

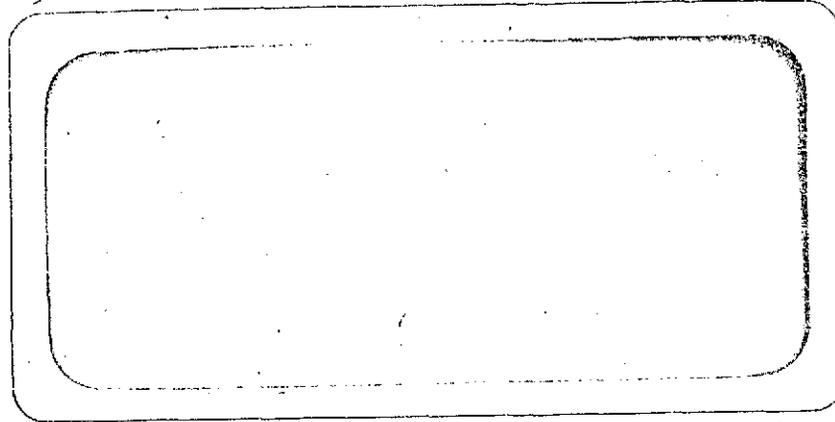
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Principal Investigator : R. Cassinis

Co-Investigators : G.M. Lechi  
C.M. Marino  
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Contribution of Space Platforms  
to a Ground and Airborne Remote-  
Sensing Programme over Active  
Italian Volcanoes

Nasa Contract FO - Ø 13

In 1970 a programme in remote sensing was started in Italy taking the geothermal behaviour of Italian Volcanoes as a first field of investigation. This report, which is the second version of the previous Type III final report submitted to NASA, illustrates the use of ERTS-1 imagery over the volcanic areas of Southern Italy. It evaluates the capacity of space platforms in the domains of regional geology, soil and rock-type classification and, more generally, to study the environment of active volcanoes. The test-sites (Fig.1) were selected and equipped primarily to monitor thermal emission, but ground-truth data was also collected in other domains (reflectance of rocks, soils and vegetation). The test areas were flown over with a two-channel thermal scanner, while a thermo camera was used on the ground to monitor the hot spots. The primary goal of this survey was to plot the changes in thermal emission with time in the framework of a research programme of the surveillance of active volcanoes ( see conclusions ). Another task was an evaluation of emissivity characteristics undertaken by observing the outputs of the two thermal channels. These results were compared with the reflectance distribution and changes observed on multispectral ERTS-1 imagery. During the SKYLAB-EREP second mission (SL-3) (September 1973) a sequence was shot by the SKYLAB photographic

package (S-190 A and S-190 B); moreover, a strip was recorded by the MSS ( bands 2,7 and 11 ).

The evaluation of this data led to some comments on the differences between ERTS and SKYLAB data.

As only uncorrected films are available, we will not comment on the MSS imagery. Data from the thermal channel ( 13 ) is not yet available.

Considering the number of ERTS-1 available passes, the repetition rate can be considered as good for rock-type discrimination and for the studies of regional geology, fair for the investigation of vegetation type and its behaviour in volcanic environments, and poor for hydrological studies, monitoring of sea currents or snow cover and sediment transport.

#### SCOPE OF THE INVESTIGATION

The problem of the control of volcanic phenomena has been carefully considered in our country over the last five years.

Remote Sensing techniques in particular have been employed by our research group over active volcanic areas due to the greater possibility they offer in the observing and quantifying of a large area in a short time.

In our research we firstly considered the multispectral method in which reflectivity characteristics of bodies are studied; secondly the thermal I.R. scanning method by which the distribution of surface temperature is analyzed.

In this framework ERTS-1 imagery over the volcanic areas of Southern Italy was primarily used for the evaluation of the capacity of space-platforms in the domains of regional geology, soil and rock-type classification and, more generally, to study the environments of active volcanoes.

The ERTS-1 data, although restricted to the visible and near I.R. parts of the electromagnetic spectrum, was considered as the forerunner of data of the same type to be provided by space platforms carrying multispectral scanners (MSS) extended to cover the thermal infrared.

#### TECHNIQUES : ENHANCEMENT AND INTERPRETATION PROCEDURES

The material received so far is only photographic and the processing only analogue. We considered it good procedure to undertake the digital approach only on tapes, having evaluated the potential of multispectral analysis for different objectives by analogue treatment.

#### Photographic Analogue Techniques

The energy collected in different bands is registered by a series of photographic layers, one for each band. For example, it is possible to obtain 4 black and white negative films describing the reflection properties of a certain surface in the blue, green, red and infrared bands.

This last band can be visualized by using a conventional colour, so converting the infrared into visible information. We have taken these bands utilizing three of the existing four each time and giving to each band a code-colour, after which the three chosen colours are combined by means of an additive projection following this expression:

$$(x,y) = A.a(x,y) + B.b(x,y) + C.c(x,y)$$

where A, B and C are the weights of the selected conventional colour, and a, b and c are the intensity modulations of the different bands.

Density slicing involves extracting isodensity levels, from the intensity modulation i.e.

$$a(x,y) = K$$

using the constant K as the parameter.

Masking : this procedure consists of the combining of a positive photographic layer of one band with the negative photographic layer of another band of the same image. In this way the final result is proportional to the distribution of the logarithm of the ratio between the bands.

Cross density slicing: this can be illustrated by the solution of the following system:

$$\begin{cases} a(x,y) = K_a \\ b(x,y) = K_b \\ c(x,y) = K_c \end{cases}$$

even for different values of the constants.

Masking slicing: the last technique considered can be clarified by the solution of a system formed by the ratio of each pair of bands:

$$\begin{cases} \frac{a}{b}(x,y) = K_{a,b} \\ \frac{a}{c}(x,y) = K_{a,c} \\ \frac{b}{c}(x,y) = K_{b,c} \end{cases}$$

This technique has been employed for the investigating of the distribution and the status of the vegetation canopy at a given time, as well as, by a temporal comparison, its seasonal changes.

### Electronic Analogue Techniques

A sharpening technique, using a 3 band TV system, can be applied to enhance the real lineaments seen in the ERTS images.

In order to detect better the possible main structural trends, a special technique was developed using band 7. The derivative of the original signal taken by the TV camera was rectified and averaged while rotating the scanning direction.

In this way we determined the amount of the contrast change related to the relative position of the TV raster and of the actual lineaments. Fig.2 represents the contrast averaged amplitude versus the raster relative direction.

In the same figure, above, the area investigated in the central part of Sicily is shown.

This device has also been used in an airborne thermal survey over the volcanoes to detect the radiance micro-anomalies by subtraction of the background. (Fig. 3).

### SCIENTIFIC RESULTS

The results regarding our two main test-sites ( eastern Sicily and the region of Naples ) are presented here separately due to the differences of environment between the Mount Etna area and the region of Naples and also from the point of view of regional geology, texture of soils and vegetation types.

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Southern Test Area : Mount Etna and Aeolian Islands.

The three false-colour composites from the passes of 8 August and 6 and 23 November 1972 can be considered as very good first material for a provisional evaluation of ERTS capabilities.

The geographical regions, the main soil types, the influence of soil type on vegetation, the main vegetation types and their seasonal behaviour (only two seasons: summer and fall) can be well observed on these composite images. New lineaments were also observed (especially during the fall pass), and these will be discussed later. The seasonal effect is clear comparing the vegetation along the coastal strip (citrus and orange trees), which appears more vigorous in the November passes, while around the summit of the cone the forest (pines and chestnuts) looks weaker. Also, along the recent lava flows the effect of the sparse brush is observed at low altitude.

A detailed analysis was made of the cone of Mount Etna. Figure 4 is a map of relative reflectivities, taken from the three bands of the summer pass. Only the lower reflectivities were considered, giving a higher weight to band 7, i.e. bare lava flows.

A relationship was observed between the age of these lavas and their relative reflectivity, the latter becoming higher as soon as sparse vegetation starts to spring up (lichens) and as the surface alteration proceeds.

The seasonal reflectivity changes in lava flows are plotted in figure 5. Between August and November, only 19% of the area covered by recent flows exhibits changes in reflectivity. This means that 81% of the area is uncovered by vegetation.

The same comparison was made for the whole volcanic cone, to ascertain both the influence and enhancement power of

seasonal vegetation changes. Band 7 was used to obtain the more effective contrast between inert and living material.

Using all available bands, passes and enhancements, the contour of the volcanic cone was plotted and compared to the known maximum extent of lavas under the typical vegetation, described on the official geological map (Fig.6). The colour-composite image of the fall pass proved to be the least misfitting (Fig. 6c).

The second and third passes show a very sharp distinction between the same type of vegetation (orange and citrus trees) grown on different soils. South of the volcano, in the plain of Catania, citrus and orange plantations look more "vigorous" than those along the slope of the lavic cone. In the first pass, this discrimination seems to be almost indiscernable.

This analysis demonstrates the capacity of the ERTS images to detect soil structure through the seasonal behaviour of the vegetation provided there is reasonable areal homogeneity of both soil and vegetation.

A detailed mapping of the vegetation cover along the slopes of Etna is presently being undertaken.

#### Comparison with the Skylab-EREP (SL-3) frames:

just considering the results on the volcanic environment of Mount Etna (no data is available over the Naples area) some preliminary comments can already be made:

- the improved geometrical resolution (in respect to ERTS imagery) leads to a successful application of masking slicing (multiband photography of S 190-A), for the detection of the influence of the soil type on the vegetation. Some small anomalies in the vegetation cover can originate from the chemical influence of the underground lavas in lateral fractures some time before forming clefts.

