GEOFISICA INTERNACIONAL

REVISTA DE LA UNION GEOFISICA MEXICANA. AUSPICIADA POR EL INSTITUTO DE GEOFISICA DE LA UNIVERSIDAD NACIONAL AUTONOMA DE MEXICO

Vol. 17 México, D. F., a 1o. de julio de 1977-78 Núm. 3

THE 29 NOVEMBER, 1978, OAXACA EARTHQUAKE: FORESHOCK ACTIVITY

L. PONCE*
K. C. McNALLY**
J. GONZALEZ*
A. DEL CASTILLO*
and E. CHAEL**

RESUMEN

El análisis de la actividad sísmica ($m \geqslant 2.8$) –registrada por medio de una red local de 6 sismógrafos durante 3 semanas previas a la ocurrencia de un fuerte temblor (29 de Noviembre de 1978, $M_s = 7.8$) en Oaxaca–, revela los siguientes aspectos (Ponce *et al.*, 1978). (1) Las distribuciones espacial y temporal de la actividad sísmica precedente sugieren que ella ocurre a lo lar-

* *Instituto de Geofísica, UNAM, México.*
** *Seismological Laboratory, California Institute of Technology, Pasadena, California 91125, USA.*

go de una dirección con rumbo N66° ± 6°W y probablemente a lo largo de otras dos direcciones con rumbo N39° ± 6°E que cruzan los flancos occidental y oriental de la zona de réplicas. (2) En una área de 3000 km^2 que rodea al temblor principal se presenta una calma sísmica (para temblores de $m \geqslant 2.8$) excepto durante dos períodos en que ocurren "temblores precursores" (a menos de 24 km del epicentro del temblor principal): el primero, a 2 semanas de la ruptura; el segundo, 21 hrs antes de la ruptura y luego la actividad declina durante 17 hrs hasta la ocurrencia del temblor principal. Este comportamiento de la actividad sísmica en el tiempo, observado inmediatamente antes de la ocurrencia del temblor principal es similar a otros casos observados mundialmente. Mientras que los temblores precursores ocurren en la mitad norte de un círculo de radio de 24 km centrado en el epicentro del temblor principal, 5 de las 12 réplicas más fuertes ($m_b \geqslant 4.0$, 30 Nov-8 Dic) ocurren dentro de este pequeño círculo, al sur de los temblores precursores. Además 8 de dichas réplicas, los temblores precursores, el temblor principal y 2 de los mayores temblores precedentes ($m \geqslant 3.9$ y 3.4) se encuentran alineados a lo largo de la dirección N-S. Se observa que existe una aceptable correlación entre los lineamientos definidos por la información sismológica y las fallas activas encontradas en base a estudios geomorfoestructurales. Un resultado importante de este estudio es la documentación de la actividad sísmica precedente a niveles de energía menores que los umbrales de detección acostumbrados ($m_b = 4$). La relocalización del temblor principal se encuentra aproximadamente a 50 km al sureste del epicentro publicado por NEIS. El análisis del mecanismo focal compuesto y la estabilidad de la razón de amplitudes de las ondas P y S para los "temblores precursores" ($m \geqslant 1.5$) indican que ellos ocurren a lo largo de dos direcciones preferenciales de dislocación; los mecanismos son del tipo de falla normal de gran ángulo de buzamiento ($\varphi_1 = 282°, \delta_1 = 80°, \lambda_1 = -72°$; $\varphi_2 = 177°, \delta_2 = 72°, \lambda_2 = -78°$) y sus rumbos se correlacionan satisfactoriamente con los lineamientos definidos anteriormente de acuerdo al análisis de la actividad sísmica y estudios morfoestructurales.

