# MICROEARTHQUAKE ACTIVITY ASSOCIATED TO LOS HUMEROS CALDERA, MEXICO: PRELIMINARY SURVEY

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## RESUMEN

Con el propósito de observar microtemblores asociados a la caldera de Los humeros, Puebla, México, entre el 12 y 24 de enero de 1977 se instalaron 3 estaciones sismológicas portátiles en su interior. Se localizaron 7 eventos de magnitud m $\simeq$ 1.0. Tres de estos eventos fueron localizados usando primeros arribos, suponiendo que ocurren a una profundidad de 1 km y $\alpha = 2.5$ km/seg. Los restantes cuatro eventos no presentan fases legibles para las ondas internas P y S; su localización se estima a partir de los tiempos de arribo de la máxima amplitud de las ondas superficiales (fase de Airy) suponiendo que este máximo está controlado principalmente por la velocidad de las ondas sísmicas de la cubierta de cenizas volcánicas presentes en la caldera. Otros eventos de menos magnitud fueron registrados en una o dos estaciones; en promedio se registraron 3 eventos/estación/día, actividad comparable a la observada en otras estructuras geológicas de interés geotérmico. De un total de 96 eventos registrados, la mitad ocurren en forma de enjambres. Además, se observaron microtemblores del tipo "A", "B" y de "Trepidación", característicos de estructuras volcánicas activas o de reciente actividad. Los datos sugieren la existencia de una zona que atenúa más intensamente las ondas sísmicas: esta zona presenta también anomalías en medidas de autopotencial y temperatura (Alvarez, este volumen).

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## ABSTRACT

From 12 to 24 January 1977 three portable seismic stations were intalled at the interior of Los Humeros Caldera in order to observe the microearthquake activity associated with it. Seven events of magnitude m $\simeq 1.0$ were located. Three of these events we located using first arrivals, fixing depth at 1.0 km and taking $\alpha = 2.5$ km/sec. The remaining 4 microearthquakes do not show legible P or S body waves arrivals; we estimated an epicentral location based on the differences of arrival time for the maximum amplitude of surface waves (Airy phase) assuming that the velocity of surface waves is controlled mainly by the deposits of unconsolidated pyroclastics that cover the caldera area. Lower magnitude events were recorded at only one or two stations; an average of 3 events/day/station were recorded. Such an activity is similar to that observed in other geological structures of geothermal interest. 96 small events were recorded; one half of them occurred in swarm sequences. Microearthquakes of types "A", "B", and "Tremor" were observed; they are typical of active or recently active volcanic structures. The data suggest the existence of a zone on the western side of the caldera, that strongly attenuates seismic waves; this zone also presents self-potential and temperature anomalies (Alvarez, this issue).

## INTRODUCTION

Microearthquake activity associated with Los Humeros caldera was observed for 8 days during January 1977. Three portable high-gain seismographs were used. The main purpose of the experiment was to find out whether Los Humeros caldera shows seismic activity similar to that observed in other volcanic structures (Minakami, 1974) of recent origin, as well as to refine the data gathering technique to be used on subsequent, more detailed observations. The present work complements other geological (Pérez-Reynoso, 1978), and geophysical (Alvarez, *et al.*, 1976; this issue; Mena and González-Morán, this issue) surveys done in the caldera. Los Humeros caldera is considered of high potential value as a source of geothermal energy (Alvarez, 1976) in the Mexican Volcanic Belt (MVB).

Los Humeros caldera is situated on the eastern part of the MVB, it has an almost circular shape that covers an area of about 200 km$^2$ (Figure 1). The MVB is controlled tectonically by a system of deep-seated trascurrent faults that run in SW-NE direction. On the eastern part of the MVB are four major displacements of a left-lateral nature, which are paralleled by numerous minor lines; a less significant set of fractures runs in a WNW-ESE direction (Mooser, 1972). Los Humeros caldera is divided by the Zaragoza Fault (Figure 1), which runs NW-SE and may constitute a continental feature well defined in satellite images but difficult to detect in aerial photography (León del Río, personal communication). This fault is crossed almost perpendicularly by the Monte Nuevo fault which runs along the SW-NE direction. There is no evidence of the presence of this second fault beyond the vicinity of the caldera border.

