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ANOMALOUS SOIL MERCURY CONCENTRATIONS AT PARICUTIN VOLCANO, MICHOACAN - GUANAJUATO VOLCANIC FIELD. MEXICO

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RESUMEN

La identificación de concentraciones anómalas de Hg (>1 200 ppb, partes en 10^9) en los suelos del flanco suroeste del volcán Paricutín proporciona nueva información acerca de la naturaleza del flujo convectivo de gases, desde el cuerpo magmático, por debajo de este cono de cenizas inactivo. Las muestras con concentraciones anómalas de Hg están localizadas en una área de aproximadamente 1 km^2; dicha área parece ser mucho más grande que la zona cubierta por fumarolas de alta temperatura (>100°C).

Muestras de suelo con concentraciones de Hg relativamente bajas (<199 ppb) están distribuídas en una área de aproximadamente 3 000 km^2, dentro del campo volcánico Michoacán-Guanajuato. Dicha concentración de Hg es considerablemente más alta que la reportada para otras áreas en estudio. La concentración de Hg suele aumentar cerca de los alineamientos de conos ciner íticos, lo cual puede estar relacionado con la presencia de zonas con alta densidad de fallas.

ABSTRACT

The identification of anomalous (>1 200 ppb) soil mercury (Hg) concentrations on the southwest flank of Paricutín volcano provides new insight into the nature of convective gas flux from magma beneath this quiescent cinder cone. Anomalous soil Hg concentrations are identified over an area of approximately 1 km^2, an area of upwelling that is much larger than is indicated by the distribution of high temperature (>100°C) fumaroles. Soil Hg samples with background (>199 ppb) Hg concentrations are mapped over an area of approximately 3 000 km^2, within the Michoacán - Guanajuato volcanic field. Background soil Hg concentrations in this volcanic field are considerably greater than those reported from other survey areas, and often increase near cinder cone alignments. High background Hg concentrations in the field may be related to a high fault density.

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INTRODUCTION

Soil Hg concentrations provide a record of the flux of gas through soils because Hg is adsorbed on to clay sized particles and can accumulate in soils over time. Anomalously high concentrations of Hg in soils are indicative of high convective heat flow associated with active geothermal systems and/or magmatism (Klusman and Landress, 1979; Phelps and Buseck, 1980; Williams, 1985. Anomalous Hg concentrations will persist as long as the rate of accumulation is greater than the rate of loss due to revolatilization and organic uptake (Varekamp and Buseck, 1984). Soil Hg surveys have proven to be an effective means of locating areas of active convective heat flow, such as along faults and fault zones (Varekamp and Buseck, 1983; Crenshaw *et al.*, 1982), and in areas of active magma intrusion (Varekamp and Buseck, 1984; Williams, 1985). In this study, an area of anomalously high soil Hg concentration is identified on and near the flanks of Parícutin volcano (19.48°N, 102.25°W), a historically active cinder cone in the Michoacán - Guanajuato volcanic field (MGVF), Central Mexico (Figure 1).

Paricutín volcano actively erupted from 1943 to 1952 (Simkin *et al.*, 1981). Three vents formed during this period: a main vent, around which a 300 m high pyroclastic cone was built, and two smaller vents, the Sapichu vent, located northeast of the main vent, and the Ahuan vent, located southwest of the main vent. Lavas were emitted predominantly from these smaller vents. Between 1983 and 1988, fumarole temperatures at the Ahuan vent varied between 350°C and 473°C; at the Sapichu vent fumarole temperatures have varied between 120°C and 275°C over the same period of time (SEAN, 1988). Numerous steam vents are found near the rim of the main vent and elsewhere on the lava flows surrounding the three vents. All of these steam vents have temperatures of less than 100°C (Figure 2).

Paricutín is one of hundreds of cinder cones found in MGVF (Williams, 1950; López-Ramos, 1981; Connor, 1984a; Hasenaka and Carmichael, 1985a, b). In addition to cinder cones: shield volcanoes, stratovolcanoes, maars and lava domes are found in the field. It is a platform-type cinder cone field (Settle, 1979) in the sense that cinder cones are emplaced independently of larger shield or stratovolcanoes. Cinder cones in the MGVF are largely calc-alkaline and are basaltic to andesitic in composition. Most cinder cones in the Parícutin area have polybaric fractionation histories and there is little or no petrologic evidence of long-lived magma chambers beneath cinder cones at shallow levels in the crust (Hasenaka and Carmichael, 1987).