INTRODUCTION

Three weeks prior to the occurrence of the Oaxaca, Mexico, earthquake $M_S = 7.8$ of 29 November of 1978, the Instituto de Geofísica, UNAM, in collaboration with California Institute of Technology installed a local network of 6 smoked paper portable seismographs in the coastal range of Oaxaca (Figure 1). The project was to define spatio-temporal patterns of local earthquakes $m_b < 4.0$ which can not be resolved from standard world-wide network. The data obtained could provide new information relevant to the Oaxaca seismic "gap" (Kelleher *et al.*, 1973; Ohtake *et al.*, 1977). Last authors observed that from the middle of 1973 the frequency of shallow earthquakes ($H < 60$ km) was unusually low in the area of Oaxaca, Mexico (95.5°W – 98.0°W). This area experienced two major earthquakes in its eastern (16.33°N – 95.80°W, $M_S = 7\frac{1}{2} - 7\frac{3}{4}$, Aug. 23, 1965) and western (16.56°N – 97.79°W, $M_S = 7.5$, Aug. 2, 1968) sides and both were preceded by intervals of quiescence (α stage) and following reasumption (β stage) of local seismicity in advance of the mainshock. The separation between those two previous aftershock zones was comparable with their dimensions. On this basis Ohtake *et al.* (1977) forecast the occurrence of a large earthquake ($\varphi = 16.5° \pm 0.5°$N; $\lambda = 96.5° \pm 0.5°$W; $M_S = 7\frac{1}{2} \pm \frac{1}{4}$) although they did not predict the time of occurrence. In Mexico, among academic and government circles, this forecast was a matter of controversy (Garza and Lomnitz, 1978); local well controlled microearthquake data could help to clarify the tectonic significance of the Oaxaca gap and the importance of the earthquake forecast.

We have obtained a unique data set of preceding and aftershock activities (Singh *et al.*, 1980). In Figure 2 we present the 48 largest preceding earthquakes ($m \geqslant 2.8$); in other paper (Ponce *et al.*, 1978) we discuss their correlation with the mainshock and aftershock locations and the surface geologic data (Sumín de Portilla *et al.*, 1978). Magnitude, m, is "relative" (without specific calibration for this region), and has been determined from earthquake coda duration (Lee *et al.* 1972).

The mainshock epicenter was relocated (15°46'N; 96°48'W) using master event techniques (Figure 1); depth for the mainshock has been estimated to be 18 km from waveform analysis (Stewart and Chael, 1978). 7 large aftershocks well located by the whole local aftershock seismic network (Figure 1) and permanent stations operated by the Servicio Sismológico Nacional and SISMEX, UNAM were used as master event. HYPO 71 was used for hypocenter determinations (Lee and Lahr, 1975). The model for compressional-wave velocities (Table 1) was selected by trials and error as no detailed crustal study of the region is available; our model is a compromise from reversed seismic profile data obtained (1) off-shore along the coast of Guatemala and (2) in continental Mexico between Pinotepa Nacional (about 150 km WNW of mainshock epicenter) and Lake of Alchichica (about 400 km inland perpendicular to the coast) (Shor and Fisher, 1961; Helsley *et al.*, 1975; Mooney *et al.*, 1975). The epicenter of the mainshock given by the Preliminary Determination of Epicenter (PDE), published by the National Earthquake Information Service (NEIS) of the U.S. Geological Survey, differs from our location by 48 km, as seen in Figure 1.

Closest to the mainshock epicenter location (less than 24 km), with the exception of one small event on the 9 November, the preceding seismic activity ($m \geqslant 2.8$) occurred during the periods 15-17 November and 28-29 November. We will call these earthquakes "foreshocks".

Small earthquakes appear to occur in linear patterns during the 3 weeks prior to the mainshock (Ponce *et al.*, 1978): the more active zone trends N66° ± 6°W and runs slightly north of the epicenter of the main event; 2 other zones may exist, trending N39° ± 6°E and crossing the western and eastern portion of the area defined by the aftershock sequence (Singh *et al.*, 1980). A N65° ± 5°W fault is well defined by geomorphostructural data (Sumín de Portilla *et al.*, 1978) and satellite image interpretation (N. Galván, personal communication) which is coincident with the more active seismic zone (Figure 2a). No faults corresponding to the N39° ± 6°E lineations of activity are clearly evident in local surface structures; however these N39° ± 6°E lineations could reflect a system of less well developed enechelon faults subparallel to a 200 km long fault that trends N30°E inland from the coastal line about 120 km west of the mainshock epicenter (Figure 2a). 30 of 48 of the preceding earthquakes might be associated with the direction at N66° ± 6°W (Figure 2d). In contrast, 8 of 12 epicenters of the largest aftershocks ($m_b > 4.0$) from 30 November until 8 December, the foreshocks, the mainshock and 2 largest preceding earthquakes (m = 3.9 and 3.4) appear to trend N-S (Fig. 2a).

