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RESEARCH ON THE USEFULNESS OF REMOTE SENSORS IN PROSPECTING FOR GEOTHERMAL RESOURCES IN THE CERRO PRIETO AREA OF BAJA CALIFORNIA NORTE.

The usefulness of remote perception during the preliminary stages in the study of an area of geothermal interest has been fully demonstrated as far as photograph interpretation is concerned and digital processing of such information apparently presents new possibilities for its use.

In order to investigate the true scope of this technology, a joint project was carried out by the Comisión Federal de Electricidad and the Instituto de Investigaciones en Matemáticas Aplicadas y en Sistemas (IIMAS) of the Universidad Nacional Autónoma de México (UNAM), with the support of the Instituto de Investigaciones Eléctricas (IIE) and the United Nations.

Within this same project, studies were included on the digital treatment of images in wave lengths that range from short visible infrared to thermal infrared, using 4 bands of LANDSAT and thermal images from an air-transported sensor in the Cerro Prieto geothermal area.

The mathematical/computational tool that had been provided to IIMAS for previous projects with other institutions was adapted and improved with some additions that would make it useful for geologic studies.

To achieve the objectives of the project, studies on three basic factors were included:

I. A statistical analysis of the LANDSAT images based on their multispectral characteristics, in order to identify areas with hydrothermal alterations.

II. Preparation of thermal mosaic of the Cerro Prieto zone for mapping temperature manifestations and traits.

III. Application of a mathematical heat transfer model to eliminate daily weather effects on soil temperature and on the calculation of thermal flow and inertia.

1.- STATISTICAL ANALYSIS OF THE IMAGES

Data processing was carried out through a powerful program for classifying the points (pixel) of the images, based on the 4 different intensities with which the image is observed on the LANDSAT bands.

The prime objective was to gather statistics to characterize the intensities with which solar radiation is reflected by the materials thought to be altered.

Even though typical hydrothermal alterations in geothermal systems present bands that allow for their identification short infrared wave lengths outside the scope of the LANDSAT satellite sensor, an attempt was made to identify them, taking advantage of the increase in visible and infrared reflecture produced by the effects of such alterations.

Based on the statistical results of this first stage, digital classification was extended to a larger area in order to identify all the sites with spectral behavior similar to that of the material considered of interest.

Eliminating the cases of no geothermal interest, the results of the digital classification were set forth on an electrostatic print (Fig. 1). Here the allegedly altered zones present certain linear trends that could be related to the structural system that controls the Cerro Prieto geothermal field, including one that seems to correspond to the extension of the Cerro Prieto Fault to the northwest.

II. PRODUCTION OF A THERMAL MOSAIC

As part of this project, three flights were made to gather thermal data on the Cerro Prieto area. They took place at key time: the first, just before sunset; the second, during the first hours of the night; and the last, shortly before sunset.

The images obtained during the last hours of the night were the most important, since solar influence is minimal then. Thus, a geometrically-corrected thermal mosaic was made with the lines from this flight and used for visual analysis.

To interpret the photo, the effects of thermal emission and inertia were taken into account, since they may cause anomalies in temperature. A notable example of such anomalies is present in the Cerro Prieto Volcano, where both effects work together to give it an aspect of high temperature (shininess), which, although it may be real, is of no

geothermal interest, since it is caused by the great heat-storing capacity in the rhyodacite and its high efficiency in emitting infrared radiation.

The high radioactive temperature of the granites and gneisses of the Sierra Cucapah seems to be caused exclusively by the effect of its elevated thermal inertia.

Mapping manifestations

In order to map manifestations in the area, an analysis of the thermal mosaic was made, using Grinnel display equipment, which makes it possible to visualize the information by highlighting with a false color. This consists of selecting an optional number of colors into which the intensities of the image are divided on a screen of colors to facilitate identifying regions that lie within the same range of temperatures.

Using this technique, it was possible to identify most of the thermal manifestations reported in Razo's hydrological map in 1969 and there were many other traits that could correspond to manifestations that have not been previously mapped. Many of the springs reported in the same paper, however, are not indicated in the photo mosaic of images in false colors extrapolated from the screen for that purpose, perhaps because their temperature is low.

Approximately 80% of the springs located in the field may be identified in the thermal image, while only 50% of the high temperature zones that may be discerned on the screen have been mapped as manifestations.

