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EFFECTS OF HIGH-FREQUENCY PLEISTOCENE SEA-LEVEL CHANGES ON A HIGHLY DEFORMING CONTINENTAL MARGIN: CALABRIAN SHELF (SOUTHERN TYRRHENIAN SEA, ITALY).

Abstract. A single-channel high-resolution seismic survey on two shelf areas of the south-eastern Tyrrhenian continental margin detected approximately 100 meters of the shelves internal structure, allowing us to reconstruct the accretionary mechanisms of the continental margin and to define the interplay between slope failure and sedimentation during the Upper Pleistocene. Because of the particular geodynamic setting of the Calabrian Arc, the continental margin, which shows a very immature physiography, underwent severe deformation that is ascribed mainly to large-scale slope failure. High-frequency sea level changes during the Pleistocene triggered the outbuilding of the shelf, causing a discontinuous frontal accretion of the margin. During eustatic lowstands, very high sedimentation rates accumulated extremely thick sequences in the basins (not surveyed in this study), while on the slope, oblique prograding sequences were emplaced by massive subaqueous channelled transport. During highstand conditions, on the other hand, sedimentation was mainly confined to the shelf, as it is on the present-day post-glacial wedge, while non-depositional surfaces were created on the starved continental slope. Because of the continuous deformation of the margin, the seismic units bounded by such non depositional surfaces, corresponding to high-order depositional sequences, show a marked stratal disconformity and a deformation degree increasing discontinuously with age.

INTRODUCTION

Understanding the main factors conditioning the occurrence and overall geometry of depositional sequences making up the continental margins has recently become the focus of geological modelling (Payton, 1977, Wilgus et al., 1988). These factors are essentially: I) relative sea-level changes, II) sedimentary input and III) subsidence. However, in very young margins, the large-scale failure of shelf-slope complexes must also to be considered as a factor conditioning the development of the sequences.

The Calabrian shelf, in the southernmost part of the Tyrrhenian margin (Fig. 1), is a good example of the interaction between depositional processes and large-scale deformation. In fact, given its particular geological setting, the margin is undergoing extreme tectonic stresses which cause a strong uplift of the Calabrian Arc and a strong subsidence of the facing basin. Such a situation leads to very high sedimentary rates, as well as to large-scale instability phenomena that strongly interact with the discontinuous outbuilding of the margin triggered by the Pleistocene high-frequency sea-level changes. Very evident angular unconformities are present at sequence boundaries in continental slope environments, where they cannot usually be seismically detected because they become "correlative conformities" *sensu* Vail and Mitchum (1977).

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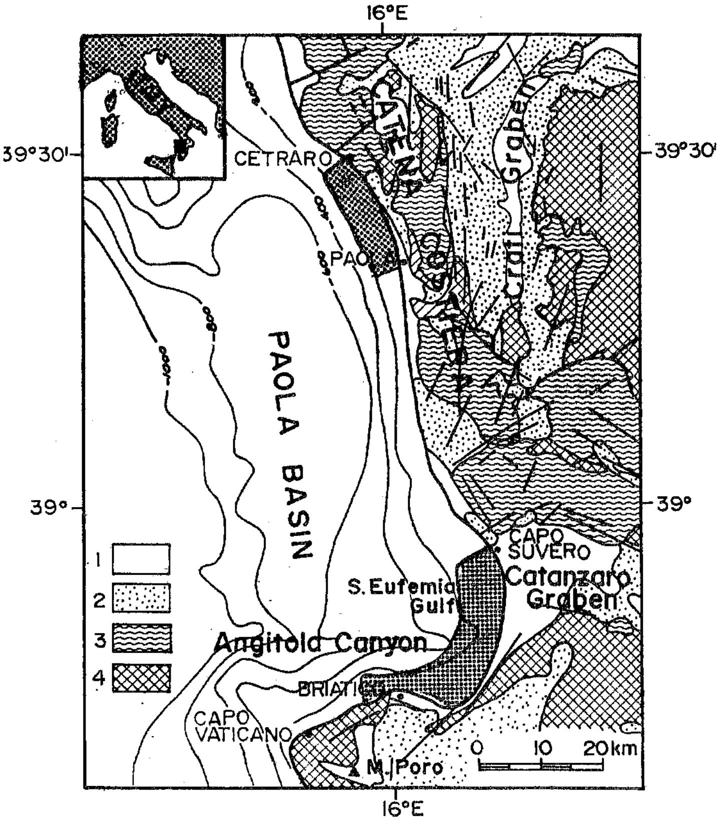


Fig. 1 - Structural sketch of the Calabrian-Tyrrhenian continental margin. Studied areas in gray. Legend of mainland geology: 1-Quaternary sediments; 2-Cenozoic sediments; 3-Metamorphic complexes; 4-Igneous rocks. Isobaths in meters.

The study is based on single-channel high-resolution seismics carried out on two areas of the Calabrian shelf (from Cetraro to Paola and from Capo Suvero to Briatico). Although the survey was conducted for mining purposes on superficial deposits, approximately one hundred metres of the shelf's internal structure were investigated. Although there is no direct datation of the investigated deposits due to the absence of exploration wells on the Calabrian shelf, sedimentary sequences show distinct geometric features that allow us to hypothesise about the Upper Pleistocene shelf evolution and depositional-deformational processes.

The seismic survey was conducted in two areas. Although the two areas are 50 km apart, they show a very similar seismic stratigraphy and structural setting of the sequences making up the continental shelf. As reconstructed by Chiocci et al. (1989), even minor paleoenvironmental variations inside the Holocene depositional sequence can be correlated between the two areas. Such behaviour, due to the regional character of the leading factors of the Quaternary shelf sedimentation, allowed this study to fully analyse the overall evolution of the Calabrian continental shelf during the upper Pleistocene.

The continental shelf was detected by 380 km of high-resolution single-channel reflection seismic profiles. The source used was a 300 joule Uniboom. The profiles trend normal to the coast (spaced about 1-2 km apart) and parallel to it (spaced about 2-3 km). Seismic echoes were analogically recorded to 0.25 seconds (t w t.) on shelf and 0.5 seconds on the shelf-break areas. Generally, the survey did not cover the continental slope. For details of procedures and the seismic network, see Chiocci et al. (1989).

After field tests, a 400-4,000 Hz frequency pass-band filter was chosen. These frequencies

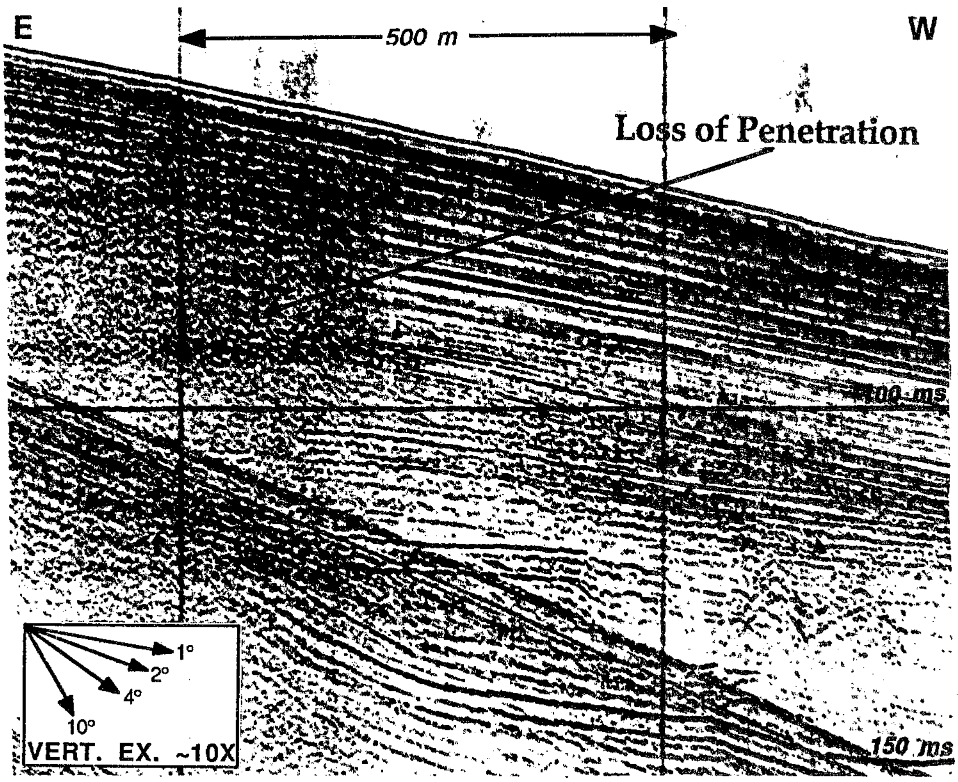


Fig. 2 - Coastward seismic pulse penetration is prevented by textural increase of inner shelf sediments. For location of seismic profile see Fig. 3.

permitted very good vertical resolution, generally less than one metre. Source energy, frequency and sedimentary textures allowed the seismic pulse to penetrate down through the first hundred meters of the continental shelf and upper slope. On the inner continental shelf, the coastward coarsening of superficial sediments prevented seismic penetration (Fig. 2).

Depth and thickness are expressed here in two-way travel times (twt). Where necessary, a 1500 m/s velocity (velocity of sound in sea water) has been used for depth conversion.

