Geofísica Internacional (1995), Vol. 34, Num. 2, pp. 221-231

Seismicity of the State of Puebla, Mexico, 1986-1989

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Received: June 22, 1994; accepted: February 15, 1995.

RESUMEN

En este trabajo se presenta un análisis de la actividad sísmica del estado de Puebla y sus inmediaciones, registrada durante el periodo de enero 1986 a agosto de 1989 por la Red Sísmica del Estado de Puebla (RESEP), perteneciente a la Universidad Autónoma de Puebla (UAP). La localización epicentral de los eventos fue determinada mediante la aplicación de los programas HYPO71PC y HYPOCENT. Se calcularon los errores teóricos en la localización de eventos mediante el programa HYPOERR los cuales coinciden con los errores estimados en las localizaciones. El análisis de los 350 eventos localizados con un residual cuadrático menor de 2, muestra que la mayoría de eventos tienen una profundidad menor de 50 km con excepción de la región sur de la zona de estudio, en la cual ocurren también sismos con profundidades mayores de 50 km. Estos últimos parecen estar asociados al contacto entre la litosfera oceánica y la continental que corresponden a las placas de Cocos y Norteamericana, respectivamente. El 92% de los eventos estudiados tiene una magnitud de coda entre 2 y 4, aunque es im-portante resaltar que en el área de estudio se han registrado eventos con magnitud mayor de 7.0.

PALABRAS CLAVE: Sismicidad, hipocentro, magnitud, estado de Puebla.

ABSTRACT

The seismic activity in the State of Puebla, Mexico and its surroundings, between January 1986 and August 1989, is discussed using data from the seismic network of the University of Puebla. The hypocentral locations were obtained using the programs HYPO71PC and HYPOCENT. The calculated theoretical errors using the program HYPOERR coincide with the estimated errors from the location procedure. A total of 350 earthquakes were located with rms less to 2. Most of the hypocenters are at depths less than 50 km, with the exception of the southern region, where events deeper than 50 km are found. These deeper events are probably associated with the contact between the oceanic and continental lithospheres, which correspond to the Cocos and North American plates. 92% of the events have coda magnitude between 2 and 4, although events with magnitudes greater than 7 have occurred in this region.

KEY WORDS: Seismicity, hypocenter, magnitud, Puebla State.

INTRODUCTION

Studies of the seismic activity in a region contribute to the determination of seismogenic zones and the elaboration of seismic zonation maps for engineering and disaster management purposes (Gutiérrez *et al*, 1991). The State of Puebla is located in a region with intermediate depth seismicity, as in the Orizaba earthquake of 1973 (M=7.3) and the October 24, 1980 Huajuapan de León earthquake (M=7.0), (González-Ruiz, J., 1986). The State is also located relatively close (≈ 350 km) to other zones of major seismic activity in south-east Mexico (Figure 1). The State of Puebla has four major urban centers, including the state capital, with a strong population, economic and industrial growth.

The State of Puebla is located between 17.8° and 20.8°N, and between 96.0° and 99.7°W. To the north and to the east, it shares boundaries with the State of Veracruz. The Sierra Norte de Puebla is a continuation of the Sierra Madre Oriental, the Cofre de Perote mountain, the Derrumbadas mountain zone and the Citlaltépetl volcano. To the south, the State borders with the States of Guerrero and Oaxaca where we find the Sierra Negra, the Mixteca Poblana and the continuation of the Sierra Madre Occidental in the Sierra Madre del Sur, its most important feature is the Tehuacán fault. To the west it borders with the States of Morelos and Mexico, where the Popocatépetl and Iztaccihuatl strato-volcanoes are located, and with the States of Tlaxcala and Hidalgo where the Malintzi volcano is situated (Figure 2). The State is traversed by five lower Miocene fault systems (Mooser, 1972); the more important ones are Popocátepetl-Chignahuapan, Malintzi and Atoyac-Minas. The seismic activity in the region may be due to tectonic movements or to volcanism.

An early seismic study of the State of Puebla and its sourroundings is by Figueroa (1974). His catalog covered from 1523 to October of 1973, including historic investigations of major earthquakes up to 1910, plus instrumental earthquakes with magnitudes greater than 3 from 1911 to October 1973. He reports a total of 231 earthquakes; 108 historical events and 123 instrumental earthquakes.

Gómez and González-Pomposo (1983), report 104 earthquakes of all magnitudes from 1976 to February 1983.

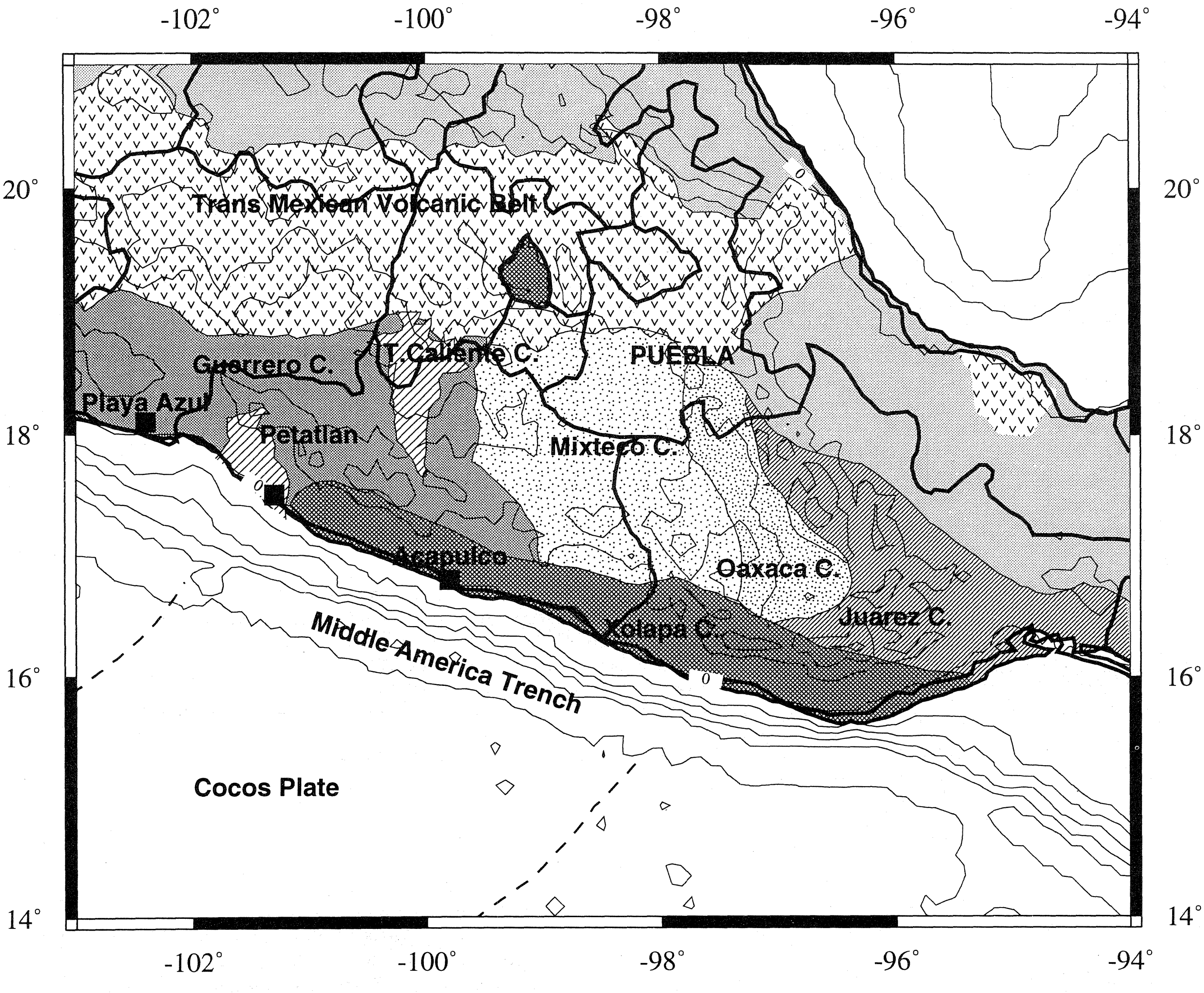

Fig. 1. Location map of the study area.