The seismotectonics of the upper layers of the MVB have not been studied partly owing to the lack of a network of high-gain seismological observatories in the Mexican territory. Nevertheless, the records of Mexico City observatories show that in the MVB seismic energy is frequently released in swarm sequences, lasting a few hours up to several weeks. The low energy seismicity associated to Los Humeros caldera has not been recorded previously. Focal mechanisms of large earthquakes mb ⩾ 6.5 that occurred in the southeastern part of the MVB have been studied in some detail (Jiménez and Ponce, 1978). Focal mechanism solutions show that the T-axis is parallel to the hypothesized Benioff zone associated to the subduction of the Cocos plate under the North America plate. However, the relationship between volcanism and seismic energy released by the subduction process is not yet clearly understood for the MVB.

Los Humeros caldera is a young volcanic structure developed from early Pliocene up to Recent. The last lava flows, Tepeyehualco and Limón, are probably only 10,000 years old (Pérez Reynoso, 1978). At the interior of Los Humeros caldera one finds cones, minor calderas, lava flows and a zone of fumaroles near the country house called Los Humeros.

## SEISMICITY AND VOLCANIC STRUCTURES

Several authors have studied the seismicity associated with volcanic structures accompanied by hot spring manifestations. Ward *et al.* (1969) and Ward and Bjornsson (1971) surveyed the Iceland mid-atlantic ridge; Eaton *et al.* (1975) studied the Yellowstone geothermal fields; Steeples and Pitt (1976) studied the seismicity associated with Long Valley caldera; Gilpin and Lee (1978) studied the Salton Sea goethermal area. The results of these works indicate that the data of microearthquake surveys should be carefully interpreted with other geological and geophysical data. The seismological approach can yield an insight on the differences between the tectonic processes occuring at the interior of the volcanic structure of geothermal interest and its surrounding areas. However, there is no unique methodology to interpret the data in relation to the estimated size and reservoir configuration (Majer, 1978).

## FIELD OBSERVATIONS

Three high-gain Sprengnether MEQ-800 portable seismographs along with Ranger SS-1 seismometers (T = 1.0 sec) were installed at the interior of the caldera area (Figure 1). According to the prevailing noise conditions a 10 Hz filter was selected for both low-and high-frequency responses; the velocity-frequency response curve has a well defined peak at 10 Hz with a magnification of 6,000 cm/cm/sec at a gain of 90 dB.

Seismograms were recorded on smoked paper with a speed of 2 mm/sec, allowing an accuracy of ± 0.1 sec in time readings. At the beginning and at the end of each 24 hour seismogram a time base was established with a WWV-receiver.

The location of the temporary stations is shown in Figure 1. The distance between each station is about 10 km. The rock components in and around the sites were recent lava flows overlaping layers of poorly consolidated material. At the South, station XCV was operated at a gain of 90 dB during 11 days; at the West FMV was operated 9 days, mostly at 102 dB; the station located in the North-central region of the caldera was operated at three different localities VHV, HDV, and CAV for a total of 8 days with gains ranging from 78 to 102 dB. The network worked simultaneously for a total of 7 days.

## DATA AND RESULTS

In the period of observation 7 events were recorded at all three stations. Their epicenters are shown in Figure 1. Three of these events occurred in the North-West part of the caldera. The epicenters were determined using a velocity $\alpha$ = 2.5 km/sec for compressional waves and fixing a depth at h = 1.0 km. The values of $\alpha$ = 2.0 to 2.5 km/sec correspond to velocities of compressional waves in tuff or fracturated and poorly consolidated rocks (Press, 1966). The presence of such material in the caldera, is supported by the gravity observations and their corresponding models (Mena and González-Morán, this issue; Alvarez, this issue). Some other sets of $\alpha$ (1.5 and 2.0) and h (0.0 and 2.0) values were considered; however the epicenter location does not drift more than 1.0 km from the position shown. The records of these three events present the characteristic of B-type earthquakes (Minakami, 1974) since they do not present a well defined S-arrival and the P-wave is weak (Figure 2a).

