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MISLOCATION OF MEXICAN EARTHQUAKES AS REPORTED IN INTERNATIONAL BULLETINS

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RESUMEN

La comparación de las localizaciones de temblores determinadas desde sismógrafos de campo o de estudios especiales con aquellos reportados en los boletines de PDE e ISC, sugieren que los temblores costeros superficiales en México están sistemáticamente mal localizados en estos boletines. En general, los epicentros tienen un corrimiento de cerca de 35 km hacia N 35°- 45°E.

ISC, con mayor frecuencia que PDE, consigna profundidades de foco basadas en fases de profundidad. Estas profundidades, aunque mayores que las estimadas mediante modelos sintéticos o datos de campo, son más precisas que las de PDE. Sin embargo, por lo que concierne a la localización epicentral, hay poco que escoger entre los dos boletines.

Un pequeño aumento en el número de lecturas de estaciones mexicanas enviadas a PDE y ISC mejora aparentemente las localizaciones cerca de 10 km.

Los errores en la localización se deben probablemente a la velocidad alta de la placa de Cocos bajo México. Estos errores sistemáticos deben de tomarse en cuenta en el uso de estos boletines.

ABSTRACT

Comparison of locations of earthquakes determined from field seismographs or from special studies with those reported in PDE and ISC bulletins suggests that shallow coastal earthquakes in Mexico are systematically mislocated in these bulletins. In general the epicenters are shifted about 35 km towards N 35°- 45°E. ISC, more often than PDE, reports depths based on depth phases. These depths, although slightly greater than the depths estimated from synthetic modeling or field data, are more accurate than the PDE depths. However, there is little to choose between the two bulletins as far as epicentral locations are concerned. A modest increase in the number of Mexican stations sending readings to PDE and ISC appears to improve the locations by about 10 km or so. The mislocations are most probably due to higher velocity of the Cocos plate below Mexico. The systematic mislocation should be taken into account in the use of PDE and ISC bulletins.

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INTRODUCTION

It has been noted elsewhere that the epicenters of shallow earthquakes along the Mexican subduction zone, as reported in the Monthly Listing of Preliminary Determination of Epicenters (PDE), are, in general, north-east of the true epicenters (*e.g.*, Singh *et al.*, 1980; Havskov *et al.*, 1982). Synthetic P wave modeling of large subduction zone earthquakes in Mexico gives depths between 10 to 20 km with the majority being at 16 km (Singh *et al.*, 1984; Astiz and Kanamori, 1984; Chael and Stewart, 1982). Recent well studied large earthquakes are located near the coast at a distance of about 70 km from the trench. For a depth of 16 km we obtain the dip of the Benioff zone as 13°, in agreement with the dip of the fault plane found from the focal mechanism studies. The epicenters of most large earthquakes as reported in PDE and other catalogs are, however, well inland. From this Singh *et al.* (1984) concluded that the epicenters are in error and that most earthquakes, in fact, occurred close to the coast. Comparing tsunami data and epicentral locations, Cruz and Wyss (1983) have suggested that the epicenters of earthquakes along the Pacific coast of Mexico are mislocated by up to 75 km; with respect to the probable epicenters the reported epicenters are shifted towards the north-east.

The cause of the systematic shift is most likely due to higher velocity of the subducted Cocos plate with respect to the standard earth model; the rays leaving the source towards North America and Europe, where most of the stations are located, arrive earlier at these stations than expected from the standard earth model. Systematic mislocation of shallow events in subduction zones from telesismic data has also been reported in Japan (Utsu, 1967, 1971), Tonga (Mitronovas *et al.*, 1969), Aleutians (Engdahl *et al.*, 1982) and west coast of south America (Lomnitz, 1974). Taken together, observations suggest that the cause of the systematic mislocations is not station residuals but a higher velocity in the subducted slabs.

Inasmuch as the locations given by PDE and International Seismological Centre (ISC) are used in seismic risk studies, in search of precursory seismic patterns, in delineating rupture areas from aftershocks, and in mapping geometry of the Benioff zone, it is of importance to quantify the mislocations in these bulletins. In this paper we accomplish this by comparing the locations of earthquakes determined from field seismographs and in special studies with those reported by PDE and ISC.

DATA

Since 1973 portable field seismograph arrays have been systematically deployed in Mexico to record aftershocks of large earthquakes ($M_w \gtrsim$ 7.0). Although good locations (epicentral error $\simeq \pm$ 5 km, depth error $\simeq \pm$ 10 km) are available for many aftershocks, only a few of these have been located by PDE and ISC because of the small magnitudes of these events. Table 1 lists mainshocks and aftershocks for which locations are available in PDE and ISC as well as from field networks. Strictly speaking, except for the earthquakes of Oaxaca (Nov. 29, 1978) and Petatlán (Mar. 14, 1979), the mainshock locations are not based on local data since no seismograph was operating within 50 km of the epicenters. Nevertheless, for all mainshocks listed in Table 1 the locations based on special studies are available. We have listed these locations in Table 1 as if they had been obtained by local field networks. Clearly the true epicentral locations of the mainshocks (except for Oaxaca and Petatlán earthquakes) are more uncertain than the aftershocks. The depths of the mainshocks (except for the Colima earthquake of Jan. 30, 1983), listed in Table 1 as if they were obtained from local data, are based on synthetic modeling of teleseismic P waves. These depths may be accurate to about ± 5 km.

With the exception of the Huajuapan de León earthquake of Oct. 24, 1980 (depth = 65 km) which was on a normal fault, all mainshocks were shallow, thrust earthquakes along the Pacific coast of Mexico.

Table 1

Hypocentral locations and origin times determined from field seismographs. For these events the values reported in Monthly Listing of Preliminary Determination of Epicenters (PDE) and the bulletin of the International Seismological Centre (ISC) are also given.

