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THE EARTHQUAKE SWARM OF FEBRUARY 1981 IN MEXICO CITY

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RESUMEN

Entre el 4 y el 15 de febrero de 1981 ocurrió en la Cd. de México una serie de temblores particularmente bien registrados. Los 5 eventos mayores aquí analizados ($2.7 \leqslant M_L \leqslant 3.2$) tuvieron hipocentros dentro de un volumen de 1 km^3, con localización media en 19.378°N – 99.196°W y una profundidad de 1.2 km. Las localizaciones relativas de estos eventos mostraron una migración de 0.7 a 1.6 km en un plano casi vertical. Se obtuvo una solución de plano de falla normal con el eje tensional en la dirección casi Este-Oeste, usando estaciones locales y regionales. El análisis espectral dio momentos sísmicos en el rango 0.5 – 2.0 x 10^{20} dinas-cm y caídas de esfuerzo de 1 a 5 bares.

Se obtuvieron parámetros similares para el evento mayor ocurrido en una serie de temblores en la misma área en febrero de 1980. Parece ser probable que estos eventos ocurran como resultado de la acumulación de tensión regional; no obstante, el hundimiento del Valle de México podría posiblemente originar tensiones orientadas similares, las cuales, si no ocasionan los sismos, los pudieran disparar.

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ABSTRACT

Between February 4 and 15, 1981, a particularly well recorded earthquake swarm occurred in Mexico City. The 5 largest events analyzed here ($2.7 \lesssim M_L \lesssim 3.2$) had hypocenters within a volume of 1 km^3 with mean location at 19.378°N–99.196°W, and a depth of 1.2 km. Relative locations of these events showed a migration from 0.7 to 1.6 km on a nearly vertical plane. A normal fault plane solution with the tensional axis almost east-west was obtained using local and regional stations. Spectral analysis gave seismic moments in the range $0.5 - 2.0 \times 10^{20}$ dyne-cm and rather low stress drops (1 to 5 bars). Similar parameters were obtained for the largest event occurring in a swarm in the same area in February 1980. It seems most likely that these events occur as a result of accumulating regional tension; however, the sinking of the Valley of Mexico could possibly produce similar oriented tensions, which, if not causing the earthquakes, might trigger them.

INTRODUCTION

On February 4, 1981, at 1340 GMT occurred the first in a series of local earthquakes widely felt in Mexico City. These events were rather large by local standard; magnitude estimates for the initial and a couple of later shocks are in the range of 3.0 to 3.4. Consequently the events were recorded as far as Oaxaca and Acapulco, Mex.

Several portable seismographs from the Institute of Geophysics and Institute of Engineering were mobilized capturing many of the later events. In general our knowledge about the local seismicity in the Valley of Mexico is rather poor and imprecise due to small number of local stations and to a large extent unknown crustal structure. However no other local event has been recorded with such a large number of local and distant stations, both digitally and analog, and this data set is definitely the best ever obtained for any event in Mexico City. In the present study only the 5 largest events, hereafter called 1 to 5, occurring between Feb. 4 and Feb. 9, 1981 will be analyzed, since they have the most complete data set. A study of all the events between Feb. 4 and Feb. 15 is under preparation at the Institute of Geophysics (R. Mota, personal communication). A comparison will also be made with the largest event of apparently a similar earthquake sequence, felt in the same region of Mexico City in February 1980.

DATA

In Table 1 all the arrival time readings used in this study have been summarized, and Fig. 1 and Table 2 show the stations used. The two nearest permanent stations recording all 5 events were the Institute of Engineering (I.I.), station ABC and the

TABLE 1

Arrival time (sec) relative to P-arrival times at station IIM. Also shown are average relative times used for locating the group of events and corresponding residuals.

	P - Time at station IIM							
Station Phase	Feb 20, 1980 4:23 10.64	Feb 4, 1981 13:40 28.70	Feb 7, 1981 22:40 25.05	Feb 7, 1981 22:46 56.45	Feb 9, 1981 2:37 06.63	Feb 9, 1981 5.53 48.40	Average for 1981 events	Residuals
IIM P	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.08
S		2.05	2.40	2.30	2.45	2.40	2.32	-0.03
ABC P		-1.10	-0.98	-0.82	-0.83	-0.85	-0.92	0.06
S		0.23	0.30	0.43	0.55	0.42	0.39	0.28
SAH S		2.46	2.15	2.35	2.20	2.05	2.24	0.14
TAC P		-1.20	-1.05	-0.85	-0.93	-0.95	-1.00	-0.17
S		-0.05		0.40	0.22	0.15	0.18	-0.23
IIC P	6.66	6.02	6.05	6.00	5.97	5.90	5.98	-0.14
IIP P	3.92	4.05	3.95	3.90	3.87	3.80	3.91	-0.09
CA2 P		28.60	28.75	28.65			28.67	1.96
III P		17.30					17.30	0.42
OXM P		7.90	7.95	8.05	8.37	7.90	8.03	0.55
TPM P		6.60					6.60	-0.09
CRX P		7.50					7.50	0.26
CGA P					-0.83	-0.95	0.89	0.01

National Seismological Service Station TAC, both at epicentral distances of about 2.5 – 3.0 km.

From TAC conventional 3 component short-period (SP) records were used; however S-arrival was difficult to read because of saturation.

The ABC station is a 3 component acceleration station transmitting to I.I. and recording in analog form on magnetic tape. Thus there is no saturation problem and playback at high speed permits very accurate readings of P and S arrivals. Fig.2 shows an example and it is seen that S-arrivals are identified unambiguously.

