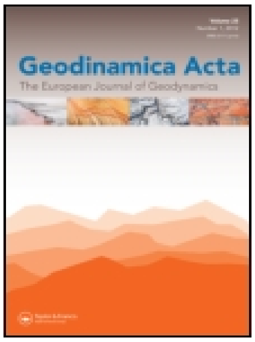

Geodinamica Acta

ISSN: 0985-3111 (Print) 1778-3593 (Online) Journal homepage: http://www.tandfonline.com/loi/tgda20

The DEM or Mt. Etna: geomorphological and structural implications

Massimiliano Favalli, Fabrizio Innocenti, Maria Teresa Pareschi, Giorgio Pasquarè, Francesco Mazzarini, Stefano Branca, Luciano Cavarra & Alessandro Tibaldi

To cite this article: Massimiliano Favalli, Fabrizio Innocenti, Maria Teresa Pareschi, Giorgio Pasquarè, Francesco Mazzarini, Stefano Branca, Luciano Cavarra & Alessandro Tibaldi (1999) The DEM or Mt. Etna: geomorphological and structural implications, Geodinamica Acta, 12:5, 279-290, DOI: 10.1080/09853111.1999.11105350

To link to this article: http://dx.doi.org/10.1080/09853111.1999.11105350

Published online: 24 Mar 2015.

Geodinamica Acta (Paris) 1999, 12, 5, 279–290

The DEM of Mt. Etna: geomorphological and structural implications

Massimiliano Favalli[a], Fabrizio Innocenti[b], Maria Teresa Pareschi[a], Giorgio Pasquarè[c], Francesco Mazzarini[a]*, Stefano Branca[d], Luciano Cavarra[a], Alessandro Tibaldi[c]

[a] CNR-CSGSDA, Via S.Maria 53, 56126 Pisa, Italy
[b] Dipartimento di Scienze della Terra, Università di Pisa, Via S.Maria 53, 56126 Pisa, Italy
[c] Dipartimento di Scienze della Terra, Università di Milano, Via Mangiagalli 34, 20133 Milano, Italy
[d] Istituto di Geologia e Geofisica, Università di Catania, Corso Italia 55, 95129 Catania, Italy

(Received 26 October 1998, accepted 1 March 1999)

Abstract – A Digital Elevation Model (DEM) of Mt. Etna is presented; it has altimetric and planimetric resolution of 1 m and 5 m, respectively, and covers an area of about 120 km^2. This 3-D view of Mt. Etna allowed both recognition and location of the main morphostructural and volcano-tectonic features of the volcano. A slope map has been generated from the DEM; on the basis of slope distributions and surface textures, five acclivity domains have been recognized. The largest domain, south of the summit craters, reflects the occurrence of old plateau lavas, distinct from central volcanoes which built the present Etnean volcanic system. Interaction between the central volcanoes, with their summit calderas and failed slopes, produced the other recognised domains. Furthermore, newly identified relevant morphostructural lines are discussed. © Elsevier, Paris

Mt. Etna / DEM / volcanology / morphostructure

1. Introduction

In volcanic areas, the study of the geomorphological aspects represents an important tool suitable for constraining their structural and volcanological evolution. This is particularly true in regions of active volcanism where supergenic processes have not had the time to deeply modify the landform. Therefore, the landscape remains an expression of the eruptive modalities, the characteristics of the emitted materials and the volcano-tectonic processes affecting the area. A thorough analysis of these aspects can be carried out by a cartographic representation of landform features, combining planar information with elevations. This tool constitutes a Digital Elevation Model (DEM) which generally is produced in the frame of the construction of a geographic information system.

In this paper, we present the DEM of Mt. Etna volcano, the largest active volcano in Europe (about 30 × 40 km), and we will show that the DEM is able to provide a sound basis for geovolcanological and structural investigations of a volcanic system through the reading of the spatial distribution of relevant topographic features.

2. Geological framework

Mt. Etna is located at the southern-western margin of the Calabro-Peloritan Arc that represents a prominent curved element among the peri-Mediterranean mountain chains linking the NW–SE-trending Appenines to the E–W-trending Sicilian Maghrebides (*figure 1*). A network of E–W striking faults and folds, mainly active during Quaternary times, characterizes the Sicilian Maghrebides thrust system, which in turn is affected by NNW transcurrent faults (Tindari-Letojanni system) and by the NNE Messina-Giardini fault system [1–3]. Although the main deformation of the Appenine-Maghrebian chain occurred during the Neogene, compression continued through the Quaternary to the Present as revealed by neotectonic field data and by seismic data [4–6].

The geology of Mt. Etna is characterized predominantly by lava flows and subordinately by pyroclastic and epiclastic deposits resting upon the sedimentary basement made up of marine clays dated to the Sicilian stage (Early–Middle Pleistocene, [7]), and the Appenine-Maghrebian terrains. The oldest volcanic products were mainly derived by fissural activity; they are dominated by tholeitic lavas of Early Pleistocene age [8, 9]. Successively, alkaline lavas were erupted either by an ancient large central volcano (primordial Etna, Kieffer [10]) or by small scattered eruptive centres [11]. The volcanic activity successively manifested through several alkaline composite volcanoes with a general west-

* Correspondence and reprints: ross@dst.unipi.it

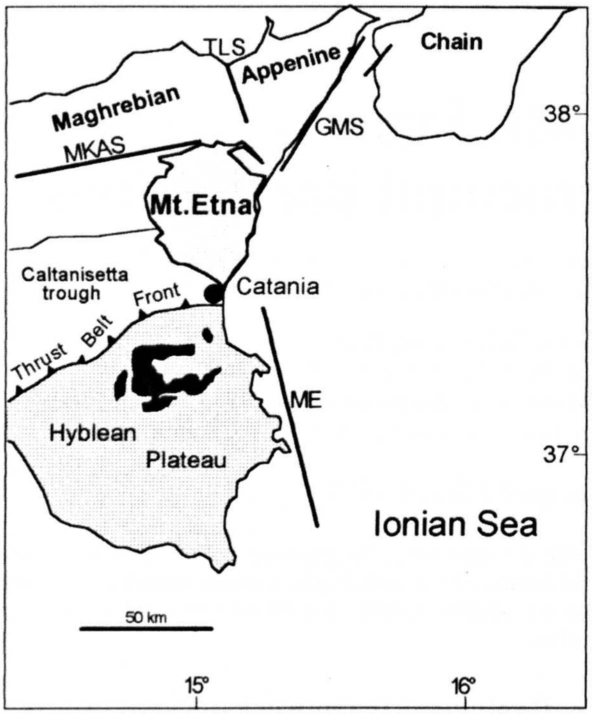

Figure 1. Structural sketch map of the Etnean area showing the main structural domains and tectonic features. ME: Malta Escarpment; MKAS: Mt. Kumeta-Alcantara System; TLS: Tindari-Letojanni System; GMS: Giardini-Messina System. Black area: Late Miocene-Pleistocene Hyblean Volcanics.

ward shift of the eruptive axis. The number and the location of the apparata remain a matter of debate [11–14] even if the most relevant centers (e.g. Trifoglietto and Cuvigghiunni) are commonly accepted. During the Late Pleistocene, the volcanic activity was focused in the presently active area where the Mongibello volcanic system developed. During the first phase of activity, ancient Mongibello produced a volcanic sequence ranging in composition from hawaiites to trachytes [15] that ended at about 15 Ka [16] with the formation of the Ellittico summit caldera. This volcanic structure has been almost completely buried by successive volcanics of recent Mongibello [17, 18].

