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Florence - Italy
August 20-28, 2004

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VOLCANIC ACTIVITY AT MOUNT ETNA (SICILY)

Leader: R. Cristofolini

Associate Leader: G. Frazzetta

Post-Congress **P32**

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AUTHOR: *R. Cristofolini (Università di Catania - Italy)*

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Front Cover:

Northwestern flank of Etna, Punta Lucia, October 2002.
The plume of white steam rises from the summit craters,
and the gray ash-laden one from the vents at 2700 m a.s.l.,
on the southern flank of the volcano.

Leader: R. Cristofolini
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Introduction

Mount Etna, one of the largest active volcanoes in the Mediterranan area and the largest in Europe, covers an area of about 1,260 km^2 reaching at its top an elevation of 3,350 m a.s.l. Etnean magmas show peculiar petrologic and geochemical features, related to a very complex structural setting.

The volcanic activity is at the base of myths and legends from classical times on; the most ancient known records on Mount Etna, one of the "workshops" of the Latin god Vulcanus, and on its eruptive activity , date back to several centuries B.C., being clearly reported in chronicles by historians (Tucydides and Diodorus) or recalled in poems (Pyndarus).

The Etnean area comprises 37 townships of the Catania Province, with a heavily urbanized peripheral belt, especially in its south-eastern sector, where about 700,000 people are living in the Catania metropolitan area, up to elevations of 800 m. Higher up, residents are much less concentrated, and a natural Park was established in 1987 by the Sicilian Region, over an area of almost 600 m^2.

Mt. Etna's products range from basal tholeiites to members of a Na-alkaline series (mostly hawaiites – mugearites), that show evidence of an imprint from calcalkaline components. The overall volcanic sequence is composed of lava flows, air-fall and (scarce) pyroclastic flow deposits and lahars, erupted by distinct volcanic centres. The field trip is chiefly aimed at giving the opportunity to discuss the diverse parameters that control the volcanological and petrological features of the volcano, and on its hazard-related issues.

Regional geologic setting

Etnan activity started around 600 ka BP (Gillot et al., 1994), after the end of Late Pliocene to Pleistocene subaqueous and subaerial eruptive activity at the north-western edge of the Iblean Plateau. Mt. Etna is a multiple stratovolcano, consisting of various edifices centered on distinct eruptive axes, the most recent of which may be still recognized. In the 19th century two main centers of activity were identified by S. von Waltershausen (1880), and C. Gemmellaro (1860): the younger of the edifices was named "Mongibello" (a combination of the Latin *mons* and Arab – *gebel*: words used as the local name for the mountain), while the older one, related to a separate magma uprising system, was called "Trifoglietto". In recent decades Etnean volcanism occurred in many different eruptive centers, grouped into five major volcano-stratigraphic units (Romano, 1982; Cristofolini et al., 1991; Gillot et al., 1994): namely, Units of the Basal Subalkaline (tholeiitic to transitional) lavas (600-250 ka), Ancient Alkaline Centers (225-100 ka), Trifoglietto (80-40 ka), Ancient Mongibello (also known as Ellittico; 35-14(-5) ka) and Recent Mongibello (14(-5) ka to Present).

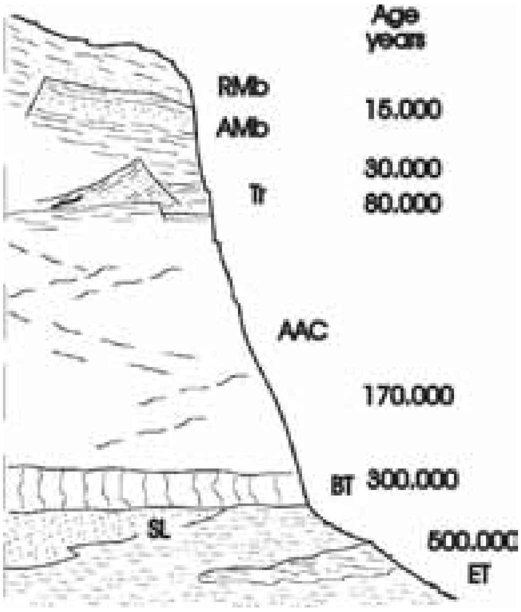

Figure 1 - Schematic representation of the Etnean succession (modified after Cristofolini and Romano, 1982). RM: Recent Mongibello; AM: Ancient Mongibello; TR: Trifoglietto Unit; AAC: Ancient Alkaline Centres; BT: Basal Tholeiitic to transitional lavas (mostly subaerial); ET: Earliest Tholeiites (submarine and subvolcanic); SL: Sedimentary pleistocene Levels

In recent years an UBSU (Unconformity Based Stratigraphic Units) approach has been adopted for the Etnean sequence (cf. Coltelli et al., 1994), as well as for other Italian volcanoes, within the framework of surveys done for a new Geological Map of Italy: a tentative correlation between the high-rank new formal Units and the earlier ones, for successions younger than 100 ka, is given in Table 1.

Mount Etna is located at the edge of a major crustal discontinuity; the subaerial edifice is actually placed over the still-uprising, uplifted footwall (Monaco et al., 1997) of a Upper Quaternary

Modified after COLTELLI et al., (1994)		Modified after ROMANO (1982)	
Syntheme	Lithosomatic Unit	Unit	Centre (Edifice)
Il Piano		MONGIBELLO	Recent Mongibello
Le Concazze	Ellittico Pomiciaro Tripodo		Ellittico
Cuvigghiuni		TRIFOGLIETTO	Vavalaci
Giannicola	Salifizio Giannicola Grande Trifoglietto		Trifoglietto 2
	Rocca Capra	ANC. ALK. CENTRES	Trifoglietto 1
			Calanna

Table 1 - Tentative correlation between UBS Units and earlier ones for the Etnean succession more recent than about 100 ka.

crustal-scale belt of normal faults (Hirn et al., 1997; Laigle, 2000; Bianca et al., 1999), which partially reactivated the Malta Escarpment, a NNW-SSE Mesozoic discontinuity separating the domains of continental crust of the Pelagian Block (Iblean Plateau; Ben Avraham et al., 1995; Torelli et al., 1998) from the thinned crust of the Ionian Sea (Makris et al., 1986). This belt intersects another regional fault system, parallel to the coast line between Taormina and Messina (NE-SW), next to the front of the south-verging overthrust pile of the Apennine-Maghrebian mountain range. This implies that complex extensional tectonics had -- and still have -- a dominant role in the time-space evolution of volcanism at Mt. Etna. Thus, the volcano appears in an anomalous position, and its tholeiitic to Na-alkaline geochemistry and regional geophysical data suggest magma sources unrelated to deep crustal slabs. The relationship between the foreland monocline, at the front of the Apennines - in the Ionian Sea rather than in Sicily -, and the extension of the Apennine arc, all should produce a right-lateral transtensional and a sort of vertical “slab window” which might explain (i) the Plio-Pleistocene uprising of mantle generated magmas in eastern Sicily and (ii) the Late Pliocene to present, right-lateral transtensional tectonics and seismicity of eastern Sicily. The area of transfer of different dip and rollback occurs along the inherited Mesozoic continental margin between Sicily and the Ionian Sea, i.e. the Malta escarpment (Gvirtzman and Nur, 1999; Doglioni et al., 2001).

The volcano is an Upper Quaternary structure, the bulk of which is composed of lavas and tephra erupted during the last 225 ka (Gillot et al., 1994).

From north to south, the volcanic cover lies above a sedimentary substratum at the front of the Maghrebian thrust belt, Upper Miocene terrigenous levels, and Lower-Middle Pleistocene foredeep sedimentary clayey successions, deposited on the flexured margin of the Pelagian block.