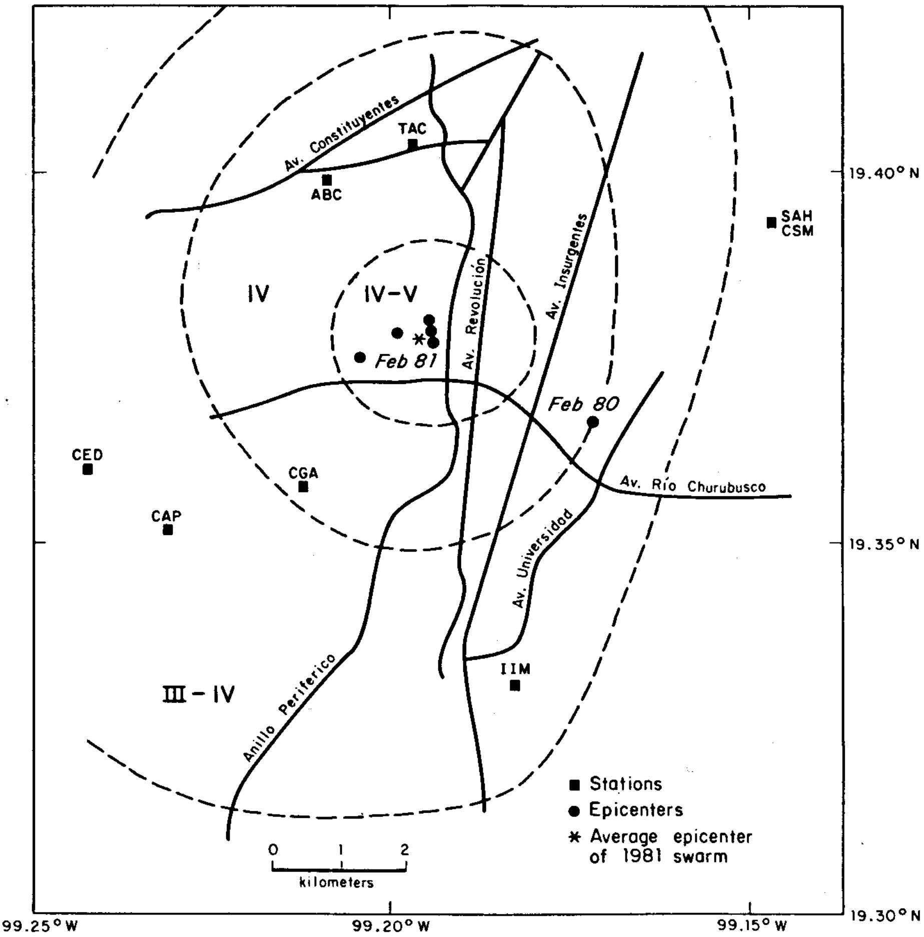

Fig. 1. Location map showing stations and epicenters. Isoseismic map of the largest event is also shown.