Only a temporal comparison would be effective in outlining

the growth of these anomalies.

As far as the ability to discriminate the bare lava flows, multispectral photography doesn't allow a sharp distinction as does the one performed by ERTS imagery ( color composite of 3 bands ).

This derives from the limitation involved in the spectral range (0.5 to 0.9  $\mu$  instead of 0.5 to 1.1  $\mu$  ).

Both the S 190 A and S 190 B I.R. color frames show the vegetation vigour and the small morphological features, very clearly as the auxiliary volcanic cones on the slopes of Mount Etna.

It is clear that, using the Skylab photographic facilities, i.e., the I.R. color frames and the four B & W bands, a lot of different information may be extracted in a inexpensive way.

By using the false I.R. color as a given standard color composite and employing single B & W bands for masking, more complete data can be collected than by ERTS imagery, at least for many objectives.

In this framework the last lateral eruption ( Feb.1974 ) offered us a new criteria for the forecasting and monitoring of these natural phenomena.

The hypothesis to be proposed consists in considering vegetation as an integrator, that is, the transfer function between the chemistry of the soil and the reflectivity of the lavas. In fact small but continuous amounts of magmatic gases filtering through the soil, could influence with a delay that has yet to be ascertained, the spectral behaviour of the vegetative canopy; this effect would be particularly strong in the near I.R. region.

In some cases the decrease of the reflectivity in the near I.R. region can be accompanied by a simultaneous increase of thermal I.R. radiance.

The data collected by the Skylab manned station during the

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SL 3 mission about five months before the paroxysmal event, were accurately analyzed.

The frames corresponding to the near I.R. band were particularly useful.

Some very interesting observations were also obtained by the analysis of the false colour image: lineaments crossing and intersecting over the area of the future eruption were discernable as well as some small circular areas where the vegetation canopy showed a reduced reflectivity.

These two observations are at present under investigation by specialists: geologists, biologists, phitopathologists and, last but not least, the Remote Sensing technicians.

#### Main geologic lineaments in central and eastern Sicily.

Figures 7a,b show a comparison of the lineaments on the official geological map of Sicily (scale 1:500.000) and those on the ERTS images (from all bands and enhancements). Some lineaments indicated as uncertain on the official map (broken lines) are clearly apparent on the ERTS images. Unknown features are also seen, especially in the central basin which is filled by several kilometers of "plastic" formations (mainly allochthonous). Owing to the great thickness of plastic sediments, it seems unlikely that these features correspond to the fracture lines that are known to occur in the deep rigid basement.

The group of lineaments that seems to cut Sicily in two ( see Fig. 7b ), from the town of Licata in the south to that of S.Stefano di Camastra on the Tyrrhenian coast, runs through different geologic provinces. They could be explained only as flexures corresponding to an active fault system separating two crustal plates. This hypothesis would seem to justify intensive field and interpretative work, including the use of geophysical methods.

From this example it appears very clear that the "lineaments"

can be classified into at least three categories:

a - lineaments corresponding to actual faults and fractures on rigid material outcrops ( Ragusan horst, SE Sicily - A )

b - lineaments which do not correspond to actual faulting on ground surface but which are due to a sharp change in lithology and vegetation type (boundaries of physiographic provinces).

This type of lineament could indicate a faulting system at depth, as in the case of the line Gulf of Gela - Plain of Catania (B) where several faults " en echelon ", discovered by the geophysical surveys, are lowering eastwards the rigid limestone rocks from a depth of 2000 m to several thousand meters.

c - lineaments which correspond to flexures of the ground produced by active faulting at depth (C).

A photogeological investigation using stereophoto pairs in scale 1:20.000 is being undertaken along a strip containing the S-N lineaments in Central Sicily. The aim of this survey is to collect information of the elements that could explain the lineaments seen in the image.

The Skylab imagery (especially the color, wide band photograph) is used for the definition of the morphological patterns (dry river beds) which can be correlated to the lineaments ( see ref. N. 16 - 17 -18 ).

#### Thermal survey of Volcanoes:

##### 1) Mount Etna.

In July 1973, Mount Etna and the other active Italian volcanoes were flown over with a Daedalus 1230 two-channels thermal scanner.

This flight was carried out also in preparation for the Skylab, Spacelab and ERTS programmes, in view of the availability of thermal channels during these missions.

A thermal image of the summit of Mount Etna is shown in Fig. 8.

Fig. 9, in which different values of contiguous steps obtained from the ratio of the two channels are plotted, can be considered as a relative emissivity map of volcanic materials.

Comparison of this map with the reflectivity steps observed by ERTS-1 is very difficult because of the scale difference.

A ground survey is in progress to try to assign the proper significance to the observed emissivity differences.

The ratio method can, however, already be considered a good fast tool for detailing the texture of volcanic materials.

We also considered the ratio and the differences in the two available IR bands. Within the small range of thermal excursion which normally occurs outside the area of the fumaroles we can accomplish the solution of a system formed by the equation:

$$\begin{cases} A - B = K_1 \\ \frac{A}{B} = K_2 \end{cases}$$

where A and B indicate the signals in the 3-5 $\mu$  and 8-11 $\mu$  ranges.

The solution to this system implies that we have only one material producing the same behaviour in both the difference and the ratio simultaneously.

#### 11) Aeolian archipelago.

The results of airborne thermal surveys have been promising, especially for that of the Island of Vulcano, where the behaviour of thermal anomalies is being followed by means of aerial and ground observations (Fig.10).

The comparison between the survey of 1970 and the latest one leads to some remarks on the radiating power involved in this geothermal area.

The radiance observed during the two flights was quantified in isoradiating steps and compared. They indicate the change in total thermal emission as well as the levels of maximum difference. In this way, a "thermal seepage drift" westwards (Fig.11) across the volcanic structure becomes very clear; we observed also a particular level of radiance related to the maximum extent of the migration.

We have drawn also what we call the "physiognomy" of the thermal gradient distribution. The type and dynamics of the heat escape at the surface are probably an indication of the stability of the volcanic system.

Comparing both physiognomies of radiance and of gradient, with a theoretical pattern in which the heat emerges from a cylindrical tube, we are quantifying the geometric and energetic distortion involved in the test area. While in the theoretical case the function describing the temperature and the gradient distribution in a radial direction can not exhibit any discontinuities or inflexions, the real thermal situation leads to some anomalies. The physiognomy curve, together with the radiance barycentres, points to spreading of the sources and their interactions.

The comparison between the thermal maps of Volcano shows appreciable heat radiating westwards, while fumarolisation does not at present follow the same path.

The vapour and gas vents corresponding to the diffuse heat have not yet changed the surface chemical structure, i.e. diffuse heat and fumarolization are oppositely directed. Individual hot spots can be discriminated by subtracting the signals of bands  $3-5\mu$  and  $8-14\mu$ , because a large thermal contrast in different regions of the IR spectrum leads to a strong difference in radiance value.

### The Volcanic Area of Naples.

The first available pass (9 August) is not very effective, especially over the mainland where the relief is smothered by cloud layers. The only clearly detectable targets are the cone of Vesuvius and the surrounding densely populated area (band 77).

Even for the pass of 27 August, the cloud cover, although more concentrated, does not allow proper use of density-slicing techniques or false-colour composites. The third pass is the only one suitable for our targets.

However, a false-colour composite of the first pass, using bands 5, 6 and 7, was made. It is very clear that in the dry season, the more vigorous vegetation in the volcanic area grows in old craters and on the northern part of Vesuvius (Monte Somma).

The results of the colour enhancement of the third pass ( 5 February 1973 ) show that the vegetation around the cone of Vesuvius has changed remarkably, probably due to microclimatic effects; the vigorous vegetation of Mount Somma (pines) has disappeared, while on the south slope the Mediterranean pines are more reflective.

The main aim of the survey was to discriminate between sediments and volcanic materials. Many attempts were made using density slicing, but they were unsuccessful in giving details mainly because of the masking effect of the cultivated fields in the area.

The highly differentiated composition of the surface around Naples does not allow coherent pattern recognition.

Nevertheless, to improve the possibility of signature identification, the "cross density slicing" techniques has been applied.

Figure 12 shows a map derived from a density-slicing section. Each band has been subdivided into 10 different isodensity levels so that, using three bands,  $10^3$  combinations were possible. A group of these is given as an example in this figure.

The results, as far as lithological discrimination capacity is concerned, are rather disappointing, due to the incoherent nature of the vegetation. The ground moisture was expected to play a major role in discriminating the tuffs from other materials, but it seems that, at least during the winter, this factor has little influence.

As regards vegetation-type discrimination, a comparison with official maps has been made but very close coincidence was not found.

In conclusion, it appears that in highly diversified regions such as the Naples area there is a need for a better resolution and more intensive coverages.

Within the framework of the already-mentioned programme of surveillance of active volcanoes, two airborne surveys were carried out in April 1970 and July 1973. The former was concerned only with the Phlaegrean Fields; the Solfatara crater was especially selected for investigation by ground and airborne thermal observation. During the July 1973 flight, the Solfatara survey was repeated and the Vesuvius area was flown over for the first time.

Figure 13a,b show the comparison of the imagery taken in the same band ( $3-5\mu$ ) during the two passes. It must be pointed out, however, that the two sets of scanning equipment, although having the same optical resolution, differ in quality.

