MT. ETNA, ITALY LAVA FLOWS

FROM REMOTE SENSING

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INTRODUCTION

Recent studies have demonstrated that remote sensing offers the potential to aid in understanding the behavior of active lava flows by providing valuable information on flow morphology (Pieri *et al., 1990*), planimetric form, temperature distribution (Realmuto *et al.*, 1992), steepness of the slope (Mouginis-Mark and Garbeil, 1993), and other terrain parameters. By adequately constraining some or all of these properties, we may be able to predict the future course of a flow (Wadge *et al.,* 1994). The social relevance of such predictions for hazards mitigation is obvious. Current technology, however, has major limitations: the high cost of satellite data; the infrequent temporal coverage of satellite data; general unavailability of appropriate instrumentation on aircraft platforms, to name a few. Nevertheless, recent investigations have demonstrated the capabilities of remote sensing for volcanological studies. In this note, we report on one aspect of our on-going remote sensing investigations at Mt. Etna, Italy using multispectra aircraft data.

MISSION AND DATA PROCESSING

The aircraft data we are analyzing were acquired by the Italian TELAER (Telespazio + Alenia) project, using an Alenia-ENEA airborne Daedalus Thematic

Mapper Simulator (TMS) scanner, The data were flown at 6:35am on April 29, 1992. This instrument acquires 12 channels of image data in the visible, near infrared, shortwave infrared (S W] R), and thermal infrared wavelength regions (Table 1). The TMS includes the 7 Landsat Thematic Mapper (TM) satellite bands, and has 5 additional channels interspersed in the wavelength coverage. The TMS was flown at an altitude of 5000 m above sea level. The instantaneous field of view of 2.5 mrad produced a variable ground resolution of 12 m to 4 m, depending, on elevation. Figure 1 is a color composite of SWIR channels 10, 9, and 7 displayed in red, green, and blue respectively. This combination corresponds to a Landsat TM composite of bands 7, 5 and 4. The TMS data were registered to a Thematic Mapper scene, acquired on January 2, 1992, by identifying common tie points in the two dat sets. Next, the TMS data were geometrically rectified to the TM coordinate base using rubber sheet stretching; nearest-neighbor resampling was used to avoid spectral resampling. A second registration to a topographic base map produced an image that is planimetrically correct. The green streaks trailing from the bright yellow areas represent artifacts due to saturation of the detectors in bands 9 and 10.

For comparison, Figure 2 shows a topographic sketch map of Etna's 1989-1992 lava flows, reported as of May 18, 1992 (Smithsonian Institution, 1992c). Of note on the map are the features marked “lava tubes and skylights” and “lava fan/tumulus development”. The lava flows of 7-12 May, indicated by the hachure pattern, do not appear on our TMS image,

A different view of the flow on April 29 is seen in Figure 3. This image uses the same TMS data depicted in Figure 1. These data were draped over a digital elevation model (DEM) of the topography, acquired by the Istituto Nazionale dei Geofisica, Italy; Landsat TM bands 5 and 7 images, in blue and green, were used to fill in the areas not covered by the aircraft data, The 3-D perspective rendering was created using the Surveyor software program, developed by JPL’s Digital image Anal ysis Laboratory.

In the 10-9-7 color composite scheme we present in Figures 1 and 3, vegetation is golden yellow. On the original data, individual trees can easily be seen. The blue colored area around the summit craters is snow. The color is produced by the higher reflectance of snow at the shortest wavelength band compared to the two longer wavelength bands.

FLOW HISTORY AND IMAGE ANALYSIS

The most recent eruptive episode at Mt. Etna started on December 14, 1991, when a fissure eruption began on the SE flank, in the headwall of the *Valle del*

Bove. Explosive activity along the fissure was accompanied by effusion of lava with a porphyritic, hawaiitic composition, Most of the lava was carried through a complex system of tubes originating at the main vent, and emerged to form a lava field through numerous ephemeral secondary vents. Activity continued, and flows reached to within 2 km of the town of Zafferana Etnea by January 3, 1992 (Smithsonian Institution, 1992a). In January and early April, a series of barriers were constructed across the lava's path in an effort to contain the flow before it reached Zafferana. Effusion of lava continued through mid-April, when the flows overtopped and flowed around the barriers, and reached 1.5 km from the town (Smithsonian Institution, 1992b). The flow end can clearly be seen on Figure 3, very near the town. Fortunately, the flows stopped on April 15.