GEOLOGICAL FRAMEWORK

The stratigraphy and structural setting of the Calabrian Arc are extremely complex. The kinematics of the Calabrian Arc have been the focus several scientific papers, since its strategic location helps one to understand the evolution of the Tyrrhenian and Central Mediterranean Sea (Bosquet, 1973; Amodio-Morelli et al.,1976; Scandone, 1979; Boccaletti et al., 1984; Finetti and Del Ben, 1986, Kastens et al.,1988).

Briefly, the Calabrian Arc is made up of "Alpine", Europe- trending, crystalline complexes, which, during the Lower Miocene overthrust on "Apennine" sedimentary units and were tectonically transported towards the Apulian foreland. Since the Late Miocene (Tortonian), the Calabrian Arc has undergone strong uplift as well as extensional tectonics (Tortorici, 1979). During the early Pliocene, the internal basins (Mesima, Crati, Catanzaro) began to subside. Finetti and Morelli (1972) relate such subsidence to the spreading of the Tyrrhenian Sea which

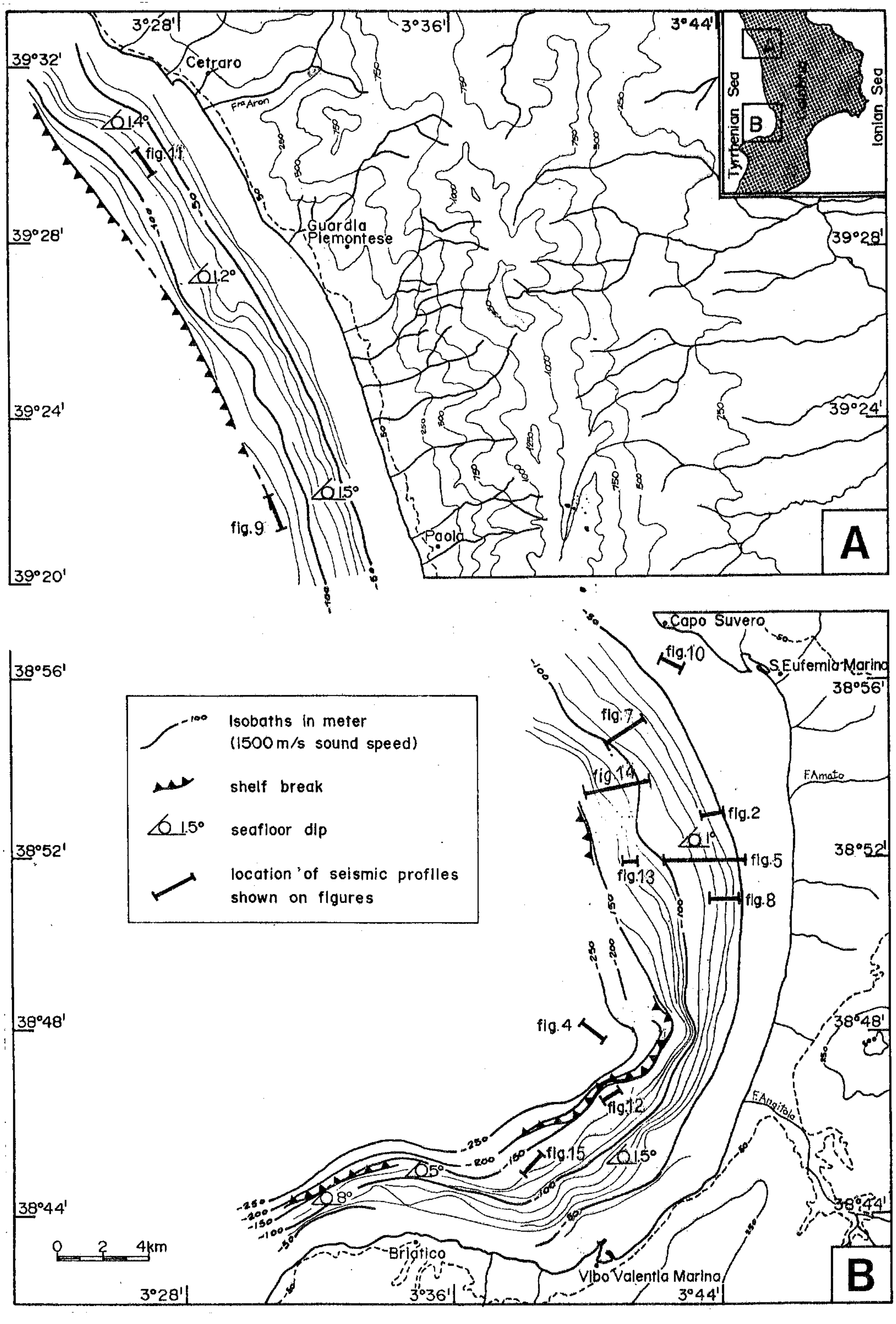


Fig. 3 - Bathymetric map and seafloor dip; bold lines indicate seismic profiles in figures.

reached its maximum expression on the south-eastern, Calabrian part of the basin (Kastens et al., 1988).

Fig. 1 shows the geological setting of the mainland areas of the continental margin studied. Between Cetraro and Capo Suvero lies the Catena Costiera, a metamorphic ridge that stretches parallel to the coast-line. To the north, the Catena Costiera is bounded by the regional dextral transcurrent Sangineto Line (just north of the upper limit of Fig. 1), to the east by the Crati Graben, and to the south by the Catanzaro Graben (Ghisetti and Vezzani, 1981). The westward continuation of the Catanzaro Graben tectonic features create the steep slope between the crystalline complexes of M. Poro and the southern S. Eufemia Gulf (Barone et al.,1982; Morelli, 1970).

The whole coast is affected by transversal tectonic disjunction both parallel and normal to the coast (see Fig. 1). Transversal tectonics define separate blocks whose differential movements continued all through the Quaternary and right up to the present time. In effect, the marine terraces are dissected by faults, with a relative uplift of the southern sectors. Uplifting values are extremely high, up to 600 m for the Plio-Calabrian terraces and up to several tens of metres for the Upper Pleistocene deposits (Damiani and Pannunzi, 1978).

Deep-penetration single-channel seismic reflection surveys were conducted on the basin areas bordering the Calabrian Arc. The results are reported in Fabbri et al. (1981) and Barone et al. (1982). Generally speaking, the sedimentary units are highly-deformed and faulted, as is usual for the southern Tyrrhenian basins (Fabbri et al. 1981), and in accordance with the well-documented tectonic activity of the mainland and the southern Tyrrhenian basins (Tortorici, 1982; Amodio-Morelli et al., 1976; Rehault et al., 1987; Bosquet, 1973).

The areas studied are faced by the Paola basin, whose depocentres are close to the coast, due to the activity of steep faults which trend parallel to the Catena Costiera and affect the continental slope. Over a bedrock referable to the geological units outcropping on the mainland, seismic surveys have identified a post-orogenic sedimentary cover (up to 4,000-5,000 m thick) that is almost continuous from the Tortonian to the present. The Paola basin depositional sequences seem to be controlled by both tectonic and eustatic events (Canu and Trincardi, 1989). The very high sedimentation rate of the Calabrian basins and slope is due to differential movements between the collapsing Tyrrhenian Sea and the uplifting Calabrian Arc. Slope instability affects the continental slope, where slumps and mud flows were reported by Gallignani (1982) and a large-scale slide was reported by Trincardi and Normark (1989).

GENERAL CHARACTER OF THE CONTINENTAL MARGIN

The continental shelf outlines the inner margin of the Calabrian Arc, trending almost parallel to the coastline (Fig. 3). The Calabrian shelf is narrower (from 2 to 10 km) and steeper (from 1 to 5°) than the other parts of the Tyrrhenian borderland (Selli, 1970). In the northern area the shelf is narrower and steeper than in the southern. The continental slope is very steep in the north area (up to 5°) and extends down to the Paola Basin (600-700 m); in the southern area the continental slope dips more gently (1-2°), reaching a final depth of 900-1000 m. The shelf is missing on the southern S. Eufemia Gulf, where the sea floor follows the steep subaerial morphology of M. Poro. Here the submarine morphology reflects both the E-W structural trend related to the Catanzaro graben and the Angitola Canyon activity. Especially during sea-level lowstands, in fact, this large erosional feature drained the slope and shelf sediments of the S. Eufemia Gulf towards the Gioia Basin, tens of kilometres south-westwards. Canyon heads are observed inside the shelf, starting at a depth of 90-100 ms twt (about 75 m). In the study area the average plunge of the canyon talweg is 4° westwards. The Angitola Canyon has evident erosional nature, as is shown by the truncation of the underlying stratified units (Fig. 4).