Foreshocks occurred within the active zones trending N66° ± 6°W and N-S. The final episode of foreshock activity ($m \geqslant 2.8$) began 21 hours before the mainshock and then subsided for 17 hours until failure; no foreshocks of lower magnitude occurred in this last period of quiescence. This pattern has been observed for foreshocks preceding other large earthquakes (Rikitake, 1976; Raleigh *et al.*, 1977; Wu *et al.*, 1978).

Figure 2a shows a clear clustering of 8 large aftershocks, mainshock, foreshocks and 2 large preceding earthquakes along a N-S trend. This trend is well correlated with the N-S direction of old deep faults (Orthogonal system formed by N-S and E-W faults) obtained from geomorphostructural analysis (Sumín de Portilla *et al.*, 1978). Figure 2a also shows that the preceding seismic activity occurring along the N66° ± 6°W lineation (Ponce *et al.*, 1978) is well correlated with the shallow and young faults with N65° ± 5°W trend; also a satisfactory correlation is observed between preceding seismic activity and weakly defined system of sub-parallel faults along N30° ± 5°E. The faults along N65° ± 5° and N30° ± 5°E constitute the diagonal system defined from geomorphostructural analysis (Sumín de Portilla *et al.*, 1978).

The cross section along a direction perpendicular to N66°W (Figure 2b) shows that most of the preceding seismic activity occurred in the continental plate; the dip of 14° of the Cocos Plate beneath Mexico is consistent with the focal mechanism for mainshock (Stewart and Chael, 1978). For reference we have also traced a dip of 20°. Figure 2c clearly shows that the foreshock region was quiet except for two periods of foreshock activity, and suggests that preceding seismic activity was present in the WNW and ESE flanks of the aftershock area during the 3 weeks of observation before the occurrence of mainshock. Figure 2d shows that most of the activity (30 of 48 preceding earthquakes) also occurred associated with the N66°W direction in the northern half of the aftershock area.

We also analyzed the stability of the ratio of amplitudes of P and S waves for all the foreshocks ($m \geqslant 1.5$) with epicenters located inside a small circle ($r \leqslant 24$ km) centered at the mainshock relocation (González, 1979). In Fig. 3a we show the results at PGO; the ratio of amplitudes of P and S waves present two well defined linear trends (I and II; Fig. 3a) suggesting that dislocations occurs along two different preferential planes. Composed focal mechanisms (upper focal sphere for each group, I and II), are given in Figures 3b and 3c (González, 1978). Results indicate normal fault mechanism for both groups; the first group have a strike of N78°E and the second of N3°E. For both cases we suggest that dislocations occurred along the more vertical plane (dip equal to 80° and 72° respectively) and that they reflect the zones of weakness of the upper layers of the continental plate as discussed previously (N65° ± 5°E and N-S respectively). Other authors (Sadovsky *et al.*, 1972; Chin *et al.*, 1978) studied the stability of focal mechanisms and ratio of amplitudes of P and S waves for preceding earthquakes occurring near the mainshock. Our results suggest that (1) even though pre-failure dislocations occurs along preferential directions they are not unique, and (2) that preexisting zones of weakness in the continental plate could play a significant rol as a triggering mechanism for large earthquakes in southern Oaxaca and may be in other zones of subduction.

Preliminary results on precursory and foreshock activities near the epicenter of the Oaxaca earthquake suggest that a detailed survey of active faults must be done in the coastal range of Mexico, as the seismic activity ($m < 4.0$) associated with them could define the sizes of tectonic units in the region (Lukk, 1978; Kasahara *et al.*, 1978) and constitute precursory activity to large destructive earthquakes (Chen *et al.*, 1979). A more systematic observation of seismic activity and multidisciplinary survey of geophysical, geochemical and geological parameters is recommended for the Oaxaca region in order to test the validity of the tectonic features discussed here. The local seismic network should permit locations of events as low as $m = 3.0$ in the region of interest.

TABLE 1

Layer	Compressional-wave velocity, km/sec	Depth to the botton of the layer, km
1	4.4	5.0
2	5.6	12.0
3	6.4	22.0
4	8.2	

Compressional-wave velocity = 1.78 Shear-wave velocity.