In figure 14 a,b the thermal images taken during the last pass, flying at lower height and using both thermal channels ( $3-5, 9-11\mu$ ) are shown.

A quantitative comparison of both the geometrical and energetic distribution of radiance is under way.

Finally, Fig. 15a,b show a thermogram made at an altitude of 2000 m over the cone of Vesuvius.

The rim effect is clearly visible.

### - Hydrological and Sedimentological Analysis

Some examples are given here of colour enhanced density slicing having as a main purpose the analysis of river plumes. The obtained results are very impressive and in part do not agree with the known trend of sea currents.

### CONCLUSIONS

For a final evaluation and summary of the results, certain considerations must be made, viz:

- the original proposal was conceived when the inclusion of the thermal channel in the ERTS B payload seemed very likely; therefore, the data of ERTS-1 was considered mainly in the light of a preparation towards thermal analysis of active volcanism.

When it became clear that ERTS-B would be a replica of ERTS-1, the objectives of the investigation were shifted towards those more suitable to the visible and near infrared portions of the e.m. spectrum. For this reason the title of this report does not correspond to the proposed title.

Nevertheless, the thermal investigation of the active volcanoes was continued using airborne sensors; some results were published and are indicated in the list of references.

- The other goals of the investigation were achieved with a variable degree of success, depending on several factors, the main one of which was the poor repetition rate. This explains the reason why some geological objectives were successfully fulfilled, while those involving the observation of transient phenomena such as the hydro-

logical and sedimentological analysis, were not so satisfactory.

The most significant results can be summarized as follows:

1) A method has been suggested for the forecasting of the lateral eruptions of Mount Etna, through the multispectral analysis of the vegetation behaviour. This analysis was carried out mainly using the Skylab imagery: the ERTS resolution seems to be rather limiting for this type of investigation.

2) Unknown geological lineaments which seem to be related to deep crustal movements have been discovered using the ERTS imagery and enhanced by the most fitting treatment.

The same lineaments are not shown in the EREP photographs, their detection being strictly connected to the seasonal and illumination conditions.

These results demonstrate the fundamental contribution of space imagery to the understanding of global and regional tectonics; the image is a basic map from which detailed investigations are planned ( geological and geophysical).

3) Results in areas other than the test sites.

Results in the geological field were obtained in the study of the general structure of the Alpine range ( ref. n.8 - 18 ) by the ERTS imagery.

In the field of official vegetation classification, ERTS-1 images were used for a preliminary study of rice fields in Northern Italy. However the geometrical resolution is rather low considering the size of the fields. Very good experimental results have been obtained using the Skylab multispectral photographs.

A report to NASA - Houston is in preparation.

4) In the field of hydrogeology and soil type discrimination discoveries of unknown paleoriver beds have been made in the North-Eastern part of the Po Valley using the multispectral imagery of EREP SL 3. The superior resolution of Skylab was a fundamental element for the success of the investigation ( see ref.10 - 17 ).

#### FUTURE ACTIVITIES

Based on the fact that the second step of this Space Programme (ERTS-B) was not approved by NASA, this section will be accomplished only by the images received, with obvious delay, from EROS data center.

We hope to by pass this problem with the aid of the Italian T.E.R.R.A. project already approved by NASA.

In the meantime seasonal flights are planned over the volcanic environment in order to have repetitive coverages of the same areas for two specific purposes:

- a) to increase the degree of accuracy in the study of volcanic behaviour in order to forecast paroxistic phenomena.
- b) To implement the bank of available data in view of possible utilization in the Spacelab and other ERTS or EOS missions.

#### ERTS-1 IMAGES RECEIVED

The images available from the period August 1972-February include two complete passes over the test sites ( 8 August and 6 November 1972 over eastern and central Sicily, 9 August 1972 and 5 February 1973 over the Naples area ). A further set of images was obtained for the eastern edge of Sicily on 23 November 1972, during a

third pass in a contiguous orbit, one cycle after the pass of 6 November (cloud cover 0%).

Other images were not employed for the investigation because cloud cover hid the target.

It must be pointed out that the enhancement and the comparison between the first and subsequent passes was quite difficult due to the different bands received (5,6 and 7 for the first pass and 4,5 and 7 for the others).

The enhancement results provided some remarks on optimum band selection. Considering the problems involved in our investigation, it seems that band 6 is redundant: better discrimination between the vegetation canopy and soil can be achieved using bands which give a maximum reflectivity contrast ( bands 4,5 and 7 ).

#### SKYLAB DATA

The photographic material received so far concerns the flights of SL 3 mission of Sept. '73.

Data are S 190A and B positive and negative prints format 70 mm and 9,5 inches.

#### AERIAL IMAGES UTILIZED

##### a) Photographic material

Aerial photographics utilized were:

- 1 - black and white contact prints of the Italian Military Geographic Institute of the following areas - Scale 1:30.000

- Phlaegrean Fields
- Vesuvius
- The Islands of Vulcano and Lipari
- Cone of Etna ( not complete )

- 2 - I.R. photographs

35 mm I.R. color images of a partial coverage of the slopes of Etna.

## b) I.R. Thermal images

- |  |  |
|--|--|
| 1 - U.S.G.S.                                     | 1969 flights over main Italian volcanic areas  |
| 2 - National Research Council 1970 flights over: | Phlaegrean Fields<br>Salina, Islands of Lipari and Vulcano   |
| 3 - N.R.C. 1973 flights over:                    | Phlaegrean Fields<br>Vesuvius<br>Islands of Stromboli and Vulcano<br>Crater of Etna                                  |
| 4 - N.R.C. 1974 flights over:                    | Solfatara ( Phlaegrean Fields)<br>Vesuvius<br>Islands of Stromboli, Lipari and Vulcano<br>Slopes of Etna and Vulcano |

## QUALITY OF THE IMAGES

We are now able to make the following remarks concerning the technical aspects of the images of our test site. (We received 70 mm transparencies and 9.5 inch black and white positives and negatives). For our type of investigation, the ability to compare images taken at different time is very important, and the same is true for images recorded during the same period in different bands. Comparison of different passes and bands proved very difficult because of the following possible sources of error:

- (i) There are remarkable differences between images of different passes due to the non-uniform density of the film background. A mask was added to each image to give a correct comparison with the next. This error varies with irregularity throughout images.

(ii) The fiducial marks at the corners of each image are not always well positioned; for this reason they are not very useful for the false-colour-composite technique.

It is often better to use some recorded landscape characteristics (shore-lines, small lakes, etc.) to achieve correct superposition.

(iii) The density of the steps in the grey scale at the bottoms of the images is not uniform. Large variations in density were found on examining each grey step.

(iv) We observed a remarkable difference in the image geometry of two passes.

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# TEST AREAS

SCALE 1:4'600'000



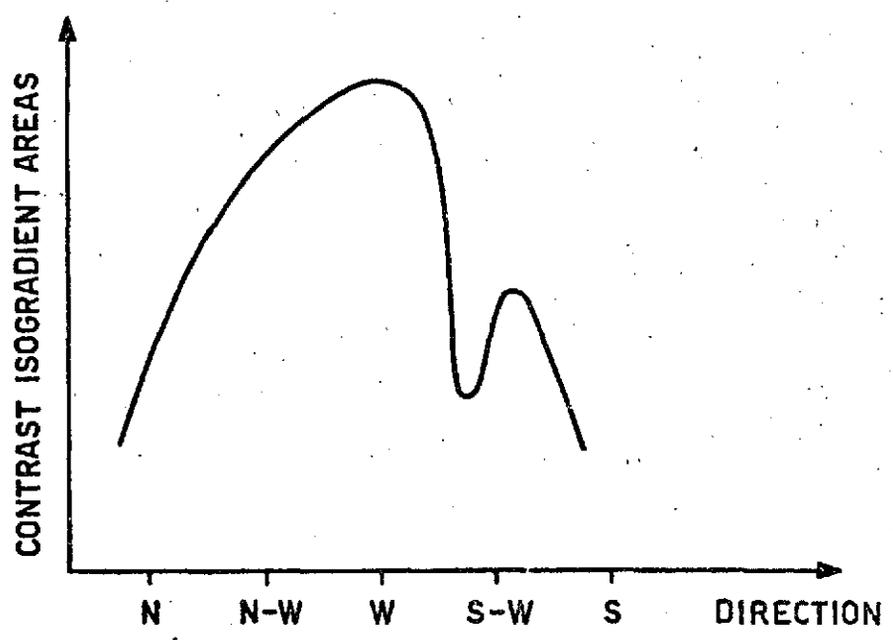
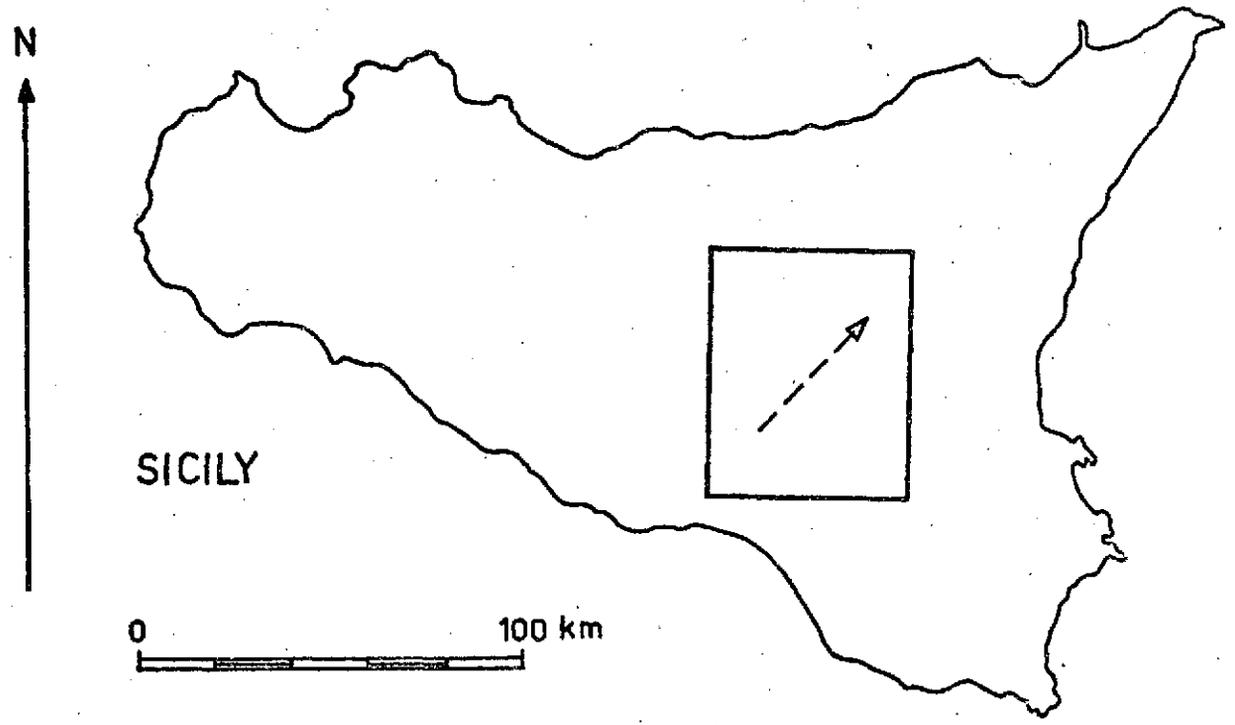