Thus all previous studies report only 227 earthquakes between 1911 and February 1983. This small number may be attributed mainly to the lack of seismic instrumentation in the region.

On November 29, 1985 the Seismic Network of the State of Puebla (RESEP) began operation. Initially RESEP had three seismic stations, in Chiautla de Tapia (CHP), Molcaxac (MOP) and Cuyoaco (CUP) (Serrano and González-Pomposo, 1985). In 1986 a station was added in Coxcatlán (CXP). In 1987 RESEP installed three more stations in Chila de las Flores (CIP), Ciudad Universitaria (UAP) and Xalitzintla (XLP) (González-Pomposo *et al.*, 1987). These seven seismic stations operated through August 1989 (Figure 3). The geographical coordinates of the RESEP stations, and of supporting stations belonging to SISMEX (IIT, IIS, IIA, IIC, III), plus those belonging to the National Seismic Network, (VHO, OXM, LVM and TPM) are shown in Table 1. All together, these stations provide a wide coverage and adequate control of hypocentral determinations in the region of interest.

INSTRUMENTATION

The equipment used in the RESEP stations was analogic, one-component Vertical and with smoke paper recording. Each station had a Ranger SS-1 seismometer

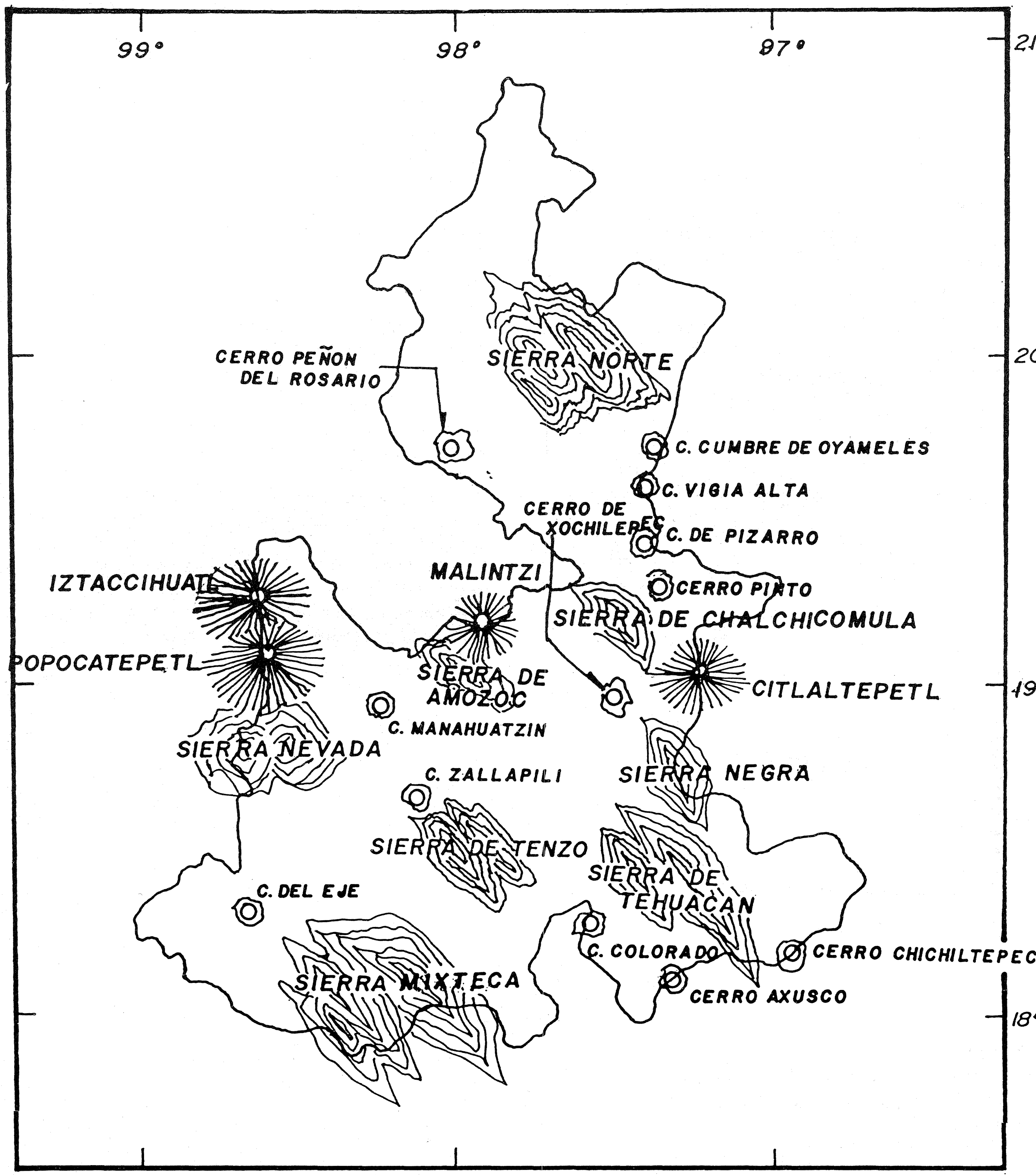

Fig. 2. Orography of State of Puebla.

with a natural period of 1 sec, with an MEQ-800-B seismograph, and a UTC radio time receiver in the 5, 10 and 15 MHZ frequency band. The housing for the equipment was designed at the School of Civil Engineering, and the power systems were built at the Department of Electronic Maintenance of the School of Physics and Mathematics, also of the University of Puebla. The stations CHP, CUP, CIP, and XLP, are on bedrock, while for stations MOP, UAP, and CXP are on a one cubic-meter concrete piers due to poorly consolidated ground. The seismic stations were visited once a week for recollection of data and for maintenance up to 1989 (Serrano and González-Pomposo, 1985).

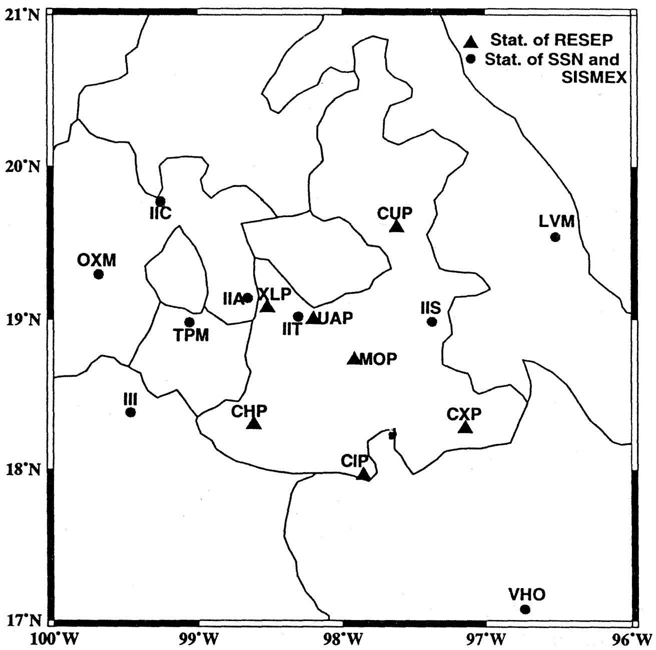

Fig. 3. Stations of RESEP.

Table 1

Coordenates of stations of RESEP

NAME	Code	Lat. N	Log. W	Altitude (m)
Chiautla de Tapia, Pue.	CHP	18.298	98.613	1030
Chila de las Flores, Puebla.	CIP	17.963	97.854	1765
Cuyoaco, Puebla.	CUP	19.603	97.619	2450
Coxcatlán, Puebla.	CXP	18.274	97.142	1280
Molcaxac, Puebla.	MOP	18.733	97.917	1840
Ciudad Universitaria, Pue.	UAP	19.001	98.203	2114
Xalitzintla, Puebla.	XLP	19.079	98.521	2600

Coordenates of station of SSN and SIXMEX

NAME	Code	Lat. N	Log. W	Altitude (m)
Alzomoni, Edo. de México.	IIA	19.143	98.655	3900
Santa Rita Coyotepec	IIC	19.757	99.258	2725
Iguala, Guerrero	III	18.376	99.468	1750
Ciudad Serdán, Puebla.	IIS	18.986	97.372	
Tonanzintla, Puebla.	IIT	19.021	98.308	2205
Laguna Verde, Veracruz	LVM	19.613	96.395	160
Oxotitlán, Edo. de México.	OXM	19.296	99.688	2700
Tepoztlán, Morelos.	TPM	18.983	99.061	1500
Observatorio, Oaxaca Oax.	VHO	17.079	96.732	1685

DATA PROCESSING

Locations of event were evaluated with the program HYPOERR (Lienert *et al.*, 1986). This program provides uncertainties estimated for a specific station distribution with a given layered model. It calculates vertical and horizontal uncertainties in hypocentral locations, as well as origin-time uncertainties. An analysis was carried on with all 16 stations in Table 1 to determine the precision in origin time, latitude, longitude and depth determination for events located within the region 96.2 to 99.2°W and 17.3° to 21.0°N, and 0 to 60 km depth at 10 km intervals.

