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Geological map of Etna volcano, 1:50,000 scale

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ABSTRACT

The new geological map of Etna volcano at 1:50,000 scale represents a significant progress in the geological studies of this volcano over the last 30 years, coming after Waltershausen's map published around the mid of 19th century, the first geological map of a large active volcano, and the ROMANO *et alii* (1979) map published about a century later, both at 1:50,000 scale. Lithostratigraphy was used for mapping volcanic units and then Unconformity Bounded Units were applied to group lithostratigraphic units into synthems. In addition, lithosomes were exploited to better represent the spatial localization of different eruptive centres according to their morphology. On the whole, we identified 27 lithostratigraphic units, grouped into 8 synthems, and 9 volcanoes. In detail, effusive and explosive deposits generated by each eruption of Mongibello and, partially, Ellittico volcanoes were mapped as flow rank. This stratigraphic framework represents the best synthesis of the geological evolution of Etna volcano using the main unconformities recognized within its complex volcanic succession. In addition, we constrain the Etna volcanic succession and its lithostratigraphic units chronologically by radioisotope age determinations. On the basis of the outlined synthemic units, it was possible to divide Etna's volcanic succession into 4 supersynthems, which correspond to 4 well-defined and spatially localized phases. The detailed reconstruction of the past eruptive activity allowed compiling the most accurate dataset in particular of the Holocene eruptions of Etna volcano, which will enable significantly improving the volcanic hazard assessment, together with petrological interpretation of erupted magmas and geophysical modelling of the volcano plumbing system.

KEY WORDS: *Mount Etna, geological map, basaltic composite volcano, stratigraphy, UBU.*

INTRODUCTION

Mount Etna is one of the most active volcanoes in the world, located on the densely inhabited eastern coast of Sicily (Italy). It is a large basaltic composite volcano covering a broad sub-rounded surface of 1178 km^2, with a maximum diameter of about 45 km, from sea level along the Ionian coast up to a height of 3328 m. Etna volcano is characterized by an almost continuous eruptive activity from its summit craters and fairly frequent lava flow eruptions from fissures opened on its flanks, as historically reported during the past 2,700 years ever since the Hellenistic age (TANGUY, 1981; BRANCA & DEL CARLO, 2004 and 2005).

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An active volcano, such as Etna, poses a variety of potential hazards whose assessment is largely based on the record of the past eruptions. Field data and evolutionary interpretations provide information on the frequency, magnitude, distribution and style of these volcanic events. The geological map is a storehouse of the past eruption data and can be used for practical purposes such as land management planning and emergency preparedness.

In the last decade, Etna has become one of the best-monitored and studied volcanoes in the world and it is considered a volcano laboratory for volcanologists and geophysicists. Until today, the geologic reference for the scientific community has been provided by the geological map published at 1:50,000 scale by Consiglio Nazionale delle Ricerche, Istituto Internazionale di Vulcanologia of Catania (CNR-IIV) in 1979 (ROMANO *et alii*, 1979). In this paper, we present the new geological map of Etna volcano at 1:50,000 scale as well as the stratigraphic and geological data of the volcanic succession collected during the field survey, which represent significant scientific progress in geological studies of this volcano over the last 30 years.

The previous mapping of volcanic products was largely performed using lithologic and petrochemical, rather than stratigraphic, criteria for the identification of the volcanic units and, therefore, rocks with similar composition have been grouped and mapped. Considering that basaltic volcanoes like Etna show a limited variation in erupted magma composition a stratigraphic approach is required to realise a modern geological map that allows reconstructing Etna's eruptive history.

The geological field survey was carried out by a team of volcanologists from the Istituto Nazionale di Geofisica e Vulcanologia (INGV), Osservatorio Etneo, sezione di Catania (formerly CNR-IIV), Università di Milano – Dipartimento di Scienze della Terra, and CNR – Istituto per la Dinamica dei Processi Ambientali, sezione di Milano. In particular, the final geological map was compiled (see field survey scheme in the geological map) on the basis of new field surveys performed during PhD theses of DE BENI (2004), GARFÌ (2004), BELLOTTI (2009; see also BELLOTTI *et alii*, 2010), as well as on revised and updated 1:10,000 scale original field surveys previously used for publishing the 1:50,000 scale sheets: Acireale, Catania, Taormina and Paternò, under the agreement of the SERVIZIO GEOLOGICO D'ITALIA (2009a and b, 2010a and b). The field surveys were completed in September 2007. Concerning the sedimentary basement, we have used data from published geological maps (CARBONE *et alii,* 1990 and 1994, LENTINI *et alii,* 2000; SERVIZIO GEOLOGICO D'ITALIA 2009b, 2010a and b and in press).

This paper is focused on the explanatory notes of the new geological map of Etna volcano, exploring in depth the methodological approach and stratigraphic data achieved that are related only to the volcanic and volcaniclastic succession. We also highlight the main advances and novelties present in this geological map with respect to the previously published maps. In addition, two short chapters are devoted to describe the geodynamic background and history of the geological mapping of Etna volcano.

The present paper is accompanied by two companion papers: DE BENI *et alii* (2011) and BRANCA *et alii* (2011) issued in this volume. DE BENI *et alii* (2011) discuss $^{40}Ar/^{39}Ar$ age determinations performed since 2002 in collaboration with the Vrije Universiteit of Amsterdam and BRANCA *et alii* (2011) present the Etna volcano geological evolution, as reconstructed on the basis of the new chronologically constrained stratigraphic framework.

GEOLOGIC AND TECTONIC SETTING OF EASTERN SICILY

Etna volcano is located between the Gela-Catania foredeep and the front of the orogenic belt overlapping the African continental plate margin named Hyblean Foreland (fig. 1), an undeformed sequence of the Pelagian Block (LENTINI *et alii*, 2006). A schematic N-S oriented crustal cross-section has been compiled in order to evidence the complex structural setting of eastern Sicily below Etna volcano (fig. 2), originating during the Neogene convergence between the African and European plates. The mountain range is a multilayer allochthonous orogenic belt forming a duplex structure. The Kabilo-Calabride Chain (KCC) tectonically overlies the so-called Apenninic-Maghrebian Chain (AMC) which, in turn, overthrusts onto the Upper Miocene and Pliocene top-levels of a deep-seated thrust system named the External Thrust System (ETS), originating from the deformation of the innermost carbonates of the Pelagian Block (fig. 1).

On the northern side of the crustal cross-section (fig. 2), the Pelagian Block is affected by a deep-seated thrust system (ETS) which is mainly buried below the unrooted nappes of the AMC (LENTINI *et alii*, 1996). The AMC units are composed of Meso-Cenozoic shallow-water carbonate successions detached from a continental type crust, the Panormide Block. The Meso-Cenozoic basinal units, that compose the AMC, can be distinguished into two main groups of sequences, originally located on oceanic crust, separated by the Panormide Block. The external units (Ionides) deposited in a basin, belonging the Ionian paleobasin, involved in the orogenesis (Imerese, Sicanian and Mt Judica Units), whereas the internal units are attributed to the Alpine Tethys (Sicilide Units) (LENTINI *et alii*, 2006). The Ionides represent the lowermost structural unit of the AMC and are composed of Mesozoic-Eocene basinal sequences, grading upwards into Oligocene-Middle Miocene terrigenous successions. The terrigenous deposits of the Ionides are represented by Tertiary foreland/foredeep deposits, which generate repeated slices apparently increasing the original thickness. The Oligo-Miocene deposits of the “Paleo-Ionian Basin” are mostly constituted by the Numidian Flysch or by glauconite-bearing cover, grading up into Middle-Late Miocene silicoclastic rocks (fig. 2). The Alpine Tethys units are represented by allochthonous tectonic units, resting on both the Panormide Units and the Ionides. Because of their “tectonic mobility”, they compose most of the frontal wedge (Gela Nappe) in the Gela-Catania foredeep. The sedimentary succession of the Sicilide Units is characterized by Upper Jurassic-Cretaceous marls and quartzarenites (Mt Soro Flysch) and by Late Cretaceous-Early Oligocene varicoloured shales, known as “Argille Scagliose” or “Argille Varicolori”. These evolve into Upper Oligocene-Lower Miocene terrigenous turbiditic successions. The Numidian Flysch belonging to the Nicosia/Mt Salici Subunit represents the external terrigenous cover. The geometric relationships of the Sicilide Units are probably the result of a progressive accretionary process accompanied by a detachment of the Tertiary terrigenous covers and by a breaching of the Mesozoic Mt Soro Flysch (LENTINI *et alii*, 2006). Finally, the KCC includes nappes of Hercynian basement and its Meso-Cenozoic cover, deformed during the Paleogene and then sutured by the Late Oligocene-Early Burdigalian Capo d’Orlando Flysch (LENTINI *et alii*, 1994 and 2000). KCC units form the bulk of the Peloritani Mountains northward of Etna.

The southern side of the crustal cross-section (fig. 2) is dominated by the Hyblean foreland units. They are bent beneath the tectonic units of the AMC by a system of NE-SW oriented normal faults (BEN AVRAHAM & GRASSO, 1990). The northward extent of the Hyblean foreland below the main thrust wedge in Sicily is confirmed by geophysical data and large-scale geological reconstructions. In particular, carbonate bodies connected to the successions of the Hyblean Plateau, but strongly deformed, have been recognized below the allochthon as far as the northern flank of Etna (CRISTOFOLINI *et alii*, 1979; LENTINI, 1982; BIANCHI *et alii*, 1987). The southern margin of Etna volcano rests on the Gela-Catania foredeep (fig. 2), which is filled by the allochthonous units of the frontal wedge of the chain, the Gela Nappe (BIANCHI *et alii*, 1987). The Gela-Catania foredeep is formed by Neogene-Quaternary sequences mostly represented by foredeep and thrust top basin deposits that were progressively involved in the orogenesis.

Finally, the neo-tectonic setting of Etna region derives from the post-Tortonian deformational events. They have modified the pre-existing thrust geometry of the orogenic belt in NE Sicily through the activation of a NW-SE oriented dextral transcurrent fault system (fig. 1) linked with the geodynamic evolution of the Tyrrhenian margins (LENTINI *et alii*, 2006). Conversely, a major lithospheric discontinuity affected the offshore of the SE Sicily, the so called Malta Escarpment, which separates the continental crust of the Hyblean Foreland from the oceanic crust of the Ionian Basin (fig. 1).

HISTORY OF THE GEOLOGICAL MAPPING OF ETNA VOLCANO

The earliest scientific text describing the volcanic phenomena of Mt Etna was published by BORELLI (1670), a physicist who wrote a detailed account of the major 1669 lava flow eruption that dramatically involved the densely populated lower southern flank. During the 18th century, several scholars investigated Etna volcano and its eruptions, setting out the first geological considerations (for details, see paragraph 1.4 of CHESTER *et alii*,

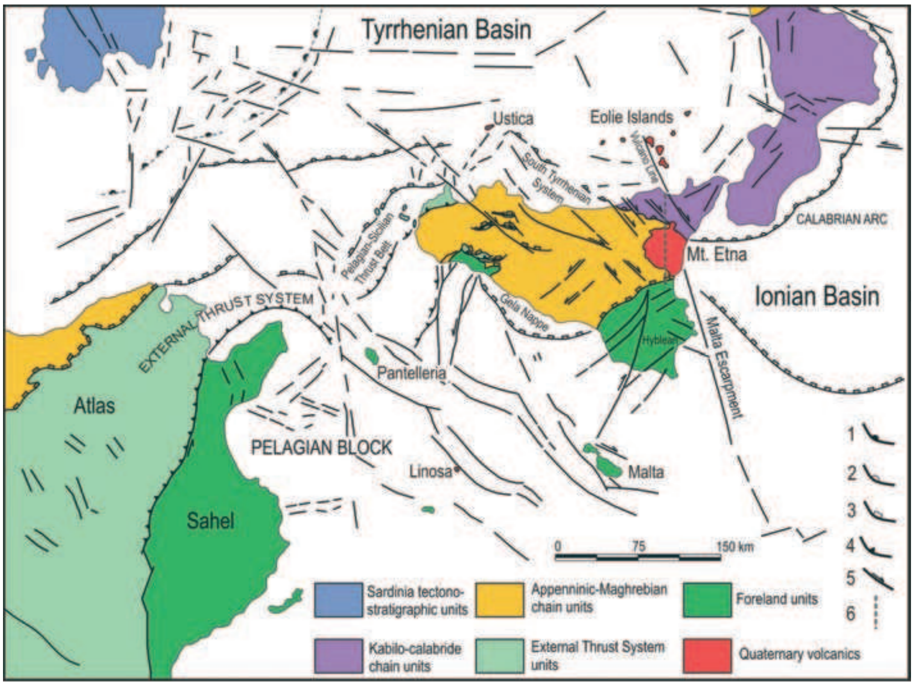

Fig. 1 - Structural setting of central Mediterranean Sea (modified from Lentini *et alii*, 2006) and location of Mt Etna: 1) Regional overthrust of the Sardinia-Corsica block upon Calabride units; 2) Regional overthrust of the Kabilo-Calabride units upon the Apenninic-Maghrebian chain; 3) External front of the Apenninic-Maghrebian chain upon the Foreland units and the External Thrust System; 4) Thrust front of the External Thrust System; 5) Main normal and strike-slip faults; 6) Location of the cross section of fig. 2.

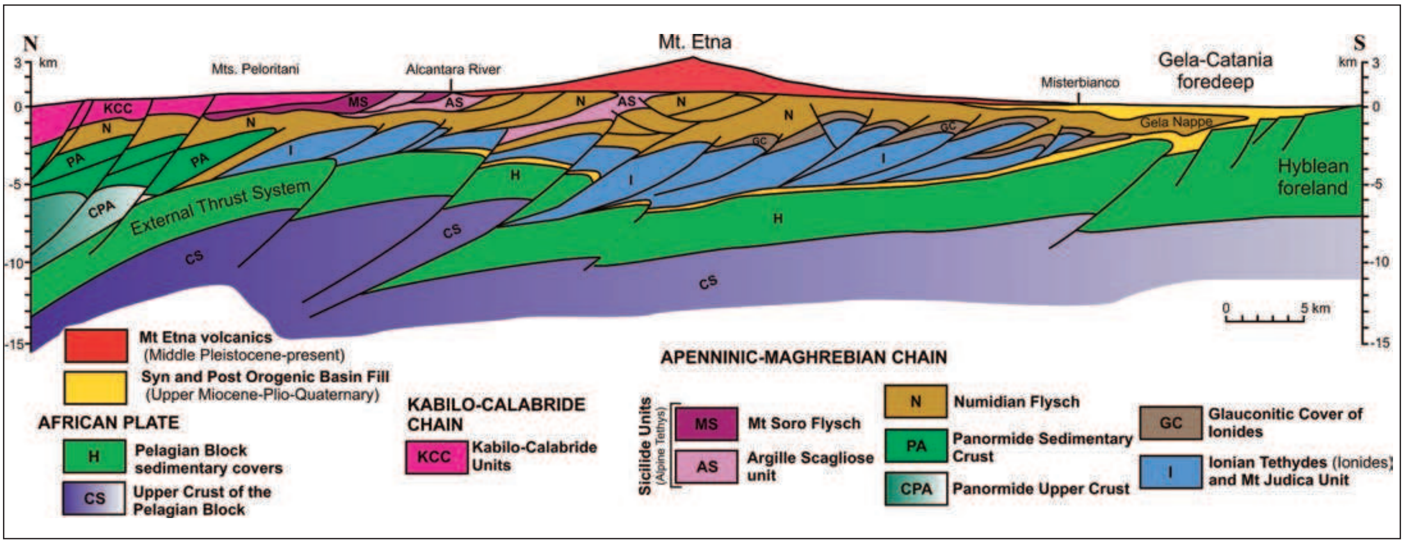

Fig. 2 - Schematic crustal N-S cross section of eastern Sicily through Etna volcano (modified from Lo Castro, 2008). The Etnean feeding system is not depicted due to the scale.

1985). Starting from the 19th century, the first studies on the geology of the volcano were carried out on Etna. In particular, De Beaumont (1836) published the earliest attempt at a geological reconstruction of the volcano edifice. During the first half of this century, systematic geological investigations were performed on Etna by a number of eminent European scientists, in particular Lyell (1859) and Waltershuasen (1880), as well as the Sicilian naturalist and geologist Gemmellaro (1858). In collaboration, the three scientists made the first studies on the stratigraphy of the volcanic succession exposed along the imposing inner walls of the broad depression known as the Valle del Bove. From their initial geological observations, they deduced that Etna volcano was the end result of a complex evolutionary history created by the superimposition of at least two main eruptive centres in time and space (fig. 3). On the basis of the geometrical reconstruction of the volcanic layers cropping out along the south-western wall of the Valle del Bove, Lyell, Waltershausen and Gemmellaro separately recognized the presence of an ancient volcanic centre in this side of the valley. The feeder system of this ancient volcano was inferred to be on the Trifoglietto plain from which it took its name: Trifoglietto. The present volcanic centre, called Mongibello, was recognized as overlying it (fig. 3). Between 1836 and 1843, Waltershausen surveyed the volcano to draw up the first geological map of Etna; this is also the first geological map of a large active volcano in

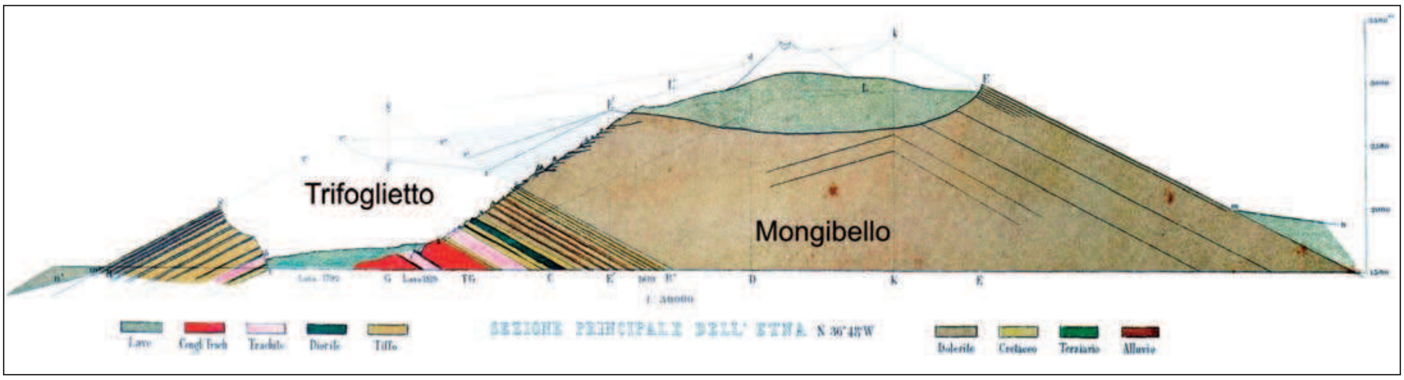

Fig. 3 - Geological cross-section of Waltershausen that evidences the polygenetic structure of Etna edifice characterized by the superimposition between Trifoglietto and Mongibello volcanoes (modified from WALTERSHAUSEN, 1880).

the world (fig. 4a). This geological map consists of thirteen sheets at 1:50,000 scale published between 1844 and 1857, and brought together with topographic maps and several paintings of Etna's geological views in the collection of tables "Atlas des Aetna" (WALTERSHAUSEN, 1844-1859). In the geological map, the author represents five main volcanic units: the oldest one, named "Basalti", groups submarine volcanics and subvolcanic bodies cropping out between the towns of Aci Trezza and Aci Castello. The upper unit, named "Formazione Centrale" comprises the products of the Trifoglietto volcano. Finally, the youngest three units include the volcanics erupted from the Mongibello volcano mapped as lava flows of unknown age, Medieval age and modern age. The geological map of Etna allowed Waltershausen to reconstruct the geological evolution of the volcano that was published posthumously in the volume Der Aetna (WALTERSHAUSEN, 1880). A few years later, in 1884, a geological map of Etna at 1:100,000 scale was published on four sheets within the set of the geological maps of Italy. The field mapping was undertaken between 1877 and 1882 by mining engineers under the scientific direction of Gemmellaro (MAZZETTI, 1884; CORTESE & MAZZETTI, 1884; TRAVAGLIA, 1885; MAZZETTI & TRAVAGLIA, 1885). In these geological maps the stratigraphic framework of the old volcanic units is simplified with respect to that proposed by Waltershuasen and the historical lava flows are grouped by century starting from 1300 AD. In the same period, SCIUTO PATTI (1872) drew up a detailed geological map of Catania and environs, at an unusual 1:21,276 scale, also presenting the first exhaustive geological evolution of this peripheral part of Etna volcano.

