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THE 1985 MEXICO EARTHQUAKE

JUAN MANUEL MORENO MURILLO
Profesor Asociado
Departamento de Geociencias-Facultad de Ciencias-Universidad Nacional de Colombia

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RESUMEN

Se incluye una revisión bibliográfica junto con la descripción de varios aspectos relacionados con el terremoto de Michoacan, México (Ms = 8.1), el cual comprendió tres eventos. Un evento premonitorio ocurrió el 28 de mayo de 1985 (Ms = 5.2). El evento principal ocurrió el jueves 19 de septiembre de 1985 a las 7h. 17m. 46.6 s. hora local de la ciudad de México. El foco se determinó a una profundidad de aproximadamente 18 km. Un segundo evento ocurrió el viernes 21 de septiembre a las 7h. 38 m. p.m., hora local. El último evento relacionado ocurrió el 30 de abril de 1986 (Ms = 7.0). Este evento fue un terrible desastre natural para México, por lo menos con 35.000 victimas y cerca de 30.000 heridos, más de 100.000 personas quedaron sin vivienda y grandes daños ocurrieron en ciudad de México y varios estados del centro del país. Este artículo incluye el ambiente tectónico global, génesis y localización del epicentro, una interpretación del mecanismo fuente y un análisis de los resultados a partir de algunas de las estaciones que registraron este terremoto. A la vez se hace una comparación entre los dos grandes terremotos ocurridos en 1985. Sin embargo, se describen únicamente los principales daños ocurridos en México y una descripción de los efectos ocasionados por el Tsunami producido por el mismo evento. El terremoto de México 1985, ocurrió a causa de los deslizamientos ocurridos por los procesos de subducción, entre las placas de Coco y Norteamérica, el cual fue descrito como un fallamiento tipo "thrust" somero entre las placas, ocurrido en la intersección del fracturamiento de Orozco con el Midlle American Trench.

ABSTRACT

This paper includes a bibliographic review with the description of the various aspects about the (Ms = 8.1) Michoacan, Mexico earthquake, which comprised of three events. The main shock of the September 19, 1985 earthquake occurred on Thursday at 7h. 17m. 46.6s. local time in Mexico City, and had (Ms = 8.1). The focus of the event was a depth of approximately 18 km. A second shock occurred on Friday evening 21 September at 7h. 38m. p.m. local time. The last aftershock occurred on 30 April of 1986 (Ms = 7.0). A prior event occurred to the September 1985 earthquake, occurred on 28 May, 1985 (mb = 5.2) and is described too. This event, was a terrible natural disaster for that country, at least 9,500 people were killed, about 30,000 were injured, more that 100,000 were left homeless and severe damage occurred in many parts of Mexico City and several states of central Mexico. According to some sources, It is estimated that the earthquake seriously affected an area of approximately 825,000 square kilometers. This paper describes a summary of the global tectonic setting, genesis and location of the epicenter, an interpretation of the source mechanism and a analyses at these results from some stations that recorded this earthquake and at the same time, a comparison between the two largest earthquake of 1985. Moreover, this paper describes the principal damage resulting and a description of effects from tsunami produced from earthquake. The 1985 Mexico earthquake occurred as a result of slipping in the subduction process between the Cocos and American plates. This was a shallow interplate thrust type event which occurred in the intersection of the Orozco fracture with the Middle American trench.

1. INTRODUCTION

On September 19-1985, a large subduction earthquake occurred in the Michoacan gap, along the Mexican trench. Figure 1 shows the section of the subduction zone in the vicinity of the Michoacan earthquake.

Repeat times for large earthquakes along any given section of the Central American trench vary from 30 to 70 years. The part of the fault which generated the 1985 event, is one of several sections that has not experienced a major event for a much longer period.

The near surface Geology of Mexico City, locality on the former lake Texoco, may be classified into three general zone: The old lake bed, characterized by a deposit of very not hard clay whit high water content; a hill zone, of which is capped by 5-30 meters of lava less than 2,500 years old and the transition zone between the two, consist of river delta and deposits with interbed intervals of clay, Figures 20 and 22. The (Ms = 8.1) Michoacan earthquake, of 19 September 1985 and its aftershocks of 21 September (Ms = 7.5) and 30 April, 1986 (Ms = 7.0) were well recorded in several stations together with its prior event (mb = 5.2) on 28 May, 1985. This event generated intensities of the order of VIII to IX in the epicentral area. The March 3 1985 Chilean earthquake (Ms = 8.0), ruptured a well studied seismic gap along the Chilean Subduction Zone. This event is another subduction thrust earthquake with a geometry similar to the September event.

This paper described the characteristic of the Mexico earthquake including the global tectonic setting of Mexico, which is strongly influenced by the interaction of several major plates as Cocos, pacific and North American. Also, is give the focal mechanism for the several events and the analyses of teleseismic long-period seismograms. Damage was restricted to 6 of 32 major states of Mexico, but caused only moderate damage along the coast. The coast states of Jalisco, Colima, Guerrero and Michoacan were strongly affected, Figures 5 and 7. Though damage was relatively sporadic probably due to their close proximity to the epicenter.

In contrast, in Mexico City, most of the damage experienced in the earthquake was restricted to buildings. The two major factors behind the severity of the seismic damage of buildings were; the resonance in the lake sediments and the long duration of the shaking.

On land, the effects of the double earthquake that affected Mexico in September 1985, were devasting, but at sea the effects were relatively minor. According to a report in the December 1985, TSUNAMI NEWSLETTER, in Honolulu, the tsunamis that rolled across the Pacific after the quake were small. Along the Mexican coast, from Manzanillo to Acapulco, scientists of International Tsunami Center in Honolulu, estimate that the tsunami ranged from 1 to 3 meters tall, but, Ecuador reported some of the tallest waves which were only 60 centimeters high.

2. GLOBAL TECTONIC SETTING-SEISMIC GAPS

Tectonically, Mexico is strongly influenced by the interaction of several major plates. The movement of the North American Plate against the adjacent Pacific and Cocos Plates has been responsible for the high incidence of volcanic and seismic activity in the west and southwest of the country (Fig.1).

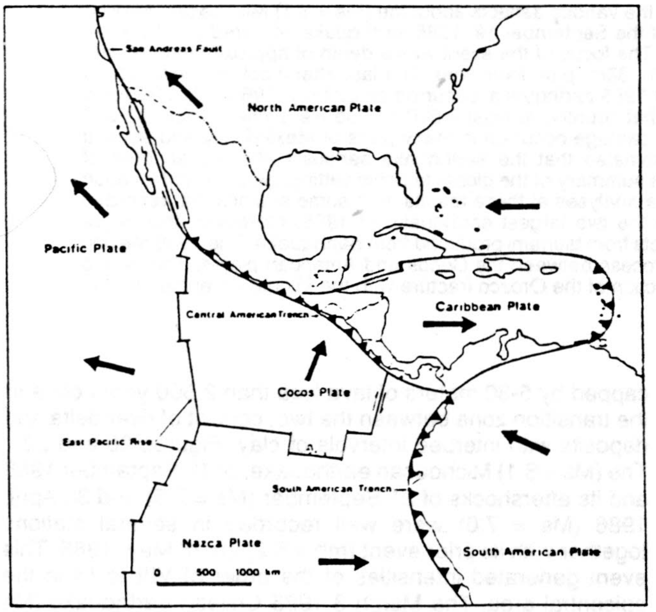

FIGURE 1. Plate tectonics of the Central American Region (From Degg, 1987)

The boundary between the Cocos Plate and North American Plate is one the most active plate margins in the world. It is here that the Cocos Plate, forming part of the Pacific floor, is moving north eastward at a rate of between 5 and 11.5 cm for year. In opposition, the North American Plate is carrying the Mexican land mass in a westerly direction. The zone of interaction between the two plate is marked by the deep oceanic trench (Central American trench or Middle American trench), formed where the oceanic crust of the Cocos Plate is thrusting beneath the continental crust of the North American Plate.

Alteration of subduction characteristic such as local decrease in the seismicity, a local change in the dip and depth extent of the Benioff zone, a local change in the stress axes of the earthquake have been observed in many other areas of topographically anomalous seafloor and are subducting (**Keller and McCann**, 1976 in **Astiz et al.**, 1987).

The Middle American trench of the coast of Mexico, has been the site of numerous large thrust earthquakes and is divided into several regions characterized for their seismic potential.

2.1 Benioff zone

The hypocentral distribution of locally recorded aftershocks of the great (Ms = 8,1 and 7.5), Michoacan September 19, and 21, 1985, earthquakes define a narrow Wadati-Benioff Zone Structure, roughly 10 km. thick, dipping 14 degrees at N23E. This is in good agreement with the geometry source obtained by waveform modeling of the 1985 mainshock, and the large 1979 Petatlan earthquake in the adjoining region. The earthquake epicentral resolution, obtained with this program, is significantly better than that for the conventional approaches (HYPO) and looks very promising for use in velocity structures with an important dipping interface like subduction zones.

Stolte, et al., (1986), used this program and presented a new velocity model describing a dipping structure derived from inversion as well as precise locations of the aftershock hypocenters based on this model.

2.2 Orozco Fracture Zone

LeFevre and McNally (1985, **in Stolte,** 1986), studied stress distribution associated with the subduction of the Orozco Fracture Zone (OFZ) (Fig. 3), and found only minor local deviations from the overall pattern along the Middle American trench of the coast of Mexico.

Coincidentally with the Michoacan Gap, the Orozco Fracture Zone intersects the Middle American Trench for about 150 km. The historical seismic record alone was not sufficient to determinate whether there was subduction of the Orozco fracture zone.