3. The DEM of Mt. Etna

The DEM of Mt. Etna, obtained with a pixel of 5 m (*figure 2*), is a continuous raster layer in which data values represent elevation. A surface shadowing provides digital perspectives where reliefs are well outlined (*figure 3*), depending on the selected sunlight azimuth and elevation.

The Mt. Etna DEM has been obtained by computing on a regular grid the elevations provided by the triangles of a modified Delaunay triangulation. Input points were derived by digitising contour lines of a 1:10000 map produced by Cartografia Tecnica Regionale Sicilia, updated in 1990. A digitalisation error of 0.5 mm on the map generates a planimetric error of 5 m on the DEM. The traditional Delaunay approach provides triangles with vertices on the input points, which reconstruct the volcano surface as a network of planar triangular facets [19]. The triangles are as regular as possible, since this triangulation satisfies the maximum–minimum angle criterion (the lowest angle of the triangles is maximum over all the possible triangulations; [20]). When points are not random (as in the case of the digitising of contour lines), the Delaunay approach may introduce false morphological features. For example, in correspondence with sharp isohypse bendings, the Delaunay method may consider flat triangles built with points on the same contour line. These triangles are preferred to narrower ones built with vertices on adjacent isohypses. In the present approach for the Mt. Etna DEM, this problem was avoided by introducing forbidden lines, automatically evaluated, which join points of local maxima of the second derivative of isohypses (e.g. maximum slope): triangulation is not allowed across these lines.

The input points totalled 1 060 916 in an area of 1 800 km^2 centred on the volcano. The average density is one point per 42 × 42 m, with a maximum of one point per 100 m^2 in the steepest regions (e.g. Valle del Bove). The number of triangles is 3 089 107 with an average area of 600 m^2.

The DEM has been used to generate a slope map with a resolution of 1°. Slope values are averaged on an area of 20 × 20 m. Frequency and cumulative slope distribution are shown in *figure 4*; a peak of slope frequency occurs at 4° (7 %), with a slope break at about 13° (23 %). Furthermore, the cumulative histogram reveals that about 50 % of the Etna surface has a slope less than 7°. In *figure 5*, slope ranges 0°–4°, 5°–7°, 8°–13° and > 13° are displayed with different colours.

4. Morphological features

Overall, the landscape of Mt. Etna is essentially dominated by compound lava flows that are expressed in the DEM image as a rough texture; however, it is possible to clearly recognise some simple lava flows made up of single flow units such as those discussed by Walker [21]. Their paths are well defined by the levees bordering the main flow, as for instance the 1610 lava flow on the western flank of the volcano (*figure 2*). Similar but shorter features are visible on the western flank of the Ellittico cone and at the head of Valle del Bove (*figures 2* and *6*).

Most of the more than 300 parasitic cones occurring on Mt. Etna [22] are clearly detected on the DEM; furthermore, other relevant morphostructural characteristics are manifest, such as breached crater walls, craterwidth and coalescing cones [23]. Locally, breached

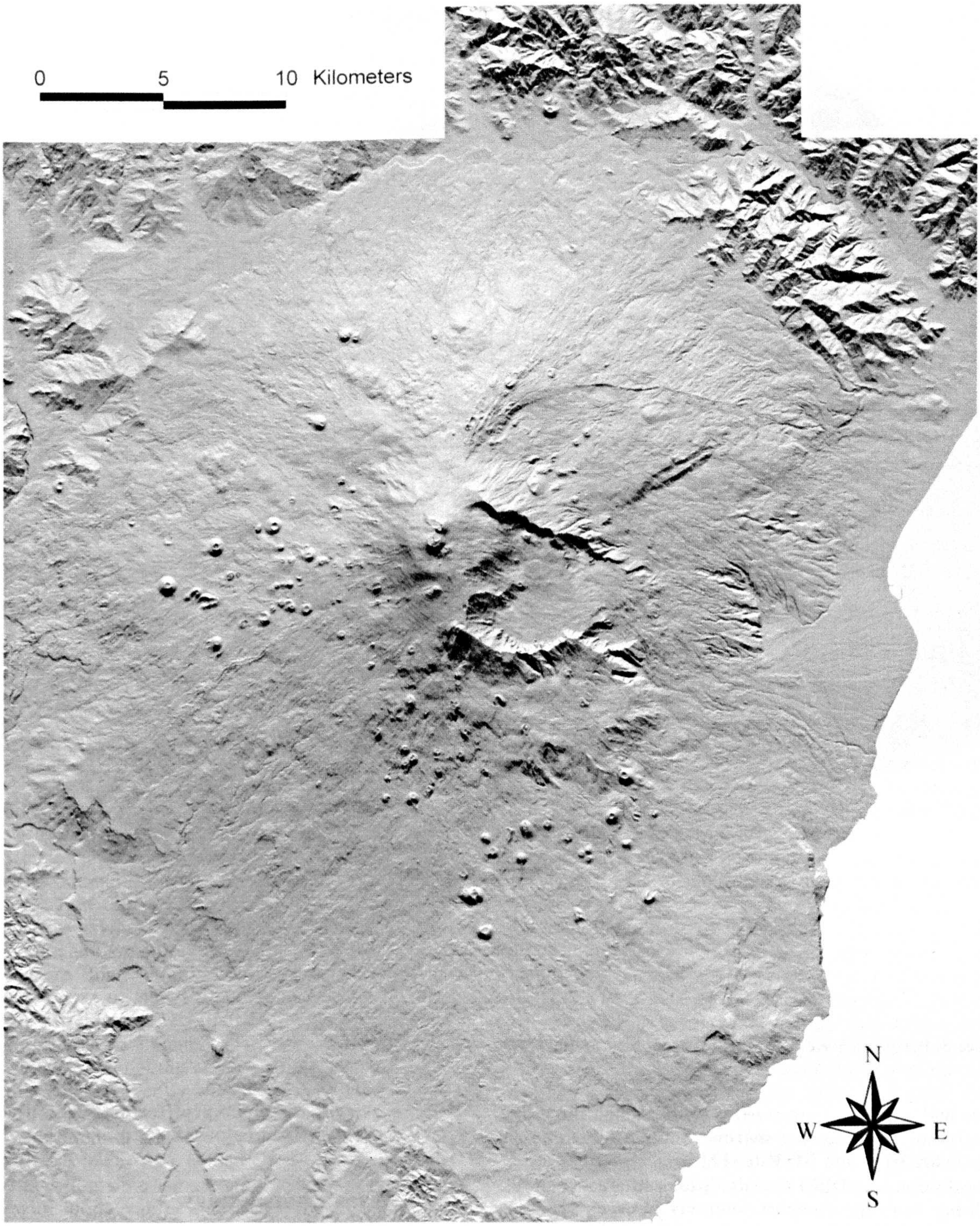

Figure 2. Shaded image of the Digital Elevation Model of Mt. Etna. The artificial illumination is from the north and has an elevation of 45°.

