RESULTS OF A RECONNAISSANCE TRIP TO MT. ETNA, ITALY: THE EFFECTS OF THE 2002 ERUPTION OF ETNA ON THE PROVINCE OF CATANIA

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ABSTRACT

This paper details the observations taken from a reconnaissance trip to Mt. Etna, Italy during the 2002 flank eruption, and utilizes those observations to identify potential hazards in New Zealand. It also makes recommendations for preparation and response to those hazards. The various types of hazards posed by Etna are primarily lava flows, ashfall and earthquakes. Lava flows caused intense damage in proximal areas, including forests, roads and the destruction of ski lifts and several buildings. Ashfall affected a much larger area, and was thus responsible for most of the damage economically. While earthquakes were not severe by New Zealand standards, the unreinforced masonry structures that predominate on Etna did not cope well with the seismic activity that accompanied the eruption. Several lessons taken from this eruption are applicable to New Zealand, both in effects of basaltic and more silicic types of volcanism.

1. INTRODUCTION/BACKGROUND

Mount Etna is Europe's largest volcano, and one of the most frequently active (after Stromboli). The volcano is situated within the province of Catania, on the east coast of Sicily. This province is home to almost 1,100,000 people, all of whom are susceptible to hazards created by the volcanic activity of this mountain. Of these 1,100,000 inhabitants about 350,000 live in the city of Catania, at the base of Etna. Many smaller towns are situated high up on Etna, relatively close to the active vents. Figure 1 illustrates the location of Etna in Sicily, and various towns referred to in the text.

On 27 October 2002, a flank eruption began that lasted 3 months, ending on 28 January 2003. Eruptive fissures opened on the south and east flanks of the volcano, producing both effusive and explosive activity. Aa lava flows caused damage to property on the flanks of the volcano, while strombolian and especially hawaiian style eruptive activity created basaltic ash that caused damage to more distal areas. Volcanic tremor and earthquakes also resulted in damage to local areas. Although only 30 million cubic metres of lava and 40 million cubic metres of tephra were produced by the 3 month eruption (Behncke & Neri, in press), the damage it caused was significant.

2. HAZARD TYPES

The eruption produced a variety of volcanic hazards including ashfall, volcanic tremors and lava flows. Bomb fallout was largely restricted to areas in the immediate vicinity of the vent, although bombs up to 400 mm diameter were observed to occasionally travel up to 1 km from source. Lapilli fallout encompassed a wider radius but did not exceed about 4-5 km from the active vent. Hazards were posed to vulcanologists and tourists that ventured too close, but little infrastructure was close enough to be threatened by lapilli fall hazard. The exceptions were the Torre del Filosofo refuge (situated at the base of the cone around the active vent) and an abandoned cable car station. The refuge was buried by scoria as the cone grew throughout the eruption, and was estimated by INGV staff to be under 6-7 m of pyroclastics (Allard *et al.*, 2002). Some lapilli landed in the Rifugia Sapienza area, but was only a few millimetres in diameter and caused no impact damage. Sulphur dioxide emission, though in large quantities (up to 20,000 tons per day) (Bruno *et al.*, 2002), was sufficiently distant from inhabited areas to be adequately dispersed by winds, causing no health problems to residents. However, concern amongst local citizens about Etna's gas emissions led to some people wearing ash masks even when ash was not falling. These would of course have been ineffective had SO_2 or H_2S gas been a problem, but they reassured those unwilling to trust official information.

2.1 Lava flows

Several aa lava flows were produced during the eruption, causing some damage to forestry plantations and infrastructure on the slopes of the volcano. This began on the first day of the eruption (27 October), with the destruction of a ski school and the hotel "Le Betulle" at Piano Provenzana. These lava flows also threatened the Ragabo forest near Linguaglossa (see Figure 1). However, although destructive, the slow movement of the flows (usually metres rather than kilometres per hour) allowed mitigation strategies to be employed. An attempt to protect the pine forest was made by ground crews from the fire department (*Vigili del Fuoco)* and the forest corps *(Corpo Forestale)*, as fires created by these flows easily spread. The ground crews were supported by helicopters water bombing lava flows from the air (*L'unione Sarda*, 29/10/02, p9). This strategy stopped fires spreading far beyond the edges of the lava flows, succeeding in restricting damage to that caused directly by the flows. Nevertheless, over 80 hectares of forest were destroyed (*La*

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Sicilia, 2/11/02). In addition to the loss of forest, several sections of road on the slopes of the volcano were destroyed when 3 m high aa lava flows passed over them (Figure 2). By 2 November the flow approaching Linguaglossa had stopped, 80 m from diversionary earthworks and 5 km from the town. Similar fire-fighting strategies were employed as flows approached forests on the west side of Etna.

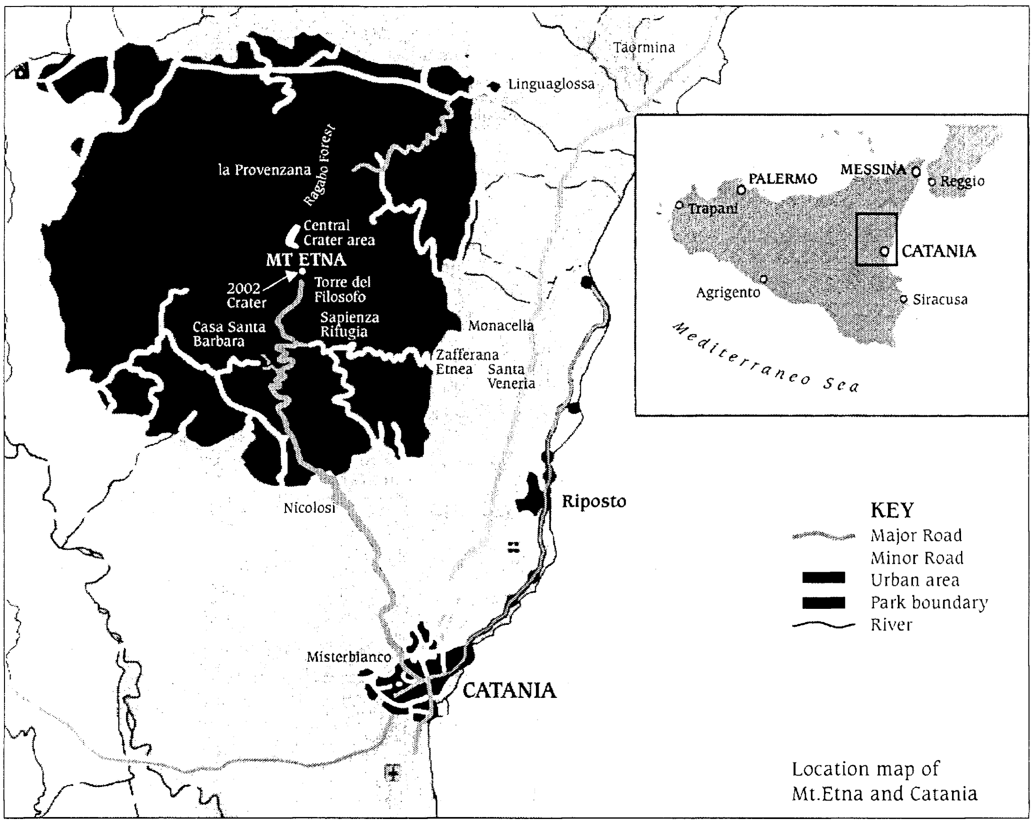

Figure 1. Map illustrating Mt. Etna and surroundings.

Lava flows also affected other types of infrastructure. Ski lifts on the southern slopes of Etna, near Rifugia Sapienza, were destroyed by lava flows on 24 November. An irrigation reservoir near Casa Santa Barbara (see Figure 1) was emptied to minimise the risk of a phreatomagmatic explosion when a 4 km long lava flow approached on 17 November; fortunately, this flow stopped a few metres before reaching the reservoir.