Nearly a century was to pass before a new and updated geological reconstruction of Etna was to be published in 1973 by Alfred Rittmann, considered one of the fathers of modern volcanology, who founded the CNR-IIV in Catania in 1969. The reconstruction of the volcano's evolution set out by RITTMANN (1973) provided the stimulus for a group of Italian and English scientists who, under the supervision of Romolo Romano, a researcher at the CNR-IIV, began a new field mapping of Etna at 1:25,000 scale in 1972. More than a century after Waltershausen's geological map, a new map at 1:50,000 scale was finally published in 1979 (fig. 4b) (ROMANO *et alli*, 1979). In this map, the volcanic products are distinguished, according to their petrographic and geochemical characteristics, into 14 units grouped into six main units named Basal subalkaline lavas, Ancient alkaline centres, Trifoglietto, Chiancone, Ancient Mongibello and Recent Mongibello that delineate a detailed stratigraphic framework of Etna's volcanics for the first time (for details see Branca *et alii*, 2011). In particular, concerning the volcanics of the past 3-5 ka (Recent Mongibello), the prehistoric lava flows were mapped in two units mainly according to their morphological state of preservation: *i*) lavas and scoria cones with degraded surface morphology and poorly defined flow boundaries (lpn); *ii*) lavas and scoria cones with well preserved surface morphology (lpd). Conversely, historical lava flows were mapped in four units: *i*) undated (lpr); *ii*) lava flows from 12th to 17th centuries; *iii*) lava flows from 18th to 19th centuries; *iiii*) lava flows of 20th century up to the 1974 eruption (the youngest lava flow reported on the map).

Since the end of the 1980s, researchers from CNR-IIV and Università di Milano started to map the volcanics cropping out along the steep walls of the Valle del Bove in detail (CALVARI *et alii*, 1994; COLTELLI *et alii*, 1994). These works have been used as a reference for the official guidelines of the Italian Geological Survey (PASQUARÈ *et alii*, 1992) for the National Geological Map Project at 1:50,000-scale (CARG: Italian acronym of the project). In particular, these geological investigations, performed in Valle del Bove were realized for the first time by means of a stratigraphic approach using lithostratigraphic and synthemic units (UBU of SALVADOR, 1987 and 1994). Later on in the 1990s and 2000s, the mapping was extended to the east, northeast, southeast and southwest flanks of Etna volcano to draw up the Foglio 625 Acireale (SERVIZIO GEOLOGICO D'ITALIA, 2009a), and then Foglio 634 Catania (SERVIZIO GEOLOGICO D'ITALIA, 2009b), Foglio 613 Taormina (SERVIZIO GEOLOGICO D'ITALIA, 2010a) and Foglio 633 Paternò (SERVIZIO GEOLOGICO D'ITALIA, 2010b) as part of the official geological map of Italy at 1:50,000 scale (CARG Project). The Italian Geological Survey maps are the last geological investigation realized before the geological map presented in this paper. Even if the new map described here draws on the previous studies, in particular using largely the stratigraphic approach of Foglio 625 Acireale (BRANCA *et alii*, 2009), it represents a new and updated geological mapping of the entire Etna volcano (fig. 4c) issued roughly 150 years after Waltershausen's pioneering work.

MAPPING METHODOLOGY

Mt Etna volcanic district is built up from the superimposition of mainly effusive and subordinate explosive volcanic products. The succession, that includes minor volcaniclastic deposits, records the constructive and destructive phases of the geological history of this large composite volcano.

The geological field survey was carried out at 1:5,000 scale on the Valle del Bove walls and at 1:10,000 scale on Mt Etna's slopes. For field mapping, we used printed topographic maps at 1:10,000 scale of the Regione Siciliana and Provincia Regionale di Catania, and color aerial photos taken in 1987 by Regione Siciliana, Assessorato del Territorio e dell'Ambiente. In addition, mapping of the historical lava flows was also achieved using the high resolution (25 cm) RGB orthoimages and 1 m spacing DEM performed by the German Aerospace Centre (DLR), Institute of Planetary Research of Berlin for INGV, Osservatorio Etneo, sezione di Catania (GWINNER *et alii,* 2006), from digital stereo data collected in July 2005 and updated for the summit area in August 2007. Furthermore, we have also done a comparison of several aerial photos of: *i*) I.G.M. in 1954, 1967, 1983 and 1989; *ii*) IIV in 1979; *iii*) Regione Sicilia in 1987; and several orthoimages of Provincia Regionale di Catania in 1999 and of DLR in 2005 and 2007; in order to enhance the lava flow fields reconstruction on the summit area and within the Valle del Bove depression.

The stratigraphic framework proposed for the Mt Etna volcanic district (fig. 5) results from the combination of three different categories of stratigraphic units: lithostratigraphic, synthemic and lithosomatic. Each type of stratigraphic unit is based on the proper definition following the guidelines of the International Stratigraphic Guide (ISG) (SALVADOR, 1994). The aim of this combination of stratigraphic units is to unveil the complex spatial and temporal relationships among the mapped volcanic products.

Lithostratigraphy represents the main stratigraphic criterion used to identify the volcanic units during geological mapping. Furthermore, we adopted the Unconformity Bounded Units (UBU) through the recognition of unconformity surfaces within the volcanic succession. This enables grouping several lithostratigraphic units in different synthems. Moreover, we use the lithosomatic units, named volcanoes, to better represent the spatial localization of the eruptive centres recognized on the basis of their morphostructural features. In the following sections we present and discuss each type of stratigraphic unit used in the geological map of Etna volcano.

LITHOSTRATIGRAPHIC UNITS

We applied the lithostratigraphic units following the procedures and standards suggested by SALVADOR (1994), also concerning the naming of formal and informal units. Etna volcanic succession was organized in lithostratigraphic units of different ranks, from formations to members, and in some cases also flows (see Geological map). During the fieldwork, numerous detailed stratigraphic sections were logged to define the position in the succession and the relationships among lithostratigraphic units.

The identification of lithostratigraphic units is fundamental during the field mapping since the lithologic properties and stratigraphic relationships of rock bodies are the only ones immediately recognizable in the field, whereas the laboratory data (petrographic, geochemical, radiometric analyses, etc.) allow improving the lithostratigraphic unit information. Following the indication of

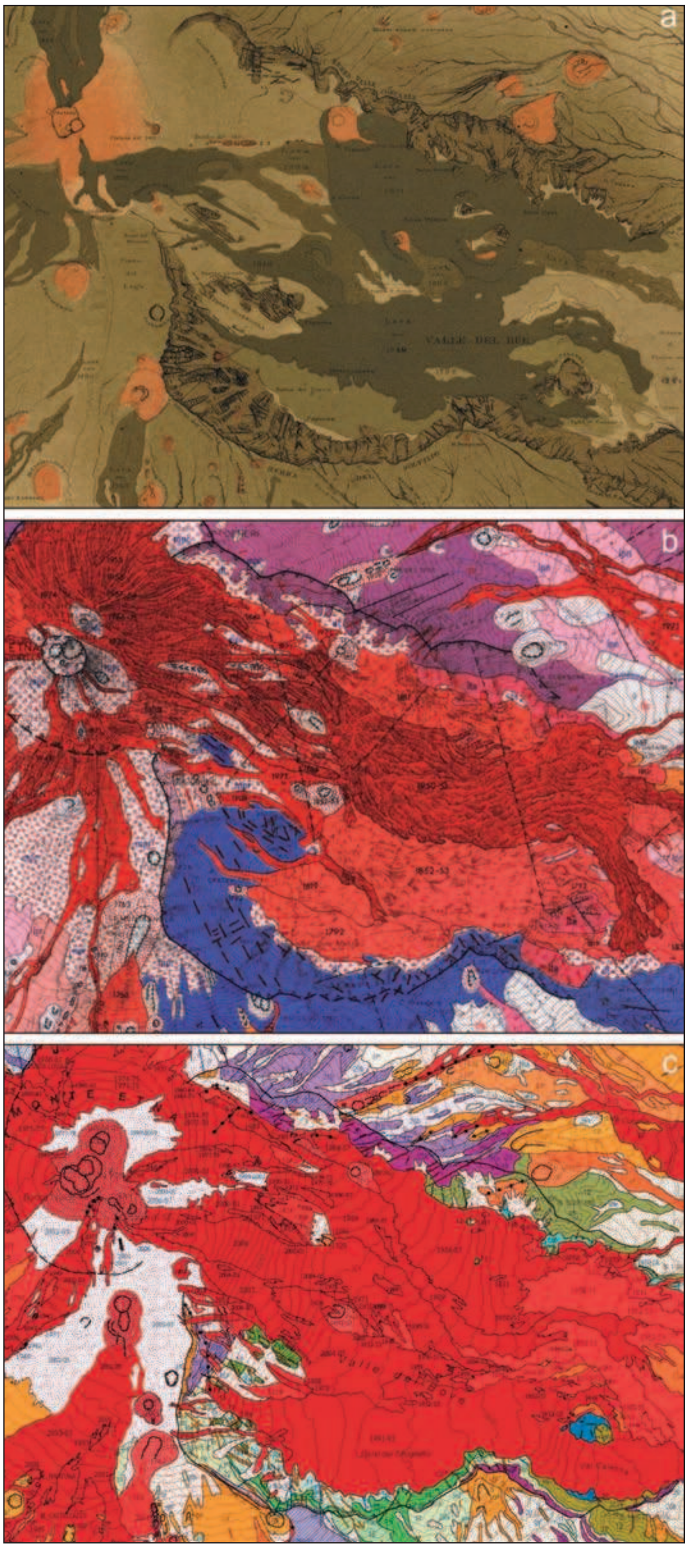

Fig. 4 - The summit region of Mt Etna and the Valle del Bove as reported in the geological maps at 1:50,000 scale of: (*a*) WALTERSHAUSEN (1844-59); (*b*) ROMANO *et alii* (1979) and (*c*) present map.

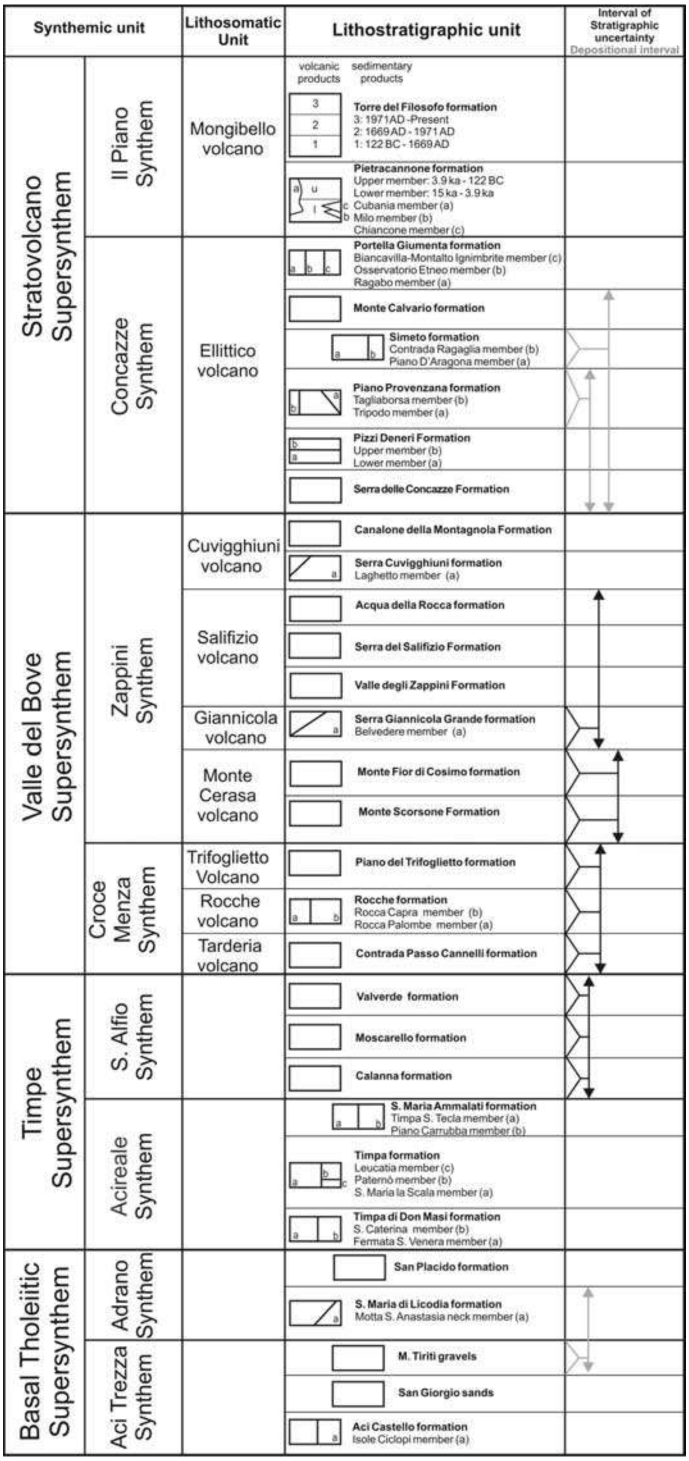

Fig. 5 - Scheme of the stratigraphic relationships reconstructed for Mt Etna volcanic district.

ISG (Salvador, 1994), we tried to reduce informal units as much as possible; where we could recognize the complete succession including the lower and upper boundaries, we defined a formal unit (cf. legend of the Geological Map and Servizio Geologico d'Italia, 2009a).

The temporal extension of the lithostratigraphic units is graphically represented in the stratigraphic relationship scheme (fig. 5) by a column on the right side. This graphic representation is adopted to show two different causes of the vertical extension of the lithostratigraphic units due to temporal or stratigraphic uncertainties. The first cause, named "depositional interval" (gray bars), is related to a long period of deposition of the unit, typically referred to heteropic and distal reworked deposits. The second cause, named "interval of stratigraphic uncertainty" (black bars), is related to temporal and/or stratigraphic uncertainties of the unit due to the lack of any geometric relationship with the other units.

In addition to the formation rank, we also used members and flows: particularly, we defined member rank when we identified a marker lithohorizon (e.g. FS lithohorizon splits the Pietracannone formation in a upper and lower member) or important lithological differences were recognized within a formation (e.g. to distinguish a subvolcanic lava body from a succession of lava flows belonging to the same formation, or to distinguish different pyroclastic or epiclastic succession from the rest of the formation, or, finally, to identify a rock body with a precise stratigraphic position within the formation).

For the youngest formations whose volcanic products are well exposed along Etna's slopes (Torre del Filosofo, Pietracannone, Monte Calvario and Piano Provenzana formations) we mapped them by using the flow rank. In this stratigraphic context, flow or stratum rank comprises all the volcanic products generated during a single eruptive event related to flank or summit eruptions. On the map the volcanic products related to each eruptive event are graphically distinguished in: *i*) proximal pyroclastic fall deposits (scoria cone and/or spatter rampart); *ii*) distal pyroclastic fall deposits; *iii*) lava flows. The volcanics younger than 122 BC are lava flows and pyroclastic deposits that, due to their limited lithological variability and their nearly continuous temporal succession, were grouped into a single lithostratigraphic unit named Torre del Filosofo formation. For the Torre del Filosofo case, an alternative cartographic solution was preferred to the general rule of assigning a unique color to a single formational unit (fig. 6a). In the present version of the map, the lava flows of Torre del Filosofo formation are grouped together into 3 time intervals with 3 different colors (differences between the possible solutions are well represented in fig. 6). Our solution allowed to maintain an acceptable representation of the time-space distribution of the recent eruptive activity (112 different lava flows recognized and mapped), a fundamental goal of the Etna geological map since Waltershausen (1844-59). Although the use of time intervals does not comply with standard stratigraphic procedures, they should nevertheless be considered in this framework and in similar setting as a practical tool for displaying a key geological and volcanological dataset. In fact, the time interval subdivision allows representing the lava flows according to the standard lithostratigraphic method, outlining the temporal and spatial evolution of the recent volcanic activity by means of the different scaled colors. The time intervals have been defined through the pinpointing of the main eruptive events that mark significant periods of the eruptive activity evolution of the past 2 ka according to the present knowledge of volcano history. The products related to these significant eruptions couldn't represent the boundaries of members within the same formation, because of the lithological similarity among the lava

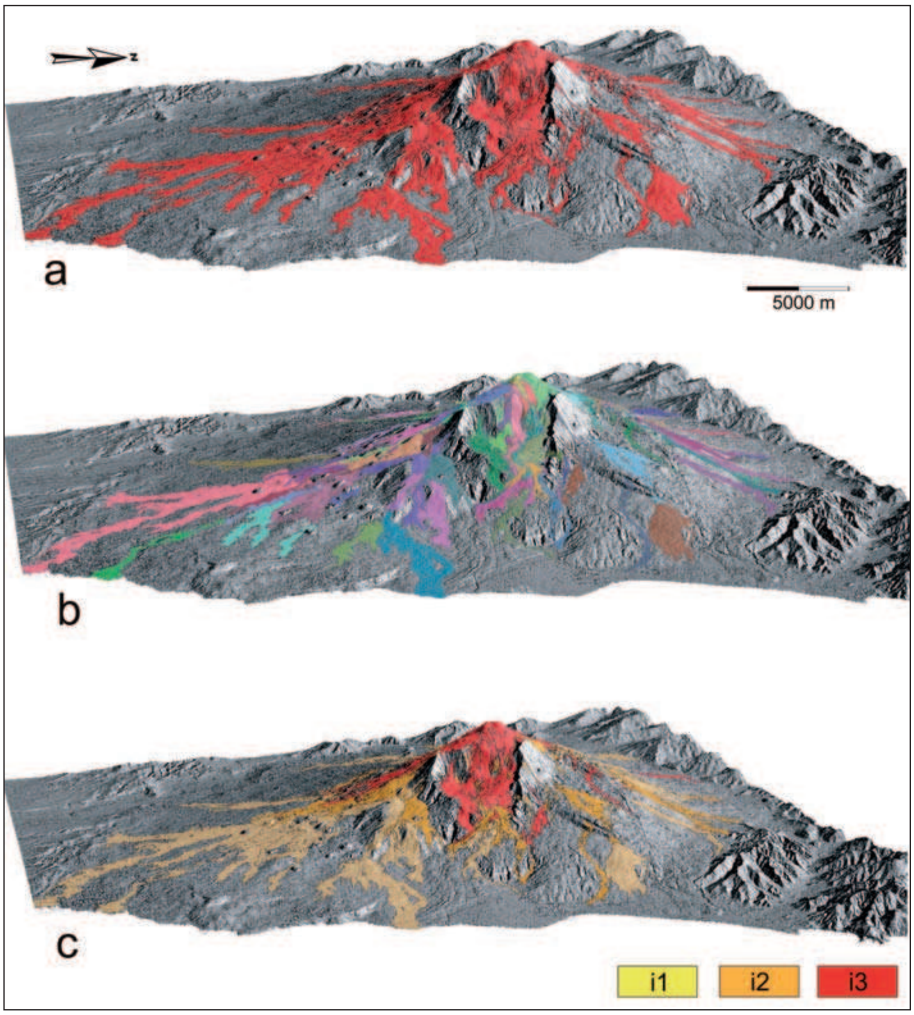

Fig. 6 - 3D views of Etna from showing the different representations of the flow ranks belonging to the Torre del Filosofo formation: *a*) volcanics of Torre del Filosofo formation are displayed with a unique colour and each flow is represented only by its boundary; *b*) every flow is displayed with a different colour producing an illegible map because of the 112 different colour/flows reported; *c*) groups of flows are displayed with different colour according to the proposed subdivision into three time intervals and each flow is represented by its boundary.

flows of the different intervals and the lack of marker beds of reliable lithostratigraphic importance. Therefore, they only represent significant temporal steps to divide a continuous sequence of flow-rank lithostratigraphic units.