The remainder 4 events do not show readable body-wave arrivals (Figure 2b). Since for each event the records at all three stations present the same character, the time corresponding to the arrival of maximum amplitude of the wave train was readed. For this arrival the difference of time between two stations varied from 8 to 12 sec, indicating that they should correspond to surface waves propagating with a very low velocity (less than 0.5 km/sec). We suggest that these events occurred at very shallow depths and the velocity of surface waves observed is controlled mainly by the layers of volcanic ash that cover the caldera area. In visible places the thickness of the cover of volcanic ash reaches 20 m; it would suffice that the thickness had an average value of 50 m to justify velocities of Rayleigh waves less than 0.5 km/sec considering that the frequency of the signals range from 10 to 15 Hz. In fact, the velocity of compressional and shear waves for sandstones can take the following values: $\alpha = 0.6$ to 1.85 and $\frac{\alpha}{\beta} = 3.0$ to 3.5 (Press, 1966). Furthermore, for $\frac{\alpha}{\beta} = 3.0$ the Poisson coefficient equals 0.44 and $V_R = 0.95\,\beta$ (Knopoff, 1952). Then $V_R$ could take values of 0.16 to 0.59 km/sec. If we assume $h = 0$ (very shallow event) and $V_R = 0.25$ km/sec (Rayleigh group velocity for the Airy phase), then the epicenters shown in Figure 1 are obtained. Other values of $V_R$ (0.2 and 0.3) were tried; for $V_R = 0.2$ km/sec the epicenters would approach the border of the caldera; for $V_R = 0.3$ km/sec they would move as much as 7 km outside from the border.

A relative Richter local magnitude for these seven events was estimated. As the attenuation factor of the caldera rocks is unknown, any correction of this kind was omitted; only the differences in maximum amplitudes, corrected for gain were considered in the computation of the magnitude (Richter, 1958). The computed magnitudes are given in Table 1. Their average is of the order of 1.0. A remarkable fact is the systematically lower magnitudes observed at the station FMV. In average, the local magnitude seen at FMV is 0.55 less than the average magnitudes seen at XCV or VHV stations. The average magnitudes determined from XCV or VHV are 1.13 and 1.14 respectively. Also, a relative "coda duration" magnitude was determined using the criteria defined by Majer (1978). The computed coda magnitudes are lower than Richter magnitudes; for one event the coda duration was imposible to read. No systematic difference in duration was observed at station FMV. This suggests that an anomalous zone might exist which strongly attenuates the energy of seismic waves but which does not affect the interference process that generate the coda of the events. This suggestion is supported by the fact that coda duration is defined for frequencies of the order of 3 Hz while maximum amplitudes are defined for frequencies of the order of 10-15 Hz; Usually lower frequency signals are less affected by local inhomogeneities of the propagating path.

In Table 2 are listed the events recorded simultaneously in only two stations. At first we discuss those two occurring in January 16, 1977. The records at XCV present an A-type character (Minakami, 1974) with well defined P and S arrivals (Figure 2c); for this station $\Delta t$ (S-P) = 1.5 sec and the P wave arrived 1.5 and 0.75 sec later at FMV for each event. If we accept 2.5 km/sec and $\alpha/\beta = 1.73$, a probable zone of occurrence is obtained at the west side of the Los Humeros fault, as shown in Figure 1. The gain at the third station was 78 db at that time, and these events were not recorded. On January 21, 1977 were recorded two events at FMV and RDV with a clear character of volcanic tremor (Minakami, 1974) their duration lasted from 90 to 120 sec and their amplitudes were almost constant (Figure 2d).

In Table 3 are listed the events recorded in a single station. Most remarkable is the swarm occuring on January 19, 1977, and recorded at XCV. The pattern of the events is identical to the A-type events observed on January 16; we assume that both swarms originate at the same active focal zone, as proposed before, near the western end of Los Humeros fault. In average 3 events were recorded per day at each station. This level of seismic activity is similar to those reported by other authors in volcanic structures of geothermal interest (Combs and Hadley, 1977).

## CONCLUSIONS

The seismicity observed at Los Humeros caldera during this preliminary survey suggests that near station FMV, on the western side of the caldera, these is a zone of larger absorption of seismic energy. This results supports the possibility of a thermally anomalous zone, as suggested by the self-potential and temperature data shown for the same area by Alvarez (this issue). The occurrence of tremor type earthquakes suggests the circulation of fluids in fractured rocks at shallow depths in the caldera (Minakami, 1974; Kubotera, 1974; Dibble, 1974). The occurrence of B-type earthquakes indicate that very shallow seismic activity is present at the southwestern part of the caldera structure (Minakami, 1974). The occurrence of A-type microearthquakes, with well defined P and S waves suggests displacement of tectonic blocks along active faults inside the caldera. In conclusion, the microearthquake activity recorded in this very preliminary work suggests that a more detailed passive seismic survey should help to delineate the tectonic setting of Los Humeros caldera. In addition, a regional microearthquake survey should help define some neighboring areas of geothermal interest, whose existence has been suggested in other studies.