Creating earthworks to divert lava flows has in the past been met with some success on Mt. Etna, this strategy was again employed during the 2002 eruption. The flow that approached Rifugia Sapienza on the night of 24 November was successfully diverted slightly to the east to protect the ski station. (Figure 3) Unfortunately, a few weeks later on the night of 16-17 December a second flow following a similar path destroyed two buildings beside the ski station. This was in spite of the local fire brigade's efforts to cool the approaching front with water, and the earthworks created with army excavators and bulldozers. A large explosion occurred as the lava flow destroyed one of these buildings, caused by a water or oil tank being trapped under the flow. As a result 32 people near the building were injured, and one car destroyed. The amount of risk posed by that flow was increased by the high number of people present in the area as it approached. As well as the danger of explosions there was a possibility that the flow could cut off access to Sapienza. Army and Navy excavators were available to clear the access road should this have occurred (*La Sicilia*, 12/12/02).

2.2 Earthquakes

Volcanic tremor damaged several buildings in towns and villages on the slopes of Etna. The seismic swarm associated with the eruption began at 10:25 pm on 26 October. During the next 24 hours approximately 110 earthquakes were recorded (Patanè, 2002). At the beginning of the eruption on 27 October, nearly continuous shaking in close proximity to the vents (within 2 km) was reported by Istituto Nazionale di Geofisica e Vulcanologia (INGV) staff. These earthquakes were sufficiently violent to make it very difficult to stand, and long enough to induce feelings of nausea (G. Sawyer, *pers. comm.*, 2002). Earthquakes continued throughout the course of the eruption. INGV reports (Azzaro *et al.*, 2002; Azzaro & Scarfi, 2002; Mostaccio & Scarfi, 2002) indicated that intensities of the earthquakes in urban areas reached up to 6 on the European Macroseismic Scale (EMS-98). (This also equates to 6 on the Modified Mercalli scale). These tremors resulted in damage to buildings in several settlements.

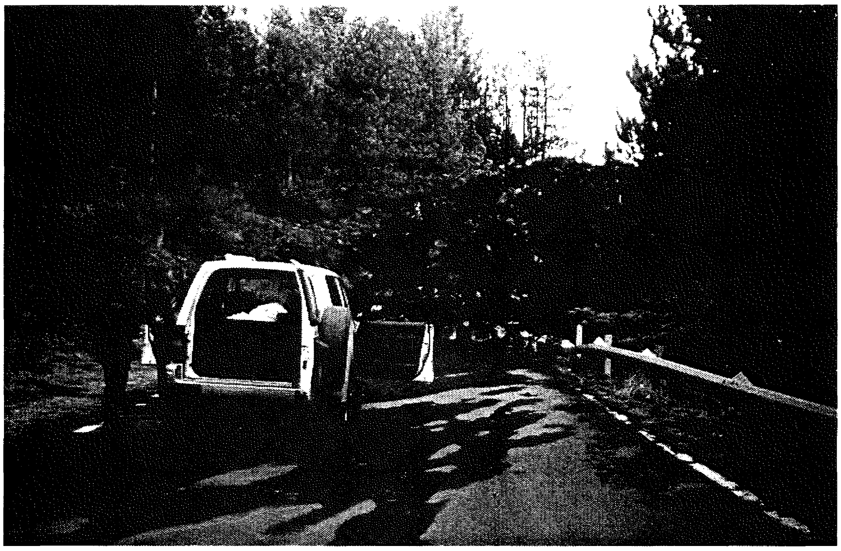

Figure 2. Aa lava flows cover the road through the Ragabo forest.

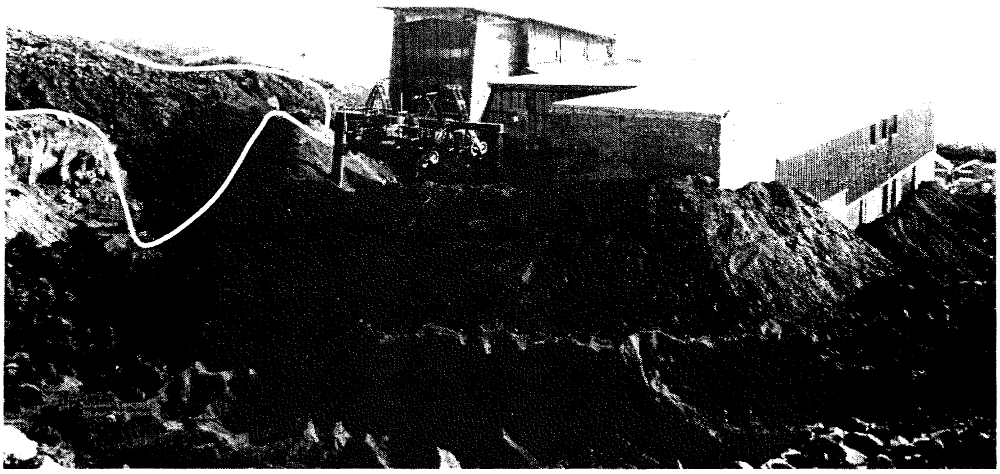

Figure 3. The protective earth dam around the ski station at Rifugia Sapienza. Note the lava flow to the left of the photo (outlined in white).

Most buildings in the region are constructed of concrete, though some older buildings are of basalt blocks. Prior to 1981 no building code for earthquake-resistant buildings existed in Italy, most buildings in the region were built before this (Behncke, 2002). Therefore, earthquakes of MM6 caused more damage than they might otherwise have done if earthquake-specific building codes had been adhered to in the construction of all buildings. Most damage was minor, consisting of cracking of concrete walls and plaster facings. However, many of the cracks caused by earlier shaking were further expanded in subsequent events (Mostaccio & Scarfi, 2002). Some older buildings became unstable; reinforcement of exterior walls using wooden struts was then employed to prevent failure. An earthquake on 2 December, felt over much of Etna, caused damage to several structures in Giarre, 4 km WSW of Riposto (Figure 1). Large pieces of masonry fell from the primary school building, which was closed as a result (Azzaro et al., 2002). An intensity of 6 on the EMS-98 scale (MM 6) was assigned by INGV (Azzaro *et al.*, 2002).

The dislodging and/or cracking of roof tiles occurred in several buildings. Concrete balconies were also prone to damage, and in some cases collapsed. This may have been accentuated by the accumulation of ash on these flat surfaces.

Dry stone retaining walls were a common casualty of the volcanogenic earthquakes; many of these had been constructed without building permits by local residents, and many collapsed (Figure 4). Retaining walls constructed and maintained by local authorities alongside roads in the vicinity of Zafferana Etnea (see Figure 1) also suffered partial collapse. The road surfaces were affected, cracks formed and disaggregation of the seal took place in some areas. Further damage occurred to roads as a result of small landslides near Piano Provenzana (Figure 1).

Figure 4. A collapsed Retaining wall in Monacella.

Panic was common among the populations of these towns. During ash sampling in Monacella on 7 November several people were observed sitting in cars in a local car park. They approached INGV staff, asking when the activity would stop, explaining that they were too frightened by earthquakes earlier that morning to remain in their homes. There were also reports of panic among the populace of Zafferana and S. Venerina because of volcanic tremors (Mostaccio & Scarfi, 2002). Many inhabitants from these towns were too scared to remain in their homes. By 29 October, four hundred households (about 2000 people) were evacuated from Santa Venerina, the evacuees housed in "tent cities" prepared by the Civil Protection (*La Sicilia*, 29/10/02). This was mainly a precautionary measure, as many masonry buildings were susceptible to damage from even relatively minor shakes of MM 5-6. In the town of Misterbianco, someone phoned a local school to enquire about the effects of a perceived (though actually non-existent) earthquake on the school buildings. This alarmed the teachers, resulting in the evacuation of 700 children from that school. (*La Sicilia*, 09/11/02, p.26).

