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AEROMAGNETIC SURVEY OF LOS HUMEROS CALDERA, MEXICO

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RESUMEN

Un levantamiento aeromagnético regional sobre la caldera de Los Humeros, Puebla, México, rindió una anomalía de tipo bipolar sobre la región central de la caldera. Esta anomalía se interpretó como causada por un prisma intrusivo fuertemente magnetizado a una profundidad de 2 km, con dimensiones horizontales de 5 km y 2 km, que subyace la parte central de la caldera.

Se presentan otras anomalías de menor intensidad sobre y fuera del contorno de la caldera. El fuerte contraste entre la intensidad efectiva del dique intrusivo volcánico y la de los flujos superficiales es del orden de 16×10^{-3} unidades cgs, lo que concuerda con otras determinaciones de magnetización hechas sobre volcanes de Hawai, Japón y otros, usando análisis de estudios aeromagnéticos. Es improbable que exista un cuerpo de dimensiones mayores y material fundido abajo de la caldera hasta una profundidad de 7 km; sin embargo, existe la posibilidad de que el cuerpo pueda estar a una temperatura menor pero cercana a la de Curie, lo cual lo puede hacer de interés geotérmico.

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ABSTRACT

A regional aeromagnetic survey over Los Humeros Caldera, Puebla, Mexico, reveals a magnetic anomaly of bipolar character over the central part of the caldera. This large anomaly is interpreted in terms of a prism whose depth to the top is 2 km with horizontal dimensions of 5 km x 2 km. The prism-like, highly magnetized, intrusive plug underlies the central part of the collapsed structure. Other smaller anomalies occur over and around the rim of the caldera. The high contrast between the effective intensity of magnetization of this intrusive, volcanic prism and the superficial volcanic flow is of the order of 16×10^{-3} cgs units, which is in agreement with effective magnetization determinations over Hawaiian, Japenese and other volcanoes, as obtained from the analysis of aeromagnetic data. Interpretation of the aeromagnetic data of this caldera implies that magma is unlikely to exist shallower than 7 km in depth. However, a temperature below, but close to, the Curie point is possible at depth, which may render such an intrusive of geothermal interest.

INTRODUCTION

An aeromagnetic survey of Los Humeros caldera, Puebla, Mexico, was conducted with the objective of determining structural relations inside the caldera, as a preliminary part of a project of evaluation of its geothermal potential (Alvarez, this issue). Aeromagnetic data acquisition was done using a total field, proton precession magnetometer covering an area of 530 km^2, with an average line spacing of 4 km and a flying altitude of 250 m above ground.

The efectiveness of aeromagnetic methods for determining the nature of volcanic structures is well established (Malahoff, 1969). The total magnetic intensity observed at a given point consists of the added contributions of the Earth's magnetic field, the natural remanent magnetization, and of the induced magnetization of nearby structures. Of these, only the last two are of geologic relevance, with remanent magnetization predominating over induced magnetization in volcanic rocks. One must distinguish, in addition, between different types of geologic bodies contributing to the measured magnetic field. In some instances the strongest contribution comes from the volcanic cones themselves (Steinberg and Rivosh, 1965), while in others the main portion of the magnetic response originates in structures buried beneath the volcanic cones (Malahoff and Woollard, 1966, 1968). Hagiwara (1965) successfully separated the magnetic contribution of superficial lavas (i.e., lavas forming the cones and caldera rims) and that arising from deeper sources, in the Hakone and Towada calderas in Japan, by means of upward continuation techniques. Such responses often give rise to normally polarized, bipolar anomalies, as in the case of Hakone caldera (Hagiwara, 1965), and Kronotsky and Krasheninnikov volcanoes (Steinberg and Rivosh, 1965).

In spite of the large number of volcanoes in the Mexican Neovolcanic Axis and elsewhere in Mexico, there are very few analyses of their geophysical characteristics available in the literature. Regarding the magnetic response of volcanic structures in Mexico one can cite the work of Wood (1974), and the work of Alvarez *et al.* (1976). The former was performed on the northwestern part of Mexico, in the Pinacate volcanic field, and the latter on an area close to Los Humeros Caldera; both studies analyse the magnetic response of volcanic explosion craters.