FIG. 2

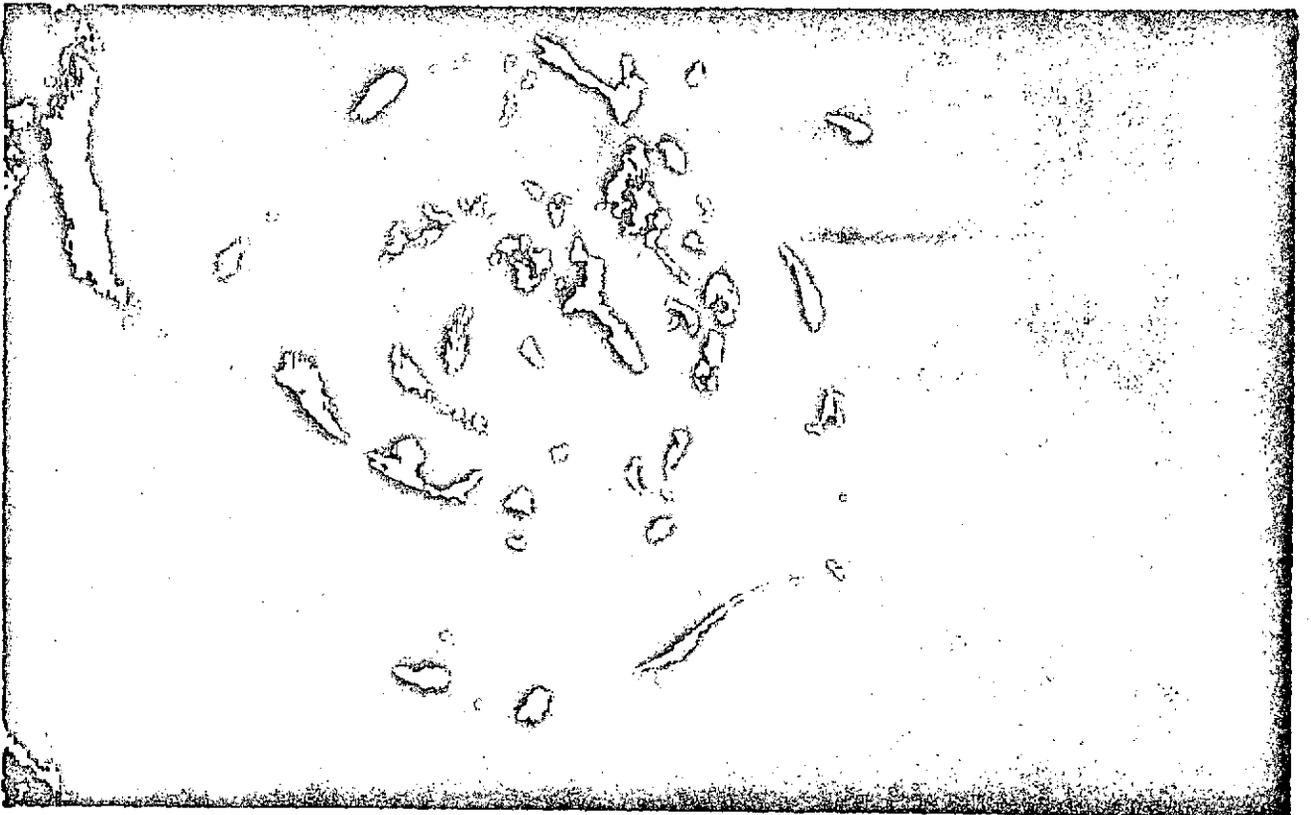
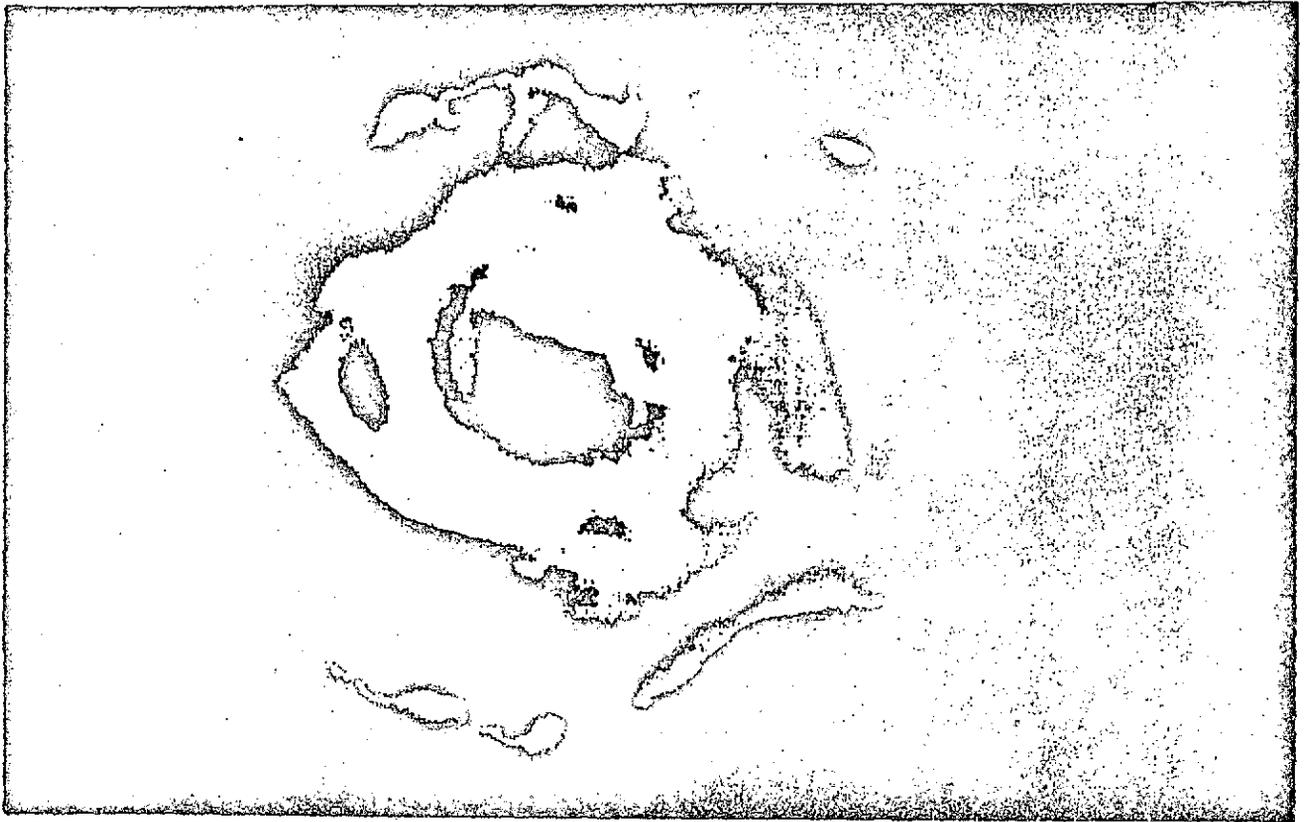


Fig. 3 - The crater of Vulcano island.

Above : thermal I.R.

Below : thermal gradients.