The opposite reaction to local tremors was also observed, as some people in real danger from unstable buildings refused to be evacuated. A family of five near Giarre temporarily barricaded themselves into their home to avoid being evacuated by the local authorities after their home was declared to be unfit for use (*La Sicilia*, 5/11/02).

2.3 Ashfall

The 2002 flank eruption of Mt Etna resulted in more ash falling on Catania than there had been in living memory. During the first three days of the eruption INGV measured a total of 2.5 kg/m^2 of ash falling on Catania (P. Del Carlo, *pers. comm.*, 2002). This equates to an average thickness of 1.6 mm. While not a great depth of ash, it was still sufficient to cause havoc in Catania; roads became extremely slippery and numerous traffic accidents ensued. During the same three days Nicolosi, approximately 13 km from the active crater, received 9.7 kg/m^2 (~6 mm), while the tourist resort of Rifugia Sapienza, within 5 km of source, received 38.9 kg/m^2 (~25 mm) (Del Carlo, 2002a).

Attributes of the ash

The grainsize of ash falling in any given area varied from day to day, as the activity at the crater waxed and waned, and the plume height varied. A continuum of eruptive styles from hawaiian to strombolian type activity was seen during the eruption. Activity changed from one style to the other on scales of hours to weeks. Often an intermediate style existed, where lava jets pulsated less continuously than hawaiian activity, but more continuously than a classic strombolian style of eruption. These changes in style affected the ratio of tachylite and sideromelane that in turn controlled the chemical composition of the ash. Tachylite dominated in quieter periods, whereas an increase in the amount of sideromelane was seen in ash taken from more explosive periods (Del Carlo *et al.,* 2002a). Minor olivine, clinopyroxene and lithics were also present to varying degrees as the eruption progressed. (Del Carlo, 2002a, 2002b; Del Carlo *et al.*, 2002a, 2002b).

Two samples were weighed and compared to their volume to determine bulk density. While this would vary as the grainsize, morphology and composition changed throughout the eruption, these samples nevertheless provided a first order estimate loading. A proximal (600 m from source) and distal (12 km from source) sample were measured. The bulk density measured from the proximal sample was 1.26 $g.cm^{-3}$, whereas the distal sample was 1.63 $g.cm^{-3}$. Grainsize varies in the proximal sample from 125 μ to 5 mm, with a modal grainsize of 750 μ. The sample from 12 km from source (in Monacella) ranged from 750 μ to 0.25 μ, the mode was 63 μ. Figures 5 – 8 illustrate both the grain morphology and the presence of extremely fine grains in samples from Catania (25 km from source), Monacella (12 km from source) and 600 m from the active crater. Leachate analysis of these ash samples was conducted by GNS to determine the levels of leachable material (Table 2).

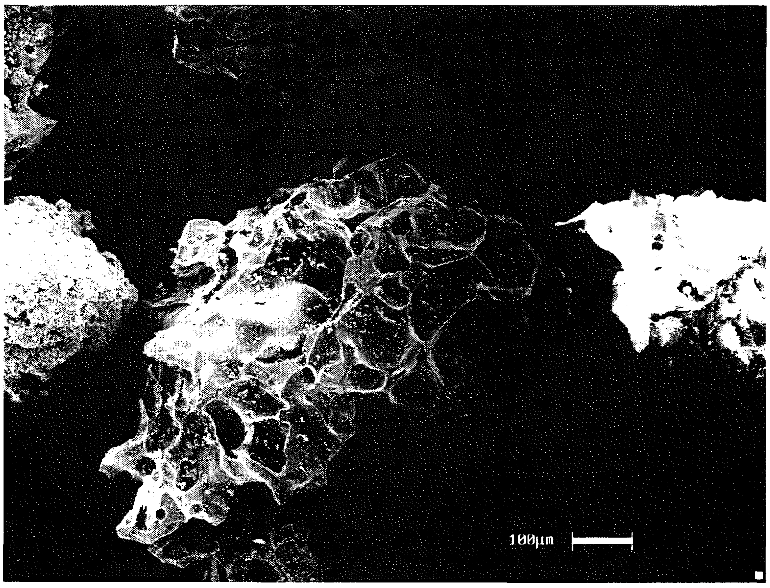

Figure 5. SEM image of sideromelane clast from ash collected in Catania, 11/11/02 (scale bar 100 μm).

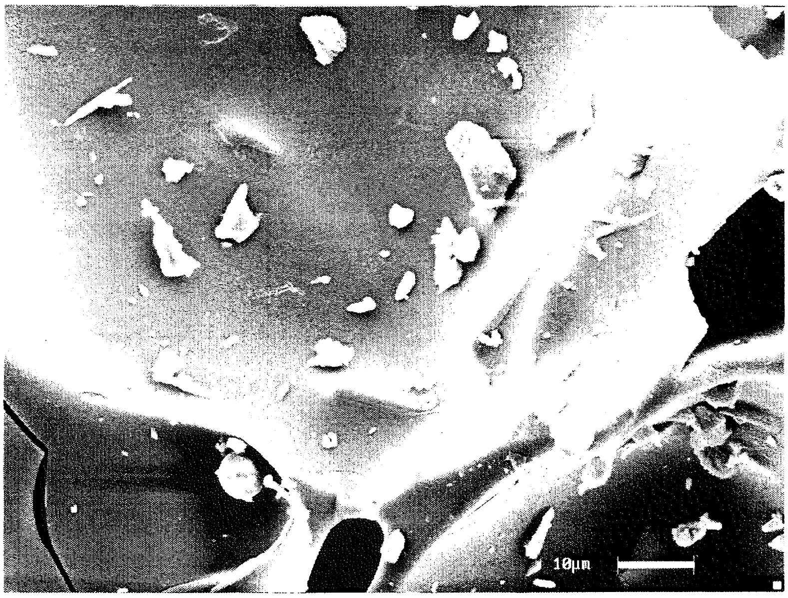

Figure 6. SEM close-up of fine grains on sample from Figure 5 (scale bar 10 μm).

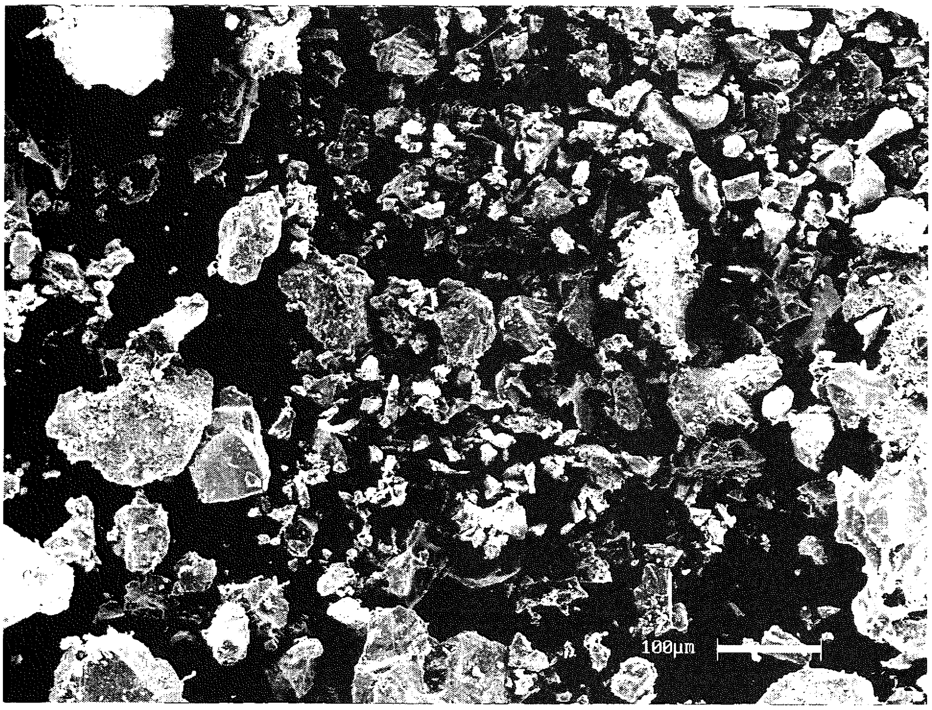

Figure 7. SEM image of Sideromelane and tachylite clasts, collected 12 km from source (scale bar 100 µm).