Etnean magmas originate from a probably heterogeneous mantle source, as shown by minor element and isotope data, before then rising up into the crust (Condomines et al., 1995; Gasperini et al., 2002). Petrographic data, as well as information on mineral phases, fluid and melt inclusions, and seismological evidence suggest that magma resides within a 20- to 15-km-deep reservoir, just above the base of the continental crust (probably a plexus of magma-filled fractures; see Figure 1), and in shallower and smaller chambers, where it differentiates and eventually gives rise to the activity of the various centers, which followed each other in time (Kamenetsky and Clocchiatti, 1996; Busà et al., 1999; Murru et al., 1999; references therein). Provided that the mantle xenoliths, carried to the surface by alkaline and hyper-alkaline magmas that erupted during the Miocene and Pleistocene in the Iblean area, (Tonarini et al., 1996; Sapienza and Scribano, 2000) are representative also of the mantle underneath Mt. Etna, their Th/Yb vs. Ta/Yb ratios suggest compositions from normal to enriched (EMS), possibly related also to an influx of intraplate components according to Pearce (1982). An HIMU source, for at least a part of the Etnean magmas, has been postulated on the grounds of geochemical data (Gasperini et al., 2002; Cristofolini R., unpubl. data). On the other hand, the Etnean volcanics, especially the alkaline ones, show some clear imprints of a calc-alkaline nature, both in their major and minor element chemistry (cf. Cristofolini & Romano, 1982; Busà et al., 1999; references therein); their isotope features, however, exclude a substantial contribution from continental crust components (Armienti et al., 1989; Barbieri et al., 1993; Carter and Civetta, 1977; Tonarini et al., 1995). Etnean magmas eventually attain a mildly potassic character, which is also associated with a LILE enrichment; these characters are still a matter of debate, and might depend on either the heterogeneous nature of the source or on contamination of the melts while ascending through the upper mantle and continental crust.

Recent geophysical data consistently shows that magma inputs from depth may be stored at different levels and eventually rise up to the surface, feeding the activity at summit and/or peripheral vents. Based on geophysical and geochemical evidence, large amounts of magma are probably removed, through gravitational convection, into subvolcanic reservoirs, where they may ultimately solidify within the crust, contributing to the accretion of a wide "plutonic complex" (Allard, 1997).

A large amount of data from structural geology and geophysics shows that the main uprising paths of Etnean magmas through the crust are aligned along the "Iblean-Maltese" belt, and that only at relatively shallow levels may other systems act as feeders of eruptions from parasitic vents (Frazzetta and Villari, 1981; Lanzafame and Bousquet, 1997; Lanzafame et al., 1997; Gresta and Patanè, 1987; Mc Guire et al., 1989; Monaco et al., 1997; Azzaro et al., 1998; Cardaci et al., 1993; Cocina et al., 1997; De Luca et al., 1997; Gresta and Patanè, 1987; Gresta et al., 1990, 1997; Lo Giudice and Rasà, !986; Patanè et al., 2002).

The seismic and deformation patterns observed at Mount Etna before and during the 1991-1993 eruption, one of the largest since the seventeenth century in terms of lava volume ($250 \bullet 10^6$ m^3), are consistent with the regional tectonics of eastern Sicily (Bonaccorso et al., 1996). The stress field in the intermediate and lower crust, defined at the local scale by fault-plane solutions (**NB** "*f-p s*" *is the common definition of assessing the trends and characters of fault-planes originating earthquakes)* of microearthquakes occurring at depths between 10 and 25 km beneath the volcano, is consistent with a strike-slip compressional regime, with σ_1 acting approximately N-S. Seismological data show that sinistral shear ruptures commonly occur along faults trending roughly NE-SW, whereas dip-slip ruptures affect approximately NNW-SSE fault zones. These were the conduits followed by the magma which fed the 1991-1993 eruption, as modeled based on ground deformation data (Bonaccorso et al., 1996). Local and temporary changes of the regional stress field may occur in the upper crust, favoring the magma's ascent into shallower levels; this might mean that uprising and intruded magma could modify the regional stress pattern (Patanè and Privitera, 2001; La Delfa et al., 2001)

After the deflation during the 1991-1993 flank

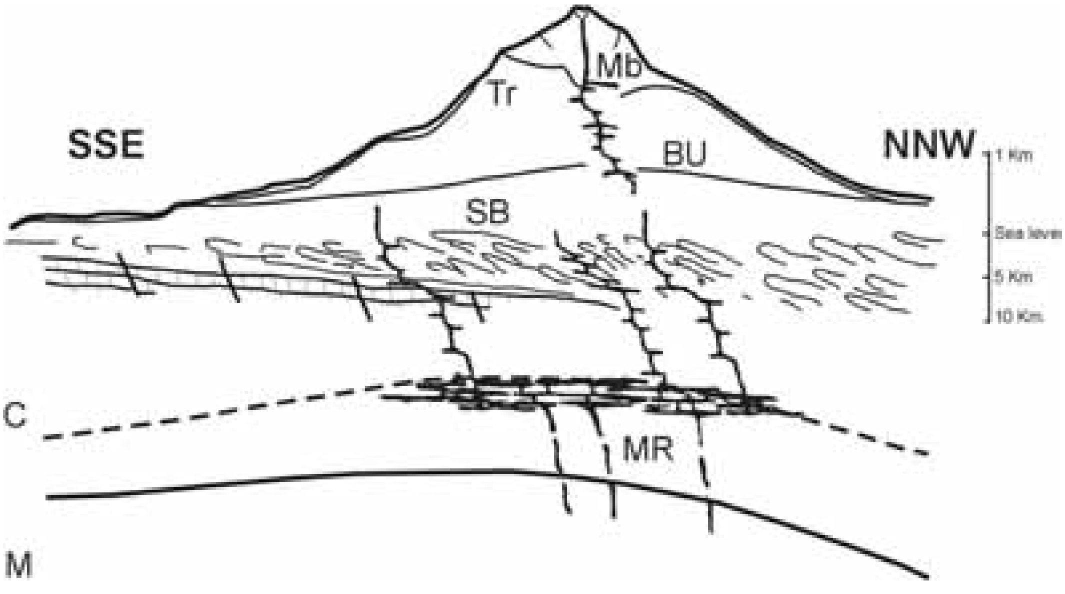

Figure 2 - Cross-section sketch, NNW-SSE (Randazzo – Summit area - Acireale) of Mount Etna, showing the relationship between the main units within the volcanic sequence and the underlying basement. Note the different scale of elevations above and below sea level (lm). Mb: Mongibello Unit; TR: Trifoglietto Unit; BU: Basal volcanic Units (older than 80 ka); SB: Sedimentary Basement Successions; MR: Main agma reservoirs; C: Continental crust; M: Mantle.

eruption, starting in 1994, Mount Etna underwent a fast inflation related to the intrusion of large volumes of magma into the volcanic structure at depths of 6 to 15 km (Patanè et al., 2003). The increased pressure within the Etnean reservoir system triggered most of the seismicity and resulted in the volcano's inflation and eruptive activity, from 1998 onward, at the summit vents and on the flanks of the volcano (Patanè et al., 2003). Microgravity data acquired at Mt. Etna over 5 years (1994-1999) showed a complete cycle of gravity increase (1994-1996) - decrease (1997-1999), in the south-eastern sector of the volcano, with a maximum amplitude around 100 mμGal peak-to-peak (Carbone et al., 2003); the gravity changes are consistent with volumes between 3 and 10 • 10^8 m^3 of magma rising into a dike-shaped reservoir trending NNW-SSE and placed 2-4 km b.s.l. under the southeastern sector of the volcano, between 1994 and 1997, and later partly sunken again to deeper levels, since most of it was not erupted or accumulated at shallower levels.

