è verificato che i loro cambiamenti sono utili per predire le tendenze nel tempo e nello spazio degli eventi eustatici.

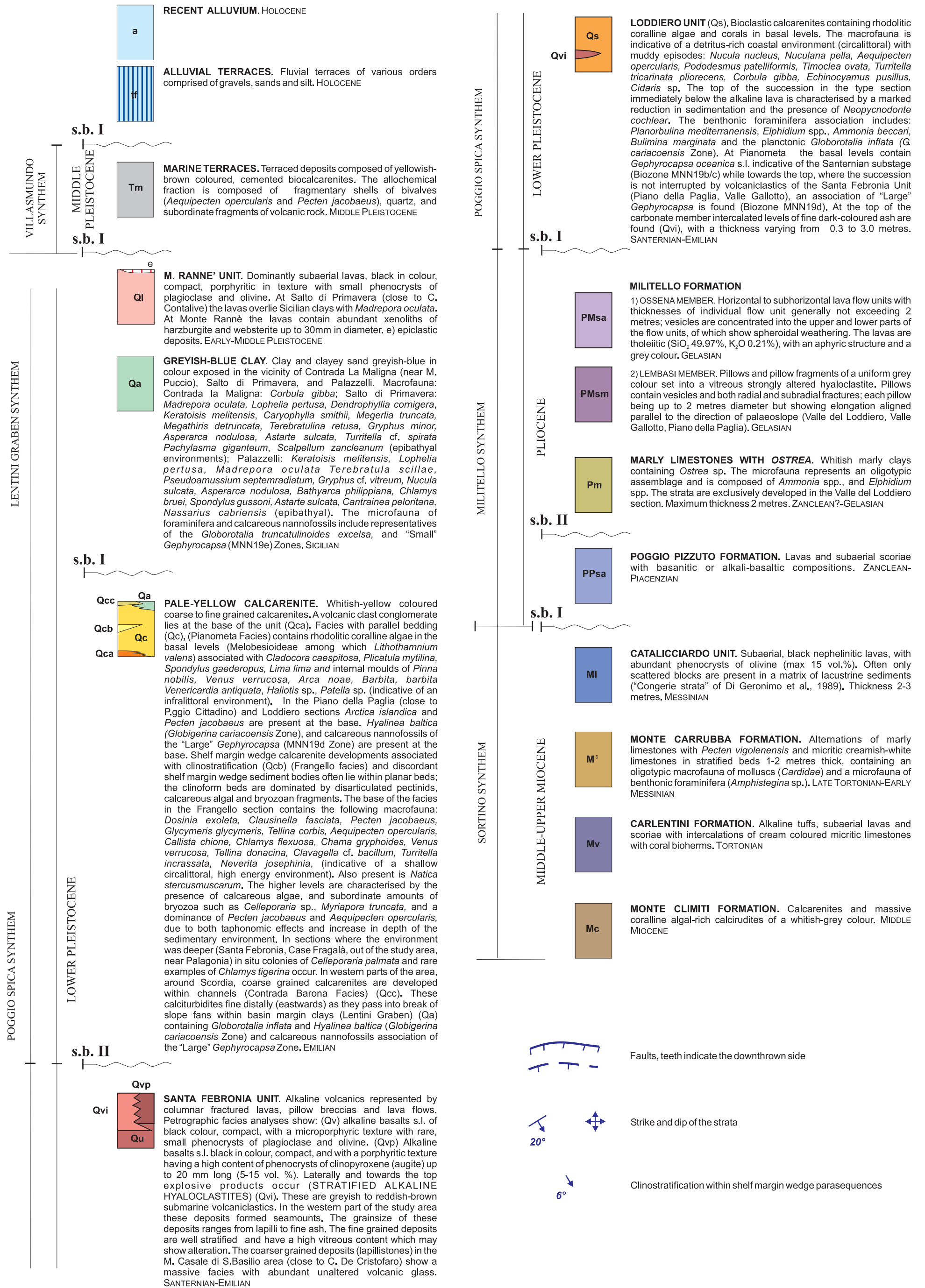


## GEOLOGICAL MAP OF THE NORTHERN MARGIN OF THE HYBLEAN PLATEAU (SE SICILY)





## Hyblean Plateau Neogene-Quaternary stratigraphy





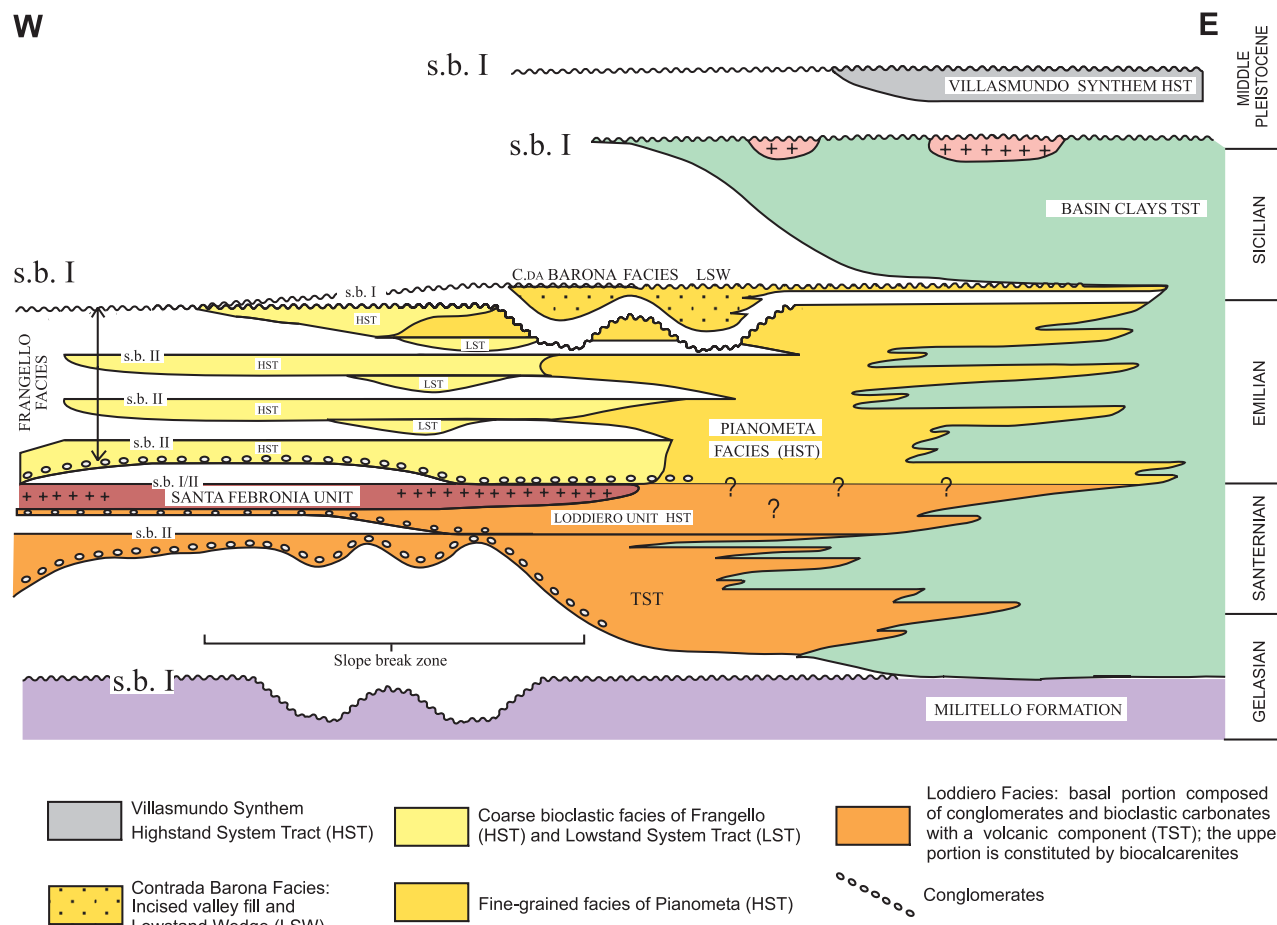


Fig. 2 - Sequence stratigraphic interpretation of the lower Pleistocene cool-water carbonates. The type II bounding surfaces correspond to locally developed parasequences. The reworked carbonates associated with these parasequences accumulated in lowstand perched sandbodies at the shelf margins. The Santa Febronia lavas are essentially an instantaneous event, but provide an important dating horizon close to the base of the carbonate succession.

### REGIONAL CONTEXT OF THE PLEISTOCENE SUCCESSION ALONG THE MARGIN OF THE HYBLEAN PLATEAU

Lower Pleistocene strata are exposed throughout the coastal areas of Sicily and occupy much of the south-central part of the island (BUTLER *et alii*, 1997). These strata contain a particularly bioclastic-rich carbonate succession deposited in marginal areas of the Hyblean Plateau of SE Sicily (PEDLEY & GRASSO, 1991). They are exceptionally well-exposed in the northern and western sectors. This extensive exposure results from almost 1 km of uplift and associated block faulting, which commenced at the end of the Early Pleistocene.

### GEOLOGICAL SETTING

The Hyblean Plateau occupies the southeast corner of Sicily east of Gela and south of Catania. The plateau is separated from the Gela Nappe (OGNIBEN, 1969) to the northwest by a narrow foredeep, Catania trough, that extends from Catania to Gela and is filled with Quaternary and Recent sediments overlying upper Pliocene to Lower Pleistocene volcanics. The Gela Nappe, a Plio-Pleistocene thrust wedge (BUTLER *et alii*, 1982), represents the external front of the Maghrebian thrust belt. This thrust belt was generated by continental collision between the northern edge of the African Plate (the Hyblean Plateau) and the Calabrian Arc which lies on the north-eastern tip of Sicily, but is largely submerged offshore northern Sicily (southern Tyrrhenian Sea). The western margin of the Hyblean Plateau is marked by a large north/northeast-trending system of transfer faults (Scicli, Comiso and Acate Faults), along which movement took place during the Plio-Pleistocene (GRASSO & REUTHER, 1988). Toward the east, the plateau is bounded by the Malta Escarpment, a zone of normal faulting and sinistral strike-slip movements (GRASSO, 1993).