Event No.	Source	Date	Origin Time h:m:sec	Lat(°N)	Long(°W)	Depth (km)	M_S	m_b	N_T	N_M	N_{MU}	Remarks
1	Local Data	30 Jan 73	21:01:18.0	18.39	103.21	32	-	-	-	-	-	
	PDE		21:01:12.5	18.481	102.996	43	7.5	6.2	190	6	4	Mainshock
	ISC		21:01:13.8	18.53	102.93	48	-	6.1	290	6	6	Colima
2	Local Data	10 Feb 73	11:53:28.1	18.41	103.63	11	-	-	-	-	-	Aftershock
	PDE		11:53:27.5	18.886	103.545	33N	5.6	5.4	65	0	0	
	ISC		11:53:29.0	18.78	103.79	42	-	5.6	182	0	0	
3	Local Data	29 Nov 78	19:52:47.3	16.00	96.69	18D	-	-	-	-	-	Mainshock
	PDE		19:52:47.6	16.010	96.591	18D	7.7	6.4	342	8	7	Oaxaca
	ISC		19:52:49.0	16.07	96.55	23/21	7.6	6.3	375	17	17	
4	Local Data	2 Dec 78	03:24:15.3	15.533	96.683	13	-	-	-	-	-	Aftershock
	PDE		03:24:21.4	15.791	96.480	50	-	4.7	48	1	0	
	ISC		03:24:20.2	15.81	96.47	36	-	4.7	68	11	11	
5	Local Data	2 Dec 78	03:55:45.8	15.567	96.733	12	-	-	-	-	-	Aftershock
	PDE		03:55:51.9	15.854	96.490	33N	-	4.2	9	0	0	
	ISC		03:55:52.6	16.08	96.39	21	-	-	13	3	3	
6	Local Data	2 Dec 78	05:36:01.7	15.483	96.733	10	-	-	-	-	-	Aftershock
	PDE		05:36:07.0	15.754	96.516	33N	4.8	4.9	55	1	0	
	ISC		05:36:07.0	15.83	96.48	23	4.9	4.9	91	12	12	
7	Local Data	2 Dec 78	20:27:36.2	15.733	96.817	13	-	-	-	-	-	Aftershock
	PDE		20:27:39.8	16.018	96.442	33N	-	4.5	14	0	0	
	ISC		20:27:41.9	16.07	96.39	50	-	4.8	22	8	8	
8	Local Data	5 Dec 78	06:32:26.2	15.717	97.300	11	-	-	-	-	-	Aftershock
	PDE		06:32:32.3	16.059	96.977	33N	4.3	4.7	37	0	0	
	ISC		06:32:33.0	16.10	96.93	31	4.3	4.8	47	3	3	

(Cont. Table 1)

Event No.	Source	Date	Origin Time h:m:sec	Lat(°N)	Long(°W)	Depth (km)	M_S	m_b	N_T	N_M	N_{MU}	Remarks
9	Local Data	5 Dec 78	23:41:32.7	15.600	96.750	24	-	-	-	-	-	Aftershock
	PDE		23:41:36.9	15.952	96.578	33N	-	4.8	27	0	0	
	ISC		23:41:36.7	15.91	96.54	34	-	4.8	39	9	9	
10	Local Data	8 Dec 78	10:51:43.4	15.800	96.783	19	-	-	-	-	-	Aftershock
	PDE		10:51:44.0	15.670	96.524	33N	3.2	4.7	31	1	0	
	ISC		10:51:46.0	15.70	96.49	53	-	4.7	44	11	11	
11	Local Data	11 Dec 78	15:28:40.9	15.500	96.850	15	-	-	-	-	-	Aftershock
	PDE		15:28:45.0	15.748	96.620	33N	3.2	4.4	9	0	0	
	ISC		15:28:43.0	15.70	96.69	19	3.2	4.4	15	5	5	
12	Local Data	14 Mar 79	11:07:11.2	17.460	101.460	20S	-	-	-	-	-	Mainshock Petatlán
	PDE		11:07:16.3	17.813	101.276	49	7.6	6.5	262	8	7	
	ISC		11:07:11.0	17.76	101.30	3/28	7.6	6.3	373	8	8	
13	Local Data	14 Mar 79	22:05:03.9	17.396	101.396	16	-	-	-	-	-	Aftershock
	PDE		22:05:08.2	17.707	101.081	61	-	4.4	15	1	1	
	ISC		22:05:14.0	17.80	100.90	104	-	4.8	24	5	5	
14	Local Data	16 Mar 79	10:10:30.9	17.339	101.376	25	-	-	-	-	-	Aftershock
	PDE		10:10:37.2	17.994	101.148	33N	-	4.4	6	1	1	
	ISC		10:10:44.0	18.00	100.70	106	-	4.8	8	1	1	
15	Local Data	18 Mar 79	20:12:30.7	17.421	101.102	25	-	-	-	-	-	Aftershock
	PDE		20:12:31.7	17.546	100.991	33N	5.4	5.4	164	7	5	
	ISC		20:12:36.1	17.72	100.89	61/44	-	5.3	195	7	7	
16	Local Data	20 Mar 79	00:27:51.7	17.336	101.442	30	-	-	-	-	-	Aftershock
	PDE		00:27:55.5	17.532	101.293	51	-	4.9	71	7	6	
	ISC		00:27:56.4	17.57	101.26	56	-	5.0	77	7	7	
17	Local Data	22 Mar 79	12:23:10.9	17.743	101.648	30	-	-	-	-	-	Aftershock
	PDE		12:23:16.2	17.961	101.540	76	-	5.1	73	7	6	
	ISC		12:23:16.9	18.02	101.52	77	-	5.1	74	7	7	
18	Local Data	28 Mar 79	13:33:49.6	17.407	101.158	30	-	-	-	-	-	Aftershock
	PDE		13:33:49.0	17.144	101.038	42D	-	4.5	20	6	6	
	ISC		13:33:54.0	17.20	100.60	99	-	4.3	25	6	6	

(Cont. Table 1)

