Geof. Int., Vol. 25-4, 1986, pp. 575–586

HYDROTHERMAL ACTIVITY DETECTED BY SELF-POTENTIAL MEASUREMENTS AT THE N-S VOLCANIC AXIS BETWEEN THE VOLCANOES "NEVADO DE COLIMA" AND "VOLCAN DE FUEGO DE COLIMA" (MEXICO)

M. AUBERT*
E. LIMA**[1]

ABSTRACT

Measurements of electrical self-potential (SP), taken on the north-facing slope of the Fuego de Colima volcano, show a large-scale anomaly non-correlated with the cone which is active at present. This may arise due to hydrothermal activity which originates in a highly fissured zone above a heat source, located deep below the surface of the earth. It is presumed that this anomaly is linked with the N-S volcanic axis, running from Nevado, the oldest volcano in the Colima volcanic chain, to Fuego, the site of the present activity.

RESUMEN

Los resultados de las medidas de potencial espontáneo (SP) obtenidos en el lado norte del volcán de Fuego de Colima muestran una importante anomalía. Esta anomalía no puede ser correlacionada con el domo actual que se observa en la cima del volcán y es debida a una actividad hidrotermal que corresponde a una área de fracturamiento asociada a una fuente de calor. Se supone que esta anomalía está relacionada con el alineamiento volcánico Norte-Sur, formado por el antiguo volcán Nevado de Colima actualmente inactivo y el cono activo del Volcán de Fuego de Colima.

* *IOPG et UAIO, 12 Avenue des Landais, 63000 Clermont-Fd. FRANCE.*

** *Instituto de Geofísica, UNAM, D. Coyoacán 04510. D. F., MEXICO.*

[1] *Present address: West Japan Engineering Consultants, Inc. Suniselco Bldg. 10th floor. 1-1, 1-Chome, Watanabe-Dori, Chou-Ku, Fukuoka, JAPAN.*

GEOLOGICAL SETTING

The Colima volcanic chain is constituted by two centres of eruption (Fig. 1): "Nevado de Colima", a strato-volcano without any previous recorded history of activity, and "Fuego de Colima", located within the caldera of an ancient volcano called "Paleo-Fuego" on the southern slope of Nevado (Luhr and Carmichael, 1980, 1982; Luhr, 1981; Robin *et al.*, 1984; Luhr and Prestegaard, 1985). The two summits, at heights of 4 260 m (Nevado) and 4 000 m (Fuego) respectively, are only 5 km apart and dominate a plateau with a N-S surface area of 22 km by 26 km. Historically,

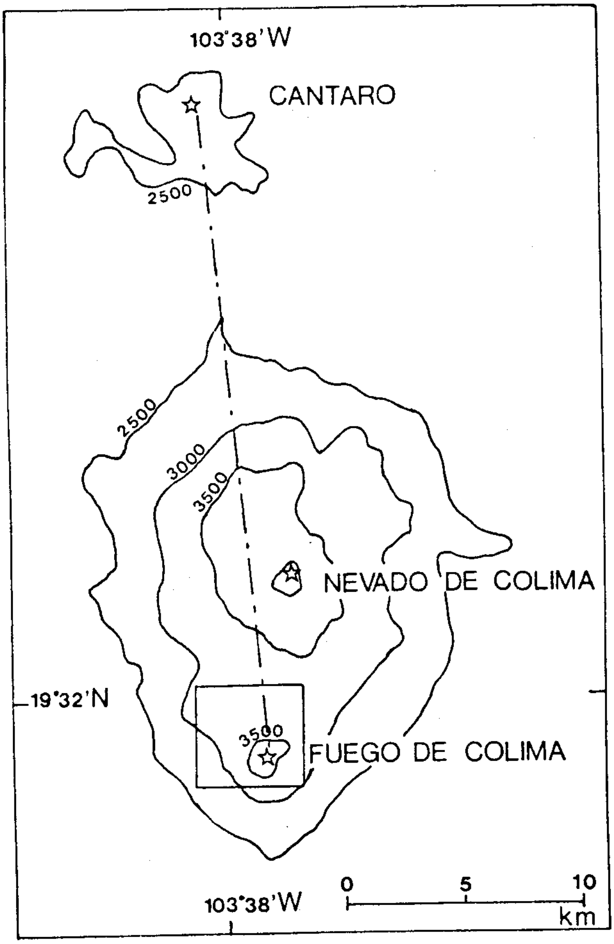

Fig. 1. Location map of the volcanic areas Cántaro, Nevado and Fuego de Colima. The rectangle represents the limits of the figures 2, 4 and 5.