The data collected by RESEP were processed as follows. First, the arrival times for the P and S waves (T_p and T_s) were read as well as they characteristics, the signal duration, and maximum amplitud of each record. We applied the criteria that the seismic events should have a $\Delta t = T_s - T_p$ of less than 20 seconds at three stations for the event to be included as belonging to the region. Records from SISMEX and SSN stations were included. If the s-p difference was larger, the readings were sent to SSN to be used in the location of regional events.

The events were then located using the computer location program HYPO71 (Lee and Stewart, 1975). This program calculates in an iterative way the hypocentral parameters. The program uses an analytic expression of first arrival travel times in a flat layered model using non-linear least squares. For the hypocentral determinations we also used HYPO-PC (Lee and Valdés, 1985). This program was tested with more than 20 stations and with a seismic model of up to 10 flat layers. In order to improve the hypocentral determination, we also used HYPOCENTER (Linert *et al.*, 1986) with the seismic model in Table 2.

Table 2

Layered velocity model

Thickness (km)	Velocity (km/s)
0 - 5	5.00
5 - 20	6.10
20 - 25	6.95
25 - 45	7.60
45 - 00	8.10

The flat layer model used in the present study (Table 2) is in agreement with the one proposed by Valdés *et al.* (1986). This model was constructed by P-wave ray-tracing in two dimensions. The seismic profile was oriented north-south across the central part of the region of study. The explosions were located in Lake Alchichica, north of the city of Puebla, and off the Coast of the Pacific Ocean. This model provided hypocentral determinations with the smallest residuals. In comparison with the layer models from SISMEX, SSN and RESMAC the hypocentral locations were less scattered and had lower residuals. Layered seismic models based on other seismic profiles (Nuñez-Cornú, 1988; Singh and Pardo, 1993) were also tested, but found to be inadequate.

Coda magnitudes were computed after Havskov and Macías (1982)

$$Mc = 0.09 + 1.85 \log(Z) + 0.0004(D),$$

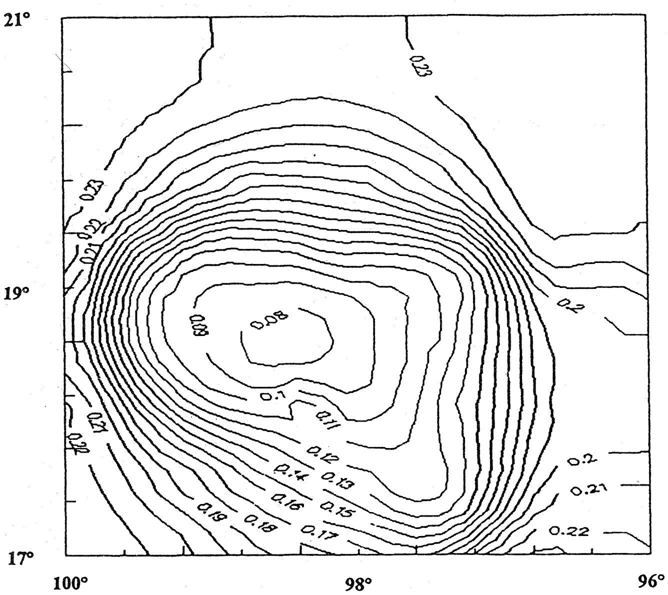

Fig. 4. Origin time (error in sec.).

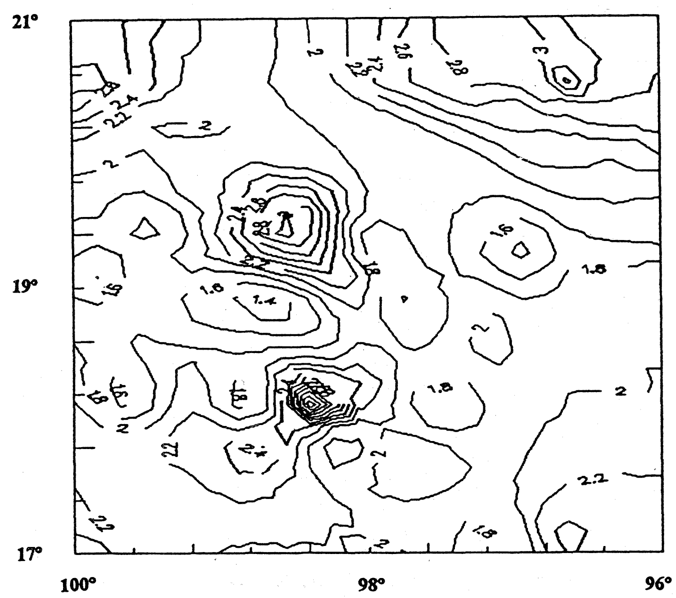

Fig. 5. Depth (error in km.).

where Z is the signal duration in seconds and D is the epicentral distance in km.

RESULTS

The results for the evaluation of the seismic network using the program HYPOERR at a depth of 30 km, shows that for the central region (~98.5° to 99.5°W and 18.5° to 19.5°N) the origin time error is less that 0.11 seconds. For the outer area the error is up to 0.23 seconds (Figure 4). The uncertainties in the latitude and longitude determination at a depth of 30 km and for the same regions values of 1.4 km and 3.5 km were calculated, respectively. In the case of the depth uncertainty, the values obtained were 1.4 km and 1.8 km for the same regions as before (Figure 5).

The maximum errors found in hypocentral determination for the central region was 1 to 3 km error in the depth calculation, and 9 to 11 km error for the outer region. The origin time errors were in the range of 0.3 to 0.4 seconds. Larger estimated errors in the north region are due to the sparse network coverage. The south region has the highest seismic activity. The evaluation of the uncertainty in the hypocenter parameter determination indicates an acceptable error range.

Figure 6 shows the seismic events located with the program HYPOCENT, as well as their errors in the latitude and longitude estimation. These errors disagree with those calculated by HYPOERR, because not all 16 stations used in HYPOERR recorded P and S waves arrivals for all events. There were a total of 580 of events registered by RESEP between January 1986 and August 1989. From these, only 350 (60 %) have an RMS error smaller than 2 seconds in origin time. Table 3 shows the hypocentral parameters.

Among 350 events, 43% had magnitudes between 2 and 3, 49% between 3 and 4, 8% between 4 and 5, and only one event greater than 5. This events is on the edge of the region of study. Figure 7 shows the magnitude vs number of events distribution. The catalog appears to be complete for magnitudes between 1.5 and 3.3. The b value estimated is 1, which is the expected value for shallow tectonic events (Bullen and Bolt, 1993).

Figure 8 shows a histogram of the monthly seismicity for the period of time studied. We observe an increment of seismicity starting in June, 1986 and reaching a peak in June, 1988, then a decrease until August 1989 when the network stopped operation. The months with hihg activity are: June, 1986 (17 events); January, 1988 (16 events), June, 1988 (28 events), September, 1988 (17 events), February 1989, (19 events) and March, 1989 (15 events).

