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Submerged depositional terraces in the Aeolian Islands (Sicily)

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GEOLOGICAL FRAMEWORK

The Aeolian Islands are located on the inner side of the Calabro-Peloritan Arc, and they represent the outer edge of Cefalù and Gioia peri-Tyrrhenian basins (Fig.1). The Aeolian volcanic district consists of seven islands (Alicudi, Filicudi, Salina, Lipari, Vulcano, Panarea and Stromboli) and several seamounts, aligned along a semi-arc structure about 200 km long. This structure is crossed southwards by the Lipari and Vulcano NNW-SSE volcanic alignment, which develops in continuity with the Patti Ridge (FABBRI *et alii*, 1980). The archipelago is bounded to the east by the Stromboli Canyon that originates from the northern Sicilian margin, then cuts the seafloor of Gioia basin with a NE-SW trend and, after a wide turn to the north of Stromboli, flows into the Marsili Basin at a depth of over 3000 m.

The volcanic Aeolian Islands are the summit of polygenetic apparata, whose base is located at 1000-1200 m on the lower slope of Northern Sicily. Extensional and transcurrent regional fault systems are responsible for the location and growth of the Aeolian apparata as well as for the seismicity and volcano-tectonic evolution of this area (DEL PEZZO *et alii*, 1984; NERI *et alii*, 1991; BARBERI *et alii*, 1994). According to the radiometric and stratigraphic data, the subaerial activity of the Aeolian volcanic district falls into the last M.y. (GILLOT & VILLARI, 1980; GILLOT & KELLER, 1993; GILLOT, 1987; FRAZZETTA *et alii*, 1985; SANTO *et alii*,1995). It is chronologically divided into two building stages on the basis of the presence or absence of Late-Quaternary raised marine abrasion terraces. The development of Panarea and Filicudi, and parts of Lipari and Salina, is generally ascribed to a "pre-erosional" stage (lower-middle Pleistocene, approximately). The final development of Lipari and Salina, and the emersion of Alicudi, Vulcano and Stromboli (the two latter show volcanic activity also during the last century) probably belong to a more recent stage (Late Pleistocene; BARBERI *et alii*, 1974; KELLER, 1980; PICHLER, 1980; DE ROSA *et alii*, 1985, 1989).

Fig.1 - *Central eastern sector of the Aeolian Archipelago.*

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The surveys carried out on the wide submerged portions of the Aeolian volcanoes between 1987 and 1992 by the University of Bologna, within the research activities of the CNR National Group for Volcanology, allowed the bathymorphological and volcanological characterization of the area and the definition of the main evolutionary stages of the volcanic apparata. Submerged abrasion platforms (down to a depth of 100-130 m) have been observed around the oldest sectors in all seven islands, including those islands where no uplifted marine terrace is present on land (ROMAGNOLI *et alii*, 1989; ROMAGNOLI, 1990, GABBIANELLI *et alii*, 1991 and 1993, CALANCHI *et alii*, 1995).

The original morphological profile of the volcanic apparata has been deeply modified by erosion during relative sea level fluctuations; the presence of wide submerged marine abrasional platforms played an important role in the stability of the subaerial volcanic flanks, subject to repeated slope failures and gravitational instability alternating with building periods (ROMAGNOLI & TIBALDI, 1994; KOKELAAR & ROMAGNOLI, 1995).

DATA COLLECTION AND ANALYSIS

A single-channel seismic reflection survey (by means of a 300-500 joule Sparker system), was carried out on September 1993 on board a small private vessel (Fig.2), in order to investigate the submerged depositional terraces on the shallower waters surrounding Vulcano, Lipari, Salina, Panarea and Stromboli (within -200 m of depth). About 300 km of seismic profiles have been located with a non differential GPS system, periodically set on reference points onshore. Only those marine sectors where the occurrence of submerged terraces had already been assessed by previous surveys (ROMAGNOLI, 1990) or was to be expected on the basis of bathymetric maps, have been investigated. Although the researches focused on the five central-eastern Aeolian Islands, submerged depositional terraces have also been detected around Alicudi and Filicudi (ROMAGNOLI, *this volume*). The new data have been checked and/or integrated with 500-1000 joule Sparker profiles (more than 1000 km) collected between 1987 and 1992 by the Bologna University and by CNR of Roma during a survey carried out around Salina in 1992, on board the CNR vessel Urania.

The data collected in the 1993 cruise have been reported and analyzed at 1:25,000 scale, on the bathy-morphological maps previously obtained by ROMAGNOLI (1990). The main depositional parametres of the submerged terraces (upper and lower boundary of the deposit, depositional edge, erosional edge of the underlying substratum) identified by the analysis of the seismic profiles, have been mapped and mostly represented on diagrams. Nomenclature and symbology used are shown in Fig.3. The distance between the profiles as presented on diagram is measured along a line trending parallel to the coast and crossing the seismic profiles approximately at the same depth. In order to avoid problems arising from the integration of data collected by means of different positioning systems (GPS or Loran C) only the data of the 1993 cruise (concerning all the terraces around the five islands) have been represented in the diagrams.

Fig. 2 - *"Incaurina Marianna", the catamaran that carried out the seismic survey on September 1993. This boat proved particularly suitable for the study of submerged depositional terraces, since its reduced draught and easy handling allowed to approach uneven coastlines and to carry out profiles normal to the coast even in very shallow waters. This boat, which flies the English flag, is a 28x14m ex sail-catamaran for transoceanic regatta modified for research works and charting.*

In order to correlate the depositional parametres of the terraces among adjacent profiles, the morphological setting, stratigraphic relations and seismic facies were taken into consideration, especially in the case of multiple terraces or terraces with a strong lateral variability. Values with little relevance to the lateral continuity have been excluded in order to focus on the main features. The data collected around the seafloor of the five islands have been statistically processed in order to recognize possible frequency peaks of the main depositional parametres (see the section Discussion).

The following chapters present the results for each island; when possible the bathymetric trends studied at sea have been compared to information on neo- or volcano- tectonics features on land.

Information on a few gravity cores and R.O.V. (Remote Operated Vehicle) recordings carried out on Salina seafloor have also been included.

Fig. 3 - *Main morphological parameters of submerged depositional terraces (SDT) and their representation in section, plan and diagrams.*

STROMBOLI ISLAND

Stromboli, along with Panarea, represents the emerged part of the volcanic alignment of the eastern Aeolian Islands, stretching NE-SW for over 45 Km. Their overall morphology indicates that both islands are controlled by fault systems with the same orientation, possible surface manifestations of a main crustal discontinuity at a regional scale (ROSI, 1980; GABBIANELLI *et alii*, 1993; PASQUARÈ *et alii*, 1993). The evolution of the Stromboli volcanic apparatus reflects this structural control, as shown by the NE-SW alignment of dykes, eruptive centres and fractures. The subaerial apparatus developed during the last 100 ky (GILLOT & KELLER, 1993); submerged abrasional platforms cut the oldest NE and SW sectors of the island, including the emerging neck of Strombolicchio. The subaerial evolution of Stromboli has often been interrupted by large-scale gravitational collapses that mainly affected its western flank, alternating with building stages and followed by a slow migration of the eruptive activity towards NW (PASQUARÈ *et alii*, 1993). The last (Holocenic) event created the volcano-tectonic depression known as "Sciara del Fuoco" on the western flank of the island.