"Fuego de Colima" has been the most active of all the Mexican volcanoes. The history of its activity has made it worthy of much scientific observations based upon which Luhr (1981) compiled the descriptions of the eruptions over the last four centuries. From this information it can be discerned that for long periods the cone of this volcano has been built up by lava flows, interrupted during the short periods when the summit of the volcano was destroyed by violent explosions. The last of such explosions occurred in 1913. Over the last decade, there have been two lava flows, one in 1975-76, and the other in 1982. Bearing this previous activity in mind, it is possible that we may witness renewed explosive activity in the near future, which will affect populated areas or areas being developed for human activity (Robin *et al.*, 1984).

Paleo-Fuego became active approximately 0.2 my ago, and the present cone of Fuego de Colima was built up within a horse-shaped "avalanche caldera", formed approximately 0.01 my ago in the same way as St Helens, Nevado de Colima continued to be active while Paleo-Fuego was growing in size.

At last, the chronological sequence of events indicates a progressive movement of the main magmatic activity towards the south. Allan and Luhr (1982) and Allan (1984) report dates on Cántaro lavas, which is situated approximately 10 km north of Nevado, of about 1 my. A large dome north of Cántaro (cerro El Ixcapil) was dated at about 1.7 my, so activity migrating southward has occurred over a long period of time (Allan and Luhr, 1982).

HYDROTHERMAL CONVECTION

We formulate the hypothesis that the Nevado-Fuego axis could be associated with a deep fissured zone, through which a process of water convection is flowing upwards. This hydrothermal convection could be confirmed by the measurements of self electrical potential.

Zablocki (1976) is apparently the first to realize the potential use of these measurements for detecting hydrothermal activity. He maped zones of deep magmatic activity in the Hawaiian archipelago, particularly in the rift-zones.

There is a number of processes which are responsible for the SP anomalies. To mention some of them the electrothermal effect, and the most important one, the electrokinetic effect (Corwin *et al.*, 1979). The latter results from the circulation of hot fluids due to convection currents, which in turn are the combination of the following two factors: a deep heat source and a highly fractured media responsible for a high vertical permeability.

These may also be electro-chemical effects in the form of various oxydo-reduction phenomena.

Aubert *et al.* (to be published) demonstrated that a convective cell reaching up to the surface in the form of a fumerole can be detected by SP measurements. The SP anomaly is related to a thermal anomaly and to an anomalous underground water content.

If the top level of the convective cell does not reach the surface because of thermal and hydrodynamic impediments, the location of the ascending path of fluid is indicated by the location of the peak of the SP anomaly. The further the top level of this convective cell is from the surface, the weaker the SP anomaly. However, in all cases SP anomalies can indicate the presence of hydrothermal convection and consequently the presence of both a hot source and a fractured zone.

PRESENTATION OF SP DATA TAKEN AT COLIMA

Figure 2 shows the location of SP profiles measured in April-May 1983, while Figures 3 to 5 indicate the SP profiles and the topographic profiles necessary in order to eventually calculate the topographic effect.

It is a standard procedure to present the data in the form of a contour map comprising a layout curves of equal value of the SP potential, defined to an arbitrary reference, these curves being iso-SP curves.

The SP measurements performed during April-May 1983 are sparse distributed, that is, these are roughly 15 km of profiles over a surface area of approximately 10 km^2. In consequence, the layout is extremely inaccurate over a large part of the sector under study. Furthermore, it was difficult to calculate eventual topographic effect from the measured profiles. Only section AB (Fig. 3) seems to indicate such an effect, which was calculated as an SP decrease of 300 mV to an increase in altitude of 100 m. In addition, it could be further calculated, though less accurately, over section HI (Fig. 5) a decrease of 250 mV for every increase in altitude of 100 m.