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M. ETNA

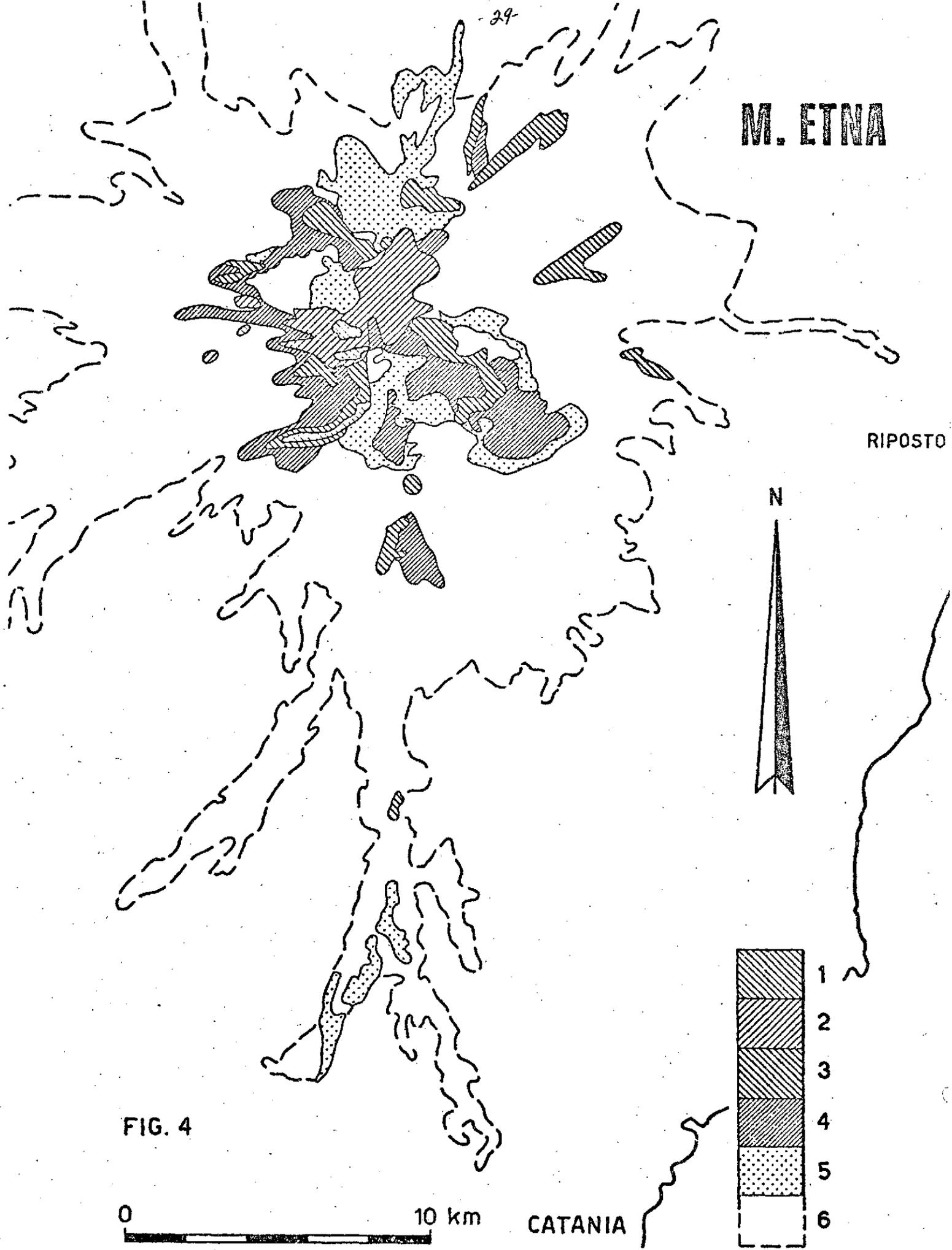
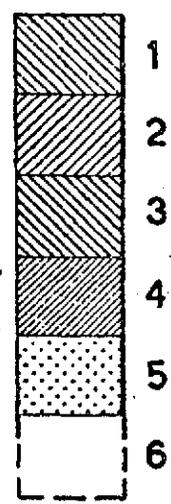
RIPOSTO

N

FIG. 4

0 10 km

CATANIA



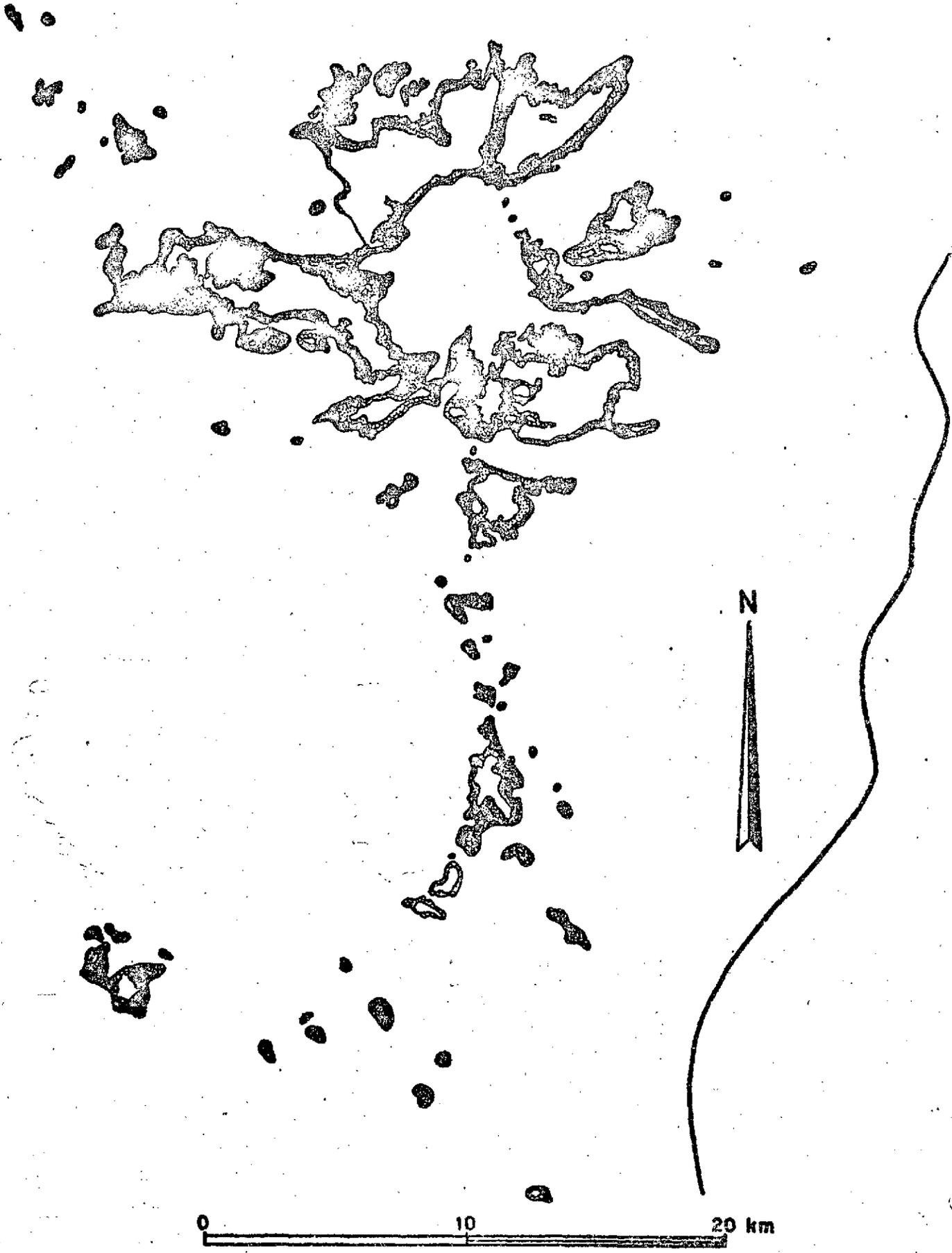
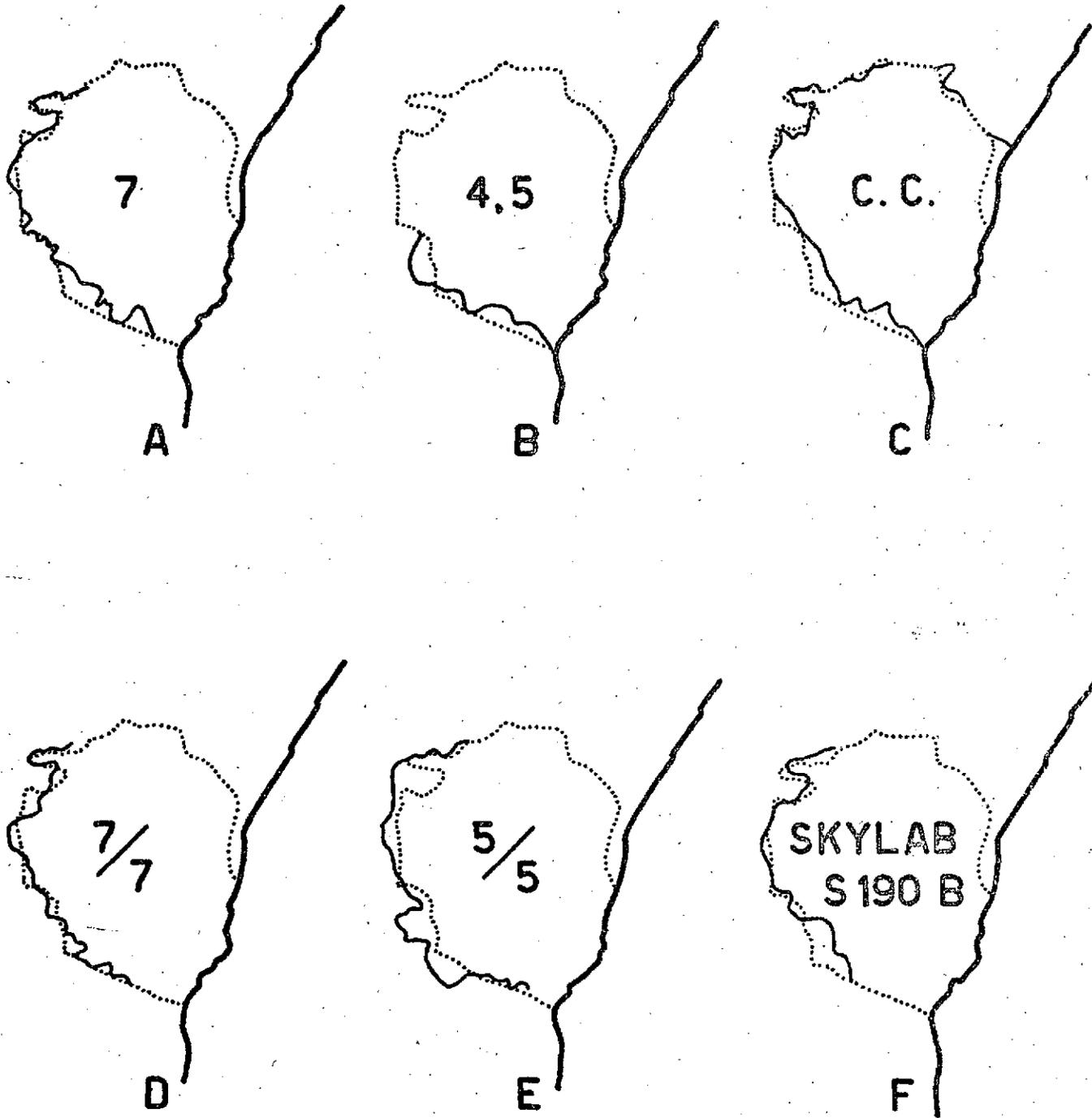


