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20131 MILANO... December 1975  
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RESULTS OF SKYLAB INVESTIGATION  
OVER ITALY

*EPN-9659*

Cassinis R., Lechi G.M., Tonelli A.M.

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EROS Data Center  
10th and Dakota Avenue  
Sioux Falls, SD 57198

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SKYLAB FINAL REPORT

P.I.: R.Cassinis *veg*  
Co-P.I. : G.M.Lechi, A.M.Tonelli

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SUMMARY STATEMENT OF SIGNIFICANT FINDINGS

1) The multispectral , high resolution photography of S 190 A has been successfully applied to the detection of paleoriverbeds in flat lands: particular enhancements (ratio) are mandatory in order to reach the objective though the determination of differential reflectivity of vegetation and of differential moisture. The exploration cost is of about 1/10 if compared to the conventional methods.

2) The results of SL-3 mission were compared to those of Landsat for two regional geological surveys (linear structures) on the islands of Sicily and Sardinia. On Sicily, the seasonal conditions were unfavourable for Skylab while Landsat played a major role in discovering long, unknown lineaments of great interest for the geodynamics of the area.

On Sardinia, owing to the vegetation type and to the geomorphic conditions, the Skylab imagery was successfully employed to describe the detailed network of linears, both regional and local. The results can be used to study the relationship between linears, actual fracturing and the occurrence of mineral deposits.

## Foreword

During the September 1973 Skylab Mission (SL-3) S 190A multispectral photography and S 190B false-color photographs were taken of the Islands of Sicily and Sardinia as well as Northern Italy.

Also some images of the MSS (S 192) were collected over Central Italy.

However, as this area was not considered as a test site in our program and owing to the lack of ground truth, we did not proceed to a complete evaluation of the results.

This report therefore describe only the evaluation of the multispectral photographs as illustrated in table 1. The following chapters deal with the investigation carried on different subjects in the selected areas.

TABLE 1

Data and local time	Test Site	Objective	Bands	Enhancement - (giving significant results)
4/9/75 14 08'	Central Sicily	Linear structure (complementary to Landsat data)	I.R. false color	-----
4/9/75 14 08'	Etna Mount (Eastern Sicily)	Geovegetative anomalies on slopes of volcano. Linear fractures on lava blanket (side eruption forecasting)	I.R. Red-orange I.R. false color	-----
	NE Sardinia	Correlation of linears and fractures and crystalline shield and mineral occurrences	I.R. Red-orange I.R. false color	Product Derivative Product x Derivative
12/9/75 12 33'	Venetian plains	Paleoriverbed detection	I.R. Red-orange	Ratio
19/9/75 13 57	River Po Delta	Vegetation and crop inventory	I.R. Red-orange Green	Ratio Product



1 - Study of regional geology of Sicily: the contribution of Skylab imagery

The regional linears and main geological features observed by the satellites were compared with known structures. According to the plate tectonics theory, Sicily is a marginal element of the African plate. Only the South-Eastern Ragusan carbonatic platform seems to be an undisturbed portion of the continental plate while the Northern belt is a folding system ("nappes") produced by overthrusting along the margin. The central part of the island is a subsidence area filled by several km of allochthonous material (mainly shales) of different lithology deposited by submarine slides from the NE. The physiographic subdivisions of Sicily are clearly shown by ERTS-1 original imagery by false-color composition of 3 bands or, better still, by the ratio of two bands, represented by density slicing.

On the original bands of different ERTS-1 and SKYLAB orbits as well as on different types of treatment, many new linears were discovered. Fig.1A plots the faults known or hypothesized from geological and geophysical surveys as they appear on the official geological map (scale 1:500.000).

In Fig.1B the outlines observed in the satellite images were plotted together with the Bouguer gravity anomalies.

The number of linears corresponds fairly well on rigid formation exposures (Ragusan plateau, northern belt, Peloritani mountains) while in the central area (Pliomiocene basin of Caltanissetta) where the outcropping formations are mainly "plastic", new linears greatly outnumber known faults.

At the same time, it can be observed that on rigid formations the "continuity" of the linears is high but the total length is generally not very large. The linears appear as very sharp cuts on the South Eastern plateau.

In the central basin, the appearance of linears is broader. They often look as if they were produced by the correlation of straight fragments generally of morphological origin

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(drainage pattern, outcrops of fragments of "rigid" material as Pliocene or upper Miocene sandstones, gypsum or sulphur bearing limestone, or even lithological contacts).

The alignment of these fragments appears to be clear only because of the synopsis potential of space images.

These remarks seem to suggest that the long lineaments in Central Sicily, sometimes crossing the whole island, are of different origin from the shorter and sharper linears on rigid formations. The latter very often correspond to actual fracturing reaching the surface, enhanced by the alteration. The former, given by the alignment of surface "indicators", reflect very deep movements. As they cross formations of different age and of different lithology, they seem to correspond to very recent stresses.

The four rose diagrams of Fig.3 illustrate the trends of lineaments observed in Central Sicily.

The results of Skylab correspond fairly well to the ERTS color composition.

A curious but as yet, unexplained feature, is the strict correspondance of a main crossing of regional linears with the strong gravity minimum in Central Sicily.

This negative value is of 80 mgal even after isostatic correction and corresponds very well to the center of the Plio-Miocenic basin.

An attempt was also made to compare linears with seismicity. Although the epicenters are plotted with a very low accuracy ( $\pm 30$  km) their pattern suggests lines of seismicity also in NNE and NE directions rather than only along the Tyrrhenian and the Ionian coasts as was generally believed.

A detailed analysis of a group of lineaments in Central Sicily was carried out using a strip of stereo pairs for comparison. The contribution of Skylab imagery seems to be scarce with respect with to that made by Landsat 1 (see Fig.2).

The season together with the solar illumination angle play a very important role in the discrimination of linear features.

The Skylab photographs were taken in September 1973, in a period characterized by a flat uniform response of vegetation coverage.

The improved optical resolution of Skylab with respect to that one of Landsat 1 seems unable to provide additional informations on regional linears. On the other hand the Landsat 1 passage over Sicily of November 1973 showed a great number of linear elements which have been successfully correlated and interpreted. It can be said that the presence of vegetation strongly influences the possibility of drawing the linears.

In the right seasons, when the vegetation is green, much informations can be extracted; on the contrary when the vegetation becomes dry, the dry vegetation blanks out all features.

In bare zones the continuity of certain phenomena indicating the existence of faults or fractures can be observed using only the I.R. band or the product of I.R. and red bands.

## 2 - Volcanic surveillance

The environment of Mt. Etna (Sicily) has been studied throughout the seasons by means of Landsat 1 images since 1972. But the low-resolution data were not able to give any useful account of volcanic phenomena. The improved resolution Skylab data allowed the study of smaller phenomena occurring at the surface of the flanks of the large volcano in particular around the green belt of Mediterranean vegetation surrounding the cone.

The Skylab images taken over Sicily on September 15th 1973 aroused the interest of the Italian Remote Sensing Group to investigate some areas which showed an interesting spectral reflectance. On the false color frame the attention of the

authors was particularly attracted by the zone where, five months later, the phenomena had taken place (De Fiore Mounts, Jan-Feb. 1974) (Fig.4).

The area contrasted with the surrounding ones owing to its low infrared reflectivity. This fact suggested that the vegetative cover could be influenced by latent volcanological phenomena such as those produced by low-lying magmatic masses. The hypothesis we would like to propose consists in considering the vegetation as an integrator, that is, the transfer function of the leaves. In fact, small but continuous amounts of magmatic gases filtering through the soil, as well as the circulation of fluids could influence, with a delay that has yet to be ascertained, the spectral behaviour of the vegetation; this effect would be particularly strong in the near I.R. region (Fig.5).

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

In the thermal infrared region, emitted energy depends on the actual soil temperature which is related to the endogenous energy and (through the thermal inertia) to solar heating. Therefore the bare soil can show a noticeable reflectivity and emissivity change only if a clear superficial seepage exists. Moreover the discontinuities which can be detected on the bare soil are much better monitored by the vegetation growing along them. In other words, the local change (fractures and faults, for example) would modify the living vegetation environment in such a manner that the discontinuity results would be enhanced. Therefore, our intention was to study the possibility of using vegetation as a volcanological and geostructural indicator. The importance of knowing the different parameters involved, such as the percentage of uncovered ground and the types of phytoassociation, as a function of the instrumental resolution, is obvious.

In July 1973 a ground truth missions was carried out on Etna. Attention focused on the woody strip extending from the cultivated areas to the ones of the outochthonous vegetation (2500 m about). Seventeen zones characterized by an unusual spectral behaviour were accurately analized.

Of almost all these areas, the anomalous spectral response was justified taking into account only the phytoassociation. A different interpretative approach had to be introduced for the remaining 3 areas.

The one directly involved in the eruption of February 1974 appeared to be deeply modified by the paroxysmal phenomenon. In short, of these three zones seen as "anomalous" from the satellite, ground observations were unable to reveal any difference with respect to their environment.

In the same period an aerial survey was carried out on the circular woody belt. Both false-color photography and thermal multispectral infrared scanning were employed (1,5-2,5 and 9-11  $\mu$  bands). The signals recorded on magnetic tape were rationed to emphasize the presence of targets with smaller infrared reflectivity and higher tharmal emission.

No anomalous areas weré thus decteted excepting for the one where the eruption occureds, which was masked by ashes and volcanic sands.

In order to form a synoptic idea of the structural situation of the west flank of Etna, a detailed analysis of lineations was also performed on the basis of Skylab images.

The 1:25.000 scale map obtained was drawn distinguishing the lineations into three classes ranging from 0,5 to over 5 Km.

The results ca be summarized as follows:

- the maximum global density is circumscribed in the eruption zone
- it was observed that the first effusive mouth of February 1974 opened up exactly ot the intersection between four linears of the 0,5-2,5 km class
- the vegetative "anomalies" correlate very well with the geometry of the lineations.

In conclusion we can say that the use of vegetation as a transducer for latent volcanic activity seems to be theoretically proven even though the ground truth was unable to confirm our working hypothesis completely.

On the other hand, the possible existing relation between the volcanic phenomena and the lineations network has received further proof.

### 3 - Relationship between tectonic features and mineral occurrences in Northern-Eastern sardinia

The Skylab photographs of September 1973 show very clearly, even on single bands, a number of linears of different length and direction. The photographs were taken in September when the vegetation was at its lowest development.

In the main part of the area the crystalline basement surfaces. Elsewhere, there are different overburdings, from the Silurian metamorphites up to the Mesozoic and the Neocene.

Despite the clear picture given by the single bands (especially the infrared) many enhancement were prepared. This was done mainly in an attempt:

- a) to separate the purely geomorphic features from real faults
- b) to distinguish regional tectonics from local features
- c) to locate crossing and understad their relationship to the main linears and, if possible, to observe alteration effects along the fractures

The tratments included the product of the red and infrared bands, the "derivative" of the infrared band as well as the product of the two.

The product enhances all the geomorphic features while the "derivative" stresses correlation of linear elements.

This treatment gave the largest number of clear lineations and was used to produced the total field map of Fig.7.

In Fig.6 the map of linears obtained from the infrared band is shown, while the figure 8 shows the main linears observed on Landsat 1 images of August 1972 (whole Sardinia).

A good agreement exists between the ore occurrences and regional or local linears, except in the direction N 20°W (the fragmentary linear) which corresponds to the oldest folding trend (Caledonian).

Higher dispersion is observed in more complex geological areas.

Skylab images play a fundamental part in the study.

Owing to the low resolution of Landsat scannings, the map of linears obtained on their basis shows a noticeable "integrative effect" stressing only the lineaments.

On the contrary, the resolution of Skylab images made it possible to trace numerous linear elements of great importance in locating fault intersections (or "knots") which could be related to the ore occurrences. Two detailed test areas were selected for further studies. These seem to be particularly interesting to find a clue to the correlation of linear intersections, the areas of intense fracturing and the mineral occurrences.

The comparison between the study of linear in Sicily and Sardinia leads to some considerations. At the same time of the year the Skylab photographs gave no interesting results over Sicily while over Sardinia its contribution was of great value. This fact can be explained by considering the fact that the linears in Sardinia are better enhanced on the bare soil than in Sicily, where in September the dry vegetation blanks out to a large extent any superficial indications.

#### 4 - Paleoriverbeds

Within the framework of the research carried out utilizing SL3 survey it was possible to detect the ancient paths of some rivers in North Italy.

This work is a good combination of recent technology and classical photogeology. For this purpose a collaboration was set up between two research centers: the Istituto per la Geofisica della Litosfera and the Laboratorio di Geologia

Applicata allo Studio delle vie di comunicazione nel Settore Alpino Padano, both sponsored by the Italian National Research Council (C.N.R.).

The search for building materials (like the ones we find in paleoriverbeds) is normally a local study, performed by geoelectrical surveys and control boreholes: we are able to form an idea of these natural resources on a regional scale, probably for the first time, by analyzing Skylab images.

The area investigated was the Venetian plain whose ground truth is well-known.

By means of multispectral analysis, with analog techniques we discovered the paleo-bed patterns of

rivers which cross the Venetian plain from North to South.

The techniques employed is rapid and precise as well as economical.

For this research we had at our disposal a complete set of data, as well as an accurate aerial photo-interpretation within a programme for supplying building material.

Synthesis of the collected data provided by Skylab frames and by enhancement techniques seems to be the right approach for the solution of the problem in question.

The data employed were obtained from the frames taken by the S 190 A multispectral camera, and in particular bands 42, 41, 38, 37 of Mission SL3 (September 1973).

The best results for the solution of the problem were achieved synthesizing the following methods: cross-density slicing, masking slicing, additive color synthesis of ratios, false color composition, electronic TV processing.

The photographic technique allowed us to prepare a special kind of band ratio: in particular we observed that by superimposing the 41 band positive to the 38 band negative we obtain the best description of paleoriverbed patterns. These results were emphasized by electronic-density slicing; in other words the graphs representing iso-ratios are described by the same color on the TV monitor. In Fig. 9B a thematic map is presented in which it is possible to see the hitherto unknown patterns of the Brenta and Astico paleoriverbeds.

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Fig. 9A shows the known paleoriverbeds before the present work. With this kind of processing it is very easy to follow the continuity of a certain phenomenon whose some local aspects of which are already known from ground based surveys.

It was possible also to plot the underground spring line with very high precision.

In this case the cost-benefit ratio is very low, taking into account the equivalent cost of a ground survey to produce the same kind of results.

A rough evaluation of remote sensing from space platform is already possible.

To follow the patterns of the buried channels and to calculate the gravel and sand volume it would be necessary to establish a network of electrical resistivity profiles with a density of at least 10 horizontal soundings per square Km; one or two boreholes per square kilometer are also needed.

The cost of these operations is about \$ 500 per square km.

Using space imagery, the cost of ground control can be reduced to one-tenth.

#### 5 - Crop investigations. Rice fields in Northern Italy.

Within the framework of the "Agreste" Project (European Community preparatory phase of ERTS-B investigation) an inventory has been made of rice cultivations using false-color Skylab images as well as the multispectral camera photograph of September 3rd.

"False color ratio" has been applied using this set up:

I.R. (enhancement in red)  
green

I.R. (enhancement in green)  
orange

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The main task of this type of enhancement is to extract the vegetation canopy from the background.

Moreover, density slicing techniques were employed to discriminate between different types of vegetation.

#### 6 - Final remarks

The results of the SL-3 mission on selected sites in Italy lead to some remarks on the application of spaceborn remote sensing:

- in the field of structural geology, geometrical resolution requirements vary according to the objective, morphology, vegetation, rock and soil type, illumination, moisture state of vegetation and the choice of optical season; for each area these parameters can reduce the resolution requirements.

The multispectral approach and the use of different enhancements is useful; in some cases (NE Sardinia) between 20% and 30% of additional lineaments were discovered using the product of two bands simultaneously with the "autocorrelation" of the I.R. band.

- In the field of soil-type discrimination and classification of vegetation, the multispectral approach is mandatory.

The superior resolution of Skylab allowed special tasks to be carried out, such as the discovery of small paleoriverbeds or the discrimination of crops where fields are of very small size (Po delta).

On the other hand, the photographs do not permit a digital approach (which is the basic method for classification) at least with the same accuracy of scanning devices.

the low orbit of Skylab offers a good opportunity for using conventional stereo techniques: in Sardinia, a noticeable improvement was obtained by studying the linear features with this method, owing mainly to the geomorphic characteristics on the explored area.

FIGURE CAPTIONS

- 1 A : Known or hypothesized faults of Sicily (official geological map scale 1:500.000)
- 2 A : Linears seen on ERTS-1 images and Bouguer gravity anomalies
- 2 : Central Sicily: linears seen on Skylab photographs
- 3 : Central Sicily: rose diagrams using:  
 A - color composition of ERTS bands 4,5,7  
 B - product of ERTS bands 5 and 7  
 C - "derivative" of ERTS band 7  
 D - Skylab false color photographs
- 4 : Lava flows of Mount Etna (ERTS-1).  
 The star indicates the location of Monte De Fiore eruption of 1974.
- 5 : Detailed Skylab multispectral investigation on Monte De Fiore area:
- 6 : North Eastern Sardinia linears (I.R.band of Skylab)
- 7 : North Eastern Sardinia linears (total field):  
 - solid lines: linears seen at least in two enhancements  
 - dotted lines: linears seen only one enhancement  
 - large dots : known mineral deposits
- 8 : Island of Sardinia: regional linears from ERTS-1 imagery (August 1972)
- 9 : Principal hydrogeological aspects of Eastern Venetian plain:  
 A - as known before Skylab research  
 B - from analogue treatment of Skylab images

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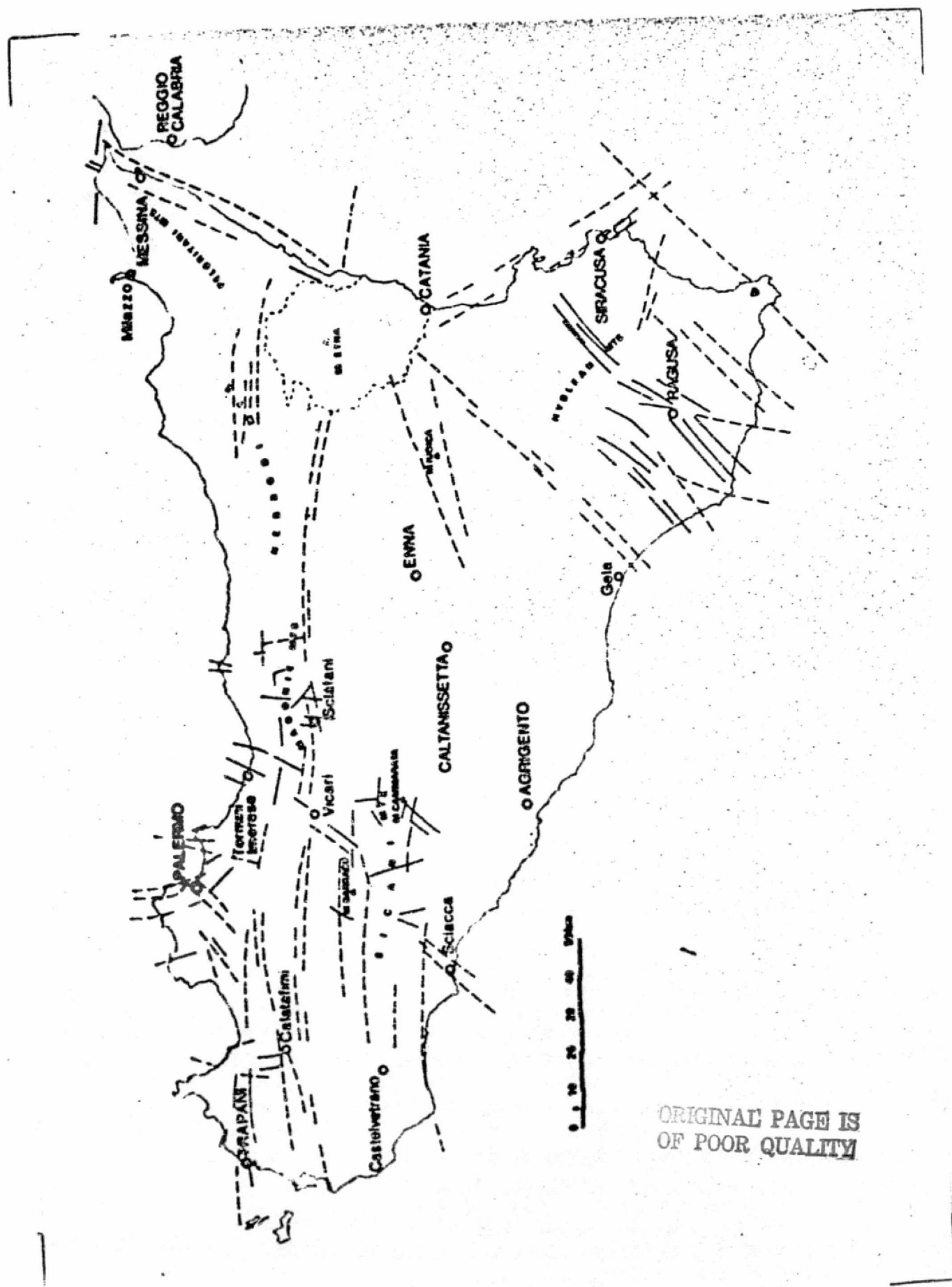