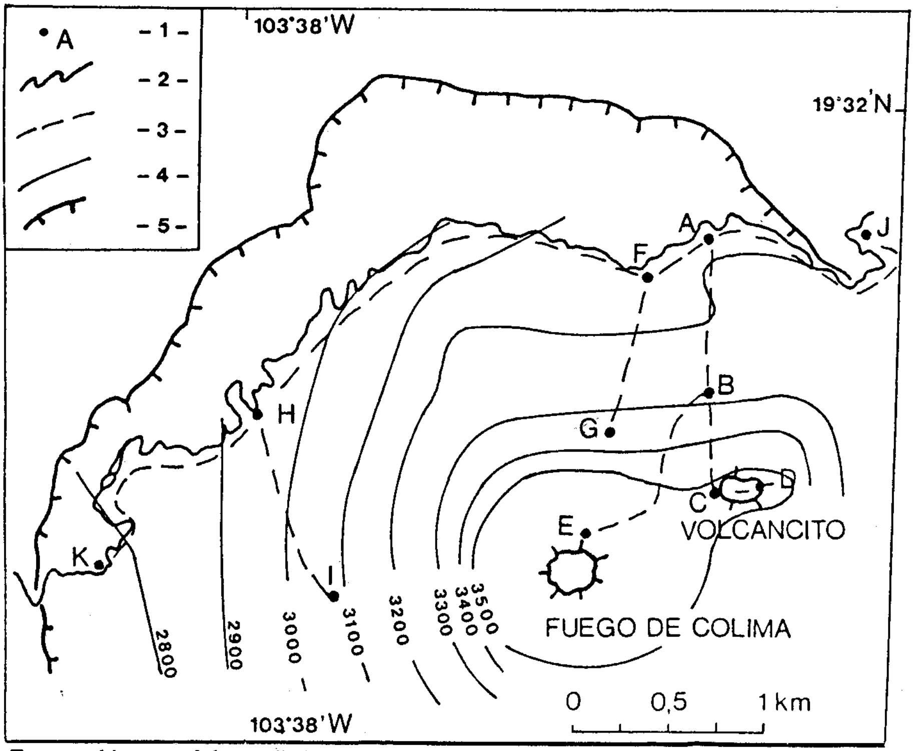

Fig. 2. Topographic map of the studied area. The symbols indicate: (1) reference station; (2) surrounding track; (3) SP profiles; (4) level curves in m; (5) caldera wall.

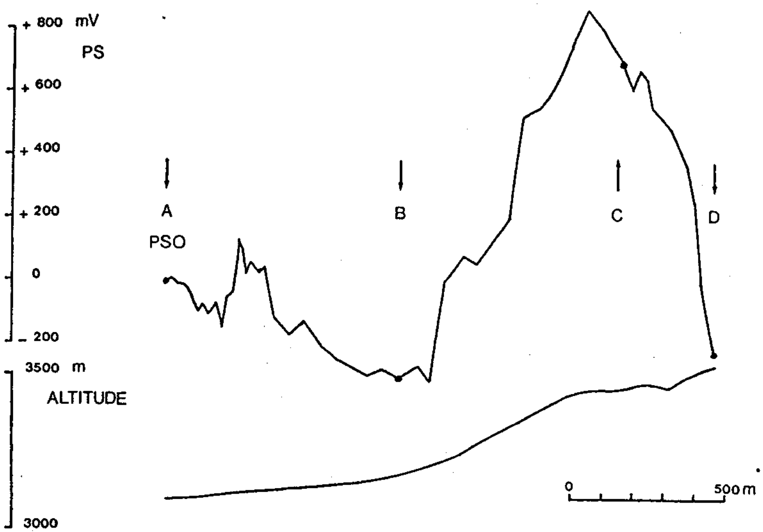

Fig. 3. SP profile ABCD and associated topography.