The failure of such studies to coincide may be due to the appearance of new manifestations during the period from 1969 to 1979 where drains and paleocanals cross, the disappearance of others and the direct mapping of soil temperature with an image that includes other manifestations in addition to springs.

Mapping of linear traits (Fig. 2)

The Cerro Prieto geothermal zone is located within an irrigation area in the Mexicali Valley, which makes it difficult to evaluate the thermal mosaic. The distribution of drains, canals, irrigated areas and crops mask a large number of traits that are useful in geological prospecting. On the other hand, there seems to be no direct relation between radioactive temperature and geophysical prospecting through gravity, magnetometric and resistivity studies, even with the most shallow probing.

Among the results of greatest interest, two thermal alignments were detected to the north of the Ejido Nayarit. One of them corresponds to a fault that has been detected geophysically, while the other is unrelated to manifestations that have been reported.

Two alignments were also detected to the north and west of the Ejido Nuevo León. The first, of a northwest-southeast direction, could be the continuation of a fault detected through a gravity survey. The second, which runs from northeast to southwest, is less clear and could be the reflection of an (unreported) fault within the trend of the Volcano system.

Finally, two unclear alignments were detected around the Juárez colony, both of dubious interpretation.

111.- APPLICATION OF A MATHEMATICAL MODEL

The section of the thermal mosaic that covered the geothermal zone was selected for the application of a model to eliminate the effects of weather on temperature. This required the thermal information logs from the three flights and the application of a numerical algorithm.

As a result of this process, three images were produced: one of albedo, another of thermal inertia and the other of heat flow.

In the first image, shades of grey are used to represent the relative percentage of solar radiation reflected by each point of land. This value is related to the efficiency with which the soil absorbs calorific energy and is a phenomenon whose effect, as previously stated, must be eliminated.

The second image uses the same method to represent the thermal inertia value of the materials included in the image. This variable measures each material's resistance to changing its thermal state, an effect that must also be corrected in order to be able to determine the heat flow of the subsoil.

The image of heat flow is the most advanced result of treating images digitally. The shades of grey here represent the relative values of heat flow.

A complete interpretation of this image has not been achieved and errors in the field measurements made during the flights made it impossible to calibrate

these values and those of the other images previously mentioned (Fig. 3, 4 and 5).

In spite of such deficiencies, it should be noted that the relative values for each variable in some Key materials are consistent with their actual behavior, as, for example, with the Cerro Prieto Volcano, which presents low albedo, high thermal inertia and low heat flow.

The greatest difficulties in interpretation are presented by water deposits and soils with high temperatures, as may be observed, pond evaporation appears to have low heat flow (perhaps owing to the effect of latent heat), while some manifestations, in contrast, show a high relative value for this parameter.

Even with such deficiencies, the results achieved represent the most advanced approach in the world for the digital treatment of images for geothermal purposes, and some aspects not used in this study could be applied more directly during the current status of geothermal development in our country.