Event No.	Source	Date	Origin Time h:m:sec	Lat(°N)	Long(°W)	Depth (km)	M_S	m_b	N_T	N_M	N_{MU}	Remarks
19	Local Data	6 Apr 79	20:22:22.1	17.453	101.631	14	-	-	-	-	-	Aftershock
	PDE		20:22:19.9	16.757	102.123	51	-	4.7	10	1	1	
	ISC		20:22:31.0	17.40	101.50	110	-	4.5	18	1	1	
20	Local Data	24 Oct 80	14:53:32.0	17.900	98.150	65S	-	-	-	-	-	Mainshock
	PDE		14:53:35.1	18.211	98.240	72	7.0	6.4	326	11	10	Huajuapan de León
	ISC		14:53:34.5	18.22	98.20	65/85	6.8	6.3	369	9	9	
21	Local Data	26 Oct 80	15:54:15.4	17.930	98.150	51	-	-	-	-	-	Aftershock
	PDE		15:54:16.0	18.069	97.931	75	-	4.3	27	9	8	
	ISC		15:54:10.0	17.60	97.81	54	-	4.4	28	7	7	
22	Local Data	25 Oct 81	03:22:13.0	17.750	102.250	16S	-	-	-	-	-	Mainshock
	PDE		03:22:15.5	18.048	102.084	33N	7.3	6.2	191	13	12	Playa Azul
	ISC		03:22:16.0	18.18	102.01	28/26	7.1	6.3	309	13	13	
23	Local Data	28 Oct 81	04:24:47.4	17.888	102.349	15	-	-	-	-	-	Aftershock
	PDE		04:24:53.8	18.464	102.476	33N	-	3.9	13	6	5	
	ISC		04:24:34.0	16.30	102.90	33	-	4.4	17	6	6	
24	Local Data	7 Jun 82	06:52:33.4	16.380	98.377	20S	-	-	-	-	-	First mainshock
	PDE		06:52:37.3	16.607	98.149	41	6.9	6.0	272	11	8	Ometepec
	ISC		06:52:34.6	16.51	98.25	19/35	7.0	5.8	327	12	12	
25	Local Data	7 Jun 82	10:59:35.9	16.477	98.551	15S	-	-	-	-	-	Second mainshock
	PDE		10:59:40.1	16.558	98.358	34N	7.0	6.3	307	13	11	Ometepec
	ISC		10:59:38.6	16.58	98.34	20/20	7.0	6.0	346	13	13	
26	Local Data	8 Jun 82	01:56:32.2	16.402	98.388	38	-	-	-	-	-	Aftershock
	PDE		01:56:33.2	16.374	98.364	33N	-	4.1	13	15	5	
	ISC		01:56:32.0	15.90	98.41	61	-	4.0	24	15	15	
27	Local Data	9 Jun 82	11:30:44.3	16.588	98.437	23	-	-	-	-	-	Aftershock
	PDE		11:30:44.8	16.658	98.333	33	-	4.9	56	14	9	
	ISC		11:30:48.7	16.86	98.38	52/33	-	4.8	72	14	14	
28	Local Data	9 Jun 82	16:11:31.5	16.358	98.505	15	-	-	-	-	-	Aftershock
	PDE		16:11:34.0	16.565	98.280	33N	-	4.6	43	17	12	
	ISC		16:11:35.7	16.54	98.22	53	-	4.5	50	17	17	

(Cont. Table 1)

Event No.	Source	Date	Origin Time h:m:sec	Lat(°N)	Long(°W)	Depth (km)	M_S	m_b	N_T	N_M	N_{MU}	Remarks
29	Local Data	13 Jun 82	08:12:59.9	16.159	98.440	20	-	-	-	-	-	Aftershock
	PDE		08:13:01.6	16.184	98.399	33N	-	4.1	19	15	8	
	ISC		08:13:02.0	16.00	98.50	33	-	4.1	28	15	15	
30	Local Data	13 Jun 82	11:07:52.7	16.509	98.403	25	-	-	-	-	-	Aftershock
	PDE		11:07:49.4	16.256	98.440	6	-	4.1	28	17	14	
	ISC		11:07:50.0	16.28	98.42	7	-	-	32	17	17	
31	Local Data	13 Jun 82	14:03:10.9	16.495	98.401	25	-	-	-	-	-	Aftershock
	PDE		14:03:09.0	16.130	98.386	33N	-	3.7	14	15	12	
	ISC		14:03:10.0	16.10	98.42	33	-	-	18	15	15	
32	Local Data	13 Jun 82	20:28:24.1	16.562	98.439	27	-	-	-	-	-	Aftershock
	PDE		20:28:21.1	16.176	98.372	34D	-	3.9	13	11	9	
	ISC		20:28:23.0	16.30	98.29	41	-	3.8	15	11	11	
33	Local Data	14 Jun 82	22:42:26.7	16.355	98.303	26	-	-	-	-	-	Aftershock
	PDE		22:42:30.2	16.602	98.047	40	-	4.8	69	18	13	
	ISC		22:42:30.7	16.55	98.05	46	-	4.7	77	18	18	
34	Local Data	15 Jun 82	03:08:42.9	16.548	98.272	24	-	-	-	-	-	Aftershock
	PDE		03:08:43.6	16.296	98.100	33N	-	4.0	12	6	4	
	ISC		03:08:40.0	15.90	98.00	33	-	-	15	5	5	
35	Local Data	15 Jun 82	17:24:16.8	16.628	98.469	30	-	-	-	-	-	Aftershock
	PDE		17:24:17.2	16.462	98.377	38	3.6	5.0	80	18	18	
	ISC		17:24:18.9	16.65	98.36	38/31	3.6	4.8	91	18	18	

In depth column S refers to depth determined from synthetic modeling, N to depth restricted to normal (33 km), D to depth phases used. For ISC the number following slash refers to depth estimated from depth phases. For others the depth as given by location procedure. N_T = total No. of stations used in location, N_M = No. of Mexican stations sending readings, N_{MU} = No. of Mexican stations used in the location. Note that N_M is relatively large for events 24 to 35.

Although for events 1, 20, 22, 24, and 25 (mainshocks) no local (distance ≤ 50 km) seismographs were operating the locations of these events have been determined from special studies and are considered more reliable than the PDE and ISC locations. The locations are listed as if they were determined from field seismographs. Local hypocentral determinations: Event 1 from Lomnitz (1977), event 2 from Reyes *et al.* (1979), event 3 from L. Ponce and L. Quintanar (personal communication, 1984), events 4 to 11 from Ruiz (1983); event 12 from Gettrust *et al.* (1981); events 13 to 19 from Zúñiga and Valdés (1980), events 20 and 21 from Toledo and Nava (1983); events 22 and 23 from Havskov *et al.* (1982); events 24 and 25 from J. Lermo (unpublished data), and events 26 to 35 from E. Nava (unpublished data). Depths listed as determined from local data of events 3 and 12 from Chael and Stewart (1982); event 20 from González *et al.* (1984), and event 22 from Singh *et al.* (1984).