SEISMIC DATA ANALYSIS

A typical seismic stratigraphy representative of the shelf is shown in Fig. 5: a wedge of

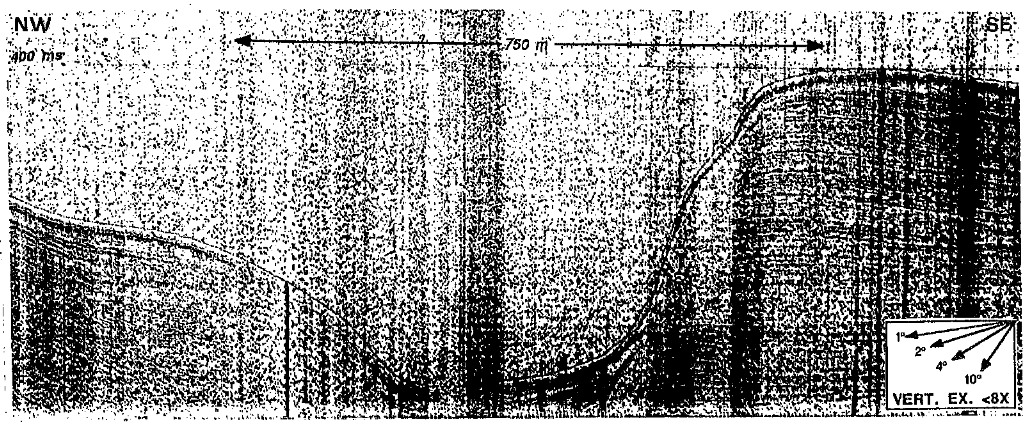


Fig. 4 - Seismic profile normal to the Angitola Canyon.

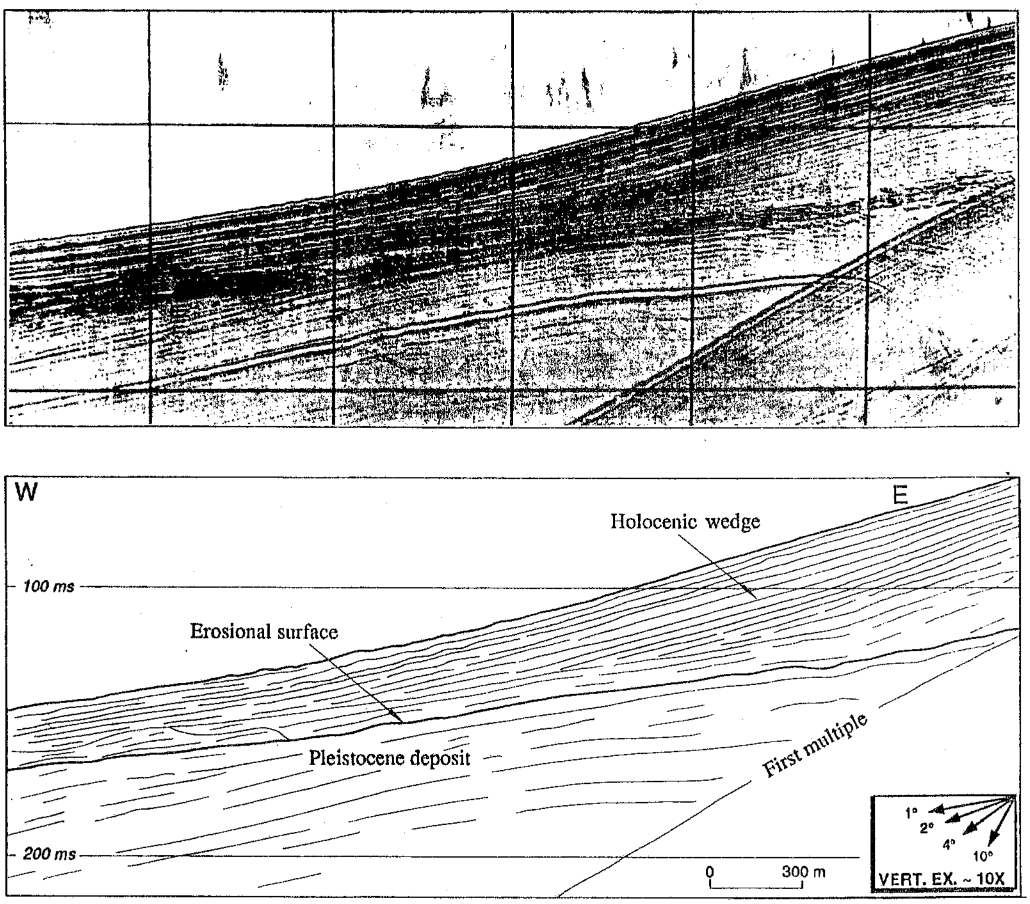


Fig. 5 - Seismic profile summarizing inner and middle shelf seismic-stratigraphy.

sub-horizontal, thin-stratified sediments lies, with angular unconformity, over roughly stratified deposits (often highly deformed) showing basinwards sigmoid-oblique progradation. The erosional surface is referred to as the Würm sea-level lowstand, both because of its similarity to other features along the Tyrrhenian margins and because it is the last widespread erosional surface of the stratigraphic column. It is over this surface, which truncates all the previous Pleistocene

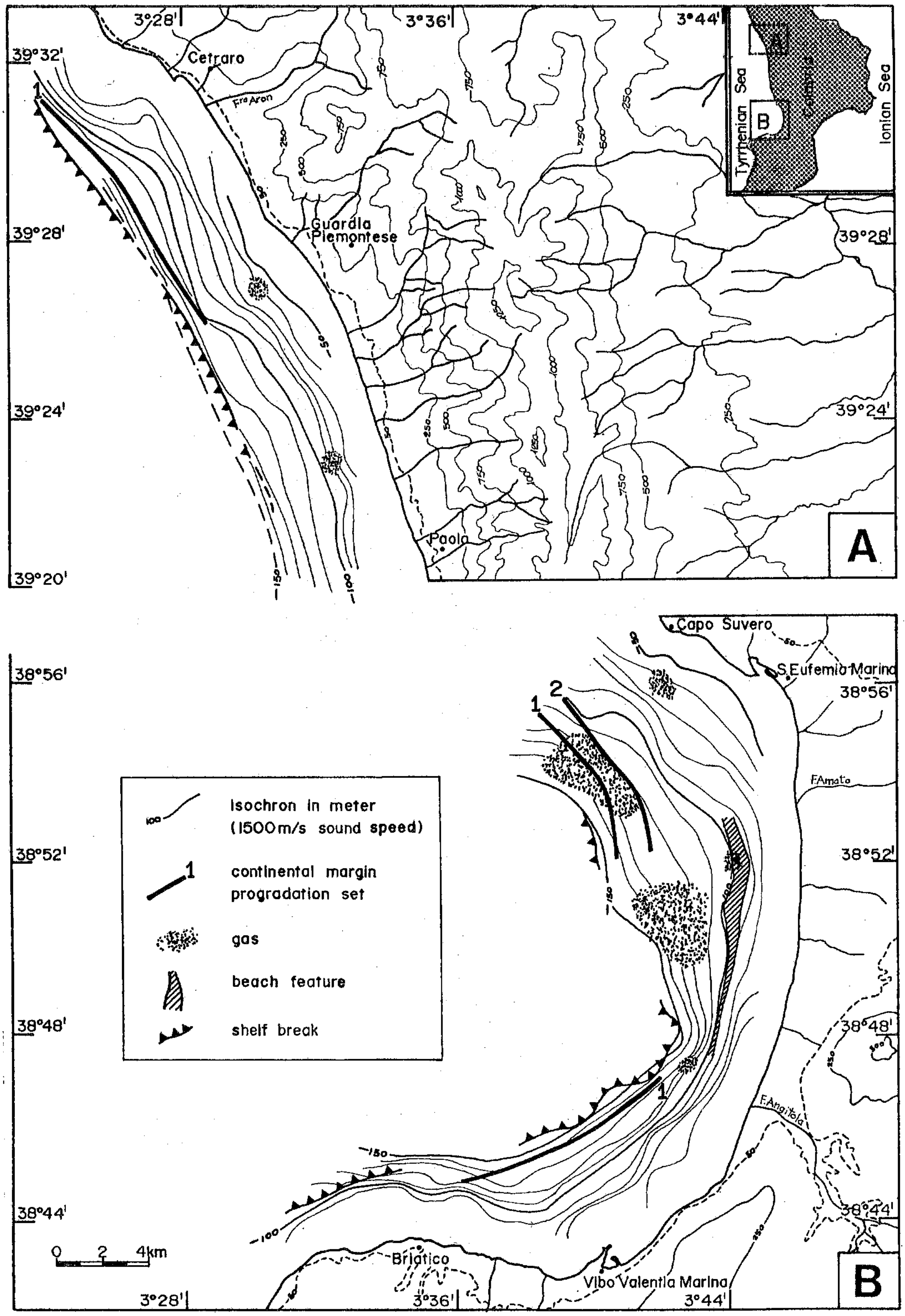


Fig. 6 - Isochron map of the Würm erosional surface.