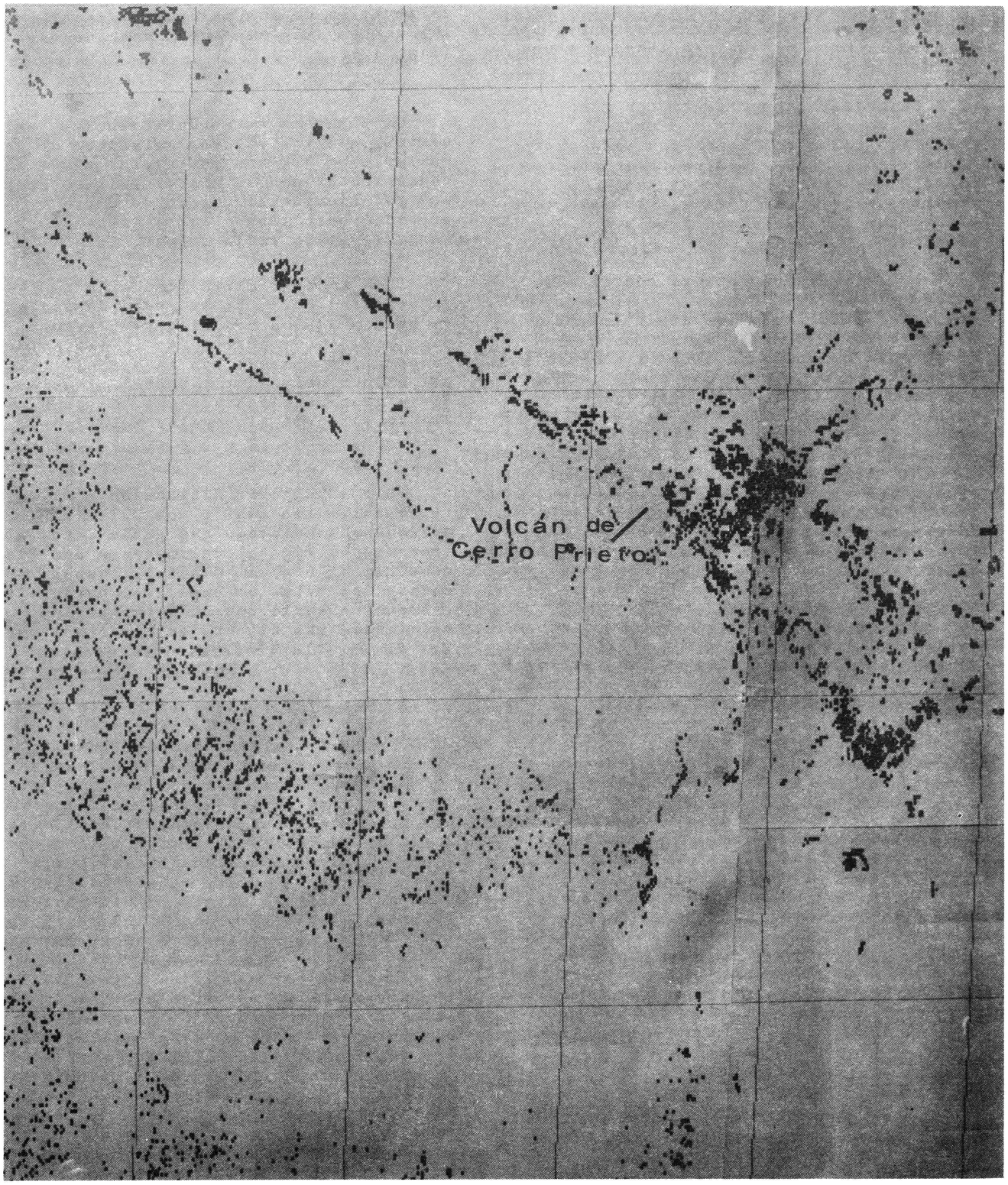
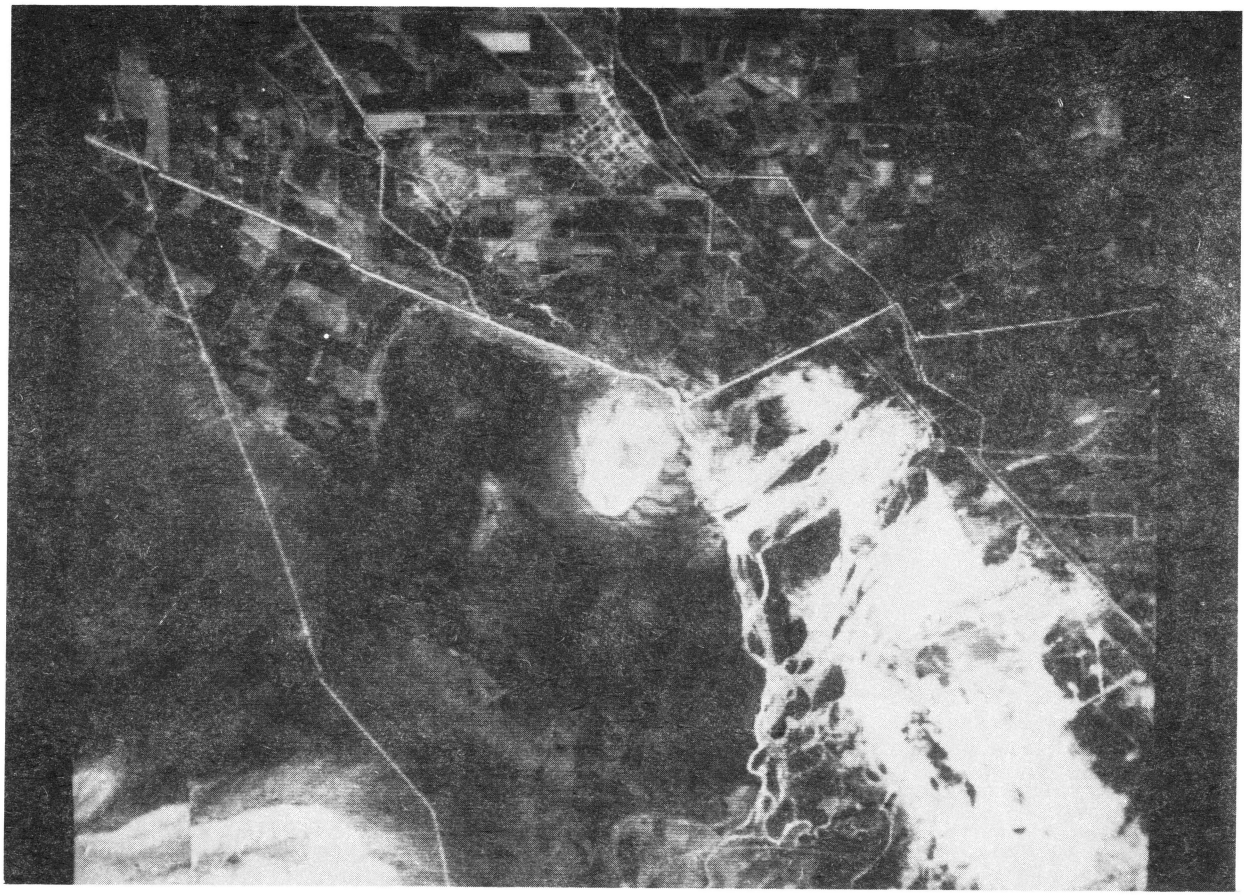