Fig.4 - *Bathymetry and main morphological and volcanological features of Stromboli. This volcanic apparatus rises from a depth between -1200 and - 2200 m up to a maximum height of 3000 m above sea level; its stretching along a NE-SW axis is particularly evident from the submerged morphology. The submerged depositional terraces (hereafter SDT) develop for stretches over 4 km long along the SW and NE coasts. Apart from this two areas, the submarine slopes of the apparatus are extremely steep and carved by active canyons; the main canyon is located in front of Sciara del Fuoco (SdF in figure); it drains the products of the present eruptive activity as far as over 3000 m below sea level* (KOKELAAR & ROMAGNOLI, 1995).

A legend of the main morphological and volcanological features is reported below the map.

Fig.5 - *A SDT morphologically very clear, with a depositional edge at an average depth of 55 ms (about 41 m), was mapped in the south-western sector of the island. Since the terrace is quite steep and not too extended transversally to the coast, it has been difficult to reconstruct in detail its inner structure. The limited development of the abrasional platform at the foot of the deposit and the high steepness of the substratum are likely reasons for its wide bathymetric range (up to 80 m). Laterally the deposit closes with the disappearance of the underlying abrasional platform. The diagram shows the depth of the edge and of other depositional parametres of the SDT (see symbology in Fig. 3 for this and the following diagrams). The depth of the edge increases gradually from SE to NW; this trend is especially evident next to the lateral terminations of the terrace.*

Fig.6 - *Seismic Sparker profile off the south-western coast of Stromboli (line C, location in Fig. 5), showing a submerged depositional terrace entirely made up of two sedimentary units; the upper unit progrades over the older one, that does not outcrop on the seafloor and has little morphological expression.*

The foresets of the (recentmost) upper prograding unit are up to 20° steep; this high steepness may account for the apparent acoustic transparency in the seismic profiles. The upper unit has a maximum thickness of 30 ms; the whole terrace is 50 ms thick.

Fig.7 -*The north-eastern sector of Stromboli has a quite complex seismostratigraphic setting. An upper terrace is located at a shallow depth (edge at 35-40 ms) in front of Ficogrande area (where a thin alluvial-littoral belt is present). The SDT reaches a maximum thickness of 20 ms (about 16 m) and it lies over another terraced deposit up to 75 ms thick (about 60 m), located in the saddle between Stromboli and Strombolicchio. The deeper terrace lies over an abrasional platform (see Fig.8). Due to the asymmetry of the substratum the terraces are located at a greater depth on the north-western flank (edge at 180-200 ms t.d, about 145-160 m) and are up to 25 ms thick (about*

20 m), while, on the north-eastern flank they are at a shallower depth (120 ms, about 95 m), and are a few ms thick. A few sediment accumulations over the erosional morphology are located to the east of Strombolicchio. The vertical trend of the SDT off the northern coast of Stromboli have not been represented on diagram due to the variability of their depth and the complexity of the different units.

Fig.8 - *Sparker 500J E-W profile carried out close to the eruptive centre of Strombolicchio (see Fig.7 for location). On its western flank a thick sedimentary wedge is present (up to 90-100 ms thick, about 70-80 m) which can be considered as a main terraced unit, consisting of different overlapping sedimentary bodies (not clearly detectable because of a strong ringing effect). Its deposition is probably due to a tilting or to a volcano-tectonic collapse that affected the western flank of the apparatus, similarly to what is known about its emerged portions (ROSI, 1980). For this reason the depositional parametres of this body are extremely variable and have not been included in the final discussion. On the eastern flank of Strombolicchio a sedimentary deposit with limited thickness, lying over an erosional terrace, is present.*

PANAREA ISLAND

Panarea (3.3 Km^2 only) and the small rocks that surround it are considered the remains of a wide volcanic apparatus, mainly of pre-Tyrrhenian age, dismantled by the sea erosion and by severe neo- and volcano- tectonics. The main volcanological and structural elements identified both on the island and on its submerged portions suggest a structural continuity with the close Stromboli apparatus, similarly controlled by tectonically-oriented NE-SW features. These indicate, for Panarea, the interaction between a volcanic activity characterized by the extrusion of several minor eruptive structures (endogenous domes) and depositional and erosional activities, partially related to relative sea level fluctuations (LANZAFAME & ROSSI, 1974; GABBIANELLI *et alii*, 1990; ROMAGNOLI, 1990). The recentmost activity (about the last 60 ky) is related to the growing of the rhyolitic dome of Basiluzzo. On the seafloor to the east of the island, in the area of the small rocks of Lisca Bianca, Lisca Nera, Bottaro and Dattilo, an intense exhalative and hydrothermal activity is located.

Fig.9 - *Panarea Island. The apparatus, slightly centred to the east of the island, has a cone shape and rises from a depth of 1000-1200 m. On its flanks there are canyons with a radial trend, alternating with volcanic ridges (for this and the following maps see legend on Fig. 4). The western portions of Panarea are made up of a "primordial" stratovolcano that represents the skeleton of the island (around 650-590 ky old,* GILLOT & VILLARI, 1980*).*

The wide submerged portions of the apparatus (about 50 km² at a depth shallower than 150m) consist of a wide abrasional platform, bounded by a continuos and defined edge. The bedrock is actually more complex than it appears from its bathymetric setting, due to the presence of several, partially buried, secondary eruptive centres, basins and structural discontinuities with a NE-SW trend. These structural features affect the thick volcanoclastic cover (thick up to 200 ms) smoothing the roughness of the volcanic substratum. A main fault system with a NE-SW trend dissects the summit of the apparatus, causing the lowering of the whole eastern sector and its subsequent infilling by volcanogenic deposits. A gravity core (PAN 92-31), collected at about -85m between Panarea Island and Secca dei Pesci, revealed volcanogenic material with a coarse lithology that prevented the Kullemberg core to penetrate into the deposit, beyond the retrieved 45 cm. In detail, under an upper layer of about 30 cm made up of reddened volcanic sands rich in pumice and lapilli, small size brownish-reddish scoriae have been sampled. The reddish color of the sampled materials shows the high degree of alteration, probably increased by circulation of hydrothermal fluids (common in the area) within the bottom sediments.

The SDT on the western and eastern coast of Panarea have been studied and mapped separately, as they are related to different morphological and structural settings.

Fig.10 - *Western and southern flanks of Panarea Island (see beside). The distribution around the island of the mapped SDT (on the left) is quite evident also from the bathymetric setting resulted from multibeam shaded-relief images (above* GAMBERI *et alii*, 1997*). From the diagrams, it results that a shallow SDT is present in the whole area. At greater depths there is a more complex setting, with quite developed and often overlapping terraces. Between P. Palisi and Scoglio La Loca (northern and western sectors of the island, corresponding to the oldest and relatively undisturbed flank of the stratovolcano) there is a main terrace with a maximum thickness of 25 ms and a deposi-*

tional edge at 50-60 ms. It progrades over an older and deeper terrace, with similar thickness and an edge at 110-125 ms (Fig. 11); it lies over an abrasional platform that parallels the coast with a 1-2° slope; the erosional edge of this platform is located between 150 and 175 ms, more than 1 km offshore. The depth of the depositional edge of the lower terrace and of the erosional edge increases from N to NW and W, while the upper terrace lies at a quite steady depth, or it even becomes shallower following the trend of the southern area.

Off Scoglio La Loca, at a depth of over 100 ms there is a small volcanic feature (see Fig.9) which interrupts the lower SDT, while the upper one develops as far as P.ta Torrione. The latter has a quite clear and steady morphology, a thickness of 25-30 ms and the depth of its edge gradually decreases eastward to 25-30ms.