THE MAGNETIC ANOMALY

Figure 1 shows the residual aeromagnetic map of Los Humeros caldera prepared by substracting the regional magnetic field from the observed data. The map shows a large bipolar magnetic anomaly located within the caldera, as well as other minor anomalies located around its inferred rim. The main anomaly is composed of a maximum (+ 820 γ) and a minimum (–580 γ) oriented within 6° of the magnetic North-South direction. Topographic corrections for the volcanic structures (Hagiwara, 1965; Steinberg and Rivosh, 1965) were not made since the size of the low altitude anomaly and the upward continuation of the residual field to a height of 2 km (Figure 2), suggest that the main central anomaly results from a deeply seated body.

In addition, the topography of the caldera corresponding to the area of the magnetic anomaly does not experience abrupt changes (2700 m average altitude), with the exception of El Hilillo volcano, which is located approximately 2 km North of the caldera center and reaches 2900 m, as well as Cerro San Antonio, a rhyolite dome on the western portion of the caldera rim. The areal extent of El Hilillo is much less than the areal extent of the magnetic anomaly and thus cannot be considered the source of it.

MODELLING OF THE MAGNETIC ANOMALY

The geometry of the magnetic anomaly clearly indicates that it is caused by a three-dimensional body. Initially a finite cylinder model (Singh and Sabina, 1978) was used to roughly estimate the various parameters. These parameters were then refined by using a finite rectangular prism model with vertical walls (Bhattacharyya, 1964). Fit to the anomaly along section A-A' (Figures 1 and 3) was done by trial and error varying the following parameters: a) prism length in the north-south direction;

b) depths to upper (z_1) and lower (z_2) boundaries of the prism, and c) dip of magnetization. The declination of the polarization vector was taken to be the same as that of the goemagnetic field (8.5°) since the line joining maximum and minimum in the map is a measure of the concordance of the two declinations (Zietz and Andreasen, 1967). The best fit was obtained with a rectangular prism of 5.0 km x 2.0 km, depth of the top of 2.0 km, a thickness of 5.0 km (Figure 3), dip of polarization vector of 31°, and an effective intensity of magnetization of 16.8×10^{-3} cgs units. It should be pointed out that the computed field is not very sensitive to changes in East-West dimension of the prism. Figure 4(a) and 4(b) show computed total fields over a 5.0 km x 1.0 km and a 5.0 km x 4.0 km prism respectively, with all the other parameters being the same as in Figure 3. Based on the nature of the observed field we have chosen 5.0 km x 2.0 km prism as our model. Consequently, the dimension of 2.0 km in the East-West direction may be considered tentative.

DISCUSSION

The central position of the intrusive body as well as its size in relation to the dimensions of the caldera and to other volcanic structures inside the caldera lead us to assume that the proposed prism possibly constituted the magma conduit during the volcanic episodes occurring prior to the caldera formation. Additional supporting evidence of such a hypothesis are the results of the gravimetric survey of Mena and González-Morán (this issue) showing a gravity low over the caldera with a central, positive anomaly that could correspond to the intrusive body. The gravimetric low over the caldera is apparently due to filling of the caldera interior with low density materials such as pyroclastics and post-caldera tuffs and flows, covering the proposed prism. Similar low gravity patterns have been observed at Yellowstone (Eaton *et al.*, 1975) and Long Valley (Kane *et al.*, 1976) calderas, where there is a low density caldera fill.

The small differences between the observed and the computed magnetic anomalies (Figure 3, z_1 = 2.0 km) can be easily accounted for in terms of geometric and magnetization irregularities of the actual body with respect to the proposed prismatic model. The computed response for the same prism at a shallower depth (z_1 = 0.5 km) corresponding to the depth to the top of the prism proposed by Mena and González-Morán (this issue) is found to be much less compatible with the observed magnetic response.

The difference between the inclination of the effective magnetization (31°) and that of the geomagnetic field (46°) may be either due to the predominance of the intensity of induced magnetization over the remanent one, or due to near parallelness of the two types of magnetizations. The latter possibility is favored owing to the well established predominance of remanent over induced magnetization in volcanic rocks (Doell and Cox, 1965). Although no magnetic intensity sampling of the surface rocks of Los Humeros has so far been done, aeromagnetic studies of Hawaiian, Japanese, Italian, and North American calderas and volcanoes (Malahoff and Woollard, 1966; Hagiwara, 1965; Yokoyama and Aota, 1965; Yokoyama, 1974; Kane *et al.*, 1976) show that the intrusive plugs have a greater intensity of magnetization (of the order of 10^{-2} cgs units) than superficial flows and pyroclastics. This fact may be accounted for in terms of the greater physical stability and the slower cooling of the intrusive rocks as compared to the extrusive rocks. Table 1 shows magnetization values for some volcanoes.