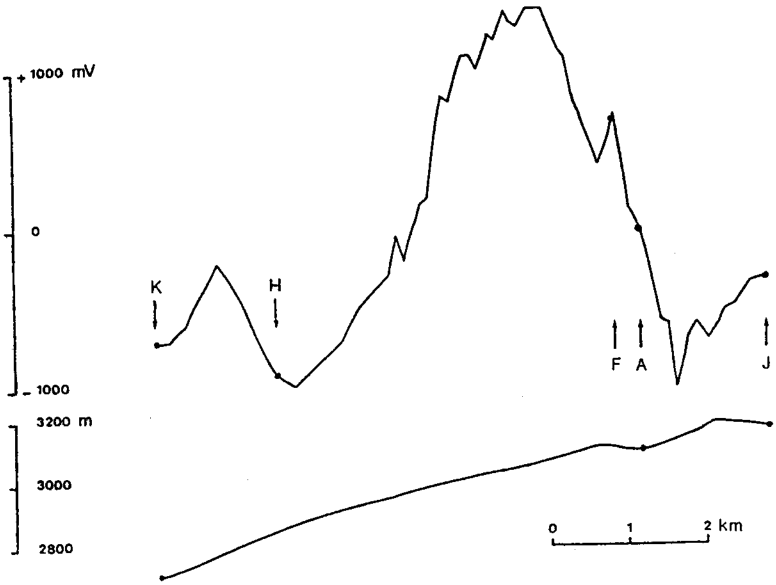

Fig. 4. SP profile JAFHK and associated topography.

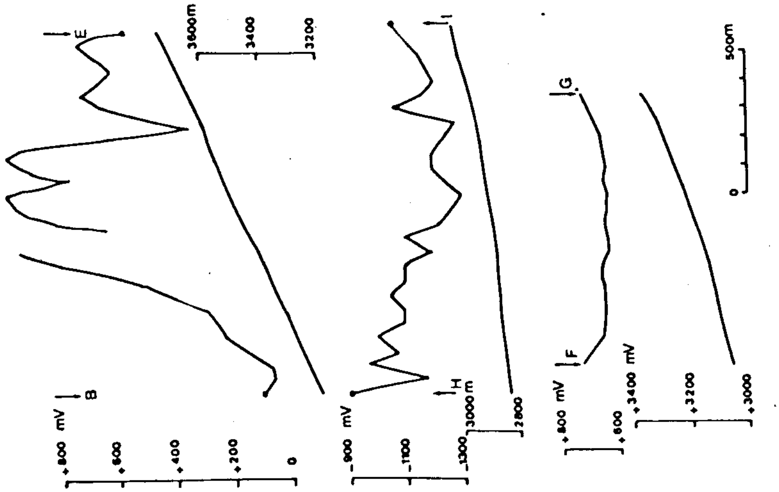

Fig. 5. SP profile BE, HI and FG and associated topography.

Given the restrictive nature of these observations, we present our SP data in two maps: the first one (Fig. 6) showing the iso-SP of the rough data, and the second (Fig. 7) representing the iso-SP of the corrected data subject to the topographic effect. This correction is presumed to be homogeneous and equal to 3 mV/m.

