GEOFISICA INTERNACIONAL

LOCATIONS OF AFTERSHOCKS OF THE OAXACA EARTHQUAKE USING SMOKED PAPER RECORDERS AND DIGITAL EVENT RECORDERS

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RESUMEN*

Dentro de un proyecto cooperativo entre CICESE y UCSD, se instaló una red de 15 sismógrafos en la región de las réplicas del temblor de Oaxaca ($M_s = 7.8$), de Noviembre 29, 1978. Ocho sismógrafos verticales con registro en papel ahumado y siete sismógrafos de 3 componentes, con graficación en formato digital, se distribuyeron logísticamente en 9 localidades sobre el área de interés. La red se inició con la instalación de la primera estación en diciembre 1°; entró en operación total el 5 de diciembre. Cientos de eventos se registraron en papel ahumado y un número considerable se detectó simultáneamente en las grabadoras digitales. Los registros digitales han sido especialmente útiles para la determinación precisa de los tiempos de arribo de la onda S. Los resultados presentados aquí, incluyen datos para el período del 3 al 18 de diciembre de 1978.

Las réplicas están distribuidas en una superficie de aproximadamente 3,000 km^2, con una longitud de 60 km, paralela a la costa, y una extensión de 35 km, en tierra firme. La distribución de hipocentros sugiere una echado de 20° para la zona Benioff. Las profundidades varían de 10 km al sur de la línea de costa, hasta 40 km hacia el norte. En el extremo norte, a 90 km del eje de la trinchera mesoamericana, la zona de ruptura parece deternerse abruptamente, debido a la existencia de una falla secundaria, normal al plano de subducción. Esta falla, por primera vez inferida en base a un estudio local, presenta un mecanismo focal compuesto de tipo normal. Probablemente el movimiento sísmico principal ocurrió en esta falla, lo cual podría explicar los graves daños causados en el área de Loxicha.

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EXTENDED ABSTRACT

In a cooperative study between CICESE and UCSD, seven stations with three component digital event recorders, and eight smoked paper recorders were deployed in the aftershock region of the Oaxaca Earthquake of November 29, 1978. The first station was installed on December 1st., and the complete array was in operation by December 5th. A total of eight sites were occupied during this time period. Hundreds of events were recorded.

In this resume we present the hypocentral determinations from December 3rd. to December 15th., 1978.

P and S wave first arrivals on the smoked paper recorders, along with S-P times observed on the digital records, were used in the determinations. Time corrections on the smoked paper recorders are estimated to be within five hundredths of a second and, within 2/10 seconds for the digital event recorders. Time corrections were provided to the analog records from the WWVB radio time code. On the digital records, timing was provided using a clock syncronizer periodically each two weeks. The digital event records are specially useful for the measurement of accurate S-P arrival times. P wave arrival times were measured on the vertical digital records, and the S wave arrivals on the horizontal. Some events show complicated wave forms without any clear correlation to magnitude. Local complexities in the crustal structure around the source and receiver, could be argued to have a significant effect on the wave forms. Additional detailed studies are currently underway.

Computer hypocentral determinations were obtained by using Hypo-76 computer program. A crustal velocity model obtained from calibration explosions in the region of the Colima Earthquake (Reyes, *et al.*, 1979), was used. Shear waves velocities were fixed from the Wadatti diagram, which gives a Vp/Vs ratio of 1.78, which compares with the value given for the Colima region of 1.77 and is slingtly greater than the normally assumed value of 1.73. Nearly 220 events were accurately located, using a maximum of 16 phases in the determinations; in average 9 pha-

ses were used. Master events defined as those with the clearest impulsive P and S arrivals, simultaneously recorded at the maximum number of stations, were used to obtain station corrections. Carefull analysis of the residuals did not show any particular tendency. The residuals average to zero with a standard desviation of 3/10 secs. which is within the standard error of the arrivals on the analog records. Station corrections were used only to reduce the travel times for station elevation. A shallow surface P-wave velocity of 5.5 km/sec, and the station elevation from the topographic maps, were used in the correction. The largest station correction was 6/10 sec, for the San Jose del Pacifico station [SJP] at an altitude of 3000 meters. In general, the station corrections average 2/10 secs. The RMS of the hypocentral determinations were less than 3/10 sec. Generally the error bars of the epicentral and focal depth estimations are not greater than 4 km for 90% of the events within the array. For events off shore, the errors are estimated to be smaller than 15 km in general.