In the southern sector of the island there are several depositional bodies, partly overlapping. Four of them, with an average individual thickness of about 20 ms, are visible in Fig.12 and have been mapped in diagram (Fig. 10). Their stratigraphical relations are not always clear; generally the age of the prograding wedges seems to increase with depth. The depth of the edges and other parametres varies in a complex way. Despite a general trend to decrease eastwards, the depth of the lowermost and more distal bodies tend to reverse this trend. The analysis of the seismostratigraphic setting of this sector suggests the occurrence of a subsident basinal area on the outer part of the platform, over which the SDT prograde (Figs.12, 13). This lowering might be genetically related to the neo- or volcano-tectonic lowering of the eastern sector of the Panarea apparatus. Eastwards the SDT is interrupted by a large canyon with a N-S trend, that deeply carves the submerged portions of Panarea and divides it from the Secca dei Pesci sector (see Fig. 9).

Fig. 11 - *Seismic profile off the northern sector of Panarea (line B, location in Fig.10). An upper terrace with an edge at a depth of 60 ms, partially covers a deeper terrace that lies over an abrasional platform and is characterized by a remarkable horizontal extension. The inner structure of the SDT is characterized by several progradational phases with a possible retrogradational setting.*

Fig. 12 - *Seismic profile off the southern sector of Panarea (line I in Fig.10). Four morphological edges on the seafloor are related to a quite complex stratigraphic setting. The upper terrace, with a limited extension, is quite defined and is located at a shallower depth than in the western sector. The lower terrace has a scant morphological expression, with two ill-defined edges at 105 and 135 ms. The buried geometry, though, reveals the presence of at least three prograding wedges in retrogradational setting. The deepest wedge shows very steep foresets (up to 8°) with a tangential base and a slope progressively decreasing from the oldest to the recentmost phases. This wedge might have an erosional top and, contrary to the general trend, it is older than the lower and outer terrace. In the outer part of the profile a partially buried volcanic body dams a thick sedimentary basin.*

Fig.13 - *Seismic profile off the south-eastern sector of Panarea (line N in Fig.10). Here it is possible to observe: 1) the disappearence of the upper terrace; 2) multiple prograding wedges seismically ill-defined that make up the lower terrace and lie over a sedimentary basin bounded by a buried eruptive centre. The basin contains sediments over 200 ms thick and it is genetically related to the collapse of the eastern sector of Panarea volcanic apparatus. It is affected by extensional faults that do not affect the deposits of the SDT.*

Fig. 14 - *In the whole sector between Secca dei Pesci and the smaller islets there is a single depositional body, with an average thickness of 10 ms and less (rarely 20ms). Its edges are ill-defined and its inner structure is generically prograding. Locally (profiles D-H) it is possible to observe two depositional edges, likely expression of two overlying depositional bodies, seismically undetectable. The trend of the main depositional parametres of the terrace suggests two sectors (Secca dei Pesci and the area around the smaller islets) where the terrace lies at shallower depth. The SDT extinguishes northwards, by the head of the canyon with an E-W trend between Basiluzzo and the smaller islets (Fig.9).*

Fig.15 - *1000 Joule Sparker Profile parallel to the eastern rim of Panarea apparatus. It shows a central depressed sector, between two minor eruptive centres (Secca dei Pesci is the southern one). This setting is probably due to a local subsidence that allowed the accumulation of a clastic filling over 50 m thick and caused the local lowering of the SDT, as indicated in Fig 14.*

Fig.16 - *Distribution of the deposits of the SDT by the small island of Basiluzzo (up on the left) and related seismic profiles perpendicular (down on the left) and (above) parallel to the coast. The SDT is quite small and extends*

*between 50 ms and 130 ms (about 37-97 m) with a depositional edge around 60 ms (45m) and a maximum thickness of 35ms. In the profile parallel to the coast the body is made up of several depositional phases. It is important to note how, even around a volcanic centre as small as Basiluzzo, presently divided from the main Panarea platform by a saddle about 70 m deep, there was enough production and accumulation of detritus to create a small SDT. This is to be related to the dismantling action of the sea on the western portion of the dome that makes up the small island, whose emission centre is located along the NW coast of Basiluzzo (*ROMANO, 1973*).*

SALINA ISLAND

Salina (about 22 km²) is the emerged portion of a polygenetic volcano consisting of six, partially overlapping, eruptive centres (Fig 17). The oldest ones (Capo, Rivi e Corvo, active between 500 and 300 ky B.P., GILLOT, 1987) are located in the NE an W sector respectively and represent the "skeleton" of the island. Their volcanic apparata have been deeply affected by marine erosion and show high coastal cliffs. The well-preserved cones of the two recentmost eruptive centres, Fossa delle Felci and Monte di Porri (as high as 762 an 860 m), give the island its characteristic bicuspidate shape. Their activity (last 127-67 ky, GILLOT, 1987) is partly coeval to the erosional episode (of likely Tyrrhenian age) related to the marine conglomerate levels outcropping on the coasts of the island (KELLER, 1980b). The resumption of the activity in the post-erosional stage, particularly in the last 40 ky, is partly coeval with the activity observed for Lipari and Vulcano, and it is located on the same structural NNW-SSE alignment. This points out a remarkable uniformity of the whole Aeolian central sector during the main building/erosional stages (ROMAGNOLI *et alii*, 1989). In the last 30-13 ky only the Pollara centre (in the farthest NW of the island) has been active. Its explosive eruptions produced a tuff-ring made up of pyroclastic materials, whose western portion has been broadly dismantled by the sea (CALANCHI *et alii* 1987). This processes generated a thick and wide submerged depositional terrace that has been object of a detailed study by means of gravity coring and R.O.V. recording.

Fig.17 - *Wide abrasional platforms extending with a semi-circular trend around the oldest portions of the island (Corvo, Rivi and Capo eruptive centres, see Fig. 18) are the main features of the submerged portion of Salina volcanic apparatus.*

On the western and northern flanks of the island, an almost continuous SDT is located. Apart from the northern coast, another smaller abrasional platform is present at the SE edge of the island; it involves the basal portion of Fossa delle Felci centre. A SDT with variable thickness (up to 50 ms) and a quite ill-defined edge develops over it. This terrace has not been mapped due to its scant lateral continuity.

Elsewhere the submerged slopes are steep and carved by several canyons draining volcanoclastic material towards the base of the island, which is located at a relatively shallow depth towards the N, E and SE flanks, next to further volcanic centres, and deepens W and southwards, down to over -1000 m.

Fig.18 - *Along the western coast of Salina (from Praiola to Punta Perciato) a thick (50-60 ms) SDT, with an edge at about 50 ms, has been recognized over the abrasional platform. It is more than 1 km wide and consists of two overlying depositional bodies. The great amount of sediments that make up this deposit is likely to originate from the dismantling and reworking of the material that made up Pollara pyroclastic tuff ring and lacustrine basin, whose preserved eastern portion outcrops in the coastal cliff between Filo di Branda and Punta Perciato (*CALANCHI *et alii*, 1987*). Along the northern coast to the east of Punta Perciato the depositional terrace is found more or less at the same depth as in the western area, except for a limited sector off Punta Fontanelle, where it is absent and the lavic basement outcrops on the seafloor. The SDT is 25-30 ms thick, and its inner structure can be related to two different progradational phases that at times create a double depositional edge ad a depth of 40-50 and 60-70 ms. Its thickness strongly thins before Capo Faro; from this point, the thickness increases again up to 35 ms, before disappearing southwards because of gravitational instability.*

See the map for the main volcanic centres of the island (asterisks) and the location of the gravity cores collected offshore the western coast of Salina (SAL92-22 and SAL92-24).