Electrical soundings directly applied over the position of the intrusive prism may help to elucidate the depth ambiguity that gravity and magnetics have established, as well as the lateral dimensions of such a prism. The only sounding available so far is a telluric line (Line 1, Alvarez, this issue) that apparently cuts a small portion of the rectangular magnetic prism between station 3E and 6E, showing a small resistivity increase at both frequencies (.05 Hz and 8 Hz).

CONCLUSIONS

A magnetic model has been constructed for the aeromagnetic data of Los Humeros caldera. Such a model supports the existence of an intrusive body that probably was emplaced during the early stages of the caldera fomation. Gravity data yields a model that also supports the existence of such an intrusive; however, it differs in the value of the depth to the top with respect to the magnetic model. Electric or electromagnetic soundings are proposed as effective means of resolving the depth ambiguity.

Regarding the role of such a body in the geothermal potential of the caldera one may establish the following considerations: (1) A magma-like body within seven kilometers from the surface may be ruled out for the central portion of the caldera, owing to the magnetization of the intrusive body, which implies temperatures below its Curie point, (2) the intrusive may have, however, temperatures at depth high enough as to be of significance for geothermal exploration, (3) the possibility of partially molten material within such an intrusive cannot be ruled out with these measurementes, (4) the present analysis has centered on the main magnetic anomaly of the caldera; there are several, minor magnetic anomalies which will have to be studied in detail in order to learn more about the conditions of the caldera perimeter. Of special interest is the western portion of this volcanic structure, in which the telluric and self-potential measurements show anomalous responses.

Volcano		Magnetization 10^{-3} cgs units	Volcano		Magnetization 10^{-3} cgs units
Krasheninnikov	*	7.7	Sakurazima	**	7.0
Ilinsky	*	7.2	Akagi	**	1.0
Mutnovsky	*	7.2	Kamijama	**	20.0
Opala	*	6.2	Kusatu-Sirane	**	8.0
Taunschitz	*	5.6	Mauna-Loa	**	6.9
Zheltovsky	*	5.2	Mauna-Kea	**	13.8
Kronotsky	*	4.4	Hualalai	**	6.9
Gamchen	*	3.8	Kohala	**	19.0
Karimsky	*	3.5	East Haleakala	**	16.0
Avachinsky	*	3.2	West Haleakala	**	18.0
Kambalny	*	2.7	Kahoolawe	**	7.0
Khodutka	*	2.3	Lanai	**	2.0
Mihara	**	30.0 50.0	East Molokai	**	12.4
			West Molokai	**	13.9
Huzi	**	30.0	Waianae	**	9.0
Mijake-Shima	**	50.0	Koolau	**	10.0
Omuro	**	5.0	Waialeale	**	5.5
Haruna	**	10.0	Niihau	**	8.0
Asama	**	4.0			

Table 1. Effective magnetizations of volcanos from Kamchatka, Japan and Hawaii, as computed from aeromagnetic anomalies; after Steinberg and Rivosh (1965) and Malahoff and Woollard (1966). The value for Los Humeros has been taken as 16.8×10^{-3} cgs units.

* Magnetization arises from the bulk of the volcanic cone.