Finally, tephrostratigraphy investigations performed by COLTELLI *et alii* (2000) and DEL CARLO *et alii* (2004) have represented an important tool with regard to the stratigraphic reconstruction of the lava flows of the past 15 ka (fig. 7) through the identification of several widespread pyroclastic fall deposits. In particular, Holocene marker beds (fig. 8): M1, TV, FS, FL, FG, FF tephra layers of DEL CARLO *et alii* (2004) (for detail description see tab. 1) were used for stratigraphic correlation and relative dating of lava flows, otherwise difficult because of their limited areal distribution.

UNCONFORMITY BOUNDED UNITS

The UBU were proposed by CHANG (1975) and their use was recommended by SALVADOR (1987 and 1994). PASQUARÈ *et alii* (1992) strongly sustained their usefulness as a tool for a objective stratigraphic reconstruction of volcanic successions and their suggestion has been adopted by several authors (CALVARI *et alii*, 1994; COLTELLI *et alii*, 1994; LANZAFAME *et alii*, 1994; MANETTI *et alii*, 1995a and b; ROSSI *et alii*, 1996; BELLUCCI *et alii*, 1999; CALANCHI *et alii*, 1999; BRANCA & CATALANO, 2000; DE RITA & GIORDANO, 2010; TRANNE *et alii*, 2002a and b; LUCCHI *et alii*, 2003 and 2010; DE ASTIS *et alii*, 2006; GIANNANDREA *et alii*, 2006; FUNICIELLO & GIORDANO, 2008; SERVIZIO GEOLOGICO D'ITALIA, 2009a, b, c, d; BELLOTTI *et alii*, 2010).

Within the volcanic successions there are several unconformities, different in rank, due to different causes: periods of quiescence, erosional phases, shifting of the volcano feeding system, abrupt changes of eruptive style, volcano-tectonic events such as caldera or sector/flank collapses. The identification of unconformity surfaces within the volcanic succession allows grouping some lithostratigraphic units in synthems, each representing a well-defined step in the geological evolution of the volcano. For this reason, it is advisable to identify the most important unconformities according to geographic extension, duration of the hiatus and geological significance. Therefore, it is necessary to rule out all geometrical unconformities formed by the progressive and continuous emplacement of the volcanics that lack any significant temporal hiatus. In particular, we consider the main unconformities as supersynthemic boundaries related to the shifting of the volcanic feeding system linked, sometimes, with a depositional hiatus or with an abrupt change of eruptive style (e.g. from fissure type to a central one). In addition, we can refer the supersynthems to the main phases of the volcanism that are in close relationship with the variation of

TABLE 1

Description of lithostratigraphic units.
The numbers of the lithostratigraphic units correspond with those of the geological map
(VdB=Valle del Bove; pl=plagioclase; px=pyroxene; ol=olivine; amph=amphibole).

ACI CASTELLO FORMATION (1)
The formation, defined in the SERVIZIO GEOLOGICO D'ITALIA (2009b), consists of subvolcanic bodies mapped as a member in rank, called Isole dei Ciclopi, and submarine deposits, which are intercalated in the upper part of the Argille grigio-azzure formation. Submarine deposits are preserved on the coastal cliff of the Aci Castello Castle Rock and inland between the villages of Ficarazzi and Aci Trezza. At Aci Castello Castle Rock volcanics consist of pillow lavas and occasionally megapillows with columnar jointing and sub-vertical lens of hyaloclastic pillow-breccia. The pillow lavas are vesiculated with interstices filled by silty sediment of the Argille grigio-azzure formation. A N-S oriented dyke crosses submarine deposits. Inland, the formation consists of pillow lavas and pillow breccia deposits made of sharp-edged pillow fragments dispersed in a yellow hyaloclastic matrix. The pillow lavas show a subaphyric texture with rare phenocrysts of ol. Zeolite minerals fill the vesicles of the pillow lavas and an intense palagonitization affects the glassy matrix. Volcanics are tholeiitic and transitional in composition (SERVIZIO GEOLOGICO D'ITALIA (2009b). The maximum thickness of the formation is about 130 m. Radiometric ages (DE BENI *et alii*, 2011): 542.2±85.8 ka, 496.1±86.8 ka.
Isole Ciclopi member
The member, defined in the SERVIZIO GEOLOGICO D'ITALIA (2009b), is formed by shallow subvolcanic bodies forming the Isole Ciclopi located offshore Aci Trezza harbour and by small bodies located inland between Aci Trezza and Ficarazzi villages. These subvolcanic bodies have bulb-shapes that are generally characterized by columnar jointing spreads from the inner part of the body. Lava shows an aphanitic texture.

S. MARIA DI LICODIA FORMATION (2)
The formation, defined in the SERVIZIO GEOLOGICO D'ITALIA (2010b), is made mainly of lava flows, proximal pyroclastic deposits and a subvolcanic body, which is mapped as a member in rank, called Motta S. Anastasia. The lava flows are porphyritic with abundant ol phenocrysts and rare glomerophyritic clusters of pl. Lava flows are characterised by a tabular morphology showing an alteration patina on the exposed surface. Close to the town of Paternò, the joints of lava flows are filled with marine incrustations (*Polycaeta*). Occasionally, the base of the lava flows shows a submarine facies made up of pillow lava fragments within a hyaloclastic matrix that is well exposed at Valcorrente. The relict of an eruptive fissure, about N-S elongated, crops out at Valcorrente and forms a pyroclastic succession consisting of an alternation of densely black scoriaceous lapilli and bomb layers and stratified ash layers. The juvenile clasts are characterised by a yellowish alteration surface and the bombs show a well-developed bread-crust surface. The pyroclastic deposits also contain sedimentary lithics. The formation crops out along the left bank of the Simeto river between Adrano and Paternò towns. Lavas are tholeiitic in composition (CORSARO & POMPILIO, 2004). The base of the formation rests on the sedimentary basement; at the top there is a strong angular unconformity associated with an erosional surface with the Timpa, Piano Provenzana and Pietracannone formations. The maximum thickness of the formation is about 30 m. Radiometric age (DE BENI *et alii*, 2011): 332.4±43.4 ka.
Motta S. Anastasia member.
The member, defined in the SERVIZIO GEOLOGICO D'ITALIA (2010b), consists of and isolated neck with a porphyritic texture containing abundant ol and rare pl phenocrysts. This subvolcanic body shows well-developed columnar jointing and is about 400 m N-S elongated, 200 m wide and about 60 m high. A pyroclastic deposit is locally preserved along the wall of the neck. Scoriaceous lapilli and bombs, with a bread-crust surface, form the deposit that occasionally includes sedimentary lithic fragments made up of heterolithologic alluvial pebbles. A small NNW trending dike cuts the northern side of the neck. Radiometric age (DE BENI *et alii*, 2011): 320.0±48.4 ka.

SAN PLACIDO FORMATION (Qm)
The formation consists of a thin alluvial deposit formed by heterolithologic conglomerate with a brown, weakly lithified sandy matrix. The conglomerate is made up of sedimentary clasts, represented mainly by quarzarenitic cobbles and rare metamorphic pebbles, and rare monolithologic volcanic clasts consisting of vesiculated lava cobbles with a brown-reddish alteration patina belonging to S. Maria di Licodia formation. Thin lens of sand and white silt are locally interbedded in the conglomerate deposit. This formation is mainly covered by soil and crops out exclusively on lava flows of S. Maria di Licodia formation at Adrano and S. Maria di Licodia towns and at Valcorrente along the left bank of the Simeto river. The maximum thickness exposed is 3-4 m.

TIMPA DI DON MASI FORMATION (3)
The formation, defined in the SERVIZIO GEOLOGICO D'ITALIA (2009a), consists of lava flows, a subvolcanic body and proximal pyroclastic deposits cropping out at the base of the Timpa di Don Masi and Ripa della Naca fault scarps and close to Nunziata and S. Venera villages. The unit is divided into two members that do not show direct stratigraphic relationships. Lavas are basaltic in composition with transitional affinity (SERVIZIO GEOLOGICO D'ITALIA, 2009a). The formation rests on the sedimentary basement and it is marked on the top by an erosive and angular unconformity with the Timpa and S. Maria Ammalati formations. The maximum thickness is about 30 m.
Fermata S. Venera member
The member, defined in the SERVIZIO GEOLOGICO D'ITALIA (2009b), is formed by massive lava flows highly porphyritic with xenocrysts of ol and px often in clusters. These lavas show a mm-thick alteration patina and frequently are disarticulated in large blocks. On Ripa della Naca fault scarp the lava flows are mainly covered by talus. The remains of a scoria cone crop out at C.da Ragaglia; cone deposits consist of dense ash-coated scoriaceous lapilli and pl-rich bombs, with sedimentary xenoliths, that show a well-developed bread-crust surface. Radiometric age (DE BENI *et alii*, 2011): 180.2±19.2 ka.
S. Caterina member
The member, defined in the SERVIZIO GEOLOGICO D'ITALIA (2009b), is formed by a thin succession of massive highly-porphyritic lava flows with ol and px phenocrysts, often in clusters, containing cm-sized mafic and ultamafic crystals and nodules that crop out at the base of the coastal cliff below Santa Caterina village. The lava flows, 8-15° dipping SW, are separated by thin reddish lithified epiclastic deposits. At the foot of the Timpa di Don Masi, a plug made up of columnar lavas crops out, grading laterally to a strombolian deposit of black and reddish flattened spatter with interlayered thin lava flows gently dipping SW. This volcanic body is 7-8 m thick and extends over the N-S direction for about 50 m.

TIMPA FORMATION (4)
The formation, defined in the SERVIZIO GEOLOGICO D'ITALIA (2009a), consists of a thick lava-flow succession cropping out from S to N along the fault scarps of Timpa di Acireale, Timpa di Moscarello (at base only), Ripa della Naca and Ripa di Piscio. Isolated and thin lava flows and proximal pyroclastic deposits crop out between Adrano and Paternò towns along the lower SW flank and between Catania and Aci Trezza towns along the lower SE flank. The formation is divided into three members each consisting of a volcanic body with homogeneous lithological and geometrical features. Lava composition ranges from basalt to mugearite (SERVIZIO GEOLOGICO D'ITALIA, 2009a). The formation rests partially on the sedimentary basement, covers with an angular unconformity the S. Maria di Licodia formation and is concordant with Timpa di Don Masi formation. The top of the formation is cut by an angular unconformity with the Moscarello, Piano Provenzana, Pietracannone and Torre del Filosofo formations. The maximum thickness is about 100 m.

Continued: Table 1

S. Maria La Scala member
The member, defined in the SERVIZIO GEOLOGICO D'ITALIA (2009a), consists of a lava flow succession that thickens from S to N (from 10 m to 100 m) made of the superimposition of several massive lava flows, 10-30° dipping SSW and SW, separated by brown-yellowish epiclastic deposits, a few meters thick. The lavas are porphyritic, with variable amounts of phenocrysts. At the base of the succession lava flows are characterized by cm-sized px, subordinate ol and abundant mm-sized pl. Toward the top the size of px decrease and the amount of pl increase. At Grotta delle Palombe, a plug made of columnar lavas grading upward to a brownish lava breccia deposit. This volcanic body is about 10 m thick on the sea level extending in N-S direction. At the base of Moscarello Timpa fault scarp several superimposed massive lava flows, 20-30° dipping NNW, crop out. These lavas are highly porphyritic with px and ol, 5-9 mm in size, and abundant mm-sized pl. A thick lava flow succession, gently dipping NW, crops out discontinuously on the NE flank along Ripe scarp; it consists of porphyritic lavas with mm-sized phenocrysts of px, pl and ol. The lava flows are generally disarticulated in large blocks. Radiometric ages (DE BENI *et alii*, 2011): 154.9±17.0, 147.7±18.0, 145.8±14.0 ka, 132.6±4.8 ka, 129.9±4.8 ka.
Paternò member
The member, defined in the SERVIZIO GEOLOGICO D'ITALIA (2010b), is formed by a limited and isolated outcrop of massive lava flows, 5-10 m thick, that are deeply weathered and eroded. These lavas are porphyritic with abundant phenocrysts of px and ol, sometimes in cm-sized clusters, and mm-sized pl. Lava exposed surfaces show a mm-thick alteration patina and sometimes alveolar structures. Locally, the massive portion of the lava flows has well-developed columnar jointing. A 500 m-wide and 100 m-high scoria cone deposit crops out over 800 m in N-S direction at Paternò town. This partially welded proximal deposit is made of scoriaceous lapilli, bombs and lithic fragments mainly of alluvial pebbles. Small lava flows originated from the Paternò scoria cone are exposed only along its slopes; they are weathered and highly-porphyritic lavas with abundant phenocrysts of ol and px often in cm-sized clusters. Radiometric age (DE BENI *et alii*, 2011): 134.2±6.6 ka.
Leucatia member
The member, defined in the SERVIZIO GEOLOGICO D'ITALIA (2009b), consists of a volcanoclastic succession cropping out exclusively at the base of a morphological scarp on the northern outskirts of Catania at Barriera del Bosco-Leucatia. The basal portion of the succession is given by a conglomerate composed of sedimentary and lava pebble grading to sand, with marine fauna (KIEFFER, 1971), and then to an alternation of thick layers of clay and silt, containing terrestrial gastropods, and thin layers of volcanic sand with a cross-stratification. The upper-middle portion of the succession is given by a thick layer of hardened volcanic sand, containing fingerprints of canes and occasional lava blocks, topped by an alternation of volcanic sand layers with cross-stratification and massive and lithified ash layers containing lavas blocks and rare sedimentary clasts.

S. MARIA AMMALATI FORMATION (5)
The formation, defined in the SERVIZIO GEOLOGICO D'ITALIA (2009a), consists of volcanoclastic deposits of both debris and alluvial origin cropping out on three distinct geographical areas: along the S. Tecla Timpa near the Ionian coast, along the left bank of Simeto river on the south periphery of the volcano, and on the lower north-eastern flank. The unit was divided into two members that do not show direct stratigraphic relations. They have been grouped together in the same formation because of their same stratigraphic position, although in different geographic areas, and represent an important phase of erosional processes in the periphery of Etna. The maximum thickness is about 80 m.
Timpa S. Tecla member
The member, defined in the SERVIZIO GEOLOGICO D'ITALIA (2009a), consists of coarse clastic deposits made of heterolythologic lava pebbles and blocks, and occasionally sedimentary pebbles that are embedded in a yellow-brown sandy-clayey matrix. The deposit is generally massive and clasts are chaotically distributed. Thin discontinuous layers of fluvial reworking are interbedded. The thickness of the member and the amount of lava blocks with respect to the pebbles increase northward. The base of the member is formed by fossiliferous sand-clay, 2-4 m thick, at Acque Grandi. This deposit is poorly lithified and weakly coarse-bedded, 20° dipping SW. The macrofauna is given mainly by *Spisula subtruncata* (DA COSTA) and *Turritella communis* (RISSO), conversely the scarce microfauna is made of benthonic foraminifera (FERRARA, 1976).
Piano Carrubba member
Alluvial deposits terraced at varying elevations. Along the left bank of the Simeto river they consist of heterolithologic conglomerate with irregularly sized clasts, formed mainly by sedimentary pebbles and cobbles, and minor lava pebbles and cobbles largely supported by a clayey-sandy yellow-brown matrix. Occasionally metamorphic clasts are present. The prevalent litho-type of the sedimentary clasts is quartzarenite. Between Paternò and Motta S. Anastasia towns the deposit is mainly made of fine to coarse sands, sometimes hardened, and coarse gravel or conglomerates poorly lithified formed by polygenic sedimentary and lava clasts with irregular size. On the lower NE flank along the right bank of Vallone S. Venera and at Serra S. Biagio hill, the deposit is composed of a heterolithologic conglomerate with strongly irregularly sized clasts of volcanic and sedimentary origins supported by a sandy-clayey matrix, which becomes mud-supported where the clasts are metric in size.

CALANNA FORMATION (6)
The formation, defined in the SERVIZIO GEOLOGICO D'ITALIA (2009a), is made of cataclastic lavas in a highly hydrothermally altered yellow clay matrix associated with a complex of dikes deeply weathered. Lava blocks and most of the dikes are affected by a strong hydrothermal alteration and cataclastic deformation. The formation crops out along Val Calanna and Mt Calanna. Lava composition ranges from basalt to mugearite (SERVIZIO GEOLOGICO D'ITALIA, 2009a). The lavas are usually strongly altered, but in a small portion it is possible to recognise porphyritic texture with large phenocrysts of px and pl. The base of the formation is not visible, at the top there is a strong angular unconformity associated with an erosional surface with the Monte Fior di Cosimo formation (visible along the southern wall of Calanna valley). The maximum thickness is over 200 m. Radiometric age (DE BENI *et alii*, 2011): 128.7±7.6 ka.

MOSCARELLO FORMATION (7)
The formation, defined in the SERVIZIO GEOLOGICO D'ITALIA (2009a), consists of a thick lava succession composed of several highly eroded superimposed massive lava flows. Lavas present a high variability of lithology showing texture ranging from sub-aphyric to porphyritic with variable amounts of pl, px and ol phenocrysts. At Cava Grande, near the succession top, crops out the remnant of a proximal pyroclastic deposit, WNW-ESE elongated, made of reddish scoriaceous bombs and spatters characterized by sub-cm-sized px and mm-sized pl phenocrysts, and loose crystals of px. On the whole, the lava succession dips from 5° up to 10° toward ESE. The formation crops out along the Moscarello Timpa fault scarp and between Macchia and Giarre towns where a narrow outcrop is also exposed, and close to Nunziata village. Lava composition is mugearite (SERVIZIO GEOLOGICO D'ITALIA, 2009a). The base of the formation rests with an angular unconformity on Timpa formation; at the top there is an angular unconformity and an erosional surface with the Serracozzo, Portella Giumenta, Pietracannone and Torre del Filosofo formations. The maximum thickness is about 150 m. Radiometric age (DE BENI *et alii*, 2011): 126.4±4.8 ka.