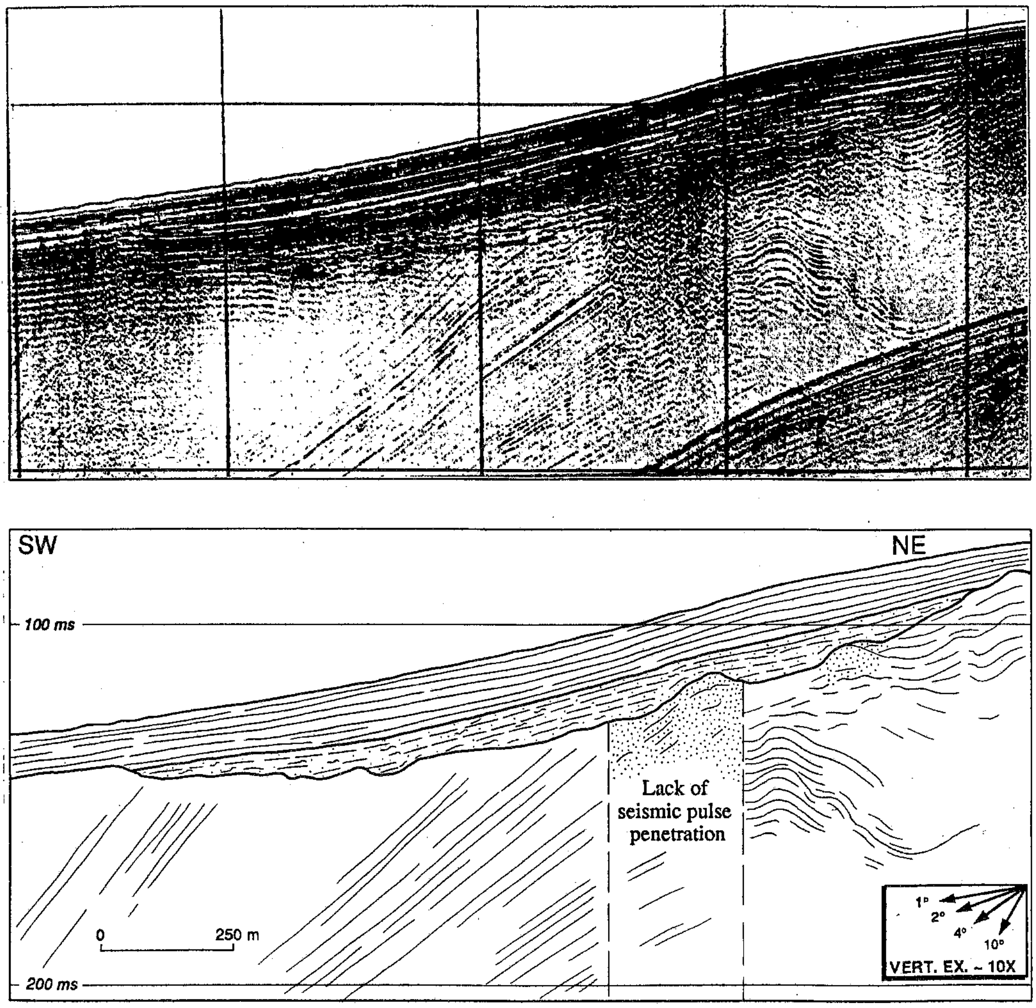


Fig. 7 - Versilian transgressive surface truncates the Pleistocene deposits making up the continental margin. The surface morphology controls the development of the transgressive deposits forming the lower part of the postglacial depositional sequence (dashed unit in figure).

deposits, that the transgression and the highstand developed during the Holocene.

Holocene deposits: the most recent depositional sequence will be only briefly summarised here because it was analysed specifically in Chiocci et al. (1989).

In the study area, the Holocene sedimentary wedge is very thick, larger than similar deposits on other Tyrrhenian shelves. The sequence is over 70 ms thick coastwards and thins down to a few milliseconds towards the shelf break. Synsedimentary creep is observable on superficial deposits (Fig. 5).

Deposits are generally stratified with progradational configurations and exhibit very variable depositional styles and thicknesses, mainly controlled by the pre-existing topography and by the position of feeding sources. The overall moderate acoustic transparency as well as sea-floor sampling indicates muddy-silty lithologies. The paleoenvironmental reconstruction involves a first transgressive phase, followed by a downlapping, coarsening-upward regressive sequence, related to the present-day sea-level highstand (Fig. 7).

Würm erosional surface: the surface at the base of the post- glacial sequence erosionally

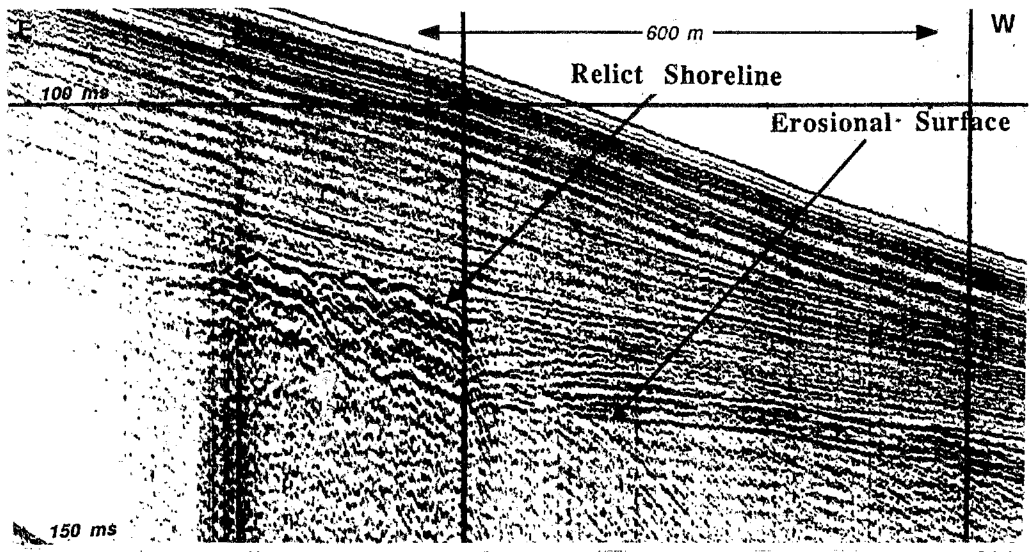


Fig. 8 - Relict beach deposit off Piana di Catanzaro, buried below Holocene deposits.

truncates the Pleistocene deposits making up the continental shelf. The seaward dip of the unconformity (Fig. 7) is lower than that of the seafloor and its morphological character repeats the seafloor features.

On the inner and middle shelf, the erosional nature of the surface is clear because of its rough morphology and strong angular unconformity with respect to the underlying deposits (Fig. 7). Seawards, at a depth of more than 200 ms, the angular unconformity disappears, and generally the stratification lies parallel to the seafloor.

Erosion is thought to have occurred during the Würm lowstand (20,000 years b. p.), which created several coastline features that lie on the erosional surface. The most noticeable one is a possible relict shoreline (Fig. 8) at about 120-130 ms twt (90-100 m). The feature rises some metres above the surrounding areas and runs strictly parallel to the isochrones for about 7 km (sliced area on Fig. 6). Its bathymetric limits are extremely constant and its width ranges between 100 and 500 m, depending on the surface dip. Seismically, the feature is characterised by a discontinuous high-amplitude seismic facies, probably due to coarser lithology and/or biological encrustations. Often it prevents seismic pulse penetration (Fig. 7).

Overall features of Pleistocene deposits: on the middle and outer shelf, the survey detected a thick stratified formation under the previously described erosional surface. The formation is fairly transparent and shows a large-scale seaward oblique progradation and is often highly deformed. Seismically, it does not display major changes in acoustic characters.

Conversely, in the inner shelf areas, lateral changes of seismic characters are frequent, and areas with discontinuous low-amplitude internal reflectors coexist with areas showing no internal stratification. However, in these cases, the absence of internal reflections may be due merely to a loss of penetration because of the textural increase of superficial sediments or to the steepness of the strata.

The clino-stratified deposits, lying below the erosional unconformity, represent the Pleistocene continental margin progradation. These deposits should correspond to the proximal and upper part of the very thick Upper Pliocene - Pleistocene unit which, in turbidic facies, is as much as 2,000 m thick in the Paola basin (Barone et al., 1982; Canu and Trincardi, 1989).

Using high-resolution seismics, several seismic units were defined inside the continental shelf, whose boundaries are non-depositional surfaces showing angular unconformity (Fig. 15). Each seismic unit is about 50 m thick and generally dips basinwards between 1° and 10°; the units correspond to distinct phases of the continental margin outbuilding process. The