Figura No.1 Clasificación multiespectral
■ zonas supuestamente alteradas.

Multispectral classification
■ allegedly altered areas.



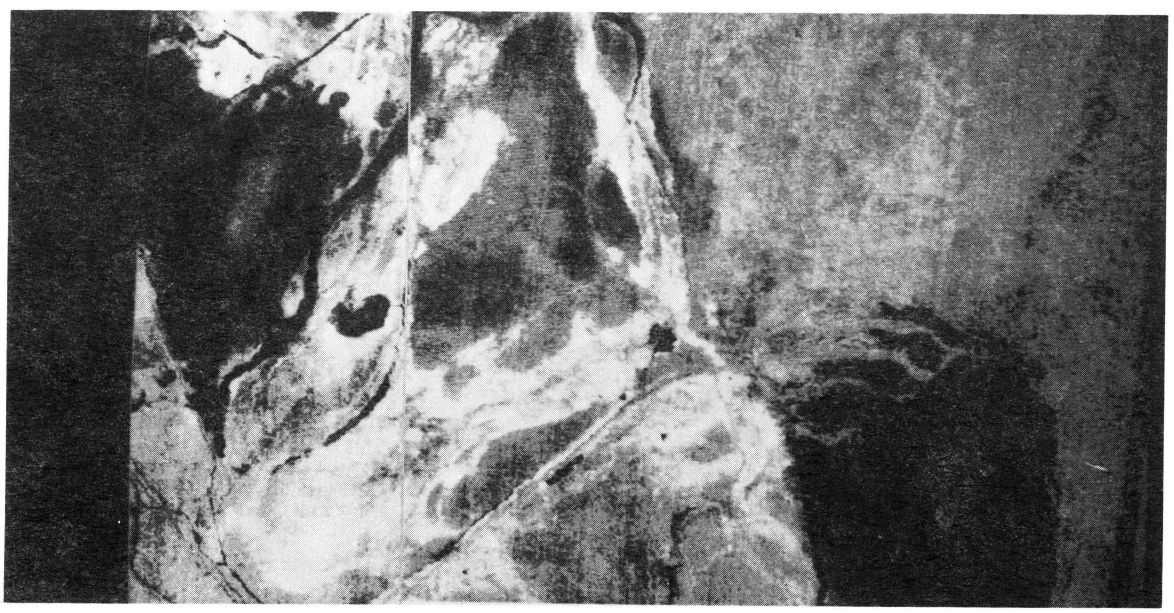
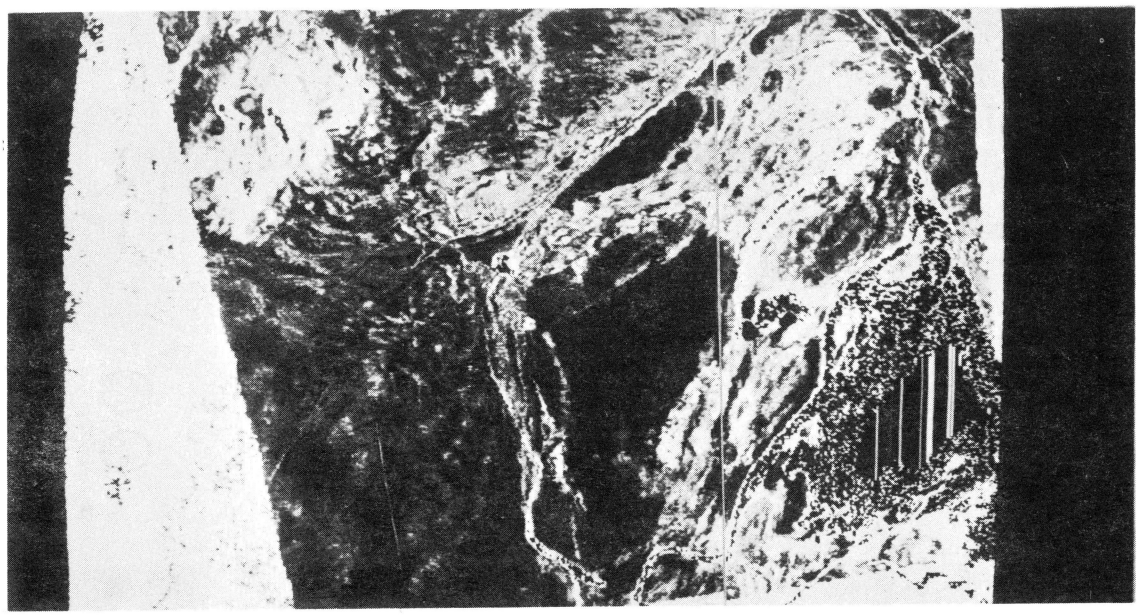