Between 96° and 100°W and 17° and 18.5°N, we located 241 earthquakes (69%). This corresponds to the Chiautla, Tehuacán, Acatlan, border of Puebla-Guerrero and Puebla-Oaxaca active regions. Thus the seismicity of the State of Puebla is concentrated in the South region. In the Central zone (18.5° to 20°N) only 26% of the events are located; this includes the regions of Zacatlán, Atlixco, Puebla City, Serdán and the border between Puebla-Veracruz, a region of moderate seismic activity. At the borders of the States of Tlaxcala-Mexico-Hidalgo (98.3° to 99.1°W and 19.4° to 20°N), only 18 events were located, 11 during May, 1986. They are probably associated with the Tlaloc-Actopan fault system. In the region know as Derrumbadas, close to

Table 3

no	Date	Hr: Min	Sec	Lat N	Log W	Depth	Mag	rms
1	860104	1538	16.00	19.6053	99.0142	37	4.2	1.3
2	860108	1220	35.15	17.9550	99.0412	24	3.7	0.6
3	860109	329	58.02	18.7260	99.3515	37	3.9	1.7
4	860210	913	28.66	18.6158	98.6148	37	3.5	0.6
5	860219	1913	40.82	18.7310	98.7300	16	4.0	1.3
6	860220	2054	51.78	18.1322	96.3017	41	4.9	1.7
7	860320	1012	34.07	19.3457	97.6137	20	3.4	1.7
8	860329	10 7	26.35	18.0110	100.0128	37	3.9	1.4
9	860502	2322	49.28	18.7183	100.3603	41	4.0	1.7
10	860508	1844	30.25	19.6685	98.6672	30	4.0	1.9
11	860508	1929	22.18	19.7908	98.6622	29	3.8	0.9
12	860508	1940	2.13	19.8372	98.7243	37	3.2	1.6
13	860508	2040	4.87	19.5992	98.8405	37	3.5	1.9
14	860509	0 4	39.41	19.7687	98.6622	37	3.6	1.4
15	860510	1645	53.42	18.3777	99.7703	32	3.7	1.1
16	860511	653	55.79	19.5892	98.8105	34	3.5	0.5
17	860511	1014	29.10	18.0807	99.4438	24	3.0	0.3
18	860511	1227	26.26	19.6573	98.6503	29	4.1	2.0
19	860512	2348	28.14	19.6538	98.7682	37	3.7	2.0
20	860512	2352	55.66	19.6722	98.7822	37	2.0	1.4
21	860513	1054	36.97	19.6778	98.7065	23	4.0	1.1
22	860513	1056	57.42	19.7118	98.7402	35	3.3	0.8
23	860520	17 1	21.46	18.9780	98.7377	37	2.8	0.2
24	860523	2 2	34.53	19.4905	99.0175	37	3.2	0.5
25	860524	1323	10.83	18.8460	99.2823	21	3.7	1.2
26	860602	10 2	8.87	18.9382	98.6310	31	2.6	0.1
27	860620	124	41.50	18.3003	98.2988	37	3.5	1.9
28	860630	430	34.62	19.2867	98.7268	37	2.6	0.4
29	860715	23 7	2.86	18.6602	99.4697	23	3.8	1.4
30	860727	955	31.10	18.3938	99.4038	32	3.9	1.1
31	860729	1217	14.56	18.1238	99.7497	56	4.2	0.5
32	860812	2119	6.19	18.7350	97.9183	68	2.7	1.3
33	860824	14 4	3.29	18.3003	98.3053	37	3.2	0.7
34	860830	1047	25.41	18.9575	99.5048	37	3.2	0.7
35	860830	1923	46.67	19.6802	98.5718	37	4.0	0.4
36	860830	2234	23.55	19.6915	98.6138	37	3.4	0.5
37	860901	340	33.53	19.6363	98.6877	37	3.4	1.9
38	860902	1617	30.60	18.7303	98.6382	37	2.9	1.6
39	860911	216	54.70	19.6375	98.7713	14	3.7	1.4
40	860925	357	33.19	18.4420	97.9183	64	2.9	1.4
41	861010	047	30.34	18.7605	98.5857	37	3.3	0.4
42	861013	312	31.80	19.1682	98.5867	11	3.3	0.5
43	861030	242	28.00	18.4592	99.4697	37	3.9	0.8
44	861119	7 7	19.38	18.1332	98.4383	37	2.9	0.4
45	861123	934	23.68	18.7747	98.6778	39	3.0	0.1
46	861206	1013	11.18	17.8485	98.2333	37	3.0	0.4
47	861207	452	27.51	18.8365	99.4697	41	3.5	1.9
48	861213	030	29.88	17.7875	98.6727	37	3.6	0.2
49	861215	2315	41.73	18.4938	97.9483	62	3.8	0.6
50	861219	8 4	8.56	18.3003	99.3323	59	2.0	1.4
51	861219	1536	20.30	18.5418	99.5415	20	4.1	1.0
52	861224	726	4.69	17.7973	97.5567	37	3.0	0.1
53	861226	1621	58.54	17.6758	96.7338	37	4.0	0.6
54	861231	2053	19.67	17.4805	96.6615	48	4.4	1.1
55	870115	2034	59.20	18.1780	98.5608	41	3.2	1.0
56	870117	2335	36.34	17.8323	98.1990	33	2.9	0.4
57	870119	4 9	57.46	19.9087	97.1978	37	2.9	1.8
58	870121	341	49.25	18.6940	96.5423	46	3.8	1.3
59	870122	539	8.35	17.8828	97.4492	46	4.0	1.9
60	870126	2357	53.03	19.0577	99.1708	30	3.3	0.6
61	870127	351	35.00	18.1623	98.4622	34	4.4	1.4
62	870129	943	42.74	18.0982	98.3563	37	3.6	2.0
63	870208	1940	38.59	19.3693	99.1965	37	2.3	1.1
64	870218	126	37.35	19.2420	97.6203	24	3.1	0.7
65	870219	8 7	38.68	18.3777	99.4697	37	3.7	1.5
66	870225	738	32.46	19.5017	99.1758	37	2.9	0.9
67	870302	1754	54.12	17.1683	94.1063	37	5.1	0.4
68	870309	1133	27.34	19.2467	97.3785	37	2.9	1.5
69	870312	1847	56.47	19.3843	99.1107	37	3.3	1.4

Table 3 (Cont.)