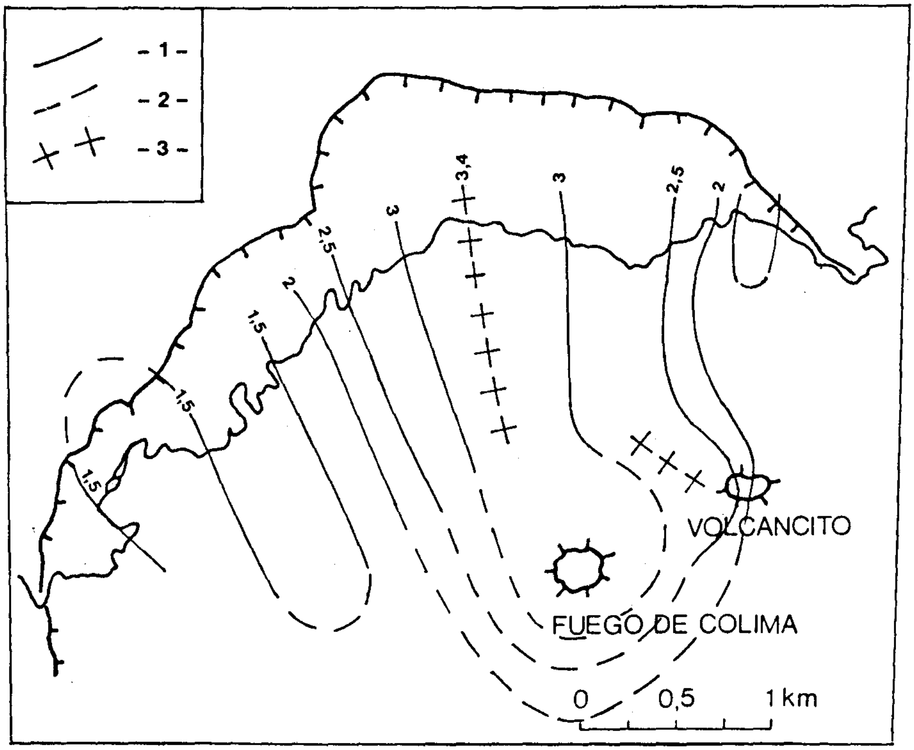

Fig. 6. SP map, values not corrected from altitude. The symbols indicate (1) iso-SP curves in volts; (2) hypothetical plotting; (3) positive anomaly axis.

QUALITATIVE ANALYSIS OF THE DATA

The examination of the two iso-SP maps (Figs. 6 and 7) permits us to interprete three major anomalies:

Anomaly associated with the terminal cone

This anomaly appears only on the contour map of corrected data (Fig. 7), and could be artificially created by the applied topographic correction which increases all the values of the high-altitude profiles. In the absence of any complementary reasoning,

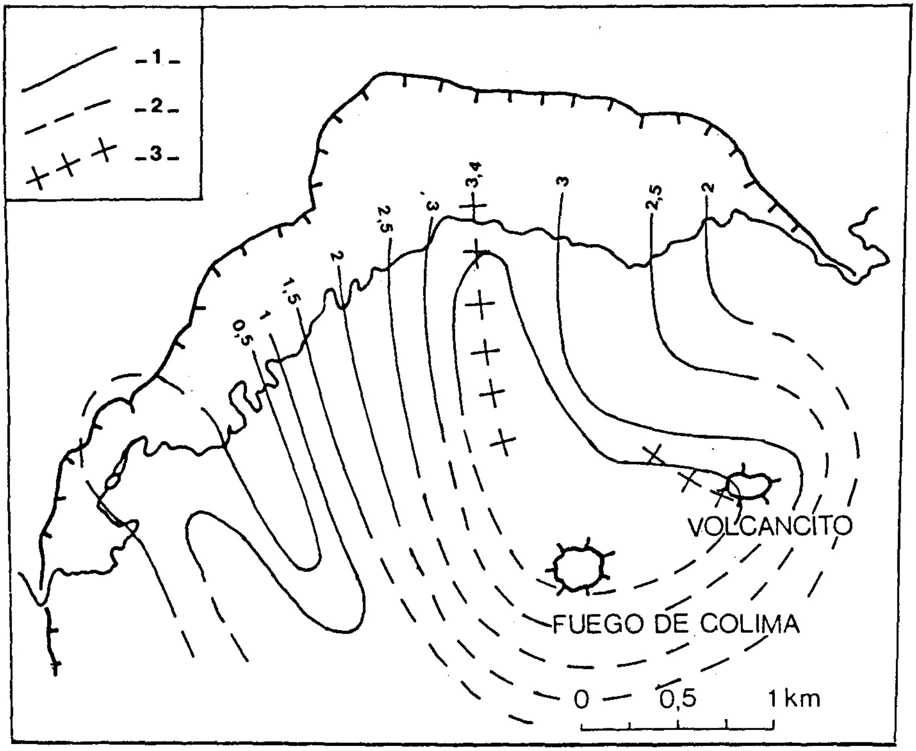

Fig. 7. SP map, values corrected from altitude (3V/km). The symbols are the same as in Fig. 6.

the presence of fumeroles at the top of the volcano leads us to believe that this anomaly is valid. We are acquainted with this anomaly on more widely studied mountains, such as Etna for example.