FIG. 5



..... GEOLOGIC MAP  
———— ERTS AND SKYLAB

FIG. 6

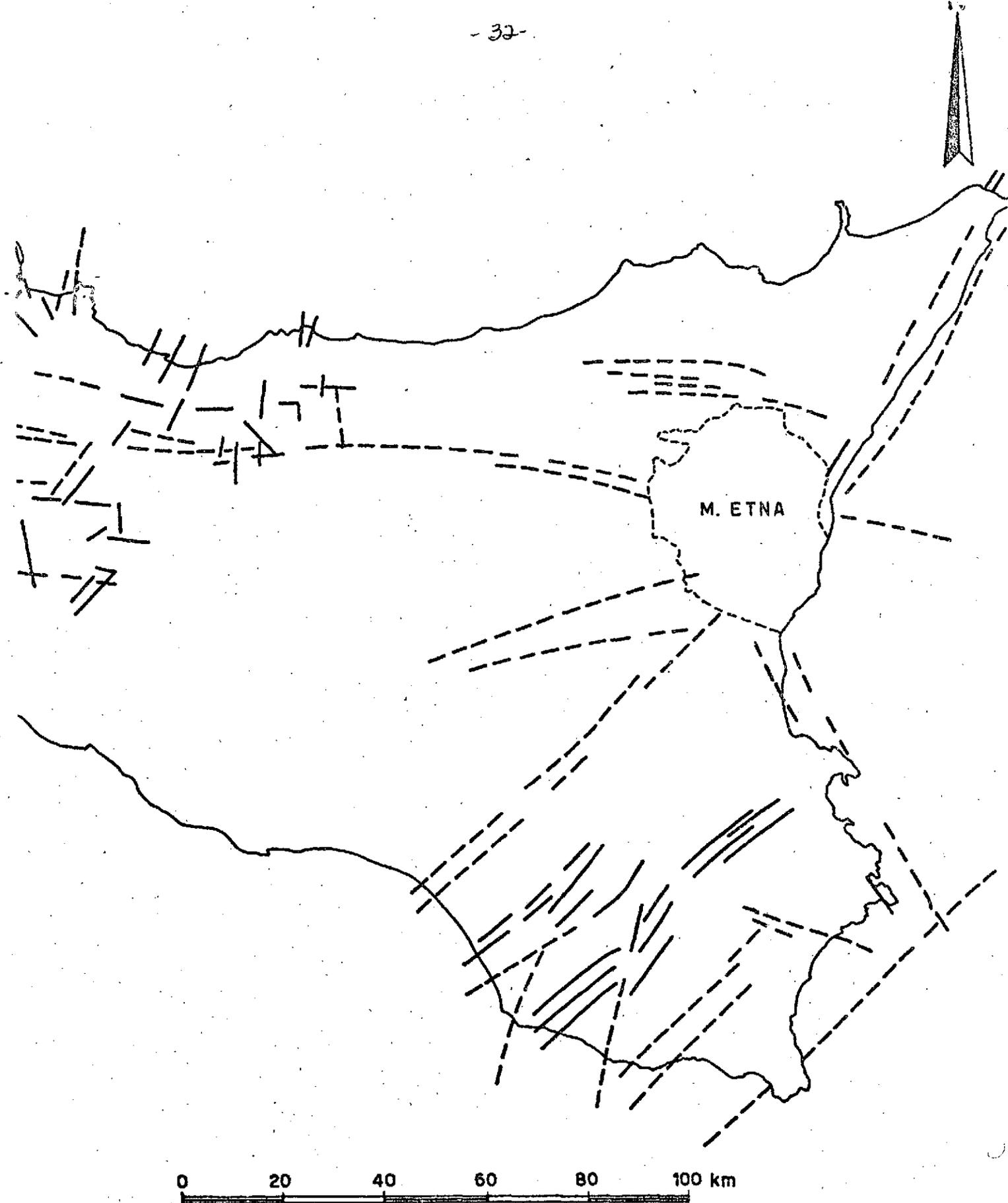


FIG. 7 a

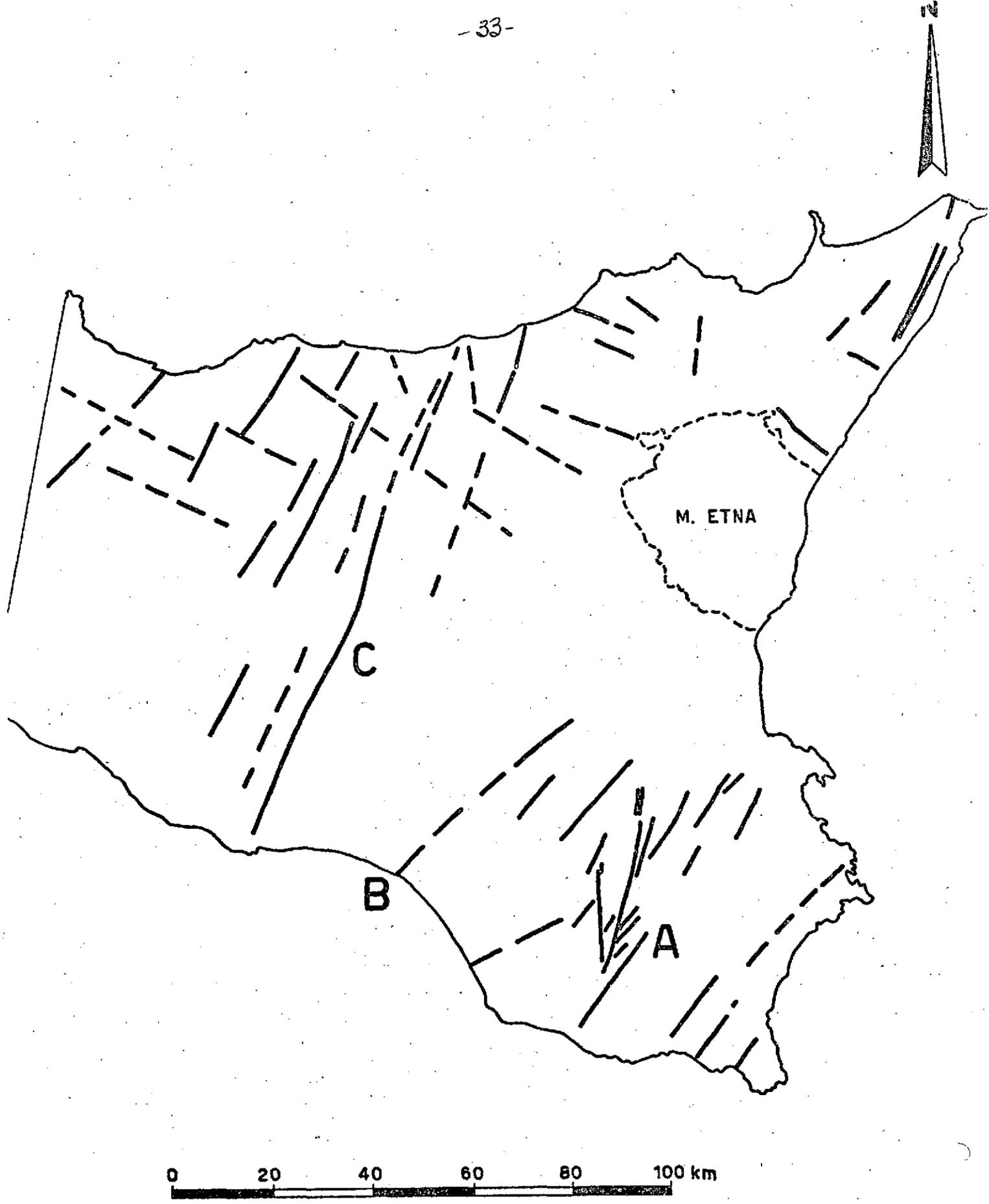


FIG. 7 b

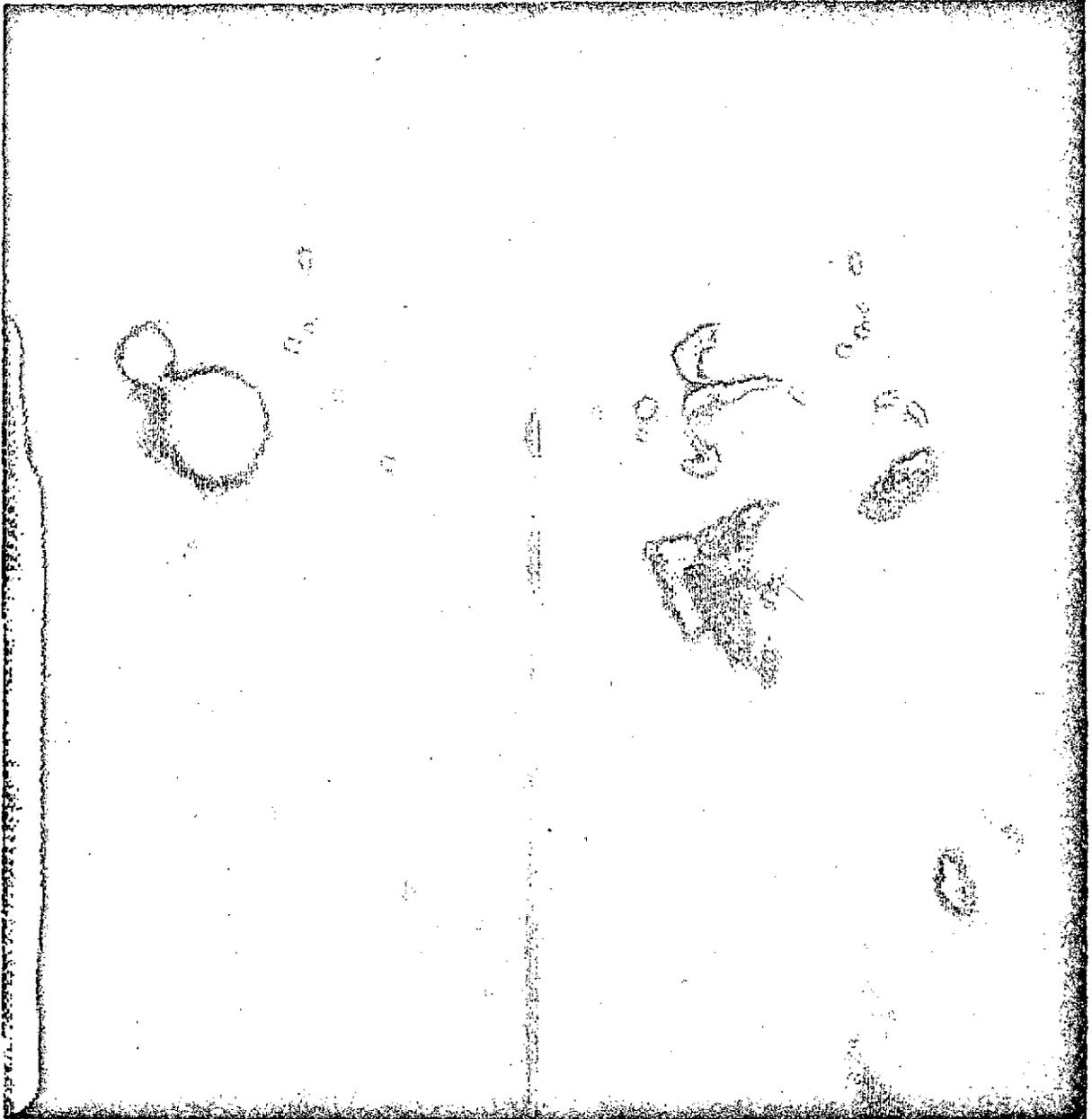


Fig. 8 - Thermogram of the summit of Mount