Mount Etna, although situated on continental crust, shows oceanic basalt affinities (Gvirtzman and Nur, 1999), with isotopic ratios of helium and carbon suggesting that it is fed by the same type of mantle source as are intra-plate oceanic basalts. Five years of gas monitoring from selected sites suggests that Mt. Etna's plumbing system extends much farther than previously reported, at least 40 km to SW, along the NE-SW regional fault, where about 200 tons/day of gas are discharged: variations of ^{3}He / ^{4}He isotopic ratios in this gas are synchronous with pulses of ascending magma in the Etnean feeding system (Caracausi et. al., 2003), thus providing a powerful tool for predicting eruptions.

Continuous activity, sometimes accompanied by violent outbursts, has been observed since 1995 in at least one of the three summit vents (NE Crater, Voragine (= *Chasm*), and Bocca Nuova), ending with a series of 20 short-lived eruptions from the SE Crater between September 1998 and January 1999. In February 1999 a mild eruption took place from a fissure on the SSE flank of the SE cone in the summit area. These phenomena might be interpreted as due to injection of mafic and gas-rich magma coming from depth into small, shallow reservoirs (likely a plexus of dikes), as shown by geophysical data. While ascending, the new magma mixed with more evolved ones, as shown by crystal zoning, melt inclusion and geochemical data (La Delfa et al., 2001). Later on, the SE Crater was characterized by violent eruptive activity between January 26 and June 24, 2000. This activity produced 64 lava fountain episodes, with rest periods from between 3 hours to 10 days. The estimated overall volume of erupted lava and tephra is about 15-20 • 10^6 m^3, and at least 2-3 • 10^6 m^3 respectively.

The eruptive dynamics of the July-August 2001 and October 2002-January 2003 eruptions at Mt. Etna provide new insights for modeling the development of magma feeding systems and their relationships to regional tectonics (Bonaccorso et al., 2002).

The 2001 eruption took place mainly on the upper part of the southern sector of Mt. Etna, with eruptive vents at the South-East crater, Piano del Lago, and Montagnola area. The eruption was preceded by a large earthquake swarm a few days before its onset, and accompanied by a relevant ground deformation and fracture opening. Erupted lavas are hawaiites to trachybasalts on the grounds of their K_20 / Na_2O (Le Maitre, 1989). Their overall features suggest feeding systems for the lower vent activity that are distinct from the summit ones as a response to local and regional tectonics. (Behncke & Neri, 2002; Monaco et al., 1997). The eruptive activity started again at the end of October 2002, and its onset was accompanied by a seismic swarm. Along the NE Rift Zone, about 20 eruptive vents, aligned between 2500 and 1900 m a.s.l., were active for about one week, whereas on the southern flank activity went on from October 2002 to January 2003, from vents placed between the summit area and the Montagnola (3000-2500 m a.s.l.). This eruption is reported as one of the most explosive of the last centuries, due also to some water-magma interaction (Dellino and Kyriakopouls, 2003), but it is not to be considered exceptional, if one takes into account the diffuse presence of very large, recent, cinder cones scattered on the flanks of Mount Etna (Del Carlo and Branca, 1998). Just as in the 2001 eruptive event, two independent feeding systems, characterized by distinct magmas, were active on the southern and northern slopes.

These eruptions, characterized by relevant seismicity, diffuse ground fracturing, strong explosive activity and petrographically distinct lava flows offered an opportunity for collecting detailed seismological, structural and volcanological data.

The oldest volcanics (600 ka BP) are submarine tholeiitic to transitional basalts, erupted at depths around 500 m b.s.l.(Corsaro and Cristofolini, 2000), in a wide gulf extending between the northern mountain chain and the Iblean Plateau to the south. These are found now, associated with Upper Pleistocene marly levels, as very limited outcrops of pillow lavas**,** hyaloclastites and sills (Corsaro and Cristofolini, 1997) along the Ionian coast, next to Acitrezza and Acicastello. Similar lavas and minor Na-alkaline products, however, are found, at the downthrow side of the NNW-SSE fault belt, on the Ionian sea floor at depths between 800 and 1,300 m b.s.l. (Coltelli M. and Pompilio M., pers. comm; Cristofolini R., unpubl. data) offshore of Acireale. Subaerial tholeiites, around 300 ka old, erupted after a strong regional uplift, are found on the oldest river terrace of the Simeto River, around 300 m higher than the present-day valley-bottom: they currently outcrop at the south-western periphery (Adrano – Paternò) of the volcanic cover, but probably spread over much wider areas; they are presently buried under later volcanics, as shown by drill-hole samples (Cristofolini et al., 1991) and by the diffuse presence of tholeiite boulders in the oldest river terraces' deposits.

These earlier levels are most commonly aphyric to oligophyric basalts, whereas the later volcanics, generally varieties related to Na-alkaline basalt magmas, mostly are markedly porphyritic hawaiites to mugearites, often joined by more differentiated benmoreites to trachytes.

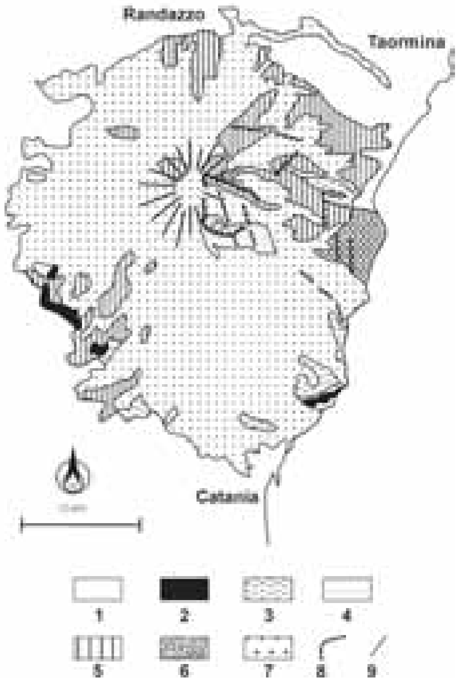

Figure 3 - Sketch map showing the distribution of the main units of the Etnean volcano. 1) Sedimentary basal levels; 2) Tholeiites; 3) Ancient Na-alkalic levels (basalts and hawaiites); 4) Trifoglietto Unit (mugearites); 5) Detrital alluvial fan originated from the Valle del Bove; 6) Ellittico volcano levels (Mongibello Unit; hawaiites to trachytes); 7) Recent Mongibello (hawaiites and mugearites); 8) Edge of the Valle del Bove; 9) Major faults.

Small central volcanoes, fed by transitional to prevailingly Na-alkaline magmas, similar to intra-plate oceanic types, started to develop (around 200 ka BP) above the earliest subalkaline volcanic levels. Most of these edifices, related to the activity of the Ancient Alkaline Centers and of the later Trifoglietto Unit, are strongly dismantled by erosion and widely covered by younger volcanics; their products chiefly crop out only along fault scarps (locally named "Timpe") or uplifted cliffs , and along the inner walls of the Valle del Bove (E flank), a prominent feature of the Etnean morphology, which is a deep horse-shoe shaped valley carving the eastern flank of the volcano. Its origin still is a matter of debate: it might have been formed by caldera collapses of ancient edifices, easterly sliding of the seaward unbuttressed volcanic mass, or rapid erosion of steep flanks (cf. Guest et al., 1984; Mc Guire and Pullen, 1989; Calvari et al., 1998). Large amounts of detrital materials derived from the Valle del Bove are now forming an alluvial fan in the vicinity of Giarre-Riposto (cf. Calvari et al., 1996).