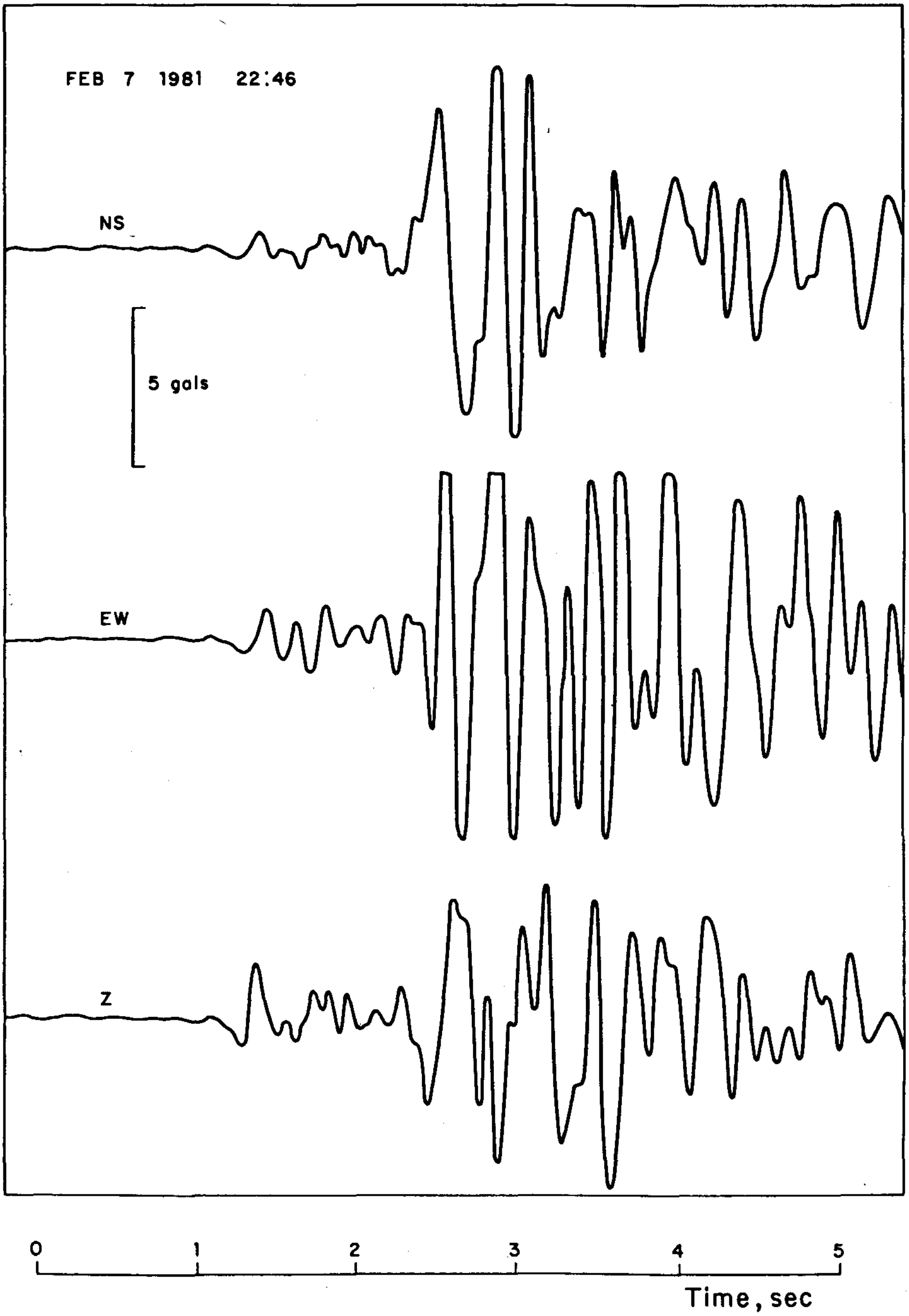

Fig. 2. Accelerograms from station ABC. Traces are plotted to show P arrival; they are clipped for S-waves. The peak acceleration was 24 gals on the EW component.

The I. I. has similar acceleration stations at SAH and IIM (Fig. 1) at epicentral distances of 5 to 6 km; however due to attenuation and low gain only S-readings could be used. These S-arrivals were of lesser quality than the ABC-readings. At station IIM there is also a SP seismometer. Thus P-readings could be picked very accurately; however S-waves saturated the tape. Fortunately Red Sismológica Mexicana de Apertura Continental (RESMAC) also operates a digital seismic station (SP-Z) close to I. I. thus permitting unsaturated recordings of all 5 events. In addition a large number of stations at epicentral distances of more than 25 km recorded the events (Table1,2); however these were only used in determining the fault plane solution.

TABLE 2

STATION COORDINATES

Station code	Latitude N	Longitude E
IIM *	19.326	99.182
ABC *	19.400	99.205
SAH *	19.393	99.147
TAC **	19.405	99.194
CGA **	19.358	99.212
ICC *	19.767	99.258
IIP *	19.347	98.918
CA2 *	17.975	100.048
III *	19.376	99.468
OXM **	19.294	99.688
TPM **	18.983	99.057
CRX ***	19.406	99.680
CAP **	19.352	99.231
CED **	19.359	99.243
CSM **	19.393	99.147

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Of the 5 largest events, only the last two were recorded clearly by one portable field station CGA operated by the Institute of Geophysics. A large number of smaller events were recorded by various field stations in the period Feb. 4 to Feb. 9. For the Feb. 20, 1980, event readings from stations IIM, IIP and IIC were used (Table 1). Both the ABC and TAC recordings are missing.

EPICENTERS

From Table 1 it is seen that the arrival times relative to station IIM have a variation of less than 0.4 seconds indicating that these 5 events occur within a small region. The same is indicated from the seismograms which are quite similar for the 5 events (Fig. 3,5). Thus to get an accurate average location average relative readings were used (Table 1). The HYPO 71 location program (Lee and Lahr, 1978) was used with the following model:

Velocity, km/sec	Depth to interface, km
2.9	0.0
4.7	2.0
6.6	4.0
7.1	30.0
8.1	35.0

The two first layers of this model is taken from a study of the crustal structure in the Valley of Mexico (Havskov and Singh, 1979) while the rest of the model is based on minimizing residuals while locating Mexican earthquakes. Since only stations within an epicentral distance of 10 km are used, the two first layers are the most important. The velocity ratio V_p/V_s was determined from the S and P readings at stations IIM, TAC, and ABC and resulted in the value 2.11. This high ratio is probably caused by water saturation lowering the S-velocity.

With the above mentioned model the average epicenter was located at 19.378°N and 99.196°W (5.8 km N and 1.4 km W of station IIM) and the depth was 1.2 km. Changing the model did not change the epicenter significantly, however the depth was sensitive to model changes, especially changing the depth of the first interface. It seems likely however that the events were very shallow considering the large surface waves generated (Fig. 3, Fig. 5).

The epicenter can be compared with the isoseismic map (Fig. 1) (J. Figueroa, personal communication) and there is good correlation between the epicenter and the region of maximum intensity.