[illegible]

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

[illegible]

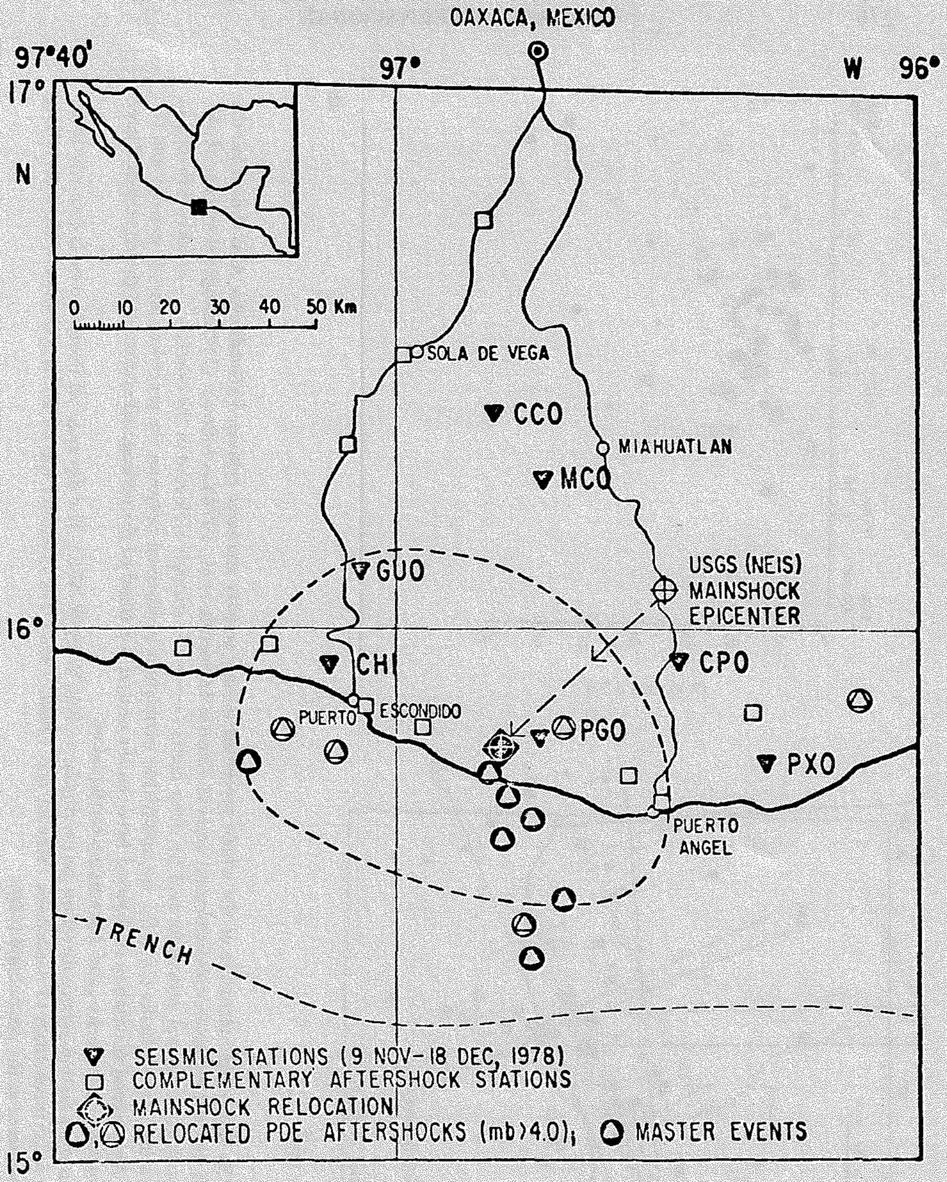


Figure 1. From 9 Nov. until 18 Dec. 1978 6 smoke paper seismographs were installed in the coastal range of Oaxaca (GUO, CHI, PGO, PXO, CPO and MCO; CCO was an alternative site for MCO). After the occurrence of the large Oaxaca earthquake ($M_S = 7.8$) on 29 November, 9 additional smoke paper seismographs were installed as shown. 7 large PDE aftershocks (2-8 Dec) were accurately located using the whole aftershock network and used as master events to relocate the mainshock (15°46'N, 96°46'W and five aftershocks. Our mainshock location differs by 48 km from USGS (NEIS) epicenter.