The map of the epicentral locations along with the topographic and bathymetry contours is shown in Fig. 1, the aftershock area outlined is approximately 3000 km. If we take the whole set of the epicentral determinations, the aftershock area will be twice as big. Within the time period if this study, five aftershocks were located by NOAA, three of those were located with the array. Those events are shown in Fig. 1 by solid circles. Magnitudes for those events [counter clock wise] are 4.2, 4.7 and 4.2 with a focal depths of 40, 50 and 90. In general, we did not found a clear systematic bias in the NOAA determinations.

Fig. 2, shows a profile for the hyponcentral determinations taken normal to the trench axis. The events located near to the trench axis do not have a good focal depth control, because of the shallow angle of the rays leaving the source to the station. Events in the distance range from 45 km to 95 km have good depth control because, they occured underneath the array. The profile shows two clearly well defined trends: one depping at a shallow angle of 20, suggesting that those events occured along the main thrust fault associated to the plate subdution, and a second trend strongly supported by the data, indicating a reverse fault plane depping at a steep angle of 70 toward the trench. This secondary fault has a width of 20 km, and a length of 40 km.

To determine the nature of this secondary faulting, a composite focal mechanism for events in this region deeper than 30 km was obtained. The equal area protection of the upper hemisphere for the composite focal mechanism shown in Fig. 3, clearly indicates normal faulting along 20 dipping plane consistent with the hypocentral trend. From the overall results we conclude that:

The aftershock sequence distribution filled the seismic gap previouslly indentified by Kelleher in 1973, and recently discussed in detail by McCann (1979). In this gap an earthquake was forecasted by Ohtake, *et al.* (1978), on the basis of seismic quiescence for small magnitude earthquakes [M $<$ 6] in the region. The aftershock distribution shows a complex pattern suggesting three linear trends, two parallel to the trench axis and one normal to it.

The analysis of the aftershock sequence distribution along with the teleseismic data suggests:

The rupture probably started at the intersection of the two faults described, propagating toward the trench axis and therefore, focusing its energy along this direction. The increased stress field due to the propagation of the initial break, probably increased the stress on the secondary fault triggering a second event that most likely focused its energy toward the high elevation regions. This secondary fault, probably stopped the main fault from extending into the deepest regions of the major plate boundary. This interpretation explains the fact that the heaviest damage was in the high elevation regions. But is inconsistent with the lack of damage in the lowlands along the coast, where we will expect the heaviest damage because of amplification effects in the low rigidity sediments. A second interpretation consistent with the teleseismic data is that, the main rupture started along the secondary fault propagating parallel to the trench axis from the deepest part of the fault toward the high elevation regions. This interpretation will be consistent with the source dimentions and rupture propagation obtained from the P wave teleseismic data; but it adds additional complexities to the rupture processes along subductions zones. The overall results of this study suggests that, the rupture process associated with this earthquakes can not be interpreted in terms of simple plate tectonic processes.