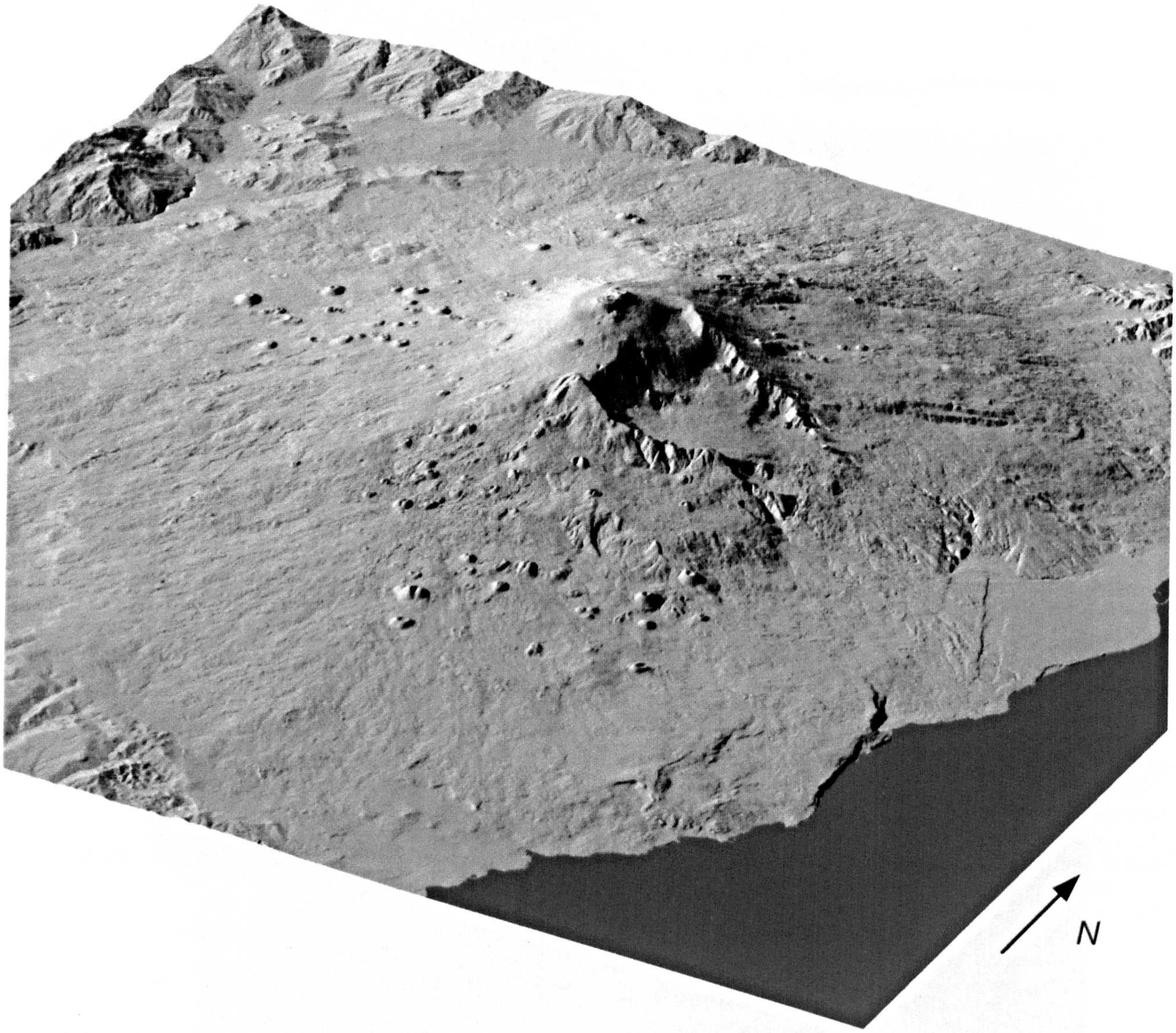

Figure 3. Perspective view of Mt. Etna from SE. Sunlight from west.

cones and pit craters are readily visible along the eruptive fissures forming the narrow eruptive NE-trending belt (*figure 6*) of the NE Rift [12].

In addition, the DEM reveals linear and areal features resulting from the complex interplay between regional and local (volcanic) tectonic regimes and the eruptive dynamic and rheological characteristics of the emitted products. Relevant morphological units are displayed in the slope distribution map, giving important insights into the volcanic system. The main results emerging from the analysis of the slope distribution map and the more evident morphological features identified by the DEM are described below.

4.1. Areal morphology

On the basis of the slope map (*figure 5*), Mt. Etna can be subdivided into five domains (A to E) that are characterized by different slope distributions and textures; *table I* summarises the data derived from frequency histograms relative to slope distribution for each of the five

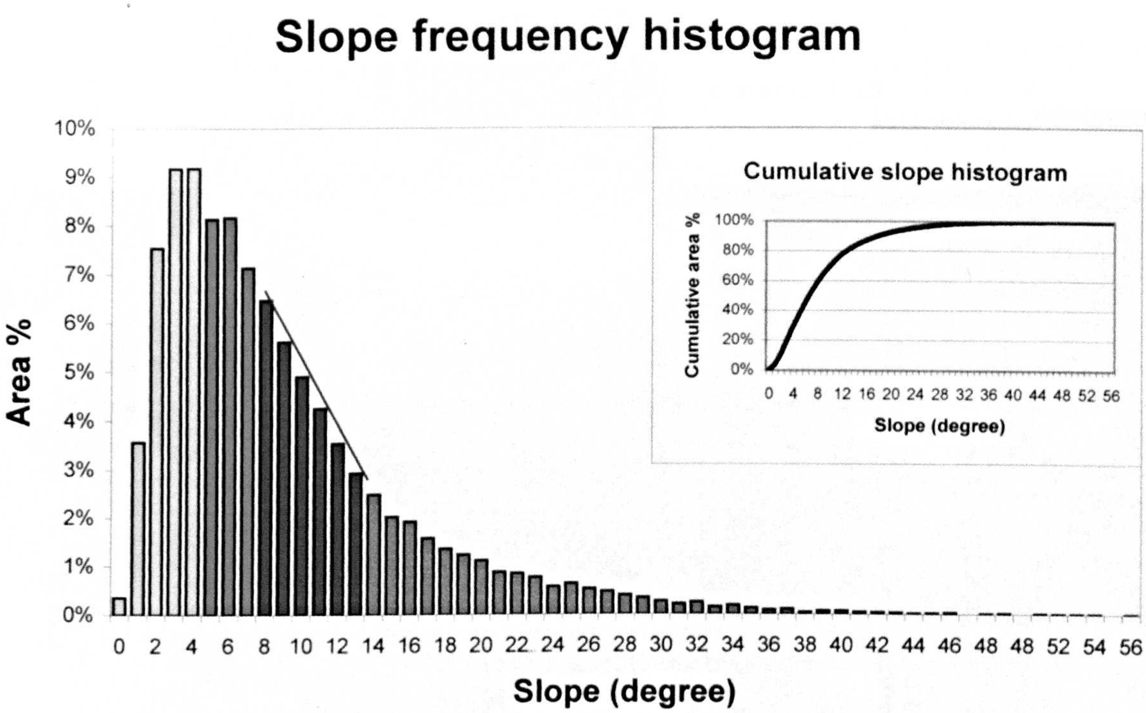

Figure 4. Slope frequency histogram of Mt. Etna. Different colours mark the limits of slope ranges used in figure 5; grey (0°–4°), green (5°–7°), sea-green (8°–13°) and orange (>13°). The blue line marks the range 8°–13°.

distinct domains. Domains from A to D each show a well-defined maximum, whereas the slope frequency distribution in domain E has a double maximum at 3° and 7°.