Anomaly associated with the west flank of Volcancito cone

This anomaly is clearly defined as shown in section BE (Fig. 5). The contour of map (Fig. 7) depicts it as seen from tangential direction respect to the cone. The location of this anomaly emphasizes the visible base of the cone from the surroundings. The SP anomaly can be originated at the area of contact between the cone and the ground which envelopes it, which in turn might be the surface through which hydrothermal fluids ascend, favoured by relatively high vertical permeability.

Principal anomaly

This anomaly trends a NNW-SSE direction and extends almost over the entire sector under study. It is clearly defined as shown in profile JK (Fig. 4) which transverse it at right angles. The topographic relief seems to affect too little this SP profile; the form of the anomaly is weakly affected by an eventual correction of a topographic effect. It reaches 2 volts for an extension of several kilometers in an E-W direction, and it takes a fairly symmetrical appearance. There are very important horizontal gradients to be noticed (up to 8mV/m over a distance of 100 m). Despite the low density of the profiles, an examination of the iso-SP contours would suggest that the anomaly is not strictly correlated to the cone, on the contrary, it stretches along the mean direction of profiles HI and FG, that is to say, roughly along a N-S direction.

Finally, on each side of the principal positive anomaly, profile JK indicates a negative anomaly whose contours cannot be accurately gauged. They reach an amplitude of 0.5 volt over an extension of roughly one km. It is hard to ascertain from the data whether or not these negative anomalies are correlated to the positive one.

MODELING

Various studies have been carried out to present models of structures responsible for SP anomalies measured on geothermal or volcanic sites. Corwin *et al.* (1981) and Fitterman *et al.* (1982) are amongst the most recent. The present value of these studies is limited to the following items:

- the possible diversity of SP generators;
- the absence of data covering the characteristics of the rock and of the fluid which affect the electro-filtration process;
- the lack of knowledge concerning electro-filtration in an unsaturated medium and in a biphasic system (water and steam).

Furthermore, the aforementioned studies refer to anomalies whose amplitude is one or even two decimal points smaller than the one measured on the Colima. This disproportion demands careful consideration before any comparison with the previous cases can be made.

According to our research on Etna (Aubert *et al.*, to be published), we present the simple model (Fig. 6) as a possible interpretation of the source of SP anomaly, where the convective cell does not reach the surface. Into the volume of the cell, we suppose that an upward watersteam flow created an electrical potential by electrokinetic effect.

This effect finally generates at the top of the cell a homogeneous distribution of positive charges and at the bottom the same distribution but with negative charges. The calculation of the potential V(x) at a point x can be made for a three-dimensional structure with parallel surfaces at top and bottom (Aubert et Ritoux, yet to be published). In the case of Figure 8, the structure is a simple rectangular parallelepiped indefinitely elongated, perpendicular to the profile. We calculate the effect

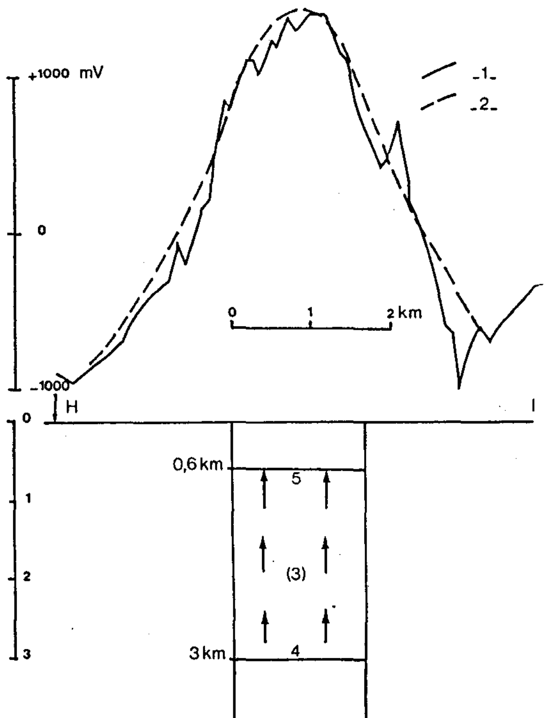

Fig. 8. Hypothetical model of a hydrothermal convective structure to explain the SP anomaly measured on the profile JH. The symbols indicate: (1) measured profile; (2) theoretical profile; (3) part of a convective zone where an upward waterstream flow creates an electrical potential by electrokinetic effect; (4) zone where the meteoric water is vaporized; (5) zone where the watersteam flow is eliminated by progressive condensation.

of different widths, depths of the top and of the bottom, to find out by successive approximations a good fit between the experimental and theoretical curves (Aubert and Ritoux, to be published). However, in fact, the real structure is not as homogeneous as that in this model and the actual depth could be variable and probably smaller than this calculated depth.

