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Geomorphological map of the Lipari volcanic island (Aeolian Archipelago – Italy)

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A 1:10,000-scale geomorphological map of the Lipari volcanic island (Aeolian Archipelago – Italy) is presented in this paper. The associated map, which includes volcanic and epivolcanic landforms, is obtained combining the available geological information with data derived from the analysis of a digital terrain model, integrated with aerial photographic observations and field surveys.

The map shows that the location of the main volcanic morphologies is strongly controlled by local tectonic structures striking NNW-SSE, while the epivolcanic morphologies are mainly related to the continuous uplift induced by the prevalence of regional tectonic processes.

The aim of this work is to provide an improved geomorphological map, with a reasonably comprehensive overview of the landforms present in the most densely populated island of the Aeolian Archipelago. This map can be also used as a support for future studies of land management on the island.

Keywords: volcanic island; Aeolian Archipelago; GIS analysis; geomorphology

Introduction

The island of Lipari is a volcanic complex which has been dormant since 580 AD. Because studies on the geomorphology of volcanoes are mainly focused on (i) the analysis of 'growth' and 'dismantling' processes (Karatson, Thouret, Moriya, & Lomoschitz, 1999), (ii) sector collapses and their inception mechanisms (Van Wyk de Vries, Self, Francis, & Kesthelyi, 2001), and (iii) the role of topography in the deposition mechanism of volcanic flows (Fisher, 1995), they are rarely dedicated to the analysis of volcanic landforms (Thouret, 1999). Therefore, in this paper we present a geomorphological map of the landforms of Lipari volcano.

According to Anders, Seijmonsbergen, and Bouten (2009), geomorphological mapping based on traditional survey strategies are often time consuming and the accuracy of these methods is questionable in steep and difficult-to-access terrain. However, we drafted the geomorphological map of the island of Lipari from the joint analyses of several published geological maps of the island (Lucchi, Tranne, & Rossi, 2010; Pichler, 1980; Tranne, Lucchi, Calanchi, Lanzafame, & Rossi, 2002), digital terrain model (DTM) and their derivatives, aerial digital photo observations and, finally, field surveys to validate the data obtained from previously mentioned investigations.

A comprehensive study of the present-day morphology of the volcano represents the necessary information for future studies on territorial management (e.g., hazard-risk analysis, evaluation and protection studies of geological heritage, etc.).

Geological setting

The island of Lipari is an emerged portion of a broad volcanic edifice that rises from the sea floor in the central sector of the Aeolian Arc, Southern Tyrrhenian Sea (Figure 1). The island consists mainly of volcanic products and, subordinately, of marine and subaerial sedimentary deposits, ranging in age from at least 223 ka to the present time, according to radiometric dates (Cortese, Frazzetta, & La Volpe, 1986; Crisci, Delibrias, De Rosa, Mazzuoli, & Sheridan, 1983; Crisci, De Rosa, Esperanca, Mazzuoli, & Sonnino,1991; Gillot, 1987). A simplified

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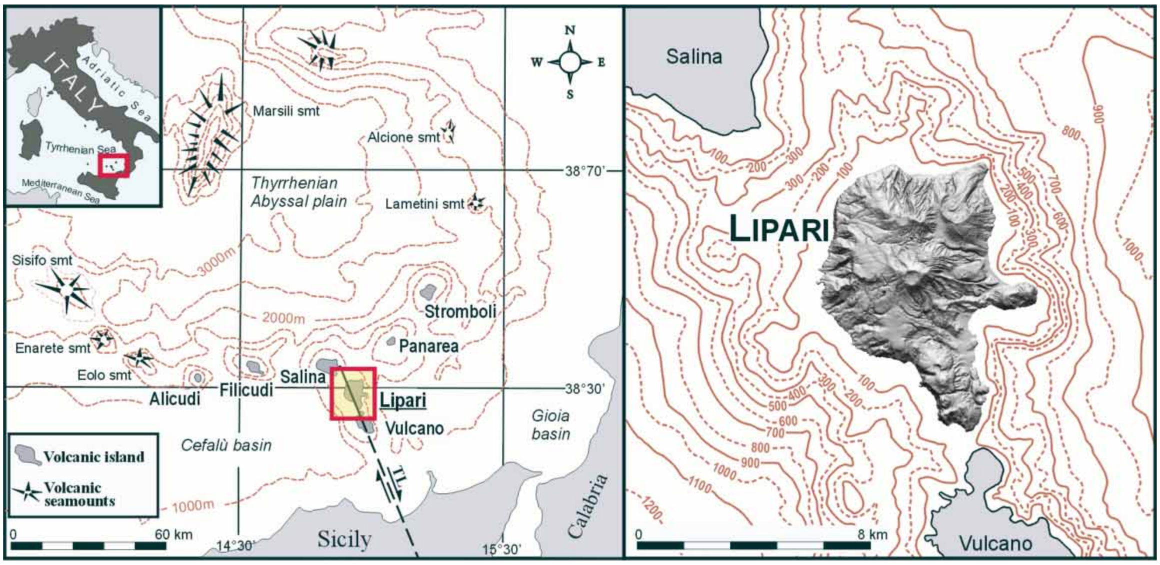

