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Distribution of (*mb - Ms*) of moderate earthquakes along the Mexican seismic zone

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RESUMEN

Se estudia la distribución espacial de los valores *mb-Ms* para 55 sismos en el periodo de 1978 a 1994, con profundidades focales de 0 a 80 km, mb de 4.5 a 5.5, ocurridos a lo largo de la Trinchera Mesoamericana entre 95° y 107°W. Los valores *mb-Ms* tienen una distribución bimodal, con picos en 0.3 y 0.8 y mínimo en *mb-Ms*=0.6. Los eventos del primer grupo, con *mb-Ms*<0.6, se distribuyeron a lo largo de la trinchera en toda la región, comprendida por los bloques Michoacán, Guerrero y Oaxaca; la mayoría de los eventos del segundo grupo, con *mb-Ms*≥0.6, se encontraron en la parte central de la región en el bloque de Guerrero. Estos datos muestran que la litosfera del bloque de Oaxaca está relativamente homogénea y genera los eventos de baja frecuencia, pero la litosfera del bloque de Guerrero está más compleja y produce los eventos de alta y baja frecuencia.

PALABRAS CLAVE: Temblor, magnitud, México, subducción.

ABSTRACT

We study the spatial distribution of *mb-Ms* for 55 earthquakes from 1978 to 1994 with focal depth from 0 to 80 km, mb from 4.5 to 5.5, which occurred along the Middle America trench, between 95° to 107° W. The *mb-Ms* values have a bimodal distribution, with peaks at values of 0.3 and 0.8 and minimum at *mb-Ms*=0.6. Events of the first group, *mb-Ms* <0.6, were distributed along the trench over the whole region, and events of the second group, *mb-Ms* ≥ 0.6, were found mainly in the central part of the region, within the Guerrero block. These data show that the Oaxaca block consists of a relatively homogeneous lithosphere, where low-frequency events dominate, while the Guerrero block is more complex radiating both low- and high-frequency events.

KEY WORDS: Earthquake, magnitude, Mexico, subduction.

INTRODUCTION

Magnitudes Ms and mb characterize the intensity of earthquake radiation in different frequency ranges. Magnitude Ms is based on the surface wave amplitude at a period around 20 s, while magnitude mb is determined by measuring teleseismic P-wave amplitude at a period of about 1 s. The difference between the mb and Ms values, *mb-Ms*, defines a relationship between short- and long-period earthquake radiation and may be an indicator of the tectonic environment of the seismic zone. This difference is widely used, for example, for discrimination between earthquakes and nuclear explosions. Normally, *mb-Ms* is about 2 to 3 for explosions and 0 to 2, for earthquakes (Denny *et al*. 1987). Prozorov *et al*. (1983) and Prozorov and Sabina (1984) used Ms-mb values for the world-wide regionalization of the active seismic zones. They showed the possibility of distinguishing between subduction zones (low-frequency events), and ridges and fracture zones (high-frequency events) using the Ms-mb discriminator. Ekstrom and Dziewonski (1988) found a systematic difference in the Ms versus seismic moment (*Mo*) relationships for continental, and ridge and fracture zone earthquakes. They demonstrated the predominance of short-period radiation for continental earthquakes.

We study the *mb-Ms* distribution along the Mexican seismic zone. This region is characterized by a complex tectonic setting. Transverse fracture zones and ridges cut the Middle American Trench (Figure 1). There are active blocks along the Mexican coast (Jalisco, Michoacán, Guerrero, Oaxaca) whose boundaries reflect these fracture zone-trench intersections. Each of these blocks is characterized by high seismic activity related to subduction of the young Rivera (Jalisco block) and Cocos (Michoacán, Guerrero, Oaxaca, blocks) plates beneath the North American plate (Pardo and Suárez, 1995).

The region of this study extends from 15° to 19°N and 95° to 107°W (Figure 2). We study only the events east of the Middle America trench, where the oceanic Cocos plate subducts under the North America plate. LeFevre and McNally (1985) noted that the region north of the Tehuantepec Ridge may be considered as homogeneously stressed.