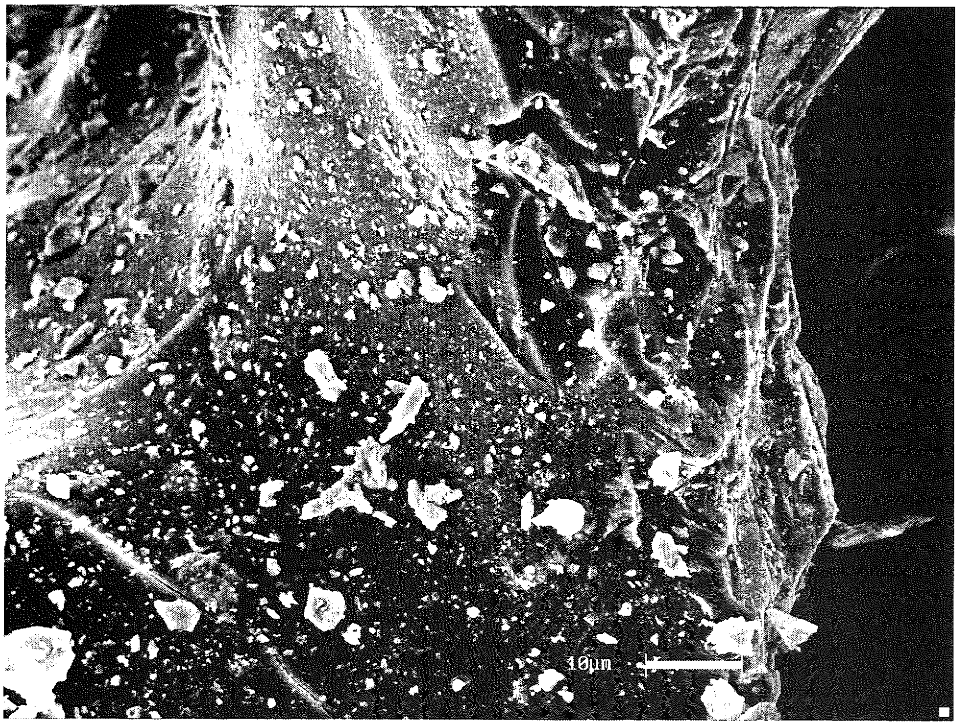

Figure 8. SEM image of finer particles adhering to a larger clast, proximal sample (scale bar 100 µm).

Table 1. The effects of ash of varying thickness

Thickness of ash	Effects
0-2 mm	Road markings obscured, traction reduced (wet and dry ash), visibility reduced as dry ash is remobilized by traffic and wind. Steep hills difficult for 2WD vehicles to climb
2-20 mm	Moderate hills become difficult for 2WD vehicles to climb, steep hills impossible. Drifts cause larger humps in road. Once dampened and compacted it becomes firmer, easier to drive on.
20-100 mm	Slight inclines may be impassable to 2WD vehicles, 4WD vehicles need differential or hub locks to climb moderate hills. Larger drifts (eg 300 mm) may hinder or stop 2WD vehicles on flat roads
100-300 mm	Uneven surfaces in the ash stop any 2WD vehicles, compacted damp ash on flat surfaces is still able to be driven on. 4WD utility type vehicles (not cars) may be able to slowly progress on the flat. Drifts may need to be cleared. Moderate inclines difficult, but may be possible for experienced 4WD drivers. Steep inclines generally impassable. Ruts easily formed on hills.
>300 mm	Compacted ash may be driven on by 4WD vehicles, softer patches may easily bog vehicles. Gradual inclines possible on compacted ash, but after a few vehicles ruts in the ash will form, hindering uphill progress for further vehicles

Table 2. Leachate analysis of samples of Etna 2002 ash. Sample collection dates and distance form source are given.

	Sample No.	**MT ETNA CT1011 25 km, 10/11/02**	**MT ETNA M7111 12 km, 07/11/02**
Lithium	mg/g of dry ash	<0.0005	<0.0005
Sodium	mg/g of dry ash	0.189	0.111
Potassium	mg/g of dry ash	0.024	0.0
Calcium	mg/g of dry ash	0.073	0.152
Magnesium	mg/g of dry ash	0.0072	0.0072
Sulphate	mg/g of dry ash	0.38	0.46
Boron	mg/g of dry ash	0.0013	<0.001
Silica (as SiO2)	mg/g of dry ash	0.014	0.027
Nitrate (as N)	mg/g of dry ash	0.0016	<0.0015
Phosphate (as P)	mg/g of dry ash	<0.0025	<0.0025
Al	mg/g of dry ash	0.0072	0.0022
Arsenic	mg/g of dry ash	0.0082	0.006
Bromide	mg/g of dry ash	<0.005	<0.005
Chloride	mg/g of dry ash	0.097	0.077
Fluoride	mg/g of dry ash	0.05	0.025
Iron	mg/g of dry ash	<0.0002	0.0004

3. EFFECTS OF THE ERUPTION

3.1 Buildings

The weight of ash on roofs caused some problems, despite the accumulated tephra falling on structures never exceeding 40 kg.m^{-2} in any three-day period, even in proximal areas such as Rifugia Sapienza (excluding the burial of the Torre del Filosofo refuge). Ashfall was usually not continuous in any one area for more than a few hours over the course of the eruption. This was due to either changes in wind direction, or the waxing and waning of the explosive activity. Residents, therefore, had time to clean ash from roofs between ashfalls. However, in the case of some badly maintained (derelict) buildings, flat or slightly pitched roofs that were not cleaned accumulated sufficient ash to cause collapse after rainfall saturation (P. Del Carlo, *pers. comm.*, 2002). Minor structural damage also occurred on some houses with pitched roofs that were not cleared of accumulated ash. Although Sapienza was subject to heavier ashfalls than more distal urban areas, the structures in this resort were designed to cope with snow loading (being situated at 1,900 m above sea level). In addition, regular cleaning of roofs helped ensure that buildings in this area did not experience damage from ashfall.

Roof guttering on buildings in towns on the flanks of Etna was damaged or destroyed in several cases by the accumulation of ash. In these cases ash blocked downpipes sufficiently that water and ash built up in the spoutings until they collapsed (P. Del Carlo, *pers. comm.*, 2002). In some cases ash was observed to have accrued at the base of downpipes to such an extent that it blocked the downpipe from the base upwards. However, many downpipes on buildings in Catania end 300 mm or more above the ground, discharging water directly onto footpaths. These were not usually affected by such blockages, as the ash was dispersed before accumulating into piles this high.

Removal of ash from rooftops was a labour-intensive exercise. This usually involved someone climbing onto the roof and sweeping the ash onto the ground. Ash in spoutings needed to be scooped out by hand. On taller buildings within the city the use of cherry pickers was employed to gain access to rooftops. Again ash was manually scooped up, and then poured over the edge into dump trucks below.

3.2 Communications

Ashfall or the presence of the ash plume had little effect on communications. Mobile phones continued to work as usual and phone lines remained intact. One exception was interference to hand held radios used by INGV staff to contact the base stations in Catania and Nicolosi from near the summit of Etna. Although these worked without problems most of the time, interference occurred on some days. This was despite similar weather conditions and attempts at contact being made from the same location on days when they did and did not function normally. It is possible that the plume was responsible for this interference. Mobile phones appeared unaffected and they were used as a backup for communication.

3.3 Electricity distribution

No effects on electrical distribution networks were reported to have occurred as a result of the eruption. Communication with electricity providers was hampered by the language barrier between local staff and the researcher.

3.4 Gas supplies

Gas supplies remained unaffected by the eruption. While moderate seismic activity may have been sufficient to burst gas mains, gas supplies in the peripheral towns on Etna are not piped, but stored in tanks on the properties of those who use it.