By virtue of its breadth and amplitude, the principal anomaly can be compared to those mesured on the rift-zones of volcanic origin in Hawaii (Jackson *et al.*, 1981). We thus formulate the hypothesis that the structure responsible for this anomaly is an area stretching along a N-S axis, characterized by a deep fissured zone through which a process of water convection is flowing upwards, and that might be produced by a deep thermal source.

This source could be a magmatic intrusion zone, linking the volcán de Fuego and volcán Nevado de Colima, perhaps stretching further northwards to the Cántaro area. Only the southern part of this axis is active at present.

Seeing as we are dealing here with andesitic volcanism involving a displacement of magmatic activity from North to South, a comparison with the term rift-zone in the Hawaiian sense must be made with the greatest care.

ACKNOWLEDGEMENTS

We would like to thank Dr. Galindo and Dr. Guerrero of the Institutes of Geophysics and Geology, National University of Mexico for their logistical support during our stay in Mexico. The expedition has been supported by the Centre National de la Recherche Scientifique (France).

BIBLIOGRAPHY

ALLAN, J. F. and J. F. LUHR, 1982. K-Ar ages of Late Cenozoic alkaline and calc-alkaline lavas of the Colima Graben, SW Mexico. EOS Transaction, AGU, Fall Meeting, V. 63, No. 45, p. 1154.

ALLAN, J. F., 1984. Geological studies in the Colima Graben, SW Mexico, Ph. D. Berkeley.

AUBERT, M. *et al.* Contribution à la surveillance de l'activité de l'Etna à partir de l'étude des zones fumerolliennes (to be published in Bull. volcanologique).

AUBERT, M. and G. RITOUX. Calcul du potentiel électrique créé par un corps polarisé. Application à la modélisation de structures du sous-sol créant des potentiels de polarisation spontanée, to be published in Note IOPG, Clermont-Fd. France.

CORWIN, R. F. and D. B. HOOVER, 1979. The self-potential method in geothermal exploration. *Geophysics, 44,* 2, 226-245.

FITTERMAN, D. V. and R. F. CORWIN, 1982. Inversion of self-potential data from the Cerro Prieto geothermal field, Mexico. *Geophysics, 47,* 6, 938-945.

JACKSON, D. B. and M. SAKO, 1981. Self-potential. Surveys related to probable geothermal anomalies. Hualalai volcano, Hawaii. U. S. Geol. Surv., Open-file report.

LUHR, J. F., 1981. Colima. History and cyclicity of eruptions. *Volcano news, 7,* 1-3.

LUHR, J. F. and I. S. E. CARMICHAEL, 1980. The Colima volcanic complex, Mexico: 1. Post-Caldera andesites from Volcán Colima. *Contributions to Mineralogy and Petrology, 71,* 343-372.

LUHR, J. F. and I. S. E. CARMICHAEL, 1982. The Colima volcanic complex, Mexico: 3, Ash- and scoria-fall deposits from the upper slopes of volcán Colima. *Contributions to Mineralogy and Petrology, 80,* 262-275.

LUHR, J. F. and K. PRESTEGAARD, 1985. Caldera formation at volcán Colima, Mexico: a large Mount St Helens-type avalanche event 4 300 years ago. *EOS, AGU. Transactions, 66,* 18, 411.

ROBIN, C. *et al.,* 1984. Les volcans de Colima. *Bull. PIRPSEV,* 87, CNRS France.

ZABLOCKI, C. J., 1976. Mapping thermal anomalies on an active volcano by the self-potential method, Kilauea, Hawaii. Proceedings of the Second U. N. Symposium on the development and use of geothermal resources. San Francisco, Calif., 2. p. 1209-1299.

(Received: April 18, 1985)
(Accepted: November 25, 1985)