ANALYSIS

Epicentral locations: The epicentral locations given by PDE and ISC are plotted with respect to the locations determined from local data in Figures 1 to 6. Each figure corresponds to one mainshock and its aftershocks. For the earthquakes of Oaxaca (Nov. 29, 1978), Petatlán (Mar. 14, 1979), and Ometepec (Jun. 7, 1982) the PDE and ISC locations are plotted separately. Each location is assigned a number which corresponds to the event number in Table 1 and a letter which refers to the number of stations from Mexican network utilized in PDE and ISC locations (Ȼ = one, C = more than one, S = none). Of the 35 events in Table 1, three earthquakes (Oaxaca, Petatlán, and Ometepec) contribute 20 events.

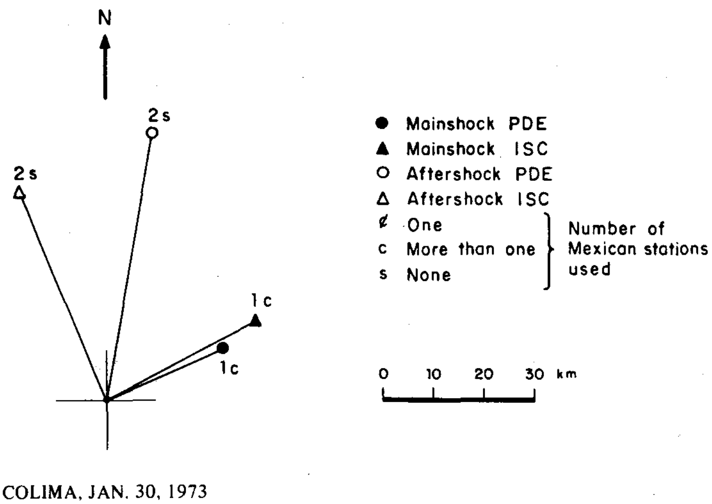
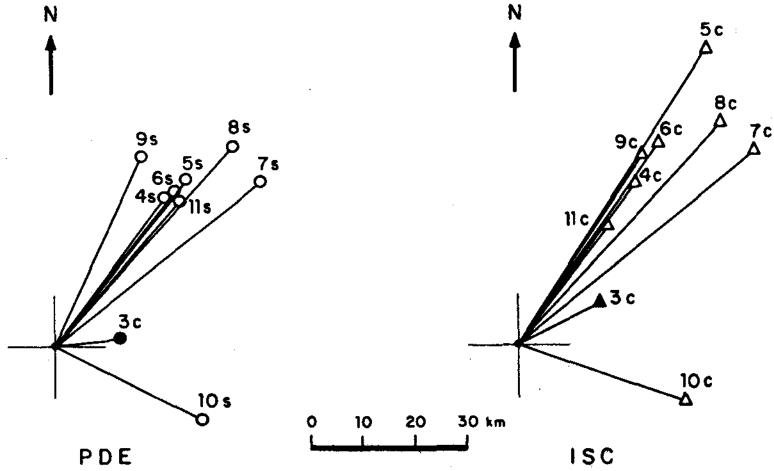


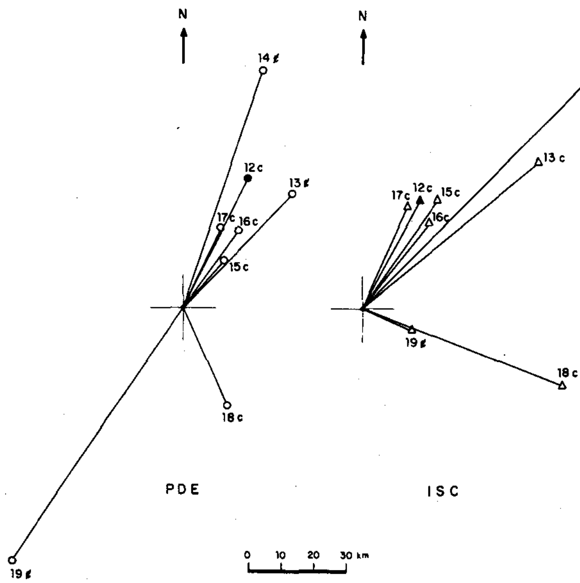
Fig. 1. Epicentral locations given in PDE and ISC with respect to the location determined from field seismographs (see text) for Colima earthquake and its aftershock. Locations determined from field seismographs are centered at the origin. Symbol and letter attached to each location is explained in Figure 1. The number associated with the location refers to the event number in Table 1.

Because the earthquake of Huajuapan de León was located well inland and was deeper than others, the rays leaving the source to teleseismic stations probably sampled a smaller part of the subducted slab. Also, only one aftershock of this earthquake was located by PDE and ISC. Since the mislocation of such events may be different than for shallow events along the coast, we shall ignore this earthquake in much of subsequent analysis.



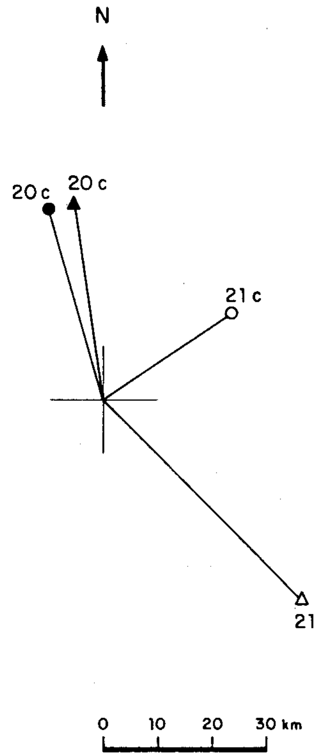
OAXACA, NOV. 29, 1978

Fig. 2. Same as Figure 1 but for Oaxaca earthquake. PDE and ISC locations are shown separately.



PETATLAN, MAR. 14, 1979

Fig. 3. Same as Figure 1 but for Petatlán earthquake. PDE and ISC locations are shown separately.