In both TMS images (Figures 1 and 3) the hot parts of the flow field are depicted in the saturated yellow color. These represent areas where incandescent lava is exposed. The spectral signature of these areas is caused by thermal radiance in the SWIR region. Field measurements of the lava have yielded temperatures of 850- 1050°C, which are near magmatic values. The high energy flux at these temperatures saturated the detectors in channels 10 and 9, so that temperature recoveries for some areas will not be possible. The images show the fissure, vent, and the complex, braided tube system downhill from the vents. Also apparent west of Monte Calanna is a sinuous hot area. We interpret this to represent a lava tube, with skylights and small breakouts producing surface flows (compare with map in Figure 2.) South of Monte Calanna are three hot flows that emerged from the secondary vents. These vents were active for many months, both before and after our data were acquired in April.

In later months, production of lava continued, but the new lava field developed on top of the existing lava field. In part this was due to a successful effort in May, 1993 to divert the main lava stream near the vent by dynamiting the existing channel, and encouraging the lava to form a new flow field far uphill from any towns. At the time of this writing (May, 1994), eruptive activity continues with new lava covering the exisitng lava fields.

Landsat Thematic Mapper data acquired on January 2, 1992 were presented by Rothery *et al.* (1992) . Their 7-5-4 image showed that the entire length of the flow was radiant, starting from the fissure vent and for a distance of 6.5 km. Rothery *et al.* also point out some of the limitations of TM data: in particular, the next cloud-free image was not recorded until March 22, indicating that these data cannot be used for frequent monitoring; saturation of the detectors and artifacts introduced by electronics overload corrupted parts of the data; obtaining the data from the vendor took severa months. Flying a similar instrument from an aircraft overcomes some of these problems: repeat coverage can be obtained whenever meteorological conditions permit, provided the instrument is available; in practice, the gains can be adjusted on individual channels to reduce saturation problems; and turnaround time to receive the data can be very short.

FUTURE WORK

Working with the TMS data, we plan to derive the temperatures of sub-pixel sized areas by comparing the calibrated radiances in two channels using the dual-band method. This technique was first discussed in detail for volcanological applications by Rothery *et al.* (1988), first used by Pieri *et al.,* (1990) for flows on Mt. Etna, and further developed by Oppenheimer *et al.* (1993). Using this method, estimates can be made of both the size and temperature of the hot areas within each pixel. Remote sensing data are the only method of measuring the temperature of an entire flow instantaneously. The temperature maps, along with coregistered DEM topographic data, will be used with flow models (Crisp and Baloga, 1 990; Pieri *et al., 1990)* to attempt to understand flow dynamics and behavior.

Additional overflights are planned for the summer of 1994 with the Italian National Research Council's new Multispectral Infrared and Visible Scanner (MIVIS) scanner. This 102 channel maging spectrometer provides high resolution spectral data in wavelength regions from the visible to the thermal infrared. In addition to being able to more accurately extract temperature measurements, we plan to monitor the SO_2 output by taking advantage of SO_2 spectral absorption features in the thermal infrared near 9 micrometers.

Another aspect of our studies of Mt. Etna is an analysis of a 12 year Landsat Thematic Mapper data base, encompassing more than 100 scenes. We plan to derive the time-history of the thermal behavior of the summit craters and any flows captured during data acquisition. We will compare the thermal history with the seismic activity and available data on other related geophysical phenomena (e.g., atmospheric SO_2 emissions, tilt, soil gas emissions), to examine the possible correlations of space-derived measurements with ground-based geophysical measurements. A correlation between seismic data and volcanic activity for a 20 year period was recently reported by Cardaci *et al.* (1993), providing a physical basis for our own studies.