Domain A, bounded on the northern side by the imaginary line Pozzillo–Monti Rossi–Adrano and to the west by the Simeto Valley (*figure 6*), represents a relatively flat acclivity domain. In fact, more than 80 % of the area has slopes < 7° with a frequency distribution displaying a high positive asymmetry (skewness 2.2; *table I*). The texture is fine and smooth (*figure 5*).

The western lower flank of the volcanic system (domain B, *figure 6*) shows a coarse and rough texture and a more variable acclivity distribution with slope values ranging between 4° and 13° in more than 70 % of the area. On the whole, the area constitutes an inclined surface that connects gently with the Simeto Valley, and exhibits only minor relatively flat zones which do not show any preferential alignment (*figure 5*).

The northern lower part of the Mt. Etna (domain C, *figure 6*) is a domain characterized by fine to medium texture, with slope values relatively high; more than 75 % of the area of this sector has slopes > 8°. Furthermore, the area is readily observed on the DEM (*figure 5*) where it appears as a bulging zone; this domain is bounded to the west by Mt. Maletto, to the north by the Alcantara Valley, to the east by the NE–Rift, and to the south by the Ellittico edifice.

The central upper sector (domain D, *figure 6*) shows a fine and smooth texture with more than 81 % of the area attaining slope values >13°; the slope frequency distribution has a low positive asymmetry (skewness 0.6; *table I*). This domain consists of the steepest flanks of the central area of Mt. Etna and has an irregular and indented shape resulting from a very complex history. In the central part of the domain, steep flanks are divided by "islands" with lower acclivity, such as Ellittico caldera and the bottom of Valle del Bove (*figure 6*). On the slope map (*figure 5*), an almost semicircular flat area standing at a relatively high elevation (mean elevation of 1 280 m; *figure 7*) is clearly visible; it is located between the southern rim of Valle del Bove and the south-facing convex scarp, just north of Mt. Ilice, and represents the sharpest morphological step on the southern flank of the volcano. The uppermost zone of this domain coincides with the summit area of Mt. Etna, dominated by the recent Mongibello cone lying inside the Ellittico caldera. About 15 % of domain D is characterized by relatively low acclivity values (between 8° and 13°, *table I*). These relatively flat areas predominate in the upper sector of the volcano and display a broad north–south alignment, interrupting the eastward continuity of Ellittico caldera.

The last domain occupies the eastern part of Mt. Etna (domain E, *figure 6*) and it is characterized by a complex texture resulting from the interaction of

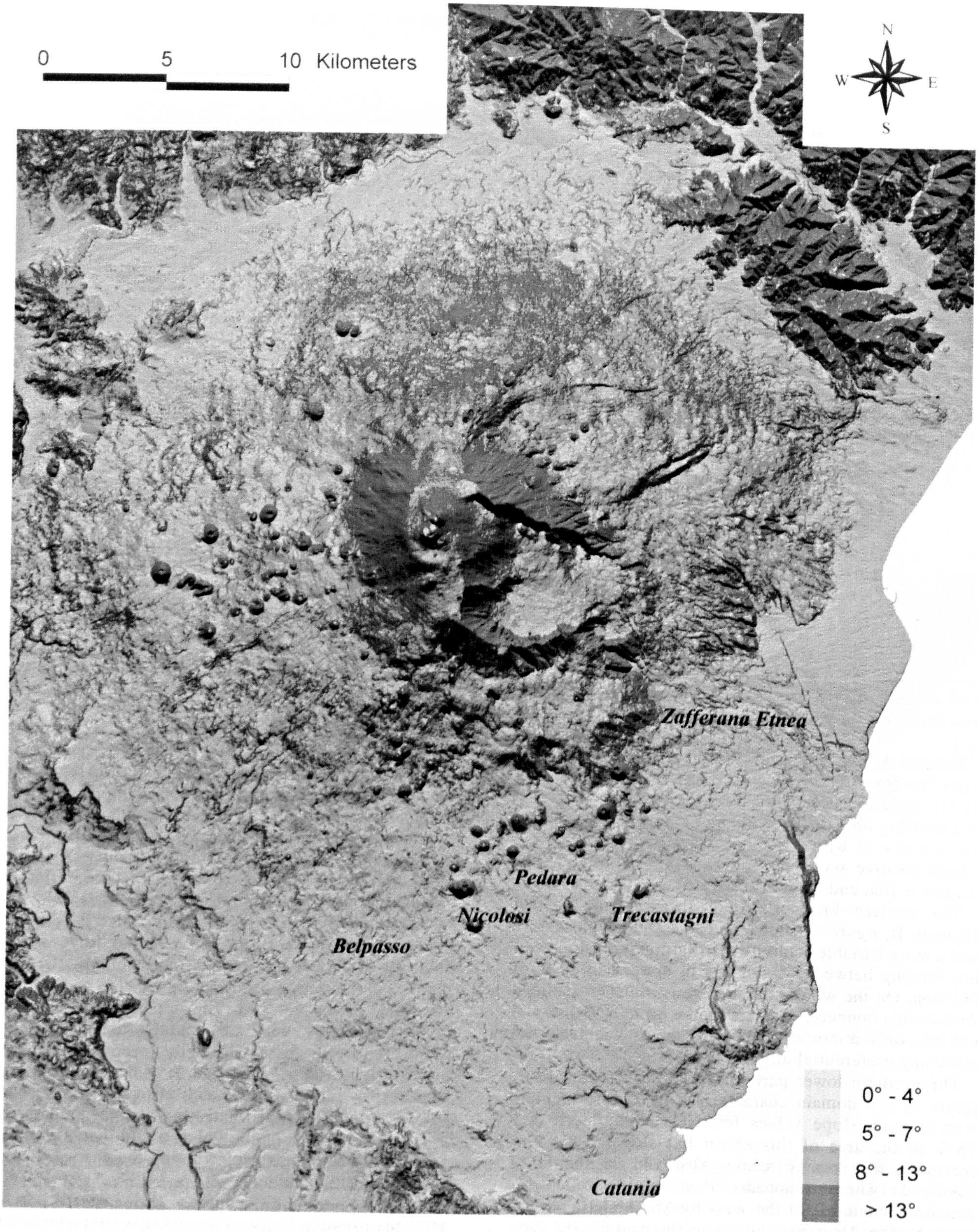

Figure 5. Slope map of Mt. Etna. Different colours identify different slope ranges as indicated in the colour-index scale.