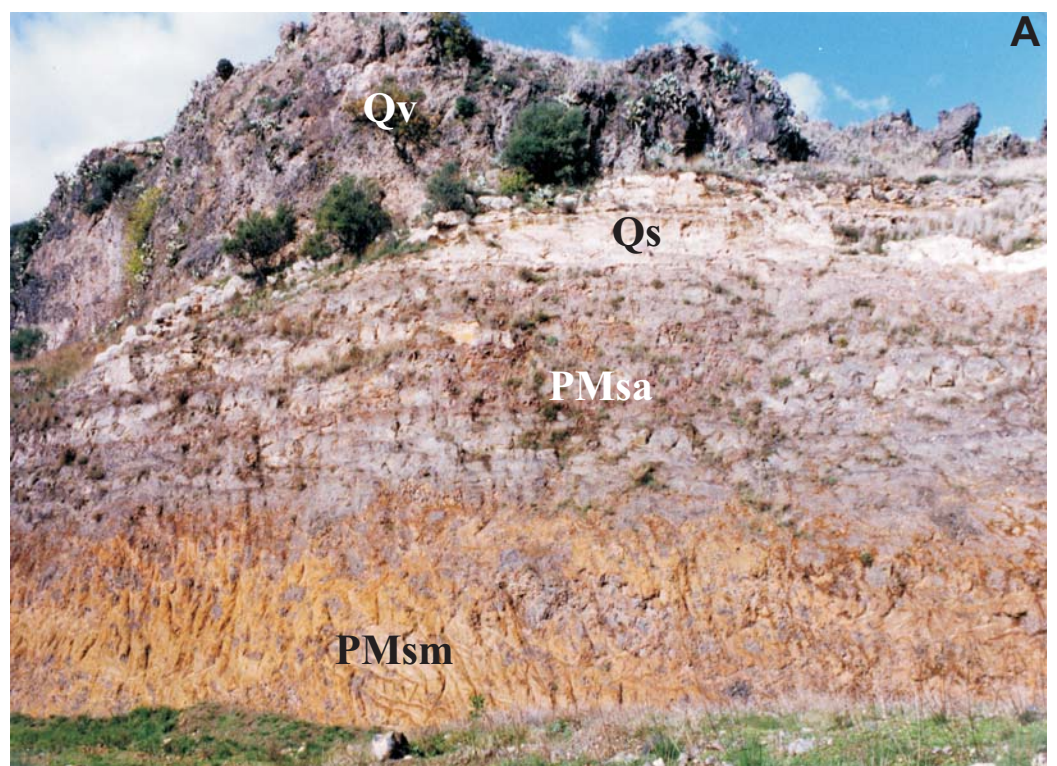


Fig. 3 - A: Stratigraphic-depositional relationship between the submarine (PMsm) and subaerial (PMsa) members of the Militello Formation in the Loddiero Valley. The Loddiero Unit (Qs) and alkalic lavas of the Santa Febronia Unit (Qv) are visible at the top; B: Schematic section through the submarine and subaerial portions of a growing lava delta (from SCHMINCKE *et alii*, 1997).

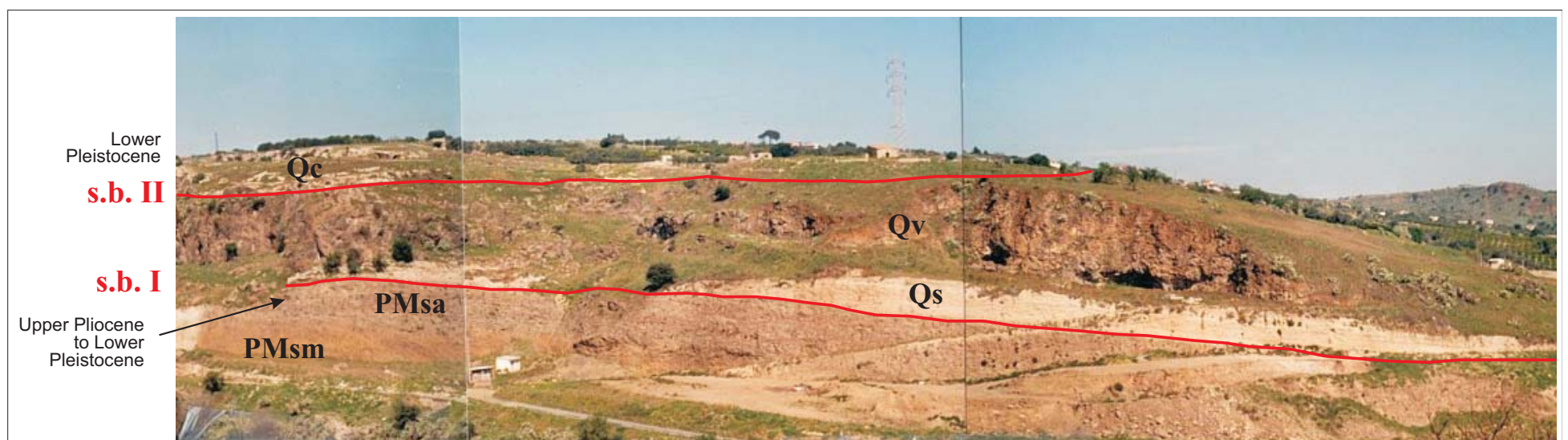
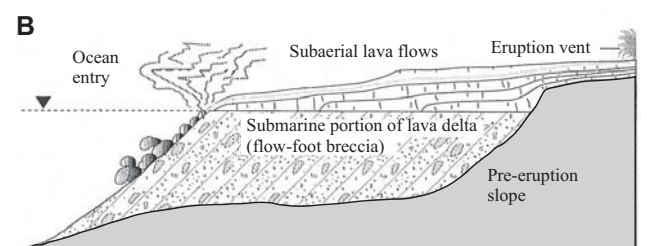


Fig. 4 - Panoramic view of the left bank of the Loddiero Valley: the Militello Formation (PMsm; PMsa) and the Loddiero Unit (Qs) are separated by a s.b. I. The Santa Febronia

Unit (Qv) is separated from the overlying Pale-yellow Calcarene (Qc) by a s.b. II (top of sequence).