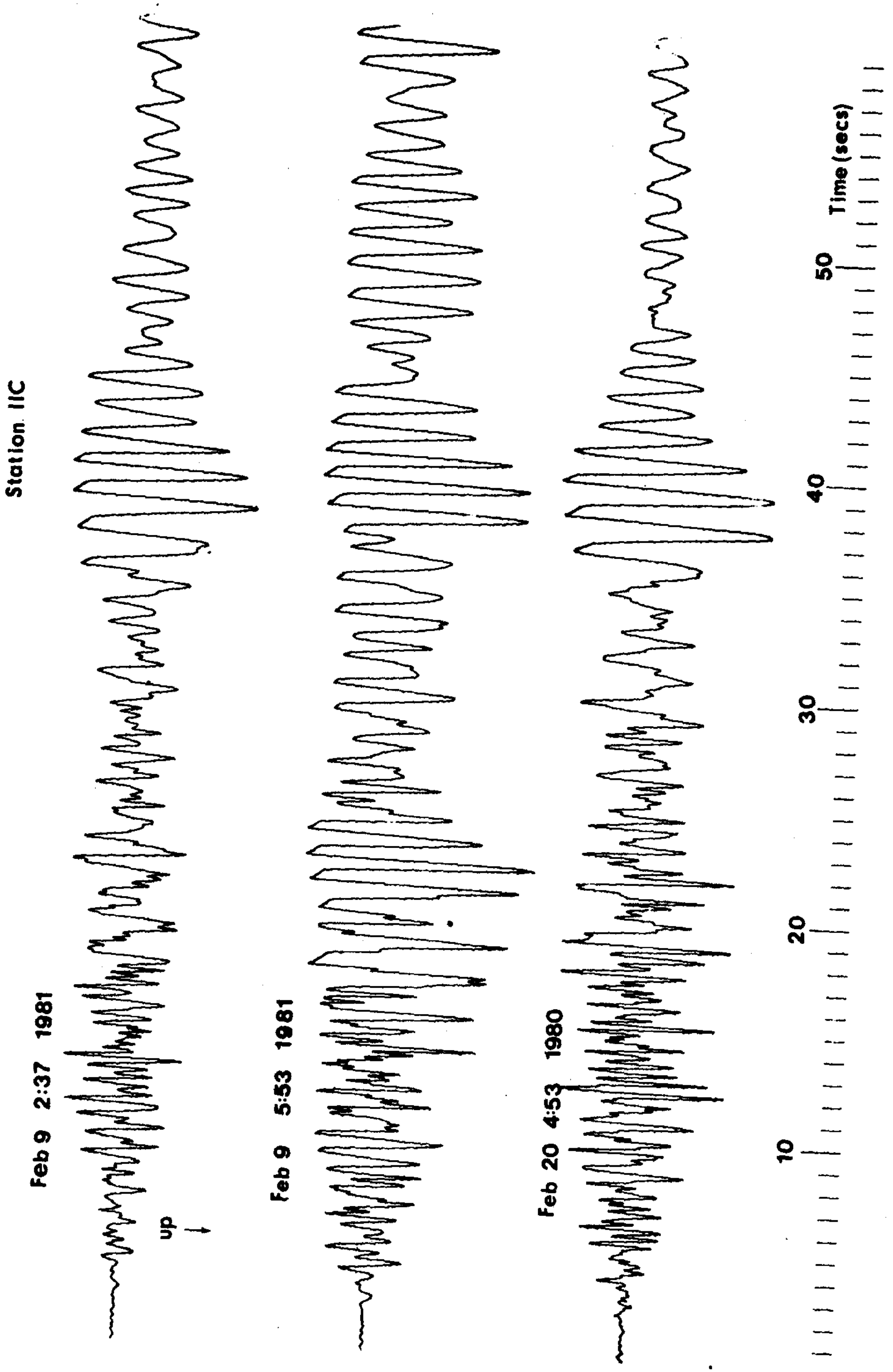

Fig. 3. Seismograms of some of the smaller events registered at station IIC.

Changing the V_p/V_s ratio to the normal value of 1.78 shifts the epicenter 1.1 km to the west, the depth to 1.0 km and increases the RMS error from 0.15 to 0.30. It thus seems that the high V_p/V_s ratio is real and not a result of misidentifying S arrivals.

Table 1 also gives the travel time residuals from all stations recording any of the 5 large events. It is seen that the readings from TAC and ABC do not agree well. There may be a clock difference between I.I. and TAC; however eliminating TAC only changes the epicenter 0.3 km to the south and depth remains unchanged.

The small changes in the relative arrival times (Table 1) indicate small but systematic changes in hypocenter location. To determine these relative changes accurately the master event technique was used with stations IIM, IIP, IIC, ABC and TAC. The residuals from the average event (Table 1) (or master event) were substracted from the readings of the 5 individual events which then were relocated.

The event of Feb. 20, 1980, was also located using the same residuals but employing only P readings from stations IIM, IIP and IIC. Thus the depth for this event was fixed at 1.2 km. Table 3 and Fig. 4 show the results. It is seen that the hypocenters 1-5 are contained within a volume of less than 1 km^3. The epicenters show relatively large standard errors (Fig. 4) making it difficult to decide on any alineation. Although the two best located events (#4 and 5) and the event of Feb. 20, 1980 could indicate a N 45°W alignment, it should be pointed out that the epicentral error of the 1980 event may be large (unknown but at least of the order of 1 km).

The two near stations TAC and ABC receive the first arrivals as direct waves while at the more distant stations, the first arrivals are refracted rays. This gives a very good constraint on depth determination since travel time-depth derivative $\partial T/\partial H$ will have different signs for near and far stations. The same is true for the epicenter determination in the north-south direction due to the predominantly north-south alignment of the stations while east-west control is poor being essentially controlled by only station IIP. Thus the spread in the epicenters in the east-west direction as seen on Fig. 4 is most likely due to error in relative location and in general it is to be expected that depths are better constrained than epicenters, as also indicated by the estimates of standard errors of location (Table 3). Thus the clear migration towards deeper hypocenters seen for the last events in the series is most likely real. This could explain higher intensities and greater damage reported for the first event as compared to the subsequent events although magnitudes were similar.