Fig.19 - *Seismic profile off Praiola coast (line B in Fig.18). At least two progradational phases are recognizable within the SDT. The recentmost one originates a morphological edge on the seafloor. Its foresets are very steep and*

its transversal extension is smaller than the underlying phase. The latter lies over a wide abrasional platform with an edge between 140 and 160 ms which develops parallel to the coast and is likely to correspond to the old Corvo apparatus (eruptive centre in Filo di Branda area). In the outer part of the profile a morphological roughness of the volcanic basement creates diffraction hyperbola; by the platform edge there is also an older, outer depositional terrace with very steep foresets, not mapped because of its limited lateral extension.

Fig.20 - *Seismic profile off Pollara sector (line E in Fig.18). Two progradational phases make up the SDT that, with an edge at 60 ms, partially lies over the abrasional platform, here affected by possible tectonic dislocations and with pockets of volcanogenic deposits.*

Fig.21 - *Cores SAL92-22 and SAL 92-24 from the frontal slope of the SDT lying in the western sector of Salina (location in Fig. 18) The cores, recovered at about 90-100 m water depth, are 80 and 120cm long respectively; they are made up of volcanic and bioclastic fine (often silty) sand with frequent lags of shell fragments and normally graded intervals.*

*Biostratigraphic analysis of both cores revealed a remarkable reworking (up to 90% of the benthonic microfauna) that does not allow any clear paleobathymetric attribution. Planktonic faunal assemblages that can be related to the Climatic Optimum (last 4-5 ky) have been recognized at the base of core SAL 92-22 (whose top could not be preserved during sampling) and between cm 20-40 in SAL 92-24. The basal portion of the latter core (cm 90-118) contains a planktonic assemblage (with G.truncatulinoides almost absent, G. ruber, G. praecalida and G. tenellus) which can be related to 8-9 ky ago (*A.Asioli, *pers. comm.). It must be noted that both cores come from a sector of the seabottom extremely well fed during the last 13 ky, due to the dismantling of the pyroclastic deposits related to the recentmost activity of the Pollara centre.*

Fig.22 - *A* R.*O.V. (*R*emote Operated Vehicle) survey was carried out offshore Salina north-western coast, along a path almost coincident with the seismic profile shown in Fig.20. While the ship was drifting in the required direction, the self-propelled* R.*O.V. investigated the seafloor and recorded the most interesting features. It was thus possible to collect continuous visual information on the seafloor between -20 and -120m. The seismic profile beside shows the approximate location of the* R.*O.V. images A-E (hereafter reproduced).*

*Near the coast, by the top of the SDT, can be observed wave ripples with a wave length between 0,5 and 0,7 m and height of 10-15 cm (image A). The sediment is made up of coarse volcanoclastic detritus; a granulometric selection is present, with larger, but lighter, pumice fragments in the ripple troughs. The bedforms were likely created by the waves reworking the thinner part of the sediment, on the top of the terrace. Deeper bedforms, probably related to the highest-energy meteomarine events, appeared to be inactive at the moment of the survey, since they are dismantled by the activity of irregular echinoids (*Spatangus purpureus) *starting from a depth of 30m (image B). Bioturbation wipes out completely tractive structures at -45 m depth; bedforms are no longer visible downward (image C). Apart from the echinoids, the seafloor is generally azoic, with no vagile bentonic organisms.*

*On the frontal slope of the SDT the sediment is made up of coarse clasts, without any fine-grained fraction. Between -65 and -80m a "praline" facies, made up of calcareous algae (Melobesia) encrusting the surface of volcanic scoria is diffused on the seafloor (image D). For the development of this particular facies is necessary for the clasts to roll on the seabed (*Peres & Picard, 1964*); this may thus indicate the occurrence of bottom flows (possibly induced by gravitational processes acting on the steep slope, which is around 10°). Rare tunicates* (Fallusia mamillata) *are present, settled on the largest (decimetric) isolated clasts.*

Silty sediments at the foot of the frontal slope of the SDT, probably derived from the abrasion of the pumiceous material, appears at first in patches, then it becomes predominant below -90m; here the "praline" facies is almost completely absent on the seafloor, while there are regular echinoids (Cidaris cidaris) *and polichaetae worms produce small mud volcanoes over 10cm high. At the end of the* R.*O.V. survey (image E) a small lava outcrop, encrusted by green and calcareous algae and likely related to an outcrop of the volcanic basement, has been observed.*

LIPARI ISLAND

Lipari is the biggest island of the Aeolian archipelago (37.5 km^2). It owes its shape to the complex superimposition of several volcanic centres, emplaced during four main periods of activity in the last 200 ky (Pichler, 1980; De Rosa *et alii*, 1985). The products of the oldest cycle of subaerial activity make up the central and north-western portion of the island and are related to the growth of about ten volcanic centres (Timponi), aligned along the main tectonic NNW-SSE trend. Two further centres make up Mt. Rosa headland that extends with a E-W trend in the mid-eastern coast of the island. These deposits are cut at different levels by marine abrasional conglomerates, presently oucropping at heights between 10 and 40 m along the N and NW coast of Lipari. They allowed the identification of two main periods of volcanic activity (pre- and post- erosional) separated by episodes of marine ingression (BARGOSSI *et alii,* 1989). The following activity (last 125 ky) shows a slight migration eastwards and originates the central-northern sector of the island; in the last 35-40 ky volcanic activity was characterized by high explosivity, extrusion of endogenous domes and acid magma composition (PICHLER, 1980; DE ROSA *et alii*, 1985). This activity took place in areas affected by volcano-tectonic collapses, such as the NE and southern sector of Lipari, and, possibly, in the submerged area between Lipari and Vulcano.

Fig.23 - *The submerged portions of Lipari show an uneven morphology due to deep incisions and several secondary eruptive centres, mostly located on the W and N flanks and aligned along a belt with an NNW-SSE trend. The development of the Lipari volcanic apparatus seems to have been tectonically controlled, since the first activity stages, by a NNW-SSE oriented structural trend. The alignment of the eruptive centres in this direction parallels the distribution of a wide abrasion platform, 12 km long, which underlyies the SDT all along the north-western and western flank of the island (between Acquacalda and to the south of Punta delle Fontanelle, see Fig.24). The platform is also present in the farthest south of Lipari (Bocche di Vulcano area), and, with a limited extension, around Mt. Rosa headcape. Pre-Tyrrhenian volcanic products outcrop on the same sector of the coast (with the exception of the southern sector of the island).*

No SDT have been observed on the Lipari eastern flank, steep and carved by several canyons and with its base at a depth of 900-1000m.

Fig.24 - *Distribution map of the SDT in the NW sector of the island of Lipari. The letters (a-e, along the coast and to the base of the diagram) indicate the location of the coastal stratigraphical sections shown in Fig.27; the symbols stand for possible structurally or morphologically-controlled discontinuities among coastal tracts, as suggested from the vertical distribution of SDT and raised marine terraces. In the diagram also the erosional edge of the presently submerged abrasion platform has been indicated.*

On the north-western flank of the island there is a continuous upper SDT 30-50 ms thick, whose edge is located between 30 and 50 ms. In detail, the depth of its edge gradually increases southward from Punta del Legno Nero to Pietra del Bagno. Also to the east of Punta del Legno Nero the depth of the depositional edge slightly increases, as in the case of a deeper SDT, about 30 ms thick, characterized by a double depositional edge and lying in front of Punta del Legno Nero. The inner geometry of this terrace is not recognizable because of the scant penetration of the seismic signal, which might indicate coarse and/or heterogeneous lithologies.