** Magnetization arises mainly from the volcanic plug.

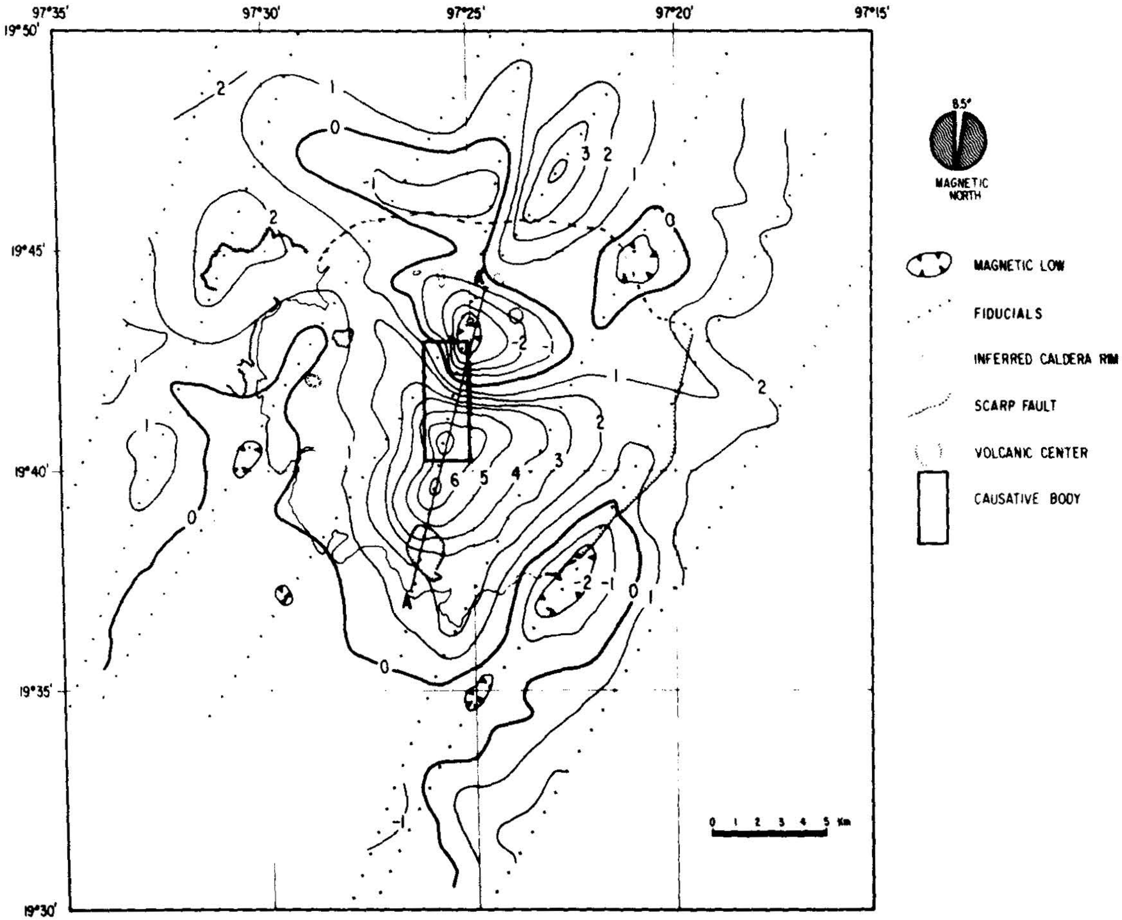

Figure 1. Three point average of total field, residual aeromagnetic map from Los Humeros caldera. Nominal flying altitude was 250 meters above terrain surface. Contour interval is 100 gammas. Flight lines, proposed causative body, major structural features and rim of the caldera (dashed where inferred) are shown.