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TABLE 1: Magnitude of events recorded in three stations

| DATE & TIME AT XCV | RELATIVE RICHTER MAGNITUDE | | | | RELATIVE "CODA DURATION" MAGNITUDE | | | |
|---|---|---|---|---|---|---|---|---|
| | XCV | VHV* | FMV | AVERAGE | XCV | VHV* | FMV | AVERAGE |
| Jan/18/1977 01:04:02.0 | 1.53 | 1.35 | 1.07 | 1.32 | | | | (+) |
| Jan/19/1977 09:02:44.0 | 0.75 | 0.95 | 0.45 | 0.72 | 0.31 | 0.36 | 0.38 | 0.35 |
| Jan/22/1977 07:25:26.5 | 1.05 | 1.26 | 0.45 | 0.92 | 0.65 | 0.75 | 0.65 | 0.68 |
| Jan/22/1977 07:29:00.5 | 1.47 | 1.50 | 0.99 | 1.32 | 0.67 | 0.70 | 0.73 | 0.70 |
| Jan/22/1977 07:29:54.0 | 1.23 | 1.13 | 0.45 | 0.94 | 0.59 | 0.56 | 0.56 | 0.57 |
| Jan/23/1977 05:33:15.0 | 1.05 | 1.05 | 0.35 | 0.82 | 0.71 | 0.70 | 0.71 | 0.71 |
| Jan/23/1977 05:33:39.5 | 0.83 | 0.75 | 0.15 | 0.58 | 0.52 | 0.59 | 0.46 | 0.52 |

(*) also HDV or CAV stations
(+) a later event disturbed the coda.

TABLE 2: Events recorded in two stations

| | ARRIVAL TIME | | | | |
|---|---|---|---|---|---|
| DATE | XCV | FMV | VHV | HDV | CAV |
| Jan/16/77* | 12:00:56.5 | 12:00:58 | ---- | ---- | ---- |
| Jan/16/77 | 12:13:43.75 | 12:13:44.5 | ---- | ---- | ---- |
| Jan/ 17/77 | ---- | 08:59:56.75 | 09:00:03 | ---- | ---- |
| Jan/21/77** | ---- | 03:56:54 | ---- | 03:56:18.5 | ---- |
| Jan/21/77** | ---- | 06.[illegible].05.5 | ---- | 06:08:44.5 | ---- |
| Jan/22/77 | 04:17:59 | ---- | ---- | 04:18:15 | ---- |
| Jan/23/77* | 00:30:26.75 | ---- | ---- | ---- | 00:30:26.75 |

(*) "A" type earthquakes probably locate in the central part of the Caldera.
(**) "VOLCANIC TREMOR" type earthquakes.

TABLE 3:Number of Events recorded in only one station

| | JANUARY | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STATION | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| XCV | 5* | 4* | -- | -- | -- | 1 | 12* | -- | 1 | 2 | 2 | 1 |
| FMV | -- | -- | -- | 4 | 5 | 1 | 3 | -- | 13* | 3 | 2 | -- |
| VHV | -- | -- | -- | -- | 6* | 1 | -- | -- | -- | -- | -- | -- |
| HDV | -- | -- | -- | -- | -- | -- | 3 | -- | 9 | 2 | -- | -- |
| CAV | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1 | 1 |