Etna. Channel 9-11  $\mu$  (left) and difference between channels 3-5  $\mu$  and 9-11  $\mu$  (right)

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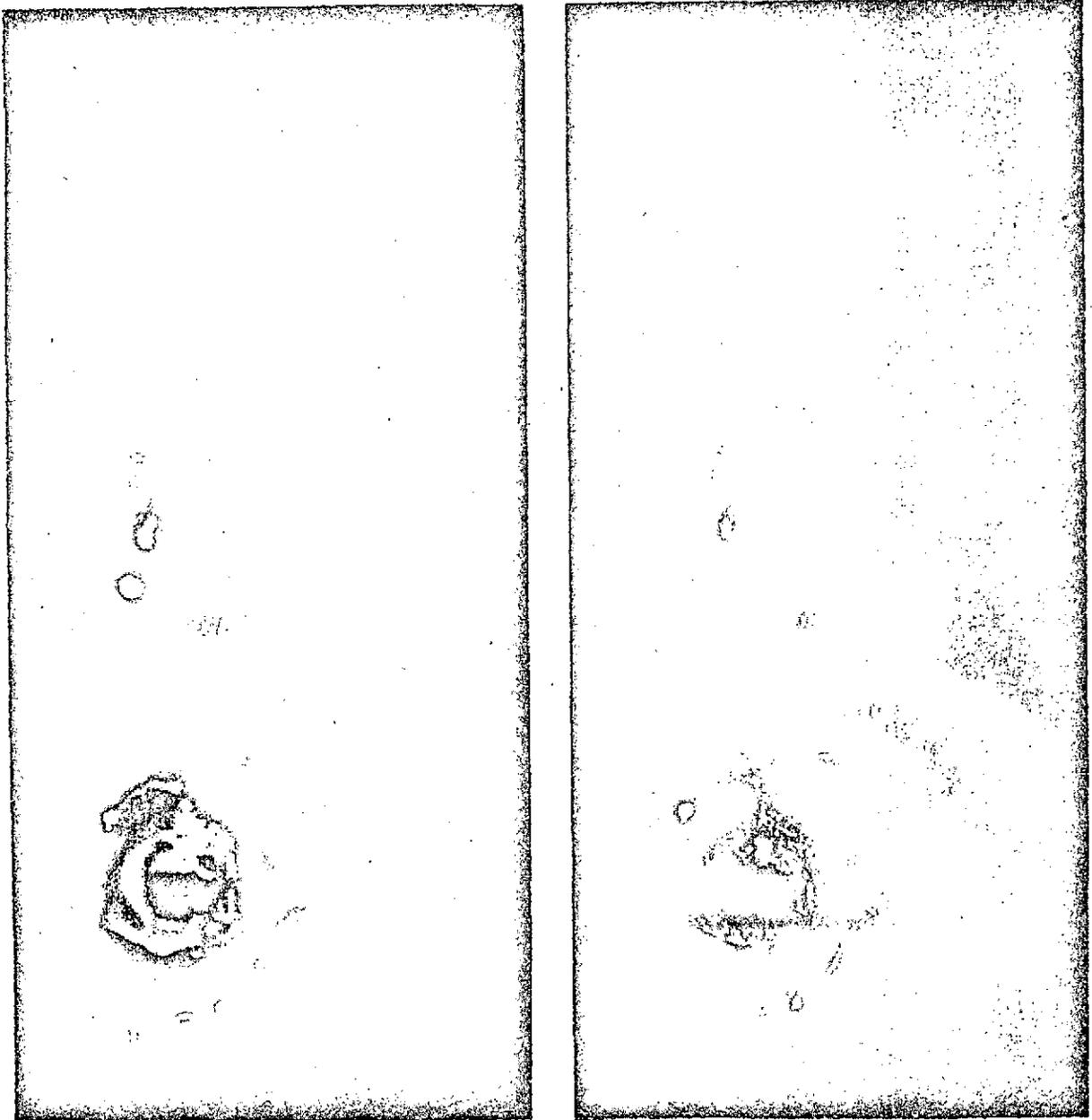


Fig. 10 - Thermal image of Vulcano crater  
flown in July 1973.