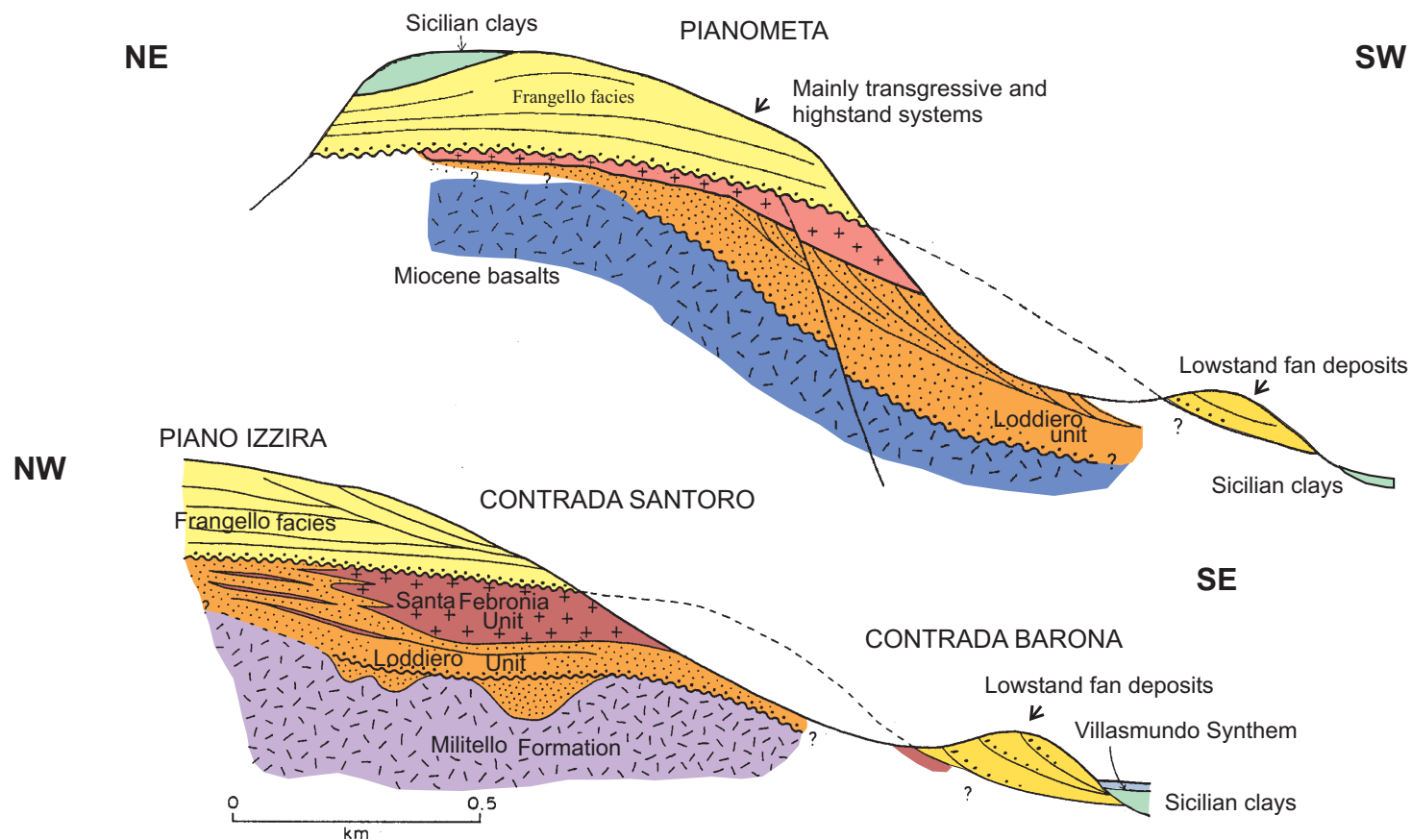


Fig. 5 - The stratigraphic relationships between the various units are best displayed along the north-facing margins of the map. Here considerable submarine topography occurred and bioclastic carbonate sediments were deposited during highstand events as drapes over these irregular surfaces. Sediment shedding to the basin (Catania Trough) was most important during s.b. II events. Initially, this was manifested in the development of shelf-perched parasequences (generally wedge-shaped, progradational bioclastic sand bodies). On several occasions progressive eustatic falls in sea-level resulted in major episodes of sediment dismantling and their redeposition as lowstand fans at the slope/basin break.

The base of the Loddiero Unit also shows the development of a ravinement surface cut into the Militello Formation. This represents the former establishment of a s.b. I event which effectively marks the base of the "Emilian" eustatic cycle (see Figs. 7 and 8).

Carbonates were developed on the palaeohighs and around their flanks within the study area, but marls and clays occupy the basins. The Catania Trough, a foredeep that became emergent at the close of the Early Pleistocene, borders the northern side of the study area. It is now occupied by the present-day Catania Plain. To the south lies the Lentini Graben, a clay filled basin, which was already established by the earliest Pleistocene (TORELLI *et alii*, 1998). These two basins contain a full record of argillaceous sedimentation extending continuously from the late Pliocene right through to the end of the Early Pleistocene.

Between the Catania Trough and the Lentini Graben lies the San Demetrio High (TORELLI *et alii*, 1998), upon which extensive carbonates developed contemporaneously with the basinal argillaceous successions. These carbonates extend further west to the towns of Palagonia and Mineo, and into the Vittoria Plain on the western margin of the Hyblean Plateau (GRASSO *et alii*, 2000). Carbonates of the same age also occupy marginal locations around the southern flank of the Lentini Graben. PEDLEY *et alii* (2001) place the entire Lower Pleistocene carbonate succession into a single fourth-order depositional unit bounded above and below by first-order sequence boundaries (s.b. I). The earliest carbonates lie above tholeiitic lavas at Vallone Loddiero (Figs. 3 and 4). Late-stage alkaline basalts underlie and are intercalated with Emilian carbonates. Tholeiitic lavas lying closely beneath the Emilian carbonates to the SW of the study area were dated by TRUA *et alii* (1997) as 1.98-2.09 Ma (Late Pliocene). The younger association of alkaline basalts gives an  $^{40}\text{Ar}/^{39}\text{Ar}$  date of 1.47 Ma in Vallone Loddiero (TRUA *et alii*, 1997). Pillow basalts of similar composition, lying at the base of the Emilian carbonates within the western part of the study area, give a K/Ar age determination of 1.35 Ma (SCHMINCKE *et alii*, 1997). Collectively, these dates indicate that carbonate deposition began some time in the Santernian substage of the Early Pleistocene. Micropalaeontological investigations (PEDLEY *et alii*, 2001) confirm a