(*) Swarm

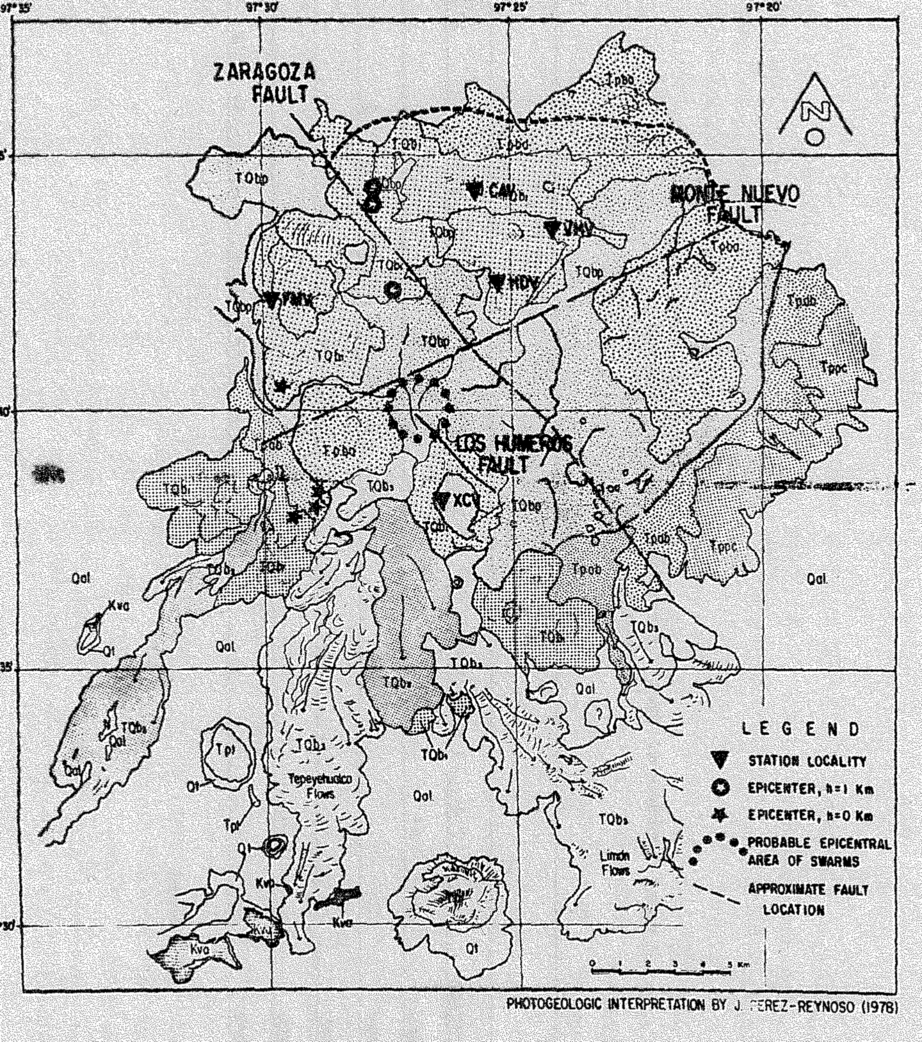