Within the old volcanic sequence, starting from at least 100 ka ago (Coltelli et. al., 2000), volcaniclastic levels (pyroclastic fall and flow deposits and lahars, largely resulting from debris-flow) are interbedded with lava flows, attesting to effusive to highly explosive subplinian to plinian activity (Busà et al, 1997; Cortesi et al., 1988, Coltelli et al., 1995, 2000; Cristofolini et al., 1991). As a consequence of this behavior, most of the edifices making up the complex structure of Mount Etna show features of strato-volcanoes. At about the same time, the main feeding systems tended to take a better defined location, probably at intersections of faults of the two afore-mentioned major regional belts (the NNW-SSE "Iblean-Maltese" and the NNE-SSW systems), which act as the preferred feeding structures of the volcano, gave rise to distinct edifices, of which the latest, and largest, is Mongibello, rising above the older ones from elevations around 1700 m up to the present-day summit.

In the eastern sector, among the earliest mafic alkaline volcanics, low-P_2O_5 (< 0.6%) alternate with high-P_2O_5 (> 0.7%) levels. Later products of the Trifoglietto Unit, generally amphibole-bearing Ti-depleted mugearites, may be interpreted as having differentiated from high-P_2O_5 basalts (Busà et al., 1999; Busà & Cristofolini, 2000).

The most recent activity (Mongibello, < 35 ka BP) was characterized by recurrent, significant explosive activity, up until a few thousand years ago. Paroxysmal eruptions gave rise to calderas, the most recent of which are still recognizable, although largely filled

Year	Flank	Duration (days)	Vent m a.s.l.	Fronts m a.s.l.	Length (km)	Area (km^2)	Volume (10^{6}m^3)
1634-38	South	1224	2050	450	9.5	12.6	105
1669	South	122	825	0	16.0	37.5	977
1792-93	South	370	1950	600	6.5	8.0	80
1892	South	173	1913	970	7.0	10.0	111
1911	North	13	2310	550	7.5	6.3	65
1928	East	18	1900	25	8.0	5.0	40
1950-51	East	372	2530	800	10.0	10.5	168
1971	South	32	2965	2500	3.5	3.4	35
1971	East	36	1820	780	6.8	4.1	40
1979	East	4	2850	870	6.5	7.5	75
1981	North	7	1883	600	7.5	6.0	30
1983	South	131	2410	1020	7.0	6.0	70
1991-93	East	473	2420	730	8.0	7.0	250

Table 2 - Some data on eruptions in historical times

by younger products ("*Ellittico caldera*", 15 ka, ca. 4.5 km across; "*Piano caldera*" 122 b.C). During the recent centuries, explosive activity of Mongibello has been quite mild, almost persistent at the summit vents, while sporadic at lateral vents. The intensity of summit vent phenomena is very variable (quiet steam emission to strombolian explosions and lava fountaining), sometimes associated with small lava effusions, lasting a few hours up to several months -- or even years. At present there are several vents in the top region (the Chasm, and the Western, North-eastern, and South-eastern vents), each behaving independently, suggesting a complex system feeds their activity.

Peripheral vents can open also at low elevations (down to 300 m a.s.l.), even outside the edge of the volcanic cover (Gravina di Catania, Mojo Alcantara). They mostly pour out lava flows, with tephra originating modest spatter ramparts to large cinder cones, either isolated or associated along the feeding fractures that mark the Etnean landscape; the most recent eruptions (summer 2001 and winter 2002) are to be ascribed to this last type of fairly explosive eruptions. The parasitic vent activity lasts from a few days to several months, and, exceptionally, for years; flow volumes and shapes depend on eruption duration and rate, as well as on flank topography. In the last 350 years, around 70 eruptions have occurred, irregularly distributed over time and space (cf. Romano and Sturiale, 1982).

Recent lavas are mostly *aa*, and less commonly *pahoehoe*, or they have their surface covered with irregular slabs, variously embricated or piled on top of each other. In these flows complicated *tube* systems may form (cf. Calvari and Pinkerton, 1999), along which the thermally insulated melt can flow over great distances, feeding lava fronts as far as 10 km or more from the vents. Almost 60% of the Etnean region has been covered by at least one lava flow since the 13th century, including even some densely populated sectors at low elevations down to sea level, among which the south-eastern one is currently the most relevant.. Even if the recent activity is only moderately hazardous for human lives, it seriously threatens all human activities in this densely populated area, because of the lava flooding's complete destruction of the surface, which then remains barren for centuries.

Even if active attempts at damage mitigation were done in 1983, 1992, 2001 and 2002 by attempts at damming and/or diverting the natural flow course, they are still to be considered preliminary, and may be tested only under favorable conditions. At present, main hazard reduction measures consist in designing detailed evacuation plans for the populated areas likely to be involved in eruptive episodes.

Field trip itinerary

Itineraries and scheduled days may be changed due to weather and/or eruptive conditions.

Day by day, with locations and main topics

DAY 1

The early volcanic activity of Mount Etna.Acicastello-Acitrezza-Acireale-Giarre-Adrano-Paternò. (Mainly by bus, with short walks; maximum elevation about 300 m a.s.l.)

The oldest submarine volcanics; tholeiitic pillow lavas and breccias associated with shallow subvolcanic masses (> 500 ka BP; Gillot et al., 1994).

Subalkaline (tholeiitic) to transitional basaltic rocks form the oldest levels of the Etnean sequence, and crop out offshore and inland of the Ionian Sea coast, between Acicastello and Acitrezza, immediately to the north of Catania. They mostly are subvolcanic masses, injected into the highest levels of Pleistocene marly claystones, associated with minor amounts of either aphyric or porphyritic pillow lavas and hyaloclastic breccias (Corsaro and Cristofolini, 1997). The offshore exposures (known as “Faraglioni”, at Acitrezza) are subvolcanic masses, intersected by WNW-ESE faults; rocks are subophitic and have transitional tholeiitic chemistry. The inland outcrops (upslope of Acitrezza and Acicastello) are tholeiitic, with porphyritic to aphyric textures.

The Acicastello outcrops are related to the offshore subvolcanic bodies. These are composed of submarine lavas with pillows closely packed onto each other, associated with heterogeneous and poorly-sorted volcaniclastic breccia lenses with sub-vertical sharp boundaries. The present-day attitude was previously interpreted as due to a local tilt, or to the seaward sliding of the entire eastern Etnean flank (Borgia et al., 1992; Tanner and Calvari, 1999; references therein), on the assumption of originally horizontal boundaries. On the contrary, careful observations (Corsaro and Cristofolini, 2000) do not match the hypothesis of a significantly tilted succession, leading, instead, to conclude that, apart from the strong regional uplift, the present Castle Rock exposure did not suffer any substantial change in its original attitude.

In the area of Acireale-Giarre-Valverde-St. Gregorio it is possible to observe some of the earliest Na-alkaline lavas (225-100 ka BP), as well as evidence for the relationship between volcanic activity and recent regional tectonics in the south-eastern sector of the Etnean volcanic district (Corsaro et al., 2002).

West of Giarre the oldest subaerial alkalic products of the Etnean activity unconformably underlie a volcanic succession that may be referred to the Trifoglietto Unit on the grounds of field data and petrologic features (Busà et al., 1999). The succession is extensively covered by products of the Mongibello Unit.