Through all of these activities, we are seeking to develop and evaluate the capabilities of remote sensing instruments for volcanic monitoring, in anticipation of new and improved satellite instruments. Better multi-temporal coverage, for example, will allow us to monitor the rate of advance of the flow front. In 1998, a future Earth Observing System instrument, the Advanced Spaceborne Thermal

Emission Reflectance Radiometer (ASTER) will provide at least 16-day repeat coverage for any place on earth in 14 channels, including 5 channels in the thermal infrared. This will be the first satellite combining such a wide range of spectral bands with minimal semi-weekly temporal sampling.

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References

Cardaci, C., Falsaperia, S., Gasperini, P., Lombardo, G., Marzocchi, W., Mulargia, F., 1993, Cross-correlation analysis of seismic and volcanic data at Mt Etna volcano, Italy, *Bull. Volcanol.*, *S5, 596-603.*

Crisp, J., Baloga, S., 1990, A mode] for lava flows with two thermal components, *J. Geophys. Res.*, 91, 9543-9552.

Mouginis-Mark, P., Garbeil, H., 1993, Digital topography of volcanoes from radar interferometry: an example from Mt Vesuvius, Italy, *Bull. Volcanol.*, *S5, 566-5'70.*

Oppenheimer, C., Francis, P., Rothery, D., Carlton, R., Glaze, L., 1993, interpretation and comparison of volcanic thermal anomalies in Landsat Thematic Mapper infrared data: Volcan Lascar, Chile 1984-1991, *J. Geophys. Res.*, 98,4269-4286.

Pieri, D., Glaze, L., Abrams, M., 1990, Thermal radiance observations of an active lava flow during the June, 1994 eruption of Mt. Etna, Geology, 18, 1018-1022.

Rothery, D., Francis, P., Wood, C., 1988, Volcano monitoring using short wavelength infrared data from satellites, *J. Geophys. Res.*, *93, 7993-8008.*

Rothery, D., Borgia, A., Carlton, R., Oppenheimer, C., 1992, The 1992 Etna lava flow imaged by Landsat TM, *Int. J. Remote Sensing,* 13, *2759-2763.*

Smithsonian Institution, 1992a, Etna, *Bulletin of the Global Volcanism Network,* **17**: *1, 13-16.*

Smithsonian Institution, 1992b, Etna, *Bulletin of the Global Volcanism Network,* **17**: *3, 6.*

Smithsonian Institution, 1992c, Etna, *Bulletin of the Global Volcanism Network,* **17**: *5,* 15-19.

Wadge, G., Young, P., McKendrick, 1., 1994, Mapping lava flow hazards using computer simulation, *J. Geophys. Res., 99, 489-504.*