OBSERVATIONS

Figure 3 shows a plot of magnitude mb versus Ms for 126 earthquakes from the Mexican seismic zone, focal depth

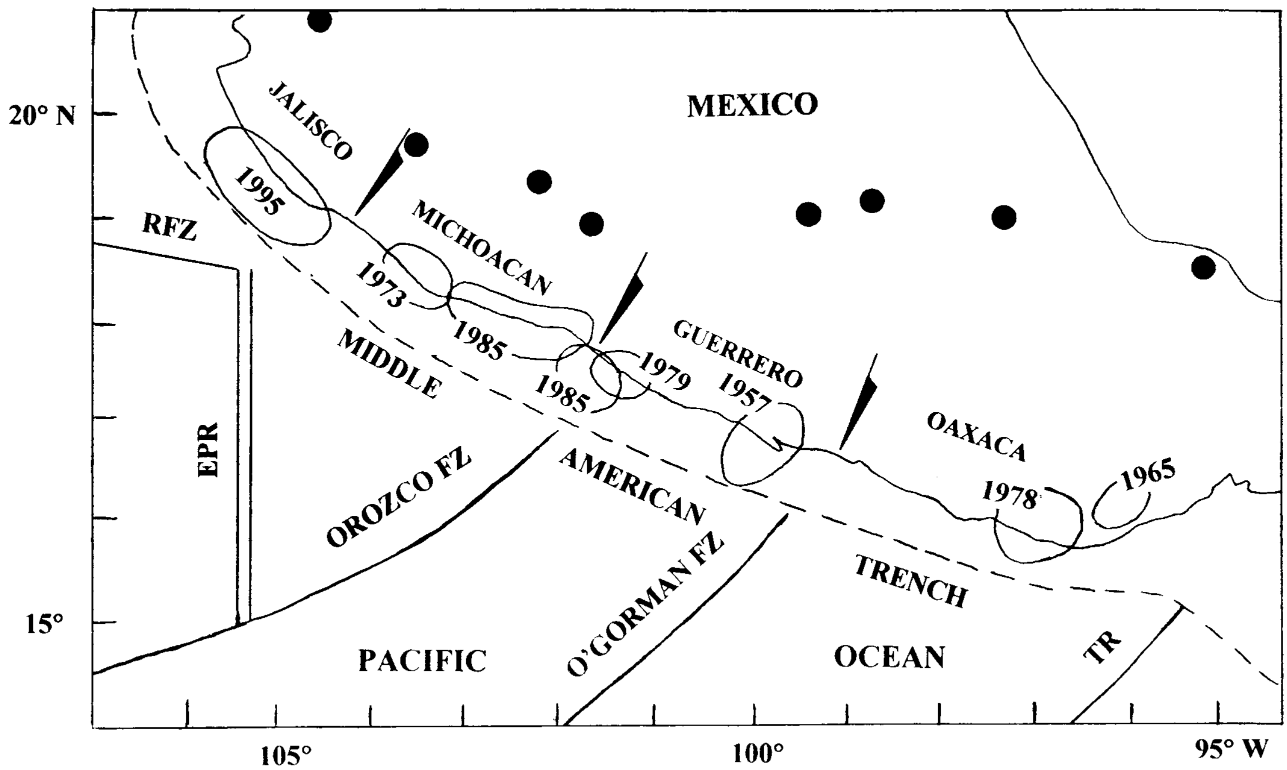

Fig. 1. Main tectonic structures of the region of study. Jalisco, Michoacán, Guerrero and Oaxaca, active blocks of the subduction zone after Singh and Mortera (1991). Black circles indicate the position of active volcanos. A dashed line shows the axis of the Middle America trench. Ovals show the rupture zones of the great earthquakes, Ms ≥ 7.5 for the last 50 years and the year of event, after Singh and Mortera (1991) and Zobin (1997). The double line shows the East Pacific Rise (EPR), the single lines show the main oceanic Fracture Zones (F Z) and Tehuantepec Ridge (TR). Arrows show the boundaries between active blocks. RFZ, the Rivera Fracture Zone.

0 to 80 km, which occurred from 1962 to 1993. Magnitudes mb and Ms were taken from the Bulletin of the International Seismological Centre (1964-1993) and Monthly Listings, NEIC (1962,1963). Data are plotted for events with magnitude mb less than 6.5.