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TABLE 3

The table gives the average location of events 1-5, the location of each of the 5 events and the location of the 1980 event. X and y are linear coordinates relative to station IIM, z is the depth, RMS are the RMS travel time residual, and ERRH and ERRZ are the horizontal and vertical standard errors in location, respectively, as given by the HYPO71 program.

Event	Latitude N	Longitude E	x(km)	y(km)	z(km)	RMS(sec)	ERRH(km)	ERRZ(km)
Average	19.378	99.196	-1.5	5.8	1.2	0.00	0.0	0.0
1	19.379	99.195	-1.3	5.9	0.7	0.05	0.5	0.2
2	19.376	99.204	-2.3	5.5	1.0	0.06	0.8	0.4
3	19.379	99.199	-1.7	5.9	1.5	0.04	0.4	0.2
4	19.378	99.195	-1.3	5.8	1.4	0.01	0.1	0.1
5	19.381	99.195	-1.4	6.1	1.6	0.02	0.3	0.1
FEB 80	19.366	99.172	1.0	4.4	1.2*	0.00	---	---

* Depth fixed

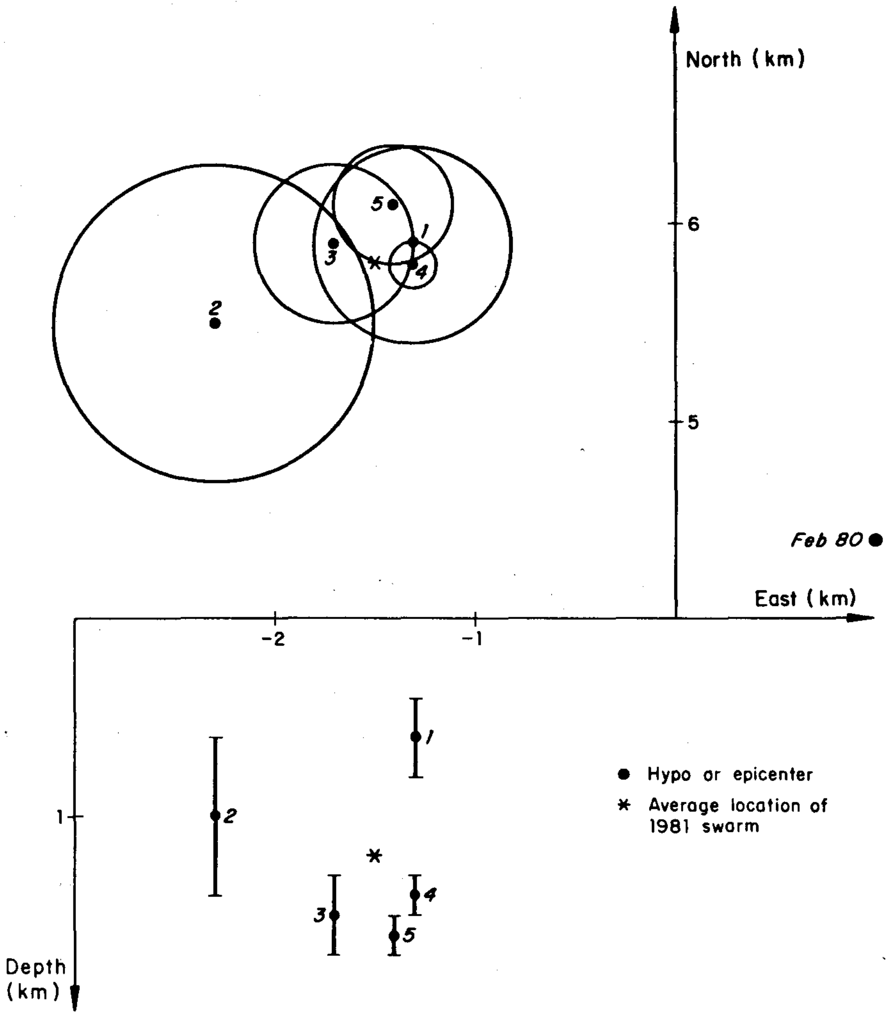

Fig. 4. Relative locations of individual events (top) and corresponding E-W profile (bottom). The origin of the coordinate system is at station IIM. The circles and error bars indicate HYPO-78 standard errors in location.

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SPECTRAL ANALYSIS

P-wave spectra were made for all 6 events using the digitally recorded data from the RESMAC station MEX, which is located less than 200 m from IIM. The signals used and the time window selected (1.7 sec) are shown in Fig. 5.

P waves were used instead of S waves since the latter were difficult to identify.

Moment, source radius and stress drop were calculated using the extension of Brune's model (Brune, 1970) to P waves (e.g. Hanks and Wyss, 1972). A P-wave velocity of 2.9 km/sec and a density ρ of 2.5 g/cm^3 were used. Spectra were calculated both with and without correction for Q (Fig. 6). Since Q is unknown, a value of 100 was chosen which is probably reasonable for the upper crust in Mexico City which consists of water-saturated sedimentary layers.