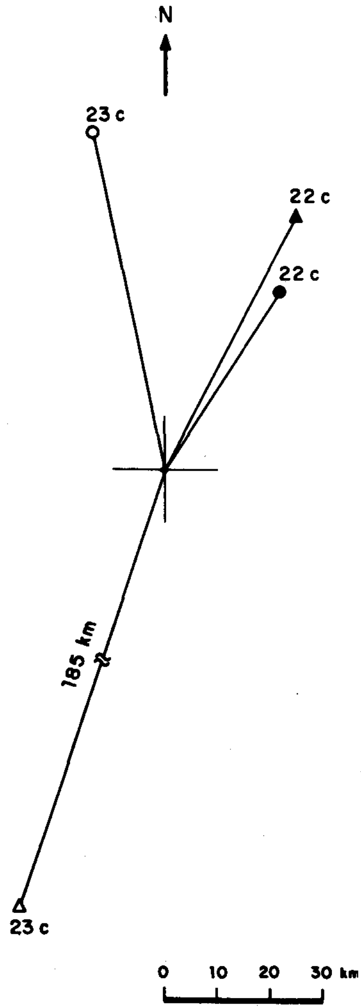
HUAJUAPAN DE LEON, OCT. 24, 1980

Fig. 4. Same as Figure 1 but for Huajuapan de León earthquake.

In Figures 1 to 6 (excluding Figure 4 which is for the earthquake of Huajuapan de León) a general shift toward north-east is observed in PDE and ISC locations, although some events fall in other quadrants. From Table 1 and Figures 1 to 6 it is seen that, with only 2 exceptions, the locations which do not fall in N 90°E quadrant or which have larger epicentral mislocations also have smaller (<40) total number (N_T) of stations used in their locations. Not surprisingly, smaller N_T is correlated with smaller body-wave magnitude, m_b, of the event.

It is instructive to learn the effect that an increase in the number of Mexican stations reporting to PDE and ISC (N_M) has on the locations. The opportunity is provided by the Ometepec sequence for which N_M

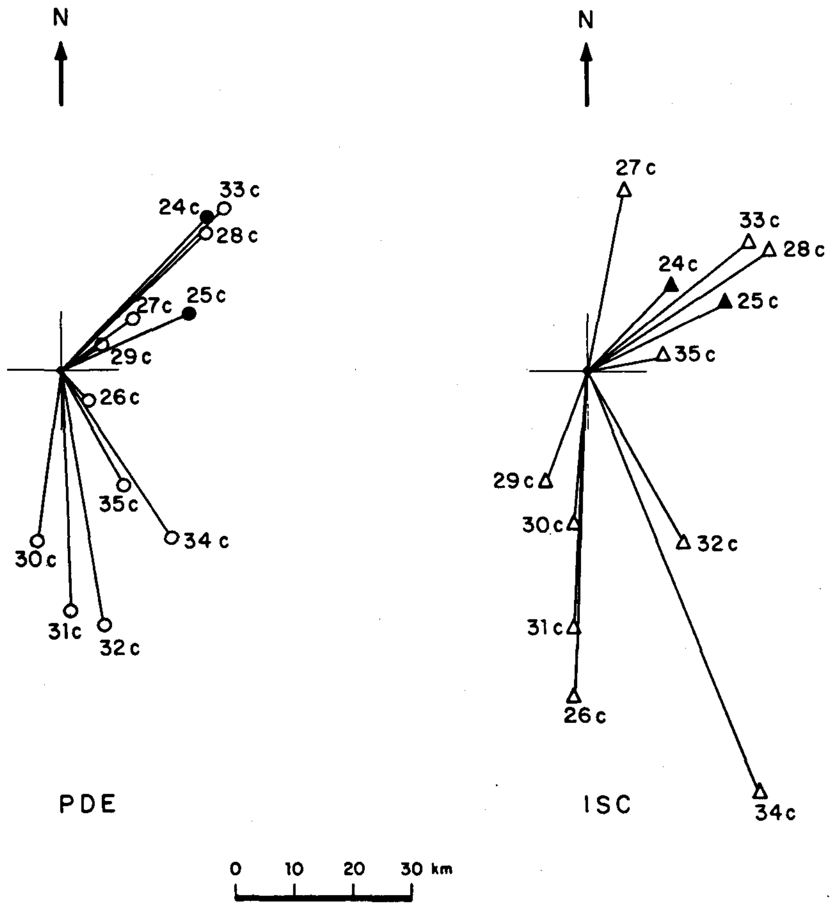
was abnormally large. The locations of those events in the sequence which had large $N_T(>35)$, fall in the N 90°E quadrant (Table 1 and Figure 6). For these events the distance mislocation, about 27 km on the average, is somewhat less than for other events. For the events in this sequence, PDE rejected some of the readings of the Mexican stations (because of large residuals) as evidenced by N_{MU} in Table 1,



PLAYA AZUL, OCT. 25, 1981

Fig. 5. Same as Figure 1 but for Playa Azul earthquake.

which refers to the number of Mexican stations used in the location. ISC did not reject any Mexican stations in locating these events but, the larger number of teleseismic stations and the weighting scheme of ISC caused a shift in the epicenters to NE which is as persistent and as large as in the case of PDE. For smaller events of the Ometepec sequence (with relatively small N_T and relatively large N_M with respect to N_T) the shift is generally not towards NE but towards south (Table 1 and Figure 6).



OMETEPEC DOUBLET, JUN. 7, 1982

Fig. 6. Same as Figure 1 but for Ometepec doublet. PDE and ISC locations are shown separately.