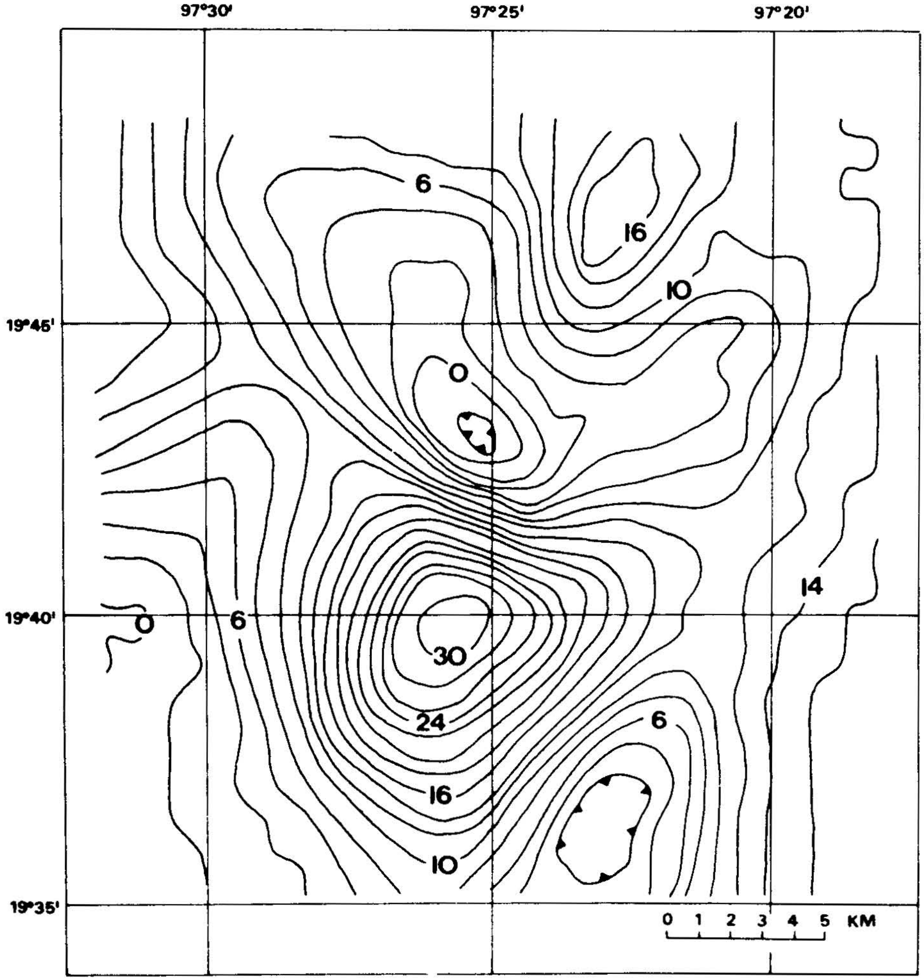

Figure 2. Upward continuation of the observed residual total field to a height of 2 km above ground level. Contour interval is 2 gammas.

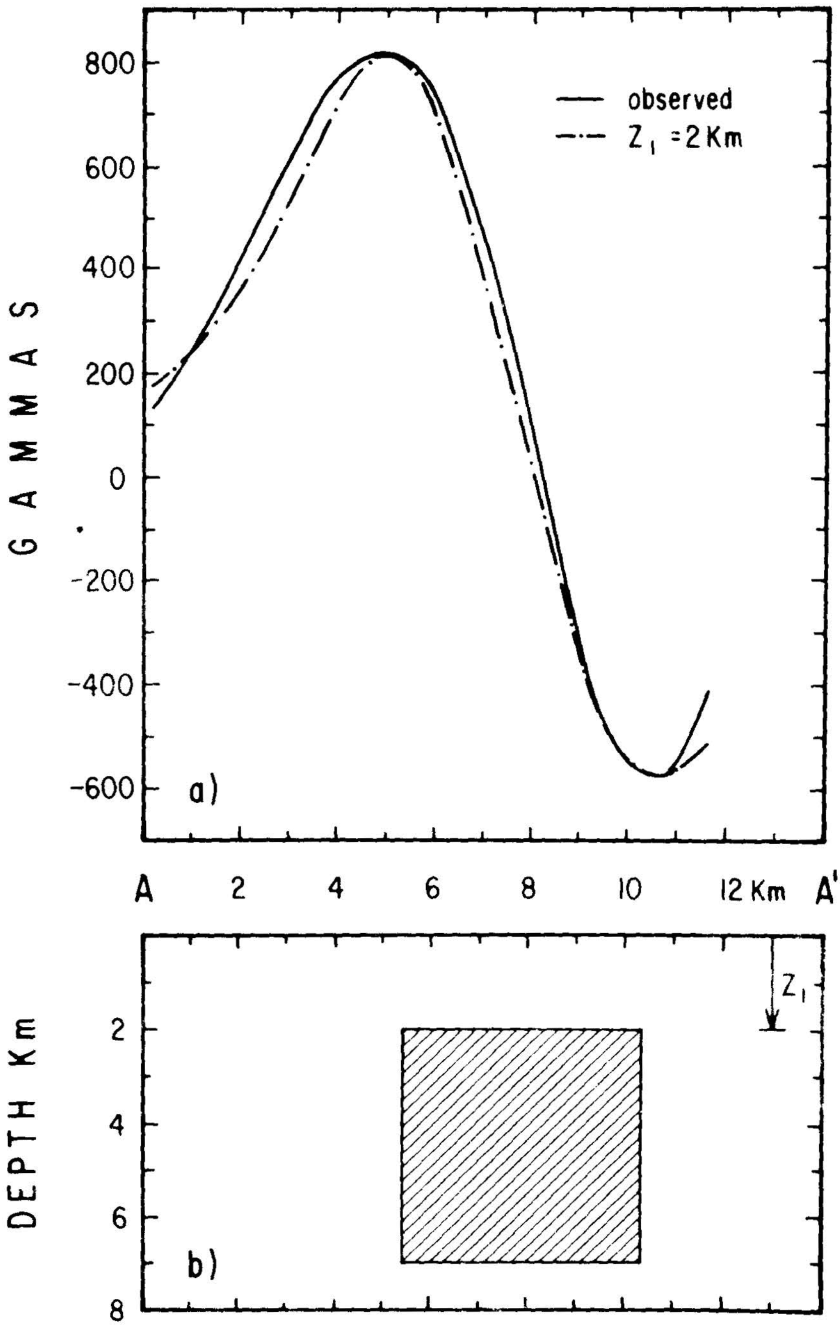

Figure 3. a) Smoothed observed anomaly (continuous line) and computed anomaly along A-A' (see Figure 1). b) Geometry of the source body: $z_1 = 2.0$ km, $z_2 = 7.0$ km. Dimensions: north-south ($\alpha = 5.0$ km). East-West ($\beta = 2.0$ km). Declination and inclination of geomagentic field ($\delta = 8.5^\circ$, $i = 46^\circ$), declination and inclination of polarization ($D = 8.5^\circ$, $I = 31^\circ$), effective magnetization 16.8×10^{-3} cgs units.

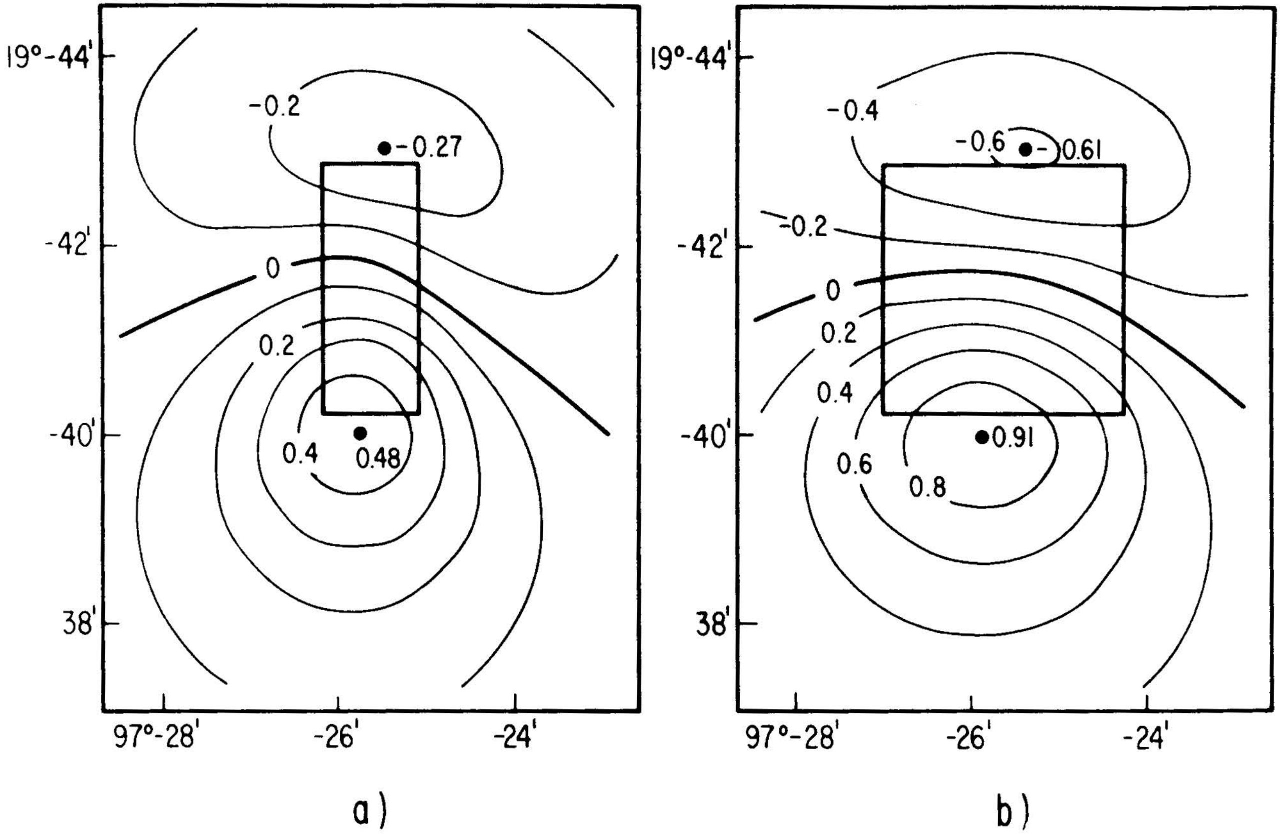

Figure 4. Normalized total magnetic intensity: a) $\alpha = 5.0$ km, $\beta = 2.0$ km; b) $\alpha = 5.0$ km, $\beta = 5.0$ km. All other parameters are the same as for Figure 3. Dots show maximum and minimum values of the normalized field.

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