VALVERDE FORMATION (8)
The formation includes a lava succession and a proximal pyroclastic deposit. The succession consists of superimposed massive lava flows, well exposed at the morphological scarp of Mt D'Oro, interbedded with thin epiclastic deposits. The lavas are porphyritic with phenocrysts in variable amount and size. Two main lithotypes are present: lavas with abundant sub-cm-sized mafic phenocrysts and subordinate mm-sized pl; and lavas with prevalent mm-sized pl and lesser mm-sized mafic phenocrysts. The lava flows generally show a mm-thick alteration patina and are mainly covered by soil and recent alluvial deposits. At Acicatena fault scarp a proximal pyroclastic deposit crops out. It is made of

Continued: Table 1

dense lapilli and bread-crust bombs with clay xenolithics inside, alternating with ash layers containing lava lithic and, occasionally, clay fragments. The formation crops out between San Gregorio, Valverde and Aci S. Filippo towns down to the coast and at the base of Acicatena fault scarp. Lava composition ranges from hawaiite to mugearite (SERVIZIO GEOLOGICO D'ITALIA, 2009b). The formation rests on the sedimentary basement and, with an angular unconformity and an erosional surface, on Aci Castello and Timpa formations. The top presents an angular unconformity and an erosional surface with the Piano Provenzana, Portella Giumenta and Pietracannone formations. The maximum thickness is about 100 m. Radiometric ages (DE BENI *et alii*, 2011): 121.2±15.0 ka, 111.9±9.2.

CONTRADA PASSO CANNELLI FORMATION (9)
The formation, defined in the SERVIZIO GEOLOGICO D'ITALIA (2009a), consists of a lava succession made of several superimposed massive lava flows with porphyritic texture of pl, subordinate mm-sized px and ol phenocrysts. These lavas are characterised by a mm-thick alteration patina and sometimes show alveolar structures on the exposed surface. The top of the lava succession is highly eroded and locally is covered by a paleo-debris flow made of lava blocks immersed in a yellow-brown sandy matrix. The formation crops out in limited areas at Mt Pò, C.da Passo Cannelli and Mt Cicirello. Lava composition ranges from hawaiite to benmoreite (SERVIZIO GEOLOGICO D'ITALIA, 2009a). The base of the formation is not exposed and the top is marked by an angular unconformity and an erosional surface with the Pietracannone formation. The maximum thickness is about 30 m. Radiometric age (DE BENI *et alii*, 2011): 105.8±9.0 ka.

ROCCHE FORMATION (10)
The formation, defined in the SERVIZIO GEOLOGICO D'ITALIA (2009a), consists of a complex succession formed by thin lava flows, autoclastic lavas and volcaniclastic deposits. The unit was subdivided into two members that do not show direct stratigraphic relationships. The formation crops out along the base of the VdB northern wall from Rocca Palombe to Mt Cagliato. Lava composition ranges from hawaiite to mugearite (SERVIZIO GEOLOGICO D'ITALIA, 2009a). The base of the formation is buried, while the top is marked by an erosive and angular unconformity with the products of the Mt Scorsone formation (Monte Cerasa volcano). The maximum outcropping thickness is 120 m.
Rocca Capra member
The member, defined in the SERVIZIO GEOLOGICO D'ITALIA (2009a), crops out at Rocca Capra locality between 1320 m and 1440 m elevation and it is formed, at the base, by thin lava flows and autoclastic lavas, with pl and px phenocrysts, showing a slight angular unconformity between them, that grades upward to an alternation of autoclastic lavas with interlayered yellowish epiclastic and grey pyroclastic flow deposits. The top is made of lava flows with pl, px and ol phenocrysts. On the whole, the sequence dipping 20-30° towards NE and it is crossed by a dense network of dikes. Radiometric age (DE BENI *et alii*, 2011): 101.9±7.6 ka.
Rocca Palombe member
The member, defined in the SERVIZIO GEOLOGICO D'ITALIA (2009a), is exposed at about 600 m W of Rocca Capra. The base of the member is formed by lava flows from aphyric to weakly porphyritic with px, ol and subordinate pl phenocrysts grading upward to a pyroclastic flow deposit, 30 m thick, consisting of reddish ash layers with scoriaceous lava blocks with irregular size. The top is made of lava flows with mm-sized phenocrysts of pl, px, ol and amph. The sequence dipping 10-30° from NNE to NNO.

PIANO DEL TRIFOGLIETTO FORMATION (11)
The formation, defined in the SERVIZIO GEOLOGICO D'ITALIA (2009a), comprises a complex succession of autoclastic breccia and epiclastic deposits interbedded with a few pyroclastic flow deposits and discontinuous lava flows. The lower part of the succession shows mainly monogenetic massive breccia layers associated with discontinuous and thin lava flows; in the middle part massive and stratified epiclastic deposits crop out interbedded with rare lava flows and pyroclastic deposits; in the upper succession lava flows prevail, associated with some episclastic and pyroclastic layers. At the top a pumice fall and flow deposits (Cava Grande lithohorizon, not mappable) crops out discontinuously at Rocca Capra and on the lower eastern flank near Giarre (fig. 7). This formation crops out continuously from Serra Giannicola Grande to Poggio Canfareddi along the western and southern inner walls of VdB. Lava composition is benmoreite (SERVIZIO GEOLOGICO D'ITALIA, 2009a). Lavas show porphyritic texture including pl, px and ol phenocrysts. The base of the formation is not exposed; conversely at the top the contact with the Valle degli Zappini Formation is marked by an angular unconformity associated with an erosional surface and epiclastic deposits. The maximum thickness is over 300 m. Radiometric ages (DE BENI *et alii*, 2011): 107.2±11.4 ka, 99.1±10.6 ka.

MONTE SCORSONE FORMATION (12)
The formation, defined in the SERVIZIO GEOLOGICO D'ITALIA (2009a), is made of a complex succession of pyroclastic flow and fall deposits, epiclastic deposits and lava flows. The basal portion of the formation is made up of yellow-brown pyroclastic flow layers interbedded with well-graded lapilli fall deposit and a massive lava flow grading upward to thin lava flows with interlayered fine-grain pyroclastic and epiclastic deposits. The texture of these lavas ranges from subaphyric to porphyritic with variable amount and size of pl, px, ol and occasionally amph phenocrysts. In the upper part of the formation the lava flows are prevalent with respect to the volcaniclastic layers that generally are less than 1 m thick. Lavas textures range from subaphyric to porphyritic with phenocrystals of pl, px and ol in variable amount and size. The volcaniclastic deposits consist of lava breccia with yellowish coarse matrix, pyroclastic fall and flow deposits locally reworked, and minor debris flows. This succession dips 20-35° towards NE and NNE. A succession of massive lava flows crops out at Cava Grande, about 10° dipping ESE. The formation crops out from the base of Serracozzo to Mt Fontane and at Cava Grande between Fornazzo and S. Alfio villages. Lava composition is most commonly mugearite (SERVIZIO GEOLOGICO D'ITALIA, 2009a). At the base of the formation there is an angular unconformity and an erosional surface with the Rocche and Moscarello formations; at the top an angular unconformity with Serra delle Concazze, Pietracannone and Torre del Filosofo formations occurs. The maximum thickness is about 250 m. Radiometric ages (DE BENI *et alii*, 2011): 101.8±14.6 ka, 100.4±11.6 ka, 99.9±8.6 ka.

MONTE FIOR DI COSIMO FORMATION (13)
The formation is made of lava flows and scoria deposits interbedded with epiclastic deposits, 20 m thick. A dike feeds the lava flow succession topping the Mt Calanna. This formation crops out in Val Calanna and Vallone S. Giacomo and at the top of Mt Calanna. Lava flows are 1 to 5 m thick, hawaiitic in composition (CORSARO & POMPILIO, 2004); they show porphyritic texture of pl, px and ol phenocrysts in variable in quantity and size. At the base the contact with the Calanna formation is marked by a strong angular unconformity associated with an erosional surface and epiclastic deposits, at the top a sharp lithological change with Acqua della Rocca and Serra delle Concazze formations occurs; the contact with Serra delle Concazze is associated with an angular unconformity. The maximum thickness is 200 m. Radiometric age (DE BENI *et alii*, 2011): 93.0±6.0 ka.

SERRA GIANNICOLA GRANDE FORMATION (14)
The formation, defined in the SERVIZIO GEOLOGICO D'ITALIA (2009a), is formed by a large neck, associated with other minor subvolcanic bodies (Belvedere member), feeding the overlying lava flow succession that is covered by light brown pyroclastic deposits and autoclastic breccias. Its exposition is limited, cropping out only in Serra Giannicola Grande and surroundings. Lava composition ranges from hawaiite to mugearite (SERVIZIO GEOLOGICO D'ITALIA, 2009a); rocks show porphyritic texture with pl, px and ol phenocrysts. The base of the formation is not exposed; at the top there is a strong angular unconformity with the Canalone della Montagnola Formation. The lava flow succession thickness is 220 m. Radiometric age (DE BENI *et alii*, 2011): 85.3±7.0 ka.
Belvedere member
The member, defined in the SERVIZIO GEOLOGICO D'ITALIA (2009a), consists of subvolcanic bodies made of pinkish massive lava with columnar jointing. Lava composition is mugearite (SERVIZIO GEOLOGICO D'ITALIA, 2009a) with a highly porphyritic texture characterized by oriented phenocrysts of pl, px, amph and rare ol. The maximum thickness is over 300 m.

Continued: Table 1

Valle degli Zappini Formation (15)
The formation, defined in Calvari *et alii* (1994) and the Servizio Geologico d'Italia (2009a), is made of thin and extensive dark lava flows interbedded with epiclastic deposits, tens of meters thick. Some small subvolcanic bodies are intruded into the Piano del Trifoglietto formation. The formation crops out from Serra Pirciata to Croce Menza along the southern wall of VdB. Lava composition ranges from mugearite to benmoreite (Servizio Geologico d'Italia, 2009a), its porphyritic texture comprises phenocrysts of pl, px and ol. At the base the contact with the Piano del Trifoglietto formation is identified by an angular unconformity associated with an erosional surface and epiclastic deposits; at the top a sharp lithological change with the Serra del Salifizio Formation occurs. The average thickness is 150 m.

Serra del Salifizio Formation (16)
The formation, defined in Calvari *et alii* (1994) and the Servizio Geologico d'Italia (2009a), is made of leucocratic thick lava flows, occasionally with columnar jointing, interbedded with thin epiclastic deposits. Some small subvolcanic bodies are intruded into the Piano del Trifoglietto and Valle degli Zappini formations. The formation crops out from Serra Pirciata to Serra del Salifizio along the southern wall of VdB. Lava composition ranges from mugearite to benmoreite (Servizio Geologico d'Italia, 2009a), with porphyritic texture of pl, px and amph phenocrysts. At the base there is a sharp lithological change with the Valle degli Zappini Formation, at the top an angular unconformity associated with a lithological change with Canalone della Montagnola Formation and Tripodo member (Piano Provenzana formation). The average thickness is 150 m. Radiometric age (De Beni *et alii*, 2011): 85.6±6.8 ka.

Acqua della Rocca formation (17)
The formation, defined in the Servizio Geologico d'Italia (2009a), is made of lava flows interbedded with thin epiclastic layers and rare proximal pyroclastic deposits. The formation crops out from Acqua della Rocca to Val Calanna along the southern wall of VdB. Lava composition is benmoreitic (Corsaro & Pompilio, 2004). Lava texture is porphyritic with phenocrysts of pl, px and rare ol. At the base there is a sharp lithological change with the Valle degli Zappini and Monte Fior di Cosimo formations, at the top its limit is highlighted by an angular unconformity associated with a lithological change with Serra delle Concazze Formation. The thickness ranges from a few meters to 100 m.

Serra Cuvigghiuni formation (18)
The formation, defined in the Servizio Geologico d'Italia (2009a), is composed of subvolcanic bodies (Laghetto member) one of those feeds a thin and rather limited lava flow succession. The formation crops out only in Serra Cuvigghiuni and Serra Vavalaci, in the western wall of VdB. Lava composition ranges from mugearite to benmoreite (Servizio Geologico d'Italia, 2009a); lava porphyritic texture comprises phenocrysts of pl, px, and amph. At the base the contact with Piano del Trifoglietto formation is an angular unconformity associated with a lithological change; at the top an angular unconformity with Canalone della Montagnola Formation occurs. The thickness ranges from 20 to 100 m.
Laghetto member
The member, defined in the Servizio Geologico d'Italia (2009a), is formed by subvolcanic bodies made of pinkish massive lava with columnar jointing from 3 to 90 m high, from 5 to 250 m wide. Lava composition ranges from mugearite to benmoreite (Servizio Geologico d'Italia, 2009a), with highly porphyritic textures comprising phenocrysts of pl, px, and amph.

Canalone della Montagnola Formation (19)
The formation, defined in Calvari *et alii* (1994) and the Servizio Geologico d'Italia (2009a), is made of thin lava flows overlapped by a thick pyroclastic and epiclastic deposits succession, variable in colour, thickness and dip, topped by another lava flow succession. The formation crops out from Serra Giannicola Grande to Serra dell'Acqua along the western wall of VdB. Lava composition is mugearitic (Servizio Geologico d'Italia, 2009a), having porphyritic texture of pl, px, ol and amph phenocrysts. At the base there is an angular unconformity associated with a lithological change with Serra del Salifizio and Giannicola Grande formations; at the top a strong angular unconformity associated with a sharp lithological change with Serra delle Concazze and Piano Provenzana formations occurs. The thickness ranges from a few meters to 300 m. Radiometric ages (De Beni *et alii*, 2011): 70.2±3.0 ka, 79.6±4.2 ka, 79.0±6.0 ka.

Serra delle Concazze Formation (20)
The formation, defined in Coltelli *et alii* (1994) and the Servizio Geologico d'Italia (2009a), consists of a complex succession with prevalent volcaniclastic deposits and lesser lava flows. Volcaniclastics are mostly made of pyroclastic flows and falls, partially reworked, coarse explosion breccia with oxidised clasts, lahars and epiclastic deposits. These different typologies of deposits sometimes show lateral relationships and, between Rocca della Valle and the 1928 eruptive vents, are channelled filling a paleo-depression. Some very thick lava flows, up to 100 m, are interbedded in this volcaniclastic succession. From the base to the top, the textures of the lava flows are: slightly porphyritic with pl and large mafic phenocrysts; from sub-aphyric to slightly porphyritic; porphyritic with large phenocrysts of ol, px and small pl; and finally porphyritic pl-rich lavas. The formation dips 15-35° towards NE and ENE. The formation crops out from Serracozzo to the base of Pizzi Deneri in Valle del Leone, along the northern, western and southern walls of VdB. Lava composition ranges from hawaiite to benmoreite (Servizio Geologico d'Italia, 2009a). At the base there is an angular unconformity with the Monte Scorsone Formation and at the top only a local angular unconformity with Pizzi Deneri Formation. The maximum thickness is about 250 m. Radiometric ages (De Beni *et alii*, 2011): 41.3±6.2 ka, 56.6±15.4 ka.

Pizzi Deneri Formation (21)
The formation, defined in Coltelli *et alii* (1994) and the Servizio Geologico d'Italia (2009a), consists of a lava flow succession interbedded with volcaniclastic deposits, subdivided into two members. Both members of the formation crop out on the north-eastern, north-western and south upper flanks of the edifice, respectively at Pizzi Deneri, Punta Lucia and along the western wall of VdB. Lava composition range from hawaiite to mugearite (Servizio Geologico d'Italia, 2009a). At the base there is only a local angular unconformity with Serra delle Concazze Formation and at the top an angular unconformity with Portella Giumenta and Pietracannone formations.
Lower member
The member, defined in Coltelli *et alii* (1994), consists of a thick succession of massive and autoclastic lava layers interbedded with breccia deposits. Lavas show porphyritic texture with phenocrysts of pl, px and ol. The thickness ranges from a few tens to about 100 m. Radiometric ages (De Beni *et alii*, 2011): 32.5±17.8 ka, 29.1±10.6 ka.
Upper member
The member, defined in Coltelli *et alii* (1994), consists of a highly porphyritic lava flow with abundant pl phenocrysts as large as 1 cm in size, minor ol and rare px, alternating with hardened mud-flow type epiclastic deposits supported by yellow fine matrix. The maximum thickness is 25 m.

Piano Provenzana formation (22)
The formation, defined in the Servizio Geologico d'Italia (2009a), includes all the volcanic products without any direct stratigraphic relationship with Serra delle Concazze and Pizzi Deneri Formations cropping out along the northern and southern wall of VdB. Numerous lava flows and some scoria cones that crop out mainly on the peripheral sectors of Etna constitute the formation (lithologic and morphologic features are described in the Digital Supplementary Materials). Furthermore, two members with homogeneous lithologic characteristics have

Continued: Table 1

been recognised even though they do not show any stratigraphic relationship between them. The formation crops out mainly along lower Etna flanks. Lava composition ranges from hawaiite to benmoreite (Servizio Geologico d'Italia, 2009a). The base of the formation rests on the sedimentary basement and, with an angular unconformity and an erosional surface, on S. Maria Ammalati and Valverde formations. The top surface is characterised by conformity with Calvario, Portella Giumenta formations. The maximum thickness is about 50 m. Radiometric ages (De Beni *et alii*, 2011): 42.1±10.4 ka, 40.9±14.4 ka, 32.9±10.6 ka, 30.8±21.2 ka, 28.7±12.6 ka.
Tripodo member
The member, defined in the Servizio Geologico d'Italia (2009a), is made of lava flow succession exposed between Serra dell'Acqua and Vallone del Tripodo. Lava is hawaiitic in composition, porphyritic with abundant phenocrysts of pl and px at the base, and subaphyric with flow banding at the top. Discontinuous ash layers are interbedded. At the base there is an angular unconformity associated with an erosional surface and epiclastic deposits with the Serra del Salifizio Formation. The thickness ranges from 10 to 50 m. The member is produced by a lateral vent activity during the Ellittico volcano activity.
Tagliaborsa member
The member, defined in the Servizio Geologico d'Italia (2009a), is formed by a succession of pyroclastic fall deposits composed of ash and scoriaceous lapilli interbedded with yellow eolian silty deposits and black sandy beds. At least 30 tephra layers from strombolian and subplinian eruption form the succession that crops out north of Giarre in the lower east flank. Tephra composition ranges from basalt to hawaiite (Coltelli *et alii*, 2000). Clasts are scoriaceous, rarely pomiceous, and often porphyritic with px, ol and amph phenocrysts variable in quantity and size. The maximum thickness is 10 m. The age is older than 15 ka (Unit C in Coltelli *et alii*, 2000).