A maximum-likelihood linear regression for $4.5 \le mb \le 6.5$ and $3.0 \le Ms \le 6.5$ yields

$$Ms = 2.49\ (\pm 0.05)\ mb - 7.96\ (\pm 0.27) \quad R = 0.85 \quad (1)$$

Here R is the coefficient of correlation. The coefficients of the equation are close to those obtained by Prozorov and Sabina (1984) for Mexico using data from 1964 to 1980.

According to this equation, mb ~ 5.5 may be considered as a boundary value; for lower values of mb, mb ≥ Ms, while for higher values, Ms > mb. Geller (1976) suggested that mb may saturate beyond 5.5. To assure a homogeneous data set and to avoid the problem of magnitude saturation, we only consider events with mb ≤ 5.5.

We selected 55 events which occurred along the Middle America trench between 1978 and 1994, with focal depth from 0 km to 80 km (Table 1). Epicenters, depth of events, and magnitudes mb and Ms were taken from ISC (Bulletin of the International Seismological Centre, 1978-1993) and UNAM (Boletin Sismológico Mensual, Instituto de Geofísica, UNAM, 1994). A map of epicenters is presented in Figure 2. Mean errors in the event locations, taken from ISC (93% of events), are 6.3 km for epicenter and 6.6 km for depth. Errors in the determination of events by UNAM (4 of 55 events) were not published. Standard deviation in the determination of Ms is 0.08 for a group of stations and 0.22 for a single station; standard deviation in the determination of mb is 0.06 for a group of stations and 0.34 for a single station (Kaverina *et al*., 1996). Most of the magnitudes were determined from several stations. The magnitudes mb were estimated from data from 10 to 83 stations and magnitudes Ms were estimated from data from 1 to 10 stations (26 estimations were made by 3 or more stations). Prozorov and Hudson (1974) showed a slight dependence of *mb-Ms* upon focal depth. Our data support this result. The coefficient of correlation is 0.164 for the 55 events (not significant at the 90% confidence level). Therefore, we neglect the depth difference as a factor on *mb-Ms* for the depth interval of 0 to 80 km.

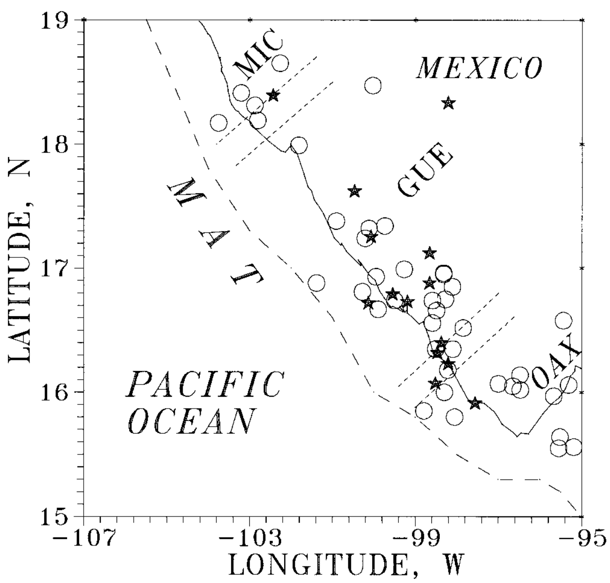

Fig. 2. Spatial distribution of events with different *mb-Ms*. Circles, *mb-Ms* < 0.6; stars, *mb-Ms* ≥ 0.6. The dashed line shows the position of the axis of the trench (MAT). The parallel dashed lines show the borders between active blocks. MIC, the Michoacán, GUE, the Guerrero, OAX, the Oaxaca blocks.