These levels are found along escarpments (“Timpe”) related to the regional NNW-SSE faults, which in turn are cut by deep gulleys connected to a minor fault system, trending WNW-ESE. In detail, these volcanics, continuously exposed at the base of the “Timpe”, show dips varying from place to place, in a way showing that several eruptive centers existed, and that they were aligned parallel to the fault escarpment. Here lavas are chiefly low- P_2O_5 (< 0.7%) and high-P_2O_5 (> 0.7%) hawaiites, distinguished by their petrographic and geochemical features, (Cristofolini et al., 1991). These levels are interlayered, suggesting that at least two distinct parent magmas might have been alternatively involved in feeding the eruptive activity (Busà et al., 1999). In the overlying sequence lava flows there are Ti-depleted mugearites to benmoreites, sub-horizontal to slightly dipping to the east. These lavas resemble the typical Trifoglietto products, and among them rare hawaiites are found, similar to the high-P_2O_5 members of the lower succession. Chemical data show that these lavas might well have originated by differentiation from a high-P_2O_5 magma (Busà et al., 1999; Busà & Cristofolini, 2000; Corsaro et.al., 2002). The westerly displacement of the eruptive activity apparently produced a consequent shift toward an uprising and differentiation of melts from only the high-P_2O_5 source. Between Adrano and Paternò, terraced subaerial tholeiite lava sheets (300 ka BP) crop out along the Simeto River valley (cf. Romano, 1982).

At Paternò the lowest elevation parasitic cone (transitional to Na-alkaline basalt; 170 ka BP) overlies a river terrace. In the whole area there is evidence for deep-welling gas (CO_2) emanations (travertine deposits, low temperature mofettes; Allard et al., 1991; Caracausi, 2003)

DAY 2

Pyroclastic fall and flow deposits; lahars. Zafferana (Cassone) - Salto del Cane - Biancavilla: evidence for important explosive episodes in the Etnean sequence (from > 50 to 15 ka BP and historic times; 122 b.C.). (Mainly by bus, with short walks; maximum elevation about 1500 m a.s.l.).

Zafferana. The eastern flank of the volcano is extensively covered by pyroclastic levels that may be referred to different stages in its volcanic history (with ages > 40 to .7 ka BP; Busà et al, 1997; Cortesi et al., 1988, Coltelli et al., 2000). Most of these levels are massive, composed of very poorly sorted ash, with textural features consistent with pyroclastic flow deposits; each of these tephra beds is associated at its base with thin (< .5 m) layers of well-sorted juvenile lapilli, followed by laminated coarse ashes, which might be related to fall-out and dry surge deposits (Cristofolini et al., 1991). Widespread outcrops of these levels are found nearby Zafferana.

A “plinian” eruption occurred in 122 b.C. (Coltelli et al., 1998). Although its feeding magma is hawaiitic in composition, this eruption is relevant as it was exclusively explosive and its tephra are dispersed over the south-eastern flank of Mt. Etna, down to the Ionian Sea between Acireale and Catania, where they are thicker than 25 cm. An exposure of fall-out tephra from this eruption can be observed at Salto del Cane, about 1400 m a.s.l.

Next to Biancavilla there are outcrops of an ignimbrite related to the Ellittico Caldera collapse (15 ka BP; Cortesi et al., 1988) and of parasitic autoclastic domes and related flows. Plagioclase-phyric lavas

Figure 4 - NNW-SSE trending dikes related to the activity of Ancient Mongibello, as seen from the edge of the Valle del Bove.

and the ignimbrite are trachytes, among the most differentiated products of the Etnean activity (Duncan, 1976; Cristofolini R., unpubl. data). The ignimbrite is correlated to fall-out deposits spread over the eastern flank of the volcano and offshore (Coltelli et al., 2000) The ignimbrite deposit, around 10 m thick, overlies autoclastic lavas; it is poorly welded, made up of matrix-supported, unsorted, juvenile and lithic fragments. Four flow units may be observed in a few gully sections, slightly differing in their textural features (grain size, grading, and juvenile-lithic ratio). One system of rough columnar jointing intersects the three upper flow units, showing that they were erupted and cooled at about the same time (De Rita et al. 1991; Duncan, 1976). Unpublished chemical data shows no significant variations across the overall deposit.

DAY 3

The summit of the volcano. Rifugio Sapienza - Montagnola - Torre del Filosofo - Summit area: vent areas (cinder cones and ramparts) and lava flow fields from very recent activity (1983 to 2002), view of the Valle del Bove, current activity at the top craters (bus, with possible walks at high altitude with sudden changes of weather conditions; maximum elevation more than 3000 m a.s.l.).

Late on the night of July 17, 2001, a parasitic eruption started along the southern slopes of Mt. Etna. A strong seismic swarm was recorded between July 12 and 18, and a 7-km-long belt of ground fractures opened up between July 13 and 20. The eruption ended on August 9, having poured out an overall lava flow volume around $48 \bullet 10\ m^3$, and a large amount of tephra (Patanè et al., 2002).

During this eruptive event, the development of surface cracks, along with the seismic pattern, showed that three known distinct eruptive systems, trending SW-NE, NNW-SSE and N-S , had been simultaneously active (Lanzafame et al., 2003). These were but the upper parts of a complex system fed by two distinct magmas: the higher (SW-NE and NNW-SSE) fractures, related to the SE crater conduit, erupted a deep-seated less differentiated magma, compared to the amphibole-bearing magma, with quartzite xenoliths, that rose up through the lower N-S system, from a closed reservoir.

Figure 5 - Ash-laden gas and vapor plume from the vent at 2500 m a.s.l. (Laghetto) during the summer of 2001 eruption.

The 2002-03 eruptions occurred both from vents north and south of the summit crater. The former vent system was active for about one week, along an extensional system (related to a left strike-slip displacement along the WNW-ESE trending Pernicana Fault); at the same time, pre-existing faults were reactivated in the low, eastern flank of the volcano (M_{max} = 4.4) as well as offshore of Catania (M = 3.4). Activity at the southern vents lasted until January 2003, and was characterized by the emission of large amounts of tephra (see previous chapter).

These last eruptions confirm that the conditions of the ascent of magmas, as well as the accommodation of deformation, at Mt. Etna, are strongly controlled by extensional structures, which are connected to a large-scale regional regime.

DAY 4

The volcano in towns. Historic flows in the context of the present–day metropolitan area of Catania. Nicolosi-Monpilieri-Belpasso-Piano Tavola-Catania
(Mainly by bus, with short walks; maximum elevation about 800 m a.s.l.)

The 1669 adventive (or parasitic) eruption at Mount Etna was quite unique among the historically dated ones, owing to both the large volume of its products (Romano & Sturiale, 1982), and to the relatively low elevation of the vents (800-850 m a.s.l.). The lava flow branches ran over long distances, flooding a fairly densely populated area and threatening several towns and villages -- among which Catania itself, which was partially destroyed. Therefore the eruption is well documented in contemporary and later records (cf. Corsaro and Cristofolini, 1996), so its volcanological and petrological evolution may be reconstructed with fair accuracy.

This eruption started on March 11 1669 (at 11 a.m.) and was preceded by the opening of a 2-m-wide fracture system, extending for 9 Km from the base of Mt. Frumento (2800 m a.s.l.) to Piano S. Leo (1200 m a.s.l.), where mild eruptive episodes took place. Shortly afterwards, in the same day, a new fracture opened from Mt. Nocilla to Mt. Fusara, with vents erupting juvenile tephra, until a lava flow poured out in the evening at the site where the main cinder cone (M. Rossi) of this eruption was eventually to develop over the next few days.

Lava flowed around Monpilieri, with two branches heading towards the nearest villages (Mascalucia to the east and Malpasso to the west), which were then reached and destroyed on March 13.