Simeto formation (23)
The formation consists mainly of alluvial and subordinate debris deposits. It was divided into two members that do not show any direct stratigraphic relationships. The two members have been grouped together in the same formation since they have the same stratigraphic position and represent an important phase of erosional processes on the periphery of Etna. The formation crops out mainly along the left bank of the Simeto river and on limited areas close to Randazzo towns and on the lower NE flank. The formation thickness ranges from a few meters up to 40 m.
Piano D'Aragona member
Terraced alluvial deposit, at varying elevations, consisting of heterolithologic conglomerate with clasts widely varying in size, formed by sedimentary and volcanic pebbles and cobbles in a yellow-brown, fine to coarse grained, sandy and locally silty matrix sometimes lithified. The prevalent litho-type of the sedimentary clasts is quartzarenite. South of Paternò town, the member consists of an alternation of yellowish sandy layers containing silty lens, silty-clay layers and conglomerate layers. These conglomerates comprise sedimentary and volcanic clasts in a yellow-brown and/or dark-grey sandy matrix poorly lithified. On the whole, the amount of sedimentary and volcanic clasts is highly variable both in the different layers and from the source area towards the mouth of the Simeto river. The member is largely covered by soil.
Contrada Ragaglia member
The member, defined in the Servizio Geologico d'Italia (2009a), consists of a complex debris succession made of a polygenetic breccia with heterolithologic lava clasts varying in size and occasionally clay fragments. Lava clasts are matrix supported. Matrix is sandy to clay varying in colour from reddish-brown to grey. At Contrada Ragaglia the upper portion of the debris deposit consists of an epiclastic deposit, varying in colour from yellow-brown to red-brown, which contains highly weathered pomiceous and scoriaceous lapilli, loose crystals of px and lava clasts. Close to Randazzo town the member is formed by an alternation of fine to coarse-grained volcanic sands, sometimes with cross-stratification, and massive debris flow layers.

Monte Calvario formation (24)
The formation consists of autoclastic lava breccia deposits, often hydrothermally altered, and lava flows erupted by a lateral feeding system NE-SW oriented. The formation crops out mainly along the lower south-western flank of Etna, from Adrano to Ragalna, as well as near to Mt Maletto (NW flank). Lava composition is benmoreite (Corsaro & Pompilio, 2004); porphyritic texture shows phenocrysts of pl, px, ol and clusters of pl and px. The base is marked by a sharp lithological change with the Piano Provenzana formation; at the top an angular unconformity associated with a lithological change highlights the contact with Biancavilla-Montalto Ignimbrite member (Portella Giumenta formation) and Pietracannone and Torre del Filosofo formations. The thickness ranges from 20 to 100 m. Lava flows are described in the Digital Supplementary Materials.

Portella Giumenta formation (25)
The formation, defined in Coltelli *et alii* (1994) and the Servizio Geologico d'Italia (2009a), consists of complex pyroclastic succession and reomorphic lava flows generated by four plinian eruptions that formed the Ellittico caldera (Coltelli *et alii*, 2000). The formation is subdivided into three members. Radiocarbon ages: 15,420±60 a, 15,050±70 a (Unit D in Coltelli *et alii*, 2000).
Osservatorio Etneo member
The member, defined in the Servizio Geologico d'Italia (2009a), consists of proximal pyroclastic fall deposits made of black scoriaceous spatters that become reddish and partially welded at the top forming agglutinated to rheomorphic spatter deposits cropping out on the relicts of Ellittico volcano caldera rims and upper flanks at Punta Lucia and Pizzi Deneri, and as vertical section exposed on the upper western wall of VdB at Belvedere. Locally, spatters form massive red and grey beds, including black aphyric portions. At the base, a yellowish pumice bed crops out. Distal deposits formed by four light grey pumice fall layers interbedded with thin grey ash beds, including oxidized lithics, and yellowish paleosols, crop out on the lower eastern flank. Pumice clasts are oligophyric with phenocrysts of pl, px, amph and ol. Composition ranges from benmoreite to trachyte (Servizio Geologico d'Italia, 2009a).
Ragabo member
The member, defined in the Servizio Geologico d'Italia (2009a), consists of rheomorphic lava flows light grey to reddish brown in colour, often banded cropping out discontinuously from Piano Provenzana to Piano Pernicana. Lava composition is benmoreite (Servizio Geologico d'Italia, 2009a) having subaphyric texture with rare phenocrysts of pl, px and amph. Rheomorphic lavas were generated by a post-depositional flow of agglutinated spatter deposit (Osservatorio Etneo member), still very hot, along the Ellittico upper northeast flank. The maximum thickness is 10 m.
Biancavilla-Montalto ignimbrite member
The member original name Biancavilla-Montalto ignimbrite was reported in De Rita (1991). It is constituted of pyroclastic flow deposits with at least four flow units, cropping out along the lower south-western flank from 1100 m of altitude to Biancavilla town. Pyroclastic flows are scoria and ash flows including agglutinate to reomorphic spatters and lithic lava blocks in abundant yellow fine matrix; locally they are hardened and show columnar jointing. Composition ranges from benmoreite to trachyte (Corsaro & Pompilio, 2004), juvenile clasts contain rare phenocrysts of pl, px and amph. The maximum thickness is 16 m.

Pietracannone formation (26)
The formation is constituted of a complex volcanic succession subdivided into five members. A lava flow succession that includes scoria cones, spatter ramparts and pyroclastic fall deposits related to flank and summit eruptions, took place between Ellittico caldera (about 15 ka) and Il Piano caldera (122 BC plinian eruption), is divided by FS lithohorizon (radiocarbon age 3960±60 a, from Coltelli *et alii*, 2000) in Upper and Lower members. A complex pyroclastic succession interbedded with eolian deposits and paleosols, named Cubania member.

Continued: Table 1

Moreover, the deposits related to the formation of VdB depression are mapped as members in rank, called Milo and Chiancone. The formation covers the main part of the older formations and at the top is characterised by conformity with the Torre del Filosofo formation.
Lower member
Lava flows, scoria cones, spatter ramparts and pyroclastic fall deposits related to flank eruptions occurred between post-Ellittico caldera and FS lithohorizon. The member includes also Elllittico caldera-filling lava flow and overflows from SE caldera rim. Lava flow fields are characterised by "aa" morphologies and, rarely, pahoehoe. Lava composition ranges from basalt to benmoreite (CORSARO & POMPILIO, 2004), aphyric to highly porphyritic in texture, with phenocrysts of pl, px and ol variable in quantity and size. The thickness is not determinable. Lava flows are described in the Digital Supplementary Materials.
Upper member
Lava flows, scoria cones, spatter ramparts and pyroclastic fall deposits related to flank and summit eruptions occurred between post-FS lithohorizon and Il Piano caldera. The member includes also proximal breccia fall and block-and-ash flow deposits. Lava flow fields are characterised by "aa" morphologies and, rarely, pahoehoe. Lava composition ranges from basalt to benmoreite (CORSARO & POMPILIO, 2004), aphyric to highly porphyritic in texture, with phenocrysts of pl, px, ol, variable in quantity and size. The thickness is not determinable. Lava flows are described in the Digital Supplementary Materials.
Cubania member
The member, defined in the SERVIZIO GEOLOGICO D'ITALIA (2009a), is formed by a succession of pyroclastic fall layers interbedded with yellowish silty to sandy eolian deposits and brown paleosols, darker and carbonaceous in the upper part. The succession includes about 80 tephra and tuff deposits made of lapilli, coarse and fine ash, with rare lava lithic fragments, which crop out discontinuously along the eastern flank. Clasts are scoriaceous and mostly porphyritic, with pl, px, ol, variable in quantity and size, their composition ranges from picritic basalt to mugearite (CORSARO & POMPILIO, 2004; COLTELLI *et alii*, 2000). Six of these pyroclastic layers are marker beds (age determinations from COLTELLI *et alii*, 2000): M1 is a sequence of scoria lapilli horizons, containing lithic clasts, alternated with fine ash with accretionary lapilli cropping out in the medium eastern flank (12240±70 a); TV is a laminated and varicoloured tuff made of fine ashes from grey to pink exposed all around the volcano (5340±60 a); FS (above named FS lithohorizon) is composed of well-vesicular ol-rich scoriaceous lapilli and rare cognate lithic clasts, in an alternation of fine and coarse lapilli beds roughly stratified also in colour from brown-grey to red (3930±60 a); FL is a complex pyroclastic deposit comprising a lower lithic-rich coarse breccia, dispersed in the northern flank, and an upper sequence of lithic-rich tuff-breccia exposed all around the volcano (3150±60 a); FG is an eruptive sequence comprised of pyroclastic fall and flow deposits divided in 7 eruptive subunits; the marker bed is mainly represented by two plinian fall deposits made of dense hawaiitic scoria characterized by large tabular phenocrysts of pl, minor ol and rare px, and abundant lithic fragments, exposed almost continuously from the volcano summit to the Ionian coast (122 BC from COLTELLI *et alii*, 1998); FF deposit is made of reverse graded, scoriaceous clast ranging from coarse ash to fine lapilli, cropping out in the medium eastern flank; scoria are black, vesicular and elongated, containing abundant phenocrysts of pl, minor ol and rare px (44 BC from COLTELLI *et alii*, 1998). The maximum thickness of the whole succession is 10 m. The age ranges between about 12 ka to 122 BC (Unit E in COLTELLI *et alii*, 2000).
Milo member
The member original name Milo lahar was reported in ROMANO (1982) and then defined as member in the SERVIZIO GEOLOGICO D'ITALIA (2009a). It is made up of an almost monogenetic debris avalanche deposit, constituted mainly of mugearitic lava pebbles up to 1 m, with jigsaw cracks, in abundant loose matrix mechanically generated from the same lava. The deposit is topped by a complex succession of matrix-supported lahar-type debris- and mud-flow deposits. The member crops out in front of the VdB opening, in the area around Milo village (eastern flank). The thickness is from a few meters up to 30 m. The debris avalanche deposit is related to the flank collapse of the eastern flank of Mt Etna occurring about 10 ka ago (CALVARI *et alii*, 2004) and forming the VdB depression.
Chiancone member
The member original name Chiancone was reported in RITTMANN (1973) and then defined as member in the SERVIZIO GEOLOGICO D'ITALIA (2009a). It is constituted by a complex volcaniclastic conglomerate-type deposit, poorly stratified and often hardened, lithologically heterogeneous, made of cm to m size rounded volcanic pebbles and gravels in a poor sandy to silty matrix. A coarse and fine alluvial sequence forms the upper part of the deposit. A lava flow of the lower member of the same formation is interbedded into the upper part of the deposit. The member forms an alluvial fan that crops out in the lower eastern flank of Mt Etna, from Riposto to Pozzillo and Stazzo villages along the seashore, and uphill to Dagala. The base of this member is not exposed; at the top there is a sharp lithological change with the lava flows belonging to the Pietracannone formation. The maximum thickness is greater than 30 m. The overall thickness inferred by wells and geophysical investigations is about 300 m (CALVARI *et alii*, 2004). The origin of this deposit is related mostly to the fluvial reworking and transportation of the debris avalanche deposit (Milo member).

TORRE DEL FILOSOFO FORMATION (27)
The formation, defined in the SERVIZIO GEOLOGICO D'ITALIA (2009a), consists mainly of lava flows and subordinate proximal and distal pyroclastic fall deposits covering almost entire Etna summit and the VdB and took place after Il Piano caldera collapse (122 BC) up to the present. Lavas are characterized by highly variable textures from aphyric to strongly porphyritic, with abundant mm to cm-sized pl phenocrysts. On the whole, the most common lithotype is characterised by a porphyritic texture containing phenocrysts of pl, px and ol in highly variable amount and size. Lava composition ranges from basalt to mugearite (CORSARO & POMPILIO, 2004). Lava flows are mainly compound lava flow fields with a prevalent "aa" morphology and/or a more complex mix of both "aa" and "toothpaste". The morphology of the lava field rarely is pahoehoe. The eruptive fissures are formed by hornitos, spatter ramparts and single or coalescent scoria cones elongated according to the fissure trend. The scoria cone deposits are generally made of an alternation of scoriaceous lapilli and bomb-rich layers. Volcanics belonging to this formation are divided into three time intervals: (1) post- 122 BC plinian eruption-1669 AD eruption; (2) post 1669 AD eruption-pre 1971 AD eruption; (3) 1971 AD eruption-present (May 2007 eruption). The formation mainly covers the Pietracannone formation. The thickness is not determinable. Lava flows are described in the Digital Supplementary Materials.

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the regional tectonic regime (BRANCA *et alii,* 2004a; BELLOTTI *et alii*, 2006). The unconformities in proximal areas are commonly represented by angular discontinuities associated or not to a temporal hiatus and generated by the shifting of the volcano shallow feeding system or by important changes in the morphology and structure of the eruptive centres (fig. 9). Conversely, in the distal areas the unconformities are mainly represented by erosional surfaces due to the fluvial pattern re-organization as a consequence of the eruptive centres shifting or, over the long term, due to important regional tectonic deformations (BRANCA & CATALANO, 2000).

Furthermore, we have also distinguished the sedimentary deposits (both non-volcanic and volcaniclastic) from the primary volcanic ones within each synthem, to highlight the relationship between volcanic activity and sedimentary processes.

Taking into account the first definitions of UBU (CHANG, 1975; SALVADOR, 1987 and 1994), their application in volcanic areas presents some problems of scale

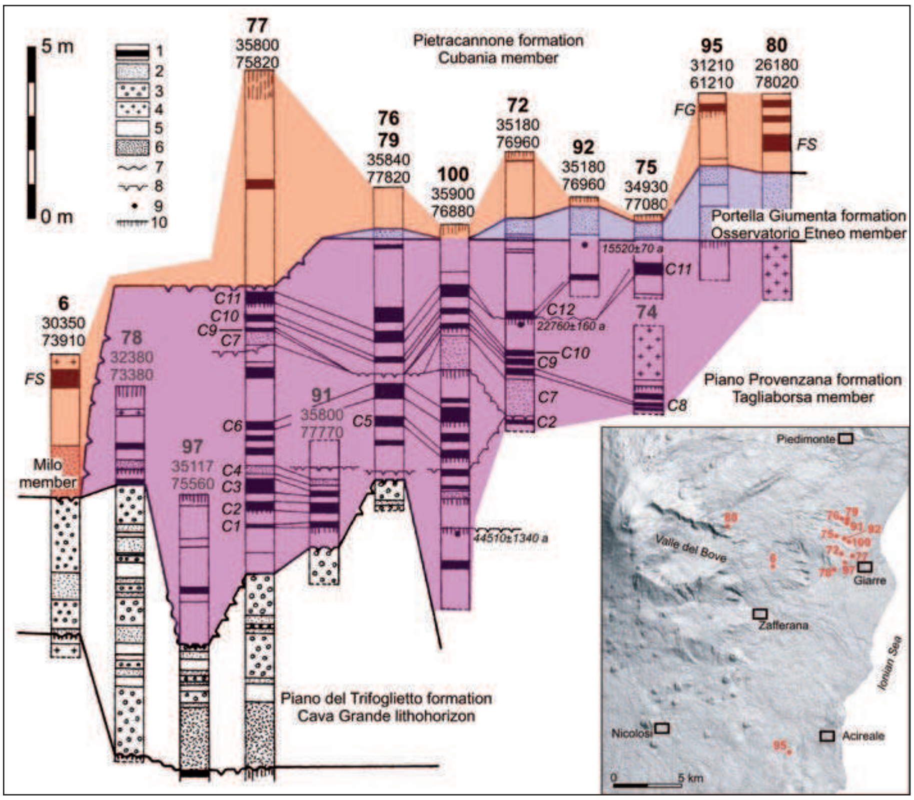

Fig. 7 - Stratigraphic correlation of Etna pyroclastic deposits (modified from DEL CARLO *et alii*, 2004) and location of the stratigraphic sections. The number of the sections is followed by the Italian National System Kilometric coordinates of the 10,000 scale topographic maps of Regione Siciliana. Tephra layers are labelled with letters and/or numbers (for detailed explanation see DEL CARLO *et alii*, 2004).

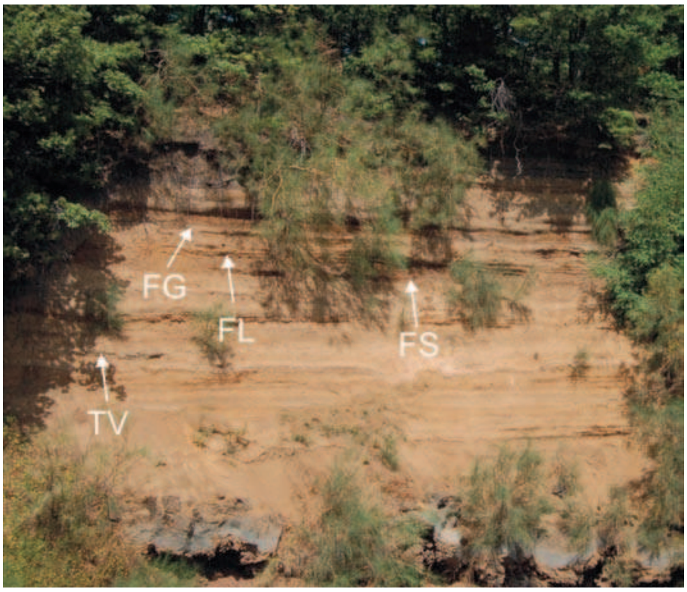

Fig. 8 - Picture of the tephrostratigraphic section 156/159 of COLTELLI *et alii* (2000) located in the NE flank at Casa del Fanciullo locality (1600 m a.s.l.) in which the Holocene pyroclastic succession, belonging to the Cubania member of Pietracannone formation, is well preserved. The tephra marker beds named TV, FS, FL, and FF are evidenced.

(temporal and spatial), because the hiatuses separating the different units usually have a short duration and a limited areal extent. Consequently, UBU are usually pertinent only for the local volcanic successions unless a widespread unconformity marking an important phase of the geological history of a region is found, as for example the sea level fluctuations leading to the formation of raised marine terraces (LUCCHI *et alii*, 2004, 2007 and 2010).

LITHOSOMATIC UNITS

Following the recommendations of PASQUARÈ *et alii* (1992), we utilized the lithosomes as informal stratigraphic units in order to define volcanic centres still morphologically recognizable. In the original definition (WHEELER & MALLORY, 1953), lithosomes are dimensionless and out of hierarchy. They account for masses of fairly uniform rocks having geometrical relationships with adjacent bodies of different lithology. We exploited the morphological meaning of lithosomes to introduce in the geological reconstruction of a composite volcano like Etna some fundamental morpho-volcanic structures (e.g. stratocones). The lithosomes were indicated with the term "volcano" followed by a geographical name. This solution also allowed us to preserve the historical names assigned to the polygenetic eruptive centres as those recognized for the first time by WALTERSHAUSEN (1880).