From Punta del Legno Nero to the South, the lower terrace is better developed, and several overlying depositional phases have been detected (Fig.25). The edge of the lower SDT deepens gradually from 115 ms at Punta del Legno Nero to 145 ms to the North of Pietra del Bagno. In detail though, the terrace is characterized by an extreme lateral variability, since it consists of bodies with a limited extension and very variable inner geometries, even within the very narrow spaced seismic grid (6-700 m). From Punta Palmeto towards the south the two depositional terraces tend to coalesce (Fig.26) and, even if the relevant depositional edges are still detectable, the relation between the two deposits is no longer clear, especially by Banco del Bagno, where the deposit is spread over the wide abrasional platform which links the shoal to the main body of the island. To the south it reaches as far as Punta delle Fontanelle, where the depositional edge is located at 140-145 ms. Farther south, on Lipari south-western portion, beside the upper SDT whose edge is located at a depth of 35-40 ms, there is a lower terrace with an edge at about 100-120 ms (this sector has not been presented on diagram due to its relatively small extension).

Fig.25 - *Seismic profile perpendicular to the coast on the western flank of Lipari (line in Fig.24). At least three SDT, made up of several prograding depositional bodies, are shown; the lowermost has not been presented on diagram in Fig.24 due to its limited lateral extension. Within the bodies a general increase of the foresets slope is observable. In the shallower terrace (edge at 35 ms) a buried incision at 20 m water depth may be also observed. These features are quite common within submerged depositional terraces and are likely due to subaqueous channalized flows in correspondance of main subaerial (coastal) streams.*

Fig.26 - *This seismic profile is close to the previous one (at a distance of 750-1500 m see line M in Fig.24). Nevertheless, differences in the morphological and seismostratigraphical setting between them can be observed. In particular, the upper SDT, which totally covers a lower progradational wedge, is affected at its foot by likely gravitational instability, as suggested by undulations in the seafloor. The lower wedge consists of two thin progradational phases. The deeper SDT, over which the depositional terraces were prograding has disappeared and replaced by the outer erosional edge of the abrasional platform, located at depth higher than -120 m.*

Fig.27 - *Stratigraphical sections of the north-western coast of Lipari (see Fig.24 for location). A comparative study of the submerged features and the coastal sectors in front of them, along which raised marine terraces are located at heights between 20 and 40 ma.s.l., was carried out. These terraces are represented by morphologies and deposits with marine origin (conglomeratic levels associated with bioconstructions rich in rests of marine organisms, indicating shallow infralittoral communities). Similar levels observed on Filicudi, Salina, Panarea and Lipari have been generally associated to Tyrrhenian highstands, on the basis of their stratigraphic position, height and paleontologic content, assuming for the volcanic apparata average uplifting rates between 0.3 and 0.6 mm/y in the last 125 ky* (KELLER, 1980B; PICHLER, 1980; RADTKE, 1986; CORSELLI & TRAVAINI, 1989; LUCCHI *et alii*, 1999*).*

*The detailed geological survey carried out along the northern and western coast of Lipari (*LUCCHI, 1999*) allowed to correlate the conglomeratic levels (represented in the stratigraphic sections) and to detect the main neotectonic features of the coastal sector. This study has been compared to the morphological trend of the SDT and to the depth values of their erosional edges. The trends shown from different coastal sectors are closely related to those of the submerged sectors in front of them; areas affected by differential vertical movements and separated by discontinuities have been locally identified (Fig.24). In detail, to the south of Punta del Legno Nero the depth of the main parameters of the SDT gradually increase as does the erosional edge of the abrasional platform, which reaches depth of 190 ms (Fig.24). Lowered sectors are located by the stratigraphic section* **a** *(where local tectonic lowering seems to occur along NW-SE structures) and* **b** *(located within a wide sector crossed by seismic lines F, G, H, I in Fig 24). In the latter case, in the lowered sector, a marked increase in the thickness of the lower SDT is observed. On the coast (section b) it corresponds to a paleoshore deposit interbedded with multiple and partly reworked conglomeratic levels, for a total thickness of about 30 m. This setting suggests the location of a morphological depocenter, filled by a large amount of sediments in relatively short times (no trend is evident in the upper SDT). Just to the north of Punta Palmeto (I-L profiles in Fig.24) a morphological high is present; to the south of it the erosional egde of the abrasion platform undergo a sudden rise of 20-40ms, also evident in the seismostratigraphic setting of the upper SDT (Figs.24 and 26). The corresponding coastal section (***c***) shows a single conglomeratic level of limited thickness, located at high elevation. Southward, towards Pietra del Bagno (seismic sections P-Q) the parametres of the SDT and the heights of the conglomerate (section* **d***) lower again; the conglomeratic deposits splits into two levels and the thickness of the interlayered sediments increases.*

VULCANO ISLAND

Vulcano is the southernmost Aeolian island and is located on the main NNW-SSE trending tectonic alignment of the area, along with Lipari island and several minor submerged centres. The subaerial activity of the Vulcano apparatus has generally been ascribed to post-Tyrrhenian times, due to the lack of raised marine terraces and deposits (KELLER 1980a; FRAZZETTA *et alii*, 1985). The Vulcano Primordiale (GILLOT, 1987), a huge composite stratovolcano that makes up the whole central-southern sector of the island, developed about 110-115 ky ago. Before the summital calderic collapse that brought to its present truncated-cone shape, it reached 1000 m above sea level. After a quiescence interval, it resumed its activity with a migration from south to north and the growth of the northern sectors of the apparatus over previously collapsed sectors, as it happened in the southern area of Lipari. The recentmost activity (Cono della Fossa, Vulcanello) seems to be more and more controlled by tectonic structures with a NE-SW trend, recognized even in the submerged portions and in the sectors presently suspected of incipient activity (GABBIANELLI *et alii*, 1991).

Fig.28 - *The bathymetric setting of Vulcano shows steep flanks carved by several canyons. The base of the apparatus, with a diametre of about 15 Km, lies at an average depth of 900-1000 m. In its submerged and shallower coastal portions a morphologic asymmetry is evident along the western flank, cut by an abrasional platform in the*

*mid-southern sector; this feature is absent from the other flanks of the island. This sector partially corresponds to the location of the peripheral volcanic center of Spiaggia Lunga, whose remains, consisting of lavas dipping in angular disconformity respect to the Vulcano Primordiale that partially covers them, are the only evidences of any previous subaerial activity (*KELLER, 1980a*). This setting suggests the occurrence of a strong alignment of probable structural origin since the beginning of the development of Vulcano and Lipari apparata (*ROMAGNOLI *et alii*, 1989*), while the subsequent activity of both islands moved eastwards. SDT develop both on the abrasional platform on the western flank of Vulcano and in the Bocche di Vulcano strait, that divides Vulcano from Lipari.*

Fig.29 - *On the western, less steep, side of Bocche di Vulcano (the strait between Vulcanello and Lipari) there is a SDT, bounded southwards by a canyon head (see Fig.28). The terrace lies over the remains of a possible buried eruptive centre, possibly responsible for phreato-magmatic activity occurred in the sector between 40 and 13 ky ago* (ROMAGNOLI *et alii*, 1989).