Previous to the September 1985 earthquake, the Michoacan area with its seismic quiescence and subducting fracture zone, was similar to the southern Oaxaca area, where the Tehuantepec Ridge is subducting and where there are no large earthquakes on historic record. One possibility suggested to explain the seismic quiescence in these areas was that features such as the Orozco Fracture and the Tehuantepec Ridge may be locally affecting the subducting process, so that the area is subducting aseismically or more slowly than adjacent regions of the plate boundary **(Singh, et al.,** 1980, **in Eissler et al.,** 1986).

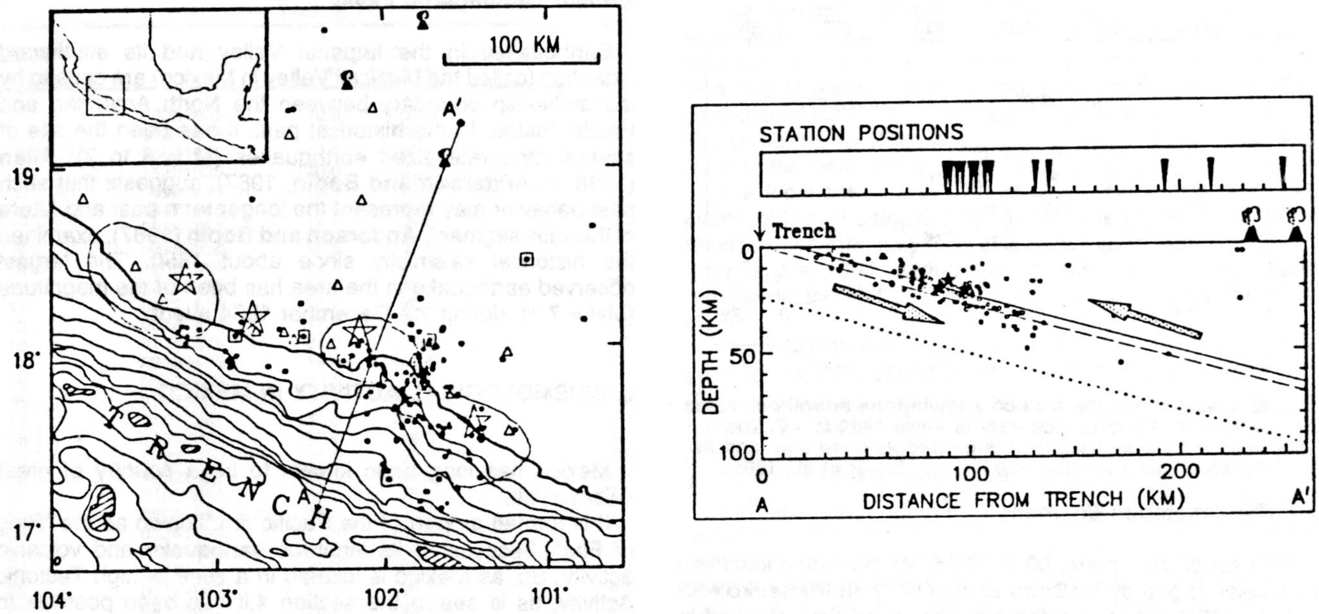

Fig. 2 -a.

Fig. 2-b.

Figure 2 (a): shows area with 1985 two mainshocks as stars, the six earthquakes used in the inversion are shown as squares. The three rings circle the aftershock zones of recent major earthquake from left to right; Colima 1973; Playa Azul 1981; Petatlan, 1979; A-A' cross section. (b): shows cross-section of the aftershocks; the plate interface inferred from the focal mechanism of the mainshocks is marked by a solid line. The stars represent recent major earthquakes, left to right, 1985 Michoacan second mainshock; 1979, Petatlan; and 1985, Michoacan first mainshocks (From Stolte, et al., 1986).

Figure 3. Seismotectonic setting of the 1985 Michoacan, Mexico earthquake. Features of the seafloor shown are Rivera Fracture Zone (RFZ), East Pacific Rise (EPR), Orozco Fracture Zone (OFZ), Tehuantepec Ridge (TR), and Middle American Trench (MAT) The Trans-Mexican Volcanic Belt(TMVB) is also shown. (From, Mungula et al. 1986).

2.3 Guerrero Oaxaca Region

To the south of the Petlatan area in the middle of the coast, the area without recent large earthquake activity is the Guerrero Seismic Gap, where four large earthquake occurred along the trench between 1899 and 1911.

The subduction zone of Oaxaca (95°-98° W), along with Taiwan, was given the highest probability (0.9) of recording accelerations grater than 0.2 g in 10 years (**Bolt and Abrahamson**, 1985, **in Anderson et al.**, 1986).

2.4 Petlatan Area

The southeast of Michoacan in the northern Guerrero, had events in 1943 and 1979 (Ms = 7.6), with 36 years interval. It is interesting to note that most of the aftershocks of the 1979 Petlatan earthquake, occurred down dip and towards the continent relative to the aftershochs of the 21 September, 1985 earthquake.

2.5 Colima Seismic Area

To the northwest, the Colima area recently had events in 1941 and 1973 (Ms = 7,5) with 32 years interval. The extend of the gap of Michoacan was constrained by the rupture areas of this event to the northwest.

2.6 Jalisco Area

The largest earthquake prior to the 1985 event, was located near to Jalisco cost, in 1932 (Ms = 8.1, Fig.4). Comparison of seismograms at Pasadena with records of other large Mexico events shows that The Michoacan Earthquake is basically the same size as the 1932 Jalisco earthquake, and clearly larger than other significant events in Mexico since 1932. The intensity in Mexico City from the 1932 event, was only V (**Figueroa**, 1959, **in Eissler et al.**, 1986). However, it was more complex and of large duration than the September 1985 shock.

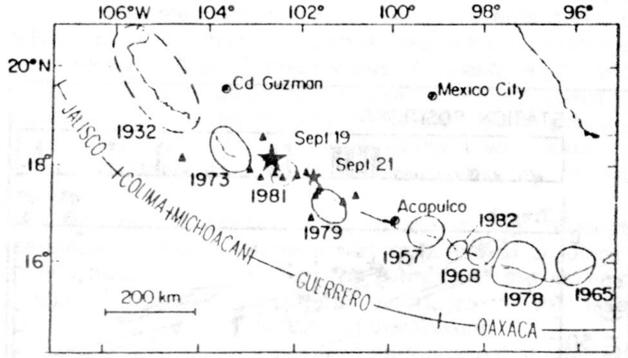

Figure 4. Map of central Mexico showing the aftershock areas (ellipses) of subduction events since 1950 M > 7. The September 1985,earthquakes is plotted as filled star, and its aftershock as a smaller star. (From, Eisler et al., 1986).

2.7 The Ometepec Segment

This subduction zone, 98.5° -99.5° W, has been identified as a seismic gap by **McCann et al.**, (1979, **in Nishenko and Singh**, 1987), based on the amount of the time elapsed in this area since a previous major earthquake.

Prior large earthquakes in this gap occurred in 1937 (Ms = 7,7) and 1950 (Ms = 7,3). On 7 June 1982, an earthquake doublet (Ms = 6.9; 7.0) occurred in the eastern portion of the Ometepec gap. This segment is adjacent to the Guerrero segment, which last ruptured as a series of large and great shocks in 1899 and 1911.

During this century, the recurrence history observed along the Ometepec segment has been what some anomalous when compared to the adjoining segment in Oaxaca and has exhibited a variable recurrence history. The majority of waveforms can be characterized as complex reflecting irregular rupture propagation and moment release.

2.8 Michoacan Seismic GAP

The September 19, 1985 event occurred in This area (Figs. 3-4), was designated as seismic gap (The Michoacan Gap), because prior to this event, at least 74 years had elapsed since the last large earthquake (Ms = 7,5). The gap has been quiescent since the 1911 event had occurred here. Segments of the plate interface immediately adjacent to the Michoacan Gap have experienced recent events at short and regular intervals.

In 1981, The Playa Azul earthquake (Mw = 7,3) occurred in the center of the Michoacan Gap. The epicenter of the September 1985 event was located in the northern segment of the Michoacan Gap between the 1973 and 1981 aftershock zones. Observations have pointed to the high seismic potential in the Michoacan Gap:

- Large recent coastal terraces suggesting tectonic uplift were found onshore near Orozco Fracturing Zone (**McNally and Minster**, 1981, **in Munguia et al.**, 1986).
- The distribution of the hypocenters and focal mechanisms indicated only minor deviations from the regional patterns of stress distribution along the Middle American Trench in Mexico. This suggested normal seismic subduction (**LeFevre and McNally**, 1985, **in Munguia et al.**, 1986).
- The source mechanism of the Playa Azul earthquake 1981, located in the middle of the gap was similar to other earthquake along the coast of Mexico (**McNally and Minster**, 1981, **in Munguia, et al.**, 1986).

2.9 Mexicali-Imperial Valley

Earthquakes in the Imperial Valley and its southward extention (called the Mexicali Valley in Mexico) are caused by the strike-slip boundary between the North American and Pacific Plates. In the historical past, it has been the site of several moderate sized earthquakes (M = 6 to 7). **Allen** (1968, **in Anderson and Bodin**, 1987), suggests that such past behavior may represent the longer term past and future of this fault segment. **Anderson and Bodin** (1987), examined the historical seismicity since about 1850. The largest observed earthquake in the area has been of the magnitude (Mw = 7.1), during the December 1934 event.

3. SEISMOLOGICAL ACTIVITY IN MEXICO

Mexico has long been known to be a country of great seismic risk.

It is formed as part of the Pacific rim, known as the "Ring of Fire", because of its vigorous earthquake and volcanic activity. So, as Mexico is located in a zone of high Tectonic Activity, as is see in the section 4,it has been possible to record the seismic activity during the last century (Table 1).