From March 14 to 25, effusive activity gave rise to a wide fan-like lava field, which subdivided downslope into three main branches, each made of several successive flow units, that headed to St. Pietro Clarenza, Misterbianco, and into the Camporotondo outskirts. On March 29, a flow unit formed south of St. Pietro Clarenza and moved quickly to the western side of the city of Catania, whose walls where reached (April 14), after having ponded in a depression at C.da Altarelli (1.5 km from the town) until April 4. The flow reached the sea,after having surrounded the near-by high standing Ursino Castle with a 2–km-wide front. In the following two months, due to the decreased effusion rate, a rather complex, compound lava field formed next to the vent, whereas the branch directed to Catania went on, being fed probably through a lava tube system, and kept slowly flowing to the sea, up to 15 km away from the vents.

According to contemporary records, perhaps the first attempt to alter the course of a lava flow occurred during this eruption. In an effort to save the city, several dozens of men, under the guidance of a churchman, Diego Pappalardo, covered with wet cowhides to protect them against heat, dug an opening through the western wall of the flow with iron bars. The attempt appeared at first successful, as a stream of lava escaped through the gap and thus moved away from the original flow, partly relieving the pressure at the front of the lava flowing towards Catania. Unfortunately, the new flow moved toward Paternò, and some irate citizens of this town drove the men from Catania away from the newly dug gap in the wall, and which, left unattended, soon clogged with cooled lava, and the main branch of the flow went on advancing towards Catania.

Almost 10^9 m^3 of lava of hawaiite-mugearite composition were poured out, covering a surface of around 37 km^2 of still barren land; about ten towns and villages were destroyed or partly damaged by the lava flow and by seismic activity preceding and accompanying the eruption.

This was but the largest and most recent of several eruptions that threatened the area of Catania and neighbouring towns, where presently more than 500,000 inhabitants are living. Such an event nowadays would be a very serious civil defense problem, which might be very difficult to be adequately faced, as precursory phenomena for adventive eruptions at Mt. Etna commonly occur within only a few days, or even hours, before the event, and may not always be unambiguously interpreted; new approaches for solving the problem have recently been suggested (Caracausi et al. 2003; La Delfa et al., 2000; Lundgren et al., 2003).

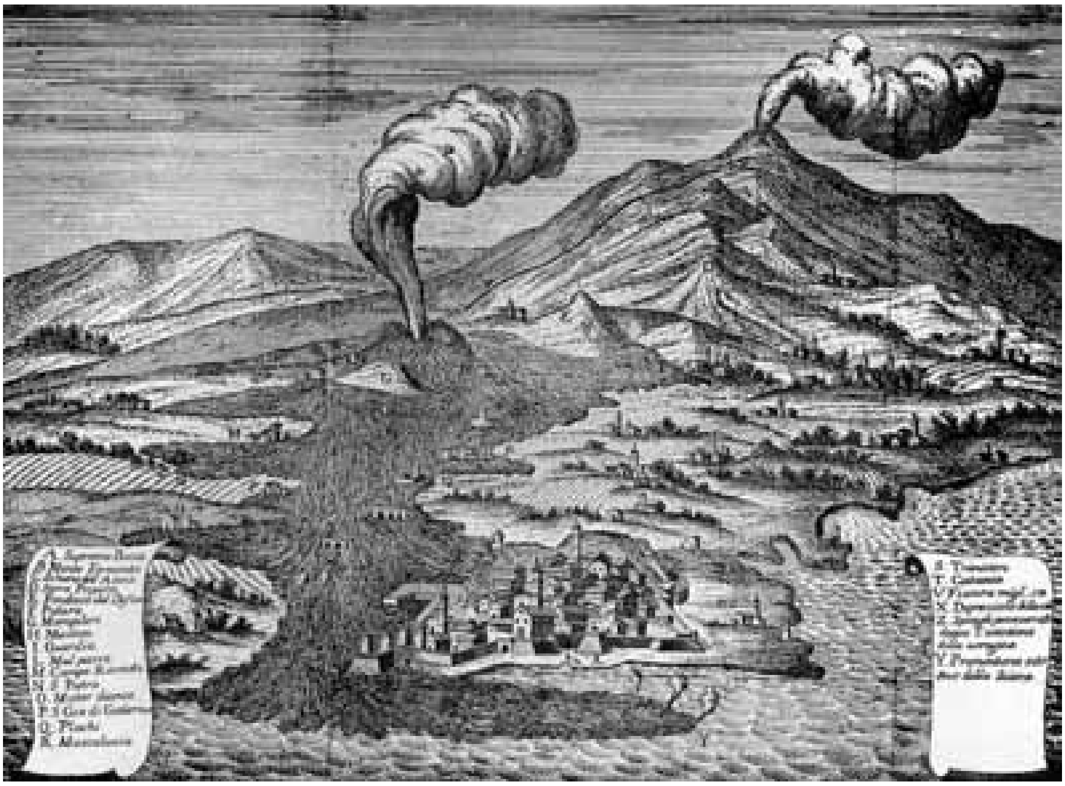

Figure 6 - The 1669 eruption, as shown in an old engraving.

This is probably the most relevant problem for town planning policies relating to volcanic hazard in the Etna region, where, as previously said, wide sectors have been at least once covered by lava flows in the last few centuries, down to low elevations, in the intensely inhabited belt between sea level and the 800 m contour line.

Nicolosi: the Monti Rossi vent area of the 1669 eruption;

Monpilieri-Belpasso-Piano Tavola: the course of the western 1669 flow branch; quarrying activities for production of ornamental stone;

Catania: the eastern 1669 flow branch (the *Benedictine Abbey*, the *Ursino Castle*). Recent flows along the coast north of the city.

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References cited

Allard, P. (1997). Endogenous magma degassing and storage at Mount Etna. *Geoph. Res. Lett.* 24. 2219-2222.

Allard, P., Carbonnelle, J., Dajlevic, D., Lebronec, J., Morel, P., Robe, M.C., Maurenas, J.M., Faivrepierret, R., Martin, D., Sabroux, J.C. and Zettwog, P. (1991). Eruptive and diffuse emissions of CO_2 from Mount Etna. *Nature.* 351. 387-391

Armienti, P., Innocenti, F., Petrini, R., Pompilio, M. and Villari, L. (1989). Petrology and Sr-Nd isotope geochemistry of recent lavas from Mt. Etna - Bearing on the volcano feeding system. *J. Volc. Geotherm. Res.* 39, 315-327.

Azzaro, R. (1999). Earthquake surface faulting at Mount Etna volcano (Sicily) and implications for active tectonics. *J. Geodyn.* 28, 193-213.

Barbieri, M., Cristofolini, R., Delitala, M.C., Fornaseri., M, Romano, R., Taddeucci, A. and Tolomeo, L. (1993). Geochemical and Sr-isotope data on historic lavas of Mount Etna. *J. Volc. Geotherm. Res.*56 (1-2): 57-69.

Behncke, B. and Neri, M. (2003). The July-August 2001 eruption of Mt. Etna (Sicily). *Bull. Volc*. 63, 1-12.

Ben Avraham, Z., Lyakhovsky, V. and Grasso, M. (1995). Simulation of collision zone segmentation in the central Mediterranean. *Tectonoph*. 243. 57-68.

Bianca, M., Monaco, C., Tortorici, L. and Cernobori, L.

(1999). Quaternary normal faulting in southeastern Sicily (Italy): A seismic source for the 1693 large earthquake. *Geoph. J. Intern.*139. 370-394

Bonaccorso, A., Aloisi, M. and Mattia, M. (2002). Dike emplacement forerunning the Etna July 2001 eruption modelled through continuous tilt and GPS data. *Geophys. Res. Lett*., 29, 2, 1-4.

Bonaccorso, A., Ferrucci, F., Patanè, D. and Villari, L. (1996). Fast deformation processes and eruptive activity at Mount Etna (Italy). *J. Geoph. Res.- Sol. Earth.* 101. 17467-480.