3.5 Water Supplies

Fortunately for the region around Etna, water supplies are derived from aquifers which were unaffected by the eruption. However, prior to the eruption the area had been experiencing a drought. This did initially affect the amount of water available when increased demand occurred as a result of people wanting to wash ash away with garden hoses. A few days into the eruption (4 November) the drought was broken as rain fell in Catania.

3.6 Stormwater/sewerage

The influx of ash into the stormwater system proved to be a problem for drainage in Catania. Siltation blocked some drains completely and restricted flow in others. Combined with rain this resulted in localised flooding on several occasions, which affected traffic flow as roads became submerged. Fortunately there was little heavy rainfall in Catania during the course of the eruption. No problems with sewerage were reported, though little data could be gathered on this subject due to some communication (language) difficulties. INGV staff were unaware of any damage to infrastructure or blockages of actual sewerage pipelines. It was their understanding that sewerage was flushed directly out to sea without any kind of treatment, though this is unverified (P. Del Carlo, *pers. comm.*, 2002). Figures 9 and 10 illustrate the effects of ash on the stormwater drains in Catania.

Figure 9. Ash blocking drains in Catania streets.

3.7 Transportation

Aviation

Catania's airport (Fontanarossa) was closed throughout much of the eruption due to the ash plume posing a danger to air traffic. Even when the wind was not blowing directly towards the airport (south) the plume caused problems, interfering with flight paths. The radar used by Fontanarossa airport is not capable of detecting the ash plume (*La Sicilia*, 12/12/02). Therefore, on cloudy days it was not always apparent where the plume was. The same applied at night, consequently during the eruption the airport adopted a timetable of opening from 7 am until 6 pm where possible (*La Sicilia*, 28/12/02). Even then the airport was not always able to open. In addition to the problems caused by the plume, ash had to be cleaned from the runways before any planes took off or landed. Some pilots reportedly refused to fly into Catania during the eruption, preferring to land in Palermo or Reggio Calabria (*La Sicilia*, 4/11/02).

Figure 10. Localised flooding in Catania caused by ash blocking stormwater drains.

Roads

Travel by road was adversely affected by the eruption. Traction was reduced by both wet and dry ash, even in very small (~1 mm) thicknesses. Stopping distances increased as vehicles skidded on the slippery surface. Corners needed to be approached with caution; a driving style similar to that used for driving on ice was necessary to avoid accidents. Frequent minor accidents and falls experienced by motorcyclists and moped riders during the first few days of the eruption led to their use being briefly prohibited within the city of Catania. However, the extensive use of mopeds as a means of transport in this region necessitated the local authorities lifting the ban and merely recommending that they were not used.

In addition to the hazard caused by the slipperiness of ash on road surfaces, airborne ash was particularly problematic for cyclists and motorcyclists; it easily entered the eyes, noses and mouths of those riding without masks and goggles, or full-face helmets. This was further accentuated as clouds of dry ash were stirred up by passing automobiles. These clouds of ash also reduced visibility on the roads, affecting all road users. Visibility was also inhibited by the rapid accumulation of ash on windscreens during heavy ashfall, with both wet and dry ash. In lighter ashfall windscreen wipers were able to effectively clean windscreens (Figure 11). However, during heavier falls it became necessary to frequently stop vehicles every few hundred metres and manually clean windscreens, using bottles of water to clean off the finer particles. The visibility of road markings was reduced to nil with only a small (<1 mm) covering of ash. Ash on roads never exceeded a few millimetres in Catania, except in the occasional drift.

Many of the villages on the slopes of Etna have at least a few roads that are steeply inclined. Driving up these steep gradients with even a thin layer of ash on the ground was not always possible in a two-wheel-drive (2WD) car, given the lack of traction. Closer to the vents different problems were experienced with thicker deposits.

Between Sapienza and the active crater at 2700 m, a four-wheel-drive (4WD) ski field service track provided access for local authorities to monitor the eruption, and to monitor the numbers of tourists that tried to approach too closely. Although ash deposits on this road were usually several centimetres deep, and at times over 300 mm, 4WD vehicles with differential or hub locks were able to successfully drive up the incline. However, drifts did have to be smoothed out to ensure their success. An unsuccessful attempt was made to climb even moderate inclines in 2WD, with both thin (<5 mm) and thicker (~50 mm) ash deposits. Table 1 details the effects of different depths of ash on vehicle mobility.

Wet ashfall prevented the ash from being remobilised by wind but also presented problems different to those posed by dry ash. Rain did not effectively remove ash, as channels formed within the deposit and the bulk of the mantle of ash remained in situ. The remaining ash compacted and hardened once it dried out. Ash left on the roads could then be driven over, rather than through. However, the presence of any wind during ashfall created drifts of ash that in turn created their own hazards. Small drifts of compacted ash acted like "speed humps" in the road, which if driven over at speed could cause damage to vehicles or even accidents to occur. At times, larger drifts blocked roads altogether until mechanically removed.

While dry ash was removed from roads with the use of road sweepers, the removal of ash that had been dampened or wetted required machinery such as snowploughs and front-end loaders. In urban areas ash was swept more regularly, with both road sweepers and workers with brooms (Figures 12 and 13). The City of Catania was forced to pay overtime rates to city council workers as this work was performed in addition to the normal work they carried out. This led to reluctance on the part of the council to clean up the streets before the eruption was over; they did not want to have to pay to do the same job twice. However, an accumulation of ash over the weeks of the eruption would have caused a greater amount of damage, and would have cost significantly more to clean up. Pressure was put on INGV to predict a date for the end of the eruption, but this was not possible. The council was eventually convinced that it was in their best interest to continue to remove ash from streets and public buildings/parks etc. (P. Del Carlo, *pers. comm.*, 2002).

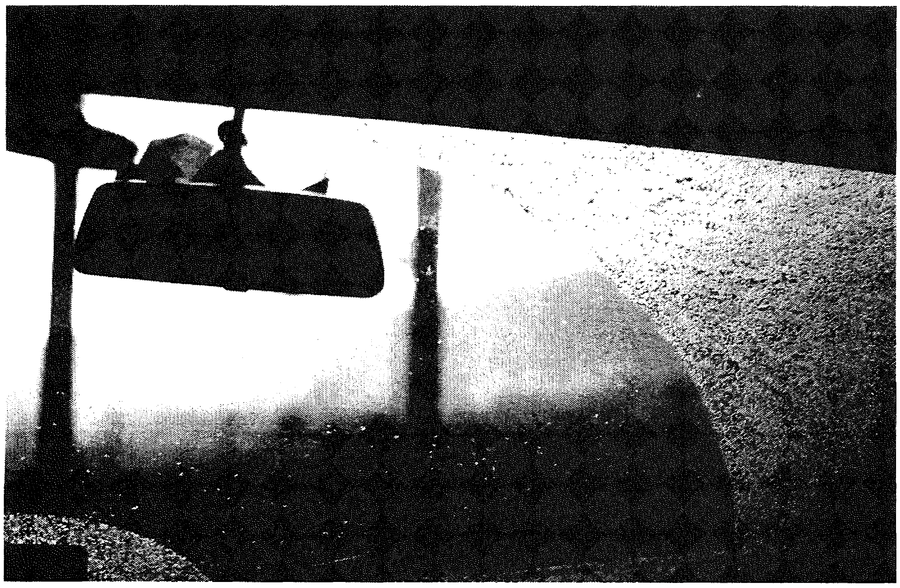

Figure 11. Light, wet ashfall on a car windscreen. This was easily coped with by wipers.