3.1 Principal earthquakes in Mexico

The table below lists the principal earthquakes in the Mexican Subduction Zone, obtained from different sources; thus, there are differences between authors, for locations, magnitude and depths from, **Priestley** (1986); **Nishenko and Singh** (1987); **Person** (1985, 1986); **Sarria** (1986); **Singh et al.**, (1987, 1988); **Anderson and Bodin** (1987); **Astiz et al.**, (1987).

3.2 Description of principal historical earthquakes

The following historical events occurred in the Middle American trench during the last century.

On May 3, 1887, a great earthquake took place in the northern Mexican state of Sonora. The largest town affected was Bavispe, which was situated on unconsolidated material and suffered heavy damage.

There were 1500 inhabitants, of whom 42 were killed. Shaking was reportedly felt from Prescott, Arizona to Mexico City distances of over 400 miles from the probable epicenter (Richter, 1958).

Gutenberg and Richter (1954, **in UMAM Seismology group**, 1986), based on the location of earthquake on June 7, 1911, (Ms = 7,9), pointed out a gap of high seismic potential in the region. The literature indicates that the intensity pattern of the 1911 events is similar with the epicenter near coastal Michoacan. Thus the 1911 events have been felt as strongly in Mexico City, but were less damaging there because of the smaller population and smaller degree of urban development at that date.

The distance from Mexico City to the Guerrero Gap is shorter than to any other region, along the Middle American Trench (Fig.5). The last major events located in the Guerrero Gap, were in 1899 (M = 8) and 1907 (M = 8). The Acapulco earthquake (Ms = 7.5) occurred in the southern Guerrero in 1957 and damaged hundreds of buildings in Mexico City. The south of Acapulco the plate interface is fairly well filled in with recent large earthquakes.

TABLE 1

EVENT	DATE	LOCATION Lat°N	LOCATION Long°W	DEPTH	Ms
1	03251806	18,9	103.8		7.5
2	05311818	19,1	103.6		7.7
3	05041820	17.2	99,6		7.6
4	11221836	20,0	105.0		7.7
5	03091845	16.6	97.0		7.5
6	04071845	16.6	99.2		7.9
7	05051854	16.3	97.6		7.7
8	06191858	19.6	101.6		7.5
9	10031864	18.7	97.4		7.3
10	05111870	15.8	96.7		7.9
11	03271872	15.7	96.6		7.4
12	03161874	17.7	99.1		7.3
13	02111875	21.0	103.8		7.5
14	09031875	19.4	104.6		7.4
15	05171879	18.6	98.0		7.0
16	07191882	17.7	98.2		7.5
17	05031887	31.0	109.2		7.3
18	05291887	17.2	99.8		7.2
19	09061889	17.0	99.7		7.0
20	12021890	16.7	98.6		7.2
21	11021894	16.5	98.0		7.4
22	06051897	16.3	95.4		7.4
23	01241899	17.1	100.5		7.9
24	01201900	20.0	105.0		7.9
25	05161900	20.0	105.0		7.4
26	01141903	15.0	98.0		8.1
27	04151907	16.7	99.2		8.0
28	03261908	16.7	99.2		8.1
29	03271908	17.0	101.0		7.5
30	07301909	16.8	99.9		7.4
31	06071911	19.7	103.7		7.7
32	12161911	16.9	100.7		7.5
33	11191912	19.9	99.8		7.0
34	06021916	17.5	95.0		7.1
35	12291917	15.0	97.0		7.7
36	03221928	16.2	95.5		7.5
37	06171928	16.3	96.7		7.8
38	09041928	16.8	97.6		7.4
39	10011928	16.3	97.3		7.6
40	01151931	16.1	96.6		7.8
41	01031932	19.8	104.0		8.2
42	01181932	19.5	103.5		7.8
43	11301934	19.0	105.3		7.0
44	07261937	18.5	96.4		7.3
45	12231937	17.6	101.2		7.5
46	04151941	18.9	102.9		7.7
47	02221943	17.6	101.2		7.5
48	01061948	17.0	98.0		7.0
49	01061948	17.0	98.0		7.0
50	12141950	17.2	98.1		7.3
51	07281957	17.1	99.1		7.5
52	05111962	17.3	99.6		7.0
53	05191962	17.1	99.6		7.2
54	07061964	18.3	100.4		7.4
55	08231965	16.3	96.0	16	7.8
56	02031968	16.3	96.0	16	5.9
57	08021968	16.6	97.7	16	7.4
58	01301973	18.4	103.2		7.5
59	08181973	18.3	96.5		7.1
60	04231975	16.5	98.9	16	6.2
61	02011976	17.0	100.3	16	5.6
62	06071976	17.2	100.88	16	6.4
63	03191978	16.9	99.9	16	6.4
64	11291978	15.8	96.8	18	7.8
65	01261979	17.3	101.0	16	6.6
66	03141979	17.3	101.4	20	7.6
67	10241980	18.2	98.3	72	7.0
68	10251981	17.8	102.6	20	7.3
69	06071982	16.6	98.4	20	6.9
70	06071982	16.4	98.5	15	7.0
71	07021984	16.8	98.5	47	6.0
72	09151985	17.8	97.2	65	5.9
73	09191985	18.5	102.7	16	8.1
74	09211985	17.6	101.8	28	7.6
75	09251985	18.2	102.9	30	5.2
76	02031986	15.0	92.0	16	4.7
77	04301986	18.2	103.1	16	7.0

The Mexican earthquake of November 19, 1912. was very widely felt but was damaging only in a rather sharply bounded area measuring about 50 by 20 kilometers centering about 10 km from Mexico city. This was a highly unusual event,with its occurrence so far from the principal seismic zone of Mexico (**Richter**, 1958).

The seismic moment and the time since the last large earthquake in Michoacan (1911), fit an empirical relation between moment and recurrence time found for the Guerrero-Oaxaca region of the subduction zone. A large earthquake (M = 7.8) occurred in Oaxaca in November 29, 1978, making another large earthquake in that region less likely in the near future (**Anderson, et al.**, 1986).

The locations of a few aftershocks of the April 15, 1941, event, obtained using S-P times recorded by stations of the Mexican network, supports the hypothesis that the rupture area of the 1941 earthquake included part of the faults broken by the 1973 Colima earthquake and by the 1985 event.

The Colima earthquake of 1973 (Ms = 7.5), to the NW, and the Petatlan earthquake of 1979 (Ms = 7.6), to the SE (Figure 1) constrained the extent of the gap with the areas of rupture in these events. Aseismic subduction or large recurrence periods for this gap were suggested by **Singh et al.** (1980, in **UNAM seismology group**, 1986).

Petatlan 1979, event, was a large earthquake that occurred in the adjoining region,to 1985 event. For this event, **Valdes, et al.** (1980 in **Stolte et. al**, 1986), derived a velocity structure from the aftershocks, in an area in the immediate vicinity of the 1985 epicenter region (Figures 5 and 6).

Huajuapan de Leon, October 24, 1980, earthquake was located well inland and was deeper than others (65 km.), which was on a normal fault. All mainshocks were shallow, with thrust earthquakes along of the Pacific coast.

The earthquake of Playa Azul on October 25, 1981 (Ms = 7.3) occurred in the central part of the Michoacan Gap, rupturing an area of over 40 by 20 square kilometers. Even after this earthquake, the seismic potential of the gap could not be defined with any precision (**UNAM Seismology Group**, 1986). This event was widely felt in southern Mexico, causing damage in the state of Michoacan and in Mexico City, where 11 people were injured and one person died.

The Ometepec earthquake of June 7, 1982, (Ms = 6.9 and 7.0) occurred in the eastern portion of the Ometepec Gap, which provided an opportunity to reexamine the rupture zones of earlier events in this region via the joint epicentral determination method (**Nishenko and Singh**, 1987). The 1950 (Ms = 7.3), 1957 (Ms = 7.7), and 1962 (Ms = 7.2 and 6,9) earthquakes and their principal aftershock ruptures, compared with that of the great 1907 earthquake (Ms = 8.0), suggests that the latter three events may represent a delayed multiple rerupture of the 1907 zone. The time interval between the 1937 and 1950 shocks was short compared to the similar sized events in Oaxaca in November 29, 1978.

3.3 Maps of location of the principal earthquakes

The following figures show different maps with the locations of the epicenters and aftershocks zones for the events which occurred in the Mexican Subduction Zone, also including the 1985 event.

4. MEXICO 1985 EARTHQUAKE

The September 19, 1985, Michoacan Earthquake (Ms = 8,1), was the most serious natural disaster to date in Mexico's history. It caused over 10,000 deaths in the Mexico City and left an estimated 250, 000 homeless. This earthquake occurred along a segment of the Coco-North American Subduction Zone, that had been identified as the Michoacan Seismic Gap (Section 4). This event was followed by another major earthquake on September 21 (Ms = 7,5) and the last aftershok occurred on 30 April of 1986 (Ms = 7,0). The earthquake occurred at 13h 17m 47.6s GMT; 7h 17m 46,6s local time on thursday 19. The shock had a surface wave magnitude of 8,1 and the aftershock of magnitude 7,5 on Friday evening 21 at 7h 38s p.m. local time.

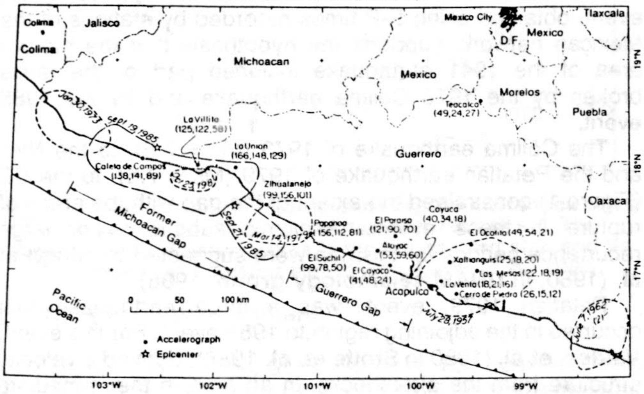

Figure 5. Map of coastal Mexico, epicenters and aftershocks zones of 1985 events and location of strong motion stations in Guerrero array on 19 September 1985. Short dashed lines show limits of aftershocks of large earthquakes in this region since 1950. Peak accelerations are given for the north, east and vertical components in parentheses (From Anderson, 1986).