FIG. 1a



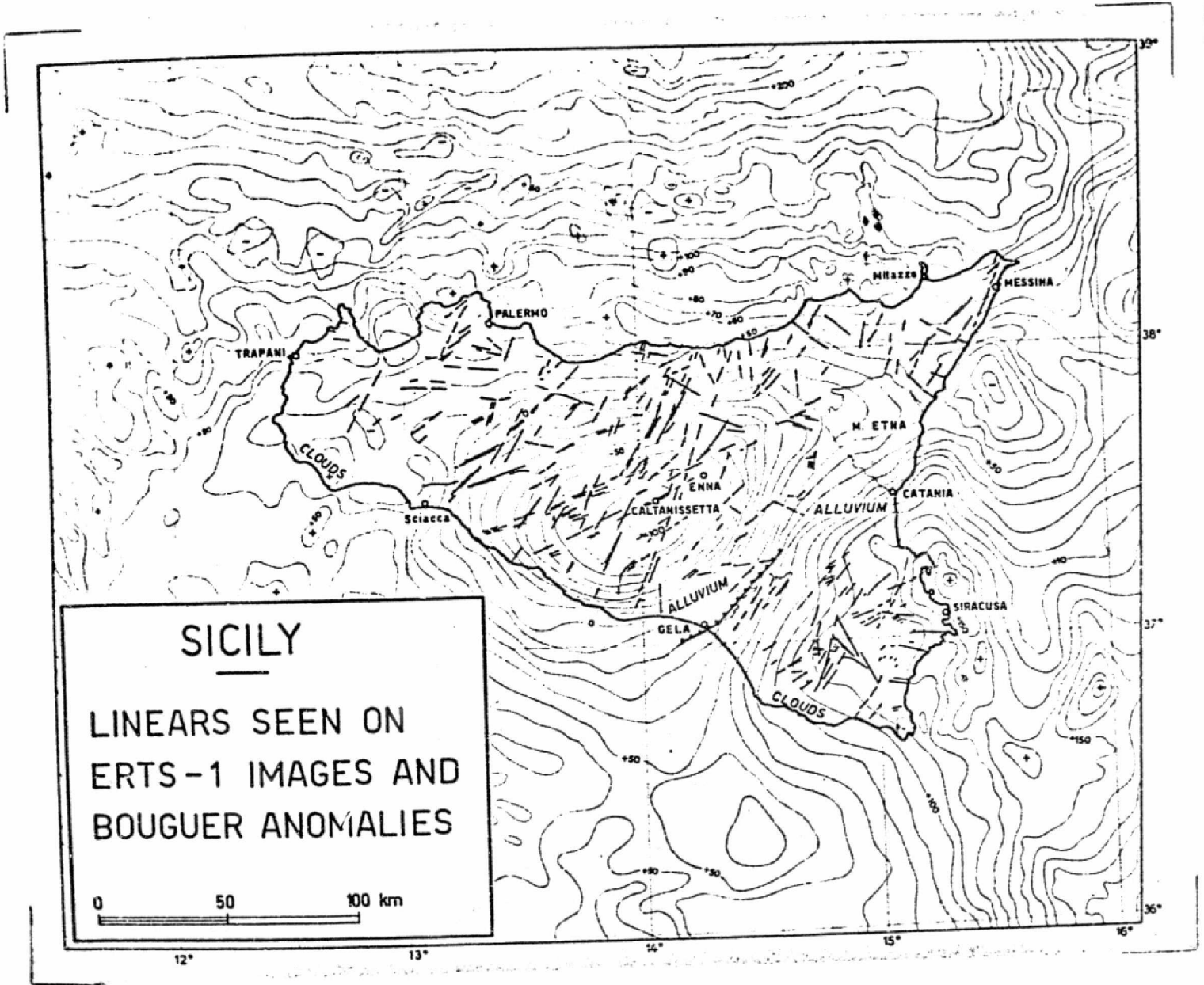


Fig. 1 b

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FIG. 2

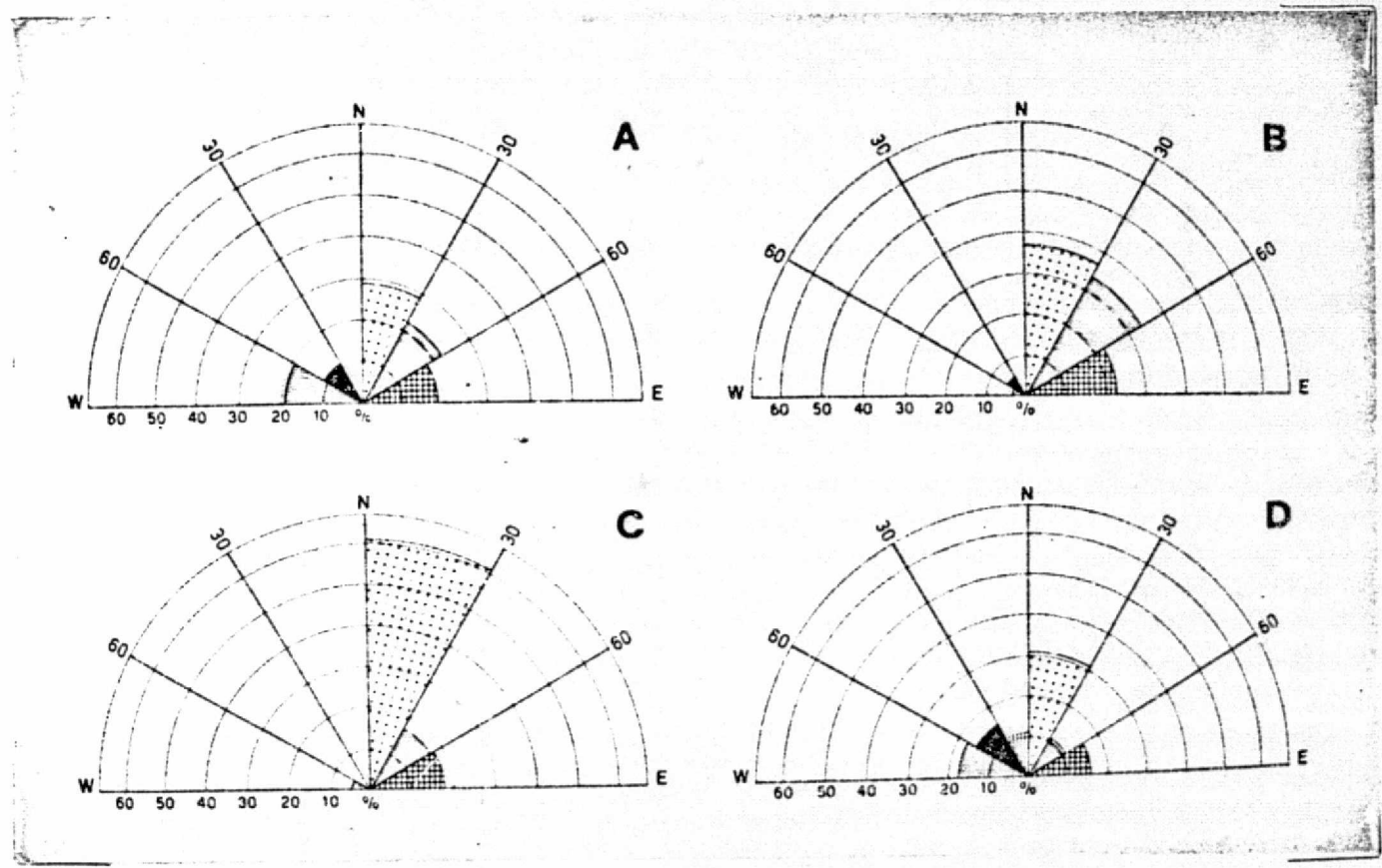


FIG. 3

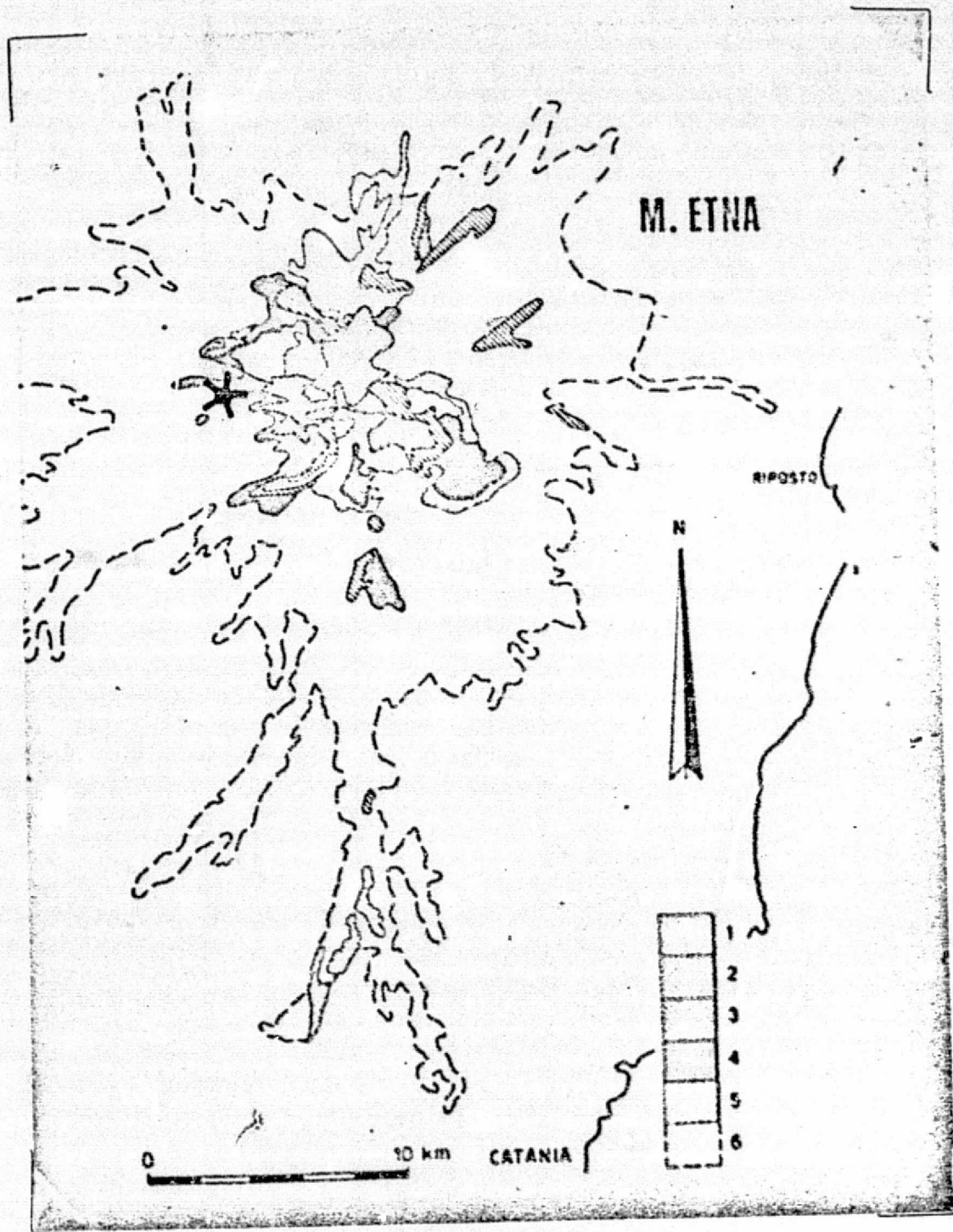


Fig.4



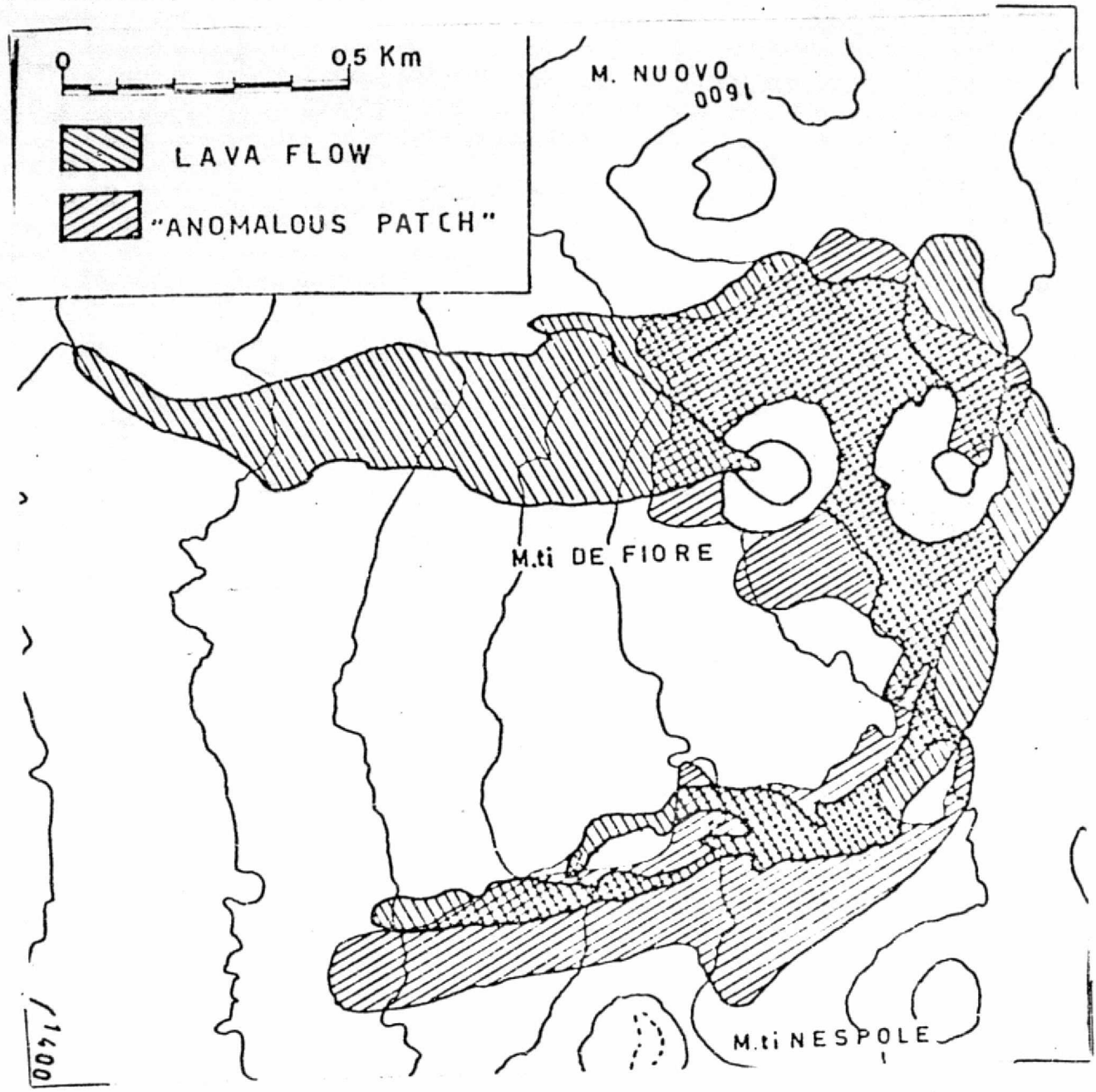


FIG. 5

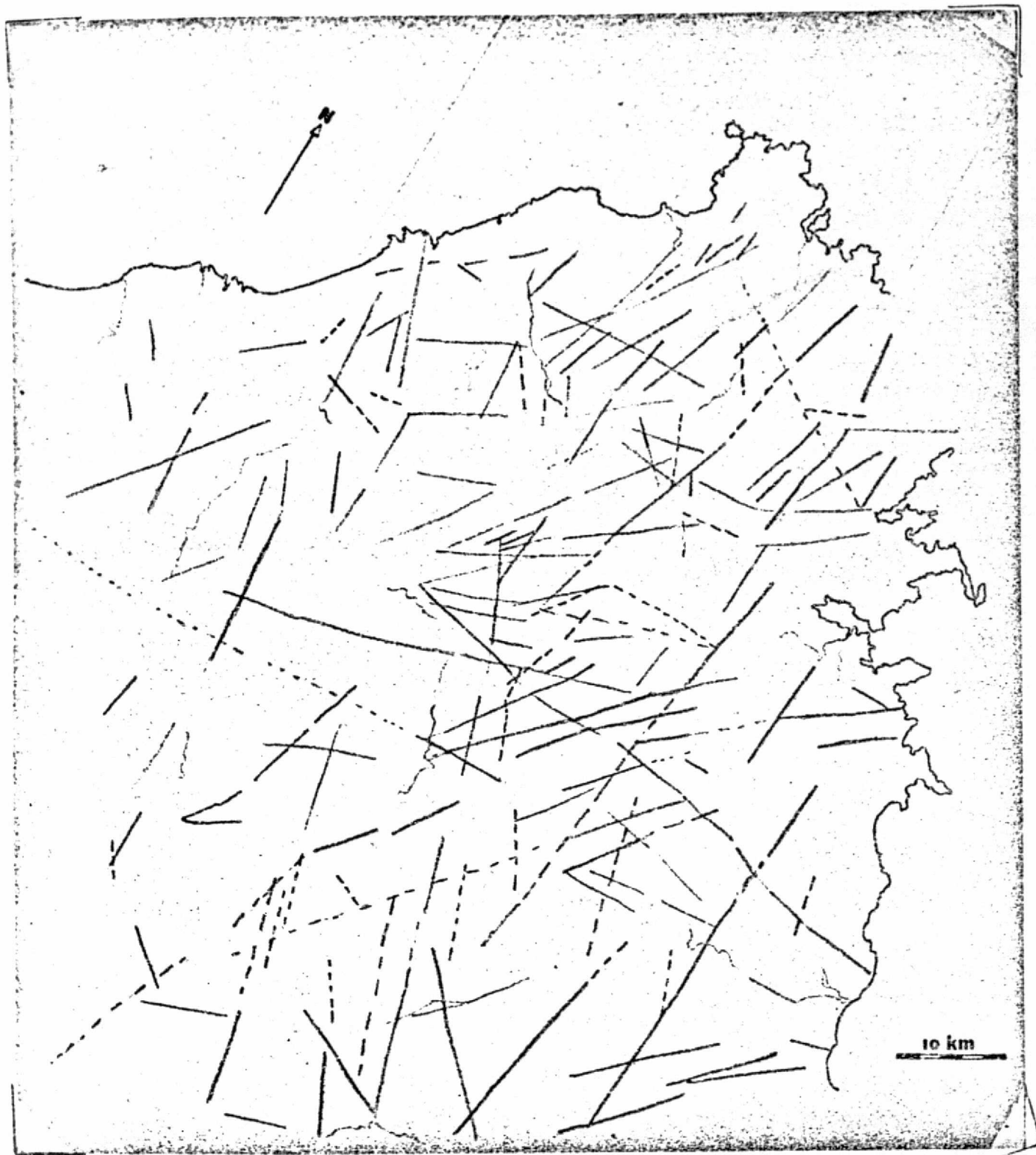


FIG. 6

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FIG. 7

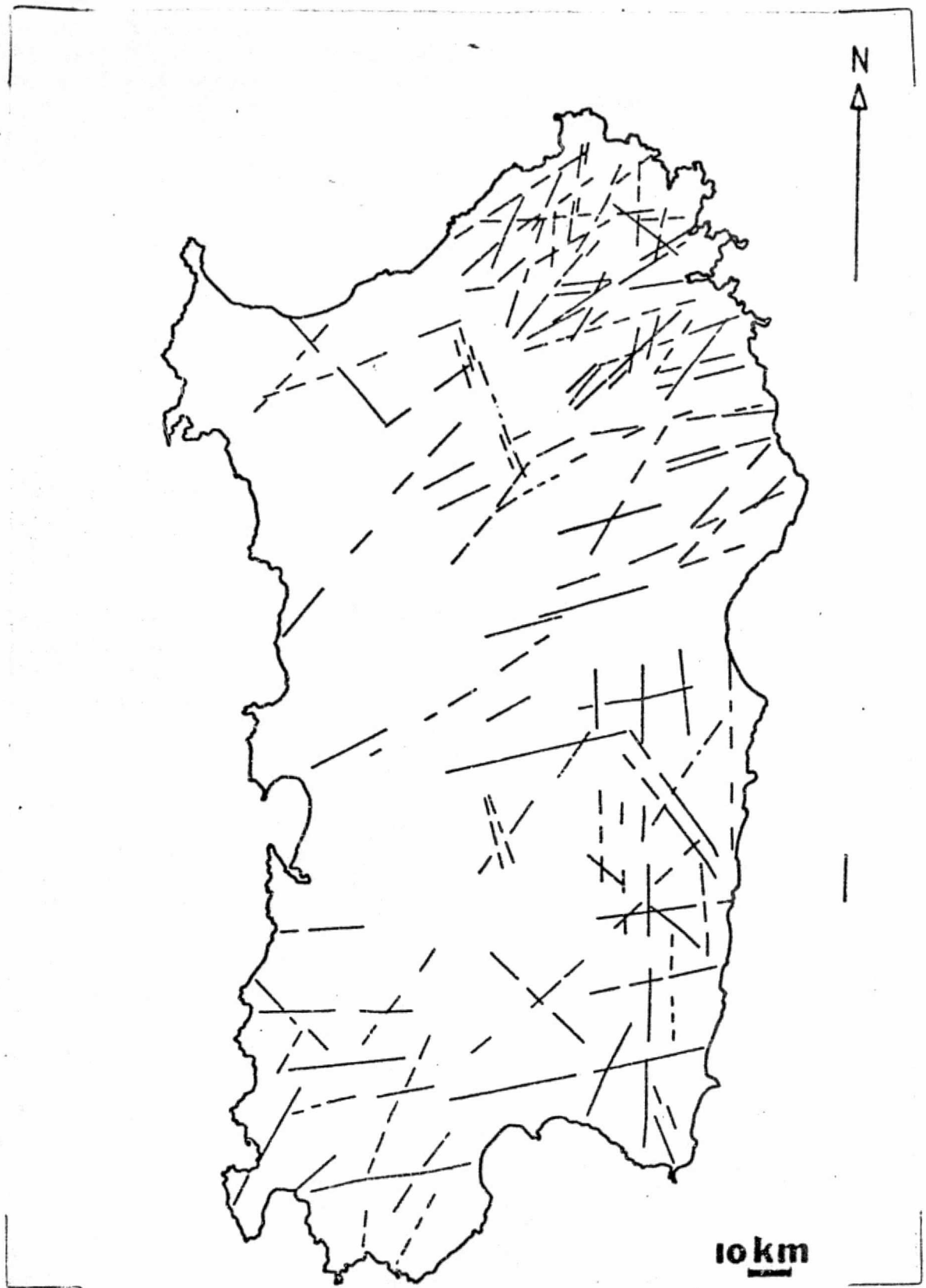
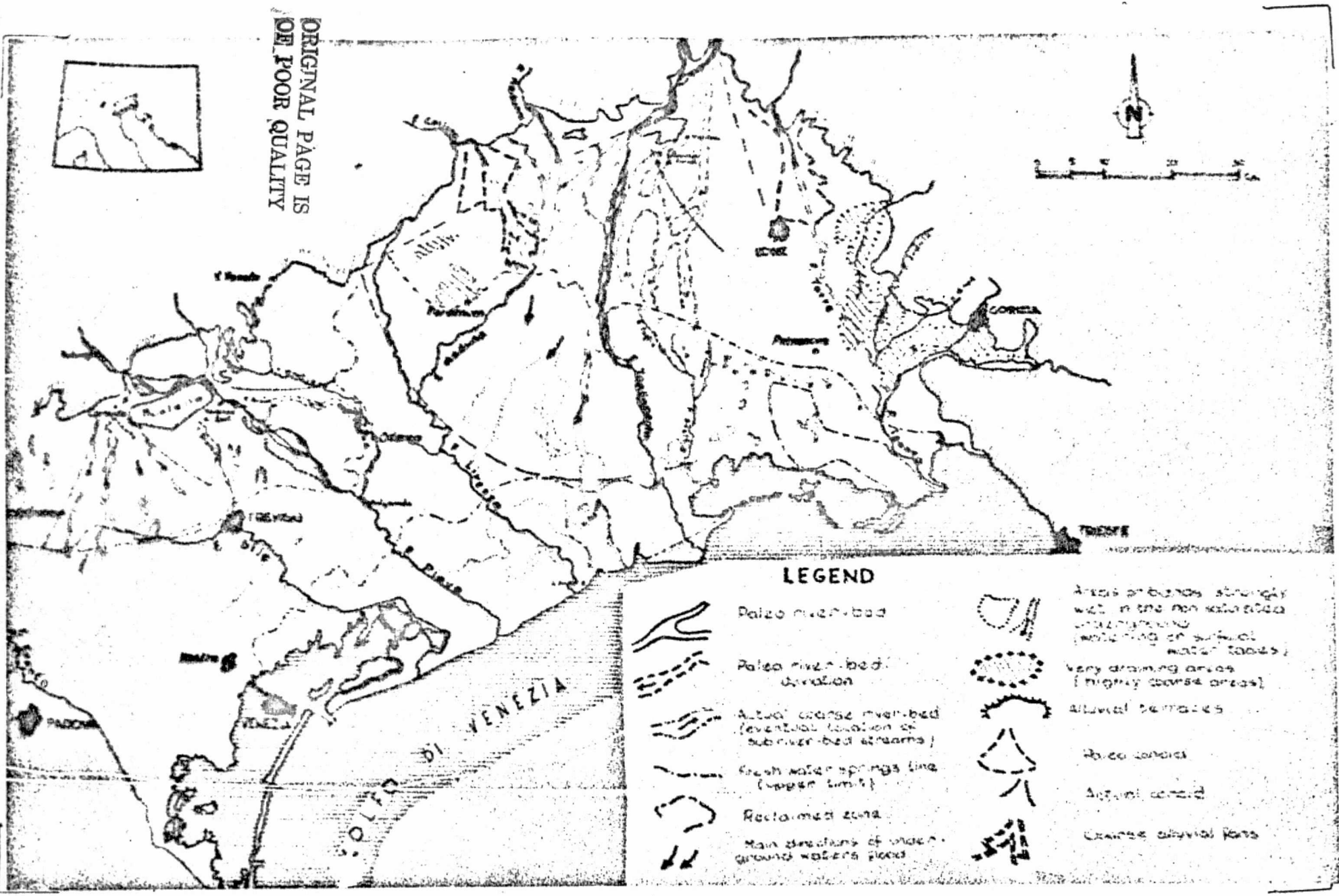


FIG. 8







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FIG. 9 b

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APPLICATION OF SKYLAB IMAGERY TO SOME  
GEOLOGICAL AND ENVIRONMENTAL PROBLEMS  
IN ITALY

A B S T R A C T

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SL 3 Skylab imageries have been successfully applied to different areas of geological and environmental interest in Italy. As far as the geological research is concerned, two principal zones were considered: the first one concerns the Venetian Plains and its hydrogeological environment, the second one the morphology and structure of Sicily. Two areas were also considered for the environmental studies: the Delta Po zone (North Italy) and the volcanic province of Etna (Sicily).

Hydrogeology: The imageries of Sept.1973 taken over the Venetian Plain have been carefully studied, treated and interpreted in order to extract the surficial features of some paleoriverbeds and the position and extension of the so called "fresh water springs line".

After making a number of analog processing using different band combinations, the best performance and synoptic view of the entire phenomenon were obtained by the use of ratio of red and orange bands (41, 38) and by the additive synthesis (false colour composition) of ratio and product of the same bands.

By using the near infrared (37) the surficial distribution of moisture was enhanced while the yellow-green band (42)

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gave interesting informations on the fields pattern.

The employed indicators consisted in:

- contour lines of the relative moisture content
- vegetative status, mainly of cultivated crops
- distribution and orientation of cultivated fields.

The results include the discovery of several unknown paleoriverbeds or the actual pattern and continuity of the ones only partially mapped.

The economical relevance of the survey can be evaluated in terms of available volume of building material and of management of aquifers, also in order to avoid the pollution of underground water.

Regional geology of Sicily: The passage of Sept.1973 has been compared with the previous data furnished by EPTS-1 in Aug. and Nov.1972.

Special care has been devoted to a long lineament formed by a number of large and small fractures and discontinuities, crossing Sicily approximately in N-S direction.

The comparison of the maps obtained on the basis of ERTS-1 and Skylab imageries and the relative treatments underlines the main trend of the linears while the analog technique used for the enhancement indicates the best fitting of each band to the season.

The results must be considered in the light of the potential of satellite investigation to suggest new hypothesis and to plan geological and geophysical investigations able to confirm these assumptions.

In particular, the seismicity maps could be better built taking these features into account.

Volcanic surveillance: The same passage of Sept.'73 has been analyzed in the framework of the studies regarding the forecasting of paroxysmal phenomena in volcanic areas. For this purpose a map of fractures on the lava blanket of Mount Etna, ranging in length from 100 m to 2000 m, has been prepared on the basis of the false colour infrared frame.

In the same time a considerable effort have been done to interpret the vegetative status as a key for the geochemistry changes, able to detect the lateral eruptions.

Crop investigations: In the crop analysis we work mainly on two subjects of investigation: (a) distinction and inventory, through the spectral signature, of rice, nonlar plantations, replanted resinous wood and beech-trees woods (b) prevision of rice production by iterative observations of multispectral response: a continuous ground truth collection was performed in the rice fields during the 1974 in order to establish a precise correlation between the vegetation growth, spectral response and final production. In this case ERTS-1 imageries were also employed.

In the area of river Po delta a satisfactory correlation has been found between the official maps of the rice fields and the same cultivations seen from Skylab.

The false colour image gave the best results in the pre-processing stage. During the phase of analog treatment ~~difficulties arose in separating~~ the signature of rice from that of alfa-alfa by means of ratio of contiguous bands; owing to the flatness of the terrain, the product has been successfully applied, obtaining the actual area covered by rice plantations.

It seems possible to follow the evolution with time of the spectral signature of rice in order to foresee the biomass, which is proportional to the volume of veld one month or earlier before the maturation time.