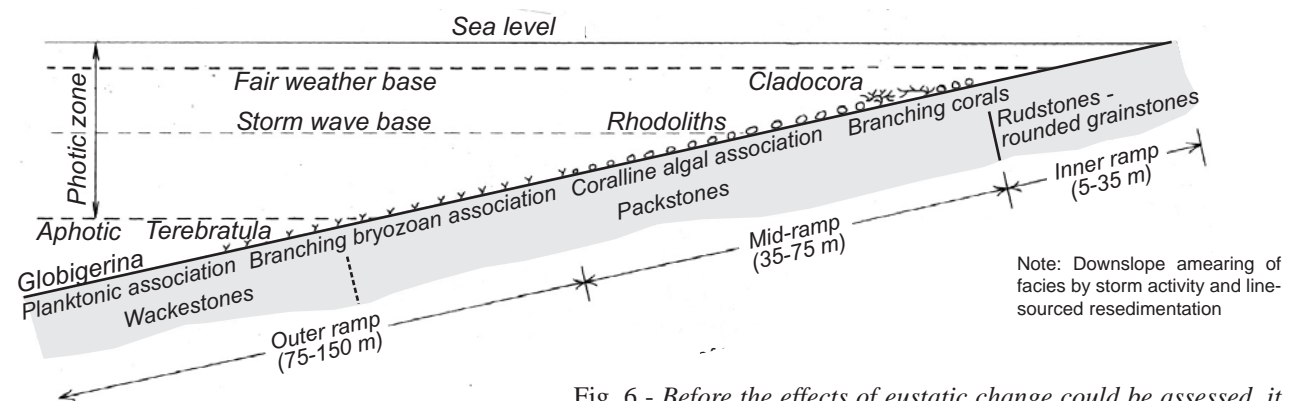


Fig. 6 - Before the effects of eustatic change could be assessed, it was necessary to investigate the sedimentological regime. This figure combines data from many sections to illustrate the nature of the Emilian cool-water carbonate ramp scenario which typifies most of the depositional pattern in the region. The figure shows the interrelationships between water-depth, photic zone, turbulence and biota distributions. Some faunas are substrate specific (e.g. *Arctica islandica*) and are not included. Lateral shifts in the relative positioning of the biofacies in any outcrop site have been used as an indication of relative shallowing and deepening within the succession. Most relative changes can be correlated across the region and provide substantial evidence that change was eustatically rather than tectonically induced (PEDLEY & GRASSO, 2002).

Fig. 7 - s.b. I events: the base of the Pleistocene carbonate sequence is a major planation surface, found throughout the region irrespective of substrate type. The thin basal part of the carbonate sequence is dominated by reworked conglomeratic material, usually associated with interstitial deeper-water lime mud and bioclastic matrices. Generally speaking, there is a marked absence of cross-stratification and tidal influence in the deposits. Location: Loddiero Valley.



Fig. 8 - Ravinement surface (red line): in areas where the basal Emilian marine planation surface (s.b. I boundary) is not deeply incised, relict fluvial channels are preserved. These are infilled with mixed bioclastic and volcanic cobble deposits, similar to those present regionally above the basal sequence boundary. This infilled channel is about 30 m wide and is cut into the top of the Militello Formation lavas. Location: Loddiero Valley.



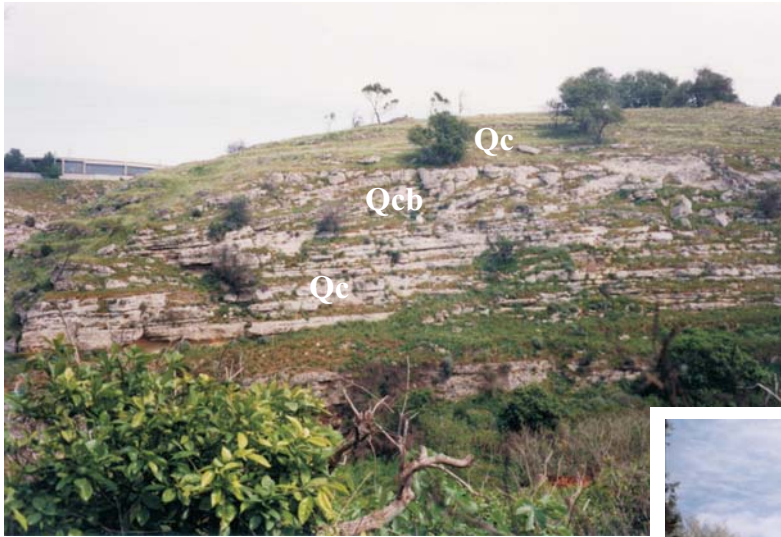


Fig. 9 - Shelf-perched, bioclastic sand body: at intermediate depths along the depositional slope, basinward prograding carbonate sand wedges (Qcb) are developed within the mid-outer ramp setting. Characteristically, they show a tangential transitional base, but a truncated planar top. They represent sedimentation during minor falls in sea-level (10-30 m) during the overall Emilian highstand event. They are usually succeeded by high-stand carbonate drapes which show a return to mid-outer ramp settings. As many as six of these events probably occurred. However, rarely are more than two seen in any natural section. Location: W side of Lentini town.

late Santernian start to carbonate deposition (*Globigerina cariacensis* Zone). No chronometric dates are available for the youngest alkaline basalts. Nevertheless, on micropaleontological grounds, these appear to lie close to the base of the Sicilian substage, i.e. about 1.2 Ma according to CITA & CASTRADORI (1995) but 0.8 Ma according to ZAZO (1999). The carbonate episode correlates with a major glacio-eustatic excursion within the TB3.8 cycle of HAQ (1991), which culminated in a highstand between 1.3 and 0.8 Ma, in association with an estimated sea-level rise of about 80 m. Overall, this Emilian succession provides an ideal opportunity to examine the processes and products of a eustatically-controlled, cool-water carbonate succession that developed within a microtidal sea. The Lower Pleistocene carbonate episode began during the Santernian. However, primary carbonate production had switched off by the late Emilian. A conservative estimate of 500,000 years is assumed for the duration of carbonate production based on the chronostratigraphic chart of HAQ (1991). This is in general agreement with the age of the oldest Pleistocene marine (high-stand) terrace in the Calabria Region of southern Italy, which is correlated with the Emilian chronozone (*Hyalinea baltica*), and is estimated by ZAZO (1999) to have developed between 1.3 and 0.8 Ma. However, limited local downslope resedimentation continued into the earliest part of the Sicilian substage during the ensuing regression.