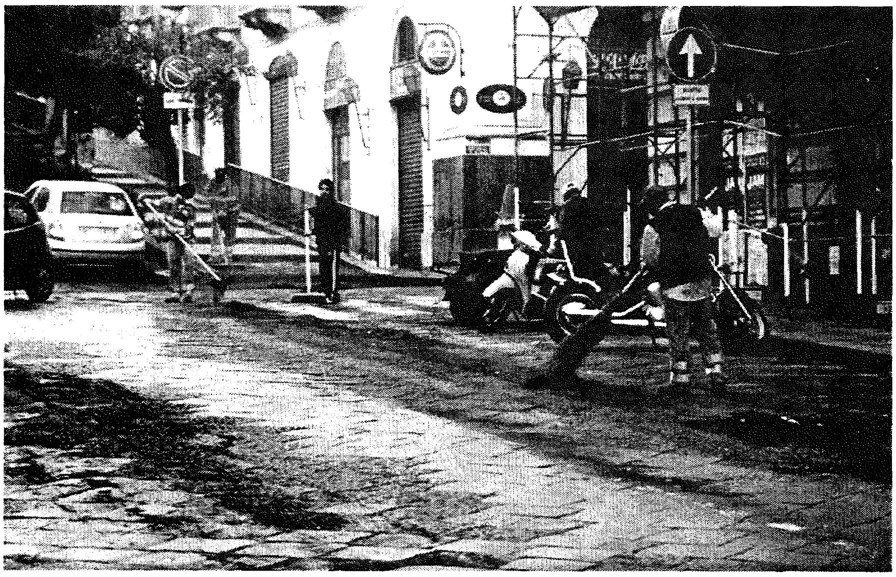

Figure 12. Council workers sweeping a road in Catania.

3.8 Ash Disposal

In rural areas disposal of the ash covering roads was usually simple – it was dumped at the side of the road. On Etna itself this was behind "Armco" barriers or stone walls onto recent (within the last century or so) non-vegetated lava flow deposits. The basaltic ash is fertile enough that vegetation quickly begins to establish itself. This property of the ash led to some of the ash being sold by the local council as fertilizer. Some ash from the cities was used to fill in landfills, the remainder has been dumped into the sea (P. Del Carlo, *pers. comm.*, 2002).

3.9 Nuisance value

Many problems associated with the ashfall were not serious enough to be deemed 'hazards', but were still seen as a nuisance. This included things like the curtailment of outdoor dining – restaurants could not serve food outdoors as falling ash would land on meals, making them less than palatable. Even when ash was not falling directly it could still be blown about and into food. This had negative economic repercussions on dining establishments with outdoor dining areas. Hanging out washing to dry with ash falling resulted in soiled clothing. Shopkeepers had to continually sweep pavements to minimise ash carried into shops on the soles of the shoes of customers. Fortunately the majority of shops in Catania have wooden floors, which made cleaning ash from inside easier.

Figure 13. A road sweeper in Catania makes slow progress.

3.10 Agriculture/forestry

Agriculture was adversely affected by the 2002-2003 eruption, at least in the short term (in the long term the basaltic ash that covered crops will act as a fertilizer, enriching the soils). Industry associated with forestry, horticulture and farming all suffered losses because of this eruption. Although ashfall was never heavy enough to damage the forests, lava flows destroyed 80 hectares of forestry near Linguaglossa (see Section 2.1). On 14 and 15 November further damage occurred to plantations near Casa Santa Barbara (on the west side of Etna) as aa flows bisected a forested area. Fortunately, these flows largely followed the same path as those from the 2001 eruption of Etna, thus killing only a small number of trees.

Drought conditions throughout October meant little grass had grown around Etna in this month. This lack of fodder for stock, combined with a thin covering of ash on the ground, meant that farmers had to bring in feed for sheep and cattle that would otherwise have been able to find adequate grazing on the lower slopes of Etna (*La Sicilia*, 29/10/02).

Fruit and vegetable growers were hit hard economically. Ashfall damaged fruit and drastically reduced its value. Almost one third of Italy's oranges, along with other citrus fruit, are grown in the region of Catania (*La Sicilia*, 09/12/02). Fifty percent of these were lost in the first 3 days of the eruption, ruined by ash both pitting the skin and being absorbed into the fruit (*La Sicilia*, 29/10/02). Ash on the surface also made the fruit difficult to pick, and contactors feared that it could damage machinery used in the picking and processing of fruit. Even harder hit were vegetables; 80 % of crops were lost (*La Sicilia*, 26/12/02). This damage occurred both in the province of Catania, and that of Siracusa, where crops over 50 km away from the active vents were similarly damaged. Giuseppe Guastella, President of the Sicilian branch of Italy's federation of farmers "Coldiretti", estimated that agricultural damages to the Catania region cost € 80 million and Siracusa a further € 60 million (Coldiretti, 2002). Furthermore, 75 % of agricultural jobs were lost during this season, as crops were unable to be harvested (*La Sicilia*, 21/12/02).

Locally produced fruit sold in local markets and shops during the course of the eruption was recognisably damaged, or covered in ash. This was not always easy to remove. For example running water over bunches of grapes was not sufficient to remove all of the ash, it was necessary to manually rub the ash off each grape to ensure the fruit was clean. This demonstrates how crops can easily be ruined economically, as the labour needed to clean the fruit or vegetable affected costs more than the value of the produce itself. This damage was not caused by heavy ashfall; most of the affected area was subjected to less than 3 mm of ash by the time this damage was done.

3.11 Tourism

Tourism in the region was also adversely affected by the eruption. The closure of the airport was partly to blame for this, which under normal circumstances is Italy's 3rd busiest airport. Italy's tourism association (Assoturismo) reported a downturn in business for hotels etc. of 75 %. The same association said that business was down by 25-30 % in restaurants and pizzerias, 25 % in travel agencies and 30 - 35 % in ticket offices (La Sicilia Multimedia, 2002). Only 50 % of the usual number of visitors to Catania (for the time of year) were present during the course of the eruption according to an estimate by staff at Catania's visitor information centre.

3.12 Effects of the eruption on the populace

Reactions to the eruption ranged from panic to intense curiosity. While some people were too scared to remain in their homes, other people wanted to get as close to the activity as possible to obtain better views of the eruption. Both types of behaviour caused problems for local authorities. The evacuation of over 2,000 people from Giarre and S. Venerina was necessary, given earthquake damage to houses, but some residents in other areas affected by the tremors also wanted to be evacuated – even if this was not necessary. Most people were worried to some degree, especially those with property on the flanks of the volcano. However when asked, many people expressed the view that it was just nature, the volcano was just doing what it had always done. They accepted that they lived beside or on the volcano and thus had to live with the consequences.

The desire to witness the spectacle of lava erupting from Etna from close up motivated many other people (both locals and tourists) to attempt to climb to the active vents or to the front of lava flows. Not only did this put people in immediate physical danger, at times the number of people approaching flows obstructed emergency services. To attempt to prevent this police put up roadblocks on many roads to restrict access to the mountain.

The Department of Civil Protection (*Protezione Civile*) oversaw the emergency and directed staff from the fire department (*Vigili del Fuoco*), municipal police (*Polizia Municipale*), national police (*La Polizia),* provincial police (*Polizia Provinciale*), financial police/alpine rescue (*Guarda di finanzia),* military police *(Carabinieri),* and forest corps (*Corpo forestale*). The Department was responsible for manning the roadblocks, preventing people from getting too close to the flows and vents, and for rescuing those that were injured or lost. The forest corps and fire fighters were there to stop the spread of fires started by lava flows burning vegetation. During late November this force comprised 232 staff (*La Sicilia*, 27/11/02). Local alpine guides patrolled the summit area.

Despite these precautions people still attempted to get up close to the volcano. Near the summit, danger is posed by bomb fallout, volcanic gases and lava flows. The terrain there is comprised of jagged (and very sharp) pieces of aa lava, bombs, blocks, scoria and ash. Temperatures can drop very quickly to sub-zero levels, as the altitude of the 2002 crater is ~2,750 m. Snow fell in this area on several occasions during the course of the eruption. These factors were often overlooked by eager tourists wanting to get a close view of the eruption, keeping the alpine rescue teams very busy rescuing lost and hypothermic sightseers (Guarda di finanzia officers, *pers. comm.*, 2002). Notwithstanding controls on people climbing up to the top, some skirted patrolled areas. On other occasions climbers/walkers were let through from Rifugia Sapienza, the climb of almost 1,000 m (vertical) over a distance of 4 km to the active area ensured that only those fit enough to climb this far would make it to the more dangerous areas.

