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Submerged depositional terraces around Linosa Island (Sicily Channel)

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GEOLOGICAL AND VOLCANOLOGICAL SETTING

The Linosa volcanic apparatus, whose summit gives rise to the Island of Linosa (about 6 Km^2), is located in the Sicily Channel, close to the western border of the Linosa Basin (as deep as 1580 m) (see Fig. 1).

The NW-SE trend of the basin borders and of its depocentre reflects the main structural system that has controlled the evolution of the Sicily Channel since Tortonian times and it is regarded as the surface expression of a generalized right transtensional tectonic regime (JONGSMA *et alii*, 1985; BOCCALETTI *et alii*, 1987; GRASSO *et alii*, 1991).

Fig.1 - *Location map and bathymetry of Linosa Island.*

This tectonic regime originated several pull-apart basins (Pantelleria, Malta e Linosa Basins), which are now filled with Plio-Pleistocene sediments. It also directly controlled the Neogene-Quaternary volcanism (alkaline, peralkaline, and partially tholeiitic) of the Pantelleria and Linosa volcanoes, and of the several minor submarine eruptive centres in the Channel (CALANCHI *et alii*, 1989; ARGNANI, 1993).

The evolution of the apparatus of Linosa is consistent with this regional deformational pattern. A preferential lenghtening along a NW-SE direction is clear from the directional trend of its wide underwater portions, which extend for more than 11 km in a volcanic belt with the same orientation and along which some secondary eruptive centres are aligned (see Fig. 2). The subaerial volcanic activity of the Linosa apparatus is estimated to be between 1,06 and 0,53 million years old and it has been divided into three main evolutionary stages (Paleo-Linosa Syntheme, Arena Bianca Syntheme, and Mt. Bandiera Syntheme; LANTI *et alii* 1988; GRASSO *et alii*, 1991; ROSSI *et alii*, 1996). The distribution of the meso-structures and of the eruptive centres on the island (with an often coeval activity) confirms the WNW-ESE trend, and a secondary NNW-SSE trend as the trends along which there has been a tectonic control on the development of the apparatus.

According to the paleomorphological reconstruction and the analysis of the provenance of pyroclastic deposits outcropping on Linosa, some of the eruptive centres which were active during the three building phases can be located at sea, on the shallower SE and NW flanks of the island, where wide abrasion platforms shallower than 120 m can be found (Fig. 2).

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DATA COLLECTION AND ANALYSIS

In 1988, 1991 and 1992 high-resolution seismic surveys (S.B.P. 3.5 kHz; Sparker 500-1000 J, see Fig. 3) have been carried out by the Univ. of Bologna around Linosa Is., on board the C.N.R. vessels Minerva and Urania. This allowed to reconstruct the bathymetric and morphologic features and characterize the main submerged volcanic structures from a petrochemical point of view (ROSSI *et alii*, 1990). The surveys have been carried out by means of a Loran-GPS integrated positioning system; the bathymetric maps have been outlined at 1:25,000 scale. They reveal that the submerged flanks of the Linosa apparatus deepen steeply (with an average gradient of 15°), and with a very complex trend down to a depth of 450-500 m, where the sediments of the surrounding basin area onlap the volcanic basement (Fig. 2).

Fig. 2 - *Bathymetric sketch and main volcanological and morphological features of Linosa apparatus (from ROSSI et alii, 1990, modified).*

Fig. 3 - *Bathymetric and seismoacoustic profiles collected in 1988 (Sub-bottom profiler 3.5 kHz; Sparker 500 J) and '91-'92 (Sparker 1kJ).*

Local instability and reworking of the sedimentary cover can often be observed on the steep submerged slopes of Linosa (particularly along the southeast and western flanks). The island is surrounded by a radial network of active canyons which represent a preferential pathway for the sediments transit towards the base of the volcanic apparatus.A few secondary eruptive centres with subconical shape rise on the volcanic flanks of Linosa (Fig. 2) and dam small intraslope basins (as it is in the southwestern sector of the apparatus, Fig. 4).

Wide submerged abrasional platforms, with a subhorizontal trend and an erosional outer edge at a depth of 110-115 m, have been mapped as far as 2 km from the southern and northwestern coast of the island (Fig. 2). Such features, probably early portions of the evolution of the volcanic apparatus which have been largely dismantled by marine erosion, are connected at their northwestern and southeastern borders with a few secondary eruptive centres.