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BY AIR MAIL

CONSIGLIO NAZIONALE DELLE RICERCHE

LABORATORIO PER LA GEOFISICA DELLA LITOSFERA

February 12, 1975

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PROT.N.97 R.C./a.p.

Mr. Miller  
NASA  
Lyndon B. Johnson Space Center

HOUSTON, Texas 77058  
U.S.A.

Dear Mr. Miller,

Enclosed please find the fifth  
progress report on our EREP SL -3  
investigation.

Sincerely yours,

Roberto Cassinis, Director

Enclosed.: 1

c.c.: Mr.Morrison - Nasa - Washington  
→ Mr.Wilmarth - Nasa - Houston  
NASA (STIF) - College Park, Maryland



CONSIGLIO NAZIONALE DELLE RICERCHE

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SKYLAR FIFTH PROGRESS REPORT  
Fractures and lineaments of  
Sicily island  
Preliminary results on analog  
optical techniques

Principal Investigator : R. Cassinis

Written by : A.M. Tonelli -Co-Investigator

In the framework of the studies carried out with the aid of the Skylab images an additional topic of investigation is the geological structure of Sicily outside the volcanic area.

On the occasion of the ESRO meeting held at Frascati (Jan.28, 1974) the first results by ERTS-1 imagery were presented (ref.: 1 ).

At the present time this interpretation is performed by means of both ERTS-1 and Skylab imageries and by aerial photographs of some strips in the Central part of the Island.

While with the ERTS images, and in particular with bands 5 and 7, probably due to the season, the largest lineaments seem to be very well detectable, with the Skylab photographs some difficulties arose because of the season and the smoother responsivity of the simple bands.

The lineaments are drawn easy enough only if interpreted with the key of the false colour and/or the multispectral composition analysis. This fact happens probably because of many different causes describing the same structural phenomenon: fractures, moisture content and vegetation behaviour seem to be joint factors indicating the continuity of the faults.

After having drawn a first thematic map "by pencil and eye" on the false colour images, an accurate study was carried on the stereo pairs of B & W aerial photographs covering part of the area interested by a unknown fault system crossing the island in N-S direction.

Then the interest was pointed on a number of small fractures distributed over the whole Sicily.

An attempt was made, using the ERTS-1 band 7, as well as the infrared band of SL-3 multispectral camera

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to recognize the averaged trend of the system of faults in the central part of Sicily (FRTS-1 - NASA Final Report - Contribution of Space Platforms to a ground and airborne remote-sensing programme over active italian volcanoes. Nasa Contract FO-Ø 13 ) by using the derivative function applied in absolute value and plotted versus the image scanning direction. The result indicated as main trend of the central part of the island the NE-SW direction.

But the influence of the scanning lines was large in comparison with the maximum possible resolution. With the Skylab images a new analog method have been applied.

We tried to employ the maximum resolution available in order to better discriminate the targets which lead to the whole lineament through their distant correlation.

We applied, for each band, the negative support on the corresponding positive, giving at the same time a small and constant shift in two orthogonal directions.

The resulting density is given by:

$$d_a(x,y) - d_a(x + \Delta x, y + \Delta y) = \gamma \log a(x,y) + d_{max} - \gamma \log a(x + \Delta x, y + \Delta y) = \gamma \log \frac{a(x,y)}{a(x + \Delta x, y + \Delta y)} + d_{max}$$

where:

$a(x,y)$  = intensity of band a in x,y  
 $a(x + \Delta x, y + \Delta y)$  = intensity of band a in  $x + \Delta x, y + \Delta y$

$\gamma$  = contrast of the photographic material

$d_{max}$  = maximum density of the photographic material.

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The ratio stresses out the presence of a discontinuity existing between the points  $(x,y)$  and  $(x + \Delta x, y + \Delta y)$  i.e. the "derivative" function of a  $(x,y)$  in both  $x$  and  $y$  directions.

This kind of enhancement applied to different bands leads to a better understanding of the correlation factors.

In this way discontinuities were discovered, the longest ones mainly in NE - SW direction, the shorterst along a coniugate axis.

The displacement used was just a little greater than the resolution of the photographs microcontrast of the employed duplicating film.

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" Analog techniques of data enhancement applied in the study of geologic and geothermal features of Test-Sites in the Italian region (Central Alps and volcanic areas) illustrated by the images from ERTS-B and other remote sensing platforms.

In press on proceedings of: Symposium of International Society of Photogrammetry - Commission VII - Panff, Alberta (Canada) - 7-11 October, 1974.

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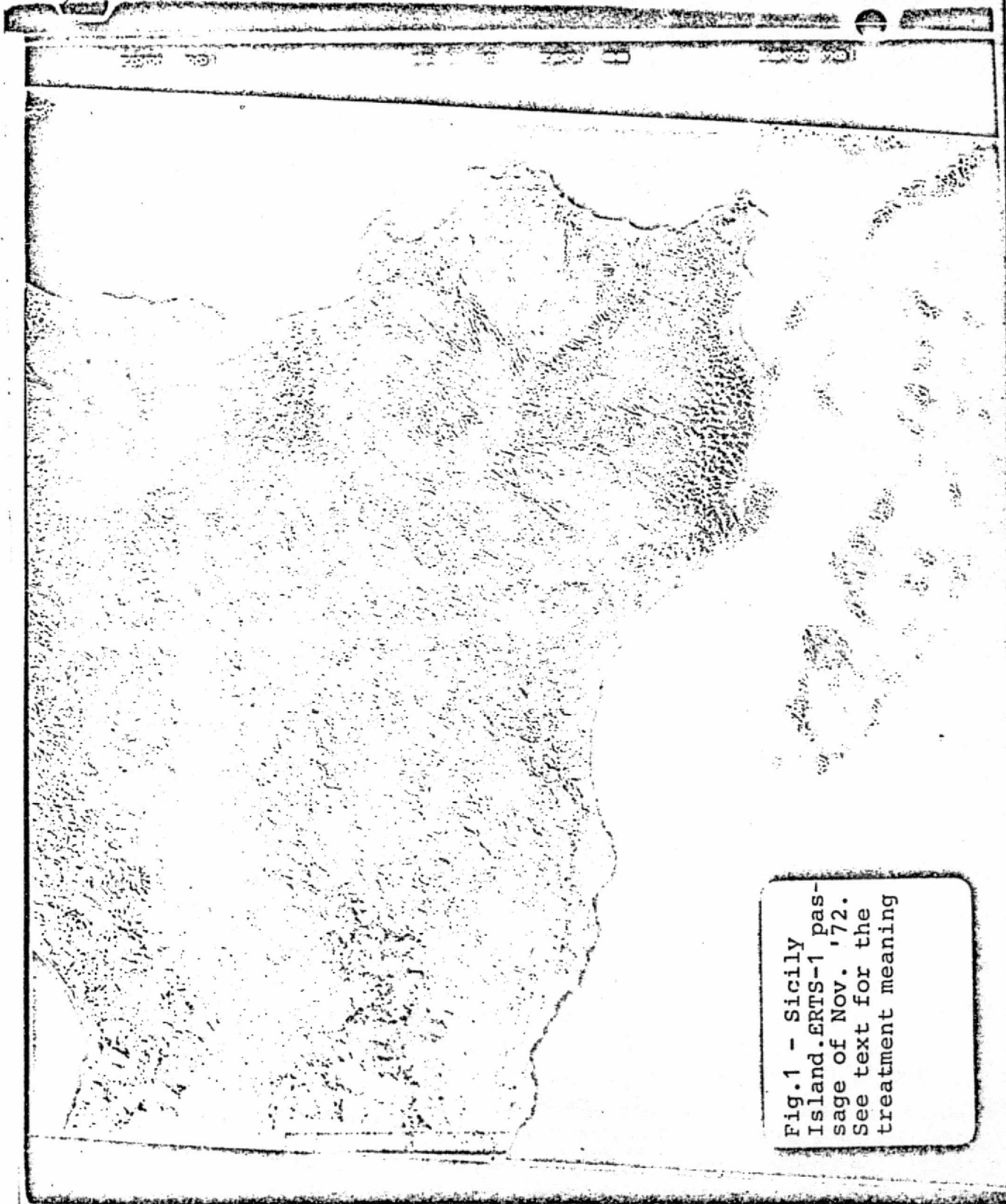


Fig.1 - Sicily  
Island.ERTS-1 pas-  
sage of Nov. '72.  
See text for the  
treatment meaning