Figure 1. Bathymetric sketch map of the Aeolian Arc and simplified bathymetry of Lipari volcanic island (modif. after Lucchi et al., 2004). TL: Tindari-Letojanni fault system.

geological framework of Lipari (Figure 2) involves five periods of volcanic activity characterized by different eruptive styles and locations of eruptive centres (Lucchi et al., 2004).

The first period includes the oldest outcropping products (scoriaceous deposits, lava flows, and subordinate hydromagmatic pyroclastics). They are related to the mainly strombolian and effusive volcanic activity that affected the west coast and, subordinately, the central-eastern sector of Lipari between about 223 ka and 127 ka (Crisci et al., 1991; Gillot, 1987).

The second period includes lavas and hydromagmatic pyroclastics related to the first phase of volcanic activity of the NNW-SSE aligned M. S. Angelo and M. Chirica stratovolcanoes, located in the central sector of Lipari. A radiometric age of about 127 ka has been obtained for these products (Crisci et al., 1991).

The third period of volcanic activity is characterized by the emplacement of wide and thick lava flows and hydromagmatic pyroclastics related to the final phases of volcanic activity of the M. S. Angelo and M. Chirica stratovolcanoes. Among these deposits are occurrences of the peculiar *'leaf-bearing pyroclastics'* (Ricci Lucchi, Calanchi, Lanzafame, & Rossi, 1988) and *'cordierite-bearing lavas'*, the latter one dated between 104 ka and 105 ka (Crisci et al., 1991). The latest lava flows of the M. S. Angelo eruptive centre are dated to 92 ka (Crisci et al., 1991).

The fourth period includes pumiceous hydromagmatic pyroclastics associated with the emplacement of volcanic domes in the southern sector of the island. Pumiceous pyroclastics are interbedded with exotic tephras to form a characteristic pyroclastic succession which occurs over the entire island (Lucchi et al., 2004). Among the exotic tephras, at least 12 layers of well-known, widespread *'Brown Tuffs'* have been identified (Tranne et al., 2002, and references therein). The volcanic activity of the fourth period ranges from 42 ka to 20 ka (Crisci et al., 1991; Gillot, 1987).

Finally, the fifth period of volcanic activity of Lipari includes widespread pumiceous pyroclastics and obsidiana lava flows (obsidian is an igneous rock that forms when molten rock material cools so rapidly that atoms are unable to arrange themselves into a crystalline structure). These range in age from 14.4 ka (Crisci et al., 1991) to about 1.3 ka (Cortese et al., 1986), and are related to different eruptive centres in the NE sector of the island.

Mapping method

The drafting of the geomorphological map was divided into four phases: (1) DTM production (10x10 m ground resolution) from digitization of topographic contours from Carta Tecnica Regionale of the island of Lipari (edited by Sicilian Region in 2002; scale 1:10,000); (2) Extraction of geomorphic features by analysis of the DTM; (3) Validation of the results obtained from the DTM analysis by aerial digital photo observations (25 cm pixel, Volo ATA0708, R.P.A., Perugia, Italy; scale 1:20,000) and field surveys; (4) Digitization of the morphological