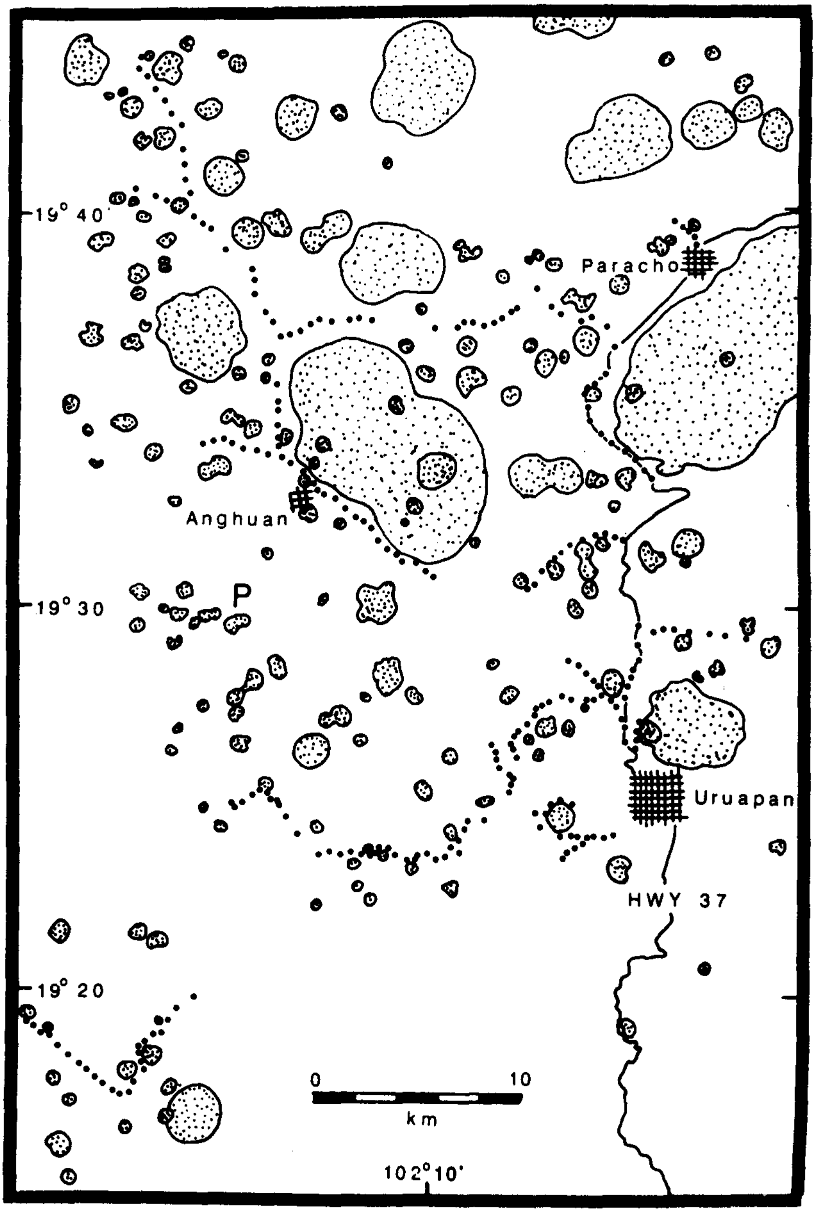

Fig. 1. Area of the soil Hg survey. Samples (solid circles) were collected on roads and footpaths. Stippled areas indicate volcanoes, including cinder cones, shields and stratovolcanoes. Paricutín volcano is labelled (P). Soil Hg samples shown on this figure have background (<199 ppb) concentrations. Soil Hg samples collected on the flanks of Paricutín are shown in figure 2.

Several authors have noted that alignments of cinder cones are common in the MGVF (Williams, 1950; Connor, 1984a; 1987a, b, c; Hasenaka and Carmichael, 1985a, b). These alignments occur at several scales. Vents sometimes align, such as the three vents of Parícutin. Alignments of three to eight cinder cones are common in the field (Connor, 1987a) and regional alignments, consisting of bands of fifteen or more cinder cones have been identified in the southern MGVF using statistical spatial analysis (Connor, 1987b, 1987c). These alignments are interpreted as reflecting structural weaknesses, such as faults or fractures, along which magma ascends. As soil Hg concentrations have been shown to increase near buried faults and fractures (Klusman and Landress, 1979; Varekamp and Buseck, 1983) and used to infer fault locations (Crenshaw *et al.*, 1982; Lescinsky *et al.*, 1987), it was hypothesized that soil Hg concentrations might increase along cinder cone alignments in the MGVF.

