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REMOTE SENSING APPLIED TO GEOTHERMAL EXPLORATION OF LOS HUMEROS GEOTHERMAL FIELD. MEXICO.

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ABSTRACT

The characterization of areas with a high potential for geothermal exploitation is attempted using Landsat MSS satellite images processing and the analyses of topographic, geologic and tectonic maps. The target area was Los Humeros geothermal field (Mexico), where exploration studies are already in an advanced stage. The location of lineaments was obtained through the application of directional filtering and artificial illumination to images and to a digital terrain model. _ Through the combination of both methods unreported faults related to wells with a good production of geothermal fluid were identified. On the basis of the occurrence of hydrothermal minerals and of fluid inclusion data, a model of the outflows of the reservoir is proposed, and these coincide with the main local recharge areas and the deepest faults and fractures related to the calderas collapse and to regional tectonics.

INTRODUCTION

Satellite images have been used in the reconaissance stage of geological exploration because of the capability to cover large areas with a single image in order to determine the surface characteristics as geologic contacts and topographic anomalies. All the features that imply topographic anomalies, such as the fault scarps, also imply differences in the illumination, depending on their position and orientation as well as on the light source inclination angle (the Sun). An MSS image can differentiate up to 256 tones, which can be processed to enhance differences in order to show surface structures clearly. Image processing techniques are not widely used, though some of them can be very useful for direct interpretation and correlation with other geological, geophysical and geochemical data.

The image processing products are especially practical for geothermal exploration due to the important role played by main lineaments in the determination of the main production areas. On the other hand, it is also necessary for the evaluation of a geothermal field to map all surface manifestations to estimate the natural heat discharge of the hydrothermal system.

GEOLOGICAL SETTING

Los Humeros is the second geothermal field within the Mexican Volcanic Belt to be developed. It is located in the eastern border of the belt (Fig. 1) within a caldera structure with a rather complicated volcanic history (Ferriz and Mahood, 1984)& regional tectonics.' The main structural systems in Los Humeros •show a NW-SE direction for the oldest features, which are crossed perpendicularly by newer ones; the most recent systems in a regional scale have a direction that varies from NNE to NNW (Cendejas, 1987). The start of volcanic activity in Los Humeros is related to the most recent tectonic system.

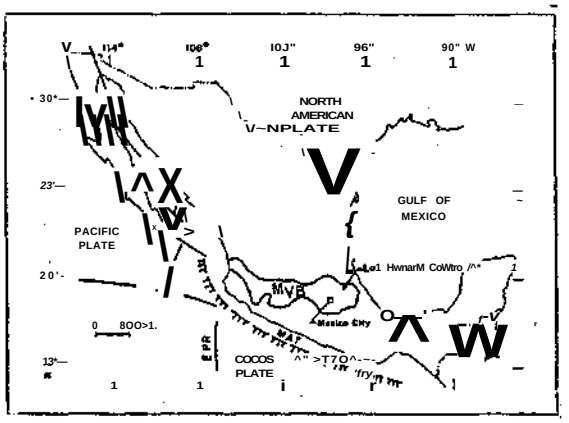

Fig- 1: Location of the Los Humeros geothermal field.

It is considered that the volcanic activity started about 0.5 m.a.b.p. and since then it continued until about 20,000 years ago. This volcanic activity produced the formation of three caldera structures: Los Humeros, Los Potreros and El Xalapasco (Fig. 2). Los Humeros Caldera contains the Los Potreros and El Xalapasco calderas and it has a diameter of more than 12 km. The vertical movements related with the collapse of the calderas, produced deep faults, which play the role of transporting channels for the geothermal fluids, as shown from the discharge output from wells.

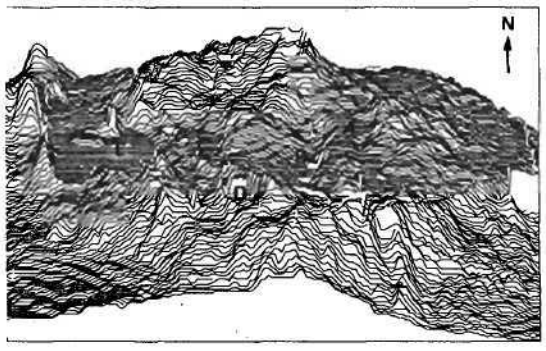

Fig. 2: Stacked profile representation of the digital terrain model (DTM). A)Los Humeros caldera, B)Los Potreros caldera,C)Central collapse and D)Xalapasco caldera.

According to data from drilled exploration wells (Fig. 3) the gross lithological structure of the field comprises a sequence of pyroclastic and lava flows deposited on limestone and siltstone layers that are considered as the local basement (Gonzalez-Negrin, 1982a, c). Observed volcanic rocks show compositions ranging from rhyolites to basalts, but andesitic rocks predominate in the area.