CONTROL OF THE VOLCANIC SEAMOUNTS ON THE PALEOBATHYMETRY AND CARBONATE FACIES DISTRIBUTION

The Early Pleistocene sea-floor topography at the time of carbonate development was strictly controlled by volcanic seamounts and adjacent basins. In the north-western areas, along the divide between the Catania Trough and the Lentini Graben, pre-Emilian synsedimentary volcanism associated with horst faulting created seamounts and ephemeral small islands. These range in size from local culmination less than 500 m in diameter to linear ridges several kilometres long. Many seamounts are truncated by pre-Emilian marine planation surfaces. Emilian bioclastic carbonates are developed around former island and/or cap extinct seamounts. Carbonates deposited on such shallow seafloor, are generally thinner than their ramp equivalents and show steep flanking dips. In addition, in the San Demetrio area, a buried



Fig. 10 - End Emilian s.b. I boundary. In mid- and outer-ramp locations, the top-most metre of carbonates shows evidence of coarsening, sometimes with thin, cross-stratified units (tidalites). Location: Piano della Paglia, southern side of Scordia town. Elsewhere, Sicilian clays begin immediately above a sharp contact, but may contain one or more resedimented, thin, bioclastic carbonate levels. Towards the inner ramp margins, the basal part of the Sicilian clay is not developed and one or more palaeosoils occupy the topmost level of the Emilian carbonate unit.

Fig. 11 - Lowstand fan deposits: These are mainly associated with development of the shelf-perched sand bodies related to s.b. I, II events (especially areas facing the Catania Trough on the northern borders of the map). Such fan deposits developed when accommodation space was not available around the shelf margin and eroded inner ramp bioclastic sediments bypassed the shelf margin zone. These bypass sediments developed into thick breaks of slope wedges and are characterized by calciturbidite-filled interpenetrative distributary channels associated with broad submarine fans. Location: P.gio Pecorella.



Miocene topography created a broad NE to SW orientated ridge upon which short ramp sequences (< 2 km long) are developed.

VOLCANISM IN THE HYBLEAN PLATEAU: SHORT-LIVED BUT COMPLEX EVENTS AND THEIR IMPACT ON SEDIMENTATION PATTERNS

The geological evolution of the northern Hyblean Plateau has been characterized not only

by sedimentation and sea level fluctuations, but also by long-lived episodic volcanism that extended over about 230 Ma. The most important impact of volcanism was the repeated construction of volcanic edifices which sometimes rose above the sea level. Much information on the character of eruptive activity and depositional processes can be gained from the study of outcrops of the more recent (~8-1.5 Ma) events. Neogene-Quaternary volcanic activity in the map area consisted of at least seven compositionally distinct episodes of short

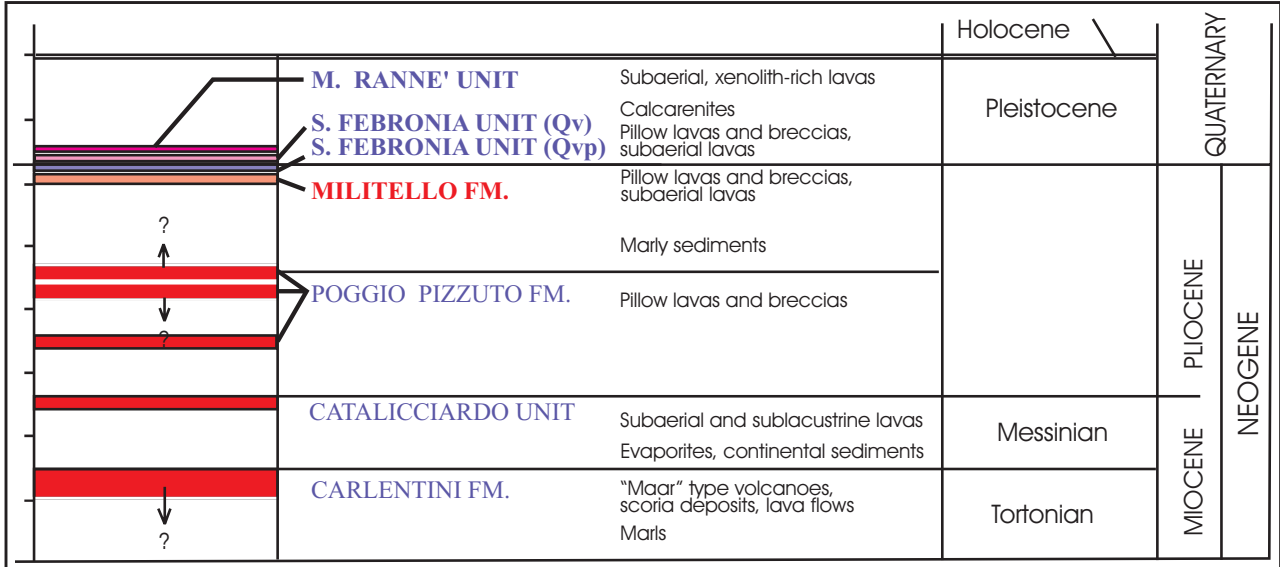


Fig. 12 - Schematic stratigraphic representation of Neogene-Quaternary volcanic events in the map area. All events, with the exception of the Late Pliocene tholeiitic Militello, event produced small volumes of alkalic basalts and probably lasted from a few days to weeks. The Militello event is thought to have lasted from a few years to a few decades at most.