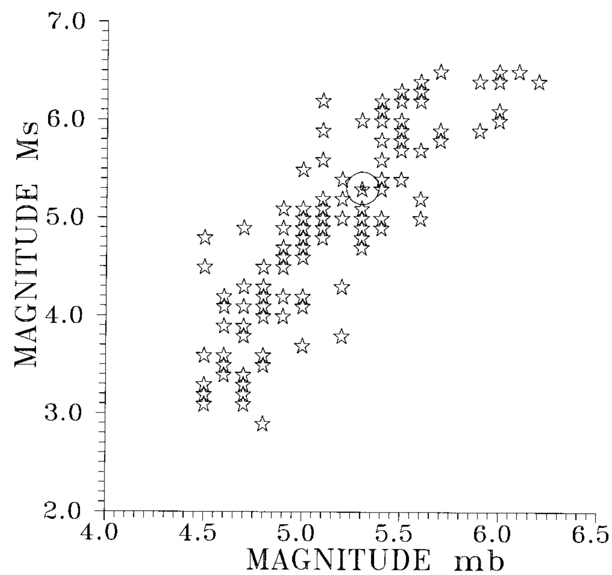

Fig. 3. Magnitude mb versus magnitude Ms plot for Mexican earthquakes , 1962-1993, depth range 0-80 km. The large circle shows the point where mb = Ms.

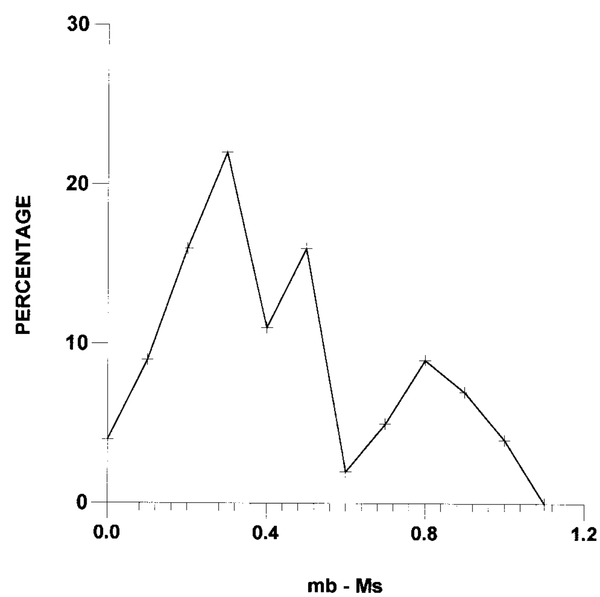

Fig. 4. The percentage distribution of the *mb-Ms* values.

Small events with magnitude mb < 5.5 appear to reflect the properties of the source better than the larger events because large events are generally complex (Singh and Mortera, 1991). Ekstrom and Dziewonski (1988) suggest that for large earthquakes the differences between short- and long-period radiation for different tectonic provinces are not as significant as for the smaller ones.

We find no dependence of *mb-Ms* upon magnitude mb (R = 0.13), but there is a slight negative dependence upon Ms (R = -0.75). Therefore, small values of *mb-Ms* indicate relatively large amount of low-frequency radiation (low-frequency events); while large values indicate small amount of low-frequency radiation by the earthquake source (high-frequency events).

DISTRIBUTION OF *mb-Ms* ALONG THE MIDDLE AMERICA TRENCH

Figure 4 shows the percentage distribution of *mb-Ms* for the 55 events, which suggests a bimodal distribution with peaks at *mb-Ms* = 0.3 and 0.8. The significance of these two peaks was tested by Student's criterion for small samples (Caulcott, 1973):

$$t=(x_1-x_2)/\sqrt{[(n_1-1)s_1^2+(n_2-1)s_2^2](1/n_1+1/n_2)/[(n_1-1)+(n_2-1)]}, \qquad (2)$$

where t is the critical value of the criterion; x_1 and x_2 are the means of two samples, with magnitude difference from 0 to 0.5 and more than 0.5; n_1 and n_2 are numbers of events in the two samples, and s_1 and s_2 are the sample standard deviations. The test was done for two cases: for all magnitudes, and for magnitudes estimated by 3 or more stations. In both cases the values of the peaks were the same (Table 2) and were significant at the 90% confidence level.