STRATIGRAPHIC DATA

In the new geological map of Etna volcano we identified 27 formations, some of them including members. The detailed description of the lithological and stratigraphic features for each unit is reported in tab. 1. The composition of the volcanic products is based on the petrographic analysis of representative samples and is in agreement with the geochemical data from CORSARO & POMPILIO (2004) and SERVIZIO GEOLOGICO D'ITALIA (2009a). Most lithostratigraphic units have been dated using radiometric techniques performed on representative samples using the

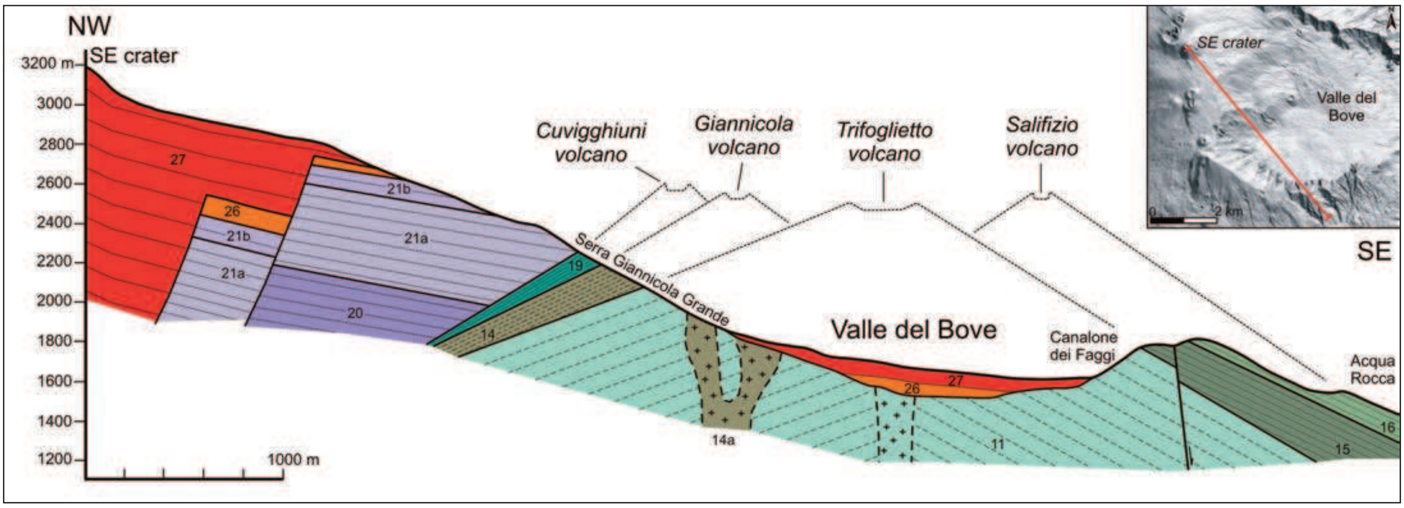

Fig. 9 - Geological cross section along the south-western wall of the Valle del Bove from the SE crater (NW) to Acqua Rocca locality (SE) (modified from SERVIZIO GEOLOGICO D'ITALIA, 2009a). The paleo-morphology of the main lithosomatic units is reconstructed. The numbers correspond to those of the lithostratigraphic units of the geological map: 27) Torre del Filosofo formation; 26) Pietracannone formation; 21a) Pizzi Deneri Formation-Lower member; 21b) Pizzi Deneri Formation-Upper member; 20) Serra delle Concazze Formation; 19) Canalone della Montagnola Formation; 16) Serra del Salifizio Formation; 15) Valle degli Zappini Formation; 14) Serra Giannicola Grande formation; 14a) Belvedere member.

$^{40}Ar/^{39}Ar$ method for lavas (DE BENI *et alii*, 2011) and C^{14} method for tephra deposits (COLTELLI *et alii*, 2000). The stratigraphic reconstruction of Etna volcanic succession benefited from numerous stratigraphic sections measured on the steep walls of the Valle del Bove depression (figs. 10, 11 and 12), and on the fault scarps of Acireale Timpa, S. Tecla Timpa and Moscarello Timpa, where the volcanic rocks belonging to the oldest volcanoes crop out. The volcanic and volcaniclastic formations were labeled from 1 to 27. When a member has been mapped, we have added a small letter to the formation number (e.g. 26a). Flow or stratum rank is labeled with two letters.

Concerning Torre del Filosofo, Pietracannone, Monte Calvario and Piano Provenzana formations, we have reconstructed the stratigraphic relationships and field distribution of 430 lava flows and related pyroclastic deposits, on the basis of their main features as lithology, morphology, location of the vent and other additional information reported in the Digital Supplementary Material. In particular, 112 lava flows are included within the Torre del Filosofo formation, 245 in the Pietracannone formation, 15 in the Monte Calvario formation and 58 in the Piano Provenzana formation.

The most recent volcano (Mongibello) covers 88% of the whole Etna edifice. The only unconformity present in the products of the last 15 ka volcanic succession, not associated with any lithological change, is related to the Il Piano caldera, formed by the 122 BC plinian eruption. Its widespread fallout deposit allows identifying two formations, Pietracannone formation, included between Ellittico and Il Piano caldera collapses, and Torre del Filosofo formation, made of the volcanics erupted after 122 BC. Within Pietracannone formation (it covers 54% of the Etna edifice) we can map two members (lower and upper) on the basis of a lithohorizon represented by a picritic scoria-fall deposit dispersed on the eastern flank of the volcano (FS layer of COLTELLI *et alii*, 2000).

The cartographic representation of the Torre del Filosofo formation is problematic, as discussed in the previous paragraph, because the volcanics erupted during

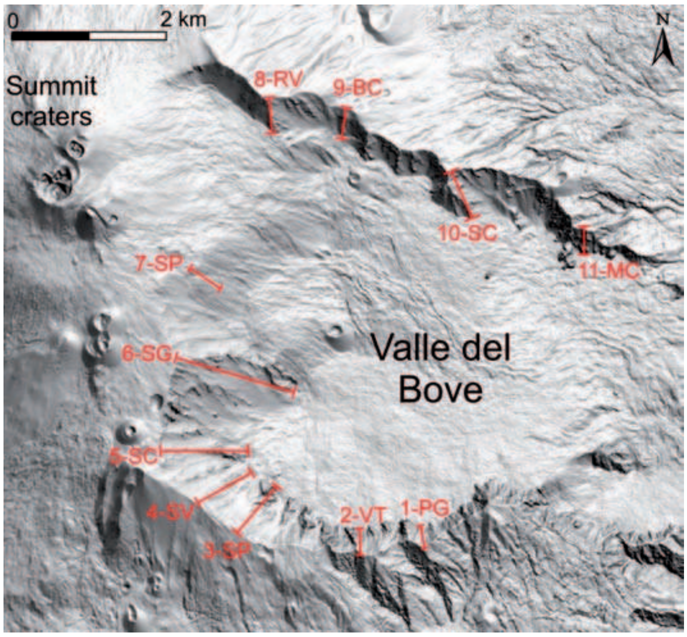

Fig. 10 - Location of the stratigraphic sections along Valle del Bove walls.

the last 2 ka cover 34% of the whole Etna edifice. Since this formation is fully mapped as flow rank, to obtain the best graphical representation of 112 different elements we grouped them into 3 time intervals on the basis of their relative stratigraphic position. Each time interval is bounded by eruptive events with an important meaning in the recent eruption history: 1) the 1669 AD flank eruption that marks the end of a period characterized by several large volume eruptions (HUGHES *et alii*, 1990); 2) the 1971 flank eruption that marks an important increase in the frequency of both summit and flank eruptions after the 1669 eruption (BRANCA & DEL CARLO, 2004 and 2005). With regard to historical eruptive activity belong-

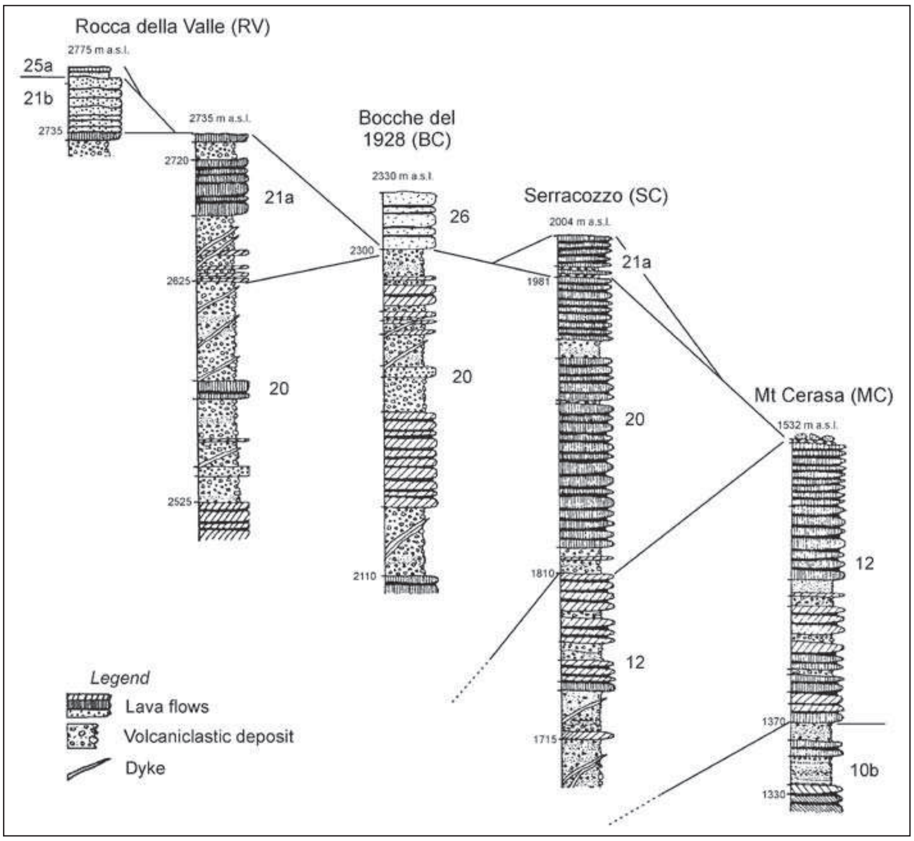

Fig. 11 - Correlation of stratigraphic sections along the northern wall of the Valle del Bove (modified after COLTELLI *et alii*, 1994 and SERVIZIO GEOLOGICO D'ITALIA, 2009a). The numbers correspond with those of the lithostratigraphic units of the geological map: 26) Pietracannone formation; 25a) Portella Giumenta formation-Osservatorio Etneo member; 21a) Pizzi Deneri Formation-Lower member; 21b) Pizzi Deneri Formation-Upper member; 20) Serra delle Concazze Formation; 12) Monte Scorsone Formation; 10b) Rocche formation-Rocca Capra member.

ing to time interval 1 of Torre del Filosofo Formation (from 122 BC to 1669 AD), we have attributed the eruption year to a lava flow only when we have found geographic references in the original chronicle allowing us to clearly establish the location of the eruption products. In addition, thanks to fruitful collaboration with Jean-Claude Tanguy, we have used data of archeomagnetic and ^{226}Ra-^{230}Th dating published in TANGUY *et alii* (2007 and 2012) in the geological map in order to constrain the lava flows age of the last 2 ka for which no historical sources are available. Among the pyroclastic fall deposits post 1971 AD (time interval 3), related to lava fountain events erupted from the summit craters that partially cover the summit area of the volcano, we have distinguished those occurring between 1999 and 2001 from the most recent ones between 2006 and May 2007. Finally, the summit cone of Etna is covered by proximal pyroclastic deposits erupted during the activity post 1971 AD (time interval 3). These deposits, generated by numerous eruptive episodes, are not distinguishable in the map and are therefore indicated with the generic label (i^3) of this time interval.

In the new geological map of Etna volcano we used two UBU ranks: synthem and supersynthem (fig. 5). According to the UBU definition we report in tab. 2 the description of the upper and lower boundary of the 8 synthemic units and 4 supersynthem units recognized and their geographic location. Therefore, the synthemic units scheme (fig. 5) shows the rock-bodies distribution related to the main stages of the geological evolution of Etna volcano identified through the unconformity boundaries (fig. 13). The oldest synthems are separated by temporal hiatus associated with an erosional period and an angular unconformity (Aci Trezza, Adrano, Acireale synthems). Later on, the unconformities become mainly angular, evidencing a local shifting of the eruptive activity associated to limited erosional surface (Acireale, S. Alfio, Croce Menza and Zappini synthems), with the exception of the S. Alfio and Croce Menza synthems boundary represented by a disconformity. Finally an important angular unconformity divides the Zappini and Concazze synthems evidencing the last main shift of the shallow feeder system that marks the starting activity of the main eruptive centres (Ellittico and Mongibello volcanoes). The youngest unconformity boundary defined on Etna divides the Concazze and Il Piano synthems and it is represented by a caldera collapse occurring about 15 ka ago. This collapse truncated the summit of Ellittico volcano consequently to the eruption of widespread pyroclastic deposits (Portella Giumenta formation) that covered the upper slopes and the lower flanks with distal pumice fall layers and block and ash flow deposit representing the marker bed of this unconformity. Since for several millenia the main activity remain concentrated within the caldera, this event caused erosional processes along the volcano periphery due to the lack of lava flows emplacement from lateral or summit eruptions (BRANCA & CATALANO, 2000).

Although the Valle del Bove flank collapse occurred about 10 ka ago (CALVARI *et alii*, 2004) and is the most prominent and evident morphological unconformity of Etna, we could not consider it as a boundary of a synthem because this unconformity cannot be extended outside the valley depression. In fact, the volcaniclastic deposit associated to the flank collapse formation (Milo member of Pietracannone formation) is characterized by very limited exposure (4.3 km^2 only along the eastern flank) and rests on the old lava succession of S. Alfio Synthem, showing a direct relationship only with a lava flow of the lower member (post-Ellittico caldera - FS lithohorizon of 3.9 ka) of the Pietracannone formation. Therefore, within this formation

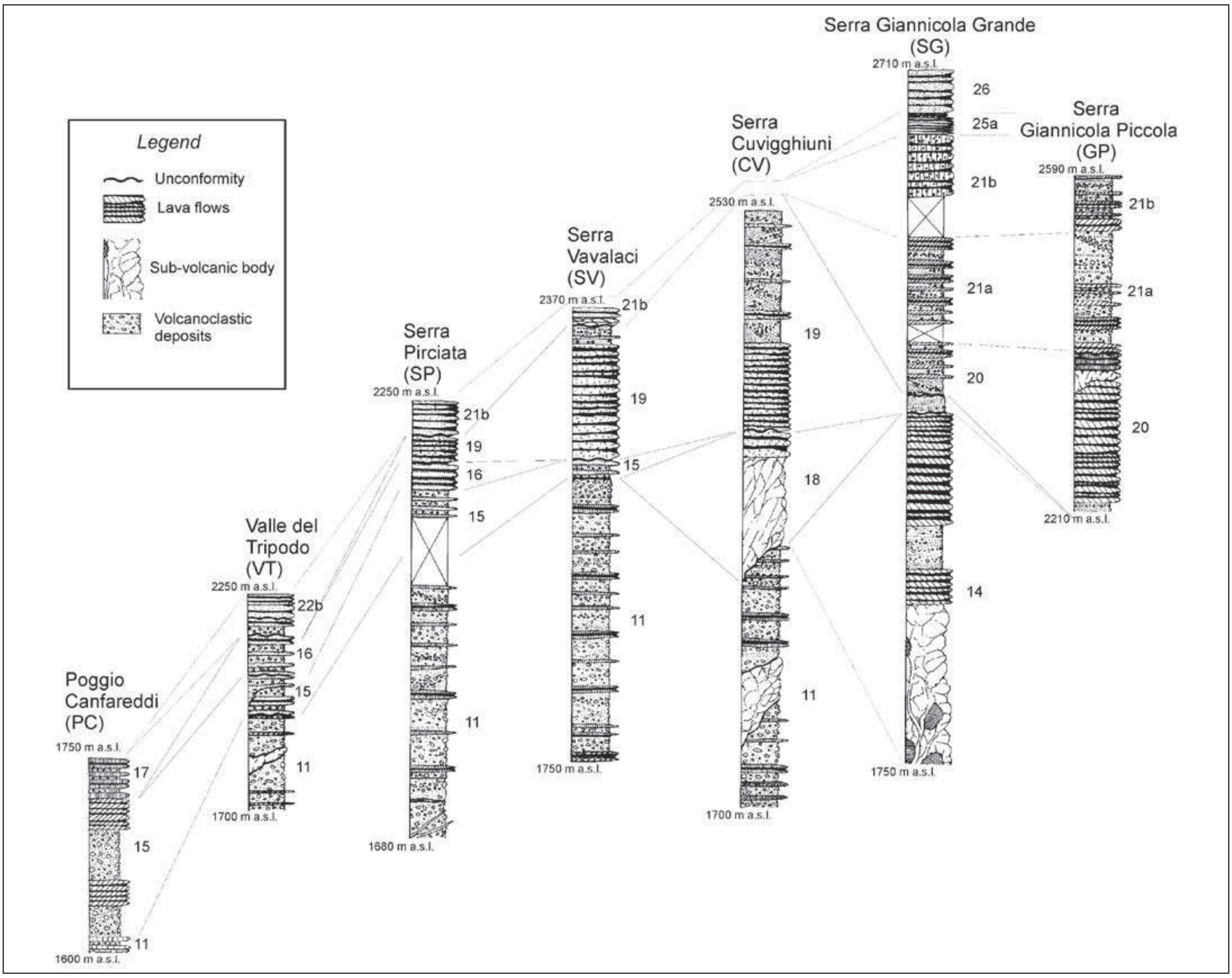

Fig. 12 - Correlation of stratigraphic sections along the south-western wall of the Valle del Bove (modified after Calvari *et alii*, 1994 and Servizio Geologico d'Italia, 2009a). The Serra Giannicola Piccola stratigraphic section (SGP), logged in 1990, is now covered by more recent lava flows. The numbers correspond with those of the lithostratigraphic units of the geological map: 26) Pietracannone formation; 25) Portella Giumenta formation; 21a) Pizzi Deneri Formation-Lower member; 21b) Pizzi Deneri Formation-Upper member; 20) Serra delle Concazze Formation; 19) Canalone della Montagnola Formation; 18) Serra Cuvigghiuni formation; 17) Acqua della Rocca formation; 16) Serra del Salifizio Formation; 15) Valle degli Zappini Formation; 14) Serra Giannicola Grande formation; 11) Piano del Trifoglietto formation.

we cannot extend the unconformity generated by the Valle del Bove flank collapse along the volcano's slopes due to the lack of a any stratigraphic marker linked to this important volcano-tectonic event. In addition, the most recent caldera collapse, occurring on Etna during the 122 BC plinian eruption, has not been considered as a boundary of synthem because the time lapse in which eruptive activity remained in the summit caldera was limited to less than 4 centuries (the first recognised flank eruption occurred in 252 AD), a period too short to form an uncoformity through erosional processes in medial and distal area, so the well-exposed plinian fall deposit on the SE flank lacks any connection surface to the rest of the volcano slopes, even if from a stratigraphic point of view it is enough to mark the separation between Pietracannone and Torre del Filosofo formations.