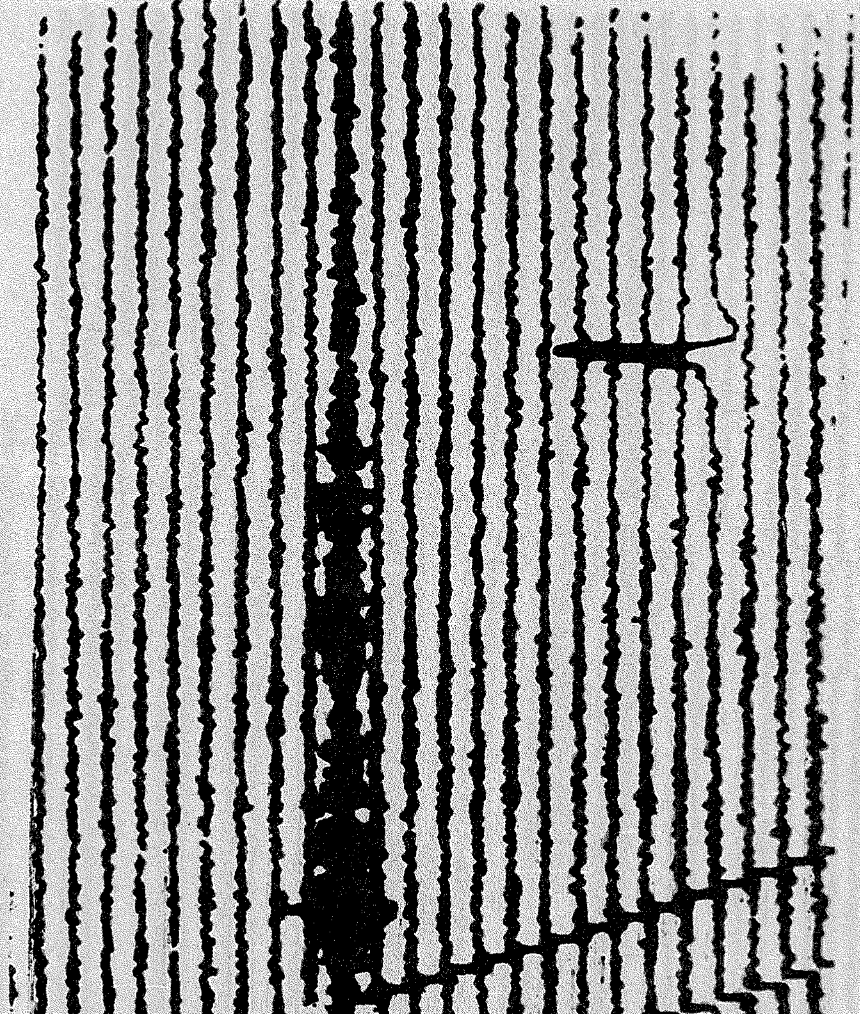
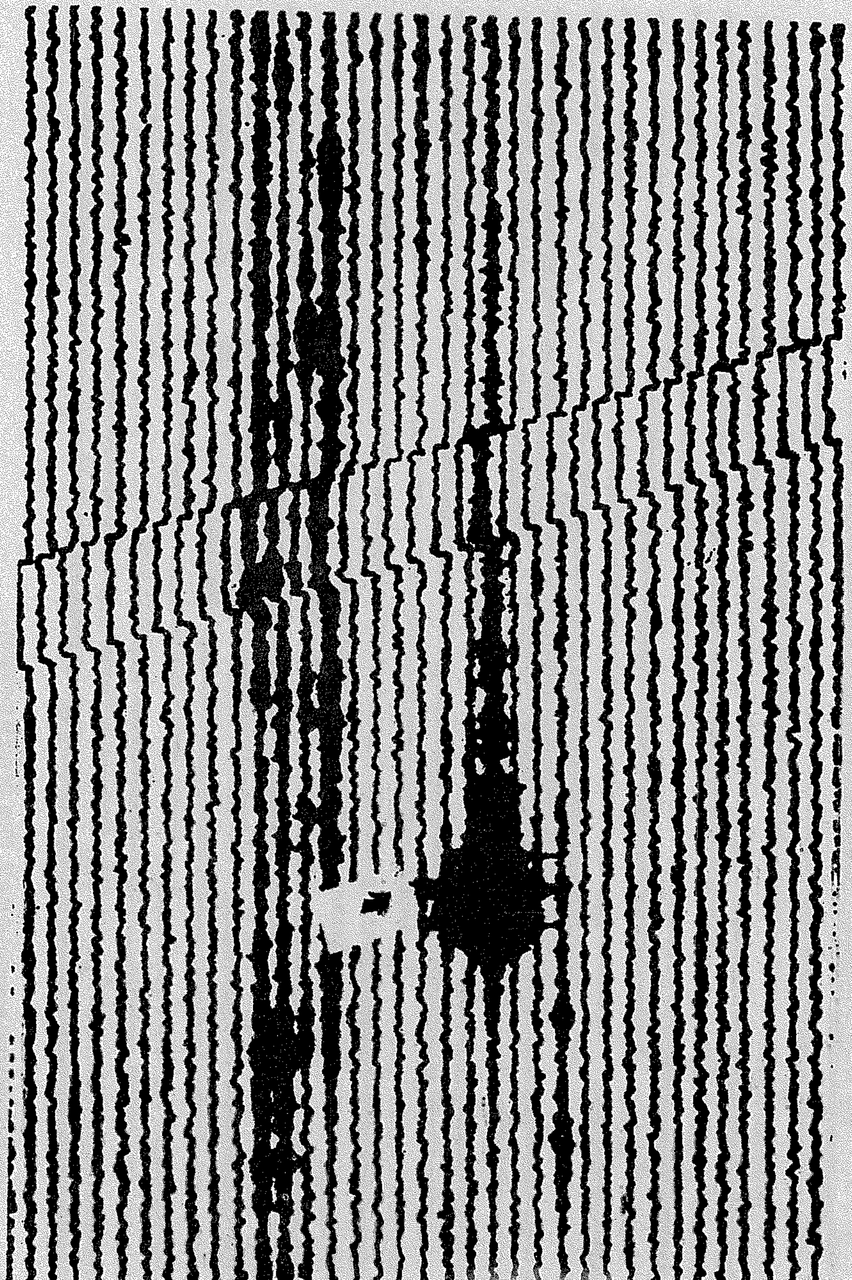