no	Date	Hr: Min	Sec	Lat N	Log W	Depth	Mag	rms
70	870326	1029	56.43	17.8025	98.1123	37	3.8	1.3
71	870401	616	9.46	18.0305	99.6802	22	4.0	1.2
72	870403	529	24.88	17.9445	99.6653	37	3.3	1.3
73	870406	523	43.84	18.5498	99.4697	50	4.2	1.1
74	870410	10 3	0.39	18.1323	98.4825	41	3.2	0.4
75	870416	524	59.84	17.7740	99.0977	21	3.2	0.7
76	870418	830	42.89	19.5335	98.3342	37	3.1	0.7
77	870422	1841	16.06	17.0712	97.6508	40	3.1	1.5
78	870424	8 7	35.93	17.8638	97.8013	37	2.8	0.3
79	870425	130	12.89	18.0065	99.8690	37	4.7	0.7
80	870501	2328	50.27	17.9870	99.5918	32	3.9	1.9
81	870508	6 0	6.41	18.8845	99.0360	37	3.8	1.4
82	870509	856	31.17	17.0990	97.7032	37	3.6	0.6
83	870513	4 8	47.96	19.2917	97.4115	25	3.4	0.8
84	870525	1240	1.30	19.2708	98.8182	41	3.0	0.3
85	870525	2143	32.03	17.8013	96.9402	37	4.1	1.2
86	870531	737	20.29	18.5152	98.5157	37	2.4	0.6
87	870612	1014	20.05	18.9757	99.2597	37	3.3	1.3
88	870617	8 6	33.89	18.1443	97.6715	37	2.8	0.8
89	870619	439	14.39	18.0707	98.8010	37	2.8	0.4
90	870622	1041	58.51	16.6625	99.0195	37	4.0	1.8
91	870626	1859	13.84	16.5817	98.8218	32	4.1	1.9
92	870627	510	49.21	17.9637	97.4302	37	3.6	0.6
93	870627	1438	30.18	17.6368	97.1435	41	4.0	0.9
94	870630	615	45.46	18.0967	97.5303	37	2.6	0.6
95	870701	1921	6.85	18.0660	97.7652	49	2.0	0.1
96	870703	147	4.91	18.5387	98.6148	41	3.0	0.9
97	870703	530	42.46	18.2642	97.8195	51	2.1	0.3
98	870720	12 1	10.19	18.1640	98.0525	50	2.6	0.4
99	870721	4 3	59.24	18.1503	97.6757	37	3.0	0.6
100	870721	727	44.59	17.5767	97.1177	39	2.8	0.8
101	870721	1520	29.64	17.8330	97.0313	36	4.0	0.9
102	870723	141	52.46	17.8620	96.8202	37	3.0	0.5
103	870723	952	57.64	17.0712	97.0985	37	3.3	1.3
104	870801	2116	18.18	18.4272	99.4507	59	3.5	1.9
105	870803	1758	42.66	18.1018	98.1012	37	2.6	0.7
106	870805	644	9.81	18.4622	98.6148	41	2.8	1.3
107	870805	1152	20.88	18.3003	98.2803	41	2.4	0.9
108	870807	1814	46.82	18.8238	100.0258	37	3.8	0.8
109	870810	1956	52.97	18.0680	98.5612	35	2.7	0.2
110	870814	534	30.85	17.9153	97.6515	48	3.2	0.6
111	870814	940	32.52	18.2028	96.8687	37	4.7	1.0
112	870816	9 3	54.11	19.3930	98.1713	32	3.1	1.0
113	870818	1149	11.08	17.9207	98.4280	37	3.0	0.4
114	870819	1347	32.95	17.7447	98.1583	39	3.4	0.3
115	870823	945	16.71	17.8417	97.7937	23	2.9	0.3
116	870831	720	33.21	17.5242	97.4147	37	3.3	1.2
117	870909	7 1	19.29	18.8260	96.3187	32	2.8	1.8
118	870909	16 0	55.59	17.2352	96.9662	37	3.6	0.5
119	870914	2357	2.74	18.1342	97.5567	45	3.3	1.1
120	870915	1921	55.94	17.9800	97.7683	54	3.4	0.3
121	870917	1010	0.68	17.9802	97.1435	37	3.5	1.7
122	870919	738	15.72	17.3697	97.2348	40	2.8	0.5
123	870920	1434	55.95	18.0080	98.5832	19	2.7	0.3
124	870925	747	44.84	17.8335	98.5102	13	3.5	0.7
125	871004	417	6.94	18.7555	98.6593	37	2.9	0.7
126	871014	7 7	54.03	18.9892	99.2318	32	3.6	1.8
127	871017	1819	22.00	18.2328	97.2910	37	2.8	0.6
128	871020	2021	34.50	19.7910	98.5415	37	3.3	1.9
129	871022	747	21.02	18.2362	99.8140	37	3.8	0.8
130	871025	432	41.52	17.9637	97.8557	41	3.0	1.2
131	871102	423	0.51	17.9003	98.8988	41	2.8	0.6
132	871102	614	26.43	17.2925	98.4443	41	3.5	0.4
133	871104	1845	24.48	19.7087	96.7987	37	3.1	1.3
134	871105	1616	23.14	18.1863	98.1378	37	2.6	0.5
135	871105	1623	26.81	18.2262	97.9192	37	3.0	0.4
136	871107	254	21.92	18.1572	98.0785	37	2.3	0.4
137	871107	2250	33.21	18.3777	99.7020	37	2.8	0.8
138	871115	329	21.71	17.3572	97.3707	53	3.9	0.5

Table 3 (Cont).

no	Date	Hr: Min	Sec	Lat N	Log W	Depth	Mag	rms
139	871124	558	44.32	17.4280	98.1970	37	3.4	0.6
140	871127	834	30.90	17.3417	98.2540	37	3.7	0.3
141	871206	2236	12.91	18.3960	97.7587	37	3.2	0.6
142	871207	2246	11.88	18.5217	98.8010	32	2.6	0.2
143	871208	9 2	54.56	18.1387	98.4640	37	2.3	0.2
144	871210	424	15.76	18.0068	98.6333	31	2.9	0.3
145	871213	130	46.06	18.0277	98.2748	34	2.7	0.1
146	871214	1244	14.49	17.9637	98.0665	37	3.6	0.7
147	871214	1654	28.83	18.2642	97.9782	37	2.3	0.3
148	871215	415	52.82	17.8017	98.3590	32	2.7	1.4
149	871215	1115	20.53	17.7085	96.9287	41	3.6	1.7
150	871218	256	36.78	18.7767	99.2733	24	2.8	0.4
151	871221	410	3.72	18.5338	97.1435	41	2.9	1.2
152	871223	1148	54.09	16.6512	98.2598	44	3.1	0.4
153	871225	720	21.22	17.7747	97.5695	40	3.1	0.8
154	871225	2139	1.38	17.5310	94.6473	37	3.9	0.5
155	871226	2011	2.04	17.6983	97.8407	64	3.8	1.1
156	871229	2337	47.27	17.1445	97.1100	23	3.6	0.5
157	880105	532	46.17	17.9408	98.2592	50	2.0	0.3
158	880119	1523	33.18	15.8143	99.5233	37	2.0	1.7
159	880124	132	44.46	17.5133	99.2620	37	2.0	1.1
160	880124	17 9	35.39	18.0293	98.1980	37	2.0	0.3
161	880129	1429	7.54	18.2250	96.9800	37	2.0	0.6
162	880130	2325	54.10	18.1303	96.2203	32	2.0	1.9
163	880131	617	9.58	18.3777	99.0992	37	2.0	1.4
164	880131	1046	22.14	17.2818	99.4227	37	2.0	0.9
165	880201	744	56.98	19.2527	97.5857	28	2.0	1.6
166	880203	741	44.17	17.0163	98.2963	37	2.0	0.8
167	880211	343	39.41	17.9230	97.9713	53	2.0	0.6
168	880216	1330	24.30	18.7147	96.6928	44	2.0	0.0
169	880218	16 7	34.97	18.3003	98.9303	41	2.0	1.6
170	880218	1830	37.46	18.0050	98.6063	32	2.0	0.4
171	880221	022	34.22	19.2157	96.4183	32	2.0	0.4
172	880221	2017	42.36	19.2887	97.1887	37	2.0	1.7
173	880222	457	54.26	18.1738	100.4007	37	2.0	0.4
174	880225	1159	37.41	18.7777	99.1807	37	2.0	0.1
175	880226	712	23.31	18.0032	97.4437	46	2.0	0.3
176	880228	2241	49.75	18.1047	98.3322	37	2.0	0.6
177	880307	333	25.16	17.8360	96.1337	22	2.0	0.6
178	880312	2213	3.11	17.9040	97.5487	37	2.6	1.0
179	880324	1325	42.45	18.0017	98.7050	37	4.1	1.3
180	880325	4 8	14.49	18.2103	98.6813	37	3.6	0.9
181	880325	720	6.46	17.9637	97.8913	42	2.6	0.2
182	880326	2358	21.83	17.8955	97.4732	48	4.4	0.8
183	880401	330	37.73	18.0230	97.9275	51	3.6	0.3
184	880401	2358	26.30	19.3247	97.4220	26	2.7	1.0
185	880409	615	41.94	18.3027	97.2497	43	2.4	0.1
186	880417	645	7.61	19.4107	97.1603	37	2.8	1.1
187	880426	2339	54.73	18.1437	97.7132	45	3.0	0.1
188	880430	236	1.16	18.1077	98.1790	37	3.1	0.6
189	880501	1641	21.43	18.1032	98.1668	37	2.3	0.5
190	880503	040	6.92	17.3890	97.4912	37	4.1	0.2
191	880503	1032	9.09	18.1150	99.3440	37	3.0	0.5
192	880504	4 9	25.18	18.7902	99.2367	37	3.4	0.6
193	880506	8 3	15.14	17.8918	99.0113	37	2.7	0.1
194	880507	2333	47.49	18.0535	96.8910	46	3.9	0.7
195	880507	2340	10.35	17.9345	98.9672	37	3.4	0.5
196	880509	037	49.10	17.9883	98.9437	40	3.8	0.4
197	880509	8 2	1.21	18.1950	97.6250	47	2.7	0.2
198	880509	2251	35.05	18.0638	98.4368	37	2.5	0.2
199	880510	633	43.21	19.1638	99.0060	15	3.8	0.9
200	880511	2314	1.90	18.1520	97.5735	50	3.1	0.1
201	880512	615	17.73	19.1533	99.0633	37	3.2	2.0
202	880512	10 1	50.99	19.0975	99.0633	37	3.1	1.8
203	880512	2122	40.11	17.9637	98.0848	50	2.4	1.4
204	880514	557	26.62	17.6080	97.4795	41	2.8	0.3
205	880515	8 3	15.49	17.9008	98.1925	37	2.6	0.2
206	880516	010	42.28	18.4605	96.8252	20	3.0	0.6
207	880517	2133	27.79	18.2142	97.6800	37	2.2	0.3