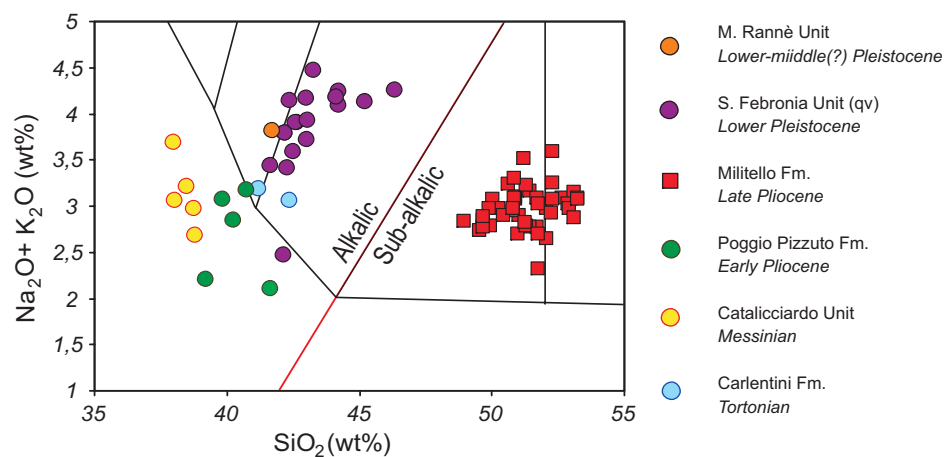


Fig. 13 - Total alkali-silica (TAS) diagram of volcanics in the map area. Note the distinct separation of the tholeiitic Militello products from the alkalic basalts of the other eruptive events. There is no clear compositional trend in time from any one event to another.

duration and separated by much longer intervals of quiescence during which carbonate sedimentation took place (Fig. 12). Most of these events were extremely short-lived (days to weeks) and produced minor volumes, mostly of lava, generally in a submarine environment, although a few volcanic edifices grew above the sea level to form small volcanic islands. The products of these minor events are alkalic basalts, ranging from nephelinites to alkali basalts (Fig. 13). However, the most voluminous and complex eruptive event, during the late Pliocene, produced tholeiitic lavas (Militello Fm.). Due to high mass eruption rates during this event and a generally shallow bathymetry, volcanic edifices rapidly grew above the sea level to form one or more volcanic islands, with nearly all eruptive activity becoming subaerial. Emplacement of lava flows on the newly formed land occurred as fairly uniform pahoehoe sheets (Fig. 14), whereas lava reaching the coasts built lava deltas, and entering the sea was transformed into pillows and associated breccias of pillow fragments and finer-grained hyaloclastite (Fig. 15). The full duration of the tholeiitic Militello event is estimated as having lasted between a period of a few years to decades, as indicated by the fairly homogeneous compositions and lack of primary sedimentary intercalations within the Militello eruptive products. At least 120 km<sup>3</sup> of magma were erupted, possibly at peak rates of 103-104 m<sup>3</sup>s<sup>-1</sup>, similar to those calculated for the Columbia River Flood Basalt (USA). Outcrops in the south-western part of the map area give spectacular sections through the submarine and subaerial lava delta facies, especially in the Loddiero Valley. Complexities such as changing directions in the dip of the deposits over short distances, intercalations of pillow lavas and breccias within subaerial pahoehoe units, as well as differences in altitude of the contact between the submarine and subaerial facies, are mostly due to instabilities during growth of the lava deltas. Such instabilities include subsidence and collapse of sections of a growing delta, caused by rapid accumulation and compaction of pillow breccias and hyaloclastite caused by the increasing weight of the overlying subaerial lavas. Post-Militello alkalic volcanism continued into the Early Pleistocene, with at least four brief eruptive episodes that produced modest volumes of submarine and subaerial lava (at times associated with hyaloclastites and pillow breccias) and local pyroclastic deposits (bombs and scoriae). The presence of subaerial deposits indicates that volcanic islands were built during

extensive NE-SW-trending fissure systems that coincide with the predominant regional tectonic alignments. A strong tectonic control on volcanism is thus likely, at least as far as eruption sites and, possibly, eruption times are concerned.

Fig. 14 - Photograph of subaerial pahoehoe lava flow units of the tholeiitic Militello Fm, a few meters above the transition from the underlying submarine (pillow lava and hyaloclastite) facies. The thickness of individual flow units ranges from 0.1 to 0.5 m in the lower half of the photograph; the uppermost flow unit is up to 2 m thick. The basal and top parts of each flow unit show a higher degree of vesicularity than the massive inner portion. Light-brown intercalations of palagonitized clastic material are tephra generated by explosive interaction of lava with sea water at the nearby coast; in a few cases this tephra was baked by overlying lava flows, as is visible in the bottom-right of the photograph. Location: active quarry a few kilometres north of Vizzini.



Fig. 16 - Sequence boundaries and lime-mud cements: the truncated tops of many shelf-perched sand bodies contain quantities of lime mud, sometimes associated with planktonic foraminifera. In contrast, the lower parts of clinoform beds within the prograding wedges contain significantly less lime mud and no planktonic foraminifera. Such lime-mud infiltration after planation of the perched sand body is considered to be related "to catch-up" surface development. The phenomenon indirectly demonstrates the rapidity of eustatic sea-level rise compared to bioclastic carbonate production (the thicker the lime-mud infiltration zone, the longer the time span before the truncation surface is overstepped by prograding highstand carbonates). Location: Pinnatazza (Scordia).