TABLE 1. Thematic Mapper Simulator Bands

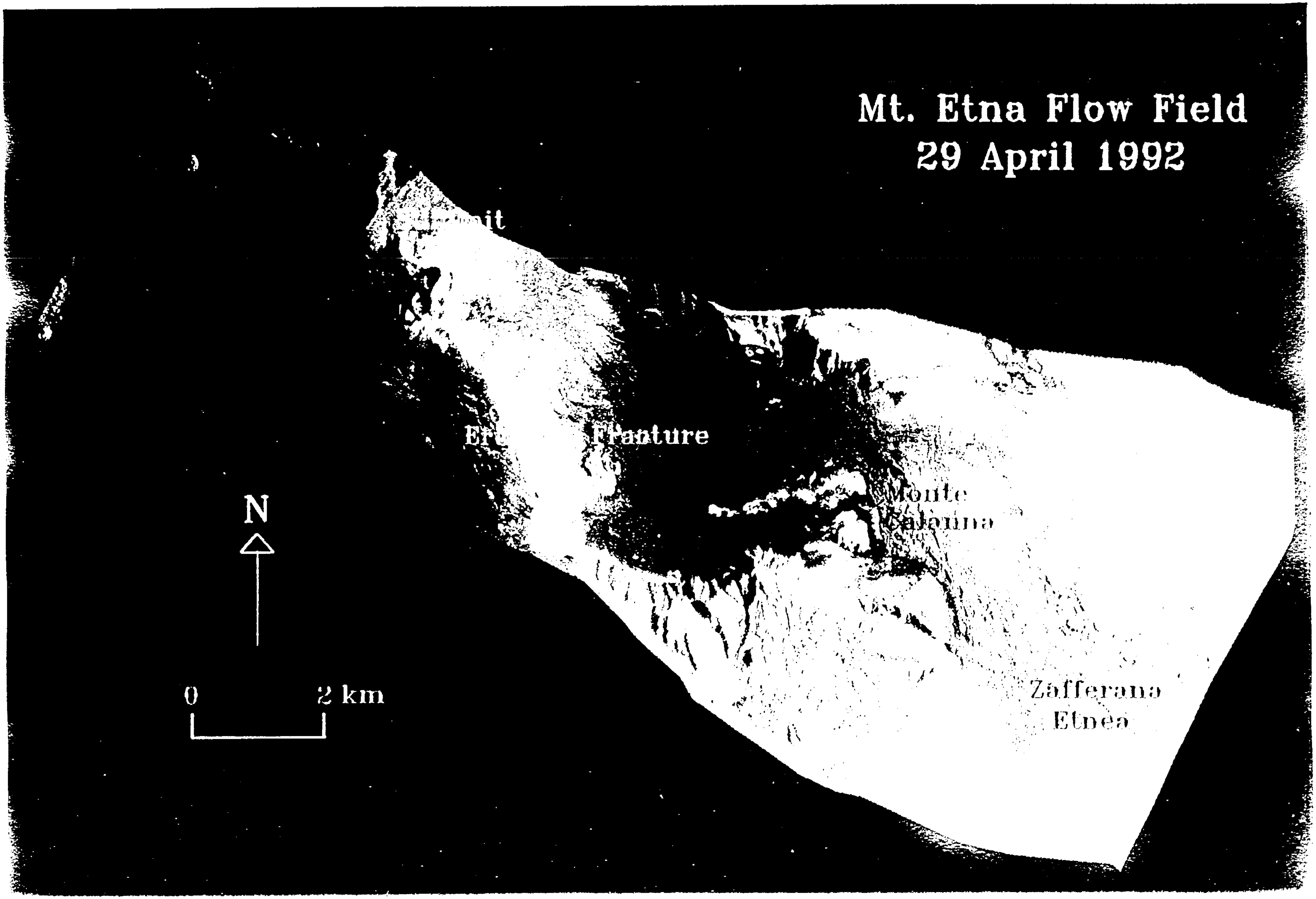
TMS Band	TM Band	Wavelength, μm
1		0.42-0.45
2	1	0.45-0.52
3	2	0.52-0.60
4		0.60-0.62
5	3	0.63-0.69
6		0.69-0.75
7	4	0.76-0.90
8		0.91-1.05
9	5	1.55-1.75
10	7	2.08-2.35
11	6	8.5-14.0 Low Gain
12	6	8.5-14.0 High Gain