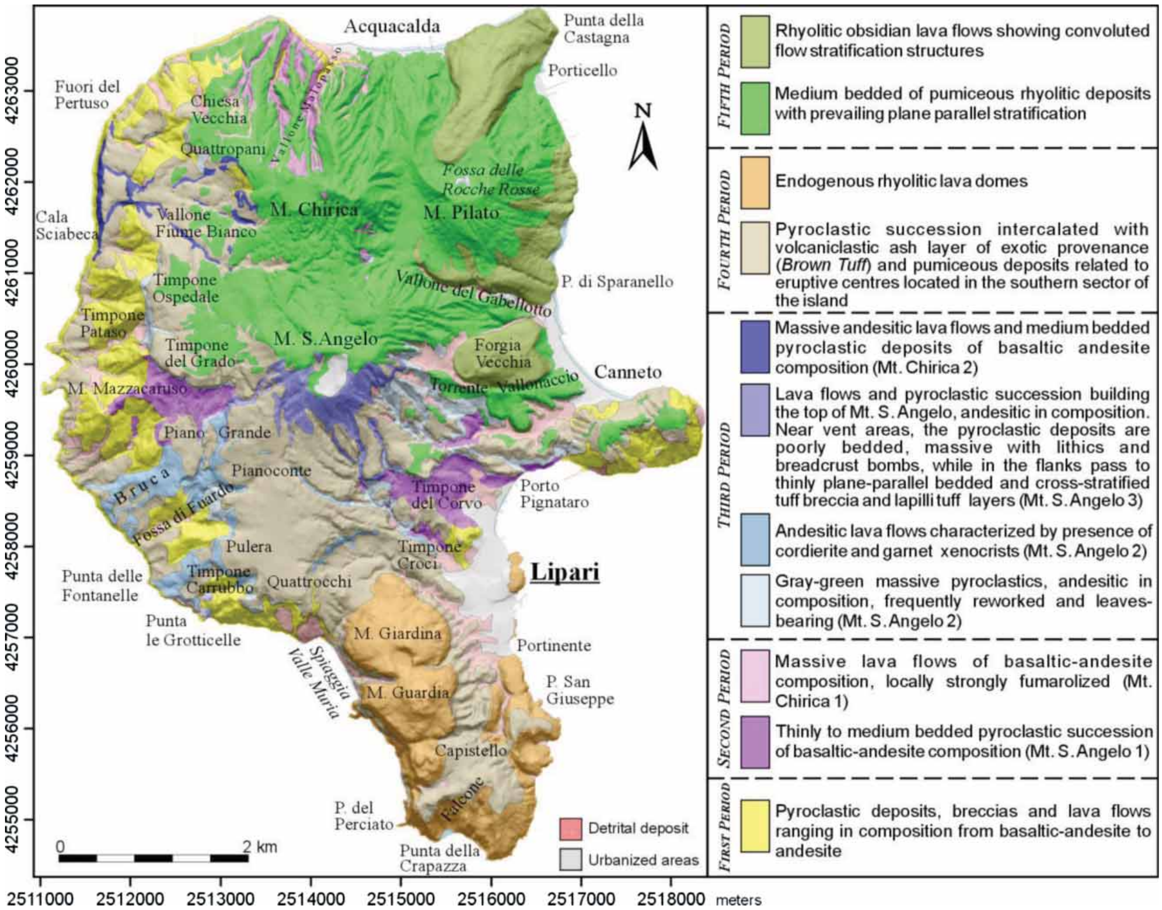

Figure 2. Geological sketch map of Lipari (modif. after Lucchi et al., 2004 and Lucchi et al., 2010).

informations obtained in this way, and introduction of all thematic layers into graphic design software for the production of the final map.

The extraction of the geomorphic features was performed, following in part the techniques of Ventura et al. (2005), by photo interpretation on sharp light tone gradients of a set of low sun angle shaded relief images derived from the DTM (elevation angle: 10°, 30° and 45°; azimuth coverage: for each elevation angle one image each 30° in a clockwise trend from N = 0°). Results of the shaded relief images analysis allowed the identification of the main geomorphological features of the island of Lipari (e.g., ridges, valleys, morphologic depression rims, etc.). DTM-extracted data also include the drainage pattern (Figure 3).

After validation of the results obtained from photo interpretation of shaded relief images by aerial photos and field surveys, the final phase was the map design. Most of symbols used in the map follow the scheme proposed by the Italian Geological Survey (Quaderni SGN, series III, vol. 4 – 1994 and vol. 10 – 2007) for the compilation of the Geomorphological Map of Italy.