Submerged depositional terraces (i.e. progradational wedges as thick as up to 40 milliseconds, about 30-35 metres) were mapped above and near the outer edge of the abrasional platforms, showing a fairly good lateral continuity and a marked morphologic expression (see Fig. 5 and 9, and Fig. 2 for location). The depositional terraces have been characterized on the basis of the analysis of seismoacoustic profiles, by means of seismoacoustic facies, internal structure, and main depositional parametres, such as the depth of the outer edge and of their upper and lower boundaries. On the other side, there are no direct observations on the lithologies making up these progradational bodies, that are likely to originate mainly from volcanogenic deposits with a medium-coarse grain size, as it seems to be suggested by the high steepness of the foresets.

Fig. 4 - *1 KJ Sparker profile on Linosa southwestern flank. A depositional terrace lies at the edge of the abrasion platform. This is the lower or outer terrace mapped all along the southern sector of the island (see Fig.5). At a greater depth, the sedimentary cover is not in equilibrium on the steep flanks of the volcanic apparatus, and this gives rise to diffuse surficial instability, until the sediment gathers into a small intraslope basin at a depth of 265-270 m. This is dammed by a secondary eruptive centre (whose morphology is partially hidden by diffraction hyperbola in the acoustic signal).*

Fig. 5 - *As far as the southern flank of Linosa apparatus is concerned, it has been possible to map (in milliseconds) the main morphological and depositional features of the two depositional terraces which extend along the island coast for over 4 km, in two subparallel belts (see Fig.2 for location).*

Legend: *1- lower and upper limits of the deposit; 2- depositional edge; 3- erosional edge; 4- secondary eruptive centre.*

The suggested location at sea of the eruptive centres of Cala Pozzolana di Levante and Punta Calcarella has been indicated near the southern coast of Linosa (LANZAFAME *et alii*, 1994).

The submerged depositional terraces in the southern sector (Fig. 5) slope down the subhorizontal abrasional platform, following its regular trend. The upper terrace shows a semicircular trend and a thickness of about 40 milliseconds. It is internally characterized by an oblique-sigmoidal progradation, with an increase in the foreset steepness upwards. The morphologically evident depositional edge is almost always located at a depth of 45 metres (60 milliseconds).

Due to the difficulties in approaching the coast, the upper boundary of the terrace has seldom been observed (at a depth of 25-30 m). For the same reason its lateral termination has not been mapped. Its lower limit ranges from 70-75 m in the central sector to about 90 m on the western and eastern ones, where it become prograding onto the lower terrace.

The lower depositional terrace develops near the edge of the underlying abrasion platform and extends from a depth of about 80-90 m to 120-140 m. Its depositional edge is located at an average of 90 m in the central sector of the terrace, tending to deepen a few metres towards SW and SE. The lower terrace is about 20-30 milliseconds thick but it may even reach 40 milliseconds; the internal structure, where it is recognizable from the seismic profiles, appears steeply prograding. Westwards it has been possible to detect the lateral termination of the terrace, beyond which the erosional outer edge of the abrasional platform is still recognizable. Eastwards the terrace extends along the southern flank of a volcanic ridge with a ENE-WNW trend and it develops over a deeper prograding wedge (not mapped in figure). Both the depositional edge and the lower limit of the terrace deepen in this sector (up to 120 m and 140 m; respectively, see Fig. 8).

Fig. 6 - *S.B.P. 3.5 kHz profile of the two submerged depositional terraces to the south of the island. Both progradational bodies show an evident morphological expression and are probably made up of sediments with medium-coarse grain size, as suggested by the low penetration of the acoustic pulse. See Fig.5 for location.*

Fig. 7 - *Sparker 500 J profile (Fig. 5). The innermost upper depositional terrace is internally characterized by a sigmoidal progradation with steeper foresets upwards and basinwards. This terrace lies over an erosional surface and partially extends over the lower terrace which, though not easily detectable on the seismic profiles, seems to be characterized by an oblique progradation and is partially affected by gravitative instabilities.*

Fig. 8 - *1 Kj Sparker profile through the volcanic ridge southeast of Linosa Island (see Fig. 5 for location). A secondary eruptive centre (acoustically deaf) rises up to a depth of 33 m from the top of the ridge, which is bounded on the north by a sharp erosional edge. On the southern side, the lower depositional terrace (mapped along the whole submerged southern flank of Linosa - see Fig. 5) extends with sigmoidal progradation in unconformity over another sedimentary wedge, which develops up to a depth of 200 m (possibly a further depositional terrace?).*

A sharp erosional surface makes up the nearly flat shoal top, detected at a waterdepth of 25-33 m. The flanks of Secca di Tramontana appear to be asymmetric, with a steep eastern side which has an active canyon at the base (see Fig. 2) and a wider western side with a smoother slope, joining to the north-east with a few minor volcanic structures.