The amount of interest in the eruption meant that it was impossible to keep absolutely everyone away from danger. Reports of impending damage to Rifugia Sapienza as lava flows approached on 24 November resulted in thousands of spectators trying to drive there to witness the sight. On this occasion the roadblocks were emplaced further down the mountain to keep tourists at bay. Queues of traffic several kilometres long stretched from just outside Nicolosi to the roadblocks. This hampered emergency services in gaining access to Rifugia Sapienza. On most nights spectators could be encountered parked along both sides of the road.

The impact of the sight of a large strombolian explosion, even from four to five kilometres away is not to be underestimated. This created hazards in itself. On return from fieldwork near the active vents it was not uncommon to see cars that had simply stopped in the middle of the road, after the drivers rounded blind corners and were confronted with a spectacular volcanic eruption. Following traffic had to then react quickly to avoid crashing into the stationary vehicles.

3.13 Health Effects

The short-term effects of basaltic ash on the region's inhabitants were largely of discomfort, rather than anything serious. Ash getting into peoples eyes was both painful and difficult to remove. It has the potential to scratch the cornea if eyes are rubbed as opposed to being washed out with water. The wearing of masks to filter out ash particles was a common sight in Catania during the course of the eruption (Figure 14).

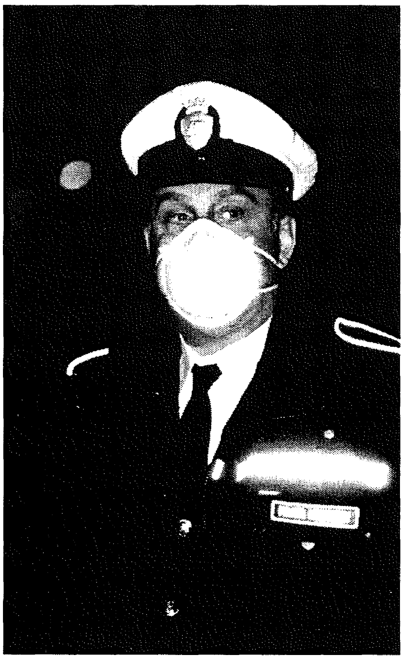

Figure 14. A Policeman on traffic duty wearing an ash mask (Catania).

Red Cross volunteers were often present on the streets in Catania during ashfall, handing out ash masks to pedestrians. Civic authorities recommended that people should try to keep outdoor physical activity to a minimum during ashfall, and that asthmatics remained indoors during those times (*La Sicilia*, 07/11/02).

Staff from the University of Catania's Institute for Respiratory Diseases and the Department of Microbiology are currently conducting investigations into the long-term effects of the ash on human health.

3.14 Economic effects of the eruption

The cost of the eruption is not easy to evaluate. A loss of € 140 million was described by the National Confederation of Farmers (Coldiretti, 2002). Over 80 hectares of forestry plantations were lost, several buildings were destroyed by lava flows, roads near Linguaglossa and Sapienza were covered and at least one car was destroyed. Earthquake damage affected many buildings, retaining walls and roads, all off which need to be repaired. As well as damage directly caused by the eruption, several costs need to be taken into account:

- Loss of employment resulted for fruit pickers and processors as crops were destroyed.
- Local authorities needed enough manpower to both monitor the eruption and keep the overcurious far enough away to avoid being injured of killed by the eruption. This involved over 200 people for three months (*La Sicilia*, 27/12/02).
- 2000 evacuees needed to be put into tents and fed. A further unknown number of evacuees were housed by relatives or rented alternative accommodation.
- Clean-up operations took many hours, and were performed by council workers in addition to their normal duties, at overtime rates. (P. Del Carlo, *pers. comm.*, 2002). As well as roads and public facilities/buildings, the drains had to be cleared of a build up of ash.
- Traffic accidents occurred as vehicles skidded on slippery surfaces.
- The cost of closing the airport alone was said by the mayor of Catania (Umberto Scapagnini) to be around € 500,000 per day (*La Sicilia*, 29/10/02).

Judging the loss experienced by the tourism industry is more complicated given the large number of variables, although the decline in tourism during the eruption had repercussions for local restaurants, retailers, hotels and the hospitality industry in general.

Italy also had to cope with several other natural disasters during this time, notably a landslide in Lombardy and earthquakes in Molise and Puglia. An aid package of € 700 million, funded by the government was announced in February 2003. This package was to cover all of the emergencies from late 2002 until that time. Catania received a significant portion of this, though the exact amount is unknown (*La Sicilia*, 07/02/03). The many costs involved in coping with the eruption make it impossible to place an accurate figure on the cost of the emergency. However, it will certainly be in the hundreds of millions of euros.

4. SUMMARY

The main hazards posed by the 2002 Etna eruption resulted from lava flows, earthquakes and ashfall. Lava flows destroyed over 80 ha of forests, a ski school, ski lifts, a hotel and two buildings at Rifugia Sapienza. Earthquakes caused damage to many retaining walls, roads and unreinforced masonry buildings, and resulted in the evacuation of over 2000 residents from villages on the slopes of the volcano. To those living closest to the volcano, it was earthquakes that caused the most fear. Ashfall however, caused the most widespread damage, as is the norm from volcanic eruptions in populated area. While deposits were light, they were sufficient to cause €140 million damage to crops, many traffic accidents, blocked drains and collapsed balconies, gutterings and in some cases roofs. The airport was closed for most of the duration of the eruption because of the ashfall, causing further economic damage to the region as people were not able to easily reach it, and airport through-traffic was lost. The three month duration of the eruption contributed significantly to the magnitude of economic damages to Sicilia, though physical damage resulting from ashfall was largely sustained during the first few days of the eruption.

5. LESSONS FOR NEW ZEALAND

The 2002 eruption of Mt Etna demonstrated the amount of damage and disruption that may be caused by what was a relatively small eruption (0.07 km^3 of material) (Behncke, 2002). The vulnerability of the horticultural industry was highlighted as crops up to 50 km away were devastated by light ashfall. Deposits less than 3 mm deep were sufficient to cause this. The horticultural industry in New Zealand is equally vulnerable; many North Island regions close to active volcanoes intensively use fertile volcanic soils for growing crops. For example, much of the Bay of Plenty region is devoted to agriculture and horticulture. An eruption from the Okataina Volcanic Centre would likely cover much (if not all) of the region with ash, as has happened in the past e.g. the 1886 Tarawera eruption, and the ~1305 C.E. Kaharoa eruption (Smith, 1887; Nairn *et al.*, 2001). White Island could also potentially affect the Bay of Plenty region, if an eruption occurred during wind from the north. Market gardens around Auckland would be equally vulnerable in the event of an eruption from the Auckland Volcanic Field. The same applies to Taranaki should Taranaki/Egmont erupt. Fortunately, the climate of the Central Plateau and its distance from large urban centres prevents such intensive land use from taking place around the Tongariro Volcanic Centre.

Anywhere in the North Island could potentially be affected by ashfall from one or more of the New Zealand volcanoes, depending on the size of the eruption and wind directions. Note that high elevation wind directions may carry ash in unexpected directions. This may produce a bimodal ash distribution if high-level wind is flowing in a different direction to low-level wind. The vulnerability of the horticultural industry can quickly be appreciated given the many sources of tephra and the subsequent potential for damage to crops.

One of the social impacts of volcanism not fully appreciated in New Zealand is the allure of a spectacular magmatic eruption for members of the populace. While the sight of an erupting volcano will send most people running in the opposite direction, there will still be many who try to get closer to the volcano – as evidenced during the Etna 2002 eruption. This will be most applicable to basaltic activity, as it is more likely to result in spectacular hawaiian-style fire fountaining, incandescent strombolian bomb showers and/or lava flows. These may not appear as threatening as an explosive andesitic or rhyolitic eruption.