Results

The results obtained by DTM analysis, aerial photo observations, and field surveys were further validated by comparison with geological maps of the island of Lipari (Lucchi et al., 2010; Pichler, 1980; Tranne et al., 2002). All data allowed us for the identification and classification of the volcanic and epivolcanic landforms shown on the geomorphological map.

The volcanic landforms, related to the five periods of volcanic activity on the island, consist of volcanic edifices *sensu stricto* (M.S. Angelo, M. Chirica, M. Pilato in the central-northern sector of the island), crateric and caldera depressions, lava domes (e.g., M. Giardina, M. Guardia, M.S. Lazzaro in the southern part of the island), and lava flows. Among the latter, the well-known rhyolitic obsidian lava flows of Rocche Rosse and Forgia Vecchia, located

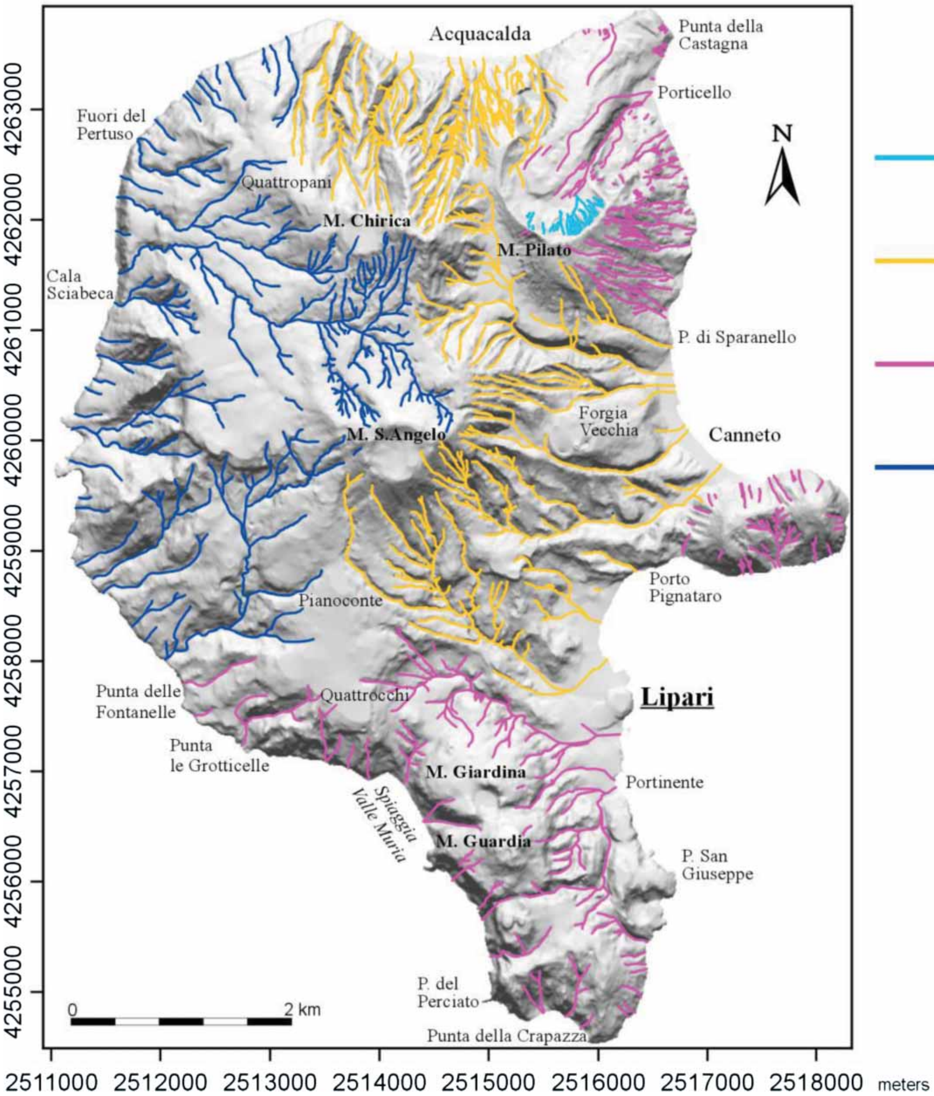

Figure 3. Drainage pattern map of the Lipari volcanic complex.