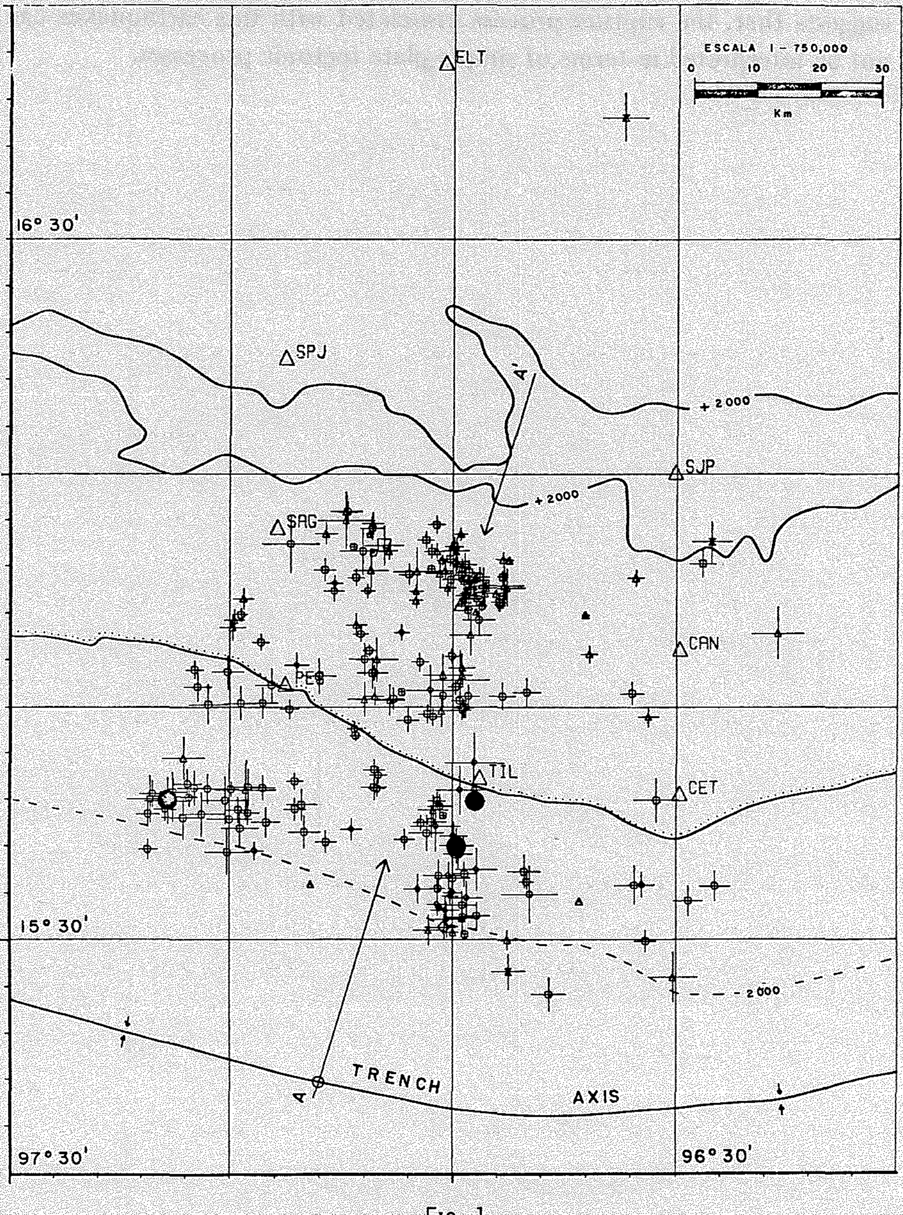
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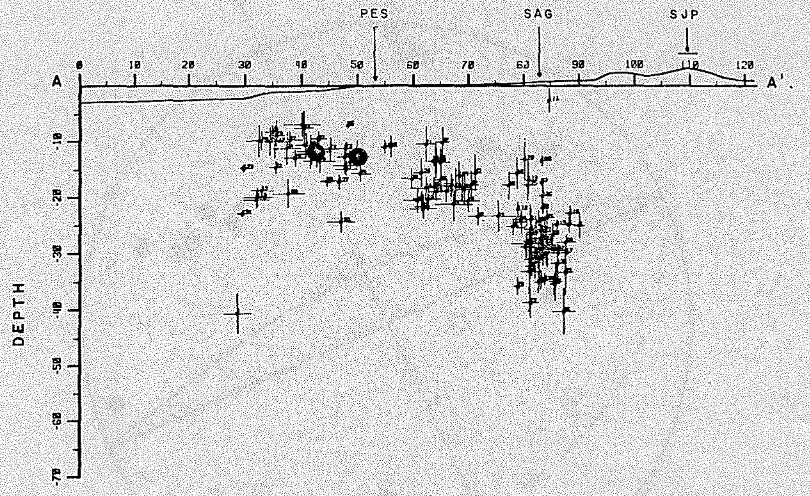
FIG. 1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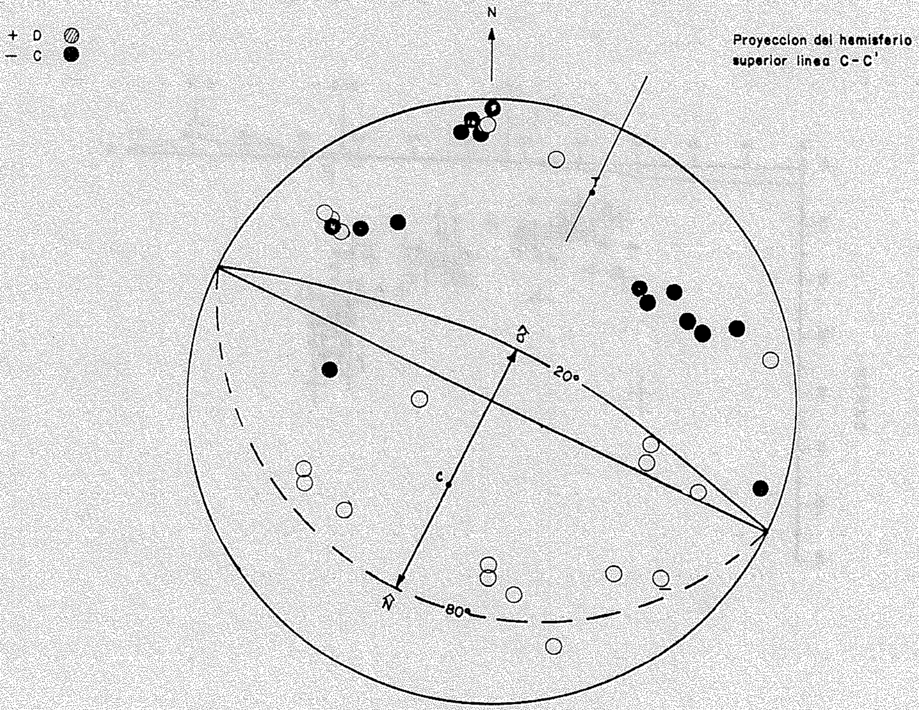
DEPTH