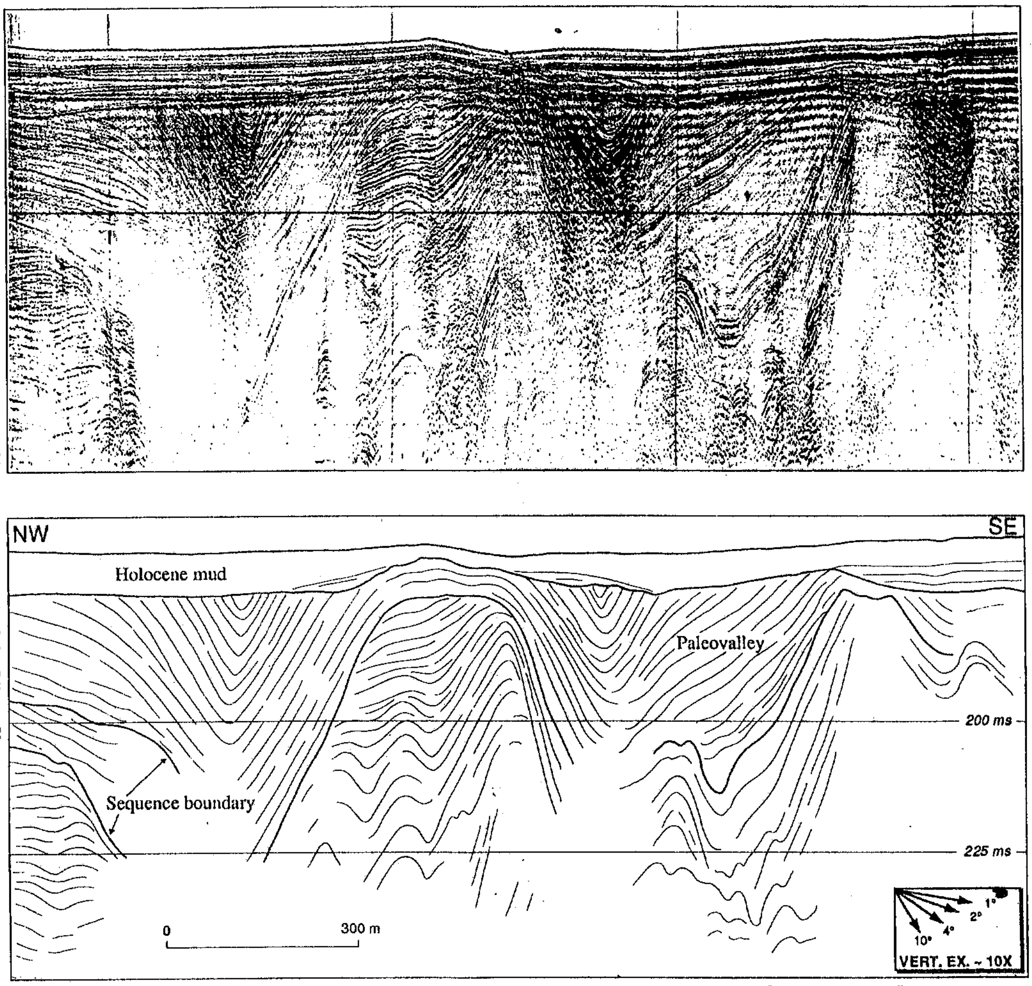


Fig. 9 - Seismic profile parallel to the coast showing large paleochannels, syndepositional growth and deformation inside seismic units making up the shelf.

reconstruction of non-depositional surfaces indicates that each of seismic units involves a frontal accretion of the shelf by about one kilometre (bold lines on Fig. 6).

The internal reflector configuration is generally parallel, although in some instances differential growth and synsedimentary deformation are observable (Fig. 9).

Inside the unit, no patterns are detectable in seismic facies changes. Only in the most recent units it is possible to detect a slight upward loss in transparency that may correspond to an upward textural increase. High frequency penetration in the Pleistocene deposits indicates fine lithologies (mud to fine sand). The textures appear to be finer in areas where the shelf is wider (i.e. central S. Eufemia Gulf).

Evidence of channelled transport in Pleistocene deposits: in the inner shelf, seismic profiles parallel to the coast detect small scours just below the erosional surface (Fig. 10). Such features are now buried by the Holocene wedge and may represent the subaerial stream network during sea-level lowstands.

On the outer shelf, seismic profiles parallel to the coast show large features which are interpreted as paleo-valleys, trending roughly parallel to the slope (Fig. 9 and 11). Valleys form at the shelf-break as erosional features (see erosional truncation of valley flanks in Fig. 9) and

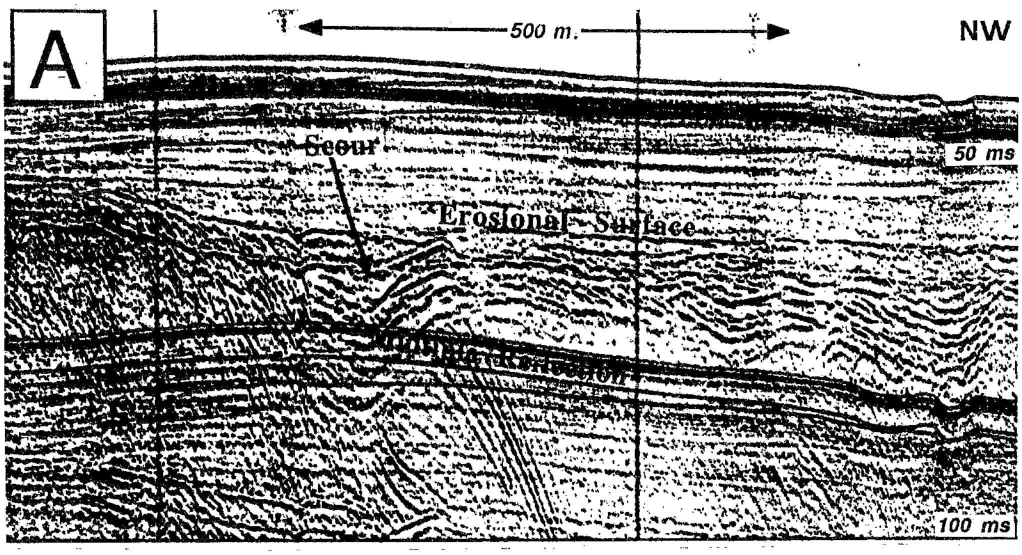


Fig. 10 - Scours on the erosional surface, in the inner shelf area.

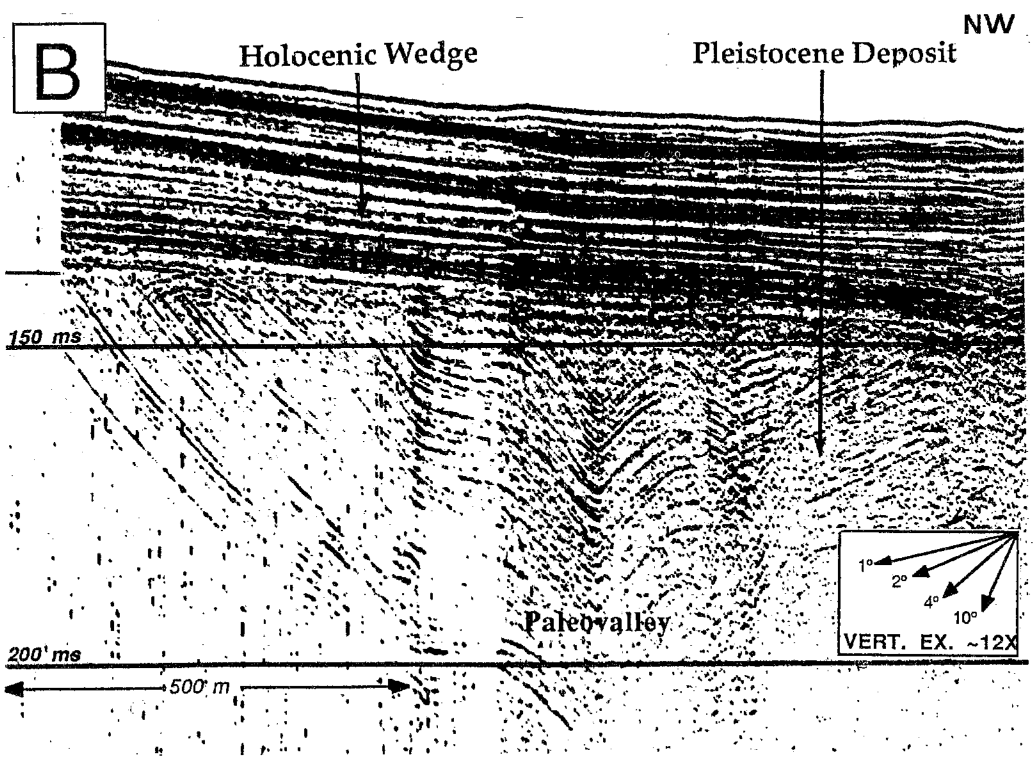
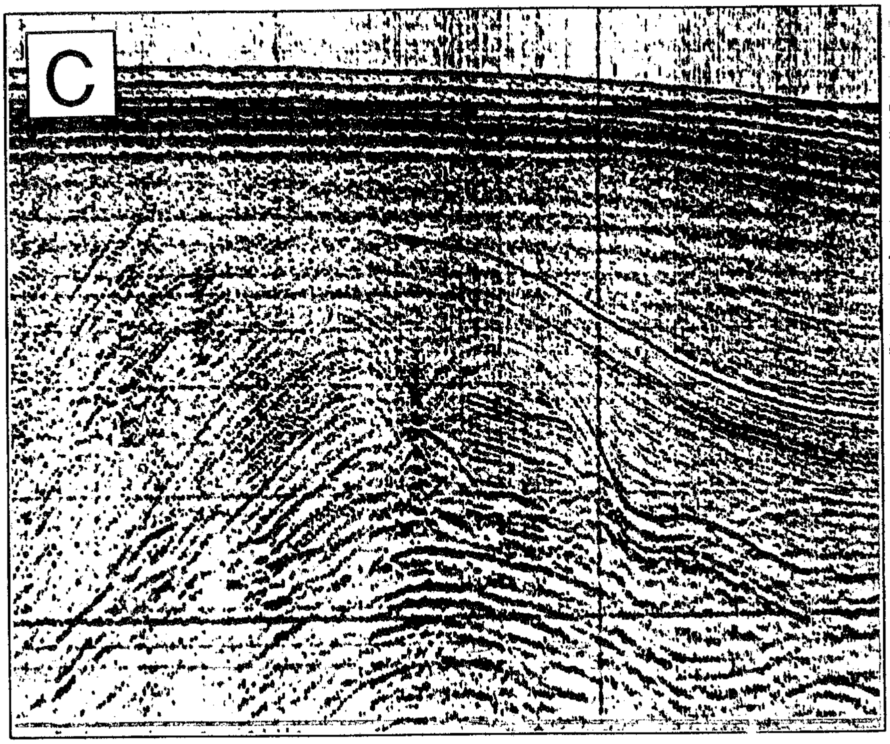


Fig. 11 - Pleistocene paleovalley inside the continental shelf, in the outer shelf area.