Table 4 gives the moment, source radius, stress drop, magnitude (M_L) and displacement on the fault, with and without correction for Q. It is seen that selection of Q is not critical in determining the spectral parameters. The magnitude M_L was estimated from the relation (Hanks and Kanamori, 1979, Singh and Havskov, 1980)

$$M_L = \left(\frac{2}{3}\right)\log M_o - 10.55 \qquad (1)$$

and displacement D was obtained from

$$\bar{D} = \frac{M_o}{\mu \pi r^2} \qquad (2)$$

In Eq 2 the rigidity μ was calculated from $\mu = \beta^2/\rho$, where β is the S wave velocity. Using $\beta = 1.4$ km/sec and $\rho = 2.5$ gives $\mu = 4.7 \times 10^{10}$ dyne/cm^2. Table 4 also gives the coda length τ(sec) measured at station IIC and the corresponding coda magnitude M_C calculated from (Real and Teng, 1973)

$$M_C = -1.01 + 1.89 \log \tau$$

Relative consistency in the magnitudes estimated from M_O and coda duration suggests that M_O estimates are not in gross error. Since the moments and the magnitudes of all events are nearly equal, the sequence has been called an earthquake swarm. Stress drops are rather low, which could be expected for events occurring in sedimentary layers and although the stress drop is the least well determined parameter, it seems that later (and deeper) events have lower stress drop.

The source parameters for the 1980 and 1981 events are similar, indicating a similar cause for their origin.

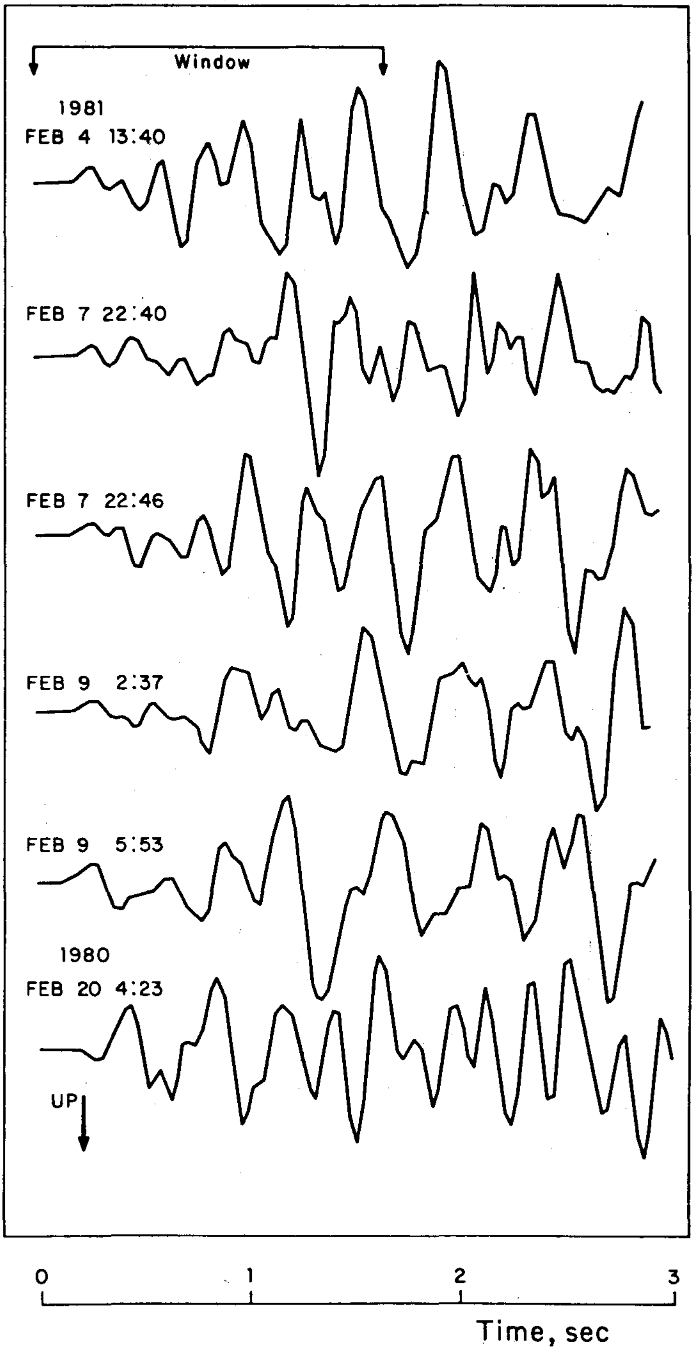

Fig. 5. The first 3 seconds of the seismograms as recorded at RESMAC station MEX. Traces are scaled such that the plotted peak amplitude of all the events is the same. Also shown is the time window used for spectral analysis.

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TABLE 4

FOCAL PARAMETERS

M_L is the local magnitude, estimated from moment, M_C coda magnitude and u the displacement on the fault

				Q = ∞				Q = 100					
	Time of event	Corner frequency (H_z)	Source Radius (km)	Moment x10^{20} dyne-cm	Stress drop, bars	M_L	u(cm)	Moment x10^{20} dyne-cm	Stress drop bars	M_L	u(cm)	Coda Length (sec)	M_C
1981	Feb 4, 13:40	4.0	0.27	2.01	4	3.1	1.9	2.42	5	3.3	2.2	220	3.4
	Feb 7, 22:40	4.0	0.27	1,03	2	3.0	1.0	1.50	3	3.1	1.4	220	3.4
	Feb 7, 22:46	3.8	0.28	1.00	2	3.0	0.9	1.59	3	3.1	1.4	205	3.4
	Feb 9, 2:37	3.4	0.32	0.38	0.5	2.7	0.3	0.43	0.6	2.8	0.3	150	3.1
	Feb 9, 5.53	3.5	0.31	0.48	0.7	2.8	0.3	0.61	0.9	2.9	0.4	180	3.3
1980	Feb 20, 4.23	4.1	0.26	0.65	2	2.9	0.7	1.03	3.0	3.0	1.0	150	3.1