Table 3 (Cont).

no	Date	Hr: Min	Sec	Lat N	Log W	Depth	Mag	rms
208	880518	1014	30.78	17.4172	97.2178	55	2.4	0.2
209	880525	923	56.51	16.7777	99.1543	37	3.6	1.4
210	880525	1541	12.96	19.3713	97.5155	37	3.5	1.5
211	880527	821	50.99	18.8077	99.2045	29	2.8	1.0
212	880528	1413	20.74	17.8515	98.5348	39	3.5	0.7
213	880529	611	48.92	18.3777	99.4697	20	4.6	1.1
214	880529	1029	17.92	18.2242	99.4697	37	4.0	1.9
215	880530	9 6	32.15	17.3337	98.2168	37	2.8	0.9
216	880531	727	53.45	17.7057	97.1435	40	3.8	0.3
217	880602	1139	21.26	18.6568	98.0443	41	3.0	1.6
218	880610	1434	28.13	17.7045	98.9108	42	3.7	0.7
219	880611	939	17.68	18.2455	98.5865	40	3.1	0.4
220	880612	10 5	47.71	18.1530	97.8845	46	2.6	0.1
221	880615	10 8	36.16	18.2078	97.8167	49	2.6	0.2
222	880616	1557	42.57	17.9848	98.4027	38	2.8	0.1
223	880617	10 6	7.11	18.1192	97.9957	51	2.6	0.3
224	880625	1227	27.06	17.5967	97.4992	41	3.9	0.3
225	880629	15 9	52.06	18.0618	97.9520	41	3.9	0.7
226	880706	1957	42.40	17.9637	97.5205	37	2.6	1.5
227	880708	3 5	19.44	17.8933	98.4625	37	3.2	1.1
228	880709	424	48.55	18.0905	97.6452	37	2.4	0.7
229	880713	1058	2.23	17.8795	98.7007	32	3.4	1.7
230	880714	538	25.83	18.0212	96.0407	41	3.4	1.2
231	880718	2120	34.33	17.2693	96.7338	37	3.1	1.9
232	880724	1542	8.46	17.8558	97.9887	46	2.9	0.1
233	880725	431	42.41	17.9465	98.2090	33	3.4	0.9
234	880728	2342	38.77	17.7945	98.6148	24	2.6	0.4
235	880801	1621	7.36	18.0622	99.2058	37	3.2	1.9
236	880802	055	52.90	18.3003	98.8675	37	4.2	1.2
237	880802	623	3.43	17.4783	96.7338	42	2.6	0.7
238	880802	2326	24.64	17.9825	97.0877	59	2.9	0.8
239	880803	248	39.36	17.4745	96.6580	37	3.6	1.3
240	880804	2054	3.36	17.8117	98.3043	22	2.4	0.3
241	880809	2357	0.16	18.2770	97.3800	37	2.7	1.1
242	880810	2048	24.01	18.2770	96.1347	37	3.4	1.0
243	880810	2318	55.43	17.9598	98.1648	38	2.6	0.1
244	880811	1036	31.98	17.3158	97.6425	33	3.9	0.8
245	880813	2218	20.75	17.7805	95.6303	37	4.2	0.4
246	880816	1236	39.63	18.0843	98.4622	16	3.6	0.4
247	880819	1111	31.35	16.7538	96.1847	23	4.1	1.2
248	880820	322	45.75	17.8338	96.2387	37	3.3	1.0
249	880820	616	37.05	15.9653	98.2555	37	4.2	1.8
250	880828	421	57.12	16.0297	97.1993	18	3.9	1.5
251	880831	1957	28.82	18.5838	95.7337	32	2.9	1.7
252	880908	1419	29.26	18.0957	98.0642	42	2.5	0.2
253	880912	755	38.48	17.1953	96.6915	37	3.2	0.3
254	880913	2212	46.71	17.9037	97.6123	54	2.6	0.1
255	880914	2121	0.55	17.1117	96.6912	27	3.9	1.1
256	880919	19 0	36.19	18.1497	98.1227	37	2.5	0.4
257	880922	824	43.29	17.0323	99.2933	41	3.9	0.8
258	880925	1747	0.13	18.1527	98.5375	37	2.8	0.4
259	880925	2354	2.00	18.4342	98.0170	37	2.0	1.2
260	881010	13 7	13.92	18.5285	97.8557	37	3.8	0.4
261	881010	2333	48.66	17.9497	97.2472	46	4.0	0.3
262	881012	1145	51.75	17.6307	97.2692	54	2.8	0.0
263	881012	1642	0.16	18.0347	98.2797	37	2.5	0.4
264	881017	2230	54.63	17.7830	98.1440	39	2.7	0.2
265	881022	1234	48.91	18.0633	98.4790	29	3.6	0.4
266	881023	1334	9.92	17.9783	96.9270	41	3.0	1.1
267	881028	1315	33.64	17.5172	99.4077	56	3.2	0.3
268	881029	22 5	2.21	19.1603	96.2747	32	3.4	1.1
269	881104	1515	2.97	17.9528	97.8603	50	2.5	0.0
270	881106	659	29.72	18.1012	98.1488	38	3.1	0.2
271	881112	11 1	12.48	18.2527	97.3225	47	3.4	0.4
272	881120	023	49.47	16.7905	98.1462	24	3.4	0.6
273	881125	1830	45.96	17.3140	96.7250	37	3.0	0.9
274	881205	1231	58.47	18.1923	98.0553	41	3.4	0.6
275	881208	826	7.87	16.9590	97.8557	32	3.3	1.2
276	881209	1547	28.69	17.9223	96.9240	37	2.9	0.8

Table 3 (Cont).

no	Date	Hr: Min	Sec	Lat N	Log W	Depth	Mag	rms
277	881210	2117	53.86	18.1983	97.6915	37	2.6	0.6
278	881212	643	40.30	17.2082	96.0435	18	3.8	1.2
279	881224	1732	54.79	16.7858	99.0988	32	4.3	1.8
280	881230	736	46.13	17.9567	98.3662	37	3.3	1.6
281	890101	3 6	1.47	17.9865	98.3553	37	2.2	0.2
282	890101	5 3	17.37	18.0917	98.0663	44	2.6	0.3
283	890101	9 3	4.67	18.0250	97.7878	41	3.6	0.5
284	890101	2332	28.67	17.5982	97.2697	50	3.1	0.1
285	890104	1320	6.03	17.9947	97.8422	49	3.0	0.0
286	890106	531	39.98	17.0547	98.9157	37	3.8	0.3
287	890114	2314	55.05	18.0698	97.9073	44	2.7	0.1
288	890115	17 8	33.87	17.9637	97.7228	37	2.4	0.8
289	890117	442	40.17	18.0858	98.2123	37	2.8	0.4
290	890118	4 4	32.84	17.9637	97.5710	40	2.8	0.7
291	890118	1643	19.46	17.5930	97.0255	34	3.0	0.4
292	890120	618	47.66	17.9657	97.3742	48	2.8	0.2
293	890122	530	19.02	18.0677	97.0527	37	3.2	1.5
294	890122	1633	15.55	17.7913	95.9080	41	4.0	1.3
295	890124	752	12.86	17.1785	96.9332	37	4.0	0.6
296	890124	1146	8.41	18.5705	99.5563	30	3.9	1.1
297	890125	0 5	2.20	16.2997	98.4878	37	4.1	0.9
298	890126	1555	8.40	17.3988	97.2583	37	3.2	0.3
299	890126	16 0	13.18	17.5822	97.0005	51	3.1	0.2
300	890201	1650	17.63	17.8792	97.8765	47	2.5	0.1
301	890201	2321	14.12	17.9637	97.6312	39	2.5	0.7
302	890203	454	20.65	17.8283	99.4697	37	2.5	1.2
303	890206	651	22.21	17.4395	97.2737	48	2.9	0.1
304	890207	1241	54.38	17.9453	97.9355	43	2.8	0.0
305	890209	14 6	59.31	18.0902	98.7662	40	3.5	0.8
306	890209	2149	53.70	17.9928	99.1067	33	2.3	0.4
307	890212	1120	9.85	17.9178	98.6942	37	3.1	0.6
308	890213	149	4.21	19.1678	95.9627	24	3.8	0.1
309	890224	20 0	56.21	19.0588	98.6148	37	2.4	1.5
310	890226	1413	8.42	18.0837	95.9550	41	3.5	0.6
311	890227	2011	25.43	17.9467	98.6837	43	2.7	0.3
312	890313	330	59.90	16.8142	99.6528	37	3.8	0.5
313	890313	16 0	16.99	16.2342	98.2430	37	4.0	1.9

Citlaltépetl volcano, 13 events were located as shown in Figure 6. North of the State no events were located. Figure 6 shows the overall seismicity between January, 1986 and August, 1989.