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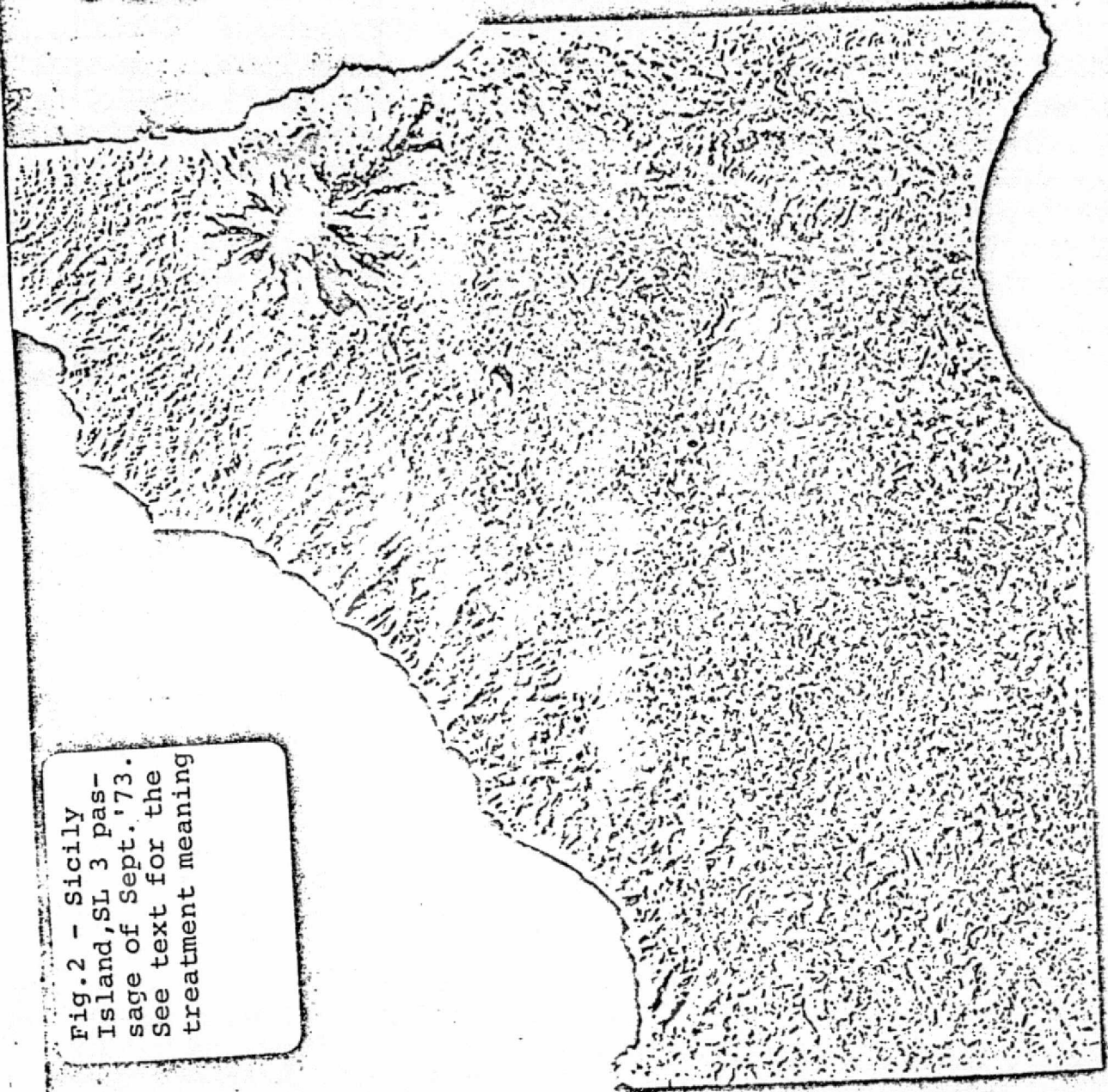


Fig. 2 - Sicily  
Island, SL 3 pas-  
sage of Sept. '73.  
See text for the  
treatment meaning

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NASA JSC SL3  
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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

Principal Investigator : R. Cassinis

Co-Investigators : G.M. Lechi

C.M. Marino

A.M. Tonelli

Contribution of Space Platforms  
to a Ground and Airborne Remote-  
Sensing Programme over Active  
Italian Volcanoes

Nasa Contract FO - Ø 13

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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.

*Something is wrong here...  
"a" should be the log of the density (d) of  
the film (x,y). Perhaps, something is wrong  
the translation  
20/11/55*

### 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

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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. 5). 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:

i) 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.

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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.

#### ii) 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. 14) 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 fumarolization 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 selection. 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.

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## - 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-

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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 <sup>u</sup>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.

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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 |

*IRB*  
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.

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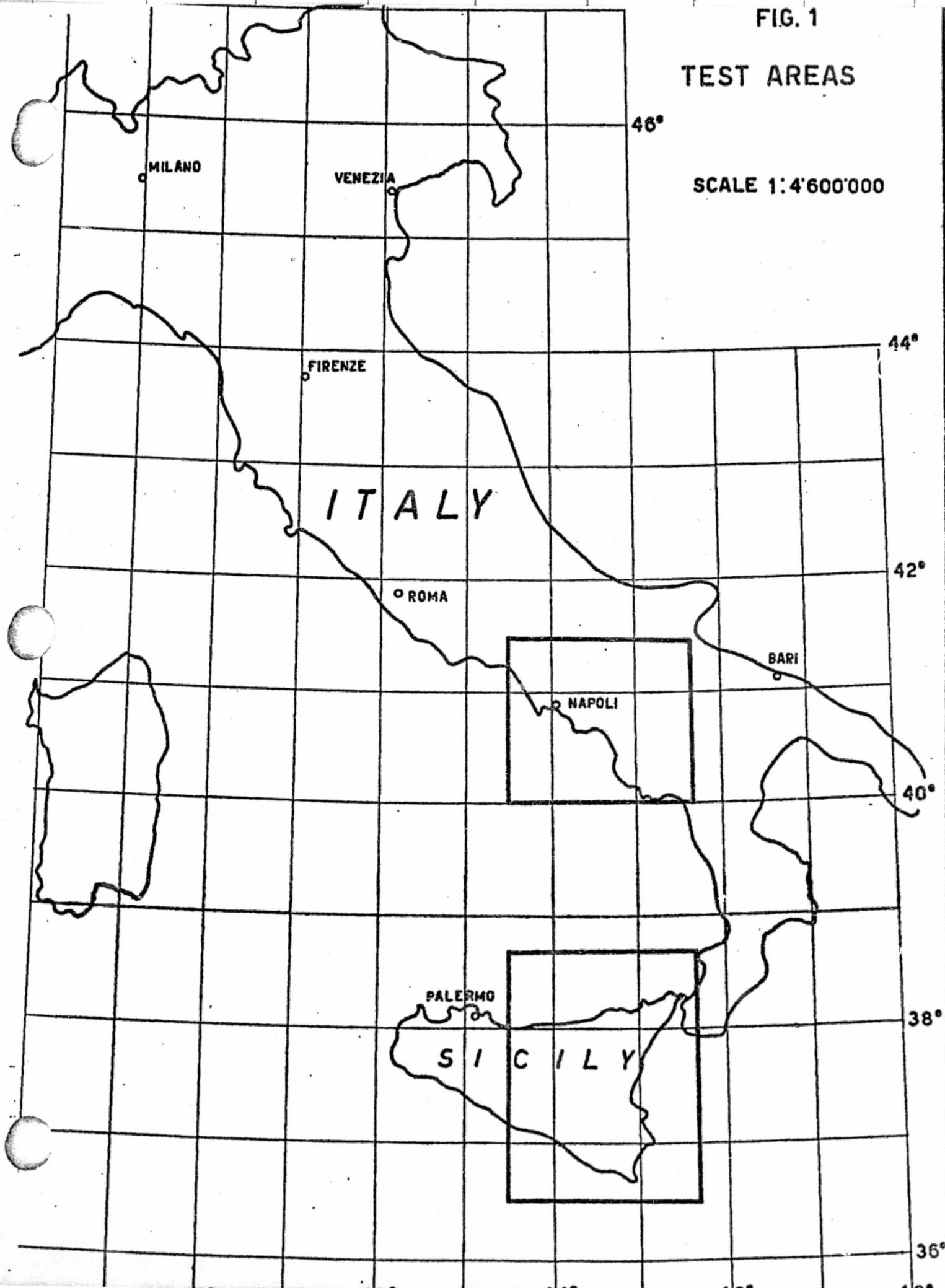
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In press on : Bollettino di Geofisica Teorica ed Applicata - Trieste

FIG. 1

TEST AREAS

SCALE 1:4'600'000





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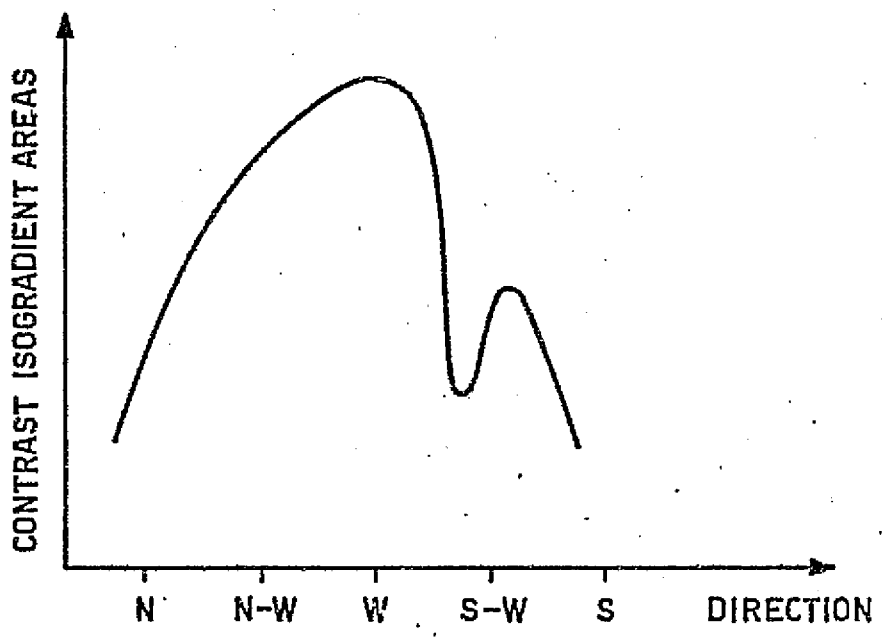
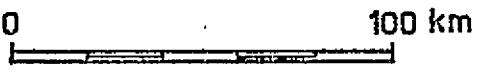
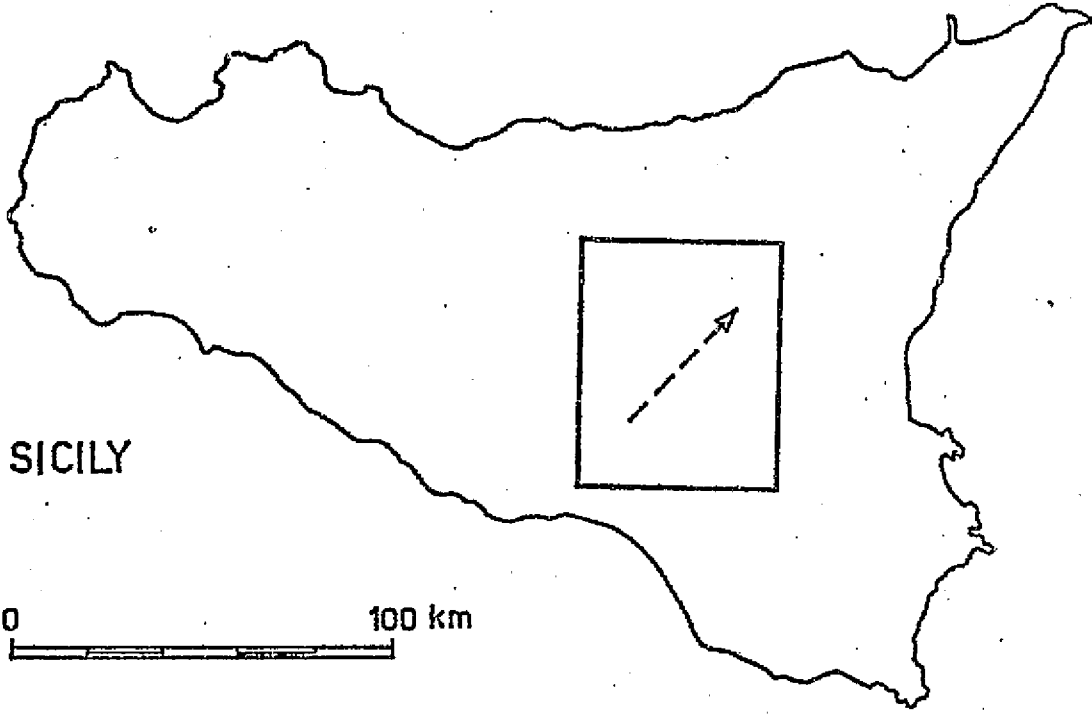


FIG. 2

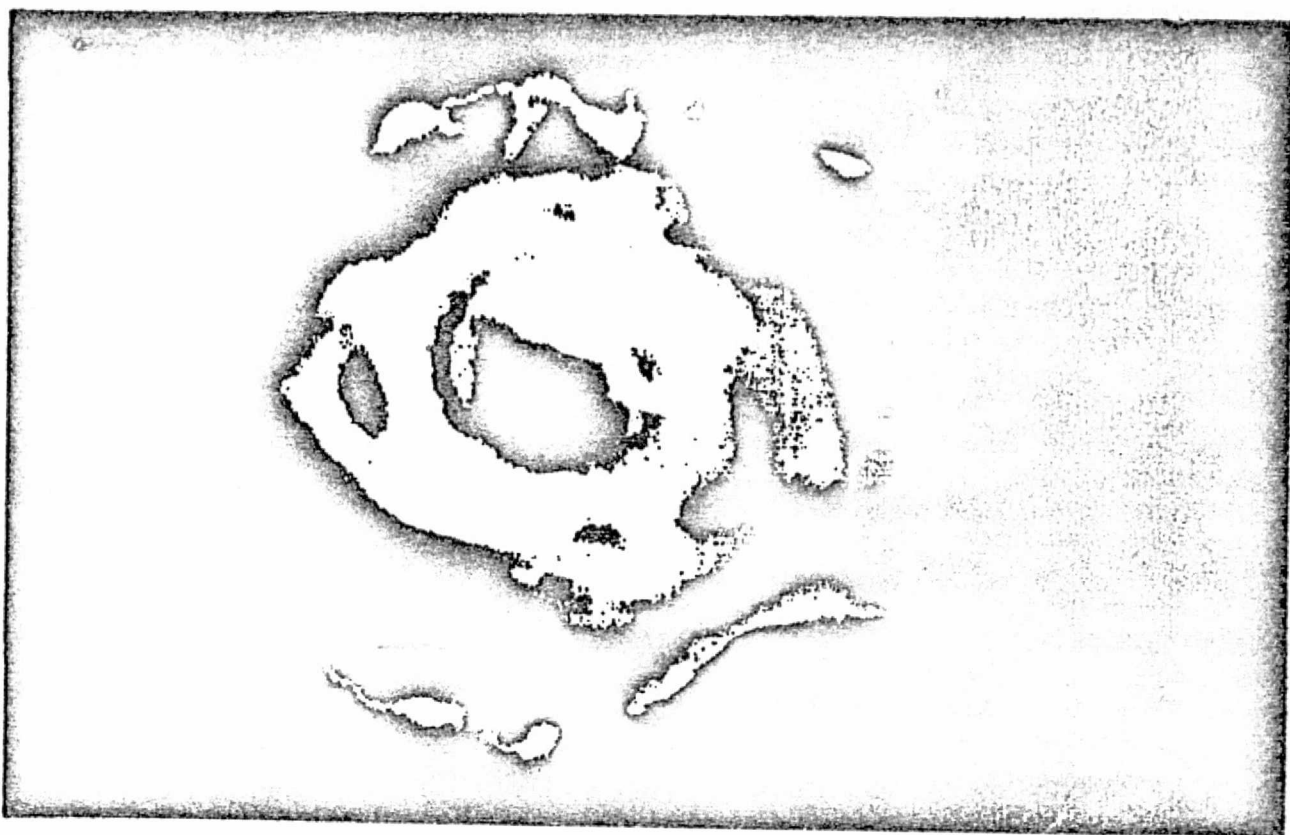


Fig. 3 - The crater of Vulcano island.

Above : thermal I.R.

Below : thermal gradients.

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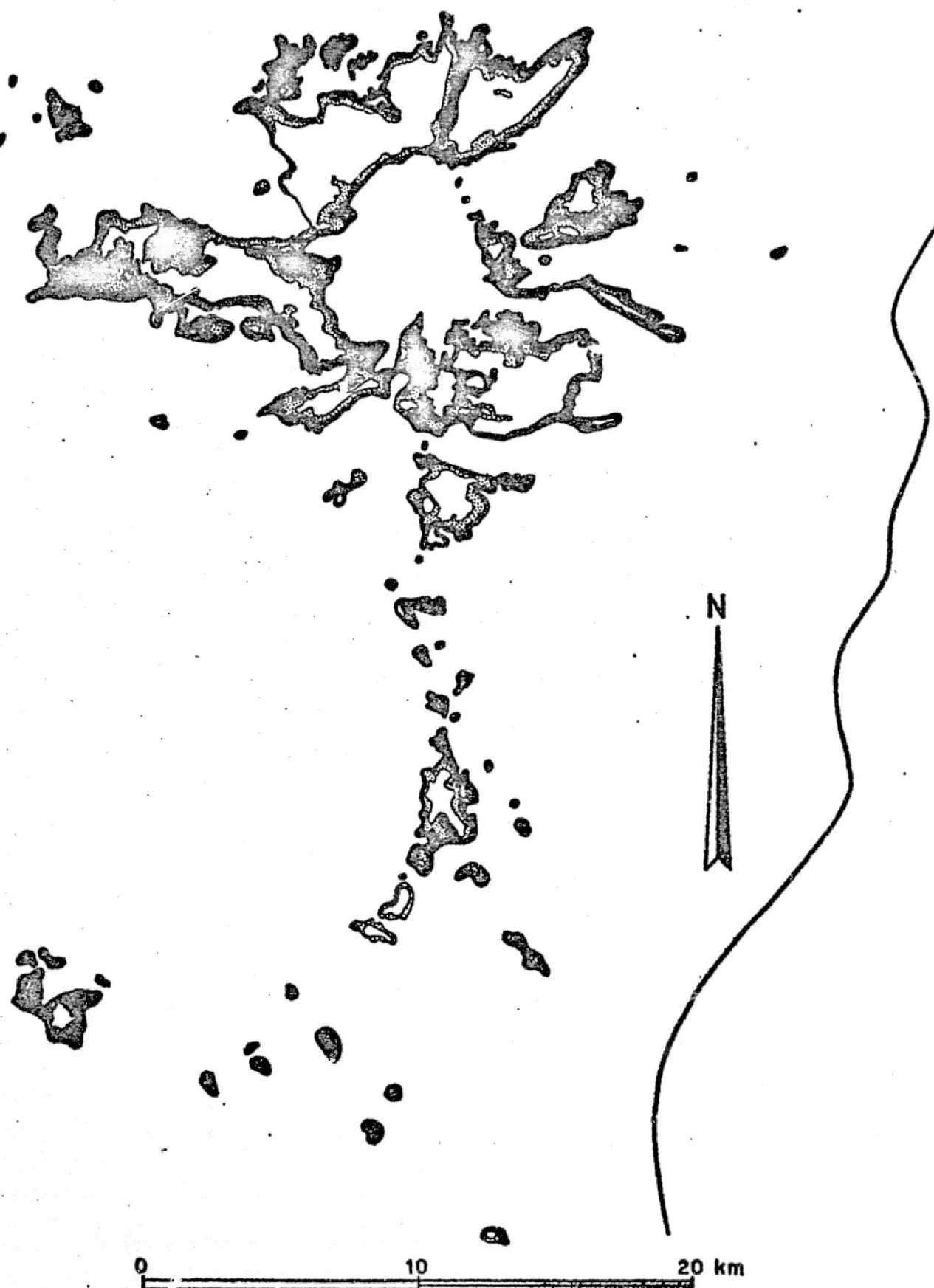
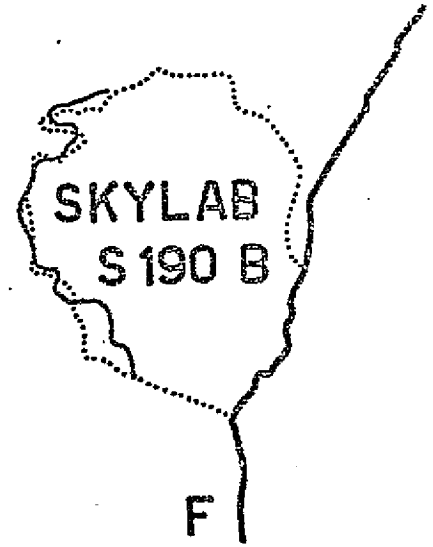
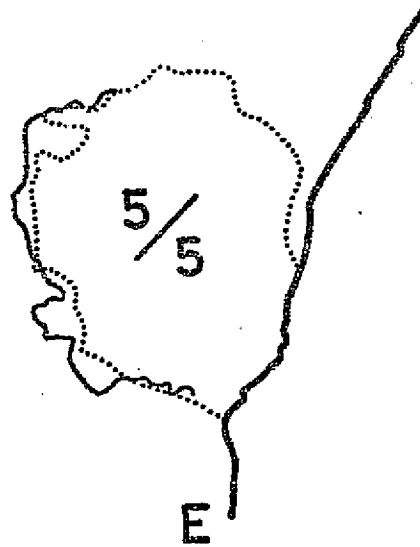
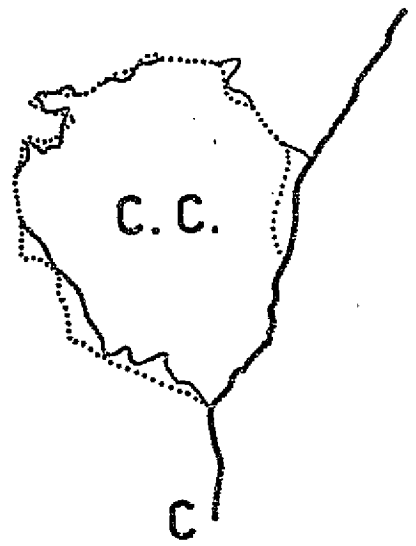
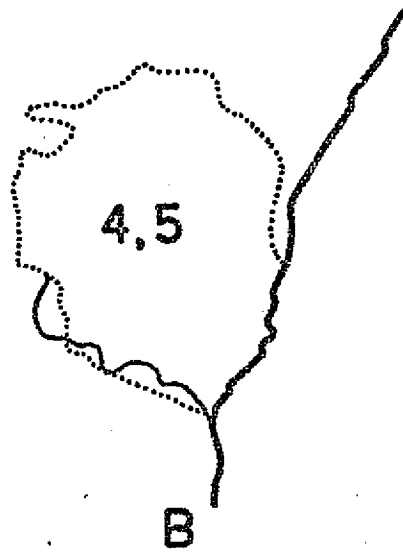