Fig.30 - *This 500 J Sparker profile, carried out along a E-W line between Lipari and Vulcano, shows the SDT lying on the western side of the strait. The area covered by this deposit is quite limited, but it is up to 50 ms thick, with an edge between 70 and 115 ms. The strong tridimensionality of the terrace and its curvilinear trend have lateral effects on the inner reflectors of the deposit. The edge is well defined and the inner structure of the SDT is prograding (two progradational phases can be observed), with concave foresets downlapping tangentially to the basal surface. The SDT of Bocche di Vulcano was not considered on diagram in Fig. 34 due to its scant lateral extension.*

Fig.31 - *The seismostratigraphic setting of the western flank of Vulcano is far more simple of Lipari western flank. There is only a SDT between Punta Capo Secco and the southern point of the island. This terrace is 30-40 ms thick, with a depositional edge at an average depth at 50 ms. The deposit is bounded northward by a canyon whose head is located by Punta Capo Secco. After a new interruption by Punta Conigliara due to erosion, it extends in small strips as far as the southern point of the island.*

Fig.32 - *SDT on the western flank of Vulcano (line D, Fig.31). The inner structure of the deposit is relatively simple with quite steep foresets and frontal slope (over 20°).*

Fig.33 - *Seismic profile normal to the coast by the northern end of the terrace (area in front of Spiaggia Lunga; line B in Fig.31). The substratum of the SDT is less steep than in the previous profile; nevertheless it is affected by gravitational dislocation, causing offsets to over 10m on the seafloor. The mild frontal slope (6°) might have been caused by the morphological readjustment of the gravitational dislocations.*

DISCUSSION

LOCATION OF SDT WITH RESPECT TO VOLCANIC APPARATA

The occurrence of the SDT around the central-eastern Aeolian Islands shows that multiple terraces, located at different depths, are mainly distributed on the oldest portions of the volcanic apparata (Panarea, western Lipari, northern Salina). On the apparata with a more recent age (western Vulcano, southern Stromboli) only a single, shallow water terrace has been detected. The distribution maps (Figs.4, 9, 17, 23 and 28) also show that SDT are preferentially located on the submerged abrasional platforms that border most of the apparata. As far as Lipari, Salina and Panarea are concerned, these platforms cut pre-Tyrrhenian volcanic products (Fig. 34). On the contrary, on the younger islands (Vulcano, Stromboli and Alicudi, ROMAGNOLI 1990; CALANCHI *et alii*, 1995) SDT are found on the apical portions of the emerging apparata (covered by volcanic products older than 100-110 ky, according to the dating quoted in GILLOT & VILLARI 1980; GILLOT & KELLER, 1993). The presence of pre-existing abrasional platforms seems to favour the development and/or preservation of the SDT. The depositional bodies, in fact, often close laterally in correspondance of the disappearance of the underlying platforms, whose gradient and width seem to control not only the development of the SDT, but also their geometry (e.g.: foresets slope). The availability of clastic materials also plays an important role. The thickest SDT (up to 60ms), with a remarkable extension both parallel and transversal to coast, are located off those sectors where a big amount of low-coherency sediments was made available from the dismantling of pyroclastic deposits in the adjacent coasts (e.g. Pollara, western coast of Salina). Similar influences on the distribution of the SDT are observed around Linosa volcanic apparatus (ROMAGNOLI, *this volume*).

Where the abrasional platform are absent, the steepness of the primary volcanic flanks does not allow the permanence of the sediment in shallow waters, and it often causes its gravitational reworking towards the base of the volcanic apparata.

Fig.34 - *Distribution of marine abrasional platforms around the islands of the Aeolian central sector and, particularly, in correspondence of the pre-Tyrrhenian in aree volcanics of Salina and Lipari and of the products related to the earlier subaerial activity for Vulcano island.*

DEPTH DISTRIBUTION OF SDT

The depth of the most relevant morphological parametres of the SDT (i.e. upper boundary and depositional edge) are presented in the histograms of Fig. 35. The depths show meaningful distributions, indicating at least three major groups. The largest one (about fifty observations from all five islands) is quite sharp, with an edge at about 30-40 m of depth (40-55ms) and the upper boundary about 15 m of depth higher. A second group (36 cases, observed mostly at Lipari and Panarea) has an edge at 75-100 m of depth (100-130 ms) with a upper boundary about 15 m higher. It must be noticed that the depths of the latter group are much more spread than those of the shallower one. This may be related to the effects of neo- or volcano-tectonics on the apparata, causing vertical dislocations, often restricted to small sectors, as reported for Panarea, Lipari and Stromboli (Figs.8, 9, 10, 24 and 27). Thus, the depths of the depositional edge of a few SDT observed in the southern sector of Panarea, affected by tectonic dislocations, make up a further and deeper group at about 128-155 m of depth (170-210 ms). The location of SDT over small basins on the submerged flanks of the volcanic apparata can also be related to the deepening and thickening of the SDT, due to local compaction of volcaniclastics and following subsidence, as it seems the case for southern and western Panarea (Figs.10 and 15).

No SDT have been observed at depths greater than 155 m or below the erosional edge of the abrasional platforms over which most of them develop. In a few cases, wide erosional disconformities, cutting progradational deposits and/or basin fillings, have been observed. These surfaces lie below the recentmost SDT and are located at depths comparable to those of the erosional edge of the abrasional platforms (which in most cases show values between -105 and -120 m, i.e. 140 and 160 ms).

Fig. 35 - *Histograms of the depth of the upper boundary and depositional edge of the SDT observed around the five islands of the central-eastern sector of the Aeolian Archipelago.*

POSSIBLE GENESIS OF THE SHALLOWER SDT

Shallow-water SDT (upper boundary at 15-25m, edge at 30-40m) with seismoacoustic facies and geometry very similar to the deeper ones, have been observed around every island. They are probably related to present-day depositional processes (Fig. 36), and their formation is likely recent, being occurred during the eustatic high-stand which started 6 ky ago. This interpretation might be also supported by the little dispersion of depth values of their depositional parametres (Fig.35).

It must be noticed that the SDT are not connected with present-day beaches on the islands. These are, in most cases, represented by gravelly pocket beaches, a few metres thick and with a limited extension. On the contrary, the SDT are a few tens of metres thick, with a lateral continuity, and a transversal development up to several hundreds metres. They are also present off coastal sectors characterized by high cliffs and absence of littoral deposits.

It might be assumed a completely subaqueous formation for the SDT, with their upper boundary close to the sea level and the edge a few tens of metres deeper, possibly matching the wave-base level. The mobilization of the sediments produced by coastal erosion and/or biogenic activity may occur during very high-energy marine storms, and they may be carried offshore by unidirectional downwelling currents balacing storm wave-surge. The deposition thus is likely to occur below the wave-base level, along slopes approximating the angle of repose of the sediments. It must be remembered that a strong vertical exaggeration of high-resolution seismic profiles greatly amplifies the slope of the depositional features (see the box on the lower right corner of the figure). This interpretation may account for: a) the absence of link to present-day beach deposits for the SDT, b) the high slope of the foresets, c) the occurrence of shallow-water SDT around all the islands and the consistency of their depth. A similar interpretation has been proposed by Chiocci & Orlando (1996) for SDT in Palmarola Island (Pontine Isl.s). The top of the SDT and the depth of its edge are likely to be controlled by the base-level of the wave motion of higher energy meteomarine episodes, not easily determined. In the case of the Tiber River delta (over 400 km far) the wave-base-level where the reworking of sediments occur, coincides with the edge of the delta front, located at -25m (Bellotti & Tortora, 1985). If this level (D) is assumed to correspond with the shoaling zone limit (according to Elliot, 1986), the corresponding wave length (L) is around 100-150 m (D=L/4-6). According to AIRY's wave theory (Bretschneider, 1969) and SWAMP's (1984) empirical relation H=0,06T2, confirmed by Grancini *et alii*, (1979) experimental data, we obtain a 8-11s period and a 4-7 m wave height. The 7m value corresponds to a wave with a 30% of possibilities to occur in a 10 years span, according to Cavalieri *et alii*, (1985) tables of the Central Tyrrhenian Sea. By applying procedures, tables and relations from the Central Tyrrhenian area to the Aeolian Islands, we obtain heights of 5-8,7 m, periods of 9-12 s, wave lengths of 110-180 m and an effective base level of 27,5-30,5 m. This value is quite close to that of the depositional edge of shallow-water SDT.