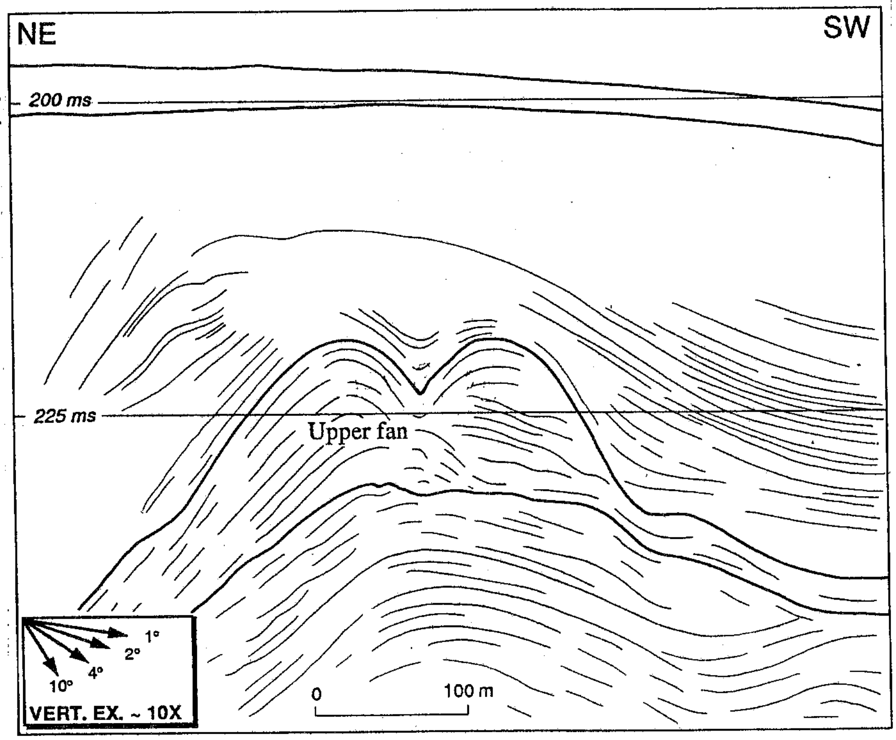


Fig. 12 - Upper fan feature in S. Eufemia Gulf, buried on the continental slope.

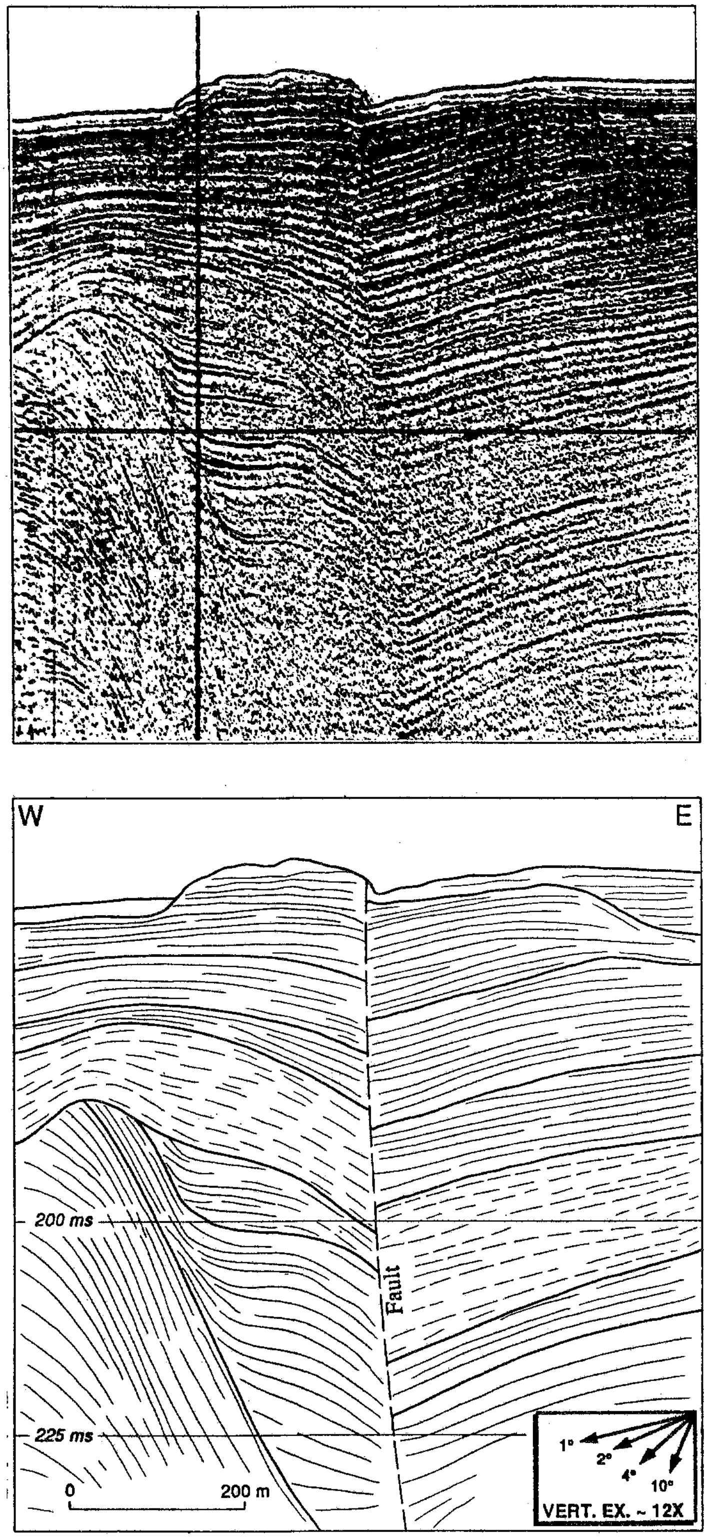


Fig. 13 - Fault uplifting outer shelf off Piana di Catanzaro. Note offset increasing with depth.

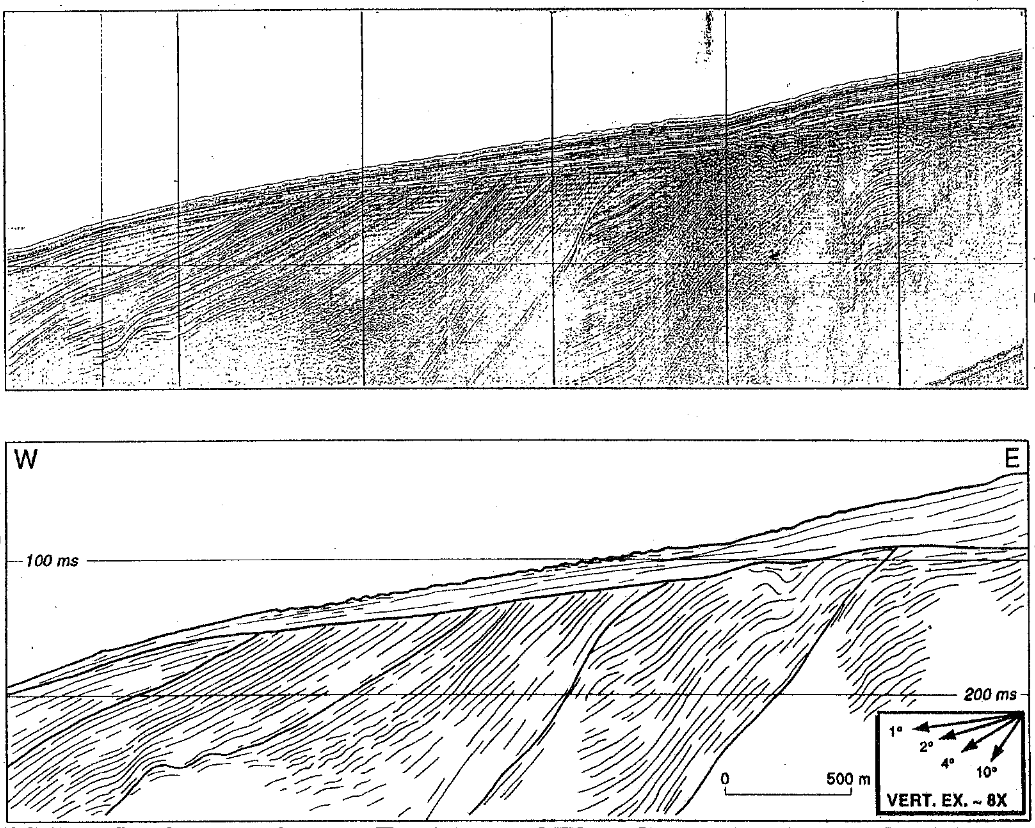


Fig. 14 - Seismic profile normal to contours off Catanzaro plain. The continental margin is made up of prograding sequences, bounded by non-depositional unconformities. Note the upward loss in transparency within each sequence, suggesting a cyclic regressive sedimentation.

are preserved by rough-draping sedimentation owing to a constant channelled subaqueous transport. Sometimes a differential growth of the channel levees is detectable (left-hand part of Fig. 9). The features detected are similar in shape to the gullies detected on the upper slope off the Tiber River mouths (Chiocci and Normark, 1992).

