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Submerged depositional terraces of the Pontine Islands (Southern Latium)

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GEOLOGICAL FRAMEWORK AND METHODS

The Pontine archipelago is made up of two groups of (predominantly) volcanic islands located on the eastern Tyrrhenian continental margin that underwent a transpressive tectonic activity in the Pleistocene (MARANI & ZITELLINI, 1986). The western group is made up of the Islands of Palmarola, Ponza and Zannone and the small Botte Rock, while the eastern group is made up of Ventotene Island and the islet of S. Stefano. The western group was developed during the Plio-Pleistocene on the outer margin of the Latium shelf, while the eastern group consists of a subconic volcanic apparatus of about 800 meters in height standing at the center of the Gaeta Gulf (Fig. 1).

During the Pliocene, the southern Latium continental margin was affected by tectonic movement that created the Palmarola and Ventotene basins (DE RITA *et alii*, 1986). At the end of the Pliocene, the outer edge of the shelf was continually affected by normal faulting which besided the volcanic activity that created the archipelago.

The volcanism which developed in the three western islands, Zannone, Ponza and Palmarola, has a complex nature that depends partly on the substrate and partly on the position of the relative sea level during the emplacement of the volcanites (CARMASSI *et alii*, 1983).

The island of Zannone is characterized by overthrusted units of metamorphic and sedimentary rock of various ages (from the Paleozoic to the Messinian) on which rests a unit of subaerial volcanites coming from Ponza and Palmarola apparatuses (DE RITA *et alii*, 1985). Ponza, the main island of the archipelago, is characterized by an acidic subaqueous volcanism in the early stage, and a potassic subaerial volcanism in the final phase. The island of Palmarola is mainly formed by totally subaqueous acidic volcanic products of the upper Pliocene-Pleistocene age. There are two small outcrops of upper Pliocene marl and clay only on the western side (CARRARA *et alii*, 1986).

Fig.1- *The Pontine Archipelago can be subdivided into a western group (including the islands of Palmarola, Ponza and Zannone) and an eastern group (made up of the islands of Ventotene and S. Stefano). The two groups of islands, together with the Ischia and Procida complex, form part of a volcanic ridge (trending W10-158N) that stretches for about one hundred kilometers.*

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The eastern islands of Ventotene and S. Stefano represent the emergent portion of a great strata volcano with a base diameter of about 15-20 km. The eruptive center of the volcano is located on the western part of Ventotene as evidenced also by the north-eastward dipping strike of the volcanic products (BERGOMI *et alii*, 1969).

The volcanic sequence has trachybasalts at its base that was were emplaced in a submarine environment with various flows, whose maximum thickness reaches 50 m. Above these are sandy tuffs, interbedded with layers of pumice and small lapilla, overlayed by a well-cemented tuff. The trachybasalts of Ventotene and S. Stefano have been dated to be about 1.7 and 1.2 million years old respectively (BERGOMI *et alii*, 1969).

Numerous geomorphological features testify to sea level stillstands significantly higher than the present sea level in various areas of the archipelago. This fact is probably due to the interaction between eustatic fluctuation and volcano-tectonic uplift. SEGRE (1956) identifies possible Tyrrhenian deposits at about 50 m on Ponza Island. CARRARA *et alii* (1995) describe lower Pleistocene beach deposits at 240 m (Mount Guardia, Ponza) and marine abrasion platforms from 200 to 270 m (Mount Guardia and Mount Guarniere, Palmarola), from 100 to 120 m (Ponza) and from 45 to 50 m (Ponza and Zannone). At Ventotene there is a marine erosional platform at 25m. Finally, there are beach notches at 3 m on the island of Ponza and an uplifted Holocene beach at about 10 m on Palmarol (CARRARA & DAL PRA, 1992).

The marine areas around the archipelago have been investigated during three high-resolution seismic cruises aboard CNR's R/Vs "Urania" and "Minerva". A Bubble Pulser source was used to aquire analogic data. A pass-band filter between 300 and 2000 Hz and an automatic gain control (AGC) for amplitude recovery were used in the acquisition. The survey was positioned with GPS; DGPS (Differential Global Positioning System) was used in only one survey. According to seismic source and positioning characteristics, the seismic records gave a vertical resolution of about one meter, while the error in the positioning can be assumed to be from 10 to 30 meters.