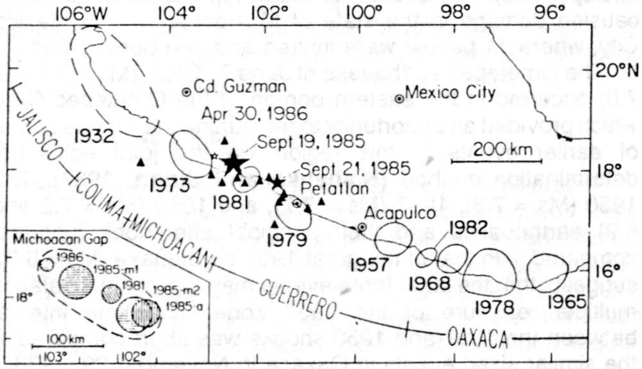

Figure 6. Map of central Mexico Showing the aftershocks areas (ellipses) of interplate thrust events since 1950 with M > 7. The September 1985 is plotted as a filled star and its aftershock as smaller star. The epicenter of the M=7.5 aftershock of April 30 1986 is show as an open star (From Astiz, et.al., 1987).

The Modified Mercalli intensity was IX at Lazaro Cardenas, 30 km from the epicenter. Astoundingly it was also IX in parts of the Capital City 400 km. away. There is no other historic earthquake having an intensity of IX in Mexico.

Analysis of body waves and long-period surface waves from this event, shows that the event was fault plane with a low dip angle (8,9°) striking parallel to the Middle American Trench; fault plane azimuth of 288° and small component of left lateral motion (=72°) with a point source depth of 18 to 25 km and a seismic moment in excess of 1.0x10 to 1.7x10 dyn-cm. The earthquake was a multiple event with a second source of identical moment, fault geometry and depth occurring approximately 26 seconds after the first.

Instrumental records seem to indicate that the rupturing process was a complex one with several breaks occurring along the fault line in quick succession. As a result of this, the earthquake that was generated was one of the long duration. Ground shaking in coastal regions lasted up to five Minutes **EEFIT**, (1986 in **Degg**, 1987), and parts of Mexico City were Shaken for three minutes.

4.1 Epicenter location

Mexico, has a surface area of approximately two million square kilometers. It is situated between the Pacific Ocean and the Gulf of Mexico bordering the United States in the north and Guatemala and Belize in the south.

The epicentral region of the major event was located off the Pacific coastline near to the small town of Lazaro Cardenas in the state of Michoacan (Figure 5). Faulting extend parallel to the coast for a distance of 100 km. north and south of the town. It is estimated that during the earthquake thrust forward more that three meters along the length of this rupture zone.

The September 19, event, triggered a digital strong motion array installed along the Michoacan-Guerrero Coast. Relocation of first shock, (**UNAM**, 1986), useding P and S waves arrival times at stations CAL and S waves arrival time at VIL and UNI (Figure 7). Constraining the depth to 16 km. suggested by synthetic modeling. The main shock and aftershocks were located using HYPO 78 and a crustal model for the adjacent Petlatan region (**UNAM**, 1986). An approximate location of the second subevent was obtained using the strong motion data. The arrival time of S waves of the second subevent were picked by visually cross correlating the waveforms of the first and second subevents on the near field strong motion records. This analysis suggest the second subevent occurred about 95 km SE of the first one probably near UNI (**UNAM**, 1986). They give this epicentral locations for main shocks: (18,141° N; 102.707°W) and second shock (17,618°N; 101,815°W) respectively.

4.2. Acceleration signs aftershock

Mungia, et.al. (1986) described acceleration signals recorded for nine aftershocks of the September 19, earthquake. They used three A-700 teledyne-Geotech digital strong-motion instruments at two sites, La Villita Dam, and 12 km. to the west of Zihuatanejo. Peak horizontal accelerations of 0,0005 g. to 0.031 g. were recorded at epicentral distances between 10 and 75 km. for earthquake with magnitude (mb) between 4,5 and 5,3. it was observed that the peak accelerations recorded at a site on the embankment of the dam, (near the crest), are approximately three times those recorded on the abutment bedrock portion of the dam. Although these sites were spatially separated by no more than 300 m. differences among their records are also significant. Wave forms recorded at the embankment site look more complex than those from the abutment site. This fact, as well as the higher peak accelerations on the embankment provides evidence of a strong influence of the structure of the dam on the ground motion at the embankment site.

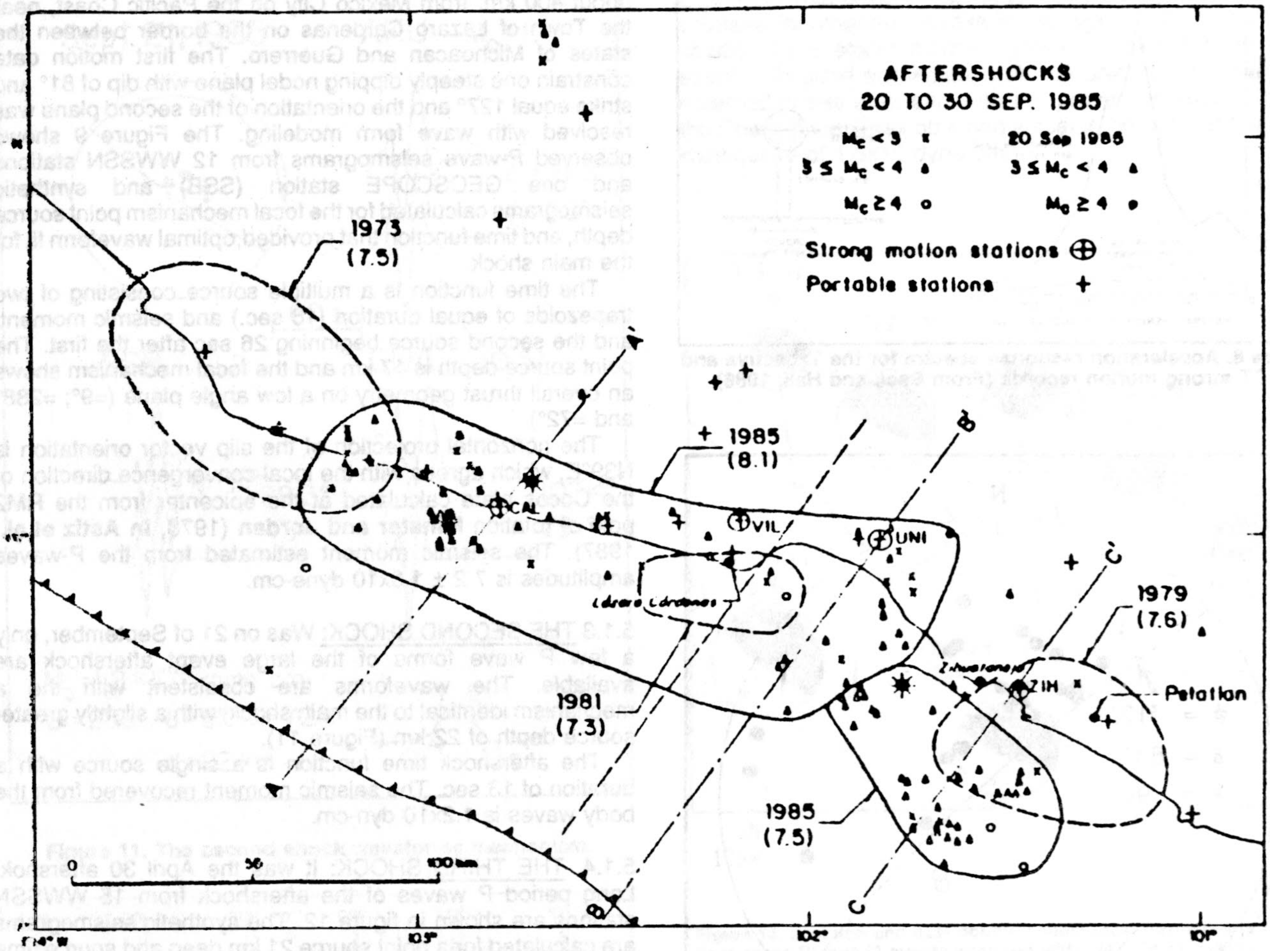

Figure 7. The location of the first and second main shocks and their aftershocks are shown. solid triangles and dots are epicenters of aftershocks which occurred between the first and second main shocks. From UNAM (1986).

4.3. Factors contributing to the catastrophe

There were two major factors contributing to the catastrophe; resonance in the sediments of an ancient lake that once existed in the Valley of Mexico, and the long duration of shocking compared with other coastal event in the last 50 years.

In **Hall and Beck** (1986), there are two simplified models which could explain the apparent resonance phenomenon; one involving body waves propagation up through there valley sediments, and the other involving surface waves propagating across the valley. The real situation is sure to be more complex, although a combination of these models may give at least a qualitative explanation. The importance of the resonance phenomenon in contributing to the structural damage is apparent from the response spectral comparison in Figure 7. It is the reason why the damage was confined to areas of Mexico City on the lake bed. It also explains why high-rise buildings suffered the most severe seismic attack.