Fig.36 - *Schematic representation of the SDT possible genesis.*

POSSIBLE ROLE OF FETCH AND COASTLINE EXPOSITION IN AFFECTING THE DEPTH OF SHALLOW SDT

By assuming that the formation of the shallow-water SDT is due to the redistribution of sediments during high-energy storms, we tried to verify the correspondence between the depths of the shallower SDT and the coastline exposition, to which the wave base-level might be roughly related. The coastline exposition has been calculated in a simplified way, by estimating the fetch transversal to coast in different sectors of the islands (Fig. 37). The structure of the archipelago is responsible for the contiguity of the more exposed coasts with sectors sheltered by other islands. When SDT are present in these sectors, the results are generally consistent.

Off the southern coast of Stromboli, the SDT is located in shallower waters (edge at 20m) to the south-east, where the coast is sheltered by other islands of the archipelago (namely Panarea), while its depth increases down to -40 m westward (on the not-sheltered flank; see Fig.5). The situation is similar for the western flank of Panarea: towards west and north-west the depth of the edge of the upper SDT is -40 m and gradually decreases southward (to -20 m) where the fetch is limited, due to the Salina-Lipari-Vulcano alignment (Fig.10). Panarea eastern flank, even if not affected by the presence of other islands, is characterized by several shoals (Secca dei Pesci to the south and Isolotti Minori a little north) that might partially account for the 30 m difference between the depth of the upper SDT edge inshore to the shoals and in the area between them (Fig. 14). The whole northern coast of Salina is exposed to hundreds of km fetches (without relevant trends in the depth of the upper terrace); in Lipari the upper terrace reaches its lowermost depth (edge at -22 m) by Punta del Legno Nero (sheltered sector of the island) while, with the increasing of the fetch, the edge of the SDT reaches -30 m eastward and -38 southward (Fig.24).

These evidences are a first clue on the role of wave energy on the formation of SDT. For a more detailed analysis it would be necessary to consider wave-refraction patterns, the variations in short distance of all the depositional parametres of the terraces and the frequency and strength of wind-driven storms in the archipelago (occurring mainly from the north and, secondarily, from south east and west, I.I.M, 1980).

Fig.37 - *Distribution of the fetch transversal to coast in different coastal sectors of the islands.*

VERTICAL MOVEMENTS IN THE COASTAL SECTORS OF THE ARCHIPELAGO

Volcanic coasts represent unsteady margins, where irregular (often alternating) vertical movements may cause fast uplift of drowning, expecially in relation with volcano-tectonic events or seismic crisis. Marine morphologies and deposits (mainly attributed to raised palaeo-shorelines of Tyrrhenian age) have been identified on several Aeolian Islands up to 100 m above the present sea level. They witness an uplifting trend occurred in the last 125 ky (PICHLER, 1980; RADTKE, 1986; CORSELLI & TRAVAINI, 1989; LUCCHI *et alii*, 1999). Recently, average uplifting trends of 0.34, 0.36 and 0.31 m/ky for the last 125 ky have been estimated, respectively, for Lipari, Salina and Filicudi Islands (LUCCHI, 1999). These values, which suggest a common pattern in the vertical mobility of the three islands, are comparable to the regional trends of crustal uplifting reported for the inner sectors of the Calabro-Peloritano Arc in a similar time frame (COSENTINO & GLIOZZI, 1988; WESTWAY, 1993). The Island of Panarea, on the other hand, seems to have been suffered from uplifting at higher (unsteady) rates: average values range from 0.69 m/ky for the last 100 ky to 1.56 m/ky in the time frame125-100 ky ago (in the same interval a strong volcanic activity was present on the island; LUCCHI, 1999, LUCCHI et al., 1999).

Observations on roman ruins and other historical remains (BERNABÒ BREA, 1947; ROMAGNOLI *et alii*, 1995) point out that a short-term, localized strong subsidence, with a probable volcano-tectonic origin, affects coastal sectors of Lipari and Panarea Isls., where it overlaps the long-term uplifting trend and is responsible for the fast drowning of these structures (Fig.38).

Fig.38 - *LIPARI ISLAND - mooring stones dated to the beginning of the seventeenth century (*NEGRO & VENTIMIGLIA, in ARICÒ, 1998). *Their periodical drowning is suggested by the presence of living* Chthamalus *barnacles and intertidal green algae on the quay* (CALANCHI *et alii,* 2002). Photo: C. Romagnoli.

The mapping of SDT shows the occurrence of structural or morphological discontinuities as the main responsible for lateral variations observed in their inner configuration and distribution in depth. However, the peaks in frequency of the depths of the main depositional parametres of the SDT (Fig. 35) suggest that, apart from the local behaviour of a few dislocated sectors, not consistent with the overall vertical mobility of the area, the volcanic apparata of the Aeolian archipelago suffered little differential vertical movements relative to each other during the last thousands years.

POSSIBLE MEANING OF THE DEEPER SDT

Assuming that deeper SDT (edge at - 75/-100 m) originated with the same depositional mechanism proposed in Fig. 36 for the shallow ones (depositional edge at -30/-40m) and in oceanographic conditions similar to the present, at the time of their formation the sea level should have been 45-60 m lower than today. Their thickness and seismo-stratigraphic appearance are similar to the shallower SDT, possibly originated during the last 6 ky, since the stabilization of the present sea-level after the Versilian eustatic rise. Then the deposition of the deeper SDT might have similarly required a sea level standstill of some thousand years. A limited group of even deeper SDT (depositional edge at -130/-150m, observed for instance at Panarea and Stromboli) is not relevant since they are located in lowered sectors of the volcanic apparata.

As far as marine abrasional and wider erosional surfaces are concerned, they have been generally observed down to 120 m of depth (without considering the sectors affected by local dislocations); thus the paleo-sea level during their formation might have been 90-110 m lower than the present one.

It is not easy to estimate the duration of coastal erosion processes responsible for the carving of abrasional platforms on lavas. According to average rates of coastal retreat it should require thousands, or tens of thousands of years (HEALY, 1981; ROWLAND *et alii*, 1984; LEBESBYE & VORREN, 1996). The evolution of the peripheral centres of Surtsey volcano (Iceland) as reported by KOKELAAR & DURANT (1983) represents an example of summital erosion of a recent submarine volcanic centre. Here volcanogenic products (probably little coherent) were degraded by the action of storm waves or currents; the fast formation of quite developed abrasional platforms at 28-44 m of depth has been observed.