Finally, on the basis of the morphologic characteristics we defined 9 volcanoes, which show a well-defined position in the Etna region. For the first two supersynthems, we were unable to define the lithosomatic units

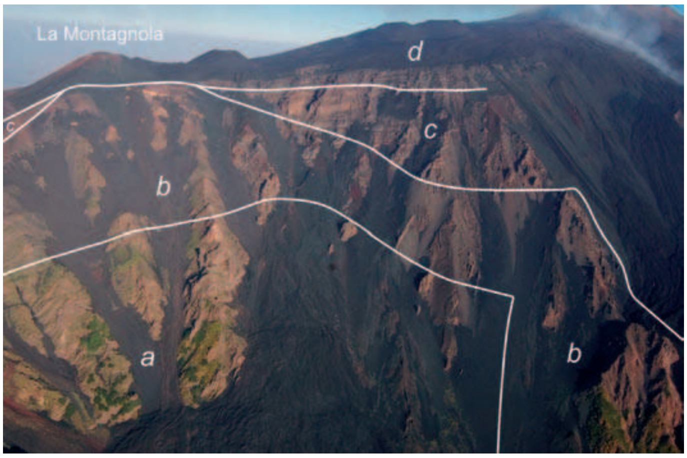

Fig. 13 - Aerial view from east of the south-western wall of the Valle del Bove, where the unconformities that separate the Il Piano (*d*), Concazze (*c*), Zappini (*b*) and Croce Menza (*a*) synthems are exposed.

TABLE 2

Description of the upper and lower boundary of the synthemic units and their geographic locations. VdB=Valle del Bove.

Synthem unit		boundary	Unconformity	Upper and lower units	Geographic location
Stratovolcano Supersynthem	Il Piano Synthem	upper	present topographic surface		summit area and on the flanks of Mt Etna edifice
		lower	caldera collapse in proximal area	Concazze Synthem	Punta Lucia and Pizzi Deneri
			erosional surface and strong angular unconformity in distal area	Concazze, Zappini, Croce Menza, S. Alfio, Acireale, Adrano, Acitrezza Synthems	on the flanks of Mt. Etna edifice, in particular along the Simeto and Alcantara valleys
	Concazze Synthem	upper	caldera collapse in proximal area; erosional surface and angular unconformity in distal area	Il Piano Synthem	Punta Lucia and Pizzi Deneri; inner walls and external flanks of VdB; on the flanks of Mt Etna edifice and in the Simeto and Alcantara rivers valleys
		lower	angular unconformity and strata pinch-out	Zappini Synthem	inner walls of VdB
			angular unconformity and strata pinch-out	S. Alfio Synthem	Moscarello area
			erosional surface and angular unconformity	Acireale Synthem	on lower southern flank close to Acireale town
			erosional surface and angular unconformity	Adrano Synthem	on the lower south-western flank along the left bank of the Simeto river valley
Valle del Bove Supersynthem	Zappini Synthem	upper	strong angular unconformity	Il Piano Synthem	inner walls and external flanks of VdB
			angular unconformity and strata pinch-out	Concazze Syntem	inner walls of VdB
		lower	angular unconformity sometimes associated to an erosional phase	Croce Menza Synthem	inner walls of VdB
			strong angular unconformity, locally erosional unconformity	S. Alfio Synthem	Calanna valley
	Croce Menza Synthem	upper	strong angular unconformity	Il Piano Synthem	base of the VdB inner wall; small outcrops located in Tarderia
			strong to light angular unconformity sometimes associated to an erosional surface	Zappini Syntem	eastern side of the northern wall of VdB; western and southern walls of VdB
		lower	disconformity	S. Alfio Synthem	Moscarello area (Cava Grande lithohorizon)
Timpe Supersynthem	S. Alfio Synthem	upper	erosional surface and strong angular unconformity	Il Piano Synthem	on the lower eastern flank of Mt. Etna edifice
			angular unconformity and strata pinch-out	Concazze Synthem	Moscarello area
			strong angular unconformity, locally erosional unconformity	Zappini Synthem	Calanna valley
			disconformity	Croce Menza Synthem	Moscarello area (Cava Grande lithohorizon)
		lower	strong angular unconformity and erosion surface	Acireale Synthem	Moscarello area and Aci Trezza hill
			erosional surface and strong angular unconformity	Acitrezza Synthem	Aci Trezza hill
			nonconformity	sedimentary basement	Aci Trezza hill
	Acireale Synthem	upper	erosional surface and strong angular unconformity	Il Piano Synthem	on the lower flanks of Mt Etna edifice
			erosional surface and angular unconformity	Concazze Synthem	on lower southern flank
			strong angular unconformity and erosion surface	S. Alfio Synthem	Moscarello area and Aci Trezza hill
		lower	erosional surface and angular unconformity	Adrano Synthem	along the left bank of the Simeto river valley
			nonconformity	sedimentary basement	Acitrezza hill, northern suburb of Catania, S. Venera village
Basal Tholeiitic Supersynthem	Adrano Synthem	upper	erosional surface and angular unconformity	Il Piano Synthem	along the left bank of the Simeto river valley
			erosional surface and angular unconformity	Concazze Synthem	along the left bank of the Simeto river valley
			erosional surface and angular unconformity	Acireale Synthem	along the left bank of the Simeto river valley
			nonconformity	sedimentary basement	along the left bank of the Simeto river valley
	Aci Trezza Synthem	upper	erosional surface and strong angular unconformity	Il Piano Synthem	Aci Castello and Aci Trezza area
			erosional surface and strong angular unconformity	S. Alfio Synthem	Aci Trezza hill
			nonconformity	sedimentary basement	Aci Castello and Aci Trezza area
		lower	nonconformity	sedimentary basement	Aci Castello and Aci Trezza area

because the volcanic activity covered a very long time-lapse forming only monogenetic fissure-type volcanic centres and a primitive lava shield volcano whose edifice is almost totally covered by younger volcanic products and has the eastern flank under the sea level (CHIOCCI *et alii*, 2011). Conversely, in Croce Menza and Zappini synthems we have recognised seven small stratocones superimposed in the area of Valle del Bove, named Tarderia, Rocche, Trifoglietto, Monte Cerasa, Giannicola, Salifizio and Cuvigghiuni volcanoes. Finally, the most recent synthems, Concazze and Il Piano, comprise two large stratocones Ellittico and Mongibello volcanoes forming respectively the main bulk of Etna edifice and the youngest and active volcanic centre that mantles with its products most of the previous stratocone. The main morpho-structural features of the lithosomes are described in tab. 3.

TABLE 3

Description of lithosomes (volcanoes).

TARDERIA VOLCANO The Tarderia volcano is located immediately south of the southern slope of Valle del Bove (VdB). Its products crop out along a morphological belt, characterised by steep slopes, forming an almost continuous arc from Tarderia up to Zafferana Etnea town. This morphological structure represents the southern flank of Tarderia volcano and is almost buried by the lava flows of Mongibello volcano.
ROCCHE VOLCANO The Rocche volcano crops out along the eastern side of the VdB northern wall. According to the strata attitude of the Rocche formation (dip from NW to NE), we may conjecture the existence of a feeding system localized between Rocca Capra and Mt Calanna. The Rocche volcano is a small polygenetic eruptive centre almost completely covered by the products of Mt Cerasa volcano.
TRIFOGLIETTO VOLCANO The Trifoglietto volcano crops out along the south-western wall of VdB. It represents the main volcanic edifice of the VdB area, a polygenetic eruptive centre largely made up of stratified volcaniclastic deposits. Trifoglietto remains are exposed from the base of Serra Giannicola Grande, along the western and southern wall of VdB, until Poggio Canfareddi, showing a basal extension of more than 3 km wide. According to the strata attitude of the Piano del Trifoglietto formation, dipping from NW to SW to SE, it is possible to reconstruct its maximum elevation of about 2600 m and the position of the main feeding system at about 500 m north of Serra dell'Acqua. Lastly, several subvolcanic bodies feeding small polygenetic centres, namely Giannicola, Salifizio and Cuvigghiuni volcanoes, intruded the Trifoglietto edifice.
MONTE CERASA VOLCANO The Mt Cerasa volcano crops out on the eastern side of VdB from Mt Scorsone to Mt Cerasa, along the northern wall, and from Croce Menza to Val Calanna and Vallone S. Giacomo, along the southern wall. According to the strata attitude of the Mt Fior di Cosimo formation (10 to 15° dipping to SE) and Mt Scorsone Formation (20 to 35° dipping to NE), we may infer the position of a feeding system located between Mt Centenari and Rocca Musarra inside the VdB. The Mt Cerasa volcano is a large polygenetic eruptive centre largely covered by the Ellittico and Salifizio volcanoes products.
GIANNICOLA VOLCANO The Giannicola volcano crops out along the western wall of VdB on Serra Giannicola Grande and surroundings. It is characterised by a main subvolcanic body (a neck, the Belvedere member) that is intruded into the Trifoglietto volcanics and fed the overlaying lava flows and pyroclastic succession. The Giannicola volcano is a polygenetic centre located on the northern flank of Trifoglietto volcano. The feeding system is exposed on Serra Gannicola Grande at about 2000 m altitude at the top of the neck. The Cuvigghiuni volcano products entirely cover the Giannicola volcano.
SALIFIZIO VOLCANO The Salifizio volcano crops out along the southern wall of VdB from Serra Vavalaci to Val Calanna. It is composed of some small subvolcanic bodies intruded into the Trifoglietto volcanics, and a lava flow succession interbedded with epiclastic deposits. The Salifizio volcano is a polygenetic eruptive centre located on the south-eastern flank of Trifoglietto volcano according to the attitude of the strata, dipping from SW to E. The products of Cuvigghiuni and Ellittico volcanoes cover the Salifizio volcano.
CUVIGGHIUNI VOLCANO The Cuvigghiuni volcano crops out along the western wall of VdB from Serra Giannicola Grande to Serra Pirciata, with the maximum thickness in Serra Cuvigghuni area, where a neck feeding lava flows is exposed at about 2500 m altitude. The succession is characterised by some small subvolcanic bodies, at the base, covered by thin lava flows and then thick pyroclastic deposits at the top. The Cuvigghiuni volcano is a polygenetic eruptive centre located on the western flank of Trifoglietto volcano. According to the attitude of the strata and the location of the necks, we can recognise at least three different vents, closely spaced along Serra Cuvigghiuni and in the Laghetto area. Ellittico volcano products cover the Cuvigghiuni volcano.
ELLITTICO VOLCANO The Ellittico volcano represents the most prominent volcanic edifice of Etna. It is a typical stratocone characterised by steep slopes in the summit portion from 1600-1700 m to ca. 2900 m a.s.l. The original shape of the edifice is well preserved along the north-eastern slope of VdB and on the north-western slope of Punta Lucia. The Ellittico volcano flanks are extended down to the boundary of the volcanic cover along the Simeto and Alcantara rivers and along the Ionian coast. According to the strata attitude of the Pizzi Deneri and Serra delle Concazze formations, the Ellittico summit may have reached a maximum elevation of about 3600 m. Four plinian eruptions caused the collapse of the summit area forming the Ellittico caldera, N-S elongated, whose rim is still preserved at Punta Lucia and Pizzi Deneri, at 2931 m and 2847 m elevation respectively.
MONGIBELLO VOLCANO The Mongibello volcano gives the present morphological setting to Mount Etna, mantling the pre-existing morphology in the summit area and almost completely covering the previous landforms in distal areas. The eastern flank of this volcano is characterised by the presence of the wide flank-collapse of the Valle del Bove formed about 10 ka ago. The summit is broken off by Il Piano caldera, formed during the 122 BC plinian eruption. The southern caldera rim was exposed at about 2900 m elevation close to Torre del Filosofo shelter (now buried by lava flows erupted after 1971). The historical eruptive activity of the past 2 ka has filled this caldera building the present summit cone, where four craters characterised by persistent activity are currently located. More than 250 monogenetic scoria cones are scattered widely on the flanks of Mongibello volcano down to 400 m elevation.

Stratigraphic novelties

The most important innovations and the main novelties in the Etna stratigraphic succession with respect to the previous geological maps of a limited part of the volcano (Branca *et alii*, 2004b; Servizio Geologico d'Italia, 2009a and b; Servizio Geologico d'Italia, 2010 a and b) are briefly discussed in the following section. The previous maps represent the precursors of the geological map presented in this paper, consequently we would like to show the development of this knowledge process.

As far as methodology used to draft the new geological map is concerned, we adopted solely lithostratigraphic units, mainly with formation rank, for the entire volcanic stratigraphic succession including volcaniclastic deposits. For the recent and historical lava flows, which are usually emphasized in the volcano geological map because of their wide extension and clear available details, we used only flow/stratum rank avoiding resorting to non-stratigraphic criteria (cf. Romano *et alii*, 1979). Most lithostratigraphic units were constrained in age with radioisotopic datings (see De Beni *et alii*, 2011). For the first time at Etna the radiometric investigation has been performed in parallel and in close relation with the field survey to obtain the finest chronostratigraphic framework (De Beni & Groppelli, 2010). Finally, we introduced the supersynthem rank in the stratigraphy of the volcanic succession of the Mt Etna district. The supersynthemic units are named as the four evolutionary phases proposed by Branca *et alii* (2004a).

New data collected for the present map suggest to introduce some changes to the previously published 1:50,000 sheets of the new geological map of Italy published by Servizio Geologico d'Italia in the Etnean area. The main new results and changes introduced in the present paper can be summarized by the following points, while in fig. 14 we show the difference in the schemes of stratigraphic relationship between the previous and the present maps.

1. On the basis of new stratigraphic evidences and radioisotopic datings we revised the upper and lower unconformity boundaries of some synthems with respect to the Foglio 625 Acireale (Servizio Geologico d'Italia, 2009a), and then we removed the Girolamo Synthem introducing 4 new synthems (details are reported in the points 3, 6 to 8).

2. For the lithosomatic units (volcanoes), we confirmed the same lithosomes (name, stratigraphic position and areal extension) established in Foglio 625 Acireale (Servizio Geologico d'Italia, 2009a) and Branca *et alii* (2004b), except for Salifizio and Ellittico volcanoes that are scaled down in areal extension (see point 14) and depositional range (see point 13); moreover we define, for the first time, Monte Cerasa volcano (see point 12).

3. We defined for the first time Aci Trezza Synthem comprising submarine volcanics interlayered in the Argille grigio-azzurre Formation.

4. Adrano Synthem: we reconstructed the interrelationship between volcanic activity and fluvial processes during the Simeto valley development.

5. We changed the name of Aci Trezza Formation, defined in the Foglio 634 Catania (Servizio Geologico d'Italia, 2009b), to Aci Castello Formation because Aci Trezza is the name of a synthem established in this work.

6. We changed boundaries and rank of the Timpe Synthem established in Foglio 625 Acireale (Servizio Geologico d'Italia, 2009a). In the new map this unit has the rank of a supersynthem since it has the same stratigraphic position of the Timpe phase of Branca *et alii* (2004a) on the basis of first-order unconformity boundaries recognized. The rock bodies formerly belonging to the Timpe Synthem, are now included in the Acireale Synthem (the inversion of the two units names was needed due to their geographic position).

7. Acireale Synthem is defined by new upper and lower boundaries that correspond to the old Timpe Synthem boundaries of Foglio 625 Acireale (Servizio Geologico d'Italia, 2009a) including also S. Maria Ammalati formation. The rock bodies belonging to Acireale Synthem of Foglio 625 Acireale (Servizio Geologico d'Italia, 2009a) were split in 3 synthems, Acireale, S. Alfio and Croce Menza (see fig. 14) on the basis of two main unconformities recognised within the volcanic succession (see description in tab. 2) and constrained by new radioisotopic datings.

8. On the basis of the new unconformities recognised in the field (tab. 2 and point 6) we defined two new synthems: S. Alfio and Croce Menza. The unconformity between S. Alfio and Croce Menza synthems is related to the change from fissural- to central-type activity in Etna region, and it is marked locally by a well-developed erosional surface (see fig. 14).

9. The Timpa formation comprises the Simeto Formation defined in Foglio 633 Paternò (Servizio Geologico d'Italia, 2010b).

10. We constrained the stratigraphic position of the Calanna formation, a highly altered volcanic rock body isolated by historical lava flows, on the basis of new radioisotopic datings (De Beni *et alii*, 2011).

11. We expanded the depositional range of Zappini Synthem unconformities to include the Girolamo Synthem of Foglio 625 Acireale (Servizio Geologico d'Italia, 2009a) on the basis of new radioisotopic datings (De Beni *et alii*, 2011). In particular, the very short temporal hiatus of the Zappini Synthem upper discontinuity (Servizio Geologico d'Italia, 2009a) and its local extension suggest not considering it as a synthemic boundary. In this new stratigraphic framework, Zappini Synthem includes Monte Cerasa, Salifizio, Giannicola and Cuvigghiuni volcanoes (see fig. 14).

12. We recognized a new volcanic centre, Monte Cerasa volcano, built inside the Valle del Bove (VdB) and on the north-eastern flank of Trifoglietto volcano, on the basis of the rock bodies geometry, the lava flows attitude, the top unconformity and the new radioisotopic dating (De Beni *et alii*, 2011). Monte Cerasa volcano comprises volcanics belonging to the Monte Scorsone (northern wall of VdB) and Monte Fior di Cosimo (southern wall of VdB) Formations (see fig. 14).

13. Monte Scorsone Formation in the previous stratigraphic works (Coltelli *et alii*, 1994; Branca *et alii*, 2004b; Servizio Geologico d'Italia, 2009a) represented the basal products of the Ellittico volcano. In the present map this formation is related to a new volcanic edifice, called Monte Cerasa volcano, based on: *i*) new radio-isotopic data (De Beni *et alii*, 2011); *ii*) attitude of strata; *iii*) an unconformity at the top.