5. INTERPRETATION OF SOURCE MECHANISMS

The focal mechanism of the first main shock from first motion data indicates a thrust-mechanism. The likely fault plane has an azimuth of 288° and dip of 9°, according to **Eissler et al.** (1986).

5.1 Teleseismic source mechanisms

Teleseismic long-period seismograms showed that the first earthquake consisted of two subevents separated in time by 27 sec subevent occurred about 95 km. SE of the first one. Teleseismic records of the September shock can be modeled by a single source.

5.1.1. PRIOR EVENT: This has an additional seismic feature. The occurrence of a moderate (mb = 5.2) event downdip from the mainshock approximately 100 km. on May 28, 1985 (3.7 months before the mainshock). This normal faulting event, together with the seismic quiescence and aftershock are included two small event (mb = 4,5 and 4,4) on January 20 and June 19 of 1985, which occurred close to the subsequent mainshock epicenter and broke the seismic quiescence Figure 9.

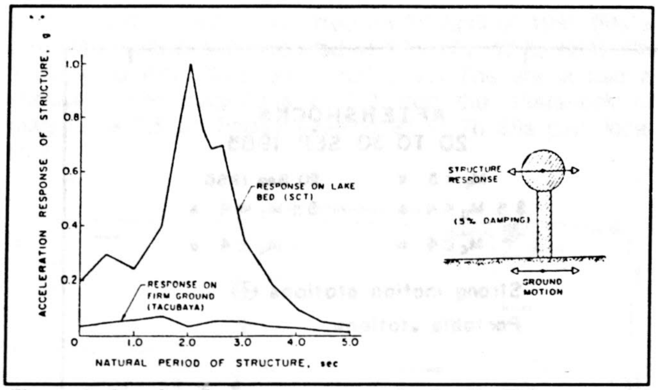

Figure 8. Acceleration response spectra for the Tabacuya and SCT strong motion records (From Beck and Hall, 1986)

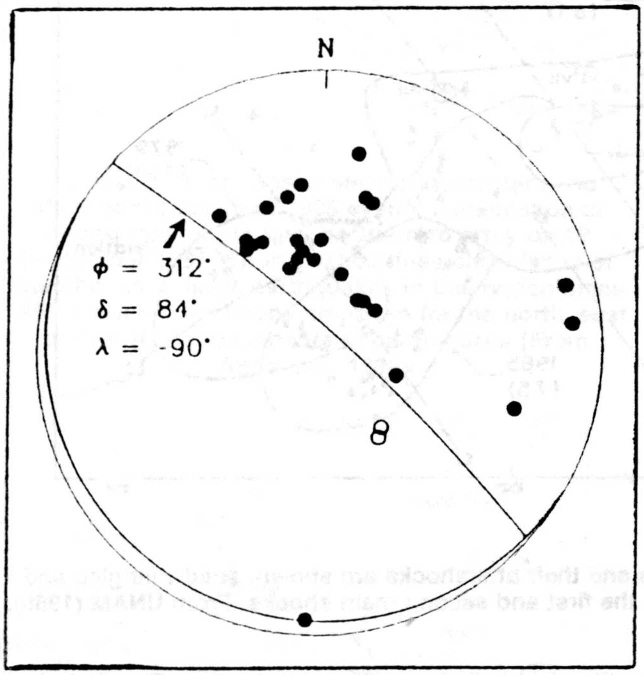

Figure 9. Fault mechanism for the May 28, 1985 (mb = 5.2) event prior

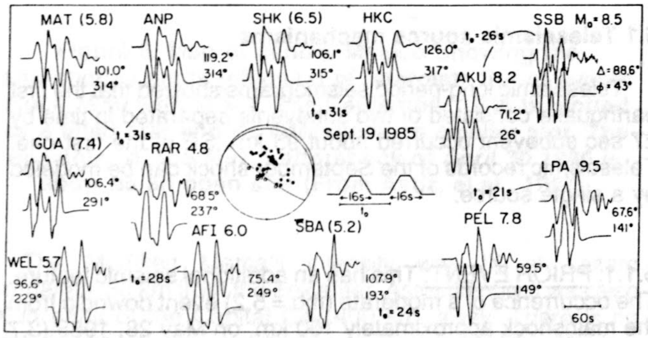

Figure 10. P waves of 19 September earthquake at teleseismic distances. Observed and calculated waveforms shown are from long- period WWSSN recordings and one GEOSCOPE station (SSB). From Astiz, et.al. (1987)

5.1.2 THE FIRST SHOCK: The main shock was centered about 400 km. from Mexico City on the Pacific Coast, near the Town of Lazaro Cardenas on the border between the states of Michoacan and Guerrero. The first motion data constrain one steeply dipping nodal plane with dip of 81° and strike equal 127° and the orientation of the second plane was resolved with wave form modeling. The Figure 9 shows observed P-wave seismograms from 12 WWSSN stations and one GEOSCOPE station (SSB) and synthetic seismograms calculated for the focal mechanism point source depth, and time function that provided,optimal waveform fit for the main shock.

The time function is a multiple source consisting of two trapezoids of equal duration (16 sec.) and seismic moment, and the second source beginning 26 sec after the first. The point source depth is 17 km and the focal mechanism shows an overall thrust geometry on a low angle plane (=9°; =288° and =72°).

The horizontal projection of the slip vector orientation is N39°E, which agrees with the local convergence direction of the Cocos plate calculated at the epicenter from the RM2 pole of rotation **Minster and Jordan** (1978, **in Astiz et.al.**, 1987). The seismic moment estimated from the P-waves amplitudes is 7.2 ± 1.6x10 dyne-cm.

5.1.3 THE SECOND SHOCK: Was on 21 of September, only a few P wave forms of the large event aftershock are available. The waveforms are consistent with the a mechanism identical to the main shock, with a slightly greater source depth of 22 km (Figure 11).

The aftershock time function is a single source with a duration of 13 sec. The seismic moment recovered from the body waves is 1.2x10 dyn-cm.

5.1.4. THE THIRD SHOCK: It was the April 30 aftershok. Long period P waves of the aftershock from 15 WWSSN stations are shown in figure 12. The synthetic seismograms are calculated for a point source 21 km deep and source time duration of 10 sec. First motion data constrain only one the nodal planes as is common for most large Mexican subduction events. The second fault plane was resolved from waveform modeling. The fault parameters determined are = 280°, = 12° and = 70°. The seismic moment for each station is given next to station code.The seismic moment is 2.0x10 dyn-cm.

5.2. The seismic moment

The seismic moment and fault geometry, were resolved from amplitude and phase spectral data of multiple Rayleigh and Love passages at 256 sec. generally following **Kanamori and Given** (1981, **in Eissler et al.**, 1986). The seismic moment is between 1.1-1.7x10 dyn-cm. (Mw=7.9-8.1), thus the event is comparable with the largest previous event en the Mexico historic record the 1932 Jalisco (Ms=8.1). The seismic moment range of the aftershock is 2.9-4.7x10 dyn-cm. (Mw=7.6-7.7).

5.3. Centroit-moment tensor method

Observations of three dimensional ground motion at a single point on the surface of the earth following an earthquake can be sufficient to determine the Zeroth Order Moment Tensor of the event. **Ekstrom et. al.** (1986) adapted the Centroid Moment Tensor Method (CMT) and apply to the September 19 event.

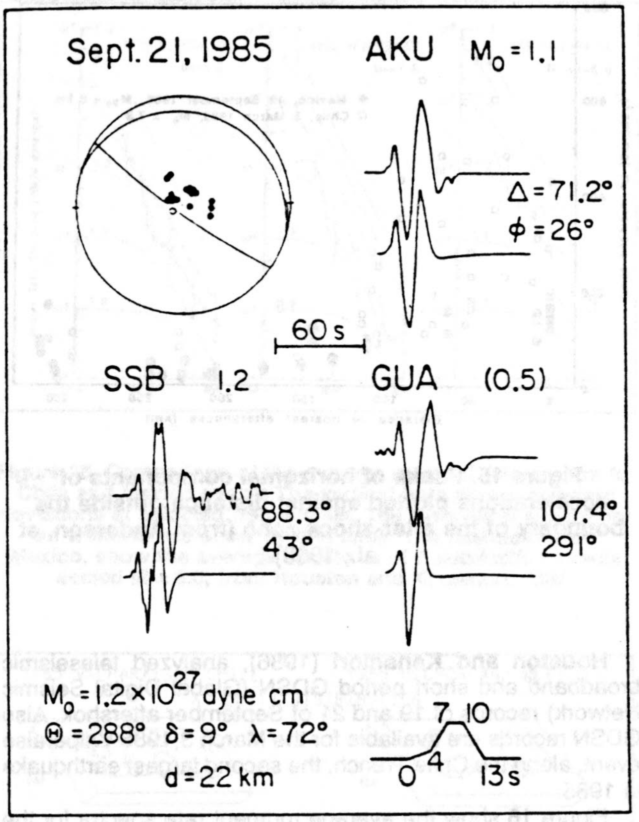

Figure 11. The second shock waveforms mechanism.

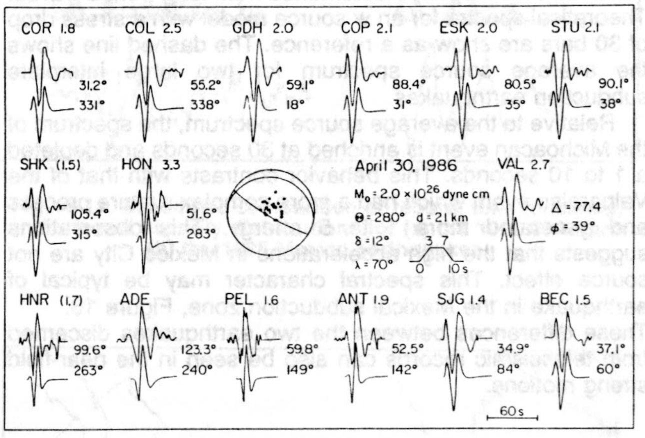

Figure 12. Long-period WWSSN recordings of P waves for the 30 April 1986 (Mw=6.9) earthquake are show by the upper traces. (From Astiz, et.al., 1987).