Figure Captions

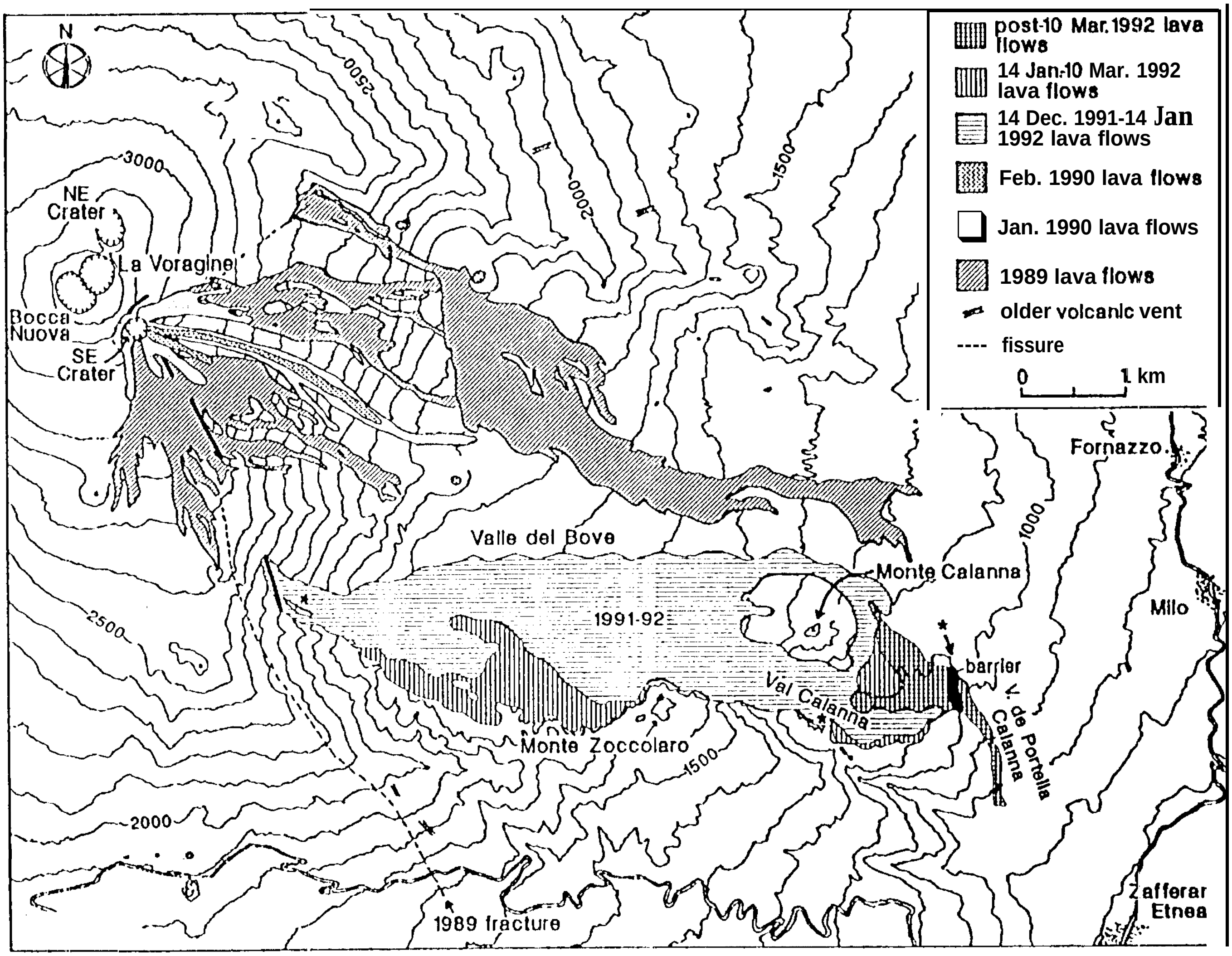
1) Airborne Thematic Mapper Simulator composite over the east side of Mt. Etna, Italy. The data were acquired on April 29, 1992 at 6:35am local time. The image combines three short-wave infrared channels, showing the active lava flows and lava tubes in yellow-orange.

2) Status of activity within Etna's flow field on May 18, 1992. Eruptive activity started in December, 1991, and continues to the present. The threatened town of Zafferana Etnea is in the lower right corner of the map (Smithsonian Institution, 1992c, p. 16)

3) Thematic Mapper Simulator data (see Figure 1), Landsat Thematic Mapper data, and Digital Elevation Model combined to produce a perspective view. The look direction is towards the west, into the Vane del Bove. The vertical exaggeration factor is 3.


Mt. Etna Flow Field
29 April 1992
N
0
2 km
Zafferana
Etnea

2



N
post-10 Mar.1992 lava flows
14 Jan.-10 Mar. 1992 lava flows
14 Dec. 1991-14 Jan 1992 lava flows
Feb. 1990 lava flows
Jan. 1990 lava flows
1989 lava flows
older volcanic vent
---- fissure
0 1 km
3000
2500
2000
1500
1000
NE Crater
La Voragine
Bocca Nuova
SE Crater
Valle del Bove
1991-92
Monte Calanna
Fornazzo
Milo
barrier
Val Calanna
V. de Portella Calanna
Monte Zoccolaro
1989 fracture
Zafferana Etnea