Table 1

List of events

yy m d	Lat., N	Long., W	Dep., km	mb	Ms	*mb-Ms*
1978 07 05	18.47	-100.03	75	5.4	4.9	0.5
1978 09 29	18.65	-102.27	86	5.4	5.0	0.4
1978 11 30	16.07	-096.98	40	5.1	4.9	0.2
1978 12 11	16.67	-099.90	42	5.4	5.3	0.1
1978 12 28	16.02	-096.47	45	5.3	4.8	0.5
1979 01 06	18.32	-102.88	56	5.1	4.8	0.3
1979 01 28	16.85	-098.11	56	5.1	4.8	0.3
1981 06 20	16.07	-098.52	22	5.1	4.2	0.9
1981 07 21	16.40	-098.38	46	5.1	4.4	0.7
1981 07 21	16.35	-098.51	36	5.2	5.0	0.2
1982 01 02	16.81	-100.28	26	5.4	5.1	0.3
1982 01 02	16.72	-100.14	19	5.3	4.5	0.8
1982 12 14	16.66	-098.49	40	5.1	5.0	0.1
1983 02 07	16.96	-098.32	60	5.5	5.0	0.5
1983 02 21	16.95	-098.32	53	5.3	4.8	0.5
1984 01 28	17.32	-100.12	58	5.0	4.7	0.3
1984 06 04	18.33	-098.21	53	5.4	4.3	0.9
1984 07 14	17.34	-099.74	48	5.3	4.8	0.5
1984 10 19	16.75	-098.28	46	5.1	4.9	0.2
1984 11 30	16.23	-098.21	36	5.3	4.5	0.8
1984 12 13	16.14	-096.48	45	5.3	4.9	0.4
1985 09 25	18.19	-102.81	30	5.3	5.2	0.1
1986 05 29	17.12	-098.66	53	5.2	4.2	1.0
1987 06 07	16.88	-098.66	41	5.5	4.7	0.8
1987 09 27	18.17	-103.75	15	5.0	4.8	0.2
1988 09 01	16.73	-099.19	52	5.0	4.1	0.9
1989 05 02	16.99	-099.27	52	5.3	4.9	0.4
1989 10 08	17.25	-100.07	58	5.0	4.1	0.9
1989 11 09	16.79	-099.55	10	5.1	4.1	1.0
1990 01 13	16.74	-099.50	10	5.2	4.8	0.4
1990 01 29	18.39	-102.44	60	5.3	4.5	0.8
1990 02 17	15.80	-098.05	10	5.1	4.9	0.2
1991 01 14	17.99	-101.82	55	5.3	4.9	0.4
1991 04 01	16.35	-098.10	40	5.1	4.8	0.3
1991 04 27	17.24	-100.21	59	4.6	4.1	0.5
1991 05 22	18.41	-103.21	45	5.0	4.6	0.4
1991 07 25	16.88	-101.39	22	5.4	5.4	0.0
1991 09 10	16.06	-095.31	48	4.8	4.7	0.1
1991 09 26	16.18	-098.22	25	5.2	4.7	0.5
1991 10 22	16.58	-095.44	46	4.6	4.3	0.3
1991 11 10	15.55	-095.55	20	4.8	4.6	0.2
1991 11 24	16.52	-097.85	44	5.2	5.1	0.1
1992 01 08	15.56	-095.19	4	5.0	4.2	0.2
1992 05 15	16.32	-098.47	8	4.8	4.2	0.6
1992 05 19	16.00	-098.30	25	4.7	4.2	0.5
1992 06 07	16.74	-098.59	51	5.3	4.9	0.4
1992 06 07	16.56	-098.59	42	5.2	4.9	0.3
1992 11 02	16.05	-096.65	46	4.8	4.5	0.3
1992 11 10	16.93	-099.95	30	4.5	4.2	0.3
1993 03 31	17.38	-100.91	30	5.3	5.1	0.2
1993 07 29	17.62	-100.47	66	5.0	4.3	0.7
1994 07 09	15.91	-097.56	21	4.2	3.4	0.8
1994 08 06	15.64	-095.52	11	5.0	4.7	0.3
1994 09 17	15.97	-095.67	15	4.8	4.6	0.2
1994 12 13	15.85	-098.79	16	5.3	4.9	0.4

Note. 1978-1993, data from ISC; 1994, data from SSN, UNAM.