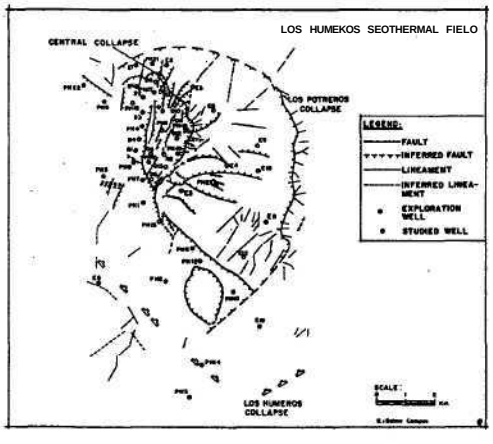

Fig. 3: Exploration wells drilled in Los Humeros and main structures within the caldera. (After an unpublished map by Comisi6n Federal de Electricidad).

The field lacks hydrothermal surface manifestations, except for a few kaolinized areas along the main faults. This absence of surface hydrothermal alteration is also evident in the core and cutting samples from the upper 300 m, where most of the primary minerals remain unaltered. A preliminary petrographic analysis of cores and cuttings from some exploration wells has been made by personnel from the Comisi6n Federal de Electricidad (Gutierrez-Negrin, 1982a, b and c; Viggiano and Fierro, 1986; Viggiano and Robles, 1988a and b). Aside from the studies of hydrothermal minerals, some fluid inclusion analyses were also carried out (Gonzalez-Partida, 1985; Prol-Ledesma and Browne, 1988). Correlation of the occurrence of the hydrothermal minerals with fluid inclusion data indicates a zonation of the temperature regime, with the highest temperatures being attained within the area of the central collapse.

A cooling effect produced by the inflow of cold waters through the Los Humeros fault was inferred after the temperature logs from well PH-4 showed a decrease of the temperature with depth below 1000 m, and the intersection of the fault with this well was assumed to be located at that depth (Gutierrez-Negrin, 1982c). However, only for well PH-1 the decrease of temperature for depth below 1000 in can be inferred on the basis of hydrothermal minerals (Gutierrez-Negrin, 1982b). The alteration patterns and the fluid inclusion data indicate the cooling effect is quite local and does not influence those Etrata that do not intersect the fault (Prol-Ledesma and Browne, 1988).

The deep isotherms and occurrence of high-temperature hydrothermal minerals at depth (Viggiano and Robles, 1988b) suggest that the main outflows of the system are located in the areas of the central collapse (Prol-Ledesma and Browne, 1988) and the Xalapasco. However, an elongation of the contours is observed towards the East. This elongation could be related to deep faults that increase the permeability of the rocks in this area and provide channels through which the fluid from the reservoir can reach shallower strata.

IMAGE PROCESSING TECHNIQUES

A section of an MSS satellite image was processed for the study of the Los Humeros Geothermal Field (Fig. 4). The section used comprises the Los Humeros Caldera area and covers a surface of 25x18 km^2 and has a resolution of 79 m. Digital processing of the image included artificial illumination (Chavez et al., 1988), directional filtering (Moore and Waltz, 1983), band ratios and first derivative. Simultaneously with the image, a digitised model (10 in contours) of the topography was analysed and processed with the same techniques. The synthetic images obtained after the processing were set over maps containing information about geological contacts, drainage, faulting and exploration wells location and data. As results with artificial illumination are encouraging enough, only these results are presented here and comparison with the first derivative and band ratios techniques will be published in a forecoming paper.

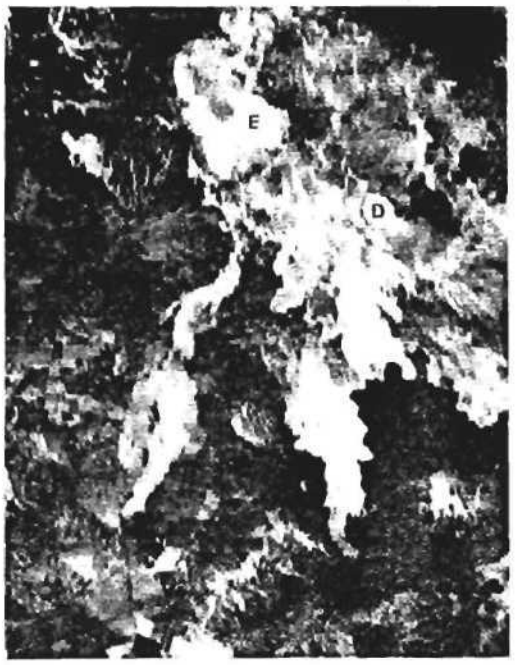

Fig. 4: MSS image of Los Humeros Caldera (band 7-near infrared).

RESULT!?