In deeper environments, subaqueous transport may be responsible for the feature reported in Fig. 12, showing bidirectional downlaps and interpreted as an upper fan feature (Mitchum, 1985). Upper fan and paleovalley morphologies are generally observed at the base of seismic units making up the continental margin.

Deformations: the Pleistocene sequences show brittle and ductile deformations. As regards brittle deformations, sub-vertical faults with small offsets (less than 10 ms) are scattered over the areas studied and are only discontinuously identified. Generally the lateral extent of such features is not great enough to correlate them through the course grid. The largest feature, a subvertical fault off Piana di Catanzaro, extends for over 2 km with a NNE-SSW direction and uplifts the shelf-margin areas with respect to the inner shelf (Fig. 13). It is possible to note a downward increase of the offset, suggesting synsedimentary activity.

The ductile deformations are more pronounced and widespread than the brittle ones, and show close interconnection with depositional mechanisms. Thus, the whole shelf seems to be affected by a high-degree of ductile deformation.

Seismic lines normal to the contours show deformation increasing from the shelf break towards the inner shelf, i.e., from younger units towards the lower part of the stratigraphic column.

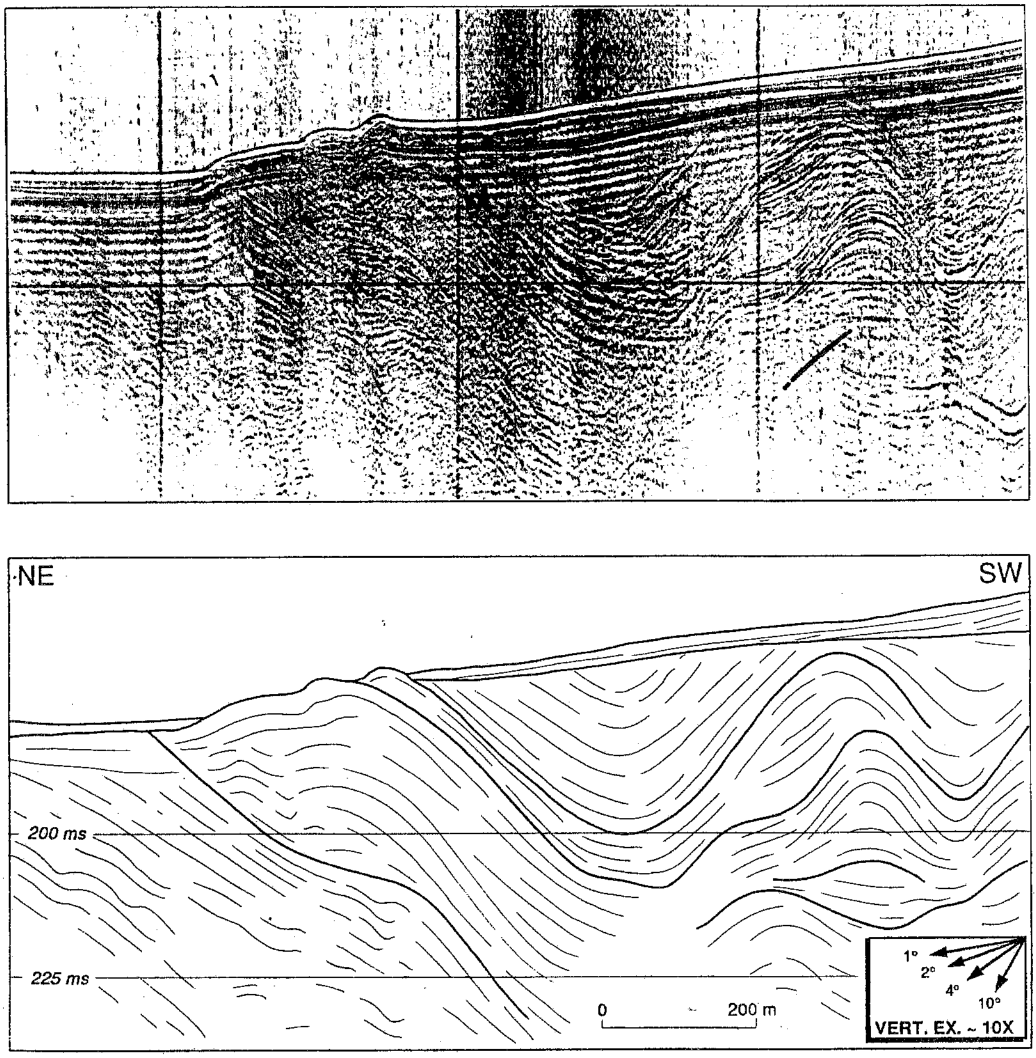


Fig. 15 - Folded Pleistocene deposits create erosional relicts on the seafloor.

Seen on the small-scale, the deformation degree increases abruptly in correspondence with the non-depositional surfaces bounding the seismic units (Fig. 14). The most recent unit is only weakly deformed and its bed attitude matches the upper slope seafloor. On the inner shelf, older and more deformed units show several narrow (short-radius) folds whose anticline culminations or strata heads create erosional relicts on the sea floor (Fig. 15). Higher-order folds and flexures are often associated with larger features. Even in this case structural deformation appears to parallel depositional processes, with synsedimentary growth of the deposits bounded by non-depositional unconformities (e.g. right part of Fig. 15).

The ductile behaviour of the Pleistocene deposits and the relative deformational style is probably due to sediment water saturation (Van Loon et al., 1985) and to gas overpressures (gas is in fact detectable on seismic profiles); at the same time they are evidence of very slow rates of deformation. Large-scale instability of the shelf-slope zone is reported to occur in prograding passive margins (Curray, 1965; Winker and Edwards, 1983). Instability acts on underconsolidated and overpressured fine-grained sediments (Brodnkowski and Van Loon, 1983), because of sedimentary loading and oversteepening, possibly triggered by seismic activity and water-level changes (Prior and Coleman, 1982); the presence of gas significantly lowers the geomechanical properties of the sediments (Whelan et al., 1976). Large slumps, gravity-driven sliding and growth-faults - often accompanied by clay or salt diapirism induced by differential loading or by gravity spreading - are quite common where high depositional rates occur, as on young margins and/or in areas subject to deltaic sedimentation (Buffer et al., 1979; Edwards, 1981; Coleman et al., 1983; Shaub, 1983). Similar features have also been observed in outcrops (Pickering, 1987).

As the features on the Calabrian outer shelf-upper slope are almost continuous along the whole margin, with constant structural characteristics, they may be interpreted as the result of large-scale slope instability at the shelf-margin, strongly connected to the rapid uplift of the Calabrian Arc with respect to the sinking Tyrrhenian basin; on the mainland of the study area, a similar stress field is responsible for brittle deformations (Guerricchio e Melidoro, 1979). Wezel (1981) interprets similar features on the Sicilian shelf as "block folding" i.e., structures due to differential permeability of crustal blocks in a vertical tensional regime. The ductile deformation structures observed cannot be interpreted as growth-faults. In fact, although in young marine sediments growth faults may cause ductile deformation, they show a preferential sedimentation on the downthrow side of the fault and the correlability between the two parts of the fault is maintained. However such behaviour was not observed on the Calabrian margin. Conversely, the fault in Fig. 13 shows the characteristics described.

Gassy deposits: inside the sedimentary units making up the shelf, evidence of gas was detected at a shallow depth. It consists of bright spots, widespread cloudy effects and gas seeps internal to the water mass. The occurrence of biogenic gas is probably related to the high sedimentation rates in the area. Larger anomalies were detected off Piana di Catanzaro (corresponding to the maximum shelf width) and are mapped in Fig. 6.

Evidence of regional uplift: the high-degree deformation of the shelf deposits is evidence of Calabrian Arc activity. Even the anomalous thickness of the Holocene wedge may be ascribed to regional uplift. Indirect evidence of vertical movements at the regional scale is supplied by the depth where the Würm lowstand features were recorded. Both in northern and southern areas, at a depth of 90 ± 10m, the erosional surface is characterised by terraces and abrasion platforms testifying to a sea level stillstand. The relict shoreline described earlier in this chapter and shown in Figs. 6, 7 and 8 lies at the same depth.

This evidence is similar to features sampled or seismically detected along other parts of the Tyrrhenian margin, thought to be littoral deposits of the Würm pleniglacial age (Longinelli et al., 1972; Lecca et al., 1983; Marani et al., 1986). Such features are constantly located at a depth of 110- 120 m. The twenty metres difference between the Calabrian and the other Tyrrhenian lowstand features may be postulated as due to the regional uplift. Although highly speculative, this hypothesis yields a 1 mm/year uplift rate, which is in agreement with the Cosentino e Gliozzi (1988) estimation for the coastal area uplift in the same sector of the Calabrian Arc, obtained by absolute dating of Tyrrhenian age terraces. In this case the behaviour of the continental shelf lying between the uplifting Calabrian Arc and the subsiding Tyrrhenian basins would be consistent with tectonic movements of the mainland.