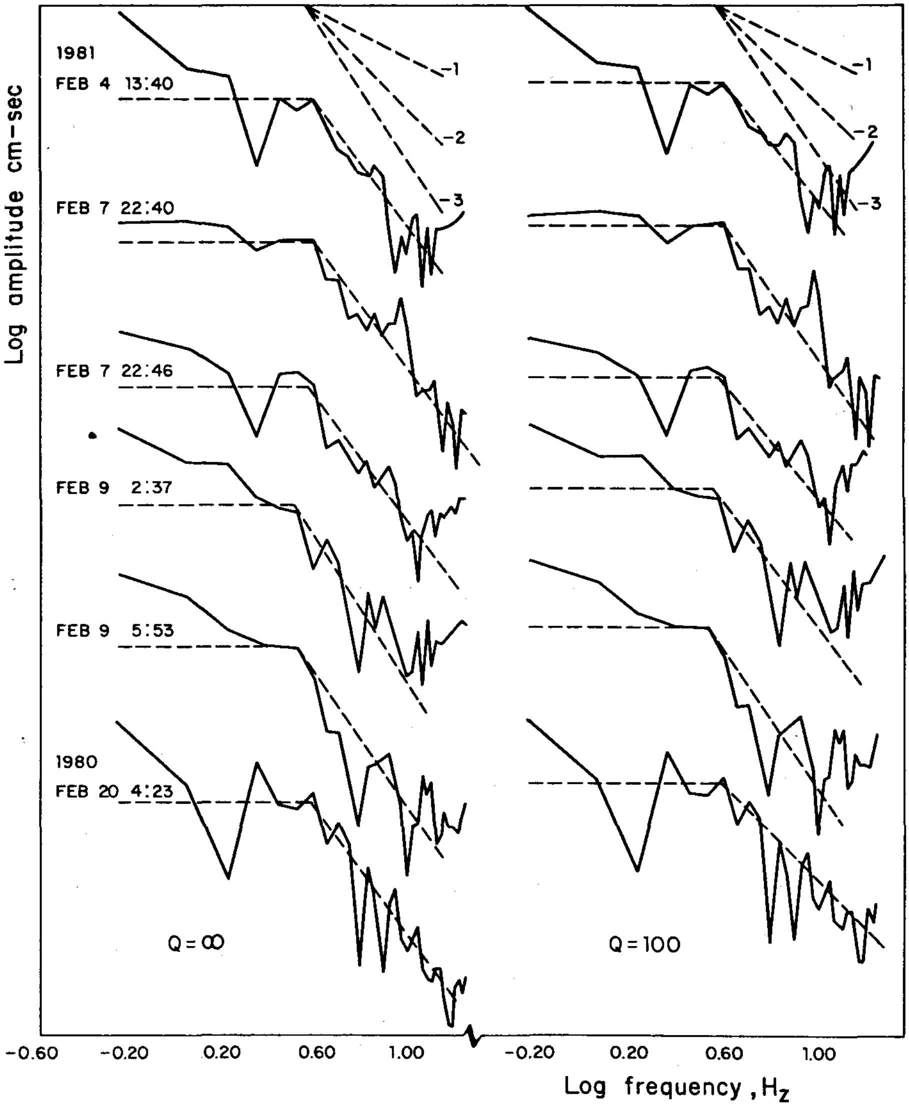

Fig. 6. The displacement spectra with and without correction for Q. The selected low frequency spectral levels and roll-offs are indicated by dashed lines. Decay rates of f^{-n}, $n = 1,2$ and 3 are indicated in the upper left hand corner. The vertical scale of individual spectra are shifted, however they are all plotted with the same scaling factor.

FAULT PLANE SOLUTION

First motions for the first event was initially used in the fault plane solution and projected on to the lower hemisphere in a stereographic equal area projection using stations TAC, IIM, IIP, IIC, III, ABC, TPM, OXM, and CA2 (Fig. 7). Since the first motions of events 2-5 on the same stations remained almost constant, it seems that the focal orientation for the individual events in the swarm did not change appreciably. Therefore, data was added from some of the later events recorded on field stations. Events 4 and 5 were recorded at station CGA while the polarities used for stations CAP, CED and CSM were read from smaller events occurring before event 5.