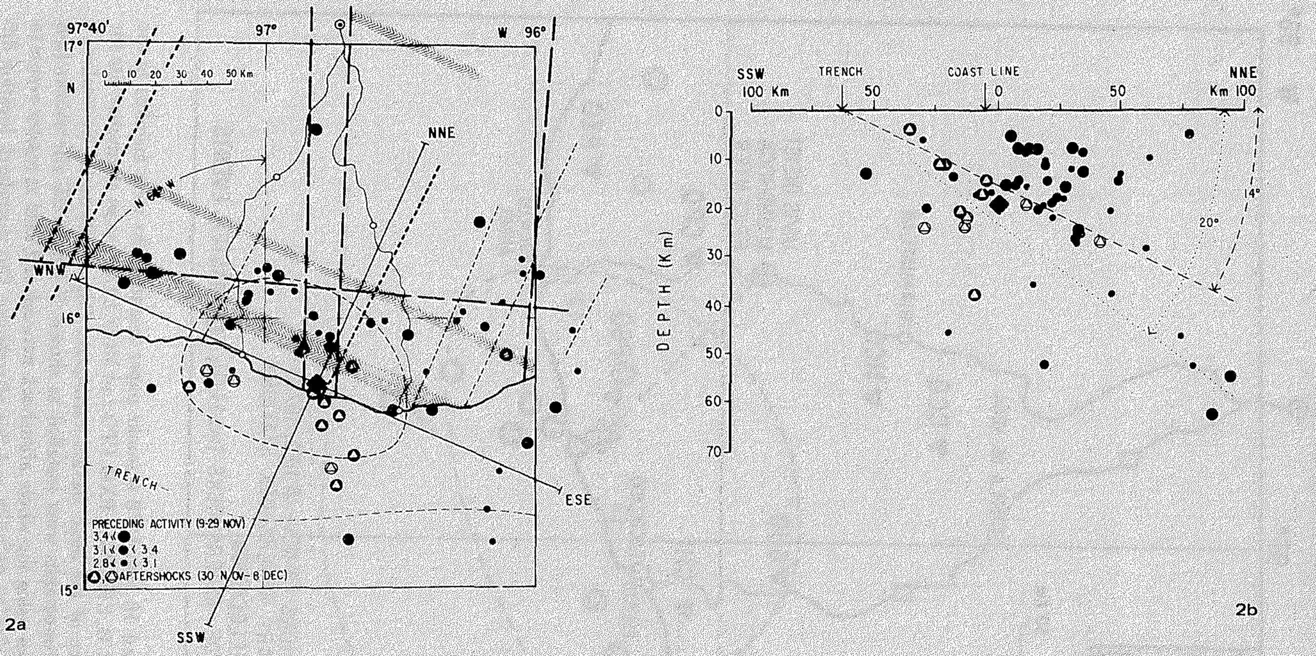
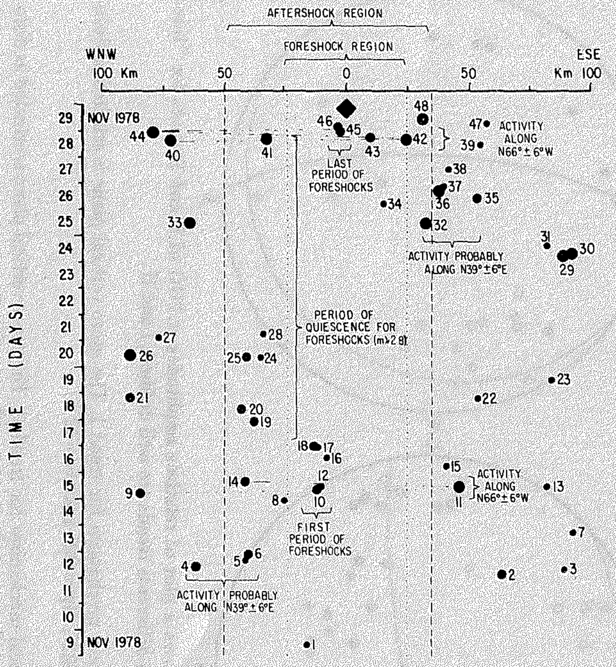
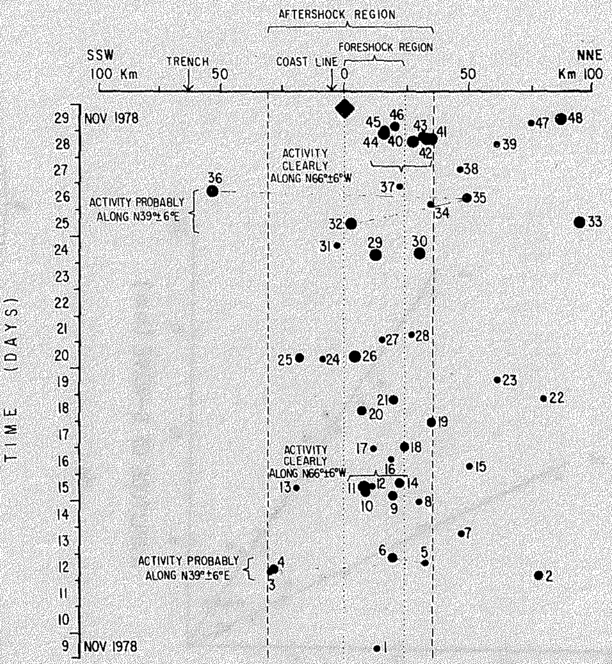