Figure 9 is a north-south profile of the seismicity in the region. The vertical and horizontal hypocentral errors are indicated, as well as the boundary of the oceanic and continental lithosphere, proposed by Valdés *et al.* (1986). The suggested Benioff zone from Bevis and Isacks (1984) and Pardo (1993) were also compared, but these two profiles either fell out of the region of study or did not agree with the hypocenters in the present study. Only 28 events occur beneath the Benioff zone. The deep seismicity ends at about 18.8°N. A concentration of events is observed at 18°N at about 45 km depth, which matches the location of the Benioff zone.

CONCLUSIONS

Ninety-two percent of the seismic events located in the region of the State of Puebla have coda magnitudes ranging between 2 and 4. Only one event, slightly outside of the region of study, had a magnitude greater than 5. This suggests that the earthquakes in this region are mainly small.

Tabla 3 (Cont.)

no	Date	Hr: Min	Sec	Lat N	Log W	Depth	Mag	rms
314	890316	2121	58.09	17.6120	98.0462	41	3.8	2.0
315	890318	749	53.39	17.9637	98.0837	41	2.7	2.0
316	890320	2022	29.03	18.0345	97.7945	49	2.6	0.1
317	890321	9 7	34.66	17.8880	98.3725	37	2.2	0.2
318	890325	1750	15.35	18.1315	98.1425	37	2.8	0.6
319	890327	1717	37.29	18.1697	98.8403	37	2.6	0.3
320	890401	548	43.69	17.9895	97.8873	40	2.8	0.4
321	890402	225	27.14	19.0877	99.3035	18	2.7	0.6
322	890403	833	26.80	18.8875	98.7517	29	3.2	1.1
323	890403	1129	37.97	18.1233	99.2930	33	4.0	2.0
324	890404	1328	27.83	19.0227	98.7057	18	3.5	1.3
325	890404	1854	0.88	18.3522	98.0278	37	2.5	1.0
326	890408	18 4	54.07	16.9543	98.4625	29	4.0	1.3
327	890412	547	14.37	17.9637	97.5187	64	2.4	1.1
328	890412	1040	14.98	19.3355	97.4428	37	3.0	1.1
329	890412	1042	3.41	19.6053	97.2820	32	2.9	1.3
330	890420	741	25.16	18.9315	99.9492	29	2.6	0.2
331	890420	830	1.42	18.7477	97.5202	42	2.2	1.5
332	890425	2234	15.86	17.8127	99.3987	37	3.3	0.4
333	890428	929	39.44	16.7128	99.4498	37	3.2	0.2
334	890428	1641	59.78	18.3145	97.6100	41	2.3	1.7
335	890503	736	1.87	18.1068	97.7102	37	2.3	0.3
336	890504	011	29.80	17.2342	99.5718	32	3.2	0.2
337	890508	1114	39.04	17.8693	97.7782	47	2.5	0.2
338	890528	1712	58.48	17.2782	99.7218	37	3.2	0.2
339	890529	4 8	9.56	17.6435	98.9272	37	3.5	0.3
340	890630	1919	10.63	17.8143	97.2815	41	2.7	1.4
341	890707	2212	12.83	17.7297	97.5310	37	2.7	0.4
342	890708	627	45.09	19.3375	97.6995	32	3.0	1.2
343	890713	1354	5.94	18.0802	98.3837	37	3.2	1.7
344	890716	1159	18.34	19.1433	99.5712	37	3.2	1.5
345	890724	1030	1.63	17.9032	97.9605	58	3.4	1.9
346	890727	1237	14.36	17.7940	99.1638	37	3.4	1.2
347	890813	23 9	24.36	18.1077	97.0500	58	2.9	0.2
348	890816	329	30.34	16.9168	98.1487	37	3.2	0.0
349	890818	029	5.61	19.3533	97.2443	37	2.7	1.7
350	890828	2025	52.80	16.4120	98.0048	37	3.4	1.4

Some earthquakes in the region attain large magnitudes, such as the Orizaba earthquake (M=7.0) of 1973 and the Huajuapan de León earthquake (M=7.0) of 1980 (González-Ruiz, 1986). About 69 % of the seismicity is located south of 18.5°N, basically in the region of the Mixteca range near the boundary between the States of Puebla-Guerrero and Puebla-Oaxaca. In the central region, between 18.5° and 20°N, 26 % of the events was located, corresponding to the Trans-Mexican Volcanic Belt. Several clusters of earthquakes occurred at the boundary between the States of Tlaxcala, Mexico and Hidalgo, where 18 shallow events with maximum magnitudes of 4.2 were located plus a cluster of 13 events in the region of Derrumbadas, near Citlaltépetl volcano.

Deep seismicity occurs in the south of the State, probably related to the contact between the Cocos and North American plates as suggested by the seismic profile of Valdés *et al.* (1986). In the central region, seismicity is shallower than in the south. It does not appear to be related to this contact, but to crustal tectonic stresses.

The larger seismic risk in the State of Puebla may be due to the subduction zone in the Pacific coast. This risk is now being studied using records from the Accelerograph