The survey was carried out on profiles perpendicular to the coast, spaced on average, every 1.5 km and tied by profiles parallel to the coast. During the acquisition of seismic profiles, echo soundings were also registered. On the northern side of Ponza Island, some Side Scan Sonar profiles were also acquired. In all, around 300 km of seismic profiles were acquired in an area of about 280 square km (Fig.7).

In the vicinity of the islands of Ponza and Palmarola, two gravity cores were also collected.

Submerged depositional terraces (SDTs) with good lateral continuity have been found both in the western islands (already partially described in CHIOCCI & ORLANDO, 1996) and the eastern ones (here analyzed for the first time). The presence of a SDT was found even around Botte Rock, an isolated structure located 7 miles SE off Ponza.

WESTERN PONTINE ISLANDS

Fig. 2 - *Three-dimensional view from the SW (as seen from above in the upper part and from the side in the lower part) of the western group of the Pontine archipelago made up of the islands of Palmarola, Ponza and Zannone and Botte Rock. The view shows that the three islands represent the apex of one large morphologic high that does not include Botte Rock, and that Ponza's southern slope is scoured by numerous canyons. A submerged depositional terrace is well visible at a shallow depth on the eastern side of the island of Palmarola (see Fig. 4).*

Fig. 3 - *Seismic profile off Ponza's southeastern coast (see Fig. 7 for location). One can observe a SDT with a prograding internal structure, a terrace edge at about 120 m and a thickness of up to 34 m. Externally, the SDT shows a very regular geometry with the terrace top sloping about 1° and a frontal slope of about 10°. The internal foresets show a similar steep slope and are therefore at the limit of seismic detection capabilities. The similarity between the dip of the foresets and that of the frontal slope confirms the depositional and non-erosive nature of the latter. The strong ringing of the sea floor reflection usually prevents a detailed resolution of the very upper part of the deposits. However, a part of the main SDT, it is possible to detect a more recent, finelly clino-stratified phase characterized by a maximum thickness of about 15 m, slightly sloping foresets and possible depositional edge at a depth of 86 m.*

Fig. 4 - *Seismic section normal to the isobaths on the eastern side of the Palmarola Island (after* CHIOCCI & ORLANDO, *1996). One can see two depositional terraces located at depths of 24 and 110m (edge depths); they are similar in form and dimension and separated by a morphologic high which might possibly correspond to a minor volcanic centre. This feature appears to have acted as a dam for the deposits making up the upper depositional terrace, and probably acted as a base for the small prograding wedge overlying the deeper depositional terrace as well. The deeper terrace is continuously observable in the entire archipelago, while the shallower terrace is found only on the eastern side of Palmarola. Its presence is observable even from the perspective view of Fig. 2 and from the isobath trend of Fig.7. The shallower terrace is made up of two depositional bodies. Very steep stratification characterises the younger and more developed body with an increase in the slope of the recentmost foresets. The older body is less developed and with only slightly dipping stratification. The top of the upper submerged depositional terrace shows a slight apparent counter-slope, probably due to the difference between the profile direction and the maximum slope direction of the terrace.*

Even the deep terrace is made up of at least two distinct progradational episodes. The geometry of the foresets is not easily identifiable but appears to be rather complex. There is a V-shaped feature, that probably represents the product of the channeled submarine flows like those described in CHIOCCI & NORMAK *(1991). Even in this case, the slope of the most recent foresets matches that of the frontal slope.*

Finally, it is also possible to observe an even older progradational phase, buried by the just described depositional terrace; it created a depositional edge at 220 m and is completely obliterated by the subsequent sedimentation. In the lower part of the figure, the line-drawing of the profile is shown without vertical exaggeration. The depositional terrace here, although less pronounced with respect to its representation in Fig.4, is a very prominent morphologic feature on the sea floor.