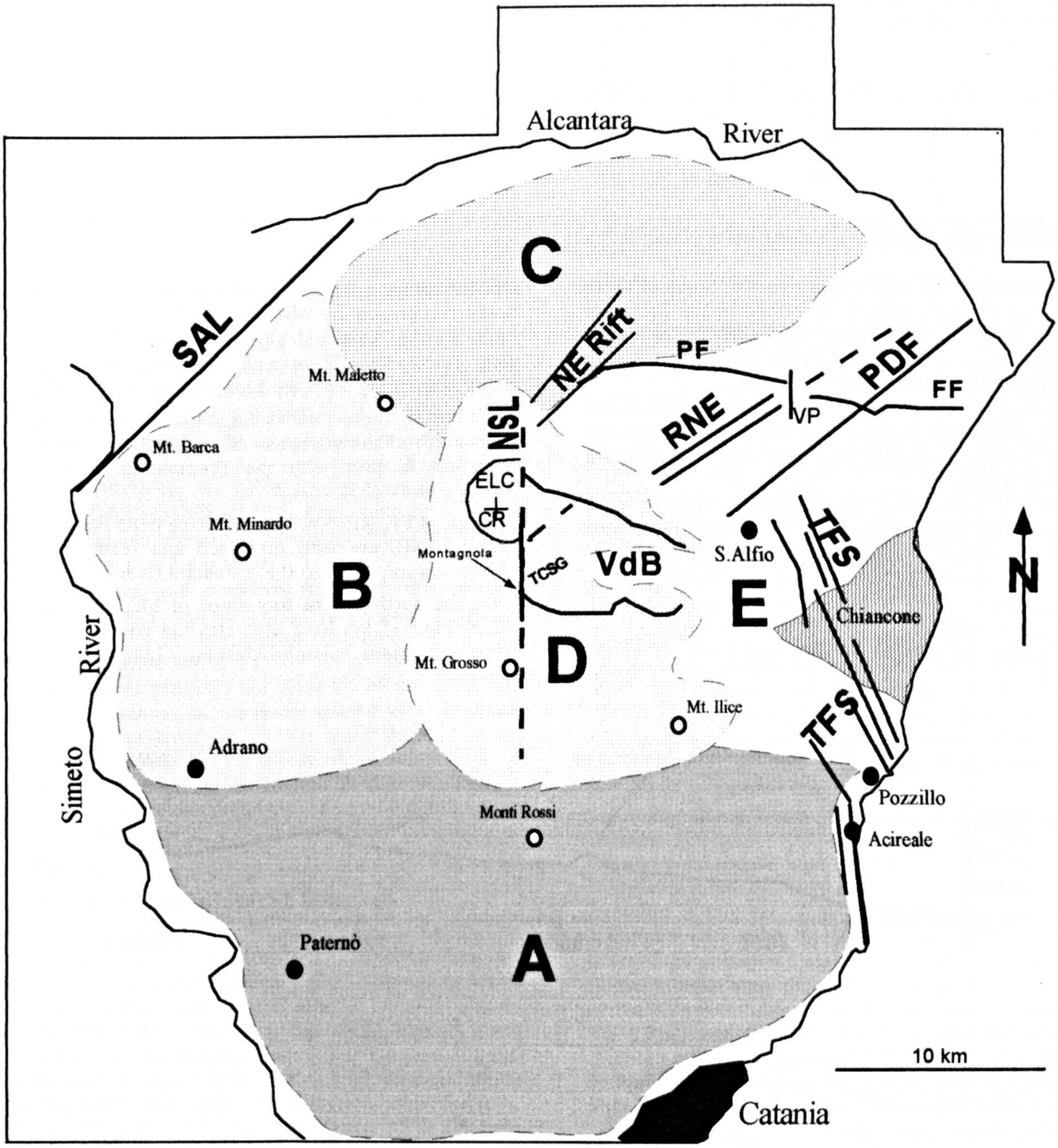

Figure 6. Morpho-structural sketch map showing the extension of distinguished acclivity domains (A to E, see text). SAL, Simeto-Alcantara Line; NSL, North–South Line; PF, Pernicana Fault; RNE, Ripa della Naca Escarpment; PDF, Piedimonte Fault; FF, Fiumefreddo Fault; VP, Vena and Presa Escarpment; TFS, Timpe fault System; VdB, Valle del Bove; TGSC, Trioglietto, Cuvigghiunni, Serra Giannicola; ELC, Ellittico Caldera; CR, Central Craters.

eruptive dynamics, recent tectonics (Timpe Fault System; *figure 6*) and coastal dynamics. The slope frequency distribution is bimodal with a first narrow relative maximum at about 3° and a second one with lower kurtosis centred at about 7°.

4.2. Linear features

Mt. Etna presents an astonishing number of linear features and lineaments which affect the areal morphology. These are best seen on the DEM (*figures 2* and *3*) and

Table I. Statistical parameters of slope frequency distribution for the different acclivity domains.

Acclivity domains	mean (°)	mode (°)	st. dev. (°)	Skew	Kurtosis	% area covered by slope classes			
						0-4°	5-7°	8-13°	>13°
A	5.2	3.0	3.7	2.2	4.0	53	30	14	3
B	9.3	6.0	5.3	1.9	2.4	12	32	40	16
C	12.3	10.0	5.7	0.7	−1.0	5	15	44	36
D	21.5	17.0	8.6	0.6	−1.2	0	2	16	82
E(*)	–	–	–	–	–	27	20	34	19

* The slope frequency distribution is bimodal with two modes at 3° and 7°.

the most relevant are outlined in *figure 6*. Some of these correspond to faults already described in the literature (e.g. [24, 25]); however, others are reported here for the first time. These lineaments will be described as single main lineaments and lineament networks.

We define as single main lineaments the rectilinear or curvilinear features prominent in the DEM texture and bearing unique geometry, and the most evident are described below.

In the NE part of the volcanic edifice, an east–west striking curvilinear lineament is readily observable (PF); it is southward facing and coincides with the trace of the Pernicana Fault [26, 27]. At a more detailed scale, the escarpment relief is higher in the central-western part of the lineament. Its morphological continuity disappears near the villages of Vena and Presa where the DEM displays a faint N–S escarpment, a feature previously recognised by Monaco et al. [25] as an active fault. Further east and along the same E–W trend, a clear lineament (FF) extends until the coastal plain, partly coinciding with the Fiumefreddo Fault [25].

PF and FF interact with a large lineament trending NE from north of the village of S. Alfio (PDF), and corresponding in part with the Piedimonte Fault as in Monaco et al. [25].

South of PF, NE–SW trending Ripe della Naca escarpments (RNE) are well displayed and seem to extend northeastward, close to the Alcantara river (*figure 6*).

On the northwestern foot-slope of Mt. Etna, a lineament about 15 km long separates the volcano from the Appenine chain (Simeto-Alcantara Lineament, SAL),