METHODS AND RESULTS

Three hundred and twelve soil Hg samples were collected and analyzed from Parícutín volcano and adjacent areas west of the towns of Uruapan and Paracho, within the MGVF (Figures 1 and 2). Of these, 51 samples were collected from ash covered lava flows within 500 m of the Ahuan vent. Sampling elsewhere near the base of Parícutín was not practical because elsewhere the lava flows lack soil or ash cover altogether. The remaining samples were collected along roads and footpaths, over an area of approximately 3 000 km^2. Soil Hg concentrations were determined using a Jerome Instrument Corporation gold film mercury detector. Samples were collected from 25 cm depth and only the fine silt ($<5\phi$) portion was analyzed, following the methods of Phelps and Buseck (1980). Repeated analysis indicates that Hg measurements are reproducible to within 10% at the 200 ppb level (where 1 ppb is 1 part in 10^9), comparable to the accuracy obtained by other investigators (Phelps and Buseck, 1980; Lescinsky *et al.*, 1987).

Following the methods of Lepeltier (1969) and Sinclair (1974), Hg analyses were plotted on lognormal probability paper (Figure 3). An inflection occurs on this plot at approximately 13%, cumulative. This inflection suggests that the Hg samples are drawn from two populations, one with a much higher mean than the other. The statistical distributions of these populations can be approximated by assuming there is little mixing of the two at high and low cumulative percentages (Sinclair, 1974).

The data were partitioned into two populations A and B, based on the inflection.