Fig. 5 - *Seismic profile located about 2 km southeast of the former profile (after* CHIOCCI & ORLANDO, *1996). The profile shows the same deeper SDT of the seismic profile in Fig. 4 but it runs along a direction not exactly parallel to the dip (see Fig. 7 for location of the profile). For this reason, the seismic horizons are less steep and it is*

therefore possible to depict the internal structure of the depositional body in detail. The SDT rests on a very uneven substrate while it shows a smooth flat top located at an average depth of 105-110m. The internal structure shows the complex composition of the SDT, made up of several depositional phases bounded by erosional surfaces. That is, it shows erosional surfaces that testify brief interruptions in the building-up of the deposit. In the figure there are at least three main growth periods that are separated by erosional disconformities. The first two phases overlie each other and are located more coastward with respect to the more recent phase. The two older phases appear to be truncated frontally by a reactivation surface that is concordant with the stratification of the most recent phase, which shows progradational concave foresets with well developed bottomsets. A gravity core sample (87 cm long) of the sea floor was taken along the seismic profile at a depth of 105 m (see the following picture).

Fig. 6 - *Marine sediment core collected by a 500 kg Kullemberg corer in the eastern part of Palmarola Island (for location, see Fig.5). The 87 cm core is predominantly composed of bioclastic medium sands with abundant silt. The upper part consists of well-sorted medium sands while the base is more silty* (CIOLLI, *1995*). *There is a gravelly layer at about 40 cm from the bottom, mainly made up of shell debris. Ostracodes, pteropods and briozoa have been identified in the sediments in addition to shell fragments of benthic organisms (in particular, gastropods) up to several centimeters long. In the upper part of the core, vegetal filaments are also abundant. The following analyses were made on the core in the positions indicated on the schematicl log:*

*1) Microscope analysis of the vegetable filaments present at 20 cm above the bottom. The fibers were attributed to the marine Phanerogam plant by comparing them to actual rhizomes of Posidonia Oceanica (*L. ARGENTI, *personal communication).*

*2) Qualitative analysis of the forams present at 10-20 cm points out a coastal environment assemblage (*M.G. CARBONI & C. VIOTTI, *personal communication).*

*3) Analysis of the macrofauna present at 38-44 cm below the sea floor indicates an upper circalittoral environment, as evidenced by shell debris with reduced taxonomic differences and elaborate forms. On the contrary, the same analysis at 60-70 cm and 81-87 cm below the sea floor shows a high-energy environment (infralittoral to supralittoral) supported by a high taxonomic diversification (more than 70 different species) probably tied to the presence of algae carpets or meadows of marine Phanerogams (*S. MONARI, *personal communication).*

4) 14C AMS dating of the vegetable fibers described in point 1). The conventional age obtained was 1,350+/-50 years (Beta 86804 sample, 13C /12C, measured age 1,230+/-50, conventional age 1,350+/-50). The dating *showed a rather young age with respect to expectations. In the present eustatic conditions (stable for the last 6,000 years), Phanerogam marine plants don't live below -40 m depth. Therefore, in order to explain such a recent age of the vegetable remains found in the core one must assume that the Phanerogam remains were transferred from the submerged beach environment down to a depth of 110 m and a distance of almost 3 km. The remains would have then been buried by about 20 cm of sand in an insular environment that, during high stand periods, was isolated from the Latium continental shelf and therefore, from the sediments coming from the peninsula. Thus, the age given by radiocarbon dating is difficult to explain, and is further complicated by the discrepancy with respect to the dating by the 230Th done just 20cm below (see next point).*

*5) 230Th dating done on small esacorals (Caryophyllia clavus) present at 38-44 cm from the top of the core (*M. VOLTAGGIO & M. BRANCA*, personal communication). The age was 7,800+/- 350 years (activity ratio:* $^{230}Th/^{234}U=0.069+/-0.00$; $^{234}U/^{238}U=1.263+/-0.056$; $^{230}Th=>40$; $Uppm=4.211+/-0.133$). *The age indicates a deposition occurring during the end of the last sea level rise, consistent with the analytical results in points 2) and 3), i.e. infralittoral material at a depth of -110 m indicating a sea level lower than the present one.*

Based on the aforementioned results, the deepest part of the core (below 40 cm) can be considered as sedimented in a high-energy inner shelf environment, while the most recent deposit was sedimented in an outer shelf environment similar to the actual one (the core was collected at a depth of 110m). According to this interpretation, the well-sorted layer of shell debris that lies at a depth of 40 cm can be considered as a transgressive lag. The lag, which marks an abrupt change between the overlying and underlying deposits, can be indicative of a sudden high-energy period of sedimentation, as shown by the burial of benthic organisms in living positions. It is possible that this episode al so brought with it a partial erosion of the underlying deposits. According to the 230Th dating, this episode should have occurred in the last phase of Versilian transgression. A more thorough reconstruction of the evolution of the depositional environment based on these data is reported in CHIOCCI & ORLANDO (1996).