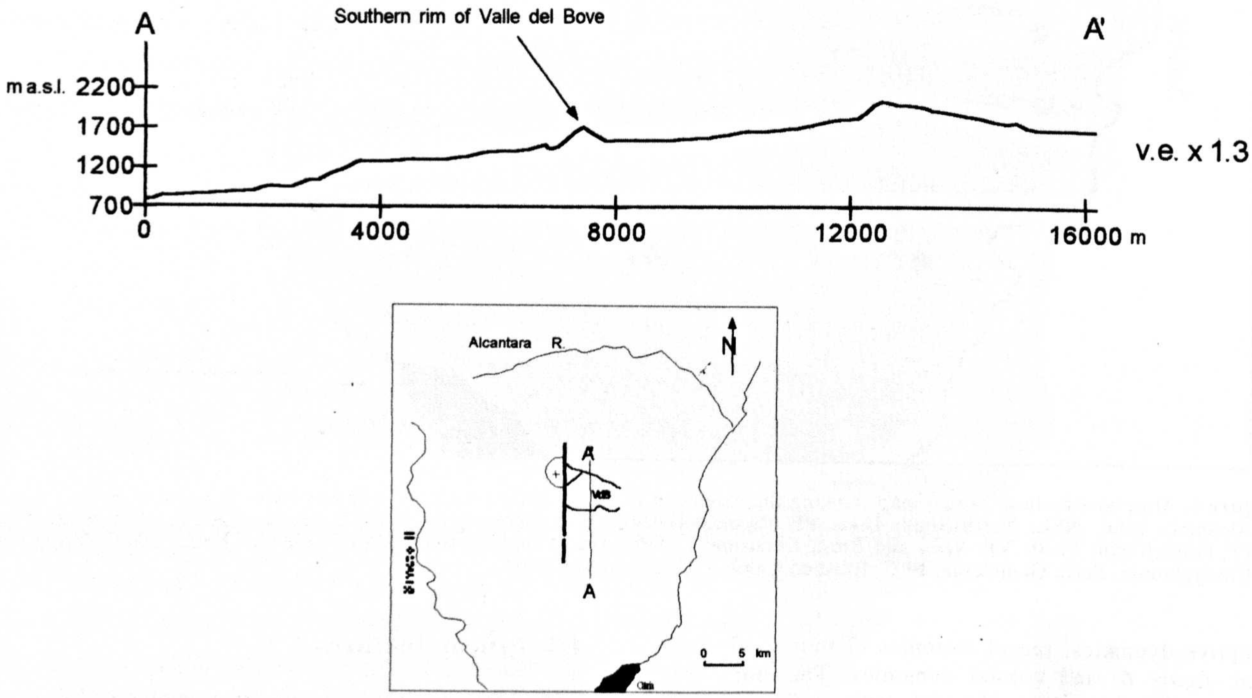

Figure 7. North–south topographic profile across the Valle del Bove, the flat area in the southern part corresponds to the ancient apparatus discussed in the text.

striking NE–SW. The SAL cuts both lava flows as well as rock-units belonging to the Appenine chain.

Mt. Etna is longitudinally divided by an important N–S trending lineament (NSL) crossing the central part of the volcano. It is marked in the summit area by the sharp termination of the ridges bounding the Valle del Bove depression and by the truncation of the eastern rim of the Ellittico caldera (*figure 6*). This line originates at the southern tip of the NE Rift where field data indicate the occurrence of N–S striking faults and fissures [28, 29]; south of the summit area, the lineament is represented by an alignment of several parasitic cones and vents running southward from La Montagnola down to Mt. Grosso.

On the eastern side of the volcano, several well-defined NNW-trending lineaments appear along a total linear extent of about 20 km from Acireale to S. Alfio (*figure 6*). The marked parallelism of all these lineaments allows them to be considered as a lineament swarm corresponding to the well known Timpe Fault System (TFS) lying on the northern extension of the regional Malta escarpment [25]. Just south of S. Alfio, these lineaments bound a tectonically depressed region ranging from 1 to 2 km wide.

The southern and northern flanks of the volcano (domains A and C, respectively; *figure 6*) are characterized by systems of intersecting rectilinear lineaments creating pervasive networks over relatively wide areas. Typically, these networks are made up of two main sets of parallel lineaments, regularly spaced at a few hundred metres, and trending NE–SW and NW–SE. A lineament network only locally affects the western flank of the volcano, whereas on the eastern flank such a pattern has probably been obscured by the recent and still active fault systems.

4.3. Other morphological features

Along the Simeto and Alcantara Valleys, the boundaries between volcanic sequences and sedimentary rocks are generally marked by several alluvial terraces, clearly visible in the DEM (*figure 2*). Two areas, located along the portion of the Simeto Valley between the Adrano and Paterno villages, were selected for morphological investigations; they make up relatively flat surfaces, with slope values < 4° for more than 95 % of their extension. The first area, south of Adrano, has a mean elevation of 578 ± 32 m and covers an area of about 6 km^2; the second area is north of Paterno at 196 ± 13 m with an area of about 2.5 km^2. The morphologies and elevations of these two areas suggest they are expressions of alluvial terraces belonging to the seventh (c.a. 300 ka) and the third (< 18 ka) rank terraces, respectively (terminology of Chester & Duncan [30]).

A fan-like morphological feature is clearly visible on the eastern shoreline of the study area (*figure 2*); it shows a fine to very fine texture, contrasting with the rough texture of adjacent lava flows. This feature corresponds to the Chiancone volcanoclastic fan consisting of a sequence of debris flows and mudflows coming out from Valle del Bove [31].

5. Discussion

The DEM and its derived slope-map provide a synoptic view of the Mt. Etna volcano, giving evidence of spatial relationships of the main morpho-structural features affecting the region. Overall, the volcanic system appears to consist of distinct sectors having different morphological characteristics (acclivity domains); furthermore, lineaments appear to affect single domains as well as, in some cases, the whole structure. In addition, important lineaments generally correspond to main faults or fracture systems, such as the Pernicana Fault, the Piedimonte Fault and the Timpe Fault System (*figures 2, 3* and *6*); particularly well depicted by the DEM is the graben-like NNW-trending structure located just southeast of S. Alfio, in continuity with the Timpe Fault System and affecting the volcanoclastic fan of Chiancone (*figures 3, 6*). *Figure 8* presents an across-strike topographic section which clearly delineates this structure.

Furthermore, the DEM reveals an important NE–SW-trending line, not previously recognised, affecting the northwestern margin of the volcano and cutting across both the volcanic and sedimentary rocks (Simeto-Alcantara Line, SAL; *figure 6*). The significance of the SAL is enigmatic, as it could be the result of reaction of the basement to volcanic loading, or, alternatively, a portion of a regional fracture.

Another conspicuous lineament affecting the whole volcanic system is represented by the NSL (*figure 6*); it broadly corresponds with the trace of a N–S sub-Etnean ridge identified by Rust and Neri [32]. This positive structure is interpreted as an area of magma intrusion (Southern Rift Zone; McGuire et al., [33]) or the SW limit of the collapsing eastern flank of the volcano [24]. In the summit area, the NSL interrupts the eastern part of the Ellittico Caldera and the bordering ridges of the Valle del Bove (*figure 6*). Taken as a whole, these geomorphic features suggest that the NSL plays a volcano-tectonic role, separating the volcano into two main morphostructural sectors. This lineament fades out into acclivity domain A which represents more than 30 % of the area covered by the Etnean volcanics and stands out because of its relatively flat morphology and extent. The eastern part of this sector is affected by a NNW-trending lineament swarm (Timpe Fault System, *figure 6*) along which the rocks drop down to the east; in this structural frame, old sub-horizontal lava flows, exposed only along the main escarpments [9], are considered as evidence of the volcanic activity preceding the building of the Etnean central volcanoes [13]. We put forward the hypothesis that acclivity domain A (*figure 6*) is the expression of a wide, old plateau lava, volcanologically