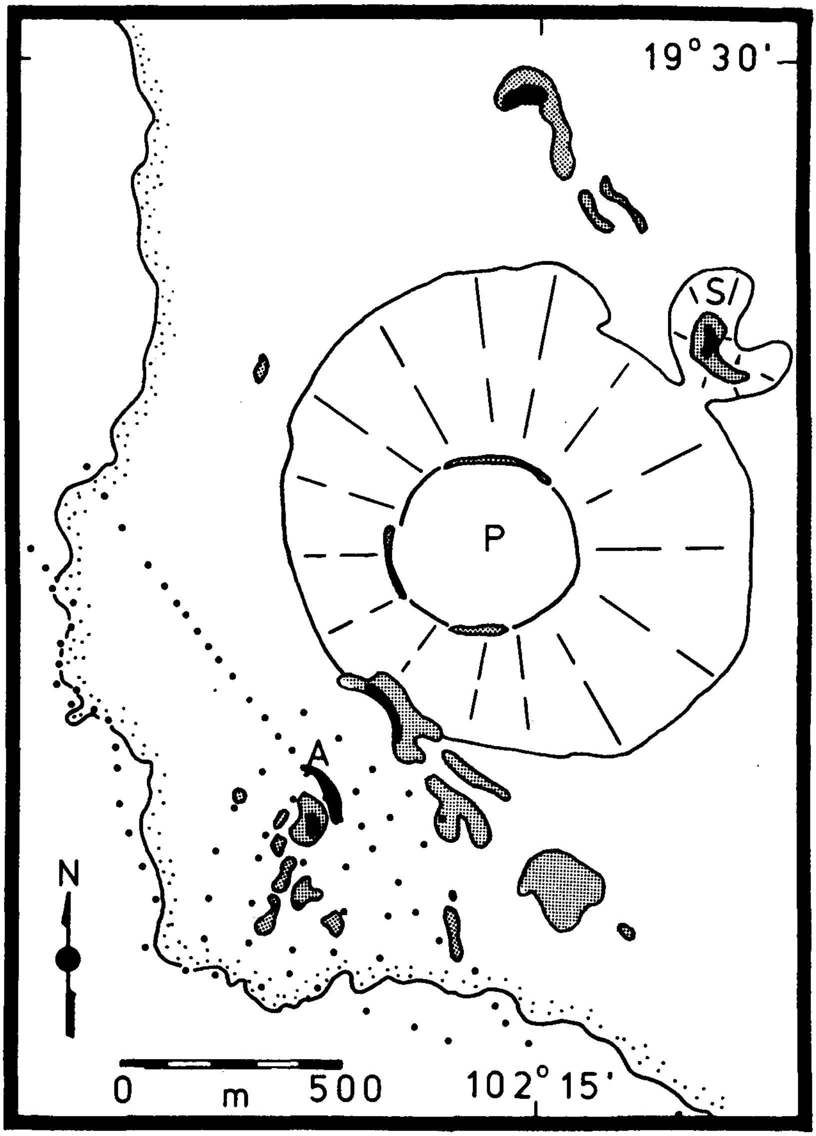

Fig. 2. Soil Hg samples were collected on the southwest flank of Paricutín. Anomalous (>1 200 ppb) samples are shown as solid circles. Threshold (1 200 ppb >Hg >199 ppb) samples are shown as solid circles with crosses. Three vents are labelled: Ahuan (A), the main crater (P), and Sapichu (S). The distribution of fumaroles is shown by temperature (solid pattern - >100°C; stippled pattern - <100°C). The west and southwest margins of lava flows surrounding the cone and indicated by the stippled border.

Since mixing of A and B is taken to be slight at high and low percentiles, the recalculated populations could be extrapolated from 1% to 99% (Figure 3).

Remixing A and B at several ordinate levels demonstrates that A and B account well for the observed distribution of soil Hg. Only very high and very low Hg values are not well approximated by mixing the two populations (Figure 3). Therefore, it seems reasonable to assume that soil Hg samples were drawn from two populations whose distributions are close to those of A and B. Threshold values of 1% B and 99% A were chosen, which divide Hg distribution into three groups. Group I samples consist of those with Hg values of less than 199 ppb. Approximately 99% of population B samples are found within group I. Similarly, group III is comprised of samples having concentrations greater than 1 200 ppb. Because 99% of A samples are greater than 1 200 ppb and 99% of B are less than 199 ppb, few samples fall within group II, which consists of samples which may have been drawn from either population A or B (Table 1). Groups I - III are interpreted as background, threshold, and anomalous soil Hg concentrations, respectively.

Anomalous Hg concentrations are only found near the Ahuan vent at Paricutín. Within this area anomalous values have little or no structure in their distribution. The highest values are concentrated approximately 50 m southeast of the hottest

Table 1

	N	%	x	x-s	x+s	t_l	t_h
all data	314	–	104	17	602	–	–
population A	–	–	4220	2240	7250	–	–
population B	–	–	50	24	94	–	–
group I	255	81.2	48	26	88	–	199
group II	7	2.2	676	521	897	199	1200
group III	52	16.6	3890	2254	6714	1200	–

Summary of the results of statistical analysis of soil Hg data. Summary statistics are presented for all of the data, the theoretical populations A and B, and groups I - III. N - number of samples, x - geometric mean, s - standard deviation, t_l - low threshold, t_h - high threshold. Values are in ppb. A dash is inserted where the statistic is not applicable.