Fig. 7- *Planimetric distribution and depth diagrams of submerged depositional terraces around the western section of the Pontine archipelago. The seismic profile available for study (subtle tracts) and the profiles shown in the figures of this article (marked tracts) are schematically represented.*

The SDT develops with high-continuity at constant depth, parallel to the coast on the flank of the volcanic complex. At the southern and western ends of Palmarola Island, the terrace is not present because of the rough topography and steep slope of the bedrock which is also scoured by numerous canyons that drain directly toward the abyssal plane.

The depth of the SDT is rather constant, with well-defined trends in various areas.

On the southern flank, the terrace develops for about 23 km between Zannone and Ponza, at first at an almost constant depth of 110m, then slightly deeper. Between Ponza and Palmarola the SDT is interrupted by several canyons and is poorly defined. For this reason it was not mapped. At the western end of the southern side of the archipelago (the first 10 km of the lower diagram) the terrace is poorly defined and rather unclear; it is only possible to identify a deposit whose edge is located at a constant depth of about 150 m.

On the northern flank it was possible to reconstruct the SDT, which develops for 18 km with great lateral continuity and constancy of characteristics, in great detail (the core described in Fig. 6 belongs to this deposit). The vertical distribution of the terrace on the northern slope of the archipelago appears very interesting and rich of neotectonic information (regarding this see CHIOCCI & ORLANDO*, 1992). In fact, while the geometry and thickness of the terrace remain similar for the entire Palmarola-Ponza-Zannone alignment, the depth of the edge and of the other depositional parameters gradually increases from 70 m to 105 m moving from west to southeast. The deepening occurs extremely gradually with a gradient of 2 m/km. Under the hypothesis of a formation of the deposit at a constant depth during the last eustatic lowstand, this value indicates an uplift rate of about 2.5 mm/year at the western end (Island of Palmarola) of the Zannone-Ponza-Palmarola alignment. This value is in surprising agreement with the uplift rate values of Palmarola Island hypothesized by* CARRARA & DAI PRA *(1992) based on totally different data and considerations (height above sea-level of an uplifted Holocene beach on the western side of the island).*

It is notable that the depth trends of the northern and southern sides of the archipelago do not agree. Yet while the northern submerged depositional terrace shows a constant gradient, the southern SDT varies in an inconsistent manner as a result of the bedrock morphology and presence of canyons. Furthermore, at the southern and western ends of the island of Ponza (the left part of the lower diagram) the southern terrace has an irregular direction and rather inconsistent characteristics.

Fig. 8- *Bathymetric profiles acquired along a zig-zag course (C/C: course change) southeast of the seaway between Ponza and Zannone Islands and the Island of Zannone itself (from* CHIOCCI & ORLANDO, 1996). *The figure includes 6 transects normal to the coast, spaced at 1200-1500 m intervals, characterized by a very high vertical exaggeration. Even based exclusively on morfobathymetric information, the presence of the SDT is clearly depicted in all of the transects (in the central one the SDT is cut by a canyon).*

EASTERN PONTINE ISLANDS

Figs. 9, 10 and 11 - *Seismic profiles acquired northwest of Venotene Island showing the extreme high lateral variability of the inner structure of this deposit. The three profiles are from the same area and intersect each other (crossing are indicated by arrow marks), depicting the SDT along three slightly different directions (see Fig. 15 for the location).*

The section in figure 9 investigates the terrace along the maximum dip direction. A SDT with complex external and internal structure rests upon a bedrock sloping 4-5°. It is possible to define an overall start of the SDT deposit at a depth of 140-145 m and the main edge at about 180 m. The external morphology is quite irregular and there are at least 3 slope breaks located at about 155, 165 and 180 m depth, corresponding to the edges formed in 3 depositional phases on the construction of the SDT. It is actually possible to define at least four distinct prograding depositional phases (shown in the figure) that caused the vertical aggradation of the deposit with progressive landward migration of the depocenters (retrogradational stacking pattern). Inside the bodies the reflectors show high-angle slope, dipping even more than the frontal slope which is about 8°. One can observe that it would be possible to add a fifth, more recent phase, with an edge of about 68 m (n. 5 in the figure), to the four retrogradational phases described above. This forms a quite thin wedge (maximum 7-8 m) whose internal structure is not seismically detectable. From the comparison of the three profiles, one can note how even at a small distance, the reciprocal relationships and the characteristics of the four depositional bodies vary significantly, especially as far as the morphological expression of the deposit is concerned.