FIG. 5

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

FIG. 6



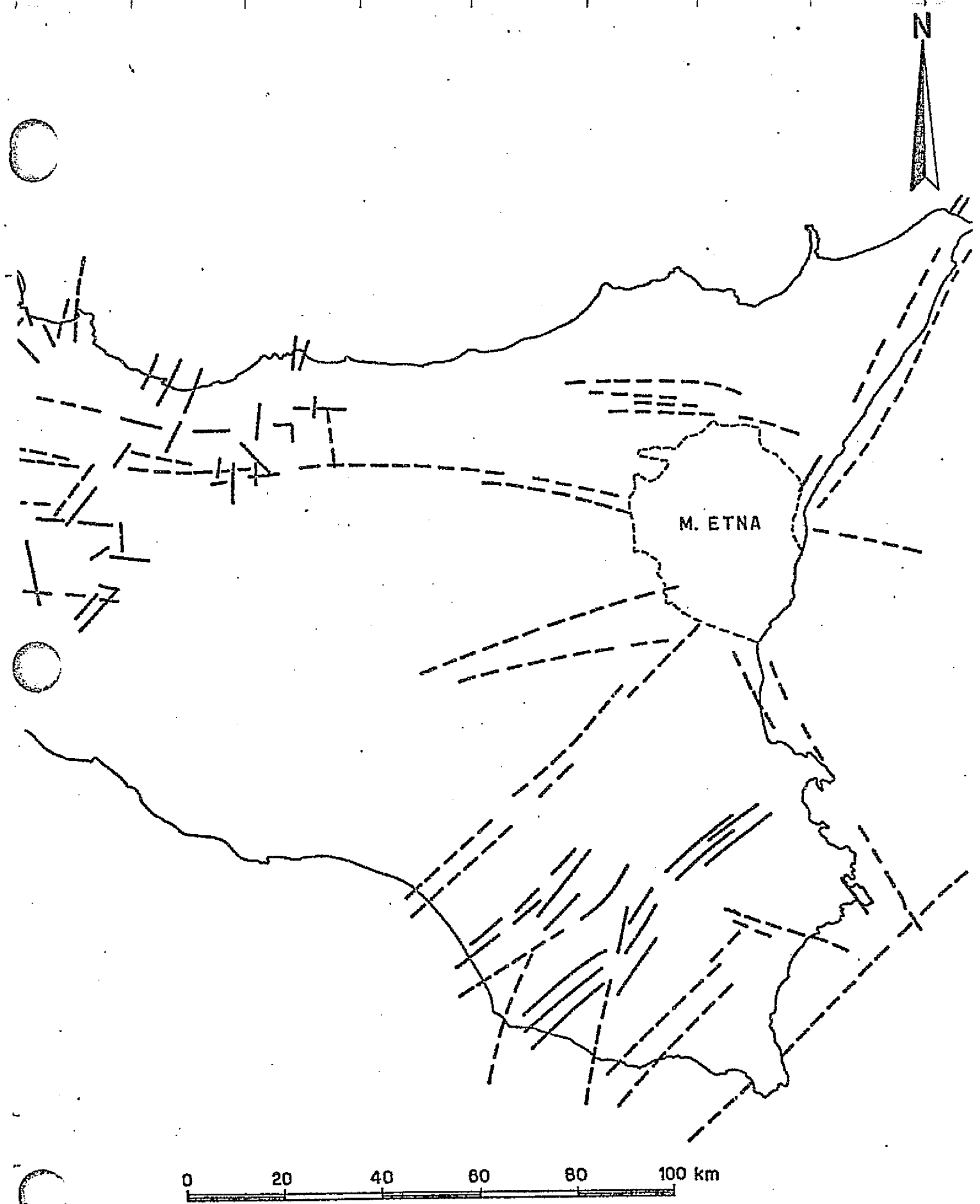


FIG. 7a

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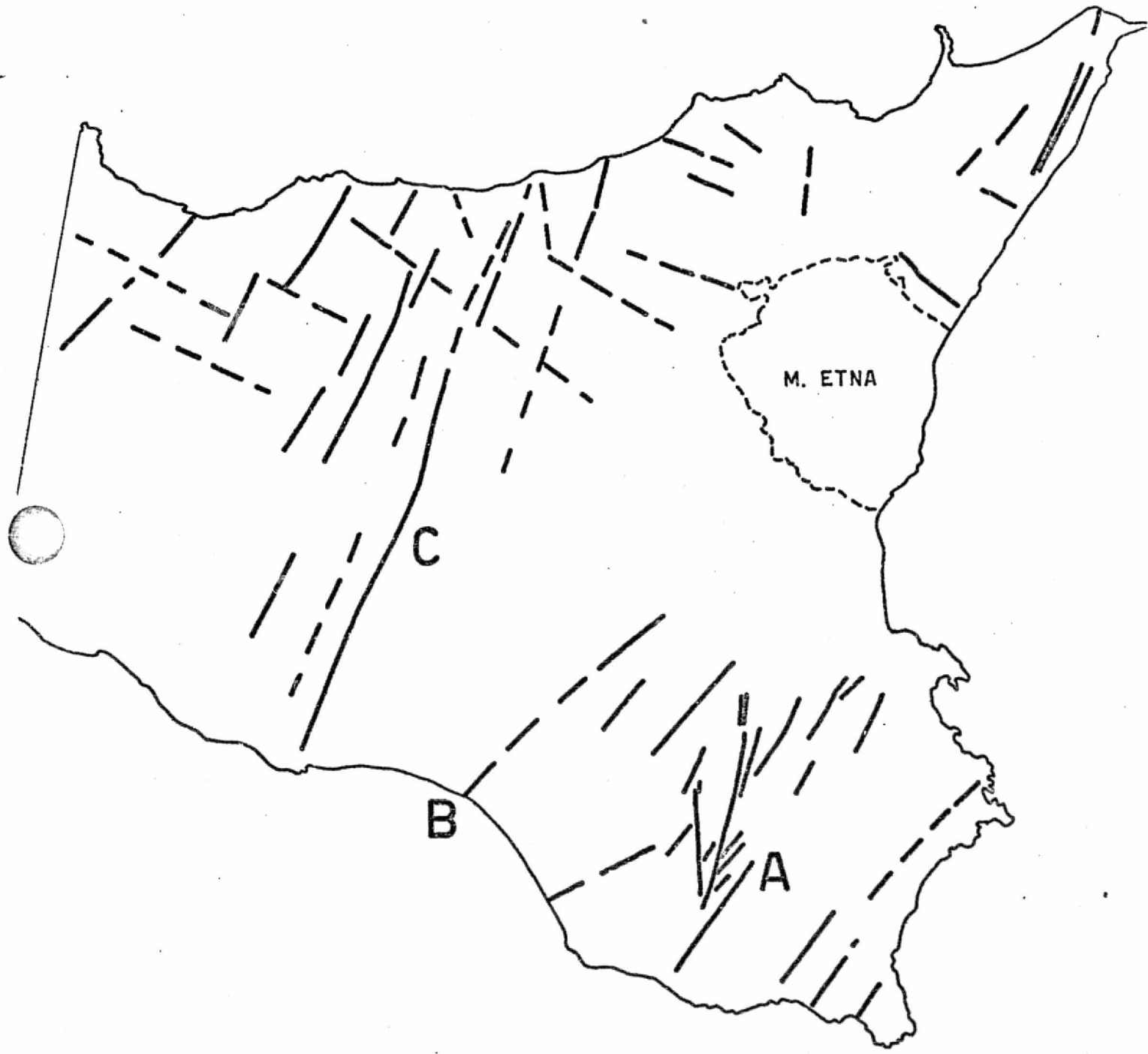


FIG. 7 b

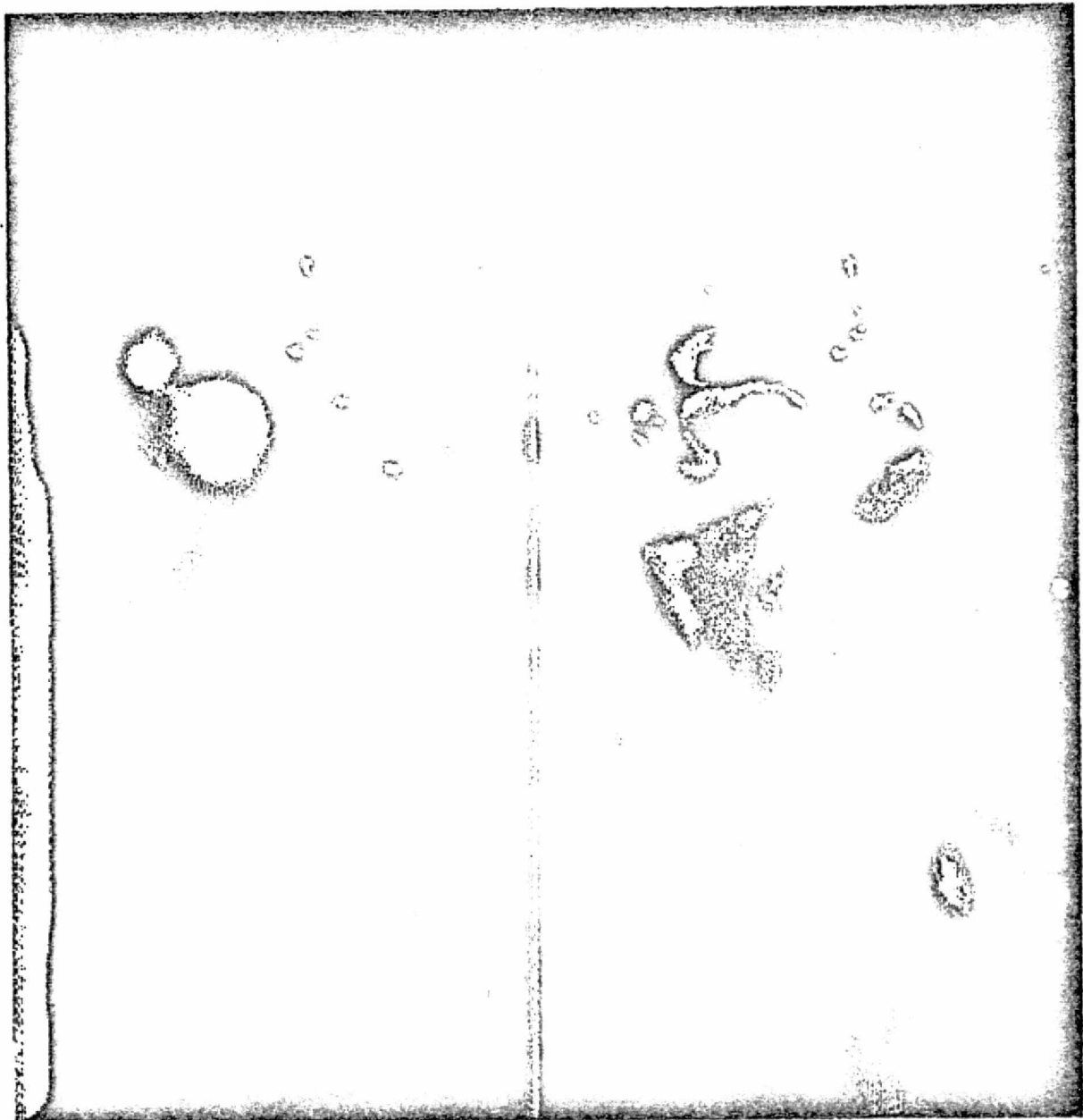
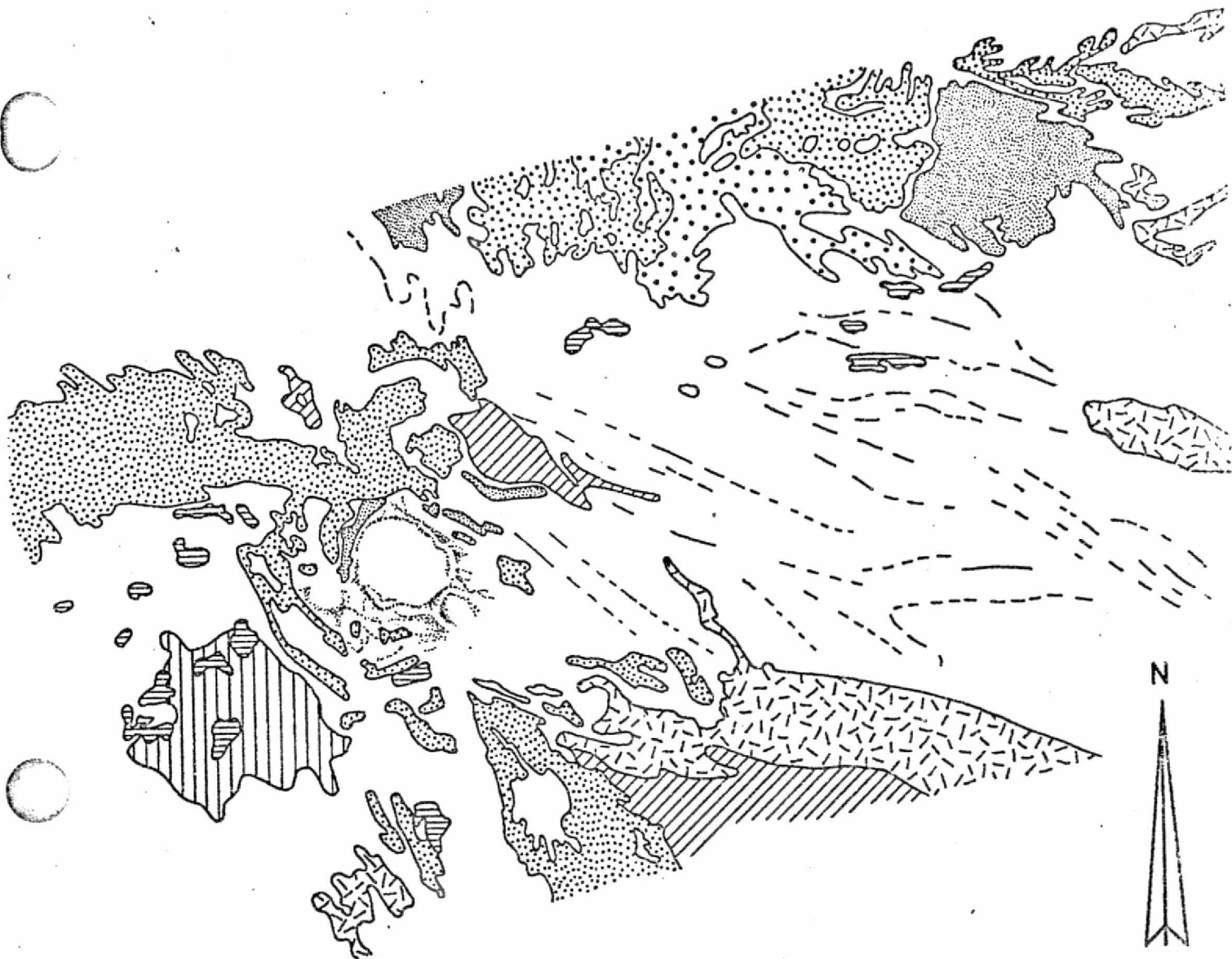


Fig. 8 - Thermogram of the summit of Mount Etna. Channel 9-11  $\mu$  (left) and difference between channels 3-5  $\mu$  and 9-11  $\mu$  (right)