Left : 3-5  $\mu$  channel

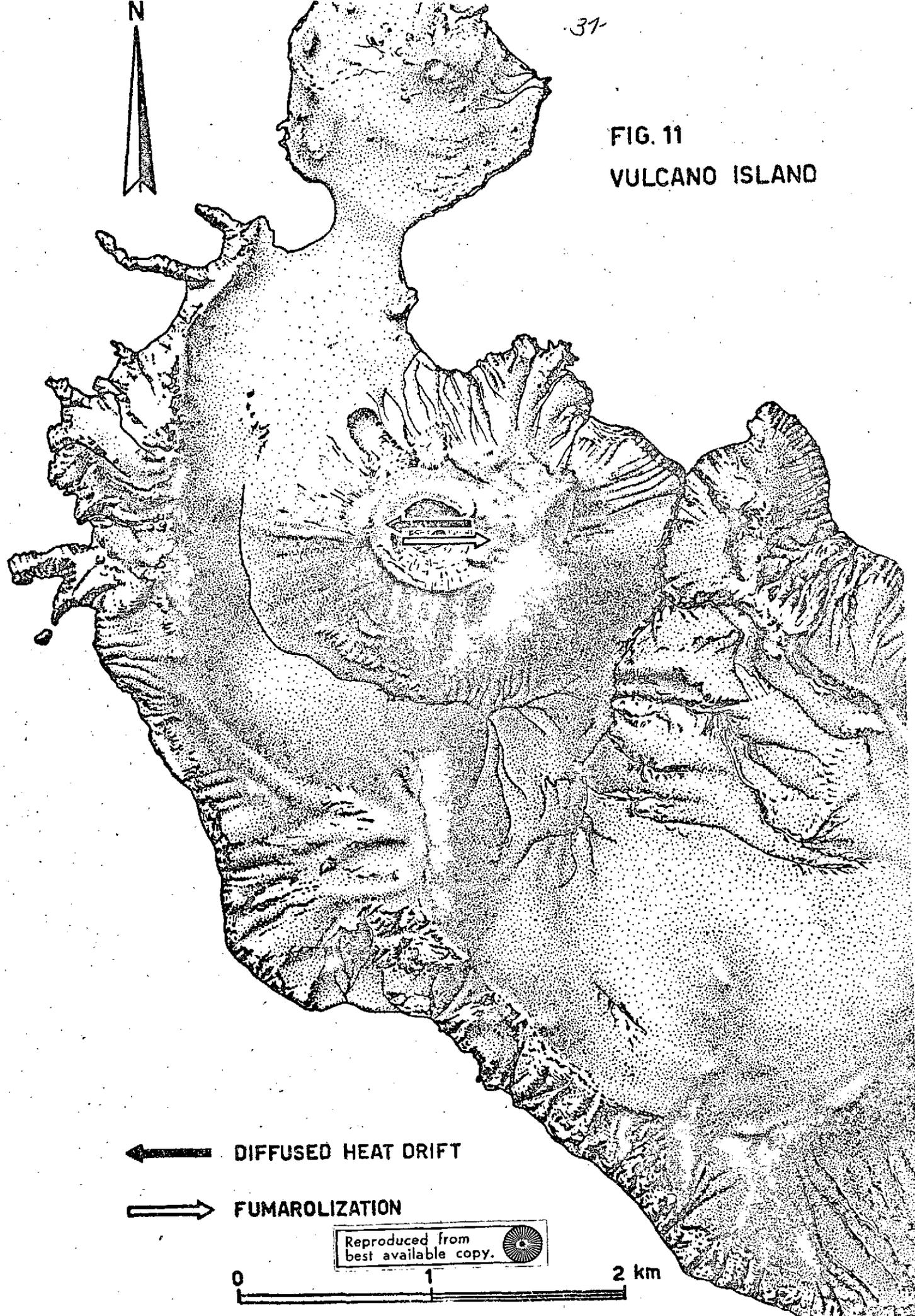
Right: difference between the two  
thermal channels.

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FIG. 11  
VULCANO ISLAND



← DIFFUSED HEAT DRIFT

→ FUMAROLIZATION

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0 1 2 km



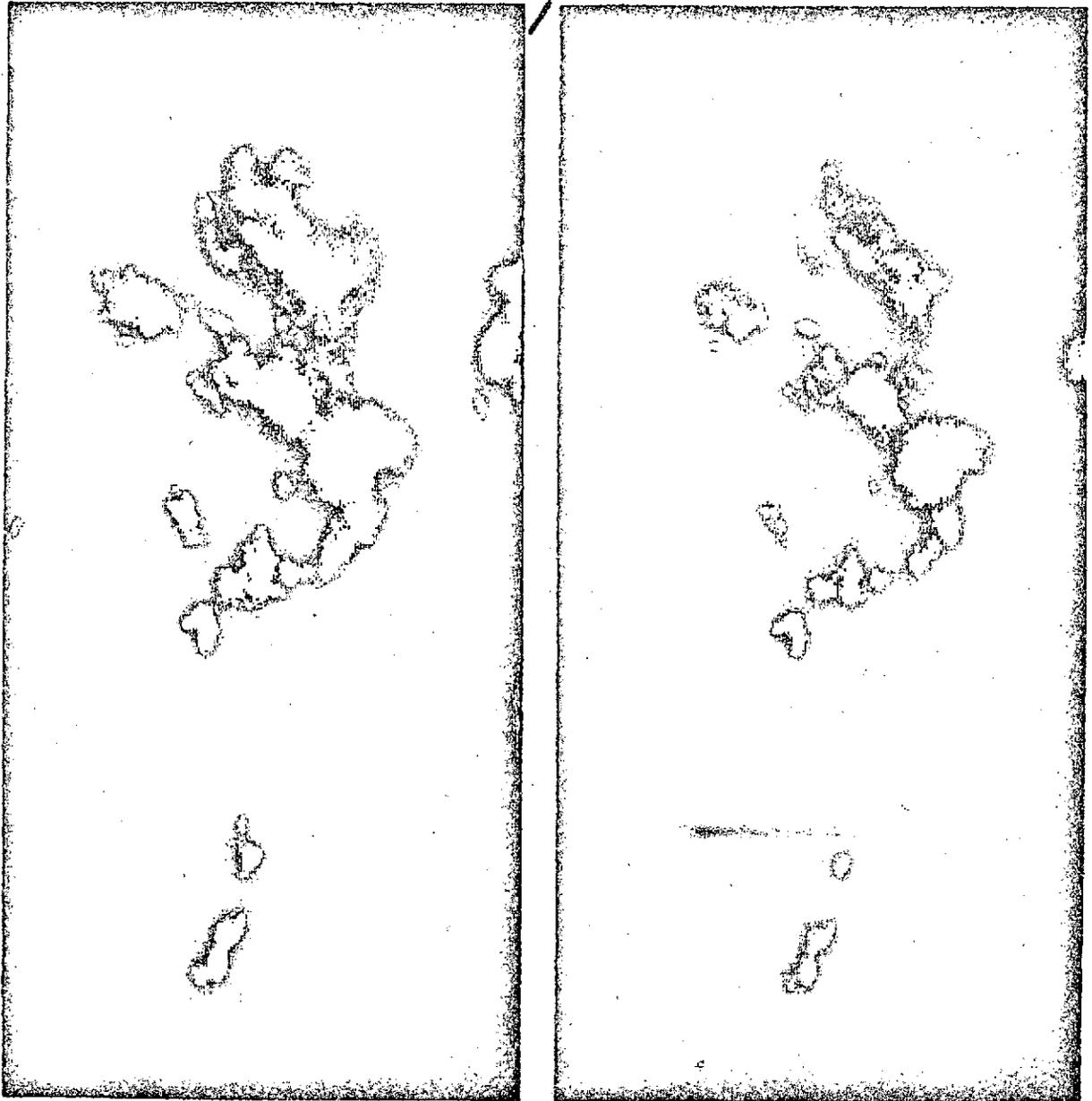
NORD  


Fig. 14 - The Solfatarara as seen in '73 at  
low altitude in channels 3-5  $\mu$   
and 9-11  $\mu$  .

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Fig. 13 - The old crater of Solfatara as observed in '70 and '73.

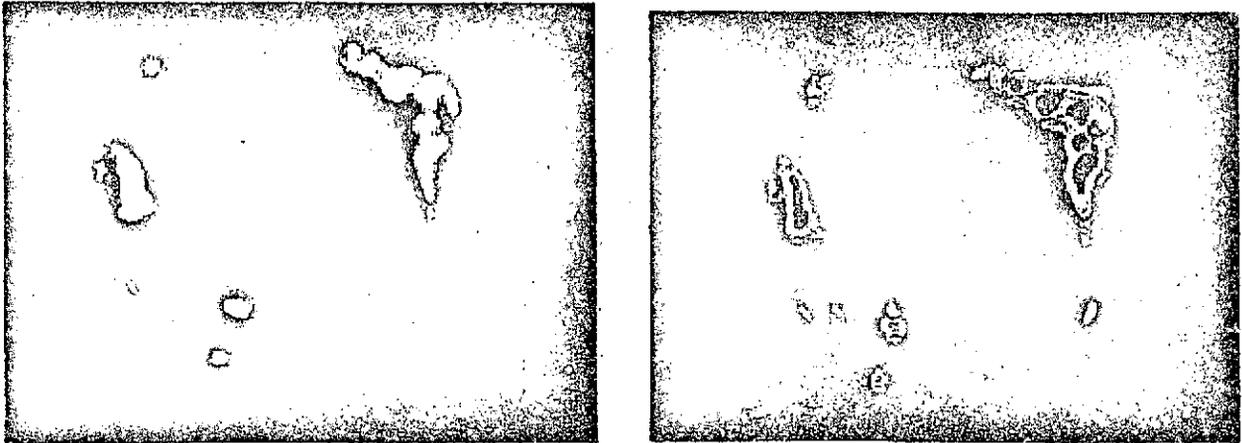


Fig. 15 - The cone of Vesuvius volcano  
Left : 9-11 A.  
Right : thermal gradients.

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