Borgia, A., Ferrari, L. and Pasquarè, G. (1992). Importance of gravitational spreading in the tectonic and volcanic evolution of Mount Etna. *Nature*. 357, 231-235.

Busà, T. Calderoni, G., Cristofolini, R. and Frazzetta G. (1997). New evidence for explosive activity on Mt. Etna over the last 50 kyr. *Per. Mineral*. 66, 287-301.

Busà, T., Clocchiatti, R. and Cristofolini, R. (1999). "High P" and "low P" alkaline magmas from Mt. Etna: their origin and evolution from the study of mineralogy and chemistry of lavas and of olivine-trapped inclusions. *Per. Mineral*. 68, 163-183.

Busà, T., Clocchiatti, R. and Cristofolini, R. (2002) The role of apatite fractionation and REE distribution in alkaline rocks from Mt. Etna, Sicily. *Mineral. Petrol*. 74. 95-114.

Busà, T. and Cristofolini, R. (2000). Geology and petrography of the volcanic sequence exposed along the Moscarello escarpment, lower eastern slope of Mount Etna: evidence for the migration of the eruptive centres. *Boll. Soc. Geol. It*. 120, 69-80.

Calvari, S. And Groppelli, G. (1996). Relevance of the Chiancone volcaniclastic deposit in the recent history of Etna volcano (Italy). *J. Volc. Geotherm. Res.* 72. 239-258.

Calvari, S. and Pinkerton, H. (1999) Lava tube morphology on Etna and evidence for lava flow emplacement mechanisms. *J. Volc. Geotherm. Res*. 90. 263-280.

Calvari, S., Tanner, L.H. and Groppelli, G. (1998). Debris-avalanche deposits of the Milo Lahar sequence and the opening of the Valle del Bove on Etna volcano (Italy). *J. Volc. Geotherm. Res.* 87. 193-209.

Caracausi, A., Favara, R., Giammanco, S., Italiano, F., Paonita, A., Pecoraino, G., Rizzo, A. and Nuccio, P.M. (2003). Mount Etna: Geochemical signals of magma ascent and unusually extensive plumbing system. *Geoph. Res. Lett.* 30.

Cardaci, C., Coviello, M., Lombardo, G., Patanè, G. and Scarpa, R. (1993). Seismic tomography of Etna Volcano. *J. Volc. Geotherm. Res.* 56, 357-368.

Carbone, D., Budetta, G. and Greco, F. (2003). Possible mechanisms of magma redistribution under Mt Etna during the 1994-1999 period detected through microgravity measurements. *Geoph. Jour. Intern.*153 , 187-200.

Carter, S.R. and Civetta L. (1977).Genetic implications of the isotope and trace element variations in the eastern Sicily volcanics. *Earth Planet. Sci. Lett.*36,168-180.

Clocchiatti, R., Schiano, P., Ottolini, L. and Bottazzi, P. (1998). Earlier alcaline and transitional magmatic pulsation of Mt Etna Volcano. *Earth Planet. Sci. Lett.* 163, 399-407.

Cocina, O., Neri, G., Privitera, E. and Spampinato, S. (1997). Stress tensor computations in the Mount Etna area (Southern Italy) and tectonic implications. *J. Geodyn.* 23, 109-127.

Coltelli, M., Del Carlo, P. and Vezzoli, L. (1995). Stratigraphy of the Holocene Mt. Etna explosive eruptions. *Per. Mineral.* 64, 141-143.

Coltelli, M., Del Carlo, P. and Vezzoli, L. (1998). The discovery of a plinian basaltic eruption of Roman age at Etna volcano (Italy). *Geology*. 26, 1095-1098.

Coltelli, M., Del Carlo, P. and Vezzoli, L. (2000). Stratigraphic constraints for explosive activity in the past 100 ka at Etna Volcano, Italy. *Intern. J. Earth Sci.* 89. 665-677.

Coltelli, M., Garduno, V.H., Neri, M., Pasquarè, G. and Pompilio, M. (1994). Geology of the northern wall of Valle del Bove, Mt. Etna (Sicily). *Acta Vulcanologica*, 4, 55-68.

Condomines, M., Tanguy, J.C. and Michaud, V., 1995. Magma dynamics at Mt Etna: Constraints from U-Th-Ra-Pb radioactive disequilibria and Sr isotopes in historical lavas. Earth Planet. Sci. Lett. 132, 25-41.

Corsaro, R. A. and Cristofolini, R. (1996). Origin and differentiation of recent basaltic magmas from Mount Etna. *Mineral.Petrol.* 57, 1-21.

Corsaro, R. A. and Cristofolini, R. (1997). Geology, geochemistry and mineral chemistry of tholeiitic to transitional Etnean magmas. *Acta Vulcanologica*. 9, 55-66.

Corsaro, R. A. and Cristofolini, R. (2000). Subaqeous volcanism in the Etnean area: evidence for hydromagmatic activity and regional uplift from the Castle Rock of Acicastello. *J. Volc. Geotherm. Res*. 95, 209-225.

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

Corsaro, R. A., Neri, M. and Pompilio, M. (2002). Paleo-environmental and volcano-tectonic evolution of the south-eastern flank of Mt. Etna during the last 225 ka inferred from volcanic succession of the «Timpe», Acireale, Sicily. *J. Volc. Geotherm. Res.* 113, 289-306.

Cortesi, C., Fornaseri, M., Romano, R., Alessio, M., Allegri, L., Azzi, C., Bella, F., Calderoni G., Follieri, M., Improta, S., Magri, D., Preite Martinez, M., Sadori, L., Petrone, V. (1988). Cronologia ^{14}C di piroclastiti recenti dell'Etna: identificazione e distribuzione dei fossili vegetali. *Boll. Soc. Geol.Ital.* 107, 531-545.

Cristofolini, R., Corsaro, R.A. and Ferlito, C. (1991). Variazioni petrochimiche nella successione etnea: un riesame in base a nuovi dati da campioni di superficie e da sondaggi. *Acta Vulcanologica* 1, 25-37.

Cristofolini, R., Failla, R., Ferlito, C. and Frazzetta, G. (1991). Contributo alla conoscenza dei depositi piroclastici affioranti tra Giarre e Nunziata sul versante orientale dell'Etna. *Mem. Soc. Geol. It.* 47, 465-483.

Cristofolini, R. and Romano, R. (1982). Petrological features of Etnean volcanic rocks. *Mem. Soc. Geol. It.* 23, 99-115.

Del Carlo, P. and Branca, S. (1998). Tephrostratigraphic dating of the pre-1300 A.D. SE flank eruptions of Mt. Etna. *Acta Vulcanol.* 10, 33-37.

De Luca, G., Filippi, L., Patanè, G., Scarpa, R. and Vinciguerra, S. (1997). Three dimensional velocity structure and seismicity of Mt. Etna volcano, Italy. *J. Volc. Geotherm. Res.* 79, 123-138.

De Rita, D., Frazzetta, G. and Romano, R. (1991). The Biancavilla-Montalto ignimbrite (Etna, Sicily). *Bull. Volcanol.* 53, 121-131.

Doglioni, C., Innocenti, F. and Mariotti, G. (2001). Why Mt Etna? *Terra Nova* 13, 25-31.

Duncan, A.M., (1976). Pyroclastic flow deposits in the Adrano area of Mt. Etna. *Geol. Magaz.* 113, 357-363.

Frazzetta, G. and Villari, L. (1981). The feeding of the eruptive activity of Etna volcano. The regional stress field as a constraint to magma uprising and eruption, *Bull. Volcanol*. 44, 269-282.

Gasperini, D., Blichert-Toft, J., Bosch, D., Del Moro, A., Macera, P. and Albarede, F. (2002). Upwelling of deep mantle material through a plate window: Evidence from the geochemistry of Italian basaltic volcanics. *J. Geoph. Res.-Sol. Earth*. 107.