The September 19, 1985 Michoacan, produced high-quality records at (HRV) Harvard, Mass. Long period surface wave data including the first orbit Rayleigh and Love waves, were used in a single station source inversion in the mantle wave band. They used seismograms of HRV for three components and the synthetic seismograms corresponding to the obtained mechanism. The variance reduction is 89%. Figure 13 shows the geographical location of the epicenter and a lower hemispheric projection of the obtained source mechanism. Also shown is the mechanism of the September 21, determined using the same approach and published CMT solutions for other earthquake in this region (1977-1985). The solution by a scalar moment given for they, for the 1985 event is in good agreement with the previous mechanisms obtained in this area and with the procedure subduction of the Cocos plate. They obtained a scalar moment for the main earthquake of 1.3x10 dyne-cm.

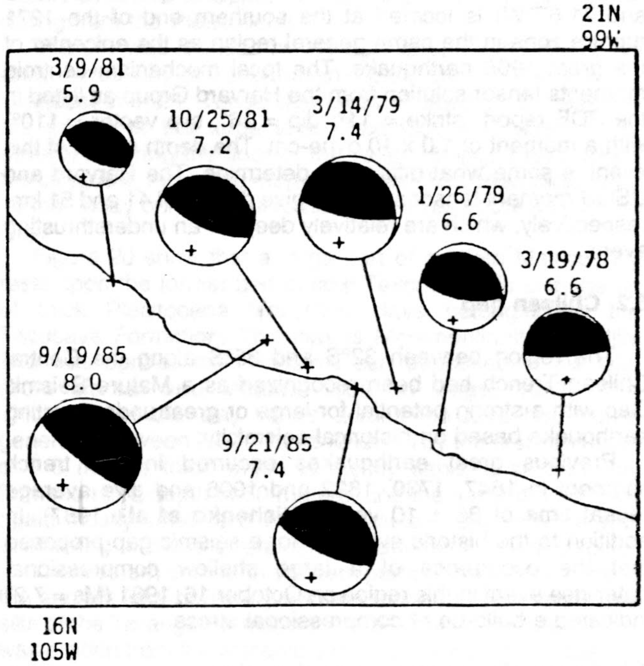

Figure 13. Location and best double couple focal mechanisms for the September 19 and 21 events analyzed with CMT. (from Ekstrom et al., 1986).

The focal mechanism obtained indicates faulting on an shallow plane consistent with the procedure subduction of the Cocos plate. A direct deconvolution of the observed P-waves train indicates that the moment release occurred in two subevents each of 20 sec duration with a peak-to peak separation in time of 25 sec (**Ekstrom et al.**, 1986).

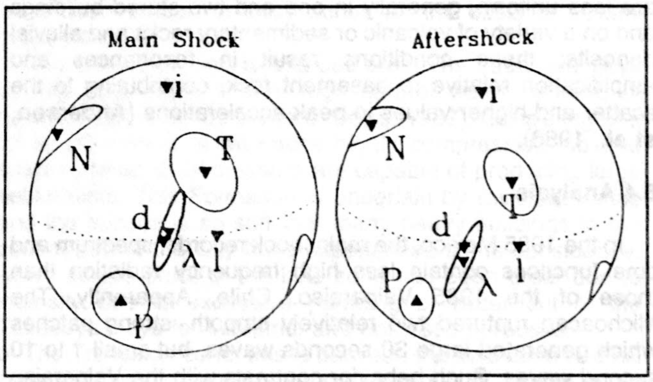

Figure 14. Source mechanisms for the Michoacan, 19 (left) and 21 (right) earthquakes from spectra Mw. T, P and N are the three principal axes. d is double couple and mechanisms vectors (From Riedesel et al., 1986).

6. COMPARISON BETWEEN 1985 EARTHQUAKES

6.1 The 1985 Valparaiso, Chile earthquake

The March 3 1985, central Chile earthquake (Ms = 7,8) ruptured a well studied seismic gap along the Chilean Subduction Zone. The epicenter of this event is located near the center of an approximately 300 km. long region which ruptured is a great event in 1906 (Mw= 8,2).

The epicenter of the March 3, 1985 earthquake (33,13° S and 71.87°W) is located at the southern end of the 1971 rupture zone in the same general region as the epicenter of the great 1906 earthquake. The focal mechanism centroid moments tensor solution from the Harvard Group as listed in the PDE report (strike = 11°; dip = 26°; slip vector = 110°) with a moment of 1,0 x 10 dyne-cm. The depth extent of this event is some what difficult to determine. The Harvard and USGS moment tensor solutions give depths of 41 and 51 km. respectively, which are relatively deep for an understhrusting event.

6.2. Chilean gap

The region between 32°S and 35°S along the Central Chilean Trench had been recognized as a Mature Seismic Gap with a strong potential for large or great underthrusting earthquake based on historical seismicity.

Previous great earthquakes occurred in this trench segment in 1647, 1730, 1822 and 1906 and give average repeat time of 86 ± 10 years (**Nishenko et al.**, 1987). In addition to the historic evidence for a seismic gap proposed that the occurrence of a large shallow compressional outer-rise event in this region on October 16, 1981 (Ms = 7,2) indicated a build-up of compressional stress.

6.3. Comparison between earthquakes

For comparison, the Figure 15 shows peak accelerations recorded during the Chile and Mexico earthquakes. The Chile, is another subduction thrust earthquake with a geometry similar to the September event. Peak accelerations for the Mexico data show much less scatter than the Chile data, and seem to be almost a lower bound. The depths to faulting in Chile and Mexico may be similar, but site conditions for the two sets of data are different. The Mexican stations at distances less than 300 km. are generally on small piers on competent rocks outcrops. The Chile site conditions are less uniform, generally in one and two-stored buildings and on a variety of volcanic or sedimentary rocks and alluvial deposits; these conditions result in resonances and amplification relative to basement rock, contributing to the scatter and higher values in peak accelerations (**Anderson, et al.**, 1986).

6.4 Analysis

In the 1985 Mexico, the mainshock records, spectrum and time functions contain less high frequency radiation than those of the 1985 Valparaiso, Chile. Apparently, The Michoacan ruptured two relatively smooth, strong patches which generated large 30 seconds waves, but small 1 to 10 second waves. Such behavior contrasts with the Valparaiso event which had a more complex rupture process and generated more 1 to 10 seconds energy. This difference is consistent with the higher nearfield accelerations recorded for the Valparaiso event.

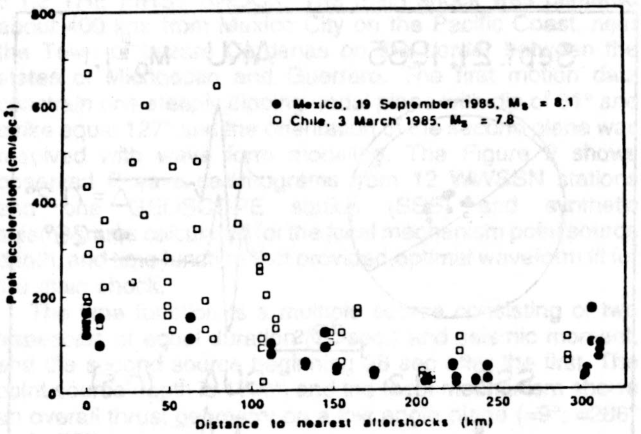

Figure 15. Peaks of horizontal components of accelerations plotted against distance outside the boundary of the after-shock zone (from Anderson, et al., 1986).

Houston and Kanamori (1986), analyzed teleseismic broadband and short period GDSN (Global Digital Seismic Network) records of 19 and 21 of September aftershok. Also GDSN records are available for the March 3,1985 Valparaiso event, along the Chile Trench, the second largest earthquake in 1985.

Figure 16 show the average moment rate spectra for the Michoacan and Valparaiso events. The spectral values at the low frequency end of the spectra were obtained from the scalar seismic moments determined from long-period waves. Theoretical spectra for an w source model with a stress drop of 30 bars are show as a reference. The dashed line shows the average source spectrum for two large interplate subduction earthquakes.

Relative to the average source spectrum, the spectrum of the Michoacan event is enriched at 30 seconds and depleted a 1 to 10 seconds. This behavior contrasts with that of the Valparaiso event which had a more complex rupture process and generated more 1 to 5 energy. This observations suggests that the high accelerations in Mexico City are not source effect. This spectral character may be typical of earthquake in the Mexical subduction zone, Figure 16. These differences between the two earthquakes discerned from teleseismic records can also be seen in the near-field strong motions.

7. DAMAGE ACROSS MEXICO

This earthquake which was felt superficially in an area of approximately 825,000 square kilometers (**Degg**, 1987). The strength of the quake was felt as far north as Houston, Texas, 1,500 kilometers from the epicenter, and generated a small tidal wave that was recorded along parts of the Mexican and El Salvadorean coast (Figure 18). The fact that Mexico City is constructed on an old lake bed has led to significant correlations between the geographical distribution of damage from September 1985 and early earthquakes and the type of subsoil underlying the damage area (**Handon and Martin**, 1987).