in the northeastern sector of the island (see map), represent the final stages of volcanic activity on Lipari. According to Favalli, Karatson, Mazzuoli, Pareschi, and Ventura (2005), these volcanic structures give the entire island a pancake-like morphology and are related to the emplacement of significant volumes of dacitic to rhyolitic and trachytic domes and pyroclastics (Crisci et al., 1991). These products are generated by fractional crystallization in shallow magma chambers within the continental crust (De Astis, Ventura, & Vilardo, 2003; De Rosa, Donato, Gioncada, Masetti, & Santacroce, 2003; Gioncada, Mazzuoli, Bisson, & Pareschi, 2003; Zanon, Frezzotti, & Peccerillo, 2003). These magmatic reservoirs are aligned along the strike-slip Tindari-Letojanni fault system that crosses this sector of the Aeolian Archipelago (Figure 1).

The epivolcanic landforms, developed mainly during the quiescent stages by endogenous processes, occur on the flanks of volcanic structures and consist of both erosional (valleys, active cliffs, etc.) and accumulation (landslides bodies, detrital deposits, etc.) morphologies.

The hydrographic network, based on its drainage density, can be roughly subdivided in two main areas, related to their different morphological and lithological features. The first area is the central-northern sector of the island, morphologically characterized by the partially coalesced conical edifices of M. Chirica, M.S. Angelo, and M. Pilato, and lithologically composed of pumiceous coverage mainly due to the fifth period of volcanic activity on the island. In this sector the drainage network displays a clear hierarchy (fourth order in the Vallone Fiume Bianco) and is characterized by a general centrifugal dendritic pattern, radially arranged with respect to the location of stratocones (Figure 3).

The second area is the southern sector of the island, where there are lava domes due to the fourth period of volcanic activity. Owing to the steep slopes and high permeability of the outcropping products, the drainage network in this area is poorly developed showing a radial dendritic pattern mainly carved around the volcanic domes.

All of the valleys are deeply incised and the shape of valley bottoms depends on the lithology and slope angle: (1) valleys carved on stony soils with steep angles, and on pumice with moderate slopes, tend to have a 'V' shaped form; (2) valleys with alluvial fill tend to be flat-floored valleys; (3) where the streams run on soils with different levels of erodibility (e.g., at the lateral margins of the obsidian lava flows of Forgia Vecchia and Rocche Rosse; see map), the valleys tend to have an asymmetrical form.

Furthermore, the south-eastern side of M. Pilato stratocone show a typical *'barrancos'* morphology due to canalized rill erosion on the pumices.

Conclusions

The geomorphological map of the island of Lipari displays the distribution of volcanic and epivolcanic landforms.

The distribution of volcanic vents on the island, is strongly controlled by the local tectonic structures (Tindari-Letojanni fault system) that affect the central sector of the Aeolian Archipelago, while the strong fluvial incision can be interpreted as indirect evidence of the regional tectonic processes that lead to the continuous uplift (average rate of 0.34 mm/a during the last 125 ka; Lucchi et al., 2004) of the whole central part of the Aeolian Arc.

In our opinion, the protocol used to make the geomorphological map can be a quick and efficient method to identify the main morphological structures of any territory under investigation (volcanic or not), allowing rapid field validation of the data extracted from the DTM. Furthermore, this map can be also used for further and more detailed studies to produce landslide, flood or erosion susceptibility maps, in order to provide local governments a useful tool devoted to the mitigation of geological hazards.

In fact, the geological fragility of the island of Lipari is well reported in local chronicles (http://notiziariodelleeolie.myblog.it) that, from 2007, recorded periodic phenomena of instability always coincident with rainfall events of high intensity. For example, the bad weather that affected the entire Aeolian Archipelago in the winter of 2010 triggered numerous small landslides (mainly debris flows) in different parts of the island causing interruption of the road network in several places with the result that several hamlets were isolated for days.

Software

ESRI ArcGIS 9.0 was utilized to generate a DTM, perform analyses, and extract morphological features from the DTM. The design of the final map was performed using CorelDRAW X.

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