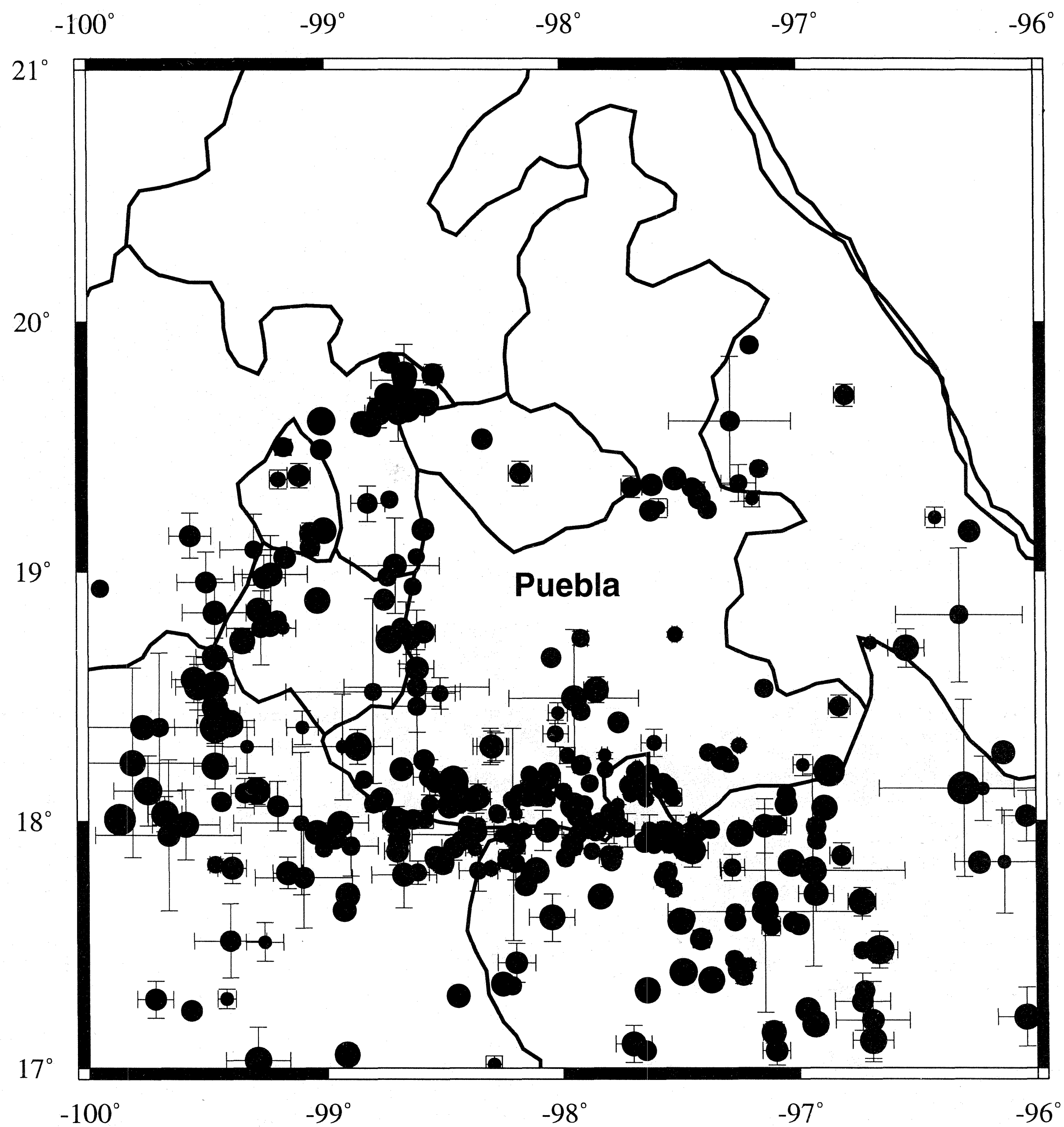

Fig. 6. Seismic epicentral distribution in the State of Puebla 1986-1989.

Network of Puebla City (Avilés *et al.* 1989). It is important to continue monitoring the seismicity in the State of Puebla, in order to understand the seismic hazard in the region and to contribute to the mitigation of destructive seismic effects.

ACKNOWLEDGEMENTS

We thank Dr. Raúl Serran L. and Eng. Jorge A. De Gante González for their contribution to the installation, maintenance and operation of RESEP; Patricia Gertrudis Júarez Serran, Franco Martínez Sánchez and Gustavo Adolfo Diego Taboada for their participation in reading the seismograms; the students of social service in the School of Civil Engineering at the UAP who participated and contributed in many different ways to the operation of RESEP; the Instituto Tecnológico de Oaxaca for providing the station Coxcatlán in 1986; and Ana Elena Posada Sánchez for her assistance in the elaboration of the seismic catalog.

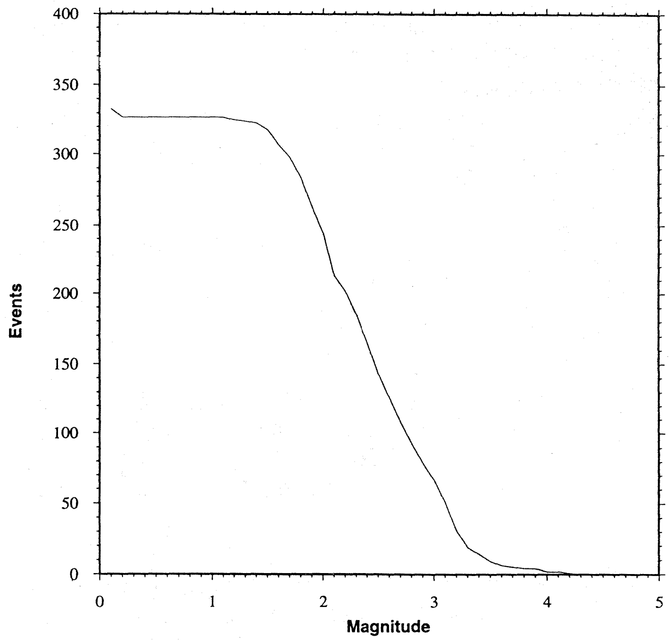

Fig. 7. Number of events versus magnitude of Coda.

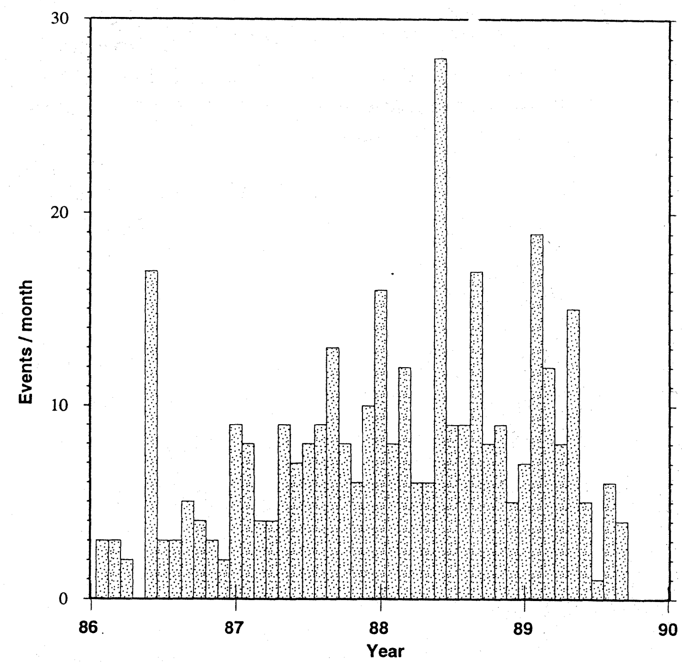

Fig. 8 Monthly seismicity histogram.

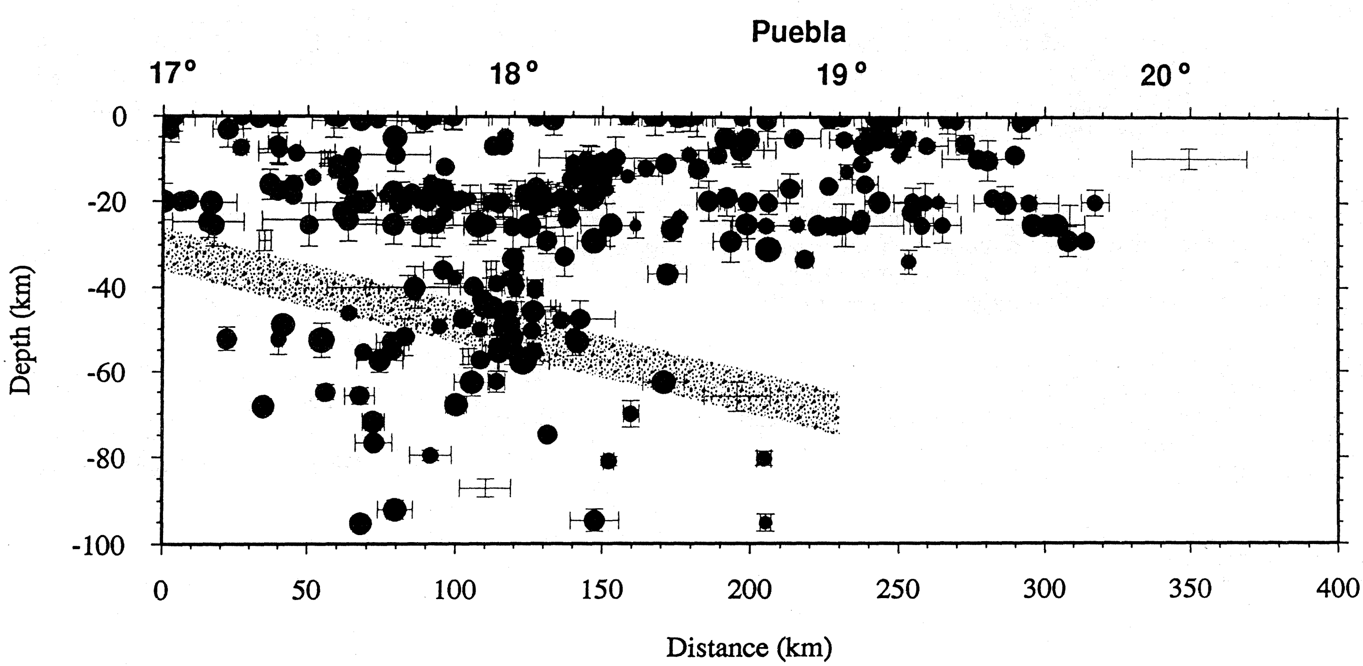

Fig. 9 Seismic cross section.

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