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FIG. 9

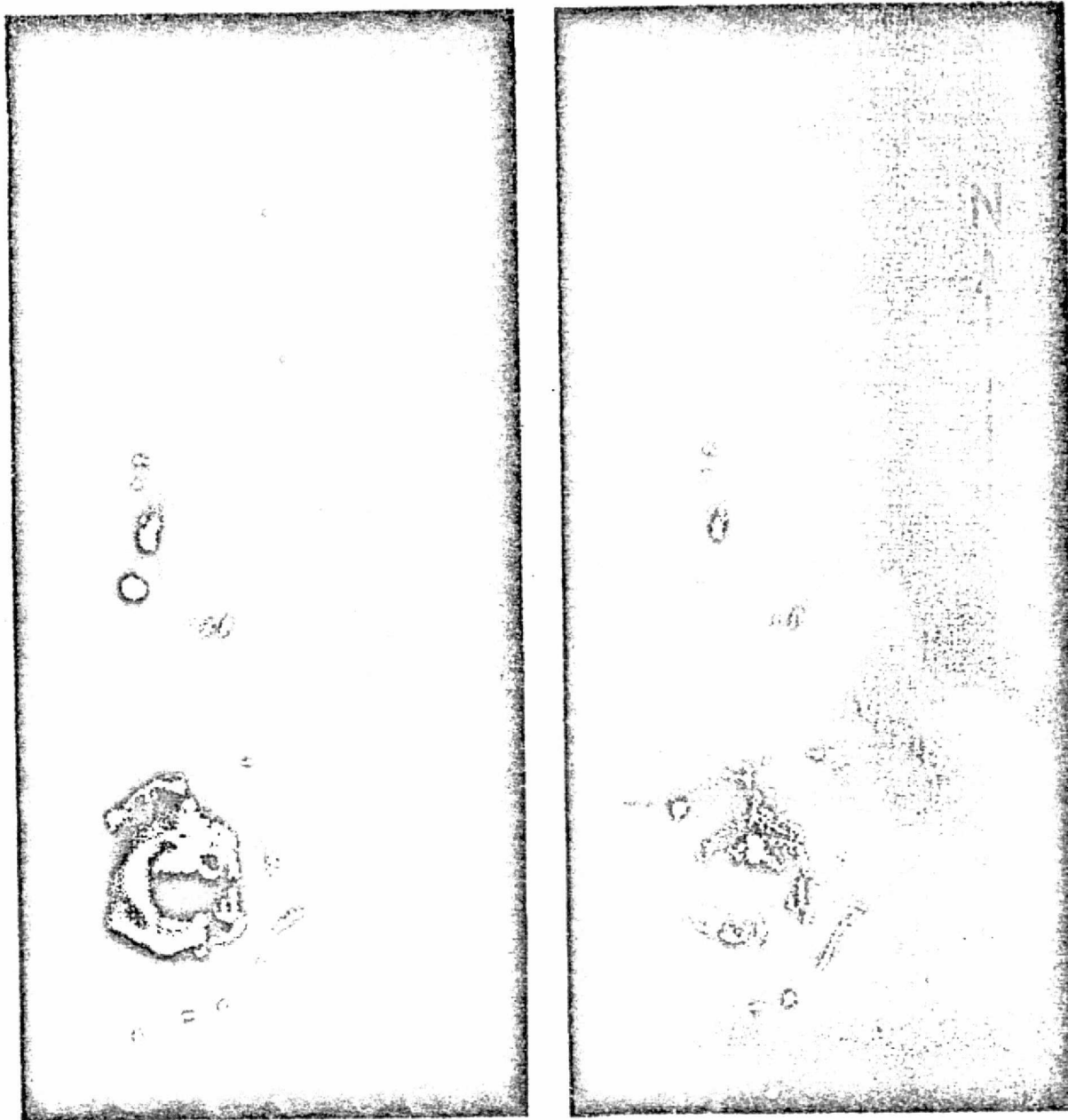
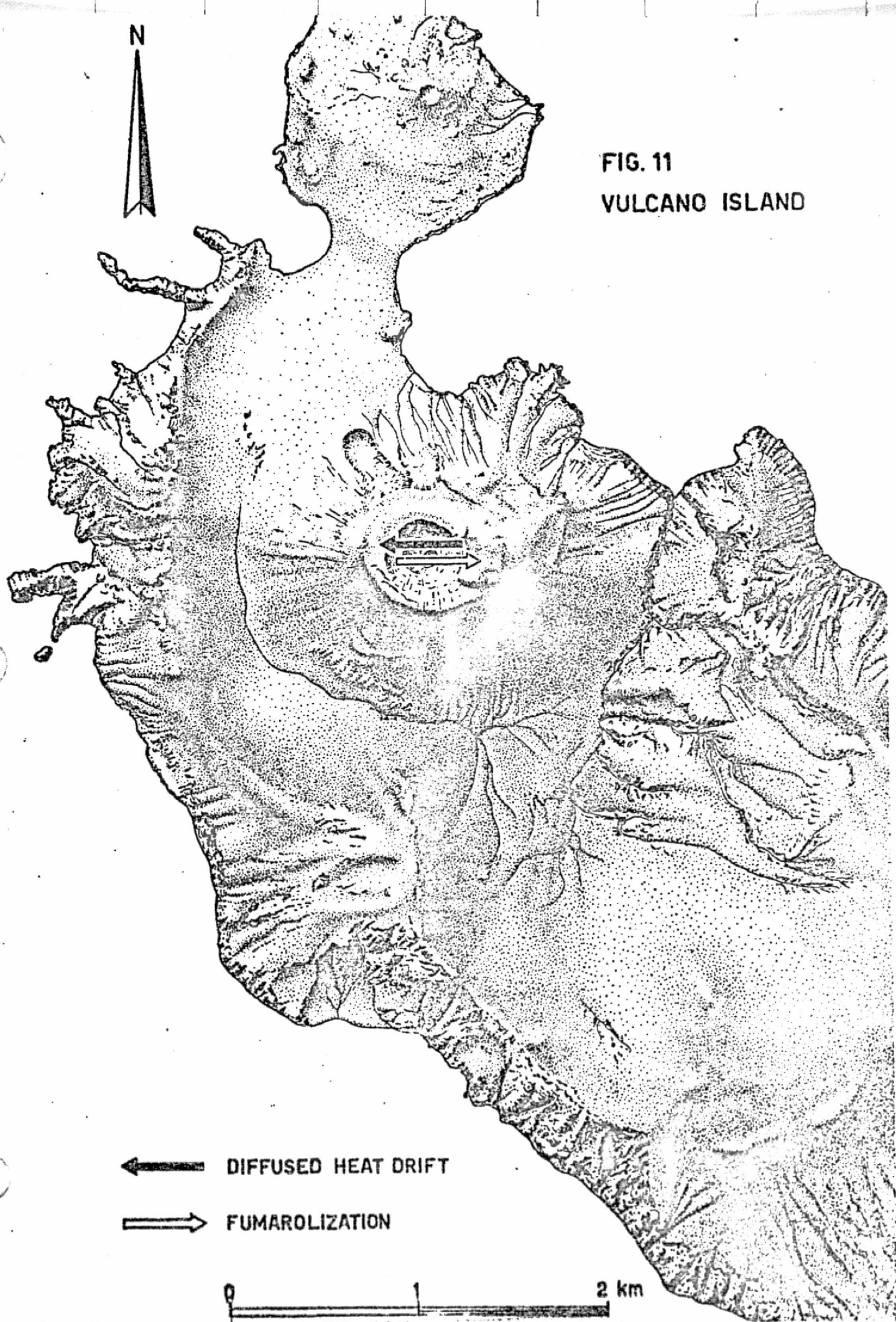


Fig. 10 - Thermal image of Vulcano crater  
flown in July 1973.  
Left : 3-5  $\mu$  channel  
Right: difference between the two  
thermal channels.

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FIG. 11  
VULCANO ISLAND



← DIFFUSED HEAT DRIFT

→ FUMAROLIZATION

2 km



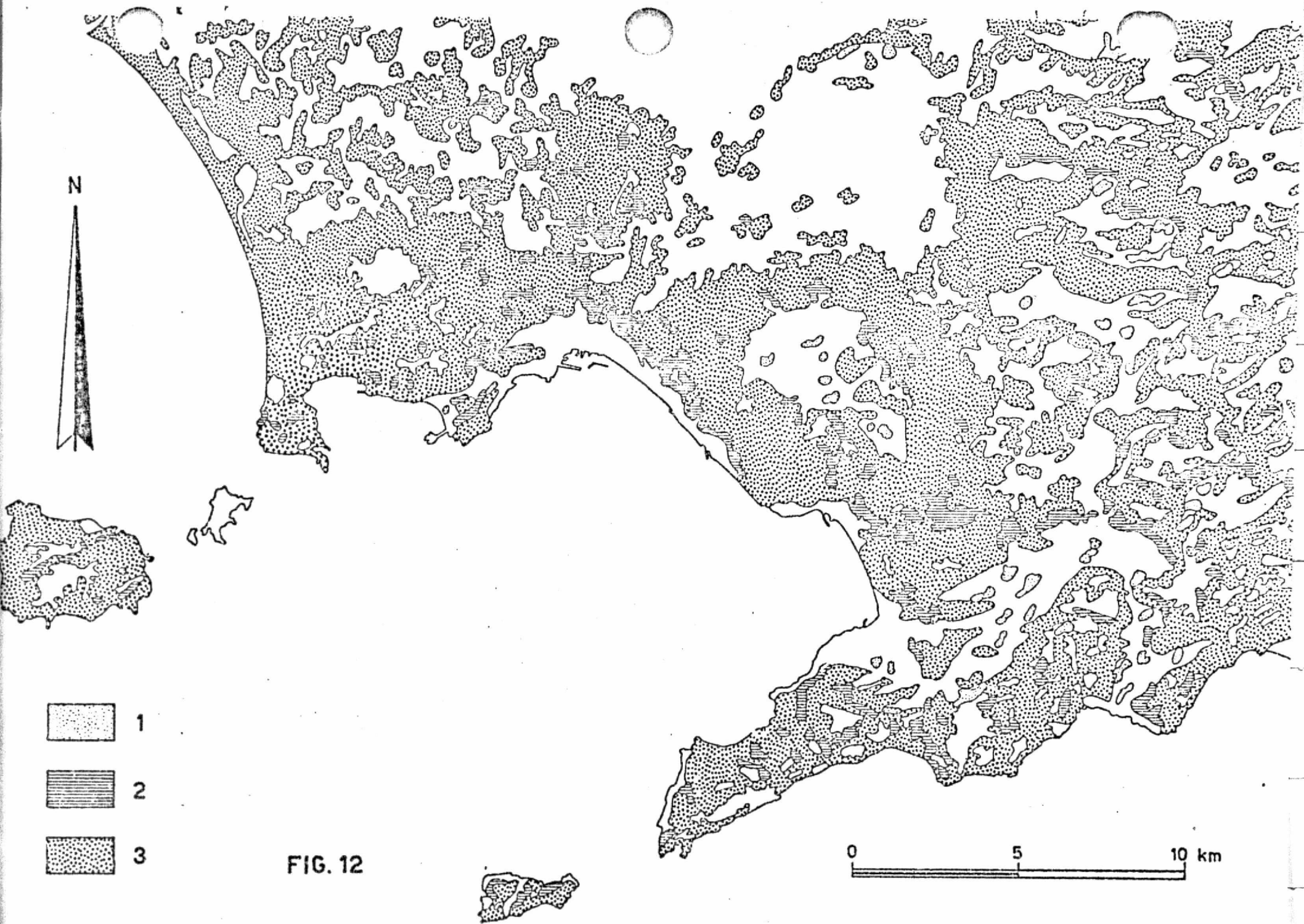


FIG. 12

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NORD

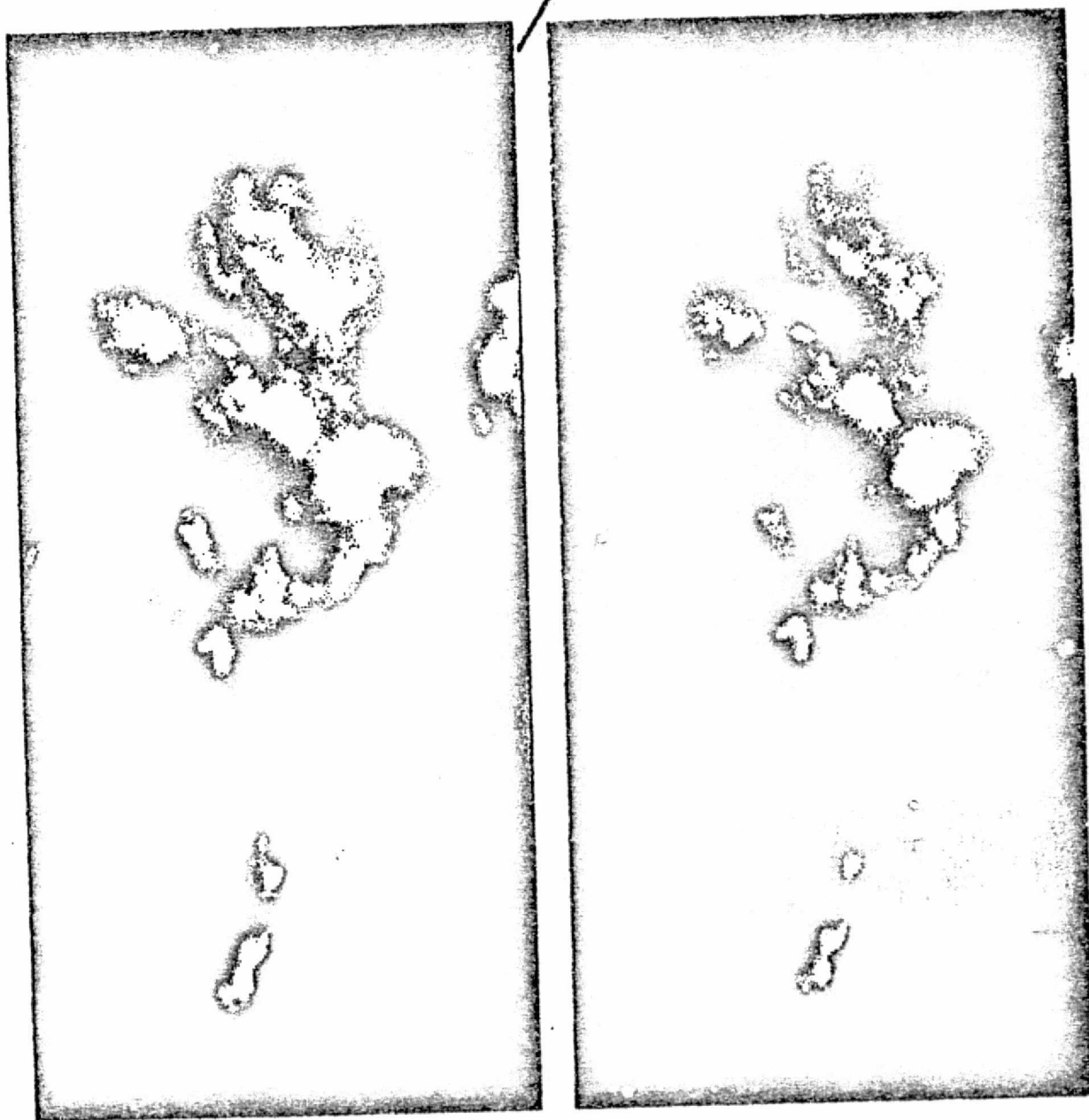


Fig. 13 - The Solfatara as seen in '73 at  
low altitude in channels 3-5  $\mu$   
and 9-11  $\mu$  .

NORD

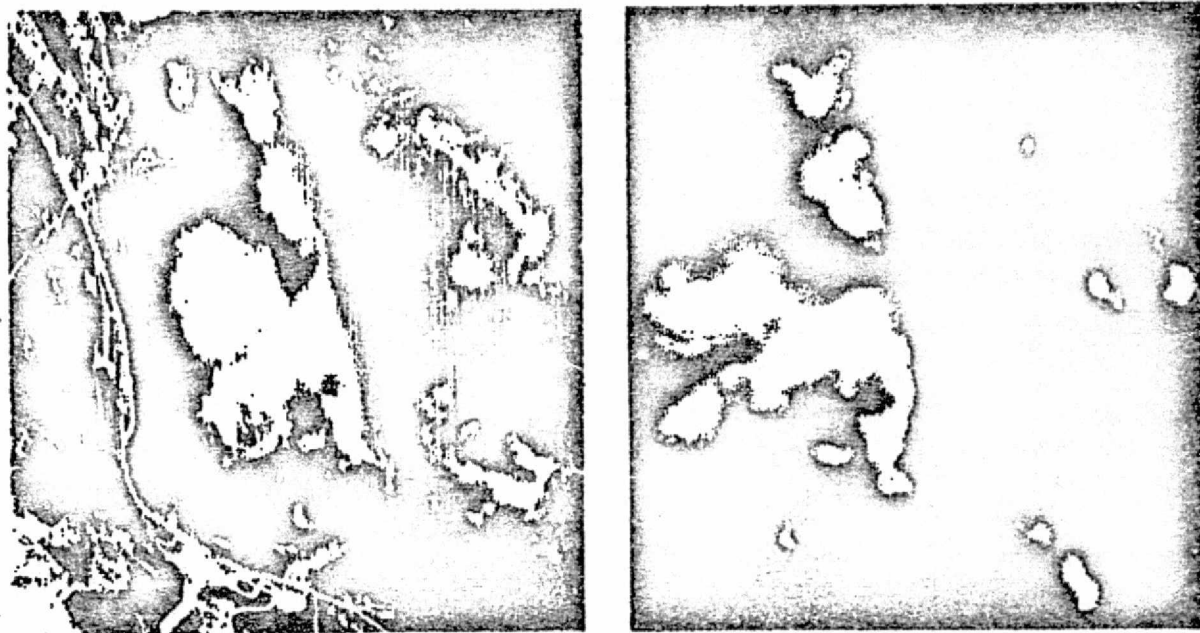


Fig. 14 - The old crater of Solfatara as observed in '70 and '73.

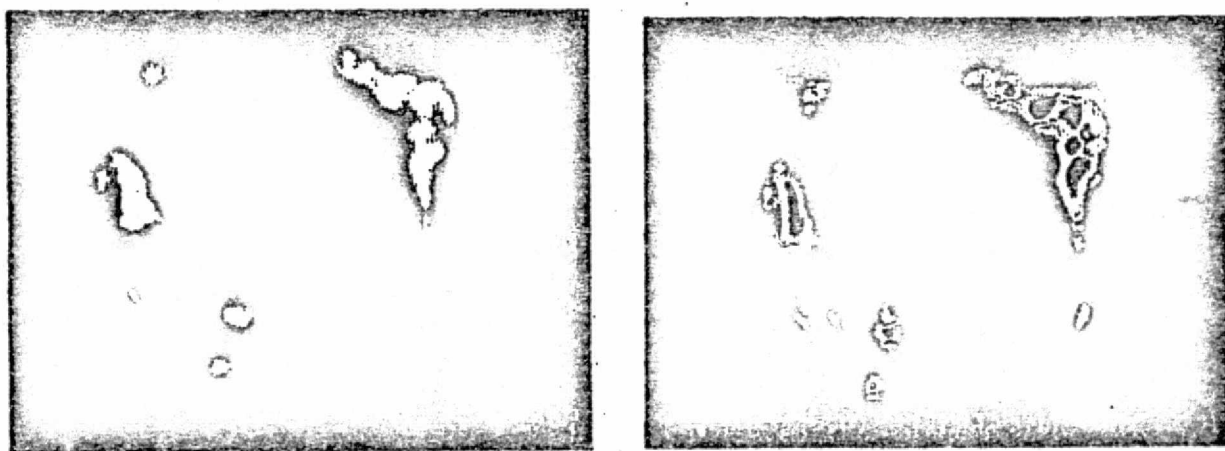


Fig. 15 - The cone of Vesuvius volcano  
Left : 9-11 /4  
Right : thermal gradients.



BY AIR MAIL

CONSIGLIO NAZIONALE DELLE RICERCHE

ORATORIO PER LA GEOFISICA DELLA LITOSFERA

December 9, 1974

20131 MILANO.  
Posta: GEOLAB, Via Mario Bianco, 9  
Telefono (02) 2840227 - 2899905

PROT.N.801 R.C./a.p.

Mr. MILLER

NASA

Lyndon B. Johnson Space Center

HOUSTON, Texas 77058

U.S.A.

Dear Mr. Miller,

Enclosed please find the fourth  
progress report on our EREP SL - 3 in-  
vestigation.

Sincerely yours,

Roberto Cassinis, Director

c.c.: Mr. Morrison - Nasa - Washington  
Mr. Wilmarth - Nasa - Houston  
NASA (STIF) - College Park, Maryland



CONSIGLIO NAZIONALE DELLE RICERCHE

ORATORIO PER LA GEOFISICA DELLA LITOSFERA

20131 MILANO, December 6, 1974  
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FOURTH PROGRESS REPORT  
Paleo river beds detection by  
means of multispectral images  
taken from Skylab.

Principal Investigator : R. Cassinis

Co-Investigator : G.M. Lechi

## INTRODUCTION

This work is the result of a joint research of the Laboratorio per la Geofisica della Litosfera and the Laboratorio di Geologia Applicata allo Studio delle vie di Comunicazione nel Settore Alpino Padano-C.N.R. - concerning the problem of the detection of gravely and sandy areas in the Venetian Plain (North of Padua).

The choice of such topic and so well defined area of investigation has been suggested by the existence of a supply programme for building materials, as well as a good scientific background, and a very precise ground truth.

In this area (Fig.1) there are two rivers, the Prenta and the Astico; by means of multispectral analysis, utilizing analog techniques, we discovered the patterns of the paleo-beds of these two rivers, by quick, precise, and economic methods.

For this research we had at our disposal a complete set of data, and an accurate aerial photo-interpretation. The synthesis of the collected data given by the Skylab frames and by the enhancement techniques, seem to be the right approach for the proposed problem.

We employed the data of the S 190 A multispectral camera, and in particular the 42, 41, 38, 37 bands of the SL 3 mission ( September 1973 ).

By the use of the cross density slicing, masking slicing, ratio's additive color synthesis, false color composition methods we achieved the best results for the solution of the proposed problem.

In particular we observed that the masking of bands 41 and 38 in the form of ratio was the best for this purpose, the masking ratio between 41 and 37 bands ranking second.

In figure 1 the investigated areas is shown; in figure 2 the masking ratio  $\frac{41}{38}$  (that is the positive of 41 band superimposed on the negative of 38 band), is presented.

In figure 3 a thematic map is shown, drawn following the results of figure 2 where it is possible to see the unknown patterns of the Brenta's and Astico's paleo river beds.

By electronic density slicing these results were emphasized; it was possible to plot the underground water rising line with a very high precision.

These positive results show that the multispectral images, treated by this methodology, not only give more continuity to the previous scattered data already known in the Venetian Plain, but point out new hydrogeological patterns.

FIGURES

Fig. 1 - The investigated area .