Gemmellaro, C. (1860). La vulcanologia dell'Etna. *Atti Acc.Gioenia*. 2, 15, 27-140.

Gillot, P.Y., Kieffer, G. and Romano, R. (1994). The evolution of Mount Etna in the light of potassium-argon dating, *Acta Vulcanol.* 5, 81-87.

Gresta, S. and Patanè, G. (1987). Review of seismological studies at Mount Etna. *Pure Appl. Geophys*. 125, 951-970.

Gresta, S., Bella, D., Musumeci, C. and Carveni P. (1997). Some efforts on active faulting processes (earthquake and aseismic creep) acting on the eastern flank of Mt. Etna (Sicily). *Acta Vulcanol.* 9, 101-107.

Gresta, S., Longo, V. and Viavattene, A. (1990). Geodynamic behaviour of eastern and western sides of Mount Etna. *Tectonophys*. 179, 81-92.

Guest, J.E., Chester, D.K. and Duncan A.M. (1984). The Valle del Bove, Mount Etna: its origin and relation to the stratigraphy and structure of the vlcano. *J. Volcanol. Geotherm. Res.* 21, 1-23.

Gvirtzman, Z. and Nur, A. (1999). The formation of Mount Etna as the consequence of slab rollback. *Nature* 401, 782-785.

Hirn, A., Nicolich, R., Gallart, J., Laigle, M., Cernobori, L. and ETNASEIS Scientific Group (1997). Roots of Etna volcano in faults of great earthquakes. *Earth Planet. Sci. Lett.* 148, 171-191.

Kamenetsky, V. and Clocchiatti, R. (1996). Primitive magmatism of Mt Etna: Insights from mineralogy and melt inclusions. *Earth Planet. Sci. Lett.* 142. 553-572.

La Delfa, S., Patanè, G. and Tanguy, J.C. (2000). Kilometer-scale heterogeneities inside volcanoes revealed by using a set of geophysical methods: variable stress field at Mount Etna, Sicily. *Phys.Earth Planet. Inter.* 121, 157-173.

La Delfa, S., Patanè, G., Clocchiatti, R., Joron, J.L. and Tanguy, J.C. (2001).Activity of Mount Etna preceding the February 1999 fissure eruption: inferred mechanism from seismological and geochemical data. *J. Volc. Geotherm. Res.* 105, 121-139.

Laigle, M., Hirn, A., Sapin, M., Lepine, J.C., Diaz, J., Gallart, J. and Nicolich, R. (2000). Mount Etna dense array: local earthquake P and S tomography and implications for volcanic plumbing. *J. Geophys. Res.* 105 (B9), 21633-646.

Lanzafame, G., Neri, M., Coltelli, M., Lodato, L. and Rust, D. (1997). North-South compression in the Mt. Etna region (Sicily): spatial and temporal distribution. *Acta Vulcanol*. 9, 121-133.

Lanzafame, G., Neri, M., Acocella, V., Billi, A., Funiciello, R. and Giordano, G. (2003). Structural features of the July-August 2001 Mount Etna eruption evidence for a complex magma supply system. *J. Geol. Soc*. London, 160, 531-544.

Le Maitre, R. (1989). A classification of igneous rocks and glossary of terms. Recommendations of the IUGS Subcommission on the Systematics of Igneous Rocks. Blackwell, Oxford, pp 1-133

Lo Giudice, E. and Rasà, R. (1986). The role of the NNW structural trend in the recent geodynamic evolution of north-eastern Sicily and its volcanic implications in the Etnean area. *J. Geodyn.* 25, 309-330.

Lundgren P, Berardino P, Coltelli M, Fornaro G, Lanari R, Puglisi G, Sansosti E, Tesauro M. (2003). Coupled magma chamber inflation and sector collapse slip observed with synthetic aperture radar interferometry on Mt. Etna volcano. *J. Geoph. Res.- Sol. Earth*. 108.

Makris, J., Nicolich, R. and Weigel, W. (1986). A seismic study in the western Ionian Sea. *Ann. Geophys.* 6, 665-678.

Mc Guire, W.J. and Pullen, A.D. (1989). Location and orientation of eruptive fissures and feeder-dykes at Mount Etna; influence of gravitational and regional tectonic stress regimes. *J. Volcanol. Geotherm. Res*. 38, 325-344.

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

Murru, M., Montuori, C., Wyss, M. and Privitera, E. (1999). The locations of magma chambers at Mt. Etna, Italy, mapped by b-values. *Geophys. Res. Lett*. 26, 2553-2556.

Patanè, D., De Gori, P., Chiarabba, C. And Bonaccorso, A. (2003). Magma ascent and the pressurization of Mount Etna's volcanic system. *Science.* 299. 2061-2063

Patanè, D. and Privitera, E. (2001). Seismicity related to 1989 and 1991-93 Mt. Etna (Italy) eruptions: kinematic constraints by FPS analysis. *J. Volcanol. Geotherm. Res.* 109, 77-98.

Patanè, D., Chiarabba, C., Cocina, O., De Gori, P., Moretti, M. and Boschi, E. (2002). Tomographic images and 3D earthquake locations of the seismic swarm preceding the 2001 Mt. Etna eruption: Evidence for a dyke intrusion. Geophys. Res. Lett., 29, 135, 1-4.

Pearce, J.A. (1982). Trace element characteristics of lavas from destructive plate boundaries. In *Andesites*, Thorpe ed. Wiley. 525-548.

Privitera, E., Sgroi, T. and Gresta S. (2003). Statistical analysis of intermittent volcanic tremor associated with the September 1989 summit explosive eruptions at Mount Etna, Sicily. *J. Volcanol. Geotherm. Res.* 120, 235-247.

Romano, R. (1982). Succession of the volcanic activity in the Etnean area. *Mem. Soc. Geol. It.* 23, 75-97.

Romano, R. and Sturiale, C. (1982). The historical eruptions of Mt. Etna (volcanological data). *Mem. Soc. Geol. It.* 23, 75-97.

Sapienza, G. and Scribano, V. (2000). Distribution and whole rock chemistry of deep-seated xenoliths from the Iblean plateau, south-eastern Sicily, Italy. *Per. Miner.* 69,185-204.

Sartorius von Walterhausen, W. (1880). Der Aetna. Lipsia, 1, XXI + 371.

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

Tanner, L.H. and Calvari, S. (1999). Facies analysis and depositional mechanisms of hydroclastite breccias, Acicastello, eastern Sicily. *Sed. Geol.* 129. 127-141

Tibaldi, A. and Groppelli, G. (2002). Volcano-tectonic activity along structures of the unstable NE flank of Mt. Etna (Italy) and their possible origin. *J. Volc. Geotherm. Res.* 115, 277-302.

Tonarini S., Armienti, P., D'Orazio, M., Innocenti, F., Pompilio, M. and Petrini R. (1995). Geochemical and isotopic monitoring of Mt. Etna 1989-1993 eruptivr activity: bearing on the shallow feeding system. *J. Volc. Geotherm. Res.* 64. 95-115.

Tonarini S., D'Orazio, M., Armienti, P., Innocenti, F., and Scribano, V. (1996). Geochemical features of eastern Sicily lithosphere as probed by Iblean xenoliths and lavas. *Eur. J. Mineral.* 8, 1153-1173.

Torelli, L., Grasso, M., Mazzoldi, G. and Peis, D. (1998). Plio-quaternary tectonic evolution and structure of the Catania foredeep, the northern Hyblean Plateau and the Ionian shelf (SE Sicily). *Tectonoph*. 298. 209-221

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