## TOWARDS A NEW CONCEPT OF COOL-WATER CARBONATES IN MICROTIDAL SETTINGS

Carbonates behave quite differently from clastics during eustasy. Typically, carbonate production is geared to highstand events, with dismantling, resedimentation and ravinement during lowstands. Far less is known about cool-water carbonate processes than about tropical carbonates and, prior to this project, even less had been established concerning the behaviour of cool-water carbonates in microtidal settings. From this and related studies, it can now be established that cool-water carbonate lithofacies are developed in much shallower depths than their counterparts in the oceans of the world. The absence of extensive tidal reworking during falling sea levels (forced regression), ensures that most of the regressive-system tract is preserved. In the case of the Emilian carbonate episode, this includes the development of progressively shallower deposits including thin "tidalite" units intercalated with palaeosols



Fig. 15 - Photograph showing detail of the submarine facies association (flow-foot breccia) of a tholeiitic lava delta (Militello Fm.). From right to left the following facies can be observed: an interval of fine-grained hyaloclastite without pillows; several thin (=10 cm) sheets of "para-pillow lava" (strongly elongated lava bodies indicating high effusion rates and shallow water depth); a thicker (~0.5 m) sheet of "para-pillow lava", which develops in its upper part (above hammer) into a pillow-like protrusion; a pillow that drained and collapsed, with multiple rinds indicating repeated influx and draining of lava; a hyaloclastite interval containing numerous pillow fragments. This complex facies association shows a rapidly changing supply of lava from a coastal platform onto the growing submarine flow-foot breccia, determined predominantly by the shifting of the points where lava flows entered the sea at the coast of a growing volcanic island. Location: Lembasi Valley, at southern margin of Militello.







Fig. 17 - *Cladocora caespitosa*: monospecific patch reefs of this cool-water ermotypic coral are common in the eastern Mediterranean today. They also occur as widespread developments in the earlier part of the Emilian carbonate of the northern Hyblean region. Significantly, they are absent from the closing phases of carbonate production. This suggests that sea water temperatures were higher at the start of the Emilian transgression than at the close of the carbonate event.

containing pulmonate gastropods.

The initiation of the Emilian transgression appears to have been relatively rapid. A thin conglomerate caps the underlying ravinement (flooding) surface. However, within one metre, the overlying carbonates have passed through an initial coralline algal-rich facies and into bryozoan dominated lime muds (outer ramp facies >75 m water depth). Shoreface sand bodies are developed only around the landward margins of the Emilian carbonate development, and there only in association with cyclic oscillations in sea level during the overall highstand.

In mid-ramp settings, these highstand eustatic oscillations are recorded by "lowstand shelf-perched sand bodies" (Figs. 9 and 16). These take the form of prograding, wedge-shaped parasequences which are developed at slope breaks. Individual clinoform beds within the parasequences are generally 2-6 m in amplitude and clinoform bed-sets can span up to several hundred metres. These parasequences have

transitional bases but frequently show truncation at their crests.

During prolonged minor lowstand oscillations within the overall Emilian highstand event, large volumes of carbonates, eroded from shoreface areas, bypassed these shelf-perched sand bodies and were shed directly to the basin margins. These sediments formed lowstand fan sand bodies (Fig. 11), which are now poorly exposed in most areas but are well seen at Contrada Barona. Generally these sediments can be distinguished from on-ramp deposits by the development of interpenetrative channelling and a dominance of calciturbidite facies. Frequently, there is also a significant admixture of small volcanic clasts and chaotic mollusc debris. Associated in-situ faunas are rare although *Terebratula terebratula* is a notable exception. Significantly, there appears to have been virtually no ravinement and dismantling of the carbonate system at the close of the Emilian warm water episode. Subsequently, the Sicilian transgression carried deep water clays over the

Emilian carbonates, again without observable erosion.

Details of the Emilian eustatic curve presented here (Fig. 18) are taken from PEDLEY & GRASSO (2002) and are based, in part, on the field details described above. It appears that the transgression resulted in a sea-level rise of between 75 and 100 m. During the highstand event, carbonate production and deposition was modified by 6 minor eustatic oscillations in sea level before polar cooling created a major regression in the earliest Sicilian.

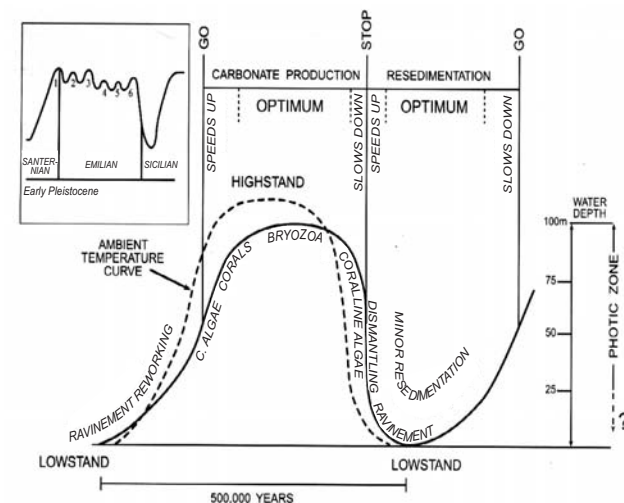


Fig. 18 - Theoretical controls, derived from this study, on the production of cool-water carbonates within the Mediterranean Emilian (Quaternary). Note that the hypothetical ambient temperature curve precedes the rise in sea-level, thereby encouraging the warmest cool-water biota early in the life of the carbonate factory. The eustatic curve is drawn with marked asymmetry in order to account for a rapid shut-down in the carbonate factory associated with a dramatic sea-level fall (probably under low rainfall conditions). The inset is an approximation of the Emilian highstand event, showing sea-level oscillations within the overall highstand event (from PEDLEY & GRASSO, 2002)

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