Figure 2. Figure 2a shows the epicenters of the whole preceding seismic activity and large relocated aftershocks. Also shown are the active zone faults defined by geomorphostructural analysis (Sumín de Portilla *et al.*, 1978) as follows: (1) Orthogonal system of old-deep faults (———); (2) Diagonal system formed by deep faults (——— strongly reflected in the relief; --- weakly reflected in the relief), and young shallow faults (////////). An acceptable correlation is observed between the preceding seismic activity and the diagonal system. Also a good correlation is observed between the central N-S trend of the orthogonal system and the cluster of 8 large aftershocks, mainshock, foreshocks , and 2 preceding earthquakes.

Figure 2b shows a cross section along a direction perpendicular to N66°W (SSW-NEE). The dip angle of Benioff zone is estimate to be 14° according to focal mechanism of mainshock (Stewart and Chael, 1978). For reference dip of 20° is also shown. Most preceding seismic activity occurred in the continental plate.



2c



2d

Figure 2c shows a projection of preceding seismic activity along the direction N66°W (WNW-ESE) versus time. The period of quiescence for foreshocks is well observed. Also seen is the preceding seismic activity occurring in the WNW and ESE flanks of the aftershock area. Preceding earthquakes occurring along the N66° ± 6°W trend are followed according to its sequence of occurrence (—.—).

Figure 2d shows a projection of preceding seismic activity along a direction perpendicular to N66°W (SSW-NNE) versus time. 30 of 48 preceding earthquakes occurred in the limits of the N66° ± 6°W trends. Activity occurring probably along the N39° ± 6°E directions are followed according to its sequence of occurrence (—.—).