This setting is mirrored by the distribution of the depositional terraces: on both sides of the shoal, morphologically quite evident, has been mapped an upper terrace with a depositional edge at about 70 milliseconds (-52 m) and a thickness of about 30 milliseconds. Its upper limit, probably located at a depth of 35-40 m, has seldom been observed in the profiles.; the lower limit has been mapped between 90 and 100 milliseconds (68-75m of depth). Only on the western side, a further deeper depositional terrace has been recognized (Fig. 10), with depositional edge at about 71-75 m and a lower limit at about 90-108 m of depth (but gradually deepening basinwards). Towards the coast, this terrace tends to merge with the upper depositional terrace and even its morphological expression becomes less evident.

Fig. 9 - *Off the northwestern coast of Linosa, submerged depositional terraces develop on both sides of Secca di Tramontana, following the NW-SE trend. Such terraces have been detected up to 1 Km from the coast. From the available seismic profiles it has not been possible to characterize their internal structure, which appear to be generally prograding. The mapping of their main depositional parameters has been carried out also on the basis of morphological*

evidence (see Fig. 5 for symbology).Offshore the NO coast of Linosa, submerged depositional terraces develop both sides of Secca di Tramontana, showing the same alignment in a NW-SE direction (Fig.9).

The supposed eruptive centres of Cala Mannarazza and Secca di Tramontana have been located (*from* LANZAFAME *et alii*, 1994).

Fig. 10 - *3,5 kHz S.B.P. profile of the two depositional terraces observed on the western flank of Secca di Tramontana, showing here distinct morphological features.*

CONCLUSIONS

The available data on the shallower portions of the volcanic apparatus of Linosa allowed the detection and mapping of submerged depositional terraces on the northwestern and southern sector of the island. Their wedge-shaped external geometry, quite clear also from a morphological point of view, shows a good lateral continuity; the internal structure is prograding, as indicated by the high-frequency seismic profiles collected in this area.

In both sectors an upper depositional terrace has been observed. It develops at a waterdepth ranging from 25-30 m to 90 m and its depositional edge is at about 45-52 m. This terrace partially progrades onto a lower depositional terrace, located at a waterdepth greater than 70-80m. The latter has been mapped in the southern and northwestern sector of the island (along the western side of Secca di Tramontana). The main depositional features of the lower terraces show variable depth values in the two sectors opposite the island, probably influenced by the morphology of the underlying bedrock.

Some thought could be given as to the presence (or the preservation?) of the observed depositional terraces, whose positions generally correspond to the location of earlier, wide and flat, abrasional surfaces, bounded by an outer erosional edge at an average depth of 150 milliseconds (-112 m). Such platforms represent the main morphological asymmetry interrupting the steep gradient of the volcanic flanks. They bear witness to the dismantling action, on volcanic apparata, of marine erosion when the sealevel was lower than at present, and/or there was a stage of quiescence in the eruptive activity. This has been frequently observed in the late development of insular volcanoes (CAS *et alii*, 1989; ROMAGNOLI, 1990; ROWLAND *et alii*, 1994; CHIOCCI & ROMAGNOLI, see the present volume). As far as Linosa is concerned the end of the major volcanic activity is chronologically consistent with different sea-level fluctuations occurred during the Upper Pleistocene; moreover, also considering a fast cliff retreat of the island (for Hawaiian basaltic lava, in oceanic regime, rates of coastal retreat of the order of 5 cm per year are reported in ROWLAND *et alii*, 1994), the development of marine platforms extended as far as 2 km offshore should indicate a policyclic origin.

The formation of submerged depositional terraces can be connected to reworking and deposition of sediments on (or at the edge of) previously formed abrasional platforms, during stillstands of the relative sea level at a depth lower than the present one, as during the sea-level rise which followed the glacial acme of about 18 ka B.P. The availability of volcanogenic deposits which fed the depositional bodies of the terraces around Linosa Isl. can be related to the dismantling of the pyroclastic tuff-rings of the eruptive centres of Cala Pozzolana di Levante and Cala Mannarazza/Secca di Tramontana. According to the stratigraphic studies carried on at Linosa, in fact, these centres were located in the shallow submerged areas, to the SE and NW of the island respectively (see Figs. 5 and 9).

It must be emphasized that the abrasion platforms, which record a stage in the development of insular volcanoes such as Linosa during which erosional processes prevailed over the constructional ones, play also an active role in holding at shallow depth volcanoclastic sediments that may, otherwise, undergo gravitational reworking along the steep subacqueous volcanic flanks and be rapidly carried down to the sorrounding basins.

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