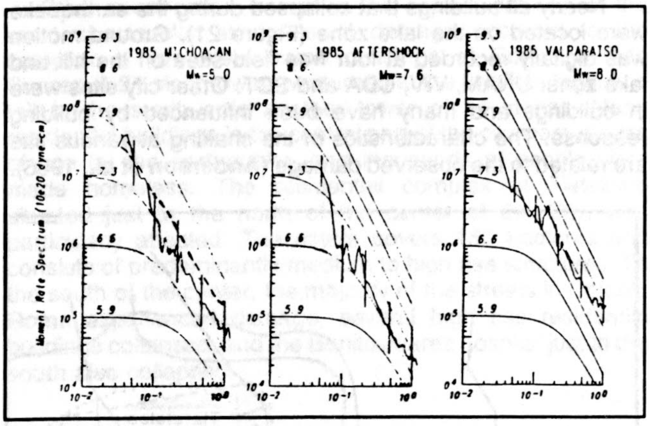

Figure 16. Comparison of the average moment rate spectra for Chile and Mexico events.The vertical bars shows standard deviations at selected frequencies. The theoretical spectra for an w model are show by thin lines. The dashed line on Mexico, show the average spectrum of 7 subduction events scaled M = 8.0, from Houston and Kanamori, 1986.

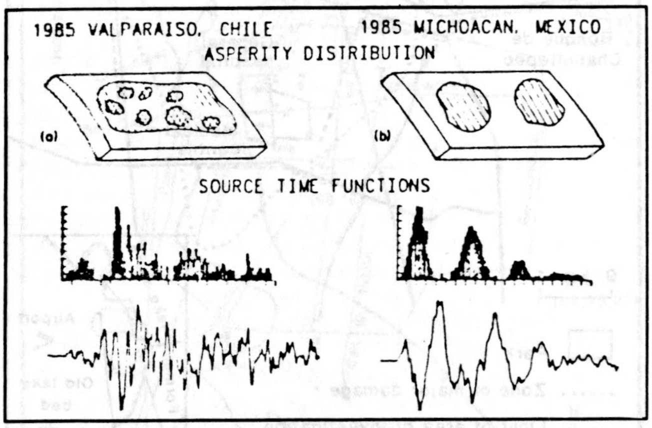

Figure 17. Schematic comparison of record, time functions, and inferred asperity distributions for (a) the 1985 Chile and (b) the 1985 Mexico earthquakes.

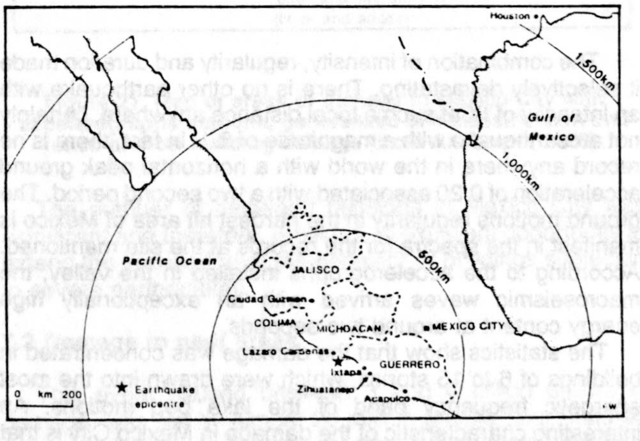

Figure 18. Areas affected in Mexico (From Degg, 1987).

7.1 Mexico City geology

Mexico City lies at an elevation of 2,250 m. above sea level and is situated at the geographical center of Mexico, on the western side of the Valley of Mexico, formed about 30 million years ago by the faulting of an uplifted plate. This is a basin 65 km by 80 km in extent, surrounded by volcanic mountains of up 5,000 meters in height. The volcanoes are mainly of Middle to Upper Tertiary age, but there also some dating from the Pleistocene.

The city was founded by the Spaniards on the site of the great Aztec City of Tenochtitlan. At the time of the Spanish conquest in 1521, Tenochtitlan was situated on an island in the middle of the large lake (Texcoco), that was one of several covering the floor of the valley (**Degg**, 1987). Since the conquest, more and more of the lake has been reclaimed, so that today only a small remnant survives to the east of the City.

Figure 20 show that a large part of modern Mexico City rests upon the former bed of lake Texcoco. This is made up of thick Pleistocene lacustrine clays belonging to the Tacubaya Formation. This clay is Montmorillonite and Illite and was derived from volcanic ash deposited in the lake (from **Marsal and Mazari**, 1959, in **Degg**, 1987). The Thickness of the clay varies across the lake bed but is generally between 7-37 meters followed by the first hard layer of 1-3 meters thick which is mostly sand; a second clay formation to a depth of 50 meters, and the second hard layer again mostly sand; and then a complex conglomerate with soil having all sizes of grains even boulders, down to rock.

The western and north-western parts of the City lie outside the ancient lake boundary and are situated upon sands and silts of the Tarango Formation. These consist of material that was eroded from the volcanic cones surrounding the valley of Mexico during the upper Pliocene and lower Pliocene and subsequently were deposited as alluvial fans. Above the highest former lake shoreline, the Tarango Formation has a thickness of approximately 600 meters.

Many high-rise buildings on the lake bed have pile foundations which pass through the soft Tucubaya clays to the more compacted layers of the Tarango beneath. The southern part of the City rests on basalt lava flows, the youngest of which date from about 2400 years ago. The lava flows are referred to in general terms as the pedregal.

Subsoil Divisions: The area and surrounding of Mexico City have been divided in three zones on the basis of subsoil properties:

a- The Lake Zone: this is lake bed area. The Tabacuya clays of this zone have a very high natural water content, of between 200 and 400 percent (**Degg**, 1987). Consisting of a 25 to 80 meters of thickness highly compressible so that small increments of pressure are capable of producing large settlements. This Formation is underlain by resistant sands and the subsoil is so soft that many heavy buildings in the central part of the City have experienced some subsidence, which across parts of the lake zone has been great due to intensify due to excessive pumping of water out of the Tabacuya clays for industrial and domestic purposes.

b- The Transition zone: this is between the lake zone and hill zone,it is comparised of a sandy silty layer of alluvial origin with occasional intervals of clay. It comprises areas which previously formed the shores of lake Texcoco, so that the thickness of the Tabacuya clay is greatly reduced as is its water content 100-200 percent (**Degg**, 1987). The clay at this zone is much less compressible that the lake zone.

c- The Hill Zone: This zone incorporates the hilly surface layer of volcanic lava flows or volcanic tuff. This part have rest upon the Tarango sands and silts which are typically dense and contain much less water that the Tabacuya deposits.

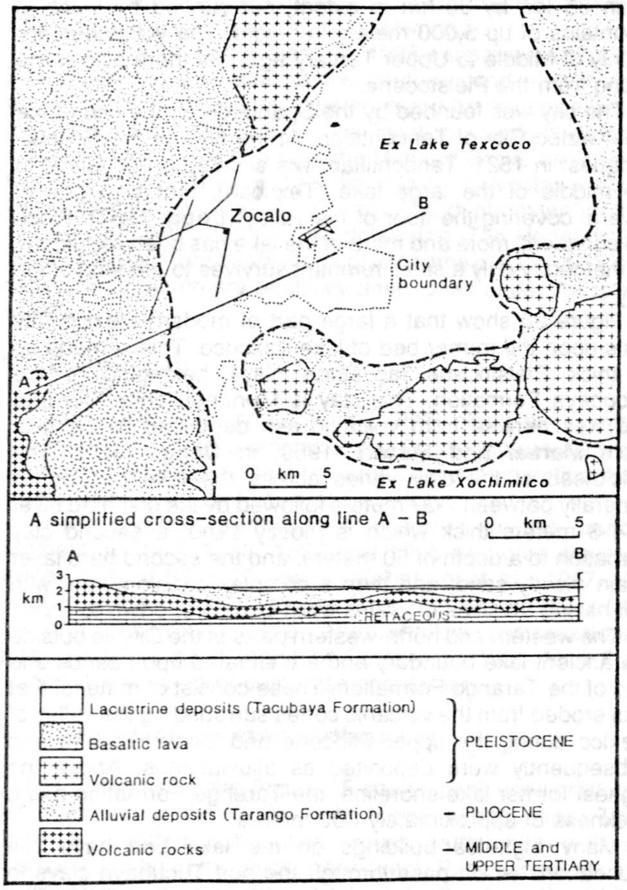

Figure 19. Geology of the Mexico City Area (From Degg, 1987).

7.2 Mexico City damage

The earthquake caused considerable damage to modern construction in Mexico City and was restricted to the western part of the lake zone and within two to four kilometers of Alameda square (Figure 20).

Several hundred buildings collapsed; more would have to be demolished and thousands reinforced. The damage in the adjacent lake bed areas was very sporadic.

One factor for this earthquake damage is that the ground-shaking was amplified because Mexico City lies on an old lake bed that resonates with the seismic waves that are the most amplified are the low-frequency signals, which can do the most damage to taller building.

The earthquake was very selective, and only a relatively small number the buildings suffered severe damage. At to time of the quake, Mexico City had one of the world's most stringent building codes, based on experience gained from several quakes in 1957 and 1979. Nevertheless, the quakes intensity in particular areas of the city was much larger than what the buildings were designed for.

Nearly all buildings that collapsed during the earthquake were located on the lake zone (Figure 21). Ground motion was digitally recorded at four free field sites on the hill and lake zone: UNAM, VIV, CDA and SCT. Other city sites were in buildings and many have been influenced by building response. The characteristics of the shaking at various site are related to the observed damage (**Anderson et al.**, 1986).