Figura No.2 Mosaico térmico nocturno.
Thermal mosaic at night.

Figura No.3 Imagen de albedo.
Image of albedo.



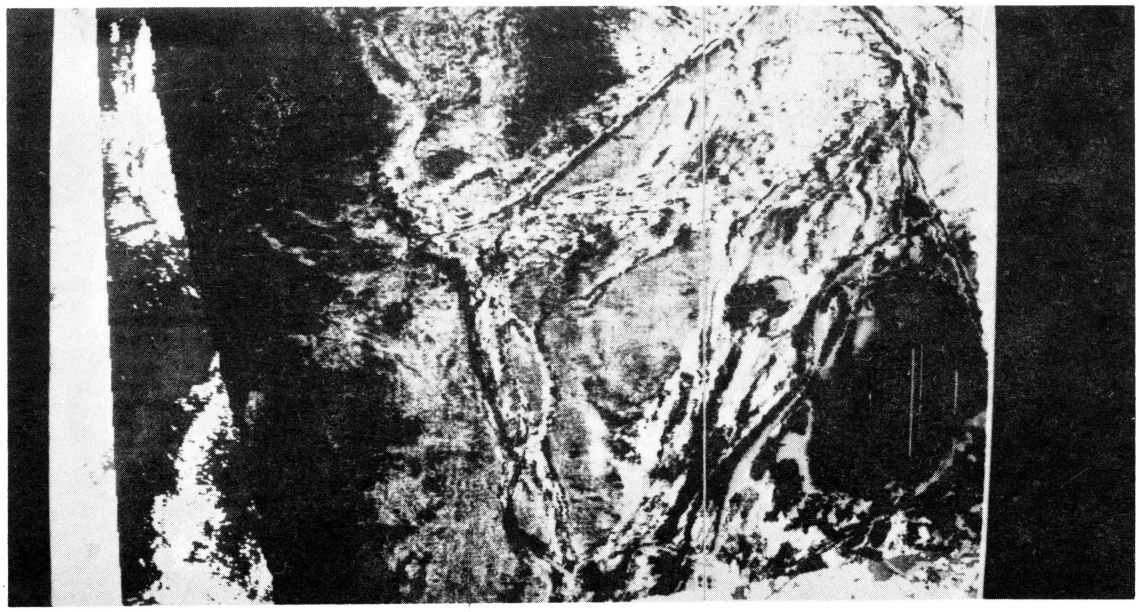


Figura No.4 Imagen de inercia térmica.
Image of thermal inertial.

Figura No.5 Imagen de flujo térmico.
Image of thermal flow.