DISCUSSION AND CONCLUSION

Over the whole area studied, an erosional surface separates the Holocene sequence from the underlying Pleistocene deposits. The surface has erosional character down to a depth of 200 ms twt (150 m) and is related to the Würmian lowstand. Seismic data analysis shows a notable difference between the Holocene sedimentation, related to the present-day eustatic level, and the underlying Pleistocene depositional sequences making up the shelf. These sequences, because of the particular geodynamic setting of the Calabrian area, are deeply affected by instability phenomena, acting both on the slope sediments (slides, slumps, mudflows), and as a large-scale failure of the whole structure of the continental margin. The non-depositional angular unconformity at the surfaces bounding the shelf progradation sets, suggests a non-continuous

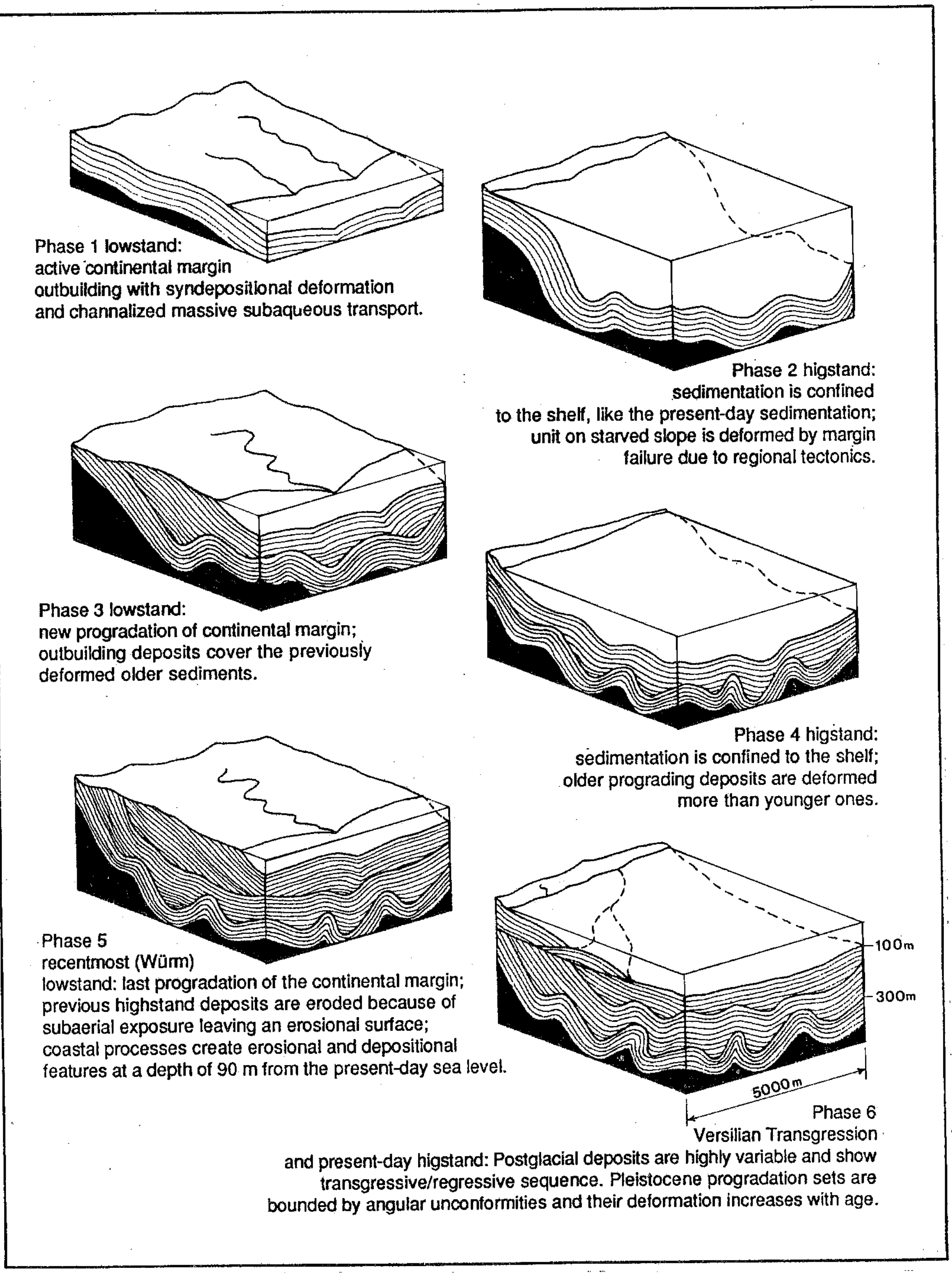


Fig. 16 - Inferred Late Pleistocene evolution of Calabrian- Tyrrhenian margin.

outbuilding mechanism of the continental margin. The abrupt changes observed in the deformation degree of the seismic units probably do not reflect variations in stresses or discontinuous movements of unconsolidated deposits. Rather, they are probably caused by sedimentation hiatuses generating breaks in the stratigraphic record. Such hiatuses were superimposed over a continuous upper-slope deformation of the very unstable Calabrian margin deposits, thus creating the angular unconformity observed between subsequent prograding sequences. In this sense, the bounding surfaces are angular unconformities *sensu strictu* (Krumbein and Sloss, 1963).

Because of the Pleistocene age of the sediments, the only phenomenon that can account for such behaviour is glacio-eustatic sea-level variation. The rate of glacio-eustatic sea-level changes is in fact much greater than any other movement of a tectonic or depositional nature (Pitman, 1978). This is particularly true for high-frequency sea-level changes, where the sea-level rise rates are in the order of millimetres per year (Chappel and Shackleton, 1986). Consequently, sedimentary hiatuses must be ascribed to sea-level highstands, while continental margin progradation seems to be mainly confined to lowstand periods.

In this sense, the continental margin progradational sets may be interpreted as lowstand systems tracts (Van Wagoner et al., 1988) and indicate high sedimentation rates, widespread channelled transport and syndepositional deformation. The seismic characteristics of each sequence suggest a coarsening-upward trend.

An evolutionary model was hypothesised on the basis of the depositional features observed and the distribution of deformations (Fig. 16). It consists of a repeated succession in time of two eustatic settings:

Sea level lowstands: during these periods, large amounts of sediment became available because of shelf exposure and base- level lowering. Moreover, the narrowing of the continental shelf, due to the shifting of the coastline seaward, caused sedimentation directly on the slope. Most of continental margin progradation seems to occur in periods of sea-level lowstand through massive, diffuse sedimentation on the continental slope. The lack of lateral variations supports this reconstruction. The vertical evolution of the seismic characteristics inside the lowstand depositional sequences (i.e. upward increase in stratification and textures, see Fig. 14) implies a regressive structure, i.e., a coastline progressively approaching the upper slope enviroment.

Widespread gas occurrences in such young sediments may also indicate high sedimentation rates. In fact, larger anomalies were found off Piana di Catanzaro, corresponding to the maximum width of the shelf.

Scours in the inner shelf, paleovalleys in the outer shelf (i.e., possible paleo-shelfbreaks) and upper fan features on the continental slope (Figs. 10, 11, and 12) suggest that, at least during the early phases of sea-level lowstands, deposition occurred via channelled subaqueous transport onto the upper slope environment. This reconstruction strongly resembles that made for the lowstand processes active on the upper slope off the Tiber River mouths (Chiocci and Normark, 1992). It is possible that some of the features detected may somehow correspond to subaerial watercourses. As the survey was not extended beyond the upper slope, it is not possible to define the effects of the gravity flows in relation to the channelled features. However, Gallignani (1982) reports gravity flow deposits occurring on the continental slope between the two areas studied.

Synsedimentary deformations of lowstand sequences indicate deposition penecontemporaneously with continuous movements of unconsolidated sediments due to gravity instability caused by the regional uplift of the Calabrian Arc.

Sea level highstands: during these periods, sedimentation was mainly confined to the shelf. An example of highstand sedimentation is the Holocene deposit lying over the Würm erosional surface. It is characterised by fine texture, wedging geometry, highly variable acoustic facies and irregular thickness, indicating that sedimentation was primarily controlled by local paleogeography and paleotopography (Chiocci et al.,1989). It is very likely that during previous Pleistocene highstands, sedimentation was similar.

Highstand deposits have a low potential of preservation due to shelf erosion during subsequent lowstands. In the area studied, the Würm erosion removed all the previous highstand deposits, leaving an erosional surface between the Holocene deposits and the underlying Pleistocene sequences. Lowstand shelf erosion may have been facilitated by the regional uplift of the Calabrian Arc. Elsewhere, regional subsidence of the shelves may preserve highstand deposits (Mougenot et al.,1983).

During highstands, very little sedimentation occurred on the continental slope. These sedimentary hiatuses, coupled with the constant sediment deformation, created angular unconformities between successive lowstand progradational sequences that have different degrees of deformation. Stress superimposition over time may explain the increase in deformation observed from younger to older units.

Lastly, it is worth emphasising the utility of very high-resolution seismics. Single-channel reflection seismic prospection gives an extremely detailed stratigraphy of the unconsolidated deposits making up continental margins. By its very nature, the method requires an extremely narrow grid of profiles, and so the analysis is generally focused on small areas. Moreover, since the high-frequency seismic pulse does not penetrate more than one hundred metres below the sea-floor, the data are suitable for sedimentological studies but do not provide a direct reconstruction of the tectonics and geodynamics of the area. Nevertheless, the single-channel profiles give a large amount of detailed information on the small-scale interplay between tectonics and sedimentation, which is not obtainable with other methods.

In this sense, single-channel seismics can be considered complementary to multi-channel data for tectonic reconstruction.

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