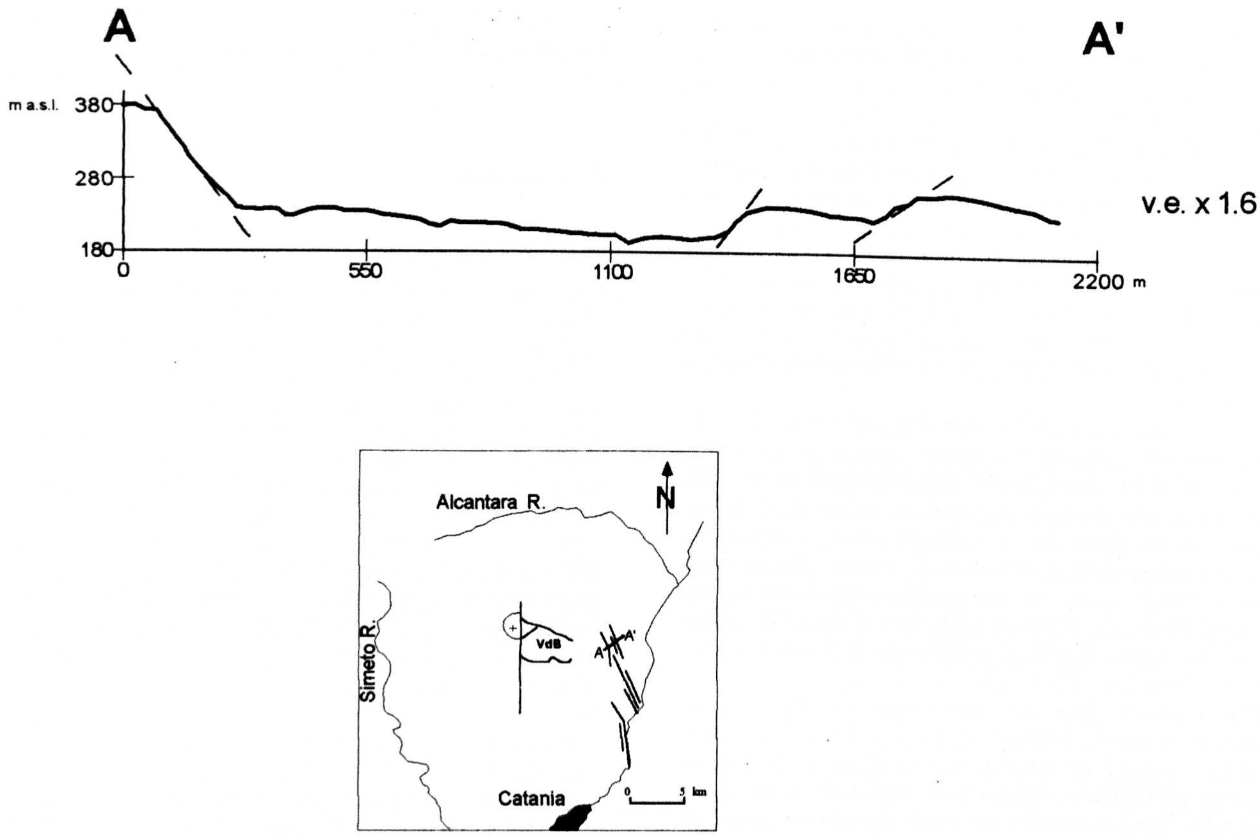

Figure 8. NE–SW across-strike profile of the Graben-like depression east of S. Alfio, fault escarpments are drawn with dashed lines.

similar to the Hyblean Plateau located south of Catania [34]. Thus, in accordance with this interpretation, it represents a volcanic unit that is both morphologically and temporally distinct from the main Etnean volcanic system which is dominated by central volcanoes. Also, the mainly tholeiitic/transitional petrogenetic affinity of the ancient products belonging to this unit is distinguishable from that of the more recent, definitely alkaline Etnean lavas [18]. The flat, wide surface of this sector contributes to hindering the advance of lava flows coming from the summit area; in fact, the only historical flows to have extensively invaded the region were generated by parasitic cones located at relatively low altitudes (generally lower than 1 000 m; e.g. the 1669 Monti Rossi eruption; [17, 35]).

The complex morphology of the central part of the volcano (domain D, *figure 6*) results from the interference of central apparata and volcanic structures having different ages (recent Moggibello, Ellittico, Trifoglietto, Cuvigghiuni, Serra Giannicola and Valle del Bove; [11, 12]). As far as the more recent products are concerned, the DEM clearly shows that the recent Mongibello lavas, when entering Valle del Bove, behaved differently in the southern portion of the depression than in the northern one. The former is constituted by the Trifoglietto–Cuvigghiuni–Serra Giannicola volcanic complexes (TCSG in *figure 6*) which seems to have represented a barrier against the Mongibello lavas. Conversely, the northern part of the depression is largely covered by the Mongibello lavas wrapping older structures, among which a high escarpment is evident, aligned with the Ripe della Naca lineament. This asymmetric morphology of Valle del Bove is probably a consequence of the fact that slope failure on Etna's eastern flank involved several central apparata.

Furthermore, the DEM allows location of another volcanic centre existing south of Valle del Bove; in fact, we consider as vestiges of such an apparatus the relatively flat area (*figure 7*) intervening between the southern rim of Valle del Bove and the semi-lunated, south-facing convex escarpment just to the north of Mt. Ilice (*figure 6*). The morphology of this relatively flat area and its southern scarp represent, in this interpretation, the relict of a summit caldera successively filled by lavas.

The synoptic view of the DEM allows better definition of this old structure that several authors [11–13, 36, 37] have tentatively recognised in the region south of

Valle del Bove, with however, extremely variable descriptions for both its dimensions and location.

6. Summary and conclusions

A DEM of Mt. Etna volcano has been presented. The good interpolation technique used to reconstruct the surface as a "continuum", the relatively high spatial resolution of the data and the opportunity to select different illumination conditions and points of views, related to the digital nature of the data, have outlined the strength of this approach in morphological analysis of volcanic and volcano-tectonic structures. The analysis of slope distribution, derived by the DEM, has been used as a valuable tool in defining the occurrence of relatively homogeneous areas reflecting older volcanic structures, wrapped but not deleted by subsequent volcanic cover. In particular, the DEM addressed the existence of an old plateau on which the central Etnean volcanoes developed. Finally, new relevant morpho-structural lines such as the SAL and the NSL have been recognised, and their important role in the structural evolution of the volcanic system has been hypothesized.

Acknowledgements

The authors thank David S. Westerman for the critical reading of earlier drafts and O. Merle for reviewing of the manuscript. Financial support for this work was provided by CNR-GNV (National Research Council-National Volcanologic Group of Italy). A GIS of Mt. Etna, including main roads, airways, inhabited areas and shaded orthogonal digital views of the DEM, is freely available on CD media [38].

A CD of Mt. Etna GIS can be requested from M.T. Pareschi: pareschi@dst.unipi.it.

References

[1] Lentini F., The geology of the Mt. Etna basement, Mem. Soc. Geol. It. 23 (1982) 7–25.

[2] Monaco C., Tortorici L., Tettonica Estensionale Quaternaria nell'Arco Calabro e in Sicilia Orientale, Studi Geologici Cameriti, Volume Speciale 2 (1995) 351–362.

[3] Lentini F., Carbone S., Catalano G., Grasso M., Elementi per la ricostruzione del quadro strutturale della Sicilia orientale, Mem. Soc. Geol. It. 51 (1996) 179–195.

[4] Bousquet J.C., Lanzafame G., Paquin C., Tectonic stresses and volcanism: in-situ stress measurements and neotectonic investigations in the Etna area (Italy), Tectonophysics 149 (1988) 219–231.