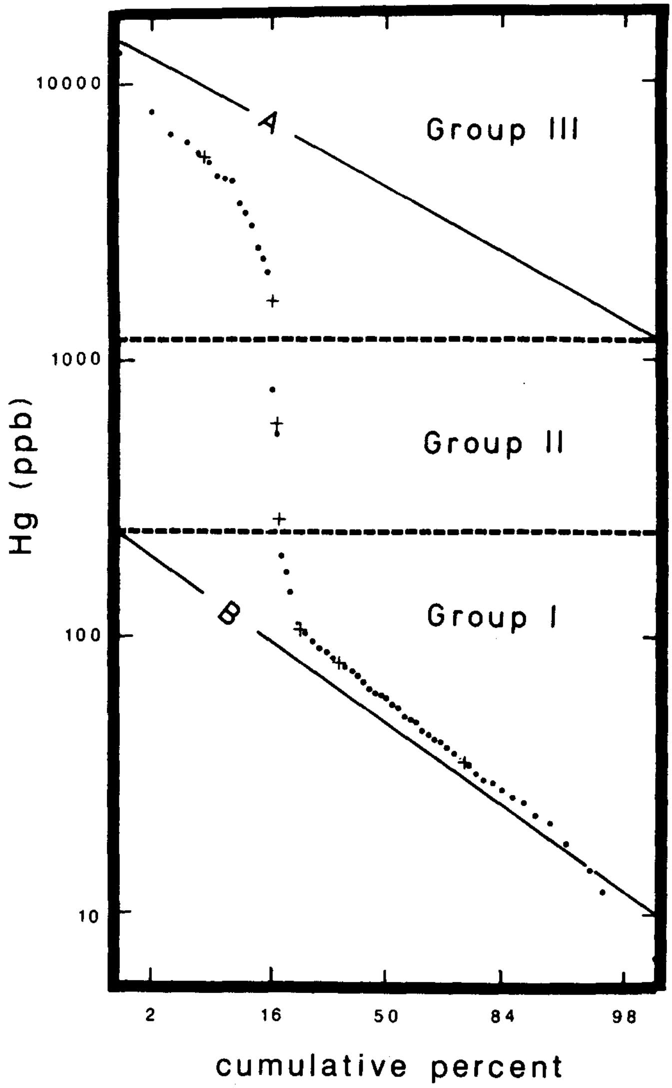

Fig. 3. Lognormal cumulative probability plot of soil Hg concentration. The observed distribution (solid circles) is well approximated by two populations, A and B, based on an inflection at approximately 13% cumulative. Mixing of populations A and B produces values indicated by plus signs. Groups I, II and III are defined by threshold values of 99% A and 1% B.

fumaroles, but very high (>10 000 ppb) concentrations are also found up to 400 m west of the Ahuan vent (Figure 2). Threshold (group II) values are found between the Ahuan vent and the main cone, within 50 m of the Ahuan vent, and haphazardly elsewhere near the vent. These lower, threshold values may be an indication of re-volatilization of Hg due to high soil temperatures near the fumaroles. Elsewhere in the survey area soil Hg concentrations are uniformly background, except for two samples, which attain threshold Hg concentrations (group II).

DISCUSSION

Results of the soil Hg survey suggest that an active geothermal system is present beneath and adjacent to Paricutín volcano. Anomalous Hg samples were found over an area of approximately 1 km^2, indicative of a large area of upwelling, at least on the southwest side of the volcano. This area of upwelling is considerably larger than is indicated by the distribution of high temperature fumaroles (Figure 2). The full extent of this anomaly was not determined by the survey. However, the anomaly in its currently mapped extent is comparable in size to Hg anomalies found in other geothermal areas, such as at Long Valley caldera, California (Klusman and Landress, 1979; Williams, 1985), Yellowstone caldera, Wyoming (Phelps and Buseck, 1980), and the Las Pailas thermal area on the SW flank of Rincón de la Vieja volcano, Costa Rica (Lescinsky *et al.*, 1987).

The geometric means of groups I-III are compared to soil Hg groups identified in other survey areas in Table 2. The geometric means observed in this survey are high

Table 2

Area	Paricutín Region	Rincón de la Vieja	Long Valley Caldera	Lassen Peak	Desert Peak	Mickey Area
background	48	15	6	31	7	12
threshold	676	56	26	100	90	69
anomalous	3890	537	260	1400	–	1600

Comparison of the background, threshold and anomalous soil Hg concentrations found at Paricutín volcano and surrounding areas with the results of other studies (Varekamp and Buseck, 1983; Williams, 1985; Lescinsky *et al.*, 1987). Values in ppb.