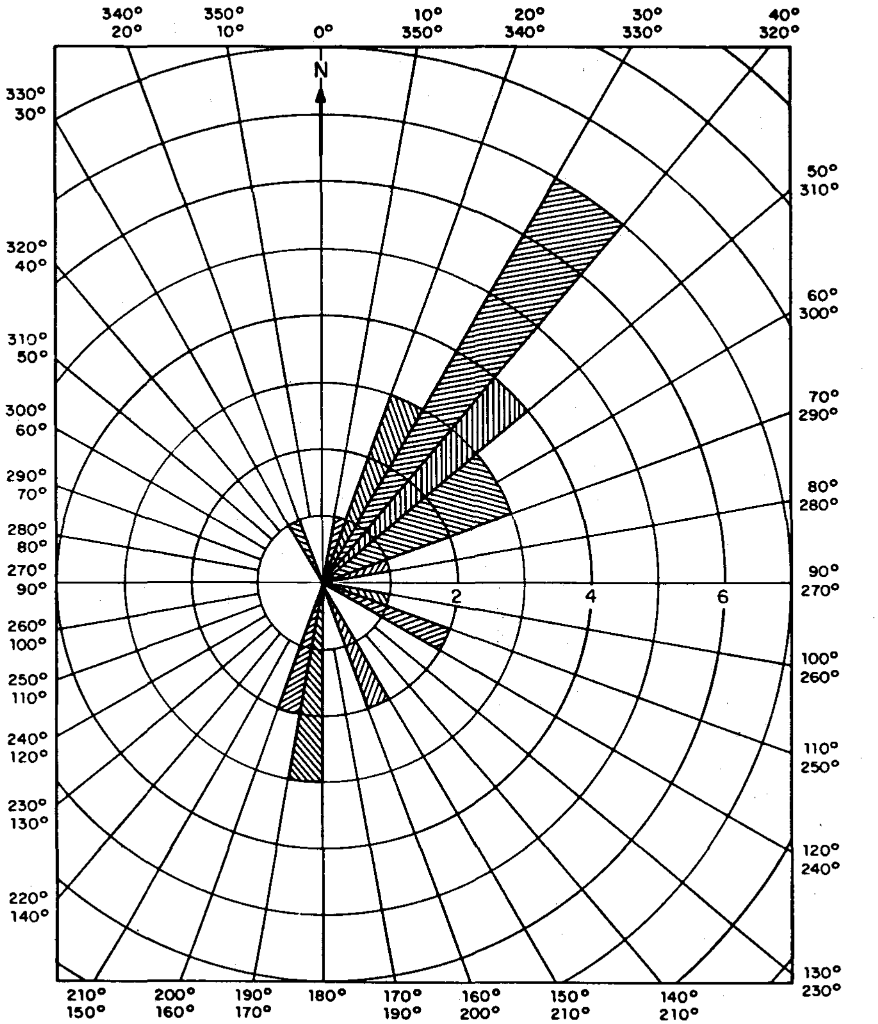


Fig. 7. Rose diagram at 10° intervals of all events located by PDE in Table 1 except Huajuapan de León. Locations determined from field seismographs are centered at the origin.

Figure 7 shows rose diagram of events at 10° intervals located by PDE with respect to the location from the field data (excluding the Huajuapan de León earthquake), The most common shift is towards N 45°E. Figure 8 shows a similar plot for ISC locations (excluding the Huajuapan de León earthquakes).

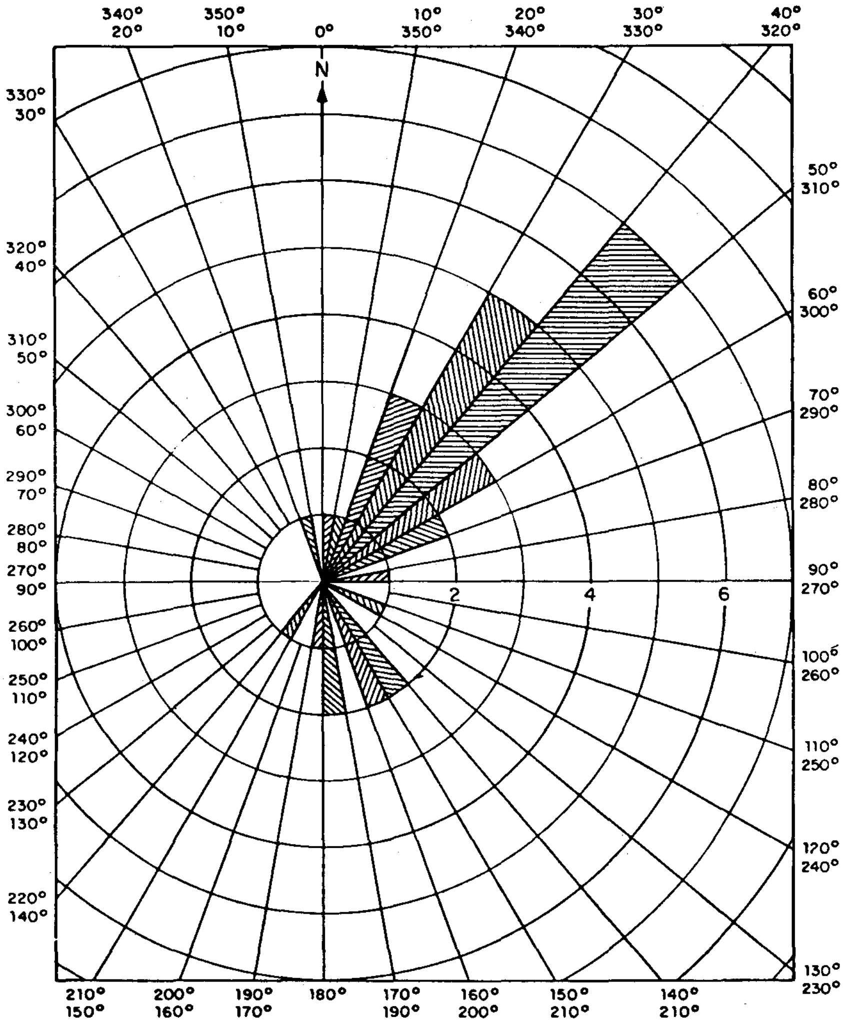


Fig. 8. Same as Figure 7 but for ISC locations.

Figure 9 and 10 give histograms of distance mislocations at 10 km intervals corresponding to the cases shown in Figure 7 and 8 respectively. On an average the distance mislocation is about 35 km both in PDE and ISC. It is a common belief that the ISC locations are better than the PDE locations. Comparison of Figures 9 and 10 suggests that, at least for the events studied here, there is little to choose between ISC and PDE epicentral locations; if anything there is less distance mislocation in PDE.