Fig. 2 - Masking ratio  $\frac{41}{38}$  bands

Fig. 3 - Map of the results



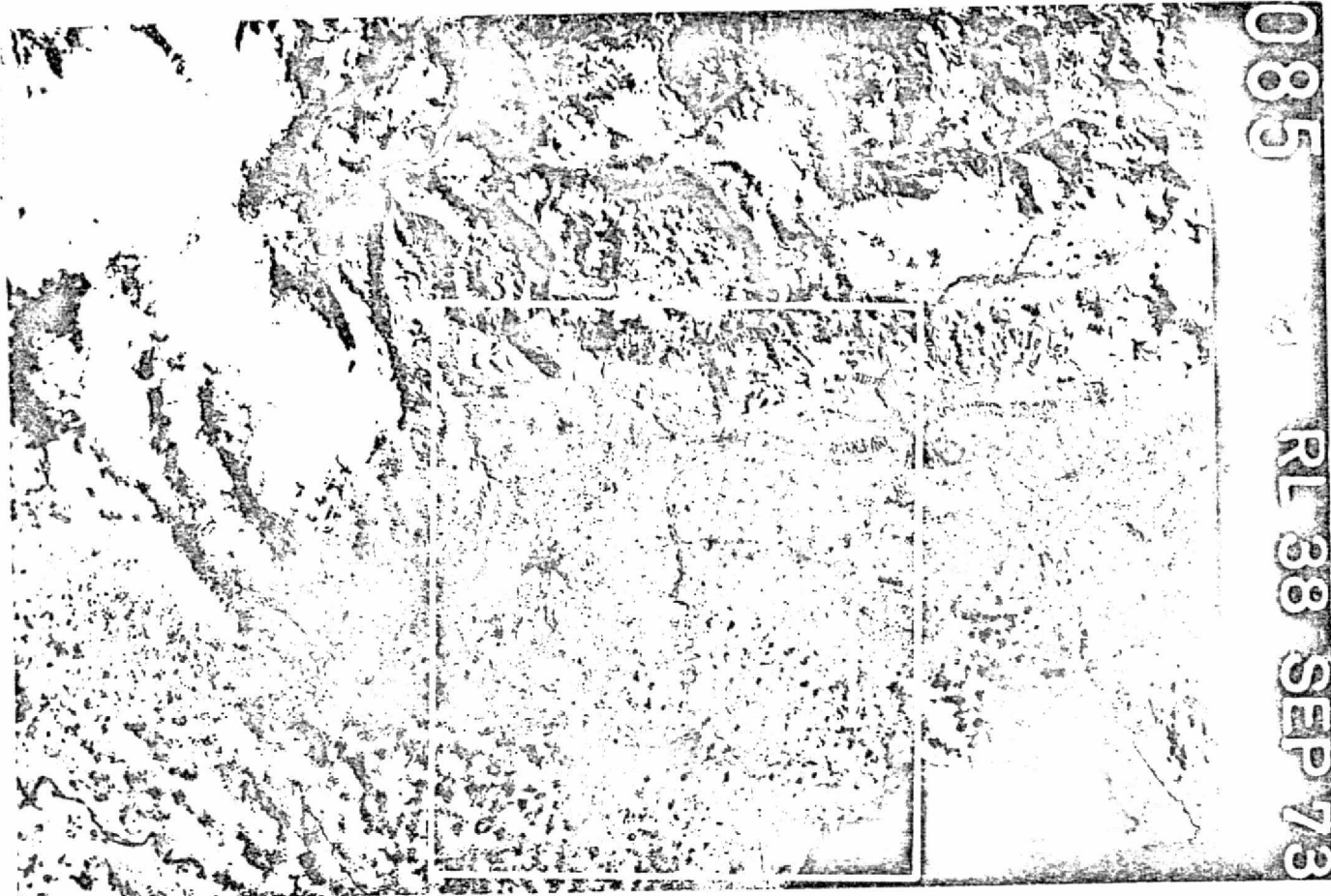


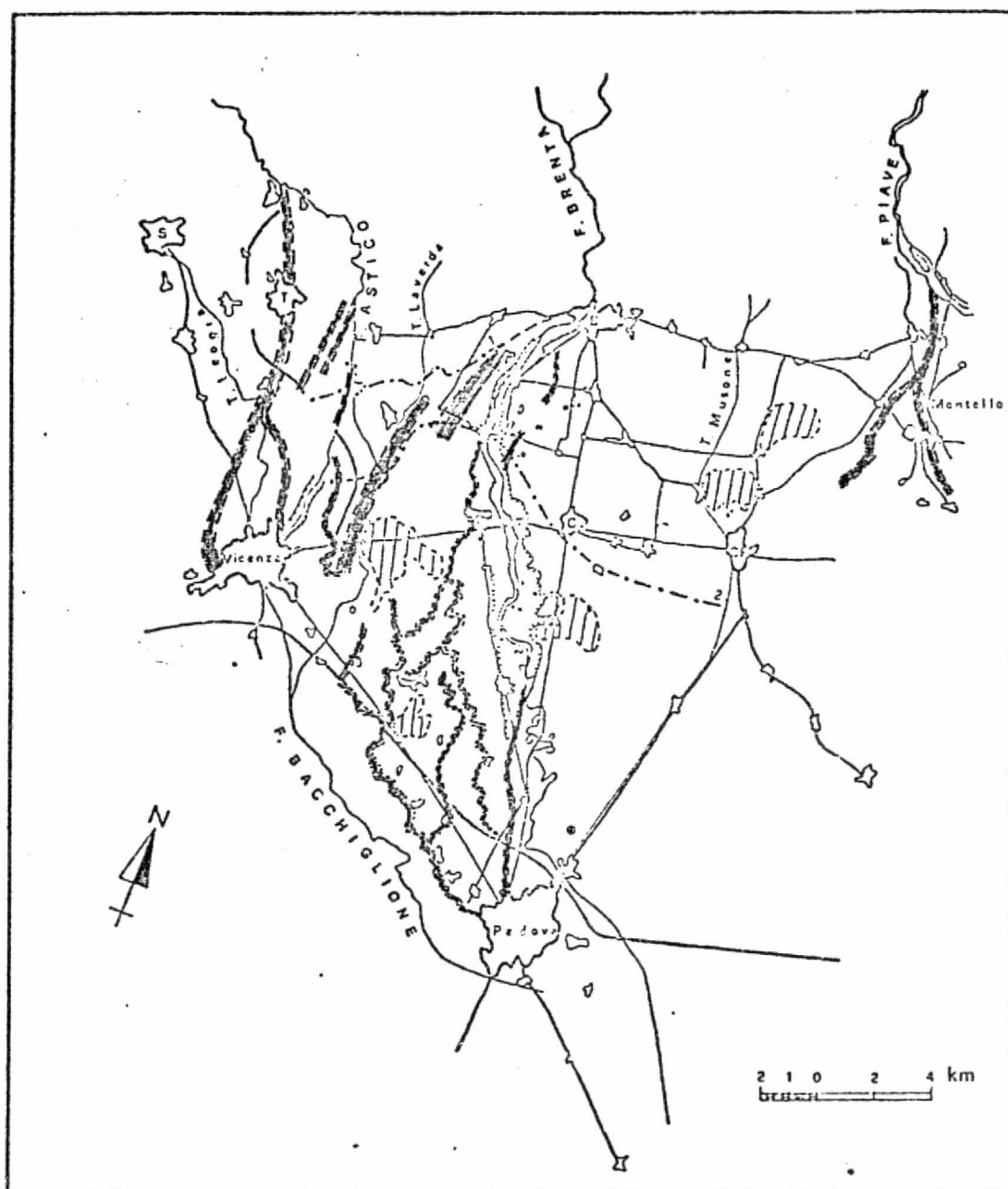
Fig. 1 The investigated area.  
Approx scale 1: 500.000

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








Fig. 2 Hard copy of the original masking ratio 41:38  
This image was utilized for the discover  
of Brenta and Astico paleo river beds that  
you can see in red in the figure 3

FIG. 3



LEGEND

- |   |                                 |   |                          |
|---|---------------------------------|---|--------------------------|
|  | Paleo river-bed                 |  | Gravel and sand deposits |
|  | Alluvial terraces               |  | Alluvial materials       |
|  | Old river winding               |  | Urban areas              |
|  | Boundary of fresh water springs |  | High way                 |
|  |                                 |  | Main road                |

CONSIGLIO NAZIONALE DELLE RICERCHE  
LABORATORIO PER LA GEOFISICA DELLA LITOSFERA

20131 MILANO, SEPTEMBER 26, 1974  
Purto: GEOLAB, Via Mario Bianco, 9  
Telefono (02) 2840227 - 2899905

BY AIR MAIL

PROT.N. 598 R.C./a.p.

Mr. MILLER  
NASA  
Lyndon B. Johnson Space Center  
HOUSTON, Texas 77058  
U.S.A.

Dear Mr. Miller,

I send you the third progress report on our investigation using the Skylab imagery. This report deals with the finding of reflectance anomalies that can be related to an impending lateral eruption on the slopes of Mount Etna Volcano.

The following reports will deal with the discovery of paleoriverbeds and with the studies on rice fields.

On the occasion I thank you for your last telephone call, and apologize for the rather confused talk.

I quite agree with your idea of organizing an European Symposium on the EREP results and look forward to receive from you further details.

Sincerely yours,

Professor Roberto Cassinis



Enclosed: Third Progress Report Skylab

c.c.: Mr. Morrison - Nasa - Washington  
Mr. Wilmarth - Nasa - Houston

NASA (STIF) - College Park, Maryland



CONSIGLIO NAZIONALE DELLE RICERCHE

LABORATORIO PER LA GEOFISICA DELLA LITOSFERA

20131 MILANO, SEPTEMBER 26, 1974  
Posta: GEOLAB, Via Mario Bianco, 9  
Telefono (02) 2940227 - 2899905

THIRD PROGRESS REPORT

Contribution of Skylab multispectral  
imagery to the remote sensing studies  
of Mount Etna volcano.

Principal Investigator : R. Cassinis

Coinvestigators : G.M. Lechi  
C.M. Marino  
A.M. Tonelli

## I. INTRODUCTION

The problem of the volcanic surveillance and control has been carefully considered over the last five years.

Particular effort has been made in the development of Remote Sensing Techniques due to the greater possibility they offer in the observing and quantifying of a large area in a short time.

Under this system we have two possibilities of carrying out our analysis; firstly we will consider the multispectral methods in which reflectivity characteristics of bodies are studied; secondly the thermal I.R. scanning method by which the distribution of surface temperature is analysed.

While with the multispectral method we are able to use the vegetation canopy as an indicator, with the thermal I.R. scanning system we analyse directly the energy radiated from the surface which is produced by internal volcanic activity.

There is a fundamental distinction to be made between the two methods. While with the M.S. a short delay-time can be observed between magma movement and reflectivity seepage at the vegetation canopy, with the I.R. method the delay between the cause and the thermal effect is considerably longer.

Another factor to be noted is that the I.R. method is applicable only in cases of secondary volcanic activity ( fumarolas, gas vents a.s.o. ) and not in the case of open chimney volcanoes.

## 2. ROLES OF MULTISPECTRAL AND THERMAL I.R. SYSTEMS FOR THE VOLCANIC CONTROL AND SURVEILLANCE

The last lateral eruption of Mount Etna ( February '74 ) 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 leaves ( Fig.1 ). 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 (Fig.2).

The data collected by the Skylab manned station during the SL3 mission about five months before the paroxysmal event, was 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. A false color composite using bands 31,32,35 was also used for the same purpose (Fig.3): a clear anomaly can be observed utilizing a strong enlargement.

These two observations are at present under investigation

by specialists; geologists, biologists, phitopathologists and, last but not least, the Remote Sensing technicians.

The multispectral analysis was followed by ground observations and by a special aerial survey. The ground-truth collection consisted primarily in observing the local geomorphology, geology and characteristics of the evergreen belt surrounding the slopes of Etna.

In July '74, four months after the eruption, an aerial survey was carried out using both 9-11  $\mu$  and 1,5-2  $\mu$  channels (Fig.4). Airborne false colour photography was also employed for the same purpose of discovering the phyto-anomalies. The path followed was that of the shape of the evergreen belt used as a geo-volcanic indicator.

It is to be noted that the evergreen belt which is formed by a fairly constant phytoassociation surrounds the slopes just at the altitude where civil disaster due to a possible eruption is impending, and the danger of lava outflows is a reality.

During the play-back phase and data processing we introduced a special kind of treatment, that of considering the ratio between the near I.R. reflected energy and the emitted one.

In fact we assumed that in an anomalous area like that of a soil affected by gas vents and covered by vegetation, the reflectivity in the near I.R. drops while the corresponding emitted radiance increases. The ratio emphasizes these small relative fluctuation occurring between the information considered above.

Some months before, during the eruption of M.Etna of February '74 another aerial survey was carried out using a thermovision scanner mounted on board an Italian Navy helicopter.



The principal task of these flights ( 7 flights were performed, with different light conditions ) was the monitoring of possible new cleft apertures in the surroundings of the eruption. The thermal anomaly close to the lava flow outlined the reduced possibility of the forecasting of volcanic eruption using only the thermal I.R. band over an active area, such as Etna. In fact heat transfer in the volcanic material seems to be very small. The surface heat distribution is strongly related to the thermal conductivity of the layers beneath the surface and to the velocity of magma movements inside the volcanic structure.

Thermal I.R. remote sensing techniques can be considered for other types of volcanoes a new tool for mapping, describing and analyzing thermal areas, and in particular for volcanic surveillance in case of secondary volcanic activity.

( See: " Remote sensing techniques applied to the study of Italian volcanic areas: the results of the repetition of the airborne I.R. survey compared to the previous data "

Cassinis R., Marino C.M., Tonelli A.M.

Proceedings of : Ninth International Symposium on Remote Sensing of Environment - Ann Arbor, Michigan - April 1974 ).