[5] Labaume P., Bousquet J.C., Lanzafame G., Early deformations at a submarine compressive front: the Quaternary Catania foredeep south Mt. Etna, Sicily, Tectonophysics 177 (1990) 349–366.

[6] Patanè D., Ferrucci F., Gresta S., Spectral features of microearthquakes in volcanic areas: attenuation in the crust and amplitude response of the site at Mt. Etna (Italy), Bull. Seismol. Soc. Am. 84 (1994) 1842–1860.

[7] Wezel F.C., I terreni quaternari del substrato dell'Etna, Boll. Acc. Gioenia Sci. Nat., Catania VI, 18 (1967) 271–282.

[8] Tanguy J.-C., Présence de basaltes à caractère tholéitique dans la zone de l'Etna, C.R. Ac. Sc. Paris, 264 D (1967) 21–24.

[9] Gillot P.Y., Kieffer G., Romano R., The evolution of Mount Etna in the light of potassium-argon dating, Acta Vulcanologica 5 (1994) 81–87.

[10] Kieffer G., Evolution structurale et dynamique d'un grand volcan polygénique: stades d'édification et activité actuelle de l'Etna (Sicilie), Bull. Volcanol. 24 (1985) 726–737.

[11] Romano R., Succession of the volcanic activity in the Etnean area, Mem. Soc Geol. It. 23 (1982) 27–48.

[12] Chester D.K., Duncan A.N., Guest J.E., Kilburn C.R.J., Mount Etna: The anatomy of a volcano, Cambridge University Press, 1985, 404 p.

[13] Kieffer G., Tanguy J.C., L'Etna : évolution structurale, magmatique et dynamique d'un vulcan « polygénique », Mém. Soc. géol. France 163 (1993) 253–271.

[14] Calvari S., Groppelli G., Pasquarè G., Preliminary geological data on the south-western wall of the Valle del Bove, Mt. Etna, Sicily, Acta Vulcanol. 5 (1994) 15–30.

[15] D'Orazio M., Tonarini S., Innocenti F., Pompilio M., Northern Valle del Bove volcanic succession (Mt. Etna, Sicily): petrography, geochemistry and Sr-Nd isotope data, Acta Vulcanologica 9 (1/2) (1997) 73–86.

[16] Condomines M., Tanguy J.C., Michaud V., Magma dynamics at Mt. Etna: constraints from U-Th-Ra-Pb radioactive disequilibria and Sr isotopes in historical lavas, Earth Planet. Sci. Letters 132 (1995) 25–41.

[17] Romano R., Sturiale C., Lentini F., Carta geologica del Monte Etna, C.N.R. Prog. Fi. Geodinamica, 1:50 000, 1979.

[18] Tanguy J.-C., Condomines M., Kieffer G., Evolution of Mount Etna magma: Constraints on the present feeding system and eruptive mechanism, J. Volcanol. Geotherm. Res. 75 (1997) 221–250.

[19] Macedonio G., Pareschi M.T., An algorithm for the triangulation of arbitrarily distributed points: applications to volume estimate and terrain fitting, Computer and Geoscience 17 (7) (1991) 859–874.

[20] Preparata P., Shimoto M.I., Computational Geometry: Springer-Verlag, New York, 1985, 391 p.

[21] Walker G.P.L., Compound and simple lava flows and flood basalts, Bull. Volcanol. 35 (1970) 579–590.

[22] Villari L., Rasà R., Caccamo A., Volcanic hazard at Mount Etna (Sicily, Italy). Some insight from geostructural pattern constraining flank eruptions, Kagoshima Int. Conf. on Volcanoes, Kagoshima, Japan, NIRA, 1988, pp. 491–494.

[23] Tibaldi A., Morphology of pyroclastic cones and tectonics, J. Geophys. Res. 100 (1995) 24521–24534.

[24] Lo Giudice E., Rasà R., Very shallow earthquakes and brittle deformation in active volcanic areas: the Etnean region as an example, Tectonophysics 202 (1992) 257–268.

[25] Monaco C., Tapponnier P., Tortorici L., Gillot P.Y., Late Quaternary slip rates on the Acireale-Piedimonte normal faults and tectonic origin of Mt. Etna (Sicily), Earth Planet. Sci. Letters 147 (1997) 125–139.

[26] McGuire W.J., Pullen A.D., Location and orientation of eruptive fissures and feeder-dikes at Mt. Etna: influence of gravitational and regional tectonic stress regimes, J. Volcanol. Geotherm. Res. 38 (1989) 325–344.

[27] Borgia A., Ferrari I., Pasquarè G., Importance of gravitational spreading in the tectonic and volcanic evolution of Mount Etna, Nature 357 (1992) 231–235.

[28] Tibaldi A., Borgia A., Neri M., Pasquarè G., Volcanism, geometry, style and rate of Holocene deformation along the northeast boundary of the instable eastern flank of Mt. Etna,

Italy. Project Seavolc: Sea-level change and the stability and activity of coastal and island volcanoes, Commission of the European Communities, Environment programme contract EV5V-CT92-0170, Final Report, May 1995.

[29] Garduno V.H., Neri M., Pasquarè G., Borgia A., Tibaldi A., Geology of the NE-Rift of Mount Etna (Sicily, Italy), Acta Vulcanologica 9 (1/2) (1997) 91–100.

[30] Chester D.K., Duncan A.N., The interaction of volcanic activity in Quaternary times upon the evolution of the Alcantara and Simeto rivers, Mount Etna, Sicily, Catena 9 (1982) 319–342.

[31] Calvari S., Groppelli G., Relevance of Chiancone volcanoclastic deposit in the recent history of Etna Volcano (Italy), J. Volcanol. Geotherm. Res. 72 (1996) 239–258.

[32] Rust D., Neri M., The boundaries of large-scale collapse on the flanks of Mount Etna, Sicily, in: W.J. McGuire, A.P. Jones, Neuberg (Eds), Volcano Instability on the Earth and Other Planets, Geol. Soc. London, Spec. Pub. 110 (1996) 169–177.

[33] McGuire W.J., Stewart I.S., Saunders S.J., Intra-volcanic rifting at Mount Etna in the context of regional tectonics, Acta Vulcanologica 9 (1/2) (1997) 147–156.

[34] Schmincke H.-U., Behncke B., Grasso M., Raffi S., Evolution of the northwestern Iblean Mountains, Sicily: uplift, Plicocene/Pleistocene sea-level changes, paleoenvironment, and volcanism, Geol. Rundschau 86 (1997) 637–669.

[35] Corsaro R.A., Cristofolini R., Patanè L., The 1669 eruption at Mount Etna: chronology, petrology and geochemistry, with inferences on the magma sources and ascent mechanisms, Bull. Volcanol. 58 (1996) 348–358.

[36] Kieffer G., Existence probable d'une caldeira d'une quinzaire de kilomètres de diamètre dans la structure de l'Etna, Geol. Mediterr. 1 (1974) 133–138.

[37] Cristofolini R., Patanè G., Recupero S., Morphologic evidence for ancient volcanic centres and indications of magma reservoirs underneath Mt. Etna, Sicily, Geog. Fis. Din. Quat. 5 (1982) 3–9.

[38] Pareschi M.T., Cavarra L., Innocenti F., Pasquarè G., Digital Atlas of Mt. Etna volcano, Acta Vulcanol. 11 (2) (1999) in press.