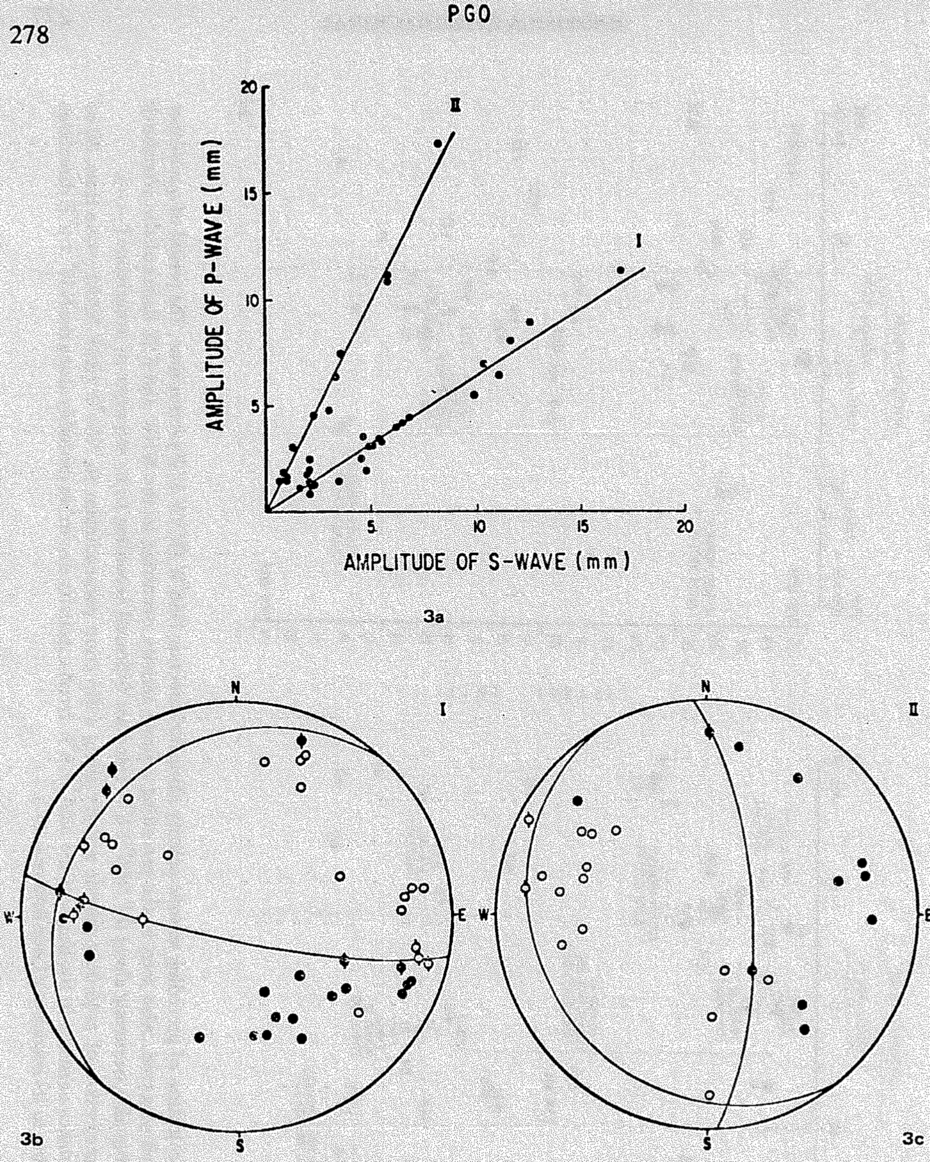


Figure 3, Figure 3a shows a plot of relatives amplitudes at PGO of P and S waves for "foreshocks" ($m > 1.5$). Two differents trends are well defined, I and II.

Figure 3b Composed focal mechanism for trend I. The more vertical plane is selected as dislocation plane. Strike = 282°, dip = 80°, rake = −72°.

Figure 3c Composed focal mechanism for trend II. The more vertical plane is selected as dislocation plane. Strike = 177°, dip = 72°, rake = −78°.

BIBLIOGRAPHY

CHEN, Z., P. LIU, D. HUANG, D. ZHENG, F. XUE and Z. WANG (1979). Characteristics of regional seismicity before major earthquakes. *International Symposium on Earthquake Prediction* (UNESCO, Paris, 2-6 April 1979, pp. 1-16.

CHIN, Y., Y. CHAO, Y. CHEN, C. YEN and Y. CHO (1978). A characteristic feature of the dislocation model of the foreshocks of the Haicheng earthquake, Liaoning province. *Chinese Geophysics, I*, 1, pp. 55-65. (English translation of *Acta Geophys. Sinica, 19*, pp. 156-164, 1976).

GARZA, T. and C. LOMNITZ (1978). The Oaxaca gap: a case history. *Methodology for Identifying Seismic Gaps and Soon-to-Break Gaps* (U. S. Geol. Surv., *Open-File Report, 78-943*) pp. 173-188.

GONZALEZ, J. (1979). Algunas características de los temblores (m 4.0) precedentes al terremoto (M_S = 7.8) de Oaxaca del 29 de noviembre de 1978. *Tesis Profesional*, Facultad de Ciencias, UNAM.

HELSLEY, C. E., J. B. NATION and R. P. MAYER (1975). Seismic refraction observations in southern Mexico. *EOS, 56, 6*, p. 452.