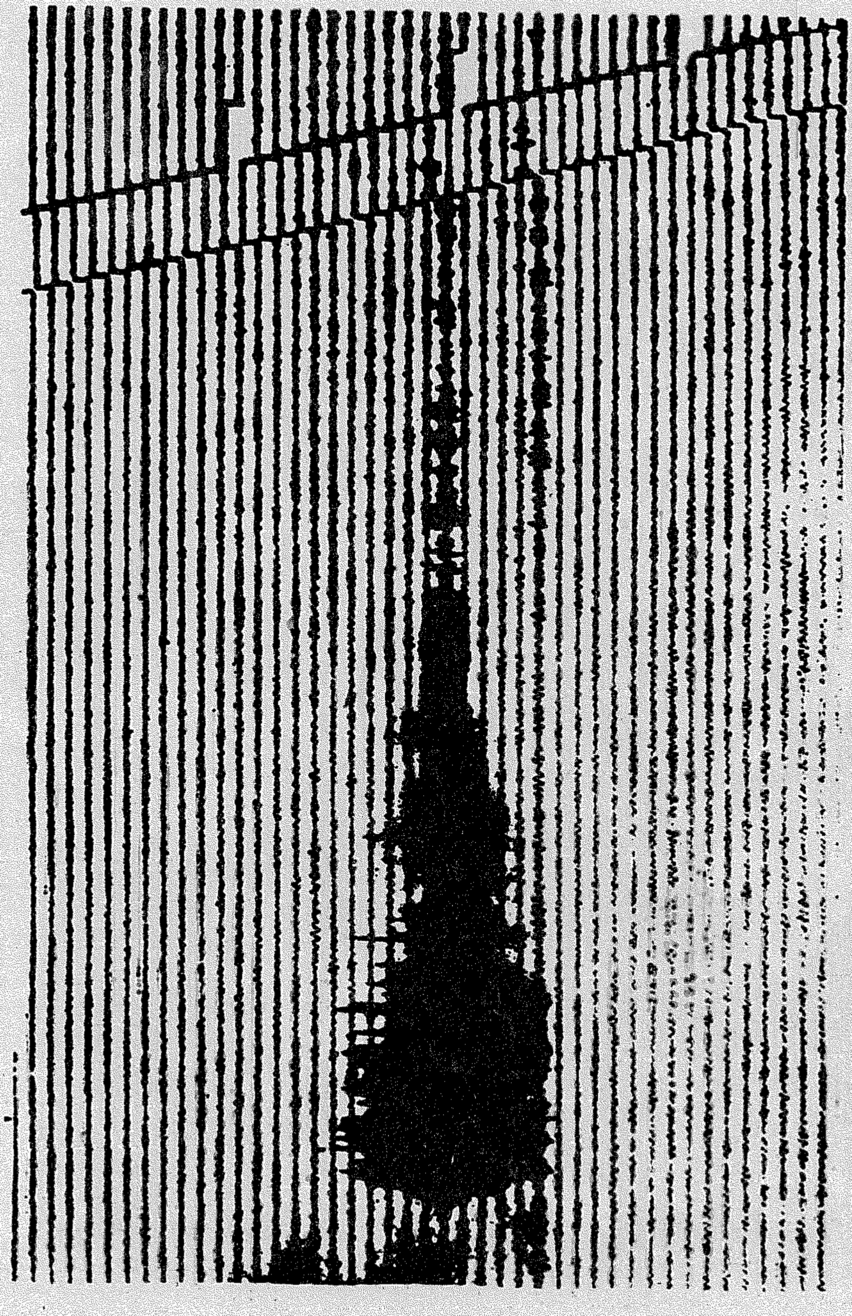

Figure 1. Station localities, epicenter locations, probable epicentral area of swarms, and approximate fault location are shown.



2a. B-Type event recorded at CAV. First arrival is indicated.



2b. B-type event recorded at FMV. Maximum amplitude of Airy phase is indicated.



2c. Swarm event recorded at XCV.

2d. Tremor-type event recorded at HDV. Duration of the order of 100 seconds.

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