FIG. 2



Mecanismo focal compuesto. (Hemisferio superior) Eventos sobre el perfil f - f'
Composite focal mechanism. (Upper hemisphe) Events on profile f - f'

BIBLIOGRAPHY

KELLEHER, J. A., L. R. SYKES, and J. OLIVER (1973). Possible Criteria for Predicting Earthquake Locations and their Application to Major plate Boundaries of the Pacific and Caribbean. *Jour. Geophys. Res.*, *78*, pp. 2547-2585.

McCANN, W. R., S. P. NISHENKO, L. R. SYKES, and J. KRAUSE (1978). Seismic Gaps and Plate Tectonics: Seismic Potential for Major Plate Boundaries. *Methodology for Identifying Seismic Gaps and Soon-to-Break Gaps (U. S. Geol. Serv. Open File Report 78-943)* pp. 441-584.

OHTAKE, M., T. MATUMOTO, and G. V. LATHAM (1977). Seismicity Gap Near Oaxaca, Southern Mexico as a Probable Precursor to a Large Earthquake. *Pure and Appl. Geophys.*, *115*, *1/2*. pp. 375-385.

REYES, A., J. N. BRUNE, and C. LOMNITZ (1979). Source Mechanism and Aftershock Study of the Colima, Mexico Earthquake of January 10, 1973. Preprint.