Fig. 12 - *Seismic section roughly parallel to the northern coast of Ventotene Island (see Fig. 15 for location). The profile shows the SDT in a direction almost parallel to its axis. One can note how the acoustically soundless bedrock shows a very evident erosive character and complex morphology that is flattened out by the first phases of sedimentation. Along the direction of the profile one can observe that the thicknesses among the diverse sub-units which compose the SDT vary gradually. The SDT is, in fact, composed on the left by at least 3 distinct sedimentary phases that on the right are reduced to 2 that can be seismically resolved. In a parallel direction to the axis of the SDT, the internal reflections are not very evident. Of note, at the extreme left of the profile is the visible intersection between the reflection generated by the frontal slope of the terrace and the horizontal ones coming from the bed on which the SDT lies (regarding this effect, see* CHIOCCI*, same volume).*

Fig. 13 - *Seismic section perpendicular to the isobaths on the eastern side of Ventotene Island (for location, see Fig.15). One can observe a SDT with a very regular external morphology but a rather complex inner structure, formed by the overlaying of several progradational phases which caused both the vertical aggradation and the frontal progradation of the deposit on an erosional substratum with an irregular morphology. The edge of the SDT in this area is found at a depth of 130 m, i.e. the minimum depth found around the islands of Ventotene and S. Stefano. One can note how the overall external morphology caused by the first depositional phase is identical to that of the last phase, and even the areas of the two phases are similar (and so are the three-dimensional hypothetical volumes). Therefore, the last phase produced a comprehensive depositional body of almost double thickness spread out across a much greater depth interval.*

Fig. 14 - *Seismic profile parallel to the slope off the southern coast of Ventotene (for location, see Fig.15). One can observe a morphologic situation that is different from the preceding ones. The morphology of the acoustic bedrock is quite complex. While retaining its erosive character, the substrate is actually shaped in steps, in which polycyclic SDTs rest. The deepest terrace (with an edge at 210 m) appears to be the oldest; thereafter one can first see two phases with a strong horizontal development which create an edge at 160 m (partially buried); above them another prograding wedge with an edge at 145 m develops. A later depositional phase (poorly resolved seismically and not shown*

in the figure) is found at a shallower depth than those of the oldest phases (edge at 120 m). The overlapping of the prograding depositional bodies has caused an articulated morphology of the sea floor. The two oldest phases show layers sloping more than those of the most recent phases which formed on less steep morphologies.

Fig. 15 - *Planimetric distribution and depth diagram of the submerged depositional terrace around the eastern section of the Pontine Archipelago. The SDT is well depicted in all of the seismic profiles taken except on the western side of the volcanic complex (where the crater is probably located and isobaths have a very uneven trend). On the southern side, the main edge of the terrace shows a depth of about 160 m, while in the west, the SDT is rather irregular and made up of several bodies in a retrogradational stacking pattern. In the eastern zone, the SDT has more regular morphologies and a stacking pattern that is essentially aggradational. On the southern side, the terrace is present at a shallower depth (around 130 m) and appears to deepen proceeding from east to west, towards the caldera area, with a difference of 30-50 meters.*

Fig. 16 - *Side Scan Sonar record (acoustic image of the sea floor in plan view) on an oblique route with respect to the SDT on the northern side of the Zannone-Ponza-Palmarola alignment. The amplitude of the zone surveyed by the side scan sonar is 400 x 900 m. The profile proceeds from the greatest depths (left) towards the shallowest (right). Even though there are not great differences in backscatter, it is possible to clearly distinguish the frontal slope of the SDT (diagonal band at the center of the image) due to the different inclination of the sea floor with respect to the seismic waves or to variations in lithology. On can observe how both the depositional edge (right limit of the band) and the slope break at the base of the SDT (left limit of the band) are extremely straight.*

The SDT was always ill-defined in side-scan sonographs; however, in all of the cases in which it was somehow depicted, it appeared to be straight and often the major reflective element was the foot of the frontal slope.