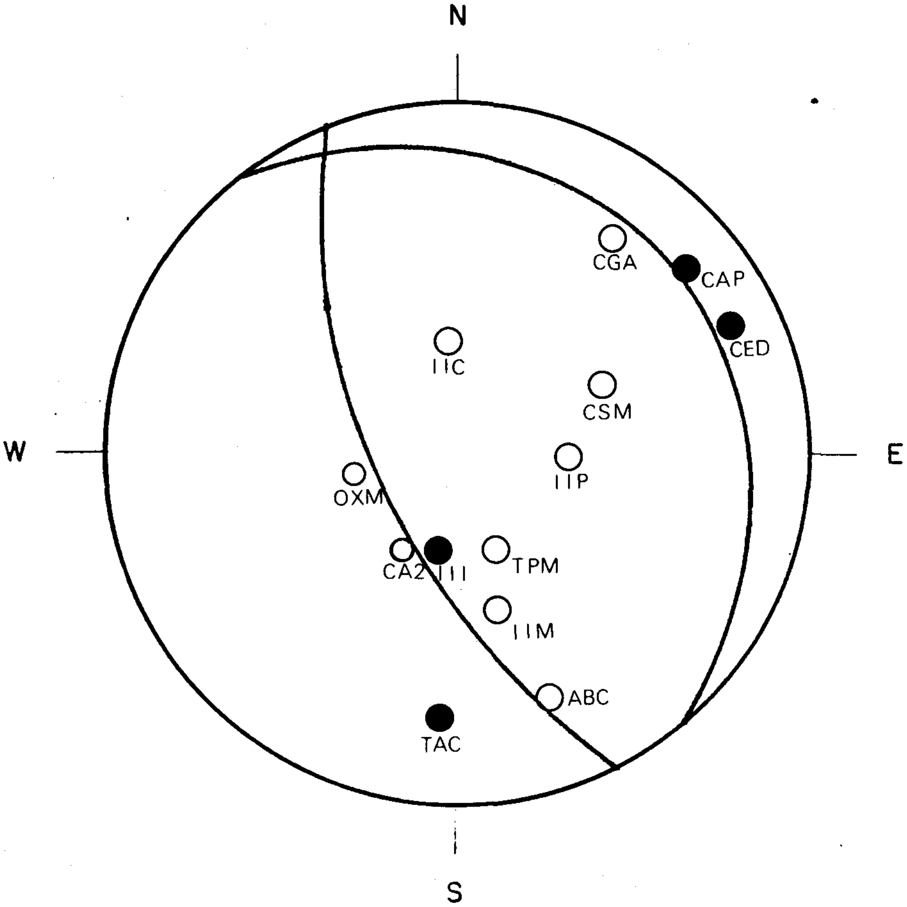

Fig. 7. Fault plane solution. Solid circles are compression and open circles dilations. All data is from the largest event except the first motions for the field stations CSM, CGA, CAP and CED which are from later events (see text).

In Fig. 7 fault plane solution is shown. Compression at III is inconsistent with the focal mechanism. Ignoring III it is possible to draw extreme fault plane solutions (not shown in Fig. 7). In any case they all show a normal fault on a nearly vertical N-S plane or a nearly horizontal E-W plane.

DISCUSSION

The seismic history of the Valley of Mexico is not known with sufficient precision to say whether the present series of earthquakes, in terms of magnitude and location, is a normal occurring sequence or something unexpected. Two possibilities for the origin are (a) the events are of tectonic origin and occur as a result of accumulation of regional stress and (b) the events are related to the sinking of the Valley of Mexico.

The fault plane solution shows a normal fault with the tensional axis going nearly east-west. Several events in the Mexican volcanic belt show similar normal fault solutions (Molnar and Sykes, 1969; Jiménez and Ponce, 1978; Singh and Wyss, 1976; Astiz, 1980) and it is possible that the February swarm was caused by this regional tectonic tensional regime. In the valley there are both older north-south and younger east-west going vertical faults (F. Mooser, personal communication) and it is possible that some of the N-S aligned faults have been activated by the regional tension. This seems to favor the near vertical fault in the fault plane solution. Although hypocentral locations are not accurate enough to assure that all events occurred on the same plane this seems likely considering the migration of the hypocenters.

The area of maximum sinking of the Valley of Mexico constitutes a nearly north-south going trough located a few kilometers to the east of the epicentral area, as known from levelling data until 1974 (Wade *et al.*, 1975) and the sinking in the period March 1970 to August 1973 was of the order of a few centimeters a year.

In Long Beach, California, a subsidence rate of a maximum of 71 cm/yr due to extraction of oil and water caused earthquakes of similar magnitudes as observed in Mexico City (Kovach, 1974). The earthquakes occurred about 1 km away from the area of maximum subsidence, and it was concluded that they were caused by horizontal tension originating from the sinking. Depths were about 500 m and borehole samples showed that slippage had occurred on horizontal planes.

In Mexico City the subsidence rate does not seem to reach similar high values; however, the sinking could cause tension in the epicentral area in the direction observed from the fault plane solution. Although the near vertical fault plane is favored, the possibility of slip along the second possible plane dipping down towards the east cannot be ruled out. Since the earthquakes are located close to the boundary of the transition zone, slip might have occurred on the contact between different geological layers.

Related to the sinking is the water pressure changes measured in wells. From 1970 to 1974 changes were largest in the western part of the valley near the epicentral area and reached values of about 1 bar (Wade *et al.*, 1975).

For the period January 1978 to October 1981 the maximum change of water pressure in wells near the epicentral area was about 0.5 bar (X. Haro, personal communication). Near dams, it has been observed that pore pressure changes of the order of 1 bar can trigger small earthquakes (Talwani, 1976) and the pore pressure changes under the valley might have some influence on the time of occurrence of tectonic earthquakes which would have occurred anyway.

CONCLUSION

The earthquake swarm recorded in Mexico City in February 1981 constitutes the best data set obtained so far for any event in the valley. The 5 largest events occurred within a volume of 1 km^3. The fault plane solution and relative hypocenter determination suggest that the hypocenters were most probably located on a single nearly vertical N-S plane. The events seem to be caused by a near E-W tensional regime which most likely has its origin in the regional tectonics, although the sinking of the valley could cause similarly oriented tension which also could influence the seismicity.

ACKNOWLEDGMENTS

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