KASAHARA, J., S. NAGUMO and S. KOREZAWA (1978). Seismic activity in Sagami Bay and off the Boso Peninsula observed by ocean bottom seismographs in 1971. *Jour. Phys. Earth., 26, 2*, pp. 199-210.

KELLEHER, J., L. SYKES and J. OLIVER (1973). Possible criteria for predicting earthquake locations and their application to major plate boundaries of the Pacific and the Caribbean. *J. Geophys. Res., 78, 14*, pp. 2547-2585.

LEE, W. H. K., R. E. BENNETT and K. L. MEAGHER (1972). A method of estimating magnitude of local earthquakes from signal duration. (*U. S. Geol. Surv., Open-File Report 72-1710*) pp. 1-28.

LEE, W. H. K. and J. C. LAHR (1975). Hypo 71 (Revised): A computer program for determining hypocenter, magnitude, and first motion pattern of local earthquakes. (*U. S. Geological Survey Open-File Report, 75-3111*), pp. 1-113.

LUKK, A. A. (1978). Space-time sequence of weak earthquakes in Garm region. *Izvestiya A. N. SSSR, Physics of the Solid Earth, 14, 2*, pp. 100-108.

MOONEY, W. M., R. P. MEYER, C. R. HELSLEY, C. LOMNITZ and B. T. R. LEWIS (1975). Refracted waves across a leading edge: Observations of Pacific shots in southern Mexico, *EOS, 56, 6*, p. 452.

OHTAKE, M., T. MATUMOTO and G. V. LATHAM (1977). Seismicity gap near Oaxaca, southern Mexico as a probable precursor to a large earthquake. *Pure Appl. Geophys. 115, 1/2*, pp. 375-385.

PONCE, L., K. C. McNALLY, V. SUMIN DE PORTILLA, J. GONZALEZ, A. DEL CASTILLO, L. GONZALEZ, E. CHAEL and M. FRENCH (1978). Oaxaca, Mexico earthquake of 29 November 1978: A preliminary report on spatio-temporal pattern of preceding seismic activity and mainshock relocation. *Geofísica Internacional*, 17:2, pp. 109-126.

RALEIGH, B., G. BENNETT, H. CRAIG, T. HANKS, P. MOLNAR, A. NUR, J. SAVAGE, C. SCHOLTZ, R. TURNER and F. WU (1977). Prediction of the Haicheng earthquake. *EOS*, *58*, *5*, pp. 236-272.

RIKITAKE, R. (1976). Earthquake Prediction. Elsevier, Amsterdam, pp. 166-177.

SADOVSKY, M. A., I. L. NERSESOV, S. K. NIGMATULLAEV, L. A. LATYNINA, A. A. LUKK, A. N. SEMENOV, I. G. SIMBIRIEVA and V. I. ULOMOV(1972). The processes preceding strong earthquakes in some regions of Middle Asia. (*Tectonophysics*, *14*, *3/4*, pp. 295-307.

SHOR, G. G. and R. L. FISHER (1961). Middle America trench: seismic-refraction studies. *Geol. Soc. Am. Bull.*, *72*, pp. 721-730.

SINGH, S. K., J. HAVSKOV, K. McNALLY, L. PONCE, T. HEARN and M. VASSILIOUS (1980). The Oaxaca, Mexico, earthquake of 29 November 1978: A preliminary report on aftershocks. *Science*, in press. (See also this issue).

STEWART, G. S. and E. P. CHAEL (1978). Source mechanism of the November 29, 1978. Oaxaca, Mexico earthquakes a large simple event. This issue.

SUMIN DE PORTILLA, V., L. PONCE, K. C. McNALLY, N. T. KOCHNEVA and S. RODRIGUEZ-LOPEZ (1978). Morphostructural analysis of Oaxaca, Mexico, applied to Seismic Studies. This issue.

WU, K., M. YUE, H. WU, S. CHAO, H. CHEN, W. HUANG, K. TIEN and S. LU (1978). Certain characteristics of the Haicheng earthquake ($M = 7.3$) sequence. *Chinese Geophysics*, *1*, *2*, pp. 289-308 (English translation of *Acta Geophys. Sinica*, *18*, pp. 164-181, 1975).