Table 2

Statistical test of significance for two peaks in the *mb-Ms* distribution

Test	n_1	x_1	s_1	n_2	x_2	s_2
1	41	0.304	0.139	14	0.828	0.113
2	26	0.308	0.138	7	0.800	0.115

t-critical at 90% confidence level of significance for 53 and 31 degrees of freedom is 1.68 and 1.70, respectively; t_1 is 13.10, t_2 is 8.63. t_1 and t_2 are >> *t*-critical.

We chose the minimum value between the two peaks in *mb-Ms* distribution, *mb-Ms* = 0.6, as a boundary between two groups: 14 high-frequency events (*mb-Ms* ≥ 0.6) and 41 low-frequency events (*mb-Ms* < 0.6).

A map of epicenters (Figure 2) shows some regularity in space distribution for these two groups of events. Low-frequency events are situated along the trench of the whole Pacific coast of Mexico while the high-frequency events cluster mainly in the middle part of the region in the Guerrero block. To test this observation we constructed a 2x2 contingency table (Caulcott, 1973) for events situated within the Guerrero and Oaxaca blocks (Table 3). The 6 events occurring on the boundary between the two blocks (Figure 2) were excluded from this calculation. The value of χ^2 criteria was obtained from a contingency table (Caulcott, 1973):

$$\chi^2 = (p_1 - p_2)^2/p\,(1- p)\,(1/n_1 + 1/n_2), \qquad (3)$$

where $p_1 = x_1/n_1$; $p_2 = x_2/n_2$; $p = (x_1 + x_2)/(n_1 + n_2)$; n_1 and n_2 are the total number of events in the blocks of Oaxaca and Guerrero, respectively; and x_1 and x_2 are the number of events with *mb-Ms* <0.6 in these blocks. This value of χ^2 was compared with χ^2 at the 90% confidence level. The test shows (Table 3) that there is a significant difference in occurrence of earthquakes with different spectral content in the two blocks. The number of events observed in the Michoacán block was not sufficient for testing.

DISCUSSION

The *mb-Ms* distribution along the Mexican seismic zone shows a difference for the blocks of Guerrero and Oaxaca. This study was based on ISC locations. Singh and Lermo (1985) noted a tendency of systematic mislocation of the 1973-1982 ISC epicenters as compared to their locations determined by the local networks installed in the near-source region. It was observed that the epicenters were shifted by about 35 km towards NE, or almost perpendicular to the trench. This one-directional systematic shift perpendicular

Table 3

Statistical test of significance for change in the *mb-Ms* distribution in the Guerrero and Oaxaca zones (a 2x2 contingency table).

Zone	Oaxaca	Guerrero	Total
mb-Ms < 0.6	13	20	33
mb-Ms ≥ 0.6	1	9	10
Total	14	29	43

χ^2-critical at 90% confidence level of significance is 2.70; our value of χ^2 = 3.30, or $\chi^2 > \chi^2$-critical.

to epicentral zone does not change our results. We can say that the Oaxaca block consists of a relatively homogeneous lithosphere, where low-frequency events dominate, while the Guerrero block is more complex, radiating low-frequency as well as high-frequency events.

The change in physical properties at the boundary between the Guerrero and Oaxaca blocks is supported by other seismological investigations. Singh and Mortera (1991) report that large earthquakes are relatively simple in Oaxaca and complex in Guerrero. They also note that the ratio of surface-wave to body-wave seismic moments for large earthquakes is smaller in Oaxaca than in the regions northwest of 99° W. Singh and Mortera (1991) propose that the existence of this boundary may be related with the different age of the subducting plate which older in Oaxaca (about 20 m.y.) and younger in Guerrero (about 13 m.y.). Castro *et al*. (1994) observe a difference in the quality factor Q for Oaxaca and Guerrero blocks which indicates greater attenuation in Oaxaca than in Guerrero.

CONCLUSIONS

The *mb-Ms* values of small earthquakes along the Middle America trench, between 95° and 107° W, have a significant bimodal distribution, with peaks at 0.3 and 0.8. Events of the first group, *mb-Ms* < 0.6, were distributed along the trench in the whole region, but events of the second group, *mb-Ms* ≥ 0.6, were clustered mainly in the central part of the region within the Guerrero block. This suggests that the Oaxaca block consists of a relatively homogeneous lithosphere, where low-frequency events dominate, while the Guerrero block is more complex radiating both low- and high-frequency events.

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