Fig.39 - *Schematic representation of the evolutionary stages of a submerged volcanic edifice in the post-eruptive degradational stage (modified after CAS et alii, 1989): a) the volcano summit is widely eroded by storm-wave action (l.b.= storm-wave base level) till the development of a wave-cut platform, with the periodic overspilling and redeposition of eroded debris over its edge; b) a relatively stable platform surface formed, no longer affected by wave action due to sea level rise and gradually colonized by marine organisms. The deposits lying on the erosional surface are occasionally reworked (due to high-energy stormy events) and swept off the platform, building progradational wedges.*

In Fig.40 the sea level curve for the last 140 ky (CHAPPELL *et alii*, 1996) has been compared with the present-day depths of the SDT and other relevant morphological features of the Aeolian Islands. By assuming the present sea-level as formation level for the shallow SDT, the development of the deeper SDT (edge at -75/-100m) would require some thousand years long stillstands of the palaeo-sea level at depth around -45/-65m. Their formation might have taken place during periods in which the sea level change rates have been relatively low. Actually, it must be considered that eustatic sea level changes combine with vertical local to regional (tectonic and/or volcano-tectonic) movements, widely recognized in this area. As previously stated, an average regional uplift of about 0.3mm/y may be assumed for the central Aeolian archipelago since the last 125 ky. However, uplift movements may be enhanced, for instance, in correspondance with stages of increased volcanic activity (as recognized for Panarea Island between 100 and 125 ky ago; LUCCHI *et alii*, 1999). By modifying the eustatic curve for a regional uplift rate of 0.3 mm/y, a relative sea-level trend is obtained for the last 140 ky. The depth range relevant to the formation of the deeper SDT matches the relative sea-level curve in correspondance to the eustatic lowstand occurred around 140 ky ago, of the time frame 75-40 ky ago and, again, during the last sea-level rise (at 12-15 ky ago approximately). Nevertheless, it should be kept in mind that depositional bodies such as the SDT might hardly be preserved during the almost complete emergence of the abrasion platforms over which they stand (as likely occurred at the Last Glacial Maximum, about 18 ky ago).

A polyciclic formation, due to repeated shoreline erosion, could be related to the submerged abrasional platforms, which are mainly carved in volcanic pre-Tyrrhenian products. But, on the other side, the -90/-110m depth range, corresponding to the possible paleo-sea level during the formation of abrasional surfaces and of main erosional unconformities, matches the relative sea-level curve of Fig. 40 only during the lowstand of 18 ky ago (unless that opposite or composite vertical movements affected the area before the last 125 ky ago). At the time of the Last Glacial maximum, the rejuvenation of the presently submerged abrasion platforms might well have occurred; because of the geometric and stratigraphic relations between the abrasional platforms and the deeper SDT (generally more recent, since they lie over them) the formation of the latter can be post-dated and mainly ascribed to deposition during the Last Post-Glacial stage.

In conclusion, the chronological attribution to the formation of the deeper SDT is still theoretical, since further data on the vertical movements of this sector in the past and on the time necessary to create the observed erosional-depositional submerged morphologies are not available for the moment.

Fig.40 - *Sea-level curve for the last 140 ky (from* CHAPPELL *et alii*, 1996) *and relative sea-level curve (dashed line) obtained by assuming an average uplift trend of 0.3 mm/y. Horizontal belts indicate the relative sea-level ranges possibly corresponding to formation of the shallower and deeper SDT, of the abrasion platforms and of the raised marine terraces (assumed heights refer to Tyrrhenian terraces studied on Lipari island,* LUCCHI *et alii*, 2001 *and* 2004).

CONCLUSIONS

The SDT around Stromboli, Panarea, Salina, Lipari and Vulcano Islands were defined in detail by means of a specific survey carried out on board a small draught boat that allowed the realization of close seismic profiles, normal to the coast, even in very shallow waters. The high-resolution profiles clearly depicted the SDT and their inner structure, although, in some cases ringing effects (up to a few tens of ms prolonged, about 7 m) apparently hid the sea floor, and, in case of extremely thin deposits, even hamper the characterization of SDT. However, even in case of scarce seismic definition, the sea floor morphology (slope breaks, distribution of even/uneven areas) generally allowed the mapping of the SDT.

Due to the marked lateral variability of the SDT in the Aeolian archipelago, the seismic line spacing (usually less than 1000 m) did not always allow a sure correlation among contiguous profiles, but a careful interpretation of the seismostratigraphic setting was needed. In order to identify the factors controlling the distribution, depth and development of the SDT, the morphological/depositional parametres defining the terraces were analyzed. The simplest parametre to be defined is the upper boundary of the depositional bodies, although its depth is often affected by the morphology of the substratum. The depositional edge is always very relevant and quite clear to define, except in the case of thin deposits or SDT affected by gravitational deformations. The depth at which the SDT close is the less relevant parametre, since it is always affected by the morphology of the substratum and its definition is quite subjective.

SDT are more frequent and thicker in those coastal sectors where portions of volcanic apparata rich in pyroclastic deposits (whose dismantling supplied the material to build up them) oucrop; they also seem to be controlled by the presence of sub-horizontal abrasional platform carved in the flanks of the volcanic edifices. The conservation of SDT is, in fact, enhanced in those sectors where the primary morphological profile and substratum slope have been previously modified. A further factor affecting the depth of the SDT seems to be the coastline and fetch exposition.

With the exception of a few cases (southern Salina, northern Stromboli, and some sectors in northwestern Lipari) the depth of the edges of the SDT (and of the other depositional parametres) gradually varies with quite defined trends for several km. This confirms the non-casual nature of the depth of the deposits, as also suggested by the frequency distribution of their depths around definite values.

The depositional characters of the SDT are quite similar on all islands (see, for instance, profiles in Fig. 20 and 26): their inner structure, when recognizable, is always basinward-prograding, with both obliquous and tangential bottomset configuration; stratification is quite thin, up to the maximum seismic resolution, the thickness is, in most cases, around 20 m.

The bathymetric range over which the SDT develop is quite broad (between -15 and -140 m of depth); their shape and the internal geometry can be quite variable (one or more depositional edges, one or more progradational phases, presence of reactivation surfaces, increase in the foreset slope). A shallow-water SDT (whose upper boundary is not always detectable since it is located at a very little depth by the shore), with an edge between 30 and 40 m, is generally observed. This terrace has a progradational inner structure and it often consists of a single-story depositional body. At a greater depth there are further SDT, often with a complex inner structure indicating a polyciclic nature. The stratigraphic relations between different deposits are variable, even though the anteriority of deeper deposits respect to the more superficial and close to the coast ones is generally acknowledged; a retrogradational setting of the SDT, with downlap terminations of sedimentary wedges respect to the top of the underlying ones, is often observed.

Laterally the SDT extinguish either gradually, becoming thinner and thinner, or abruptly, in presence of canyons; in the latter case evidences of gravitational instability phenomena are commonly observed.

It is possible to state that in the Aeolian islands:

1) SDT originate only (or mainly) when the substratum is not too steep and the erosion supplies enough volcanoclastic material to build up the terraces;

2) abrasional platforms carved on the substratum and erosional unconformities with edges at about 140-160 ms of depth (-105/-120m) are present. Both kind of morphologies are preferential sites for

the development of SDT and make for their greater horizontal development;

3) the SDT are located in the bathymetric range of -20/-150m (edge depth). Frequency peaks are observed at average depths of -30/-40 and -75/ -100 m; terraces at greater depth may be explained by local vertical dislocations of the substratum;

4) the inner structure of the SDT is always basinward-prograding, their depositional edge is generally 15 m lower than the upper boundary, their average thickness is of about 20 m, the foreset slope (and the frontal slope) varies from a few degrees to about 15°. Generally the upper SDT have a simple inner structure, while the deeper ones reveal a polyciclic structure;

5) the depth of the shallow SDT may be affected by the present sea level since it gradually varies along several km, consistently with the coastline exposition to wave action. The occurrence of local structural or volcano-tectonic features on the volcanic apparata seems to be responsible for the main lateral variations observed in the depth and in the inner structure of the SDT in adjacent coastal sectors;

6) deeper SDT must be referred to a relative sea level considerably lower than the present. Beside merely eustatic factors, this is to be ascribed to the tectonic instability of the area, affected by vertical movements with local and regional character and with a not necessarily regular and uniform trend. The retrogradational setting of the progradational wedges that make up the SDT may account for a deposition occurred during the unsteady raising of the relative sea level.

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