The artificial illumination technique was applied to band 7 data and to the topography model (Figs. 5' and 6)-

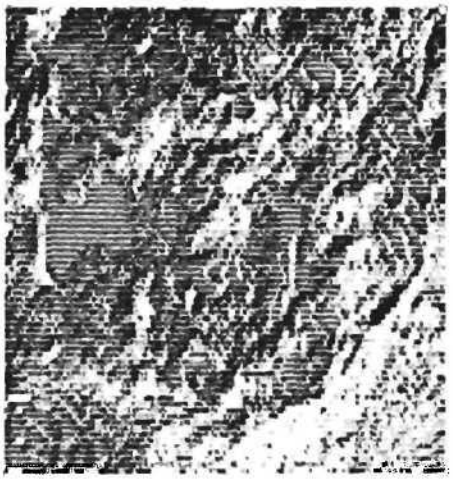

Fig. 5: Synthetic image of Los Humeros Caldera after artificial illumination process with a 30° inclination and 144° declination angles.

Fig. 6: Synthetic image of Los Humeros Caldera after artificial illumination process with a 30° inclination and 0° declination angles.

The synthethic images thus obtained were very useful to determine the main fault systems within the Caldera (Fig. 7). Two of them correspond to reported regional systems (Garduño et al., 1935) with directions NW-SE and NE-SW. The fault system reported by Cendejas (1988) that has directions varying from NNE to NNW, was also recognized with the virtual bands that resulted from the application of the artificial illumination technique. The third system observed within the Caldera seems to be local, it has a N-S direction and can be associated with the structural features of the caldera collapse. Also, it was possible to define lineaments associated with local faults that can be correlated with areas where the production wells are located. The main outflows of the reservoir coincide with zones of accumulation of local faults and with structural basins, as -for instance- the central collapse and the Xalapasco (Fig. 3).

The mapping of the drainage allowed us to recognize inflow areas within the Caldera. Drainage lines follow the hydraulic gradient down to active faults presumably unsealed where they disappear; when the faults are sealed the drainage flows over them and no inflow takes place. The drainage pattern suggests that an inflow might exist in the northern part of Los Humeros Fault, which would provide the cold water recharge that results in a cooling effect at depth. The same mechanism could be observed in the eastern section of Las Papas Fault.

The results obtained from illumination technique applied to digital terrain model allowed to clarify doubtful results from band 7 data, such as the trace of Las Papas fault.

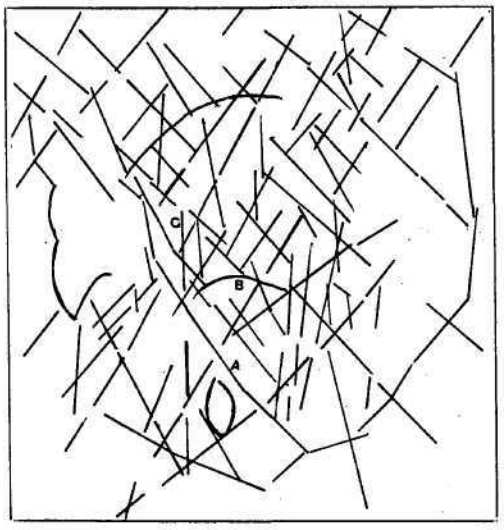

Fig. 7: Main faulting systems observed after processing of band 7 and DTM with the artificial illumination technique. A) Mastaloya fault, B) Las Papas fault and C) Los Humeros fault.

DISCUSSION AND CONCLUSIONS

Artificial illumination of the MSS image resulted in synthetic images (or virtual bands of the image) that show an enhancement of lineaments having an orientation perpendicular to the direction of illumination. The synthetic images obtained were useful to identify reported and unreported lineaments, related frequently to local and regional faulting systems. Other virtual bands were constructed using digital terrain models (DTM) and the drainage pattern.

A correlation was observed among synthetic images, the DTM and the areas where data from exploration wells indicate an outflow from the reservoir, as it is the case of the central collapse and the Xalapasco. Drainage lines proved to be good indicators of the permeability of the upper layers as well as of the faults, and lineaments density and structural basins seem to be features related to good vertical permeability too. The combination of parameters used is based on the fact that in most geothermal fields the permeability is secondary and related to local (or in some cases regional) active faults.

Aside from the already known productive zones, it is possible to propose at least one more area where the faulting and the topography indicate the existence of good conditions for vertical water movement: it is located to the south of Las Papas Fault and the only drilled exploration well yields results that may indicate an important lateral outflow.

The correlation obtained supports the usefulness of image processing in order to identify -on the early exploration stages- the local recharge or discharge areas within a geothermal field, provided the permeability in the system depends mainly on the faulting, active and recent, to assure that the faults are still capable to provide the fluid from direct channels to upper strata.

The results are encouraging, nevertheless, they may be improved by adding information from virtual bands containing information from different band ratios and geophysical data.

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