Professor Roberto Cassinis

SEPTEMBER 26, 1974

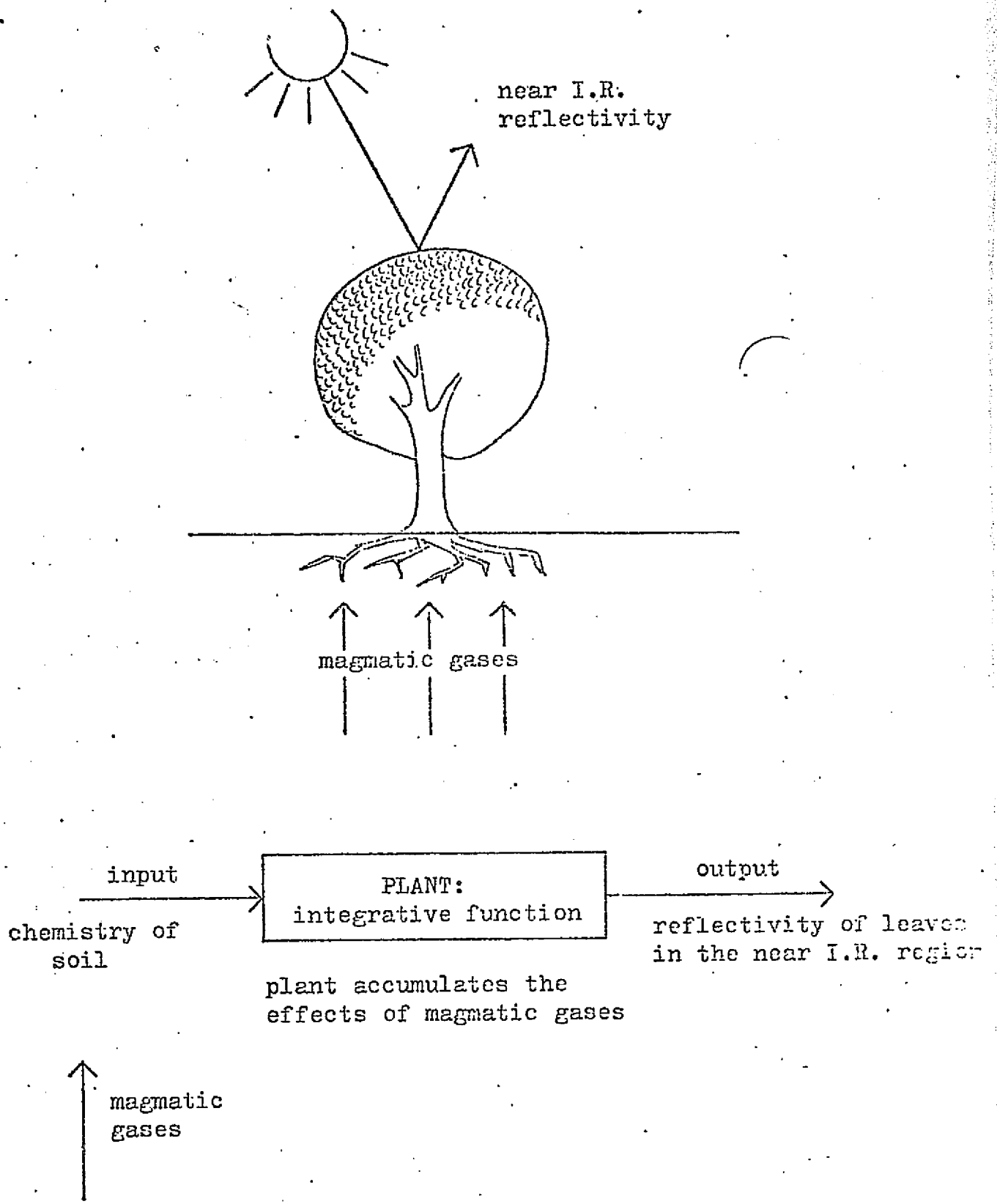


FIG. 1

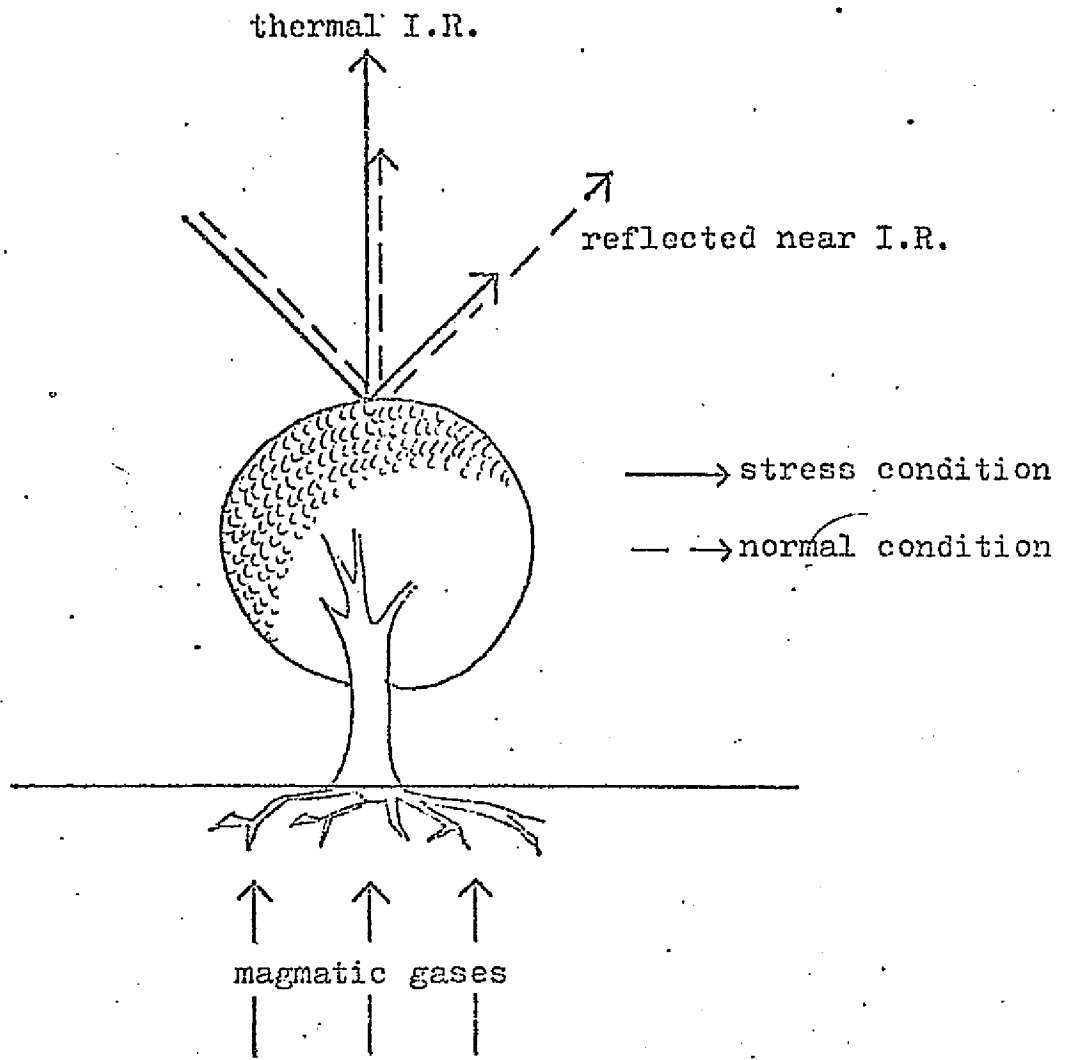
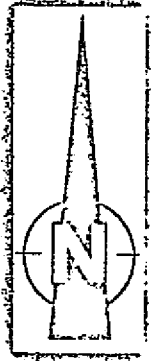
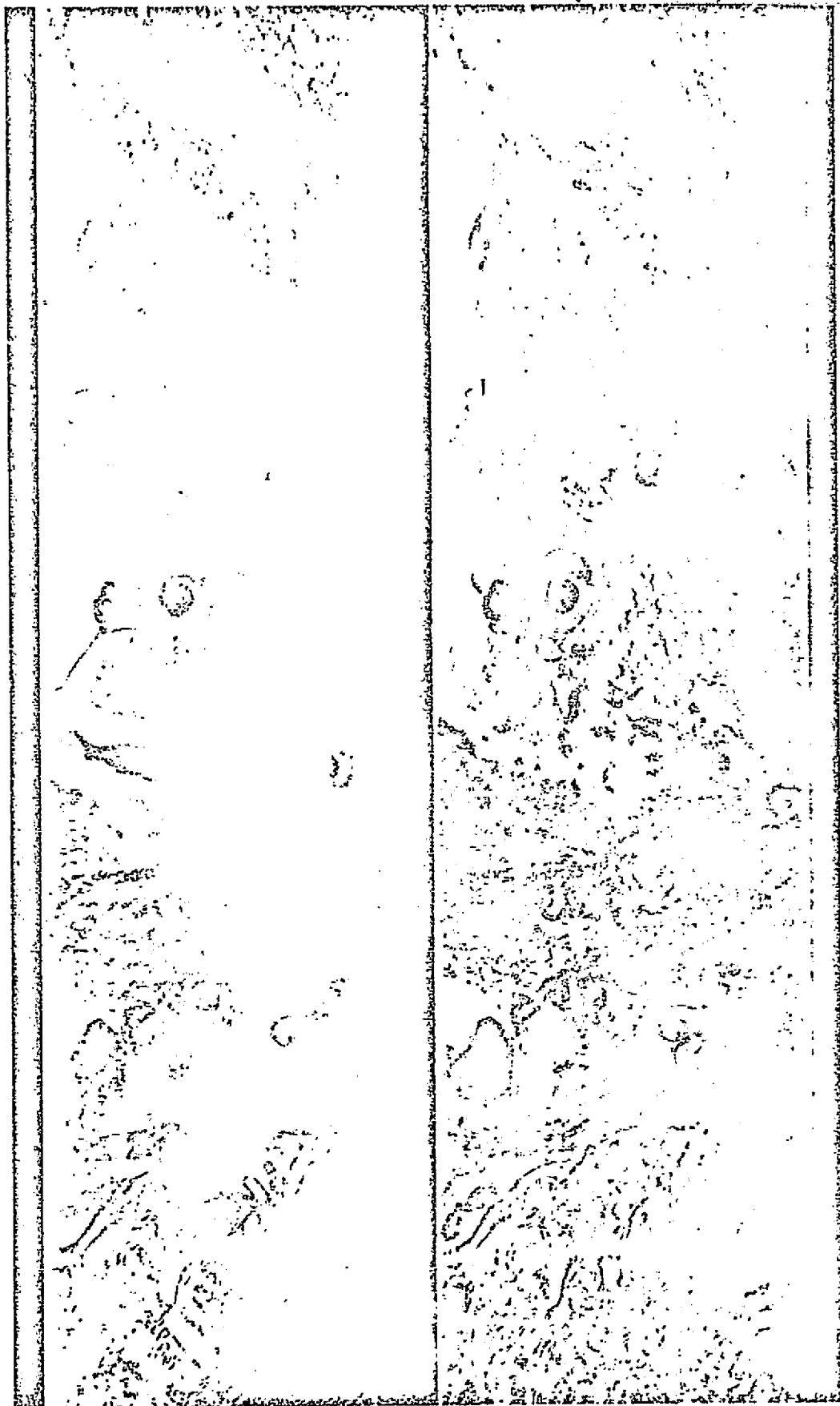


FIG. 2

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FIG. 3





A

B

FIG. 4. Thermograms of Etna volcano, in the zone of the eruption of February '74. A - near I.R. reflection ( band  $1,5-2\mu$  );  
B - thermal emission ( band  $9-11\mu$  ).



CONSIGLIO NAZIONALE DELLE RICERCHE

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Skylab E R E P - Second Progress Report

1 - Test site area: Sicily

The study of the environment of Mt. Etna will continue in the month of June with the on ground observation performed by a joint group of geologists and vegetation pathologists.

The main topic will be the comparison between the forest surrounding the area of the last lateral eruption of February '74 and the one in the northern slope of the volcano, showing, by a first observation on the images, the same drop in the near I.R. reflectance which could be originated by the gases escaping from the shallow underground lavas.

While this research is of maximum interest in order to forecast the volcanic eruptions, it must be considered in the frame of a wider study regarding the so called " spectral indicators ".

The analysis of the vegetative canopy will take into account respectively the anomalous seasonal behaviour of the brush as well as of the pinus and oak trees forming the forest belt around the large volcanic structure. In fact, the velocity of the metabolic change is strongly different for brush and high trees; as far as visible and near I.R. reflectance is concerned.

2 - Other areas

a) Delta Po area.

The pattern recognition on rice fields has been almost completed using both false color I.R. photography ( the original Skylab image ) and the color-ratio performance of the multispectral bands.

By the ratio method the presence of chlorophyll has been emphasized while by means of the false color combination the small spectral characteristic differences were pointed out.

The comparison between the ratio of bands 42-37 and 41-38 gave the best results

b) Venetian Plain Region.

The patterns of some paleo river beds have been mapped with satisfactory results using the images of S 190 A Multispectral Camera.

For this research we employed an analog TV processing system to examine the information content of the bands ratio.

By applying the integrative function it was possible to follow the continuity of the patterns influenced by the surficial moisture.

*Plan*



  
FIGURE CAPTIONS

## 1 - Delta of river Po.

The square corresponds to the investigated area ( see slides 2 and 3 ).

2 - Delta of river Po ( color slide ): additive synthesis of ratio  $\frac{42}{37}$  ( red) and ratio  $\frac{41}{38}$  ( green ).

The total surficial chlorophyll distribution is shown.

The comparison between the original false color image and this composite gives almost a complete description of the vegetation canopy. The chlorophyll content in coastal water is also observed.

3 - Delta of river Po (color slide) : additive synthesis of contiguous bands ratio (  $\frac{37}{38} + \frac{42}{41}$  ). A discrimination inside the vegetation canopy is observed.

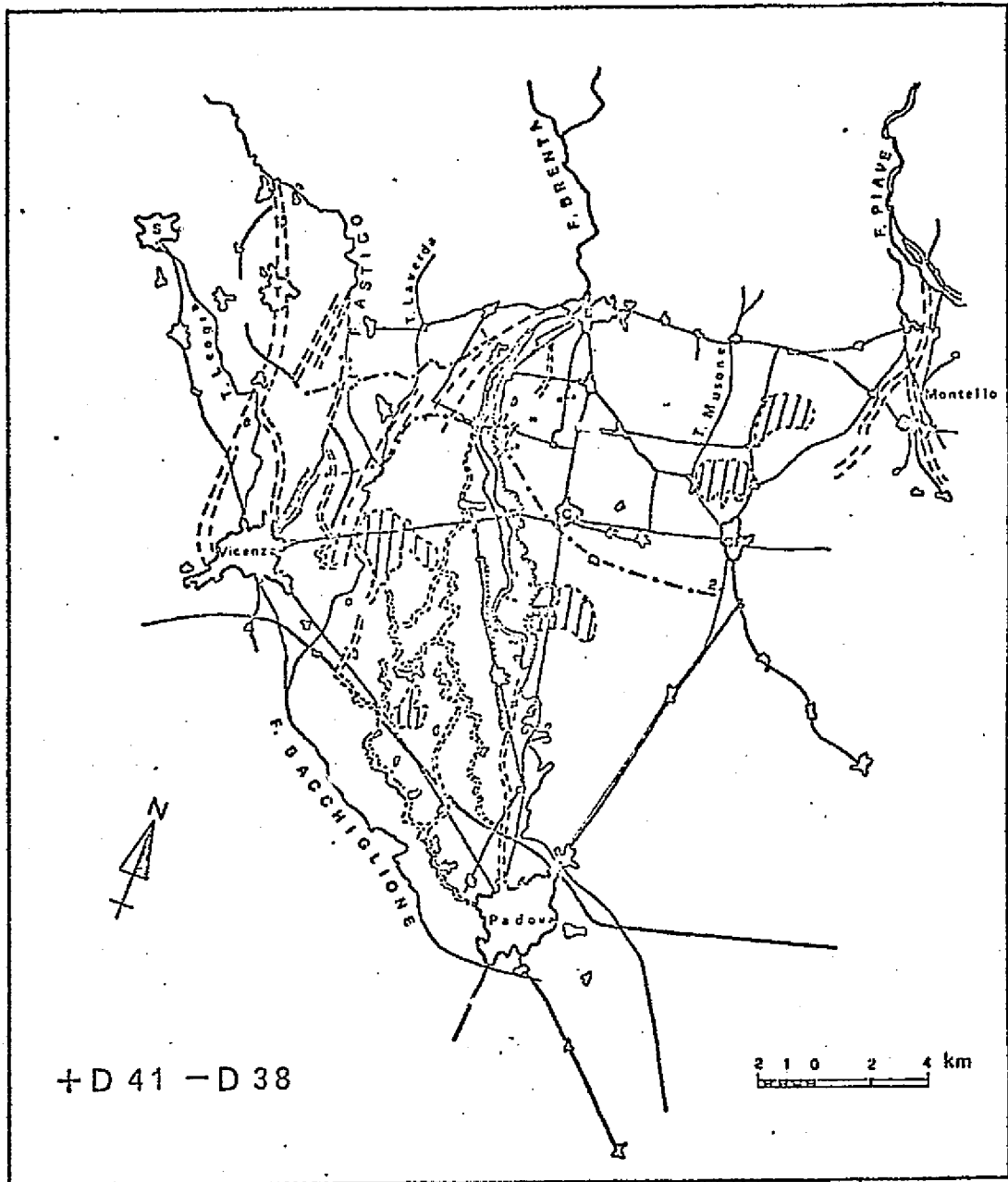
## 4 - Venitian Plain Region; encircled is shown the investigated area ( north of the city of Padua ).

## 5 - Map showing the hydrogeological knowledge ( mainly concerning old riverbeds) in the venitian plain, before the Skylab investigation. Scale : 1:75.000.

## 6 - A map of the same area ( scale 1:250.000 ) illustrating the old riverbeds and the gravel deposits found by the means of the analog technique of interpretation of Skylab images ( masking slicing and ratio additive synthesis).

FIG. 6

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+D 41 - D 38

2 1 0 2 4 km

LEGEND











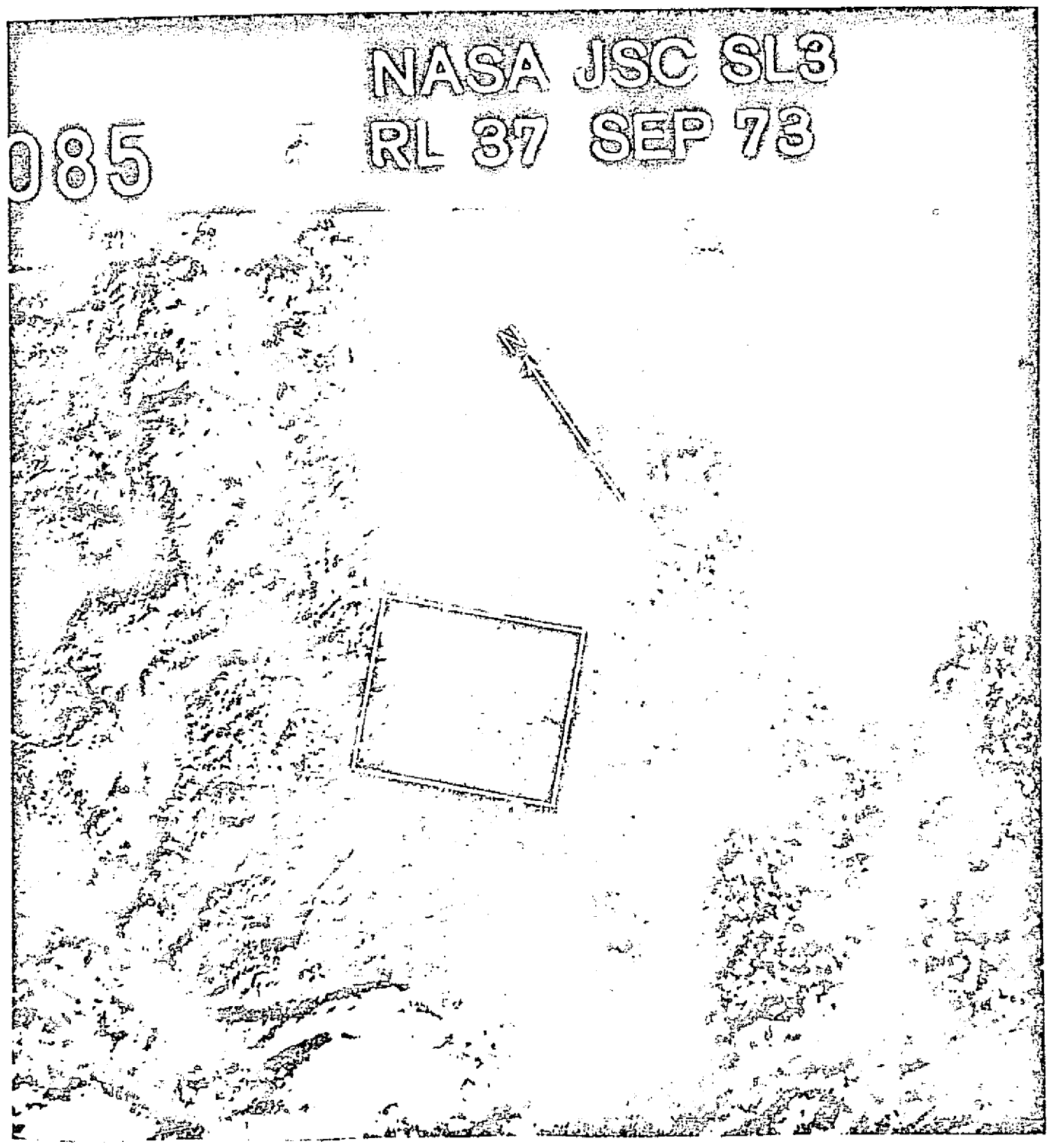
- |   |                               |  |                          |
|---|-------------------------------|--|--------------------------|
|  | Paleo river-bed               |   | Gravel and sand deposits |
|  | Alluvial terraces             |   | Alluvial materials       |
|  | Old river winding             |   | Urban areas              |
|  | Boundary of fresh water sings |  | High way                 |
|  |                               |  | Main road                |

FIG. 1

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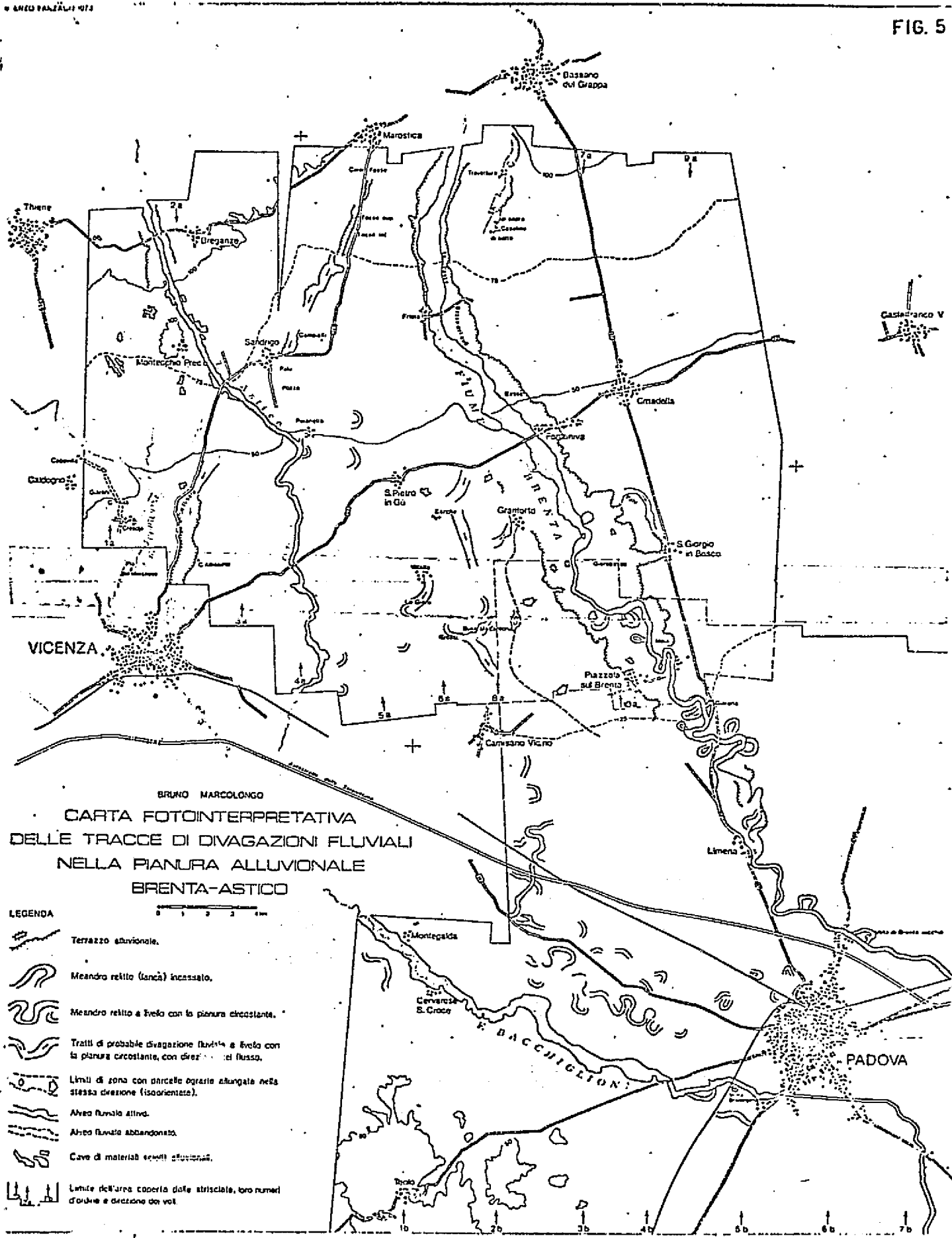


FIG. 4



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RL 37 SEP 73



BRUNO MARCOLOGO

**CARTA FOTOINTERPRETATIVA  
DELLE TRACCE DI DIVAGAZIONI FLUVIALI  
NELLA PIANURA ALLUVIONALE  
BRENTA-ASTICO**

**LEGENDA**

- Terrazzo alluvionale.
- Meandro rettilo (lancia) incassato.
- Meandro rettilo a livello con la pianura circostante.
- Tratti di probabile divagazione fluviale a livello con la pianura circostante, con direzione del flusso.
- Limiti di zona con onirulle ogivali allungate nella stessa direzione (isorientate).
- Alveo fluviale attivo.
- Alveo fluviale abbandonato.
- Cave di materiali erosi alluvionali.
- Limite dell'area coperta dalle striscie, con numeri d'ordine e direzione dei voli.

# MT. ETNA

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