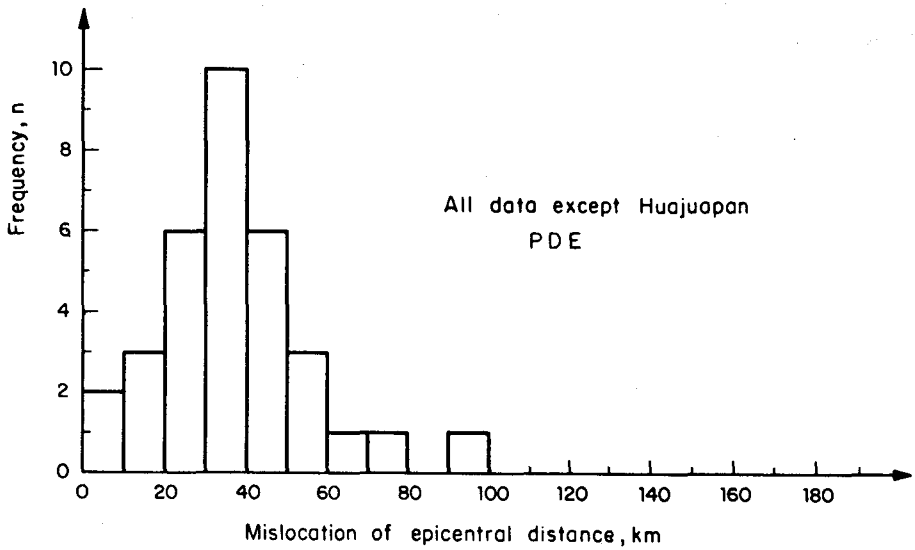


Fig. 9. Histogram of mislocation of epicentral distances at 10 km intervals in PDE locations (except for Huajuapan de León).

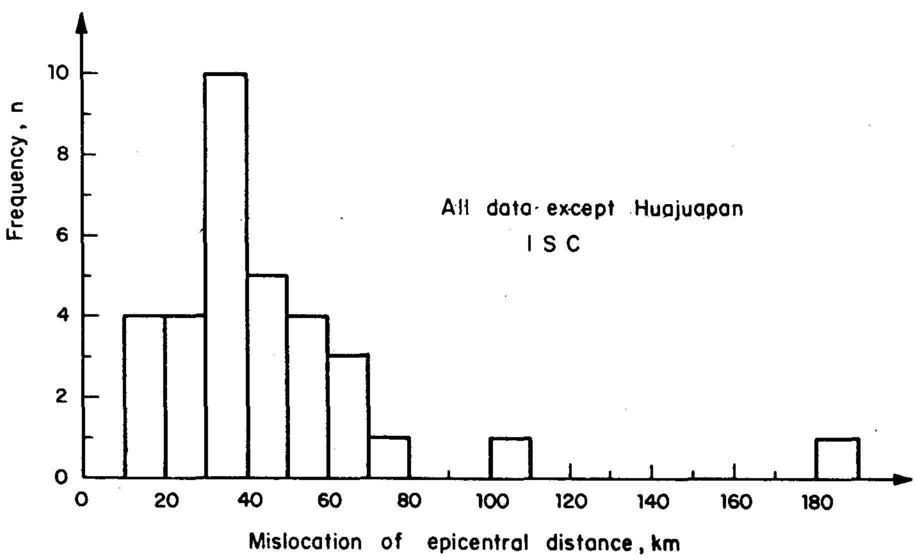


Fig. 10. Same as Figure 10 but for ISC locations.

Depths: Histograms of depths at 5 km intervals are shown in Figure 11. These histograms include all events listed in Table 1. For clarity Huajuapan de León earthquakes are marked separately. The fact that PDE

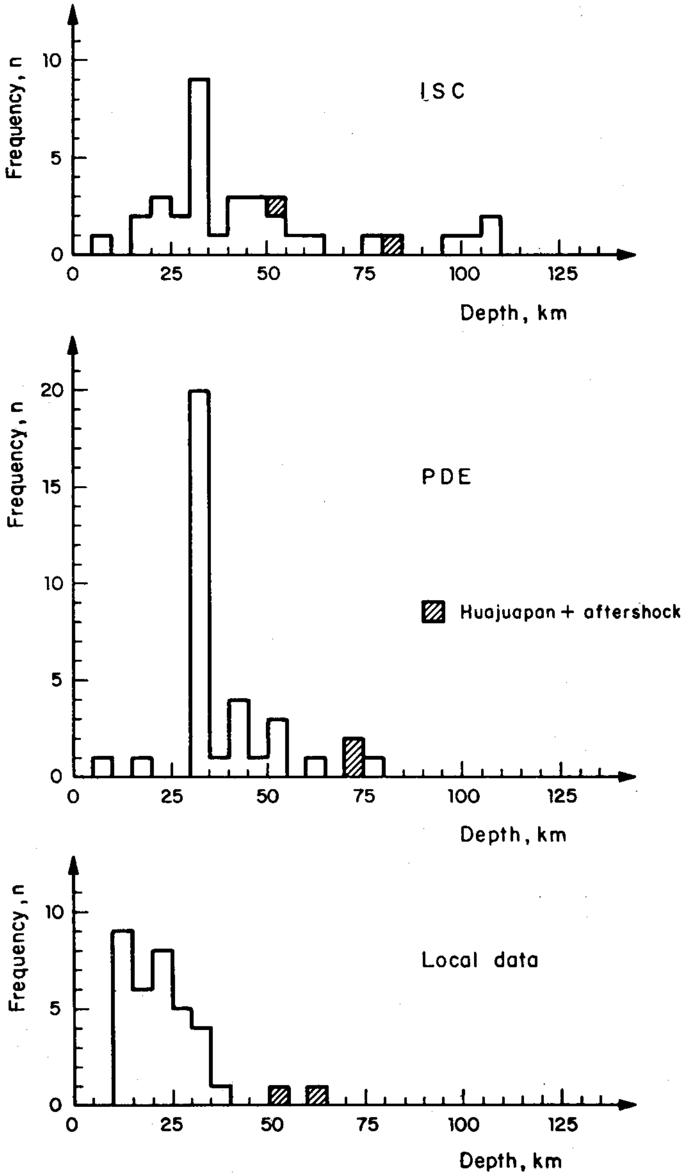


Fig. 11. Histograms of depths reported from local data (or from special studies), and by PDE and ISC at 5 km intervals. Huajuapan de León events are marked with different symbol.

assigns a normal (33 km) depth to many earthquakes is clearly seen. ISC depths are more diffused. ISC, however, uses depths phases more often in assigning depths than PDE (Table 1). For such events ISC depths, although somewhat greater than depths obtained from synthetic modeling or from local data, are more accurate than PDE depths which are, more often, not based on the depth phases.