14. We defined the new formation of Monte Fior di Cosimo, formerly belonging to Valle degli Zappini Forma-

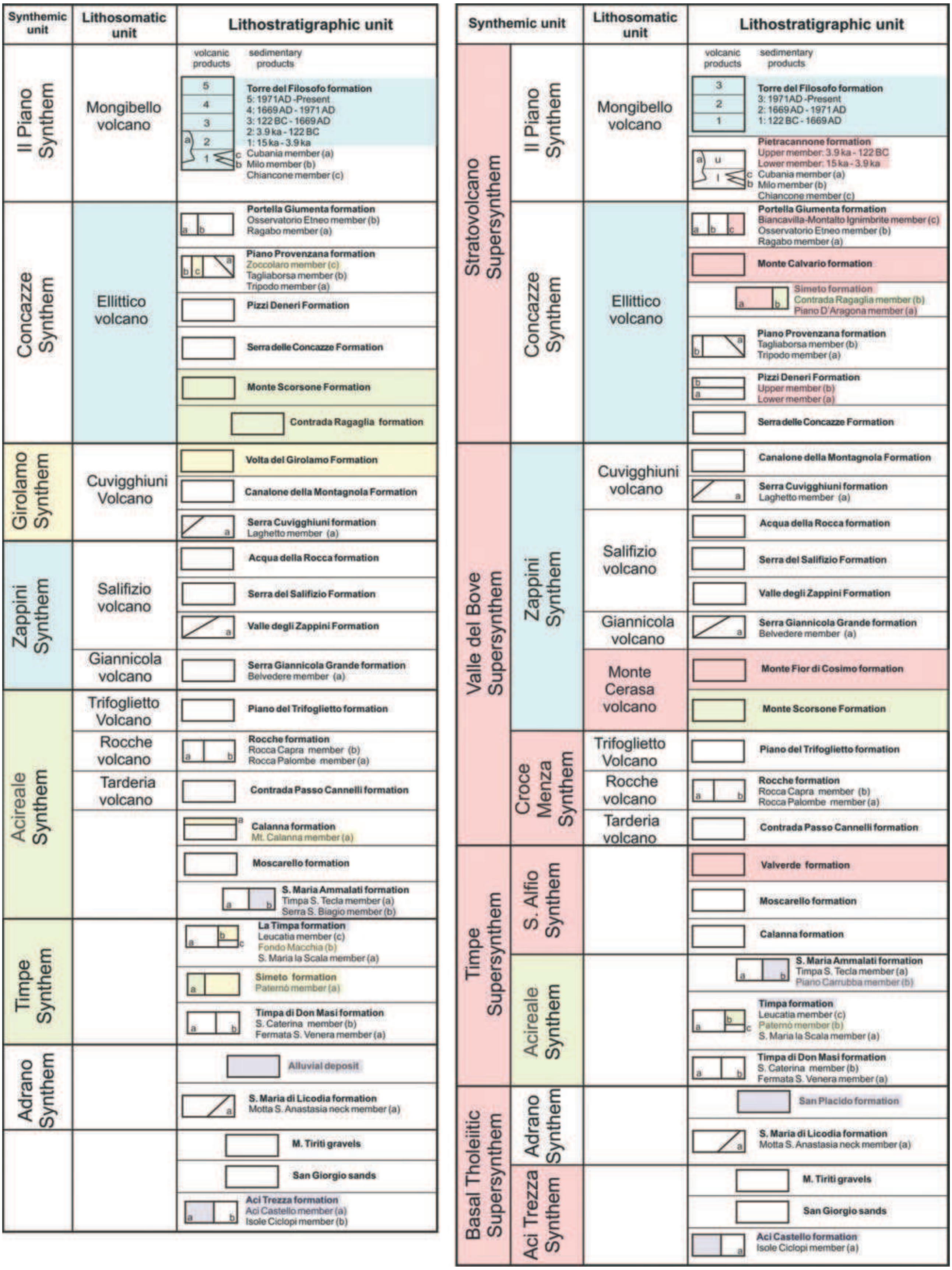

Fig. 14 - Comparison between stratigraphic relationships schemes of the CARG project maps (left) (Servizio Geologico d'Italia 2009a and b, 2010a and b) and of the present geological map (right). Legend of the colour in background: red=new stratigraphic units; light blue=modified boundaries of stratigraphic units, without changing stratigraphic position; green=new stratigraphic position and/or rank of previously defined stratigraphic units; purple=new naming of previously defined stratigraphic units without changing stratigraphic position and extension; yellow=removed stratigraphic units.

tion of Foglio 625 Acireale (Servizio Geologico d'Italia, 2009a) on the basis of a new radioisotopic dating (De Beni *et alii*, 2011) and its lithological features and stratigraphic relationships.

15. The volcanics of Volta del Girolamo formation (Servizio Geologico d'Italia, 2009a) are now attributed to the Canalone della Montagnola Formation because of their limited extension.

16. As a consequence of point 13, we shifted the base of the Ellittico volcano from the Monte Scorsone Formation (Servizio Geologico d'Italia, 2009a) to the Serra delle Concazze Formation, constraining the beginning of its activity at about 57 ka (De Beni *et alii*, 2011).

17. Pizzi Deneri Formation is made of two members (lower and upper members) as defined on the northern wall of VdB for the first time by Coltelli *et alii* (1994) mapped on the summit areas, at Punta Lucia and on the western wall of VdB.

18. We introduced the Simeto formation in the Ellittico volcano succession. It includes both the Piano D'Aragona member made of alluvial deposits and the Contrada Ragaglia member made of debris deposits (with reference to Servizio Geologico d'Italia 2009a, we changed the rank of the latter unit from formation to member). Simeto formation marks the erosional processes occurring on the slopes and at the periphery of the Ellittico volcano.

19. We mapped each lava flow and associated pyroclastic deposits belonging to the Piano Provenzana formation.

20. We defined for the first time Monte Calvario formation, made of autoclastic lava flows erupted during the final stage of Ellittico volcano.

21. Within Portella della Giumenta formation we introduced a new member, called Biancavilla-Montalto Ignimbrite, to preserve the former name of Romano (1982) and De Rita *et alii* (1991), originated from the Ellittico caldera-forming eruptions.

22. We mapped each exposed lava flow of Mongibello volcano (last 15 ka, covering 88% of the entire surface of Mt Etna) on the entire edifice (see Digital Supplementary data) that in Foglio 625 Acireale were grouped in the Torre del Filosofo Formation (Servizio Geologico d'Italia, 2009a) and now are split into two formations: Pietracannone and Torre del Filosofo.

23. We defined for the first time Pietracannone formation that groups the volcanic and volcaniclastic deposits erupted after the Ellittico (15 ka) up to Il Piano caldera collapses (122 BC). This formation has been split in two members based on a marker lithohorizon (FS fall-out layer of Coltelli *et alii*, 2000).

24. The volcanic products Torre del Filosofo formation have been restricted to the last 2 ka, previously they extended to the entire Mongibello volcano (Servizio Geologico d'Italia, 2009a). They have been displaced into 3 time intervals allowing us to show evidence of the temporal and spatial evolution of the historical eruptive activity.

2D AND 3D RECONSTRUCTION OF ETNA VOLCANIC EDIFICE

The main geological results obtained from the detailed stratigraphic reconstruction of Etna volcanic succession are clearly evidenced through the UBU distribution (fig. 15). In fact, the recognition of several first order unconformities within the volcanic succession allow defining 8 synthems that mark the main stages of Etna's geological evolution described in this volume by Branca *et alii* (2011). In particular, the 2D representation of rock distribution based on synthems (fig. 15) shows the main changes of the volcanic activity occurring in the Etna region during the past 500 ka. The early volcanic phase (Basal Tholeiitic Supersynthem) was characterized by discontinuous and scattered fissure-type volcanism occurring about 500 ka in the Pleistocene Gela-Catania Foredeep basin (Aci Trezza Synthem) now exposed near the Ionian coast, and subsequentely, about 330 ka, erupting in a subaerial environmental (Adrano Synthem) presentely cropping out on the south-western perifery of the volcano. Starting from about 220 ka (Timpe Supersynthem) eruptive activity concentrated mainly on the Ionian coast, transforming a scattered volcanism into shield volcano-forming activity (Acireale synthem). During S. Alfio Synthem the eruptive activity shifted from the Ionian coastal belt to the central portion of Etna region. In this area during the Valle del Bove Supersynthem a stabilization of the volcano feeding system occurred from at least 110 ka, as indicated by the growth of three earliest polygenic volcanic centres (Tarderia, Rocche and Trifoglietto) during the Croce Menza Synthem and other four volcanoes (Monte Cerasa, Giannicola, Salifizio, Cuvigghiuni) during the Zappini Synthem. Finally, during the Concazze and Il Piano synthems (Stratovolcano Supersynthem) the most recent north-westward shifting of the shallow feeder system of Etna volcano occurred from at least 57 ka ago, when the bulk of the present edifice formed. Therefore, from 15 ka ago, the younger volcanics mantled most of the previous edifice (88%) with a widespread cover of lava flow fields and pyroclastc deposits concentrated on the summit area and close to the numerous lateral vents.

On the basis of the 2D distribution of the synthemic units, we present a schematic geological cross section, at 1:100,000 scale in the map, in order to show the 3D structure of the volcano edifice (fig. 16). The cross-section is N-S oriented from the Alcantara River through Etna's summit craters (cutting La Voragine and Bocca Nuova craters and the west base of NE crater) down to about 500 m elevation near the town of Belpasso where it shifts toward SSW. On the south side of the cross section, the isolated volcanic neck of Motta S. Anastasia belonging to the Basal Tholeiitic Supersynthem (Adrano Synthem) is intruded into the Foredeep Quaternary sediments. Upslope, the thin volcanics of Acireale Synthem, belonging to the Timpe Supersynthem, rest on the basement along the southern border of the volcano. In the central portion of the cross section, the polygenetic structure of Etna edifice is clearly shown by the Valle del Bove Supersynthem, with the superposition of Croce Menza and Zappini Synthems, which are completely covered by the products of the Stratovolcano Supersynthem (Concazze and Il Piano Synthems) extending up to Alcantara and Simeto river valleys. At the Etna summit, Concazze Synthem is dissected by the ring-faults generated during the plinian eruptions that formed the Ellittico caldera about 15 ka (Kieffer, 1979; Romano, 1982; Coltelli *et alii,* 2000). This caldera depression is filled by the volcanics of Il Piano Synthem, which form a rather thin drape on the volcano flanks outside the caldera rim. Il Piano Synthem

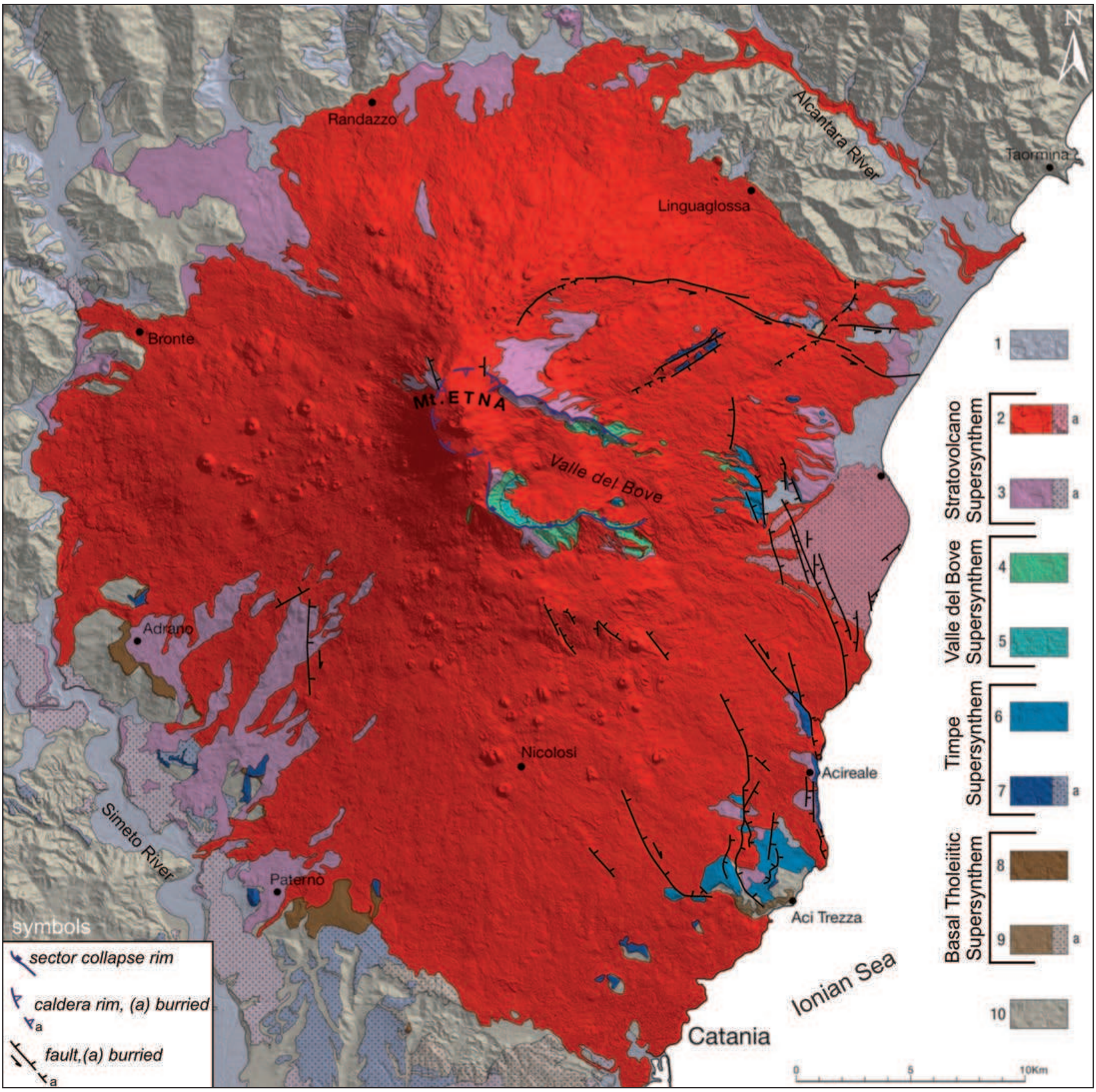

Fig. 15 - Scheme of the synthems recognized in the stratigraphic framework of Etna: 1) Present and recent covers; 2) Il Piano Synthem *a*) sedimentary deposits; 3) Concazze Synthem *a*) sedimentary deposits; 4) Zappini Synthem; 5) Croce Menza Synthem; 6) S. Alfio Synthem; 7) Acireale Synthem *a*) sedimentary deposits; 8) Adrano Synthem; 9) Aci Trezza Synthem *a*) sedimentary deposits; 10) Sedimentary and metamorphic basement.

volcanics fill the Ellittico caldera and are in turn dissected by the ring-faults generated during the 122 BC plinian eruption forming the Il Piano caldera. This historical caldera collapse caused the obliteration of the Ellittico caldera along its southern rim. The present shallow feeder system of Etna was reconstructed through seismic tomography data (PATANÈ *et alii*, 2006). We have located the top of the 122 BC plinian eruption magma chamber between 0 and 500 m a.s.l. on the basis of the pressure value estimated by the volatile content in melt inclusions of the 122 BC magma (DEL CARLO & POMPILIO, 2004). The morphology of the basement was reconstructed using the few existing information reported in literature (BRANCA & FERRARA, 2001; CASSA PER IL MEZZOGIORNO, 1983). Concerning the sedimentary basement, we grouped the lithostratigraphic units belonging to the Sicilide Tectonic Unit into subunits and according to the different sedimentation basins in Neogene basin cover and Foredeep quaternary deposits. The geometry and attitude of the sedimentary units have been reconstructed below the

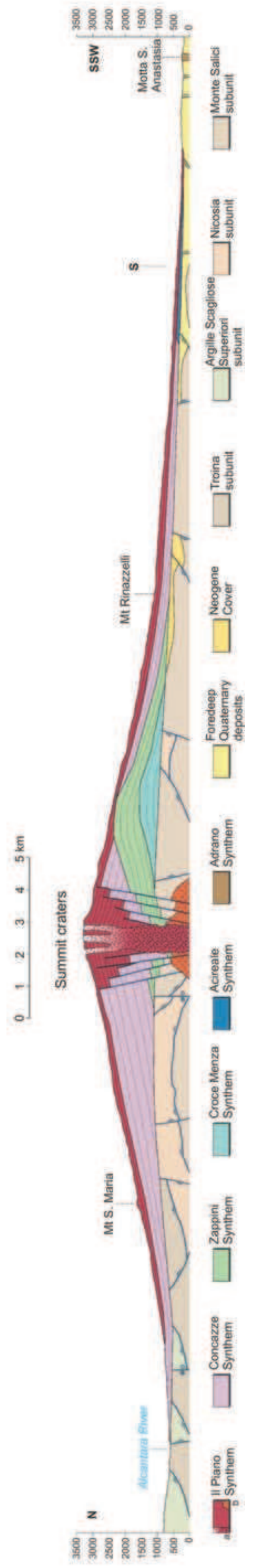

Fig. 16 - Schematic geological cross-section of Mt Etna, in which the internal structure of the composite volcano formed by the superimposition of several polygenetic stratocones is evidenced Present feeder system (*a*). 122 BC plinian eruption magma chamber (*b*).

volcano using the few borehole data in literature and projecting the attitude of the strata and the main structures cropping out immediately westward of the cross section.

CONCLUSIONS

The new geological map of Etna volcano, the third one to be published in 150 years, complies fully with the suggestions of the international commissions for geological mapping. The exclusive use of stratigraphic criteria constrained by radioisotopic datings enables elaborating a complete spatial-temporal reconstruction of Etna's volcanic succession from the early volcanics erupted in a submarine environment to the present eruptions from a large stratovolcano. Etna's volcanic succession is represented in the map by 27 lithostratigraphic units whose lithological and geometrical features allow depicting the geological evolution of the volcano in phases based on the classification in synthemic units (supersynthem rank). Indeed, the supersynthems enable to objectively summarize the geological history of Etna volcano into four main phases, as previously proposed by BRANCA *et alii* (2004a). The supersynthem unconformities mark the main changes of Etna volcanism and likewise represent a well-defined period in which the eruptions occurred with similar eruptive style. Starting from the scattered fissure eruptions of the Basal Tholeiitic Supersynthem, the volcanism reaches the central and almost persistent eruptive activity condition of the Stratovolcano Supersynthem through the Timpe Supersynthem, a polygenetic shield volcano, and then the Valle del Bove Supersynthem, the first composite central edifice, whose plumbing system was located at about 5 km southeast of the present one. This geological evolution marks the significant changes in the style of eruptive activity and, consequently, in the rate of the magma rising from the mantle and then erupted at the surface, which has increased during the volcano's life up to the present maximum.

The new geological map of Etna volcano provides an enhanced framework for the reconstruction of the past eruptive history through new detailed stratigraphic data on the recognized 357 lava flows and associated pyroclastic deposits belonging to the Mongibello volcano, the most recent volcanic centre still in eruption. Concerning the historical period, 112 lava flows were mapped from 122 BC to the present, enabling completion of the dataset of historical eruptions realized by BRANCA & DEL CARLO (2005). Spatial and temporal relationships are available for all the lava flows of the Mongibello and partially Ellittico volcanoes, even though age, vent location, and areal distribution are necessarily less precise the further back in time we go.

The reconstruction of Etna eruptive history represents the basic information for the petrological study of magma evolution. The age and volume of past eruptions can help constraining models of the chemical evolution of the magma during its ascent from the mantle and subsequent storage in the crust.

Geophysical models of the Etna plumbing system will also benefit from an accurate reconstruction of its eruptive history because the features of the past eruptions can be considered as proxies of the inner structure of the volcano and as indicators of the stress field, location of the magma reservoir and timing of its inflow and outflow. Also in this case, the age and volume of the past eruptions constrain the geophysical models and may help researchers to compute robust simulations that can be used, on the basis of the observed geophysical signals, in the probabilistic forecasting of eruptions.

Modern volcanology lends most of its effort to applied science, focusing on the mitigation of destructive effects of the volcanic eruptions mainly through monitoring, eruption forecasting and assessment of volcanic hazard. The issuing of a new geological map of Etna, associated with an updated eruptive history, can be considered the basic information for all these applications. Reconstruction of the past eruptions for magnitude, recurrence-time, vent location and eruption style, provide information that can be used in future to adapt the geophysical sensor network to best observe possible precursors and eruption sensitive parameters. For the Etna hazard assessment, the reconstruction of past eruptions is a critical element for studying the past volcanic eruptions statistically in a representative time-span, and for furnishing input data to the eruption simulations by means of numerical modeling; on the other hand, it enables using the previous eruptions as a key to interpreting short- and long-term forecasting scenarios produced by a large number of simulations needed to compile the volcano hazard map.

The previous goals may be fully achieved using the large amount of data contained in the new geological map of Etna volcano. We hope it will prove to be a keystone for new generation of volcanic studies at Etna in the spirit of the forerunner Sartorius von Waltershausen, who began the scientific investigation of this great volcano using geological tools.

ELECTRONIC SUPPLEMENTARY MATERIAL

This article contains supplementary material, which is available online to authorized users (DOI: 10.3301/IJG.2011.15).

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