CONCLUSIONS

In general, one can affirm that terrace morphologies are always present on the steep sides of the Pontine volcanic complexes, and that they are made up of sedimentary wedges 20-40 meters thick. SDTs represent the unique sedimentary units present on the volcanic bedrock and generally account for many depositional cycles. The materials which make them up (based on the acoustic facies and on the cores taken in the area) are sandy sediments with abundant bioclastic fraction. The nature of the materials and the fact that SDTs are also present on the flanks of completely isolated structures such as Botte Rock (that is totally isolated from the continental platform even during low stand), points out that the SDTs are essentially composed of intra-basinal sediments.

On average, the SDTs have an extreme high lateral continuity, interrupted only by canyons (where present) and rather gradual lateral variations in depth (a few $^{0}/_{00}$). The morphologic expression produced by the SDTs on the bathymetry is always very evident. For this reason, it is possible to detail the planimetric development and depth of SDTs with bathymetric profiles (which are more economical and easier to achieve) once the depositional nature of a submerged terrace morphology is identified with seismic profiles.

The SDTs around the Pontine Islands show a development transversal to the isobates of about 2 km and a lateral continuity that reaches about 40 km (in the case of the southern side of the western Pontines). The internal structure of the SDTs is always progradational with a strong dip of the foresets (often greater than 10°) that normally matches that of the frontal slope, pointing out the non-erosive nature of the latter. Erosional features were sometimes observed inside the deposit and are likely to represent reactivation surfaces. The SDTs of the Pontine Islands have a high variability in their external form and a very complex internal structure that is often polycyclic. In general, the more recent terraces are shallower than the older ones, giving to the whole deposit a retrogradational stacking pattern. The similarity among the deep SDTs and a rather shallow SDT found on Palmarola's east coast (Fig.4), in addition to the results of the analysis done on the cores (Fig.6), allow one to interpret the SDTs of the Pontine Islands as sedimentary depositional wedges, formed below sea level during sea level low stands. A detailed discussion on these aspects is found in Chiocci & Orlando (1996), where the neo-tectonic implications derived from the study of the SDTs are also examined - which indicate a relative uplift of the western end of the Palmarola-Ponza-Zannone alignment.

The comparison between SDTs present in the different parts of the Pontine archipelago offer interesting considerations. In the western sector, the islands of Zannone, Ponza and Palmarola present SDTs generally composed by one or at most two depositional cycles, which develop parallel to the isobaths at a depth which is constant or varies very gradually. On the contrary, the SDTs around the eastern islands of Ventotene and S. Stefano are generally found at greater depths (edges beyond 200 m) and are composed of numerous overlapping depositional episodes (up to 6), varying greatly in morphology and in depth, even within small distances.

The great depth and the multiplicity of the depositional cycles in the Eastern Pontines give evidence to a high subsidence of the volcanic apparatus of Ventotene-S. Stefano, contrasting to the stability or the uplift of the western apparatus. Under the hypothesis that the SDTs were formed during glacial sea level lowtands, the depth of the edges around the islands of Ventotene and S. Stefano is absolutely incompatible even with the deepest negative pulses experienced by the sea level during the Pleistocene glaciations. On the contrary, in the western islands, the depths of the edges of the SDTs is fairly compatible with the depths reached during glacial-eustatic lowstands and, in the case of the extreme west of the Zannone-Ponza-Palmarola alignment, one can find even shallower depths.

On the other hand, the fact that the eastern complex (Ventotene and S. Stefano) is made up entirely of subaerial volcanites, while the western one is made up of volcanites emplaced either in environments entirely below the sea level (Palmarola) or first below the sea level and then subaerial (Ponza), is in agreement with the proposed rise and fall tendencies of the two volcanic structures.

Even the relative inconsistency of the depths at which the SDTs are found around Ventotene and S.Stefano could be ascribed to difference in subsidence affecting the apparatus. Therefore, given that phenomena of differential vertical movements were also shown in the western sector, it is necessary to verify if other potentially influential factors could have possibly interfered with the structure of the SDT. Among these possibilities, the most important one could be the different morphology of the apparata. In fact, on one hand there is the eastern subconic volcanic complex, with strong variations in the flank slope and the exposition to storms. On the other hand there is a western complex with more regular and constant morphology, stretched out in ridge form, with an unchanging or very gradually changing exposure to high-energy storms.

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