CONCLUSIONS

1. With respect to shallow interplate earthquake locations determined from field seismographs or from special studies, the epicenters given in Monthly Reports of the Preliminary Determination of Epicenter (PDE) and in the bulletins of International Seismological Centre (ISC) are shifted by an average of about 35 km towards N 35°E. This conclusion is in agreement with other studies where such a shift was either inferred or simply mentioned without quantitative support.

   A larger number of Mexican stations (⩾10) reporting to PDE and ISC reduces the epicentral distance mislocation by about 10 km (although the shift is still towards NE) at least for those events for which a large number of teleseismic readings are also available. For smaller events for which the number of Mexican readings are an appreciable fraction of the total number of readings, the shift is not systematic but the mislocation in distance remains large.

2. ISC, more often than PDE, reports depths based on depth phases. These depths, although slightly larger than the depths estimated from synthetic modeling or from field data, are more accurate than the PDE depths.

3. There is a general belief that ISC locations are better than PDE locations. As far as epicentral location is concerned, we find little preference between ISC and PDE. As mentioned earlier the depths assigned using depth phases are reasonably reliable. ISC assigns such depths to more events than PDE.

4. The shifts in epicentral locations and depths are most likely due to the higher velocity of the subducted Cocos plate with respect to standard earth models used in PDE and ISC location procedures. The rays leaving a hypocenter towards north American and European stations arrive earlier at these stations than expected, causing the ob-

served shifts in the locations. Higher velocity in the subducted Cocos plate has been reported by Lomnitz (1982) and Toledo and Nava (1983) for southern Mexico.

5. Use of PDE and ISC locations in (a) seismic risk studies, (b) precursory seismic patterns, (c) delineating aftershock areas, and (d) mapping of the Benioff zone should take into account the systematic error in these locations.

6. Greater number of well located events (interplate as well as intraplate) may help in mapping the velocity structure of the subducted Cocos plate.

BIBLIOGRAPHY

ASTIZ, L. and H. HAVSKOV, 1984. An earthquake doublet in Ometepec, Guerrero, Mexico, *Phys. Earth Planet. Interiors,* 34, 25-46.

CHAEL, E. and G. S. STEWART, 1982. Recent large earthquakes along the middle American trench and their implication for subduction process, *J. Geophys. Res.,* 87, 329-338.

CRUZ, G. and M. WYSS, 1983. Large earthquakes, mean sea level, and tsunami along the Pacific coast of Mexico and central America, *Bull. Seism. Soc. Am.,* 73, 553-570.

ENGDAHL, E. R., J. W. DEWEY and K. FUJITA, 1982. Earthquake locations in island arcs, *Phys. Earth Planet. Interiors,* 30, 145-156.

GETTRUST, J. F., V. HSU, C. F. HELSLEY, E. HERRERO and T. JORDAN, 1981. Patterns of local seismicity preceding the Petatlán earthquake of March 14, 1979, *Bull. Seism. Soc. Am.,* 71, 761-769.

GONZALEZ, J., K. C. McNALLY and J. A. RIAL, 1984. Recent normal faulting in south central Mexico: A study of source processes and regional tectonic implications, *J. Geophys. Res.,* submitted.

HAVSKOV, J., S. K. SINGH, E. NAVA, T. DOMINGUEZ and M. RODRIGUEZ, 1983. Playa Azul, Michoacán, México earthquake of 25 October, 1981 ($M_s = 7.3$), *Bull. Seism. Soc.,* 73, 449-458.

LOMNITZ, C., 1982. Direct evidence of a subducted plate under southern México, *Nature,* 297, 235-238.

LOMNITZ, C., 1974. Global Tectonics and Earthquake Risk, Elsevier, Amsterdam, 320 pp.

LOMNITZ, C., 1977. A procedure for eliminating the indeterminacy in focal depth determination, *Bull. Seism. Soc. Am.,* 67, 533-535.

MITRONOVAS, W., B. ISACKS and L. SEEBER, 1969. Earthquake locations and seismic wave propagation in the upper 250 km of the Tonga island arc, *Bull. Seism. Soc. Am.*, 59, 1115-1135.

REYES, A., J. N. BRUNE and C. LOMNITZ, 1979. Source mechanism and aftershock study of the Colima, México earthquake of January 30, 1973, *Bull. Seism. Soc. Am.*, 69, 1819-1840.

RUIZ, R., 1983. Mecanismo focal de las réplicas (1-12 diciembre, 1978, $M_L \geq 3.0$) del terremoto (M_s = 7.8) de Oaxaca del 29 de noviembre de 1978, Tesis Profesional, Fac. de Ciencias, UNAM, México, D. F.

SINGH, S. K., T. DOMINGUEZ, R. CASTRO and M. RODRIGUEZ, 1984. P waveform of large, shallow earthquakes along the Mexican subduction zone, *Bull. Seism. Soc. Am.*, 74, 2135-2156.

SINGH, S. K., J. HAVSKOV, K. McNALLY, L. PONCE, T. HEARN and M. VASSILIOU, 1980. The Oaxaca, Mexico earthquake of 29 November 1978: A preliminary report on aftershocks, *Science*, 207, 1211-1213.

TOLEDO, V. R. y A. NAVA, 1983. Ondas de placa y el sismo de Huajuapan de León de 1980, Comunicaciones Técnicas, Serie Naranja: Investigaciones No.330, IIMAS, UNAM, México, D. F.

UTSU, T., 1971. Seismological evidence for anomalous structure of island arcs with special reference to the Japanese region, *Rev. Geophys. Space Phys.*, 9, 839-890.

UTSU, T., 1967. Anomalies in seismic wave velocity and attenuation associated with a deep earthquake zone, 1, *J. Fac. Sci. Hokkaido Univ., Series 7 (Geophys.)*, 3, 1-25.

ZUÑIGA, F. R. y C. VALDES, 1980. Análisis de las réplicas del temblor de Petatlán del 14 de marzo de 1979, Tesis Profesional, Fac. de Ingeniería, UNAM, México, D. F.