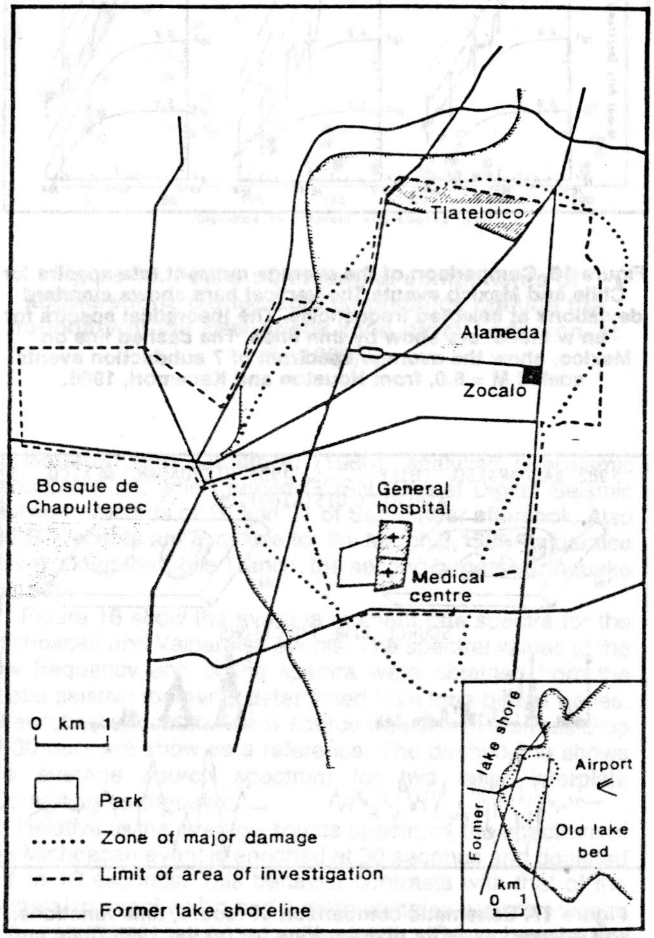

Figure 20. The zone of major damage in Mexico City (from Degg, 1987).

The combination of intensity, regularity and duration made it selectively devastating. There is no other earthquake with an intensity of IX at such a focal distance anywhere, certainly not an earthquake with a magnitude of 8.1. In fact, there is no record anywhere in the world with a horizontal peak ground acceleration of 0.20 associated with a two second period. The ground motions regularity in the hardest hit area of Mexico is manifest in the spectra for the records at the site mentioned. According to the accelerographs installed in the valley, the macroseismic waves arrived with an exceptionally high energy content at around two seconds.

The statistics show that the damage was concentrated in buildings of 6 to 15 stories, which were drawn into the most energetic frequency band of the lake bed motions. An interesting characteristic of the damage in Mexico City is that a great number of buildings collapsed in their upper stories, leaving the lower portions intact.

Steel construction is rare in the capital, yet one of the most spectacular examples of damage occurred to the complex of five steel frame buildings at Conjunto Pino Suarez. A 21 story tower overturned at the 3rd floor level and fell to the south onto another tower of 14 stories. Many residential buildings in the central part of the city were put cut of use by the earthquake, and thousands of people were made homeless. The residential complex of Tlatelolco situated just to the north of the center of the City, was particularly affected. The estate covers 150 hectares and consists of predominantly medium to high rise structures. To the south of the center, the majority of the streets in Colonia Roma experienced damage, several high rise residential buildings collapsed, and the Benito Juarez hospital just to the south also collapsed.

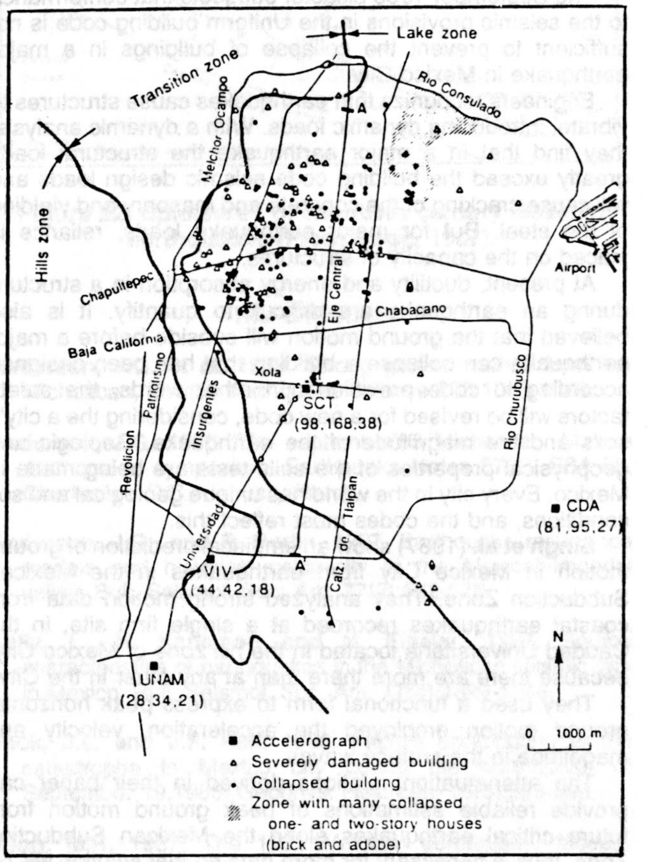

Figure 21. Map of areas of damage in Mexico City with accelerographs stations, generalized soil classification and sites of mort building damage (from Anderson, 1986)

The number of damaged buildings in Mexico City was significant and,therefore, provides an excellent opportunity to extend the knowledge of the behavior of buildings subjected to severe earthquakes.

7.3 Damage in near areas

This event caused between 3 and 4 billion dollars in damage, was felt by almost 20 million people, four hundred twelve buildings collapsed another 3,124 were seriously damaged in Mexico City,and about 60 percent of the buildings were destroyed at Ciudad Guzman, Jalisco. Damage also occurred in the states of Colima, Guerrero, Mexico, Michoacan, Morelos, parts of Veracruz and in other areas of Jalisco (Figure 5).

The Maximum Modified Mercalli intensity was IX at Mexico City, Ciudad Guzman and the Pacific coast, towns of Lazaro Cardenas, Ixtapa and La Union. Felt reports were received from Mazatlan, Sinaloa to Tuxtla, Gutierrez, Chiapas and as far away as Guatemala City, The earthquake was also felt at the cities of Brownsville, McAllen, Corpus Christy, Ingran and El Paso in Texas. It was felt very strongly by people on board the ship Nedlloyd Kyoto located at 17°35,4' North and 102° 36,9'. Landslides caused damage at Alenquique, Jalisco and near Jala, Colima. Rockslides were reported along the highways in the Ixtapa area and sand blows and ground cracks were observed at Lazaro Cardenas.

The damage in some parts depended on the population of the states, but also,it depend the hard bedrock that was beneath the coastal region and served to transmit the shock waves without amplification, For example, Acapulco, situated on granite bedrock at a distance of 270 km. from the epicenter, was strongly affected by the earthquake. Coastal cities such as Zihuatanejo and Ixtapa, only 90 km. from the epicenter, suffered only moderate damage. In contrast, parts of Mexico City were severely shaken and experienced very heavy loss, being located more than 400 km. from the epicenter. It is very vulnerable to earthquake ground motion because a large part of the city is build on the humid and not hard sediment of the former lake bed.

The two large hydroelectric plants that the Comision Federal de Electricidad are located in the epicentral region, a subduction zone of thrust faults that dip eastward beneath the Mexican coast.

The La Villita Dam, an earth and rockfill structure built on alluvial deposits, experienced a few minor superficial cracks along the downstream edge of its crest. The Infiernillo Dam, a rockfill structure with a clay core founded on rock, was undamaged Figure 5.

7.4 Tsunami

The Tsunami that was generated by the 1985 earthquake, caused some damage at Lazaro Cardenas, Zihuatanejo, and only rough sea waves observed in Manzanillo, with estimated waves heights were 3 meters at Zihuatanejo and 2,8 meters at Lazaro Cardenas located over the Mexico coast. Tide stations recorded maximum wave heights of 1.4 meters at Acapulco, Mexico; 60 cm. at La Libertad, Ecuador; 58 cm. at Acojatla, El Salvador; 24 at Kahului, Hawaii and at Pago Pago, American Samoa; 22 cm. at Hilo, Hawaii; 21 cm. at Baltra Island, Galapagos; 14 cm. at Apia, Somoa; 7 cm. at Rikitea, Gambier Islands, and 5 cm. at Paeete, Tahiti. There were some reports, still unconfirmed, that some ships off the Pacific coast of Mexico observed unusually heavy seas up to 30 meters high near the time of the earthquake and that some fishing boats were reported missing.

Seiches were observed in East Galveston Bay, Texas and in swimming pools in Texas, New Mexico, Colorado and Idaho. Water well fluctuations were recorded at Ingleside, Texas; Santa Fe, New Mexico; Rolla, Misouri; Hillsborough County, Florida and Smithsburg, Maryland. Other Tsunami effects occurred in an Island in the Balsa river delta when there is a large plant of fertimiex fertilizer. The plant is complete, and there is not any visible damage to buildings, stock, or steel towers, but there was extensive soil failures on all access roads.

Some sea water was still pooling outside Pelleting warehouse; also plenty of ground water was expelled by sand craters. Wave heights were variously estimated at 2 to 3 meters, which agrees with observations of runup visible from aircraft on small beaches south of Lazaro Cardenas, (**Lomnitz et al.**, 1986).

In on other place, the Diammonium Phosphate Mill, extensive sand cratering and cracking of roads suggests intensity IX. To north of the beach where the Tsunami flooding took place (Paso de Burras), railroad tracks running along open beach just above high sea level, were deformed into S-Shaped curves like spaghetti. Some wetted sticks showed Tsunami over-topped the rails by 30 cm. The lagoon draining into the estuary provided a handy mean sea level reference; estimated elevation of rails was 1.60 meters above mean sea level, this suggests Tsunami height was 1.90 meters above mean sea level.

This was the first positive measurement of a Tsunami in Mexico and requests resurveying of elevations at this