Danger is not only posed to those people who try to get as close as possible to the activity, but to the rescue workers that have to save them as the tourists sustain injuries or get lost.

Large numbers of officials were needed at Etna to try to prevent this from occurring (over 230 people for three months). New Zealand may not have the required numbers of emergency services personnel to effectively prevent access to some of its volcanoes over a sustained period. This is not so much a function of the numbers of people attempting to gain access to an eruption, but of the number of access routes. While reaching somewhere like Tarawera Volcano may be able to be reasonably controlled due to few roads in the area, an eruption in Auckland, depending on its exact location, may be almost impossible to cordon. The number of roads in the area would require a large number of civil defence/emergency services personnel to prevent access to tourists. This may necessitate the allocation of civil defence staff or armed services personnel who would otherwise be used in rescue or relief duties to satisfactorily restrict access to hazardous areas. The allocation of staff to these duties needs to be considered in emergency management plans.

The reconnaissance trip to Etna also effectively demonstrated how various depths of ash can affect the mobility of motor vehicles. Traction problems begin with very thin layers of ash, in both wet and dry conditions. Table 1 gives an indication of depths of ash that it may be possible to drive upon, under different conditions. This will be useful in planning for rescue/recovery during or after future New Zealand events. The slipperiness resulting from thin layers of volcanic ash on road surfaces and the resulting road accidents experienced in Catania were significant. Similar consequences can be expected in New Zealand. This will contribute to larger numbers of accidents on roads with smooth surfaces; these are more similar to many roads around Etna. The coarse chip on many New Zealand roads will help to alleviate traction problems as deeper layers of ash will be required to prevent tyres contacting the road surface; the exact amount will depend on the coarseness of road chip on any given road. Even so, immediate speed restrictions will need to be imposed (and enforced) on New Zealand roads in the event of ash covering road surfaces. This is especially applicable to smooth roads with smooth tarmac or asphalt surfaces. The reduction in visibility caused by the remobilisation of dry ash will also necessitate speed restrictions.

The importance of quickly cleaning ash off roads was illustrated by this reconnaissance trip. The compacted drifts that can easily form create obstacles that may damage vehicular suspension or cause accidents if struck at speed. Methods used in Sicily for cleaning ash off roads may be emulated here, the use of snow ploughs and front end loaders was effective in removing layers that were several centimetres deep and sweepers removed the last millimetres. Similar equipment is available in New Zealand, although the difference in population density between Sicily and New Zealand means a smaller workforce and equipment pool is available in New Zealand to perform a clean-up. This may necessitate more assistance from regions unaffected by an eruption.

Disposal of ash in New Zealand may prove to be more problematic than in Italy. For example, environmental concerns in New Zealand may prevent the dumping of ash into the sea. The large quantities of ash that need to be removed from urban areas even in relatively small eruptions soon fill up available landfills. Sites on land that may be used to dispose of such ash are limited in number and capacity. While selling basaltic ash as fertilizer makes good use of the ash, it will not account for a large proportion of it. No answers applicable to New Zealand are given by the handling of this matter in Sicily because excess ash could be dumped at sea there.

Effects on tourism in Catania were significant, not least because of the closure of the airport. Tourism in New Zealand has the potential to be negatively affected by volcanism, especially if were to close Auckland airport. This is New Zealand's most active port, it's closure would result in international air traffic being diverted to Wellington and Christchurch. The repercussions for tourism in the North Island would be severe. Cancellations of trips would also ensue, affecting tourism over the whole of New Zealand. While some volcano tourists would flock to Auckland, these would be far outweighed by the number of people staying away (note the downturn in international tourism during the 1995-6 Ruapehu eruptions).

Another lesson learned specifically from the reconnaissance trip to Etna is the importance of communication between the scientific organization responsible for monitoring volcanoes and the local/regional authorities. The reluctance of the local council in Catania to clean up the streets until the eruption was "definitely over" illustrates the importance of an understanding by the local authority about the nature of the hazard. Fortunately in New Zealand communications between The Institute of Geological & Nuclear Sciences (GNS) (the scientific body responsible for the monitoring of volcanoes in New Zealand) and regional authorities are more established than those in Italy. Regional councils employ civil defence officers, who attend courses run by GNS as part of their emergency management training. These types of links need to be maintained. The 1995 and 1996 eruptions of Ruapehu helped to provide the incentive to strengthen these sorts of ties. In the event of an eruption in New Zealand, scientific advice from GNS needs to be made available to local and regional authorities. Constantly updated information about the status of the volcano will help them decide how to react. By the same token that scientific advice needs to be heeded by the local/regional authority. The mutual understanding of responsibilities and capabilities needs to be maintained before a volcanic event takes place. Good communication between the respective organizations will ensure this.

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7. REFERENCES

Allard, P., Neri, M., Murè, F. and Spilliaert, N (2002). "Misure ed osservaziono sulla frattura errutiva meridionale: Torre del Filosofo è sepolta dalla coltre di piroclastiti", www.ct.ingv.it

Azzaro, R. & Scarfi, L. (2002) "1° Rapporto Sul Terremoto Etneo Del 29/10/2002 Ore 18:15 ", (loc.) www.ct.ingv.it

Azzaro, R., D'Amico, S. Mostaccio & Scarfi, L. (2002) "1° Rapporto Sul Terremoto Di Macchia di Giarre del 2/12/2002-ore 13:28", (loc.) www.ct.ingv.it

Behncke, B. (2002) "The 2002 – 2003 NE and S flank eruption", http://boris.vulcanoetna.com/ETNA_2002.html

Bruno N., Caltabiano T., Longo V., Salerno G.G. (2002) "Misure del flusso di SO2 dall'Etna con spettrometro COSPEC", http://www.ct.ingv.it/Etna2002/main.htm

Coldiretti (2002) "Etna: Coldiretti, nei campi danni per 140 mln di euro", http://www.mondoagricoltura.it/orgprof/cold/4trim.02/COLD559.htm

Del Carlo, P (2002a) "Rapporto ceneri Etna - 9 novembre 2002", www.ct.ingv.it

Del Carlo, P (2002b) "Rapporto ricaduta ceneri del 28/10/2002", www.ct.ingv.it

Del Carlo, P., Andronico, D. and Cristaldi A. (2002a) "Rapporto ceneri Etna 21-31 dicembre 2002", www.ct.ingv.it

Del Carlo, P., Andronico, D. and Cristaldi A. (2002b) "Rapporto ceneri Etna 10 –25 novembre 2002", www.ct.ingv.it

Mostaccio, A. & Scarfi, L. (2002) "1° Rapporto Sul Terremoto Etneo Del 24/11/2002 Ore 07:59". (ora Locale) http://www.ct.ingv.it

La Sicilia Newspaper available online at www.lasicilia.it

La Sicilia Multimedia (2002) Confesercenti: "Il turismo e in ginocchio" http://www.siciliasearch.com/Province/catania/Etna/turismo_in_ginocchio.htm

L'unione sarda Newspaper available online at www.unionesarda.it

Nairn, I. A.; Self-S., Cole-J.W., Leonard-G.S. and Scutter-C. (2001) "Distribution, stratigraphy, and history of proximal deposits from the c. AD 1305 Kaharoa eruptive episode at Tarawera Volcano, New Zealand". *New Zealand Journal of Geology and Geophysics* **44** (3) p 467-484

Patanè, D., (2002) "Aggiornamento delle attività di monitoraggio sismico all'Etna 30 Ottobre 2002" http://www.ct.ingv.it/Etna2002/Geo&Vulca/Rapporto_eruzione20021030.pdf

Smith, S. P., (1886) "The Eruption of Tarawera", George Didsbury, *Government Printer*, Wellington. 84p.