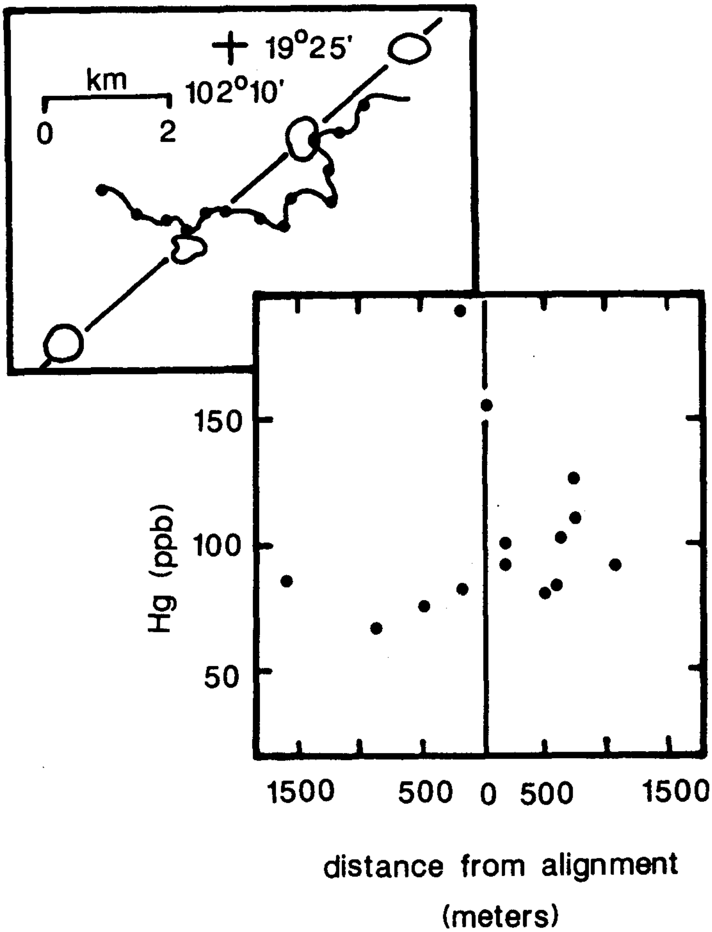

Fig. 4. Example of soil Hg traverse across a cinder cone alignment. The map view shows soil Hg samples (solid circles) collected along a road which crosses an alignment (solid line) of four cinder cones. On the graph, soil Hg values are plotted with respect to distance from this alignment (solid line). The two highest Hg values are found near the alignment. All Hg samples collected on this traverse have background concentrations.

relative to surveys conducted in other areas. In fact, background values in the Paricutín area are comparable to threshold values recognized in several other surveys, and are greater than background values identified in all of the other cited survey areas with greater than 99% confidence (Table 2).

These significantly higher background values may occur either because there is larger flux of Hg through soils in the MGVF than in the other survey areas cited, or because some Hg has been retained by soils since ancient geothermal systems, associated with older cinder cones, were active. In other areas, such as Yellowstone (Phelps and Buseck, 1980) and Masaya calderas (Crenshaw *et al.,* 1982), background levels are low, despite volcanic eruptions and areally extensive geothermal activity within these calderas over last several hundred years. Most cinder cones in Paricutín area are Pleistocene to Holocene in age, but few have apparently erupted within the last several thousand years (Hasenaka and Carmichael, 1985a). Based on this comparison, it seems unlikely that unusually high background values owe their origin to ancient geothermal systems.

Alternatively, there may be a higher flux of Hg through soils in this cinder cone field in general. Settle (1979) proposed that cinder cone volcanism in the MGVF and similar platform-type fields is structurally controlled by a network of fractures or faults. Most cinder cones are emplaced along these structural weaknesses, particularly fault intersections. In the MGVF, this hypothesis is supported by the observations that cinder cones are often aligned and that regional fault zones can be extrapolated through the field (Mooser, 1968; Connor, 1987a; Johnson, 1987).

Because high soil Hg concentrations have often been found near faults in other volcanic areas (Klussman and Landress, 1979; Crenshaw *et al.,* 1982), it is suspected that high background Hg values in the MGVF may be a result of high fault density. Many Hg samples were collected along traverses which cross cinder cone alignments. Along many of these traverses, there is an increase in soil Hg concentration where the traverse crosses either between aligned cinder cones or the projection of a cinder cone alignment (Figure 4). Increases in soil Hg concentration near cinder cone alignments, such as those shown in figure 4, were identified on seventeen of thirty-one traverses across cinder cone alignments (Connor, 1984b). It is speculated that this increase in Hg concentration is due to the presence of faults. These faults provide relatively permeable pathways, along which volatile Hg ascends. Over time this leads to an enrichment of Hg in soils and results in a higher mean background concentration. It is emphasized that these high background values are not comparable to anomalous values found at Paricutín and do not indicate the presence of anomalous convective gas flux along cinder cone alignments, as would be expected if active geothermal systems were present.

CONCLUSIONS

1) Soil Hg concentrations in excess of 10 000 ppb have been identified near the Ahuan vent of Paricutín volcano. This soil Hg anomaly indicates a high convective gas flux, likely driven by a cooling magma body beneath the volcano. The full extent of this anomaly has not been determined.

2) Background Hg concentrations in the MGVF near Paricutín volcano have a geometric mean of 48 ppb and are unusually high compared to background concentrations reported from other volcanic and geothermal areas. In the MGVF, soil Hg concentrations are often higher near cinder cone alignments. These observations suggest that a high fault density within the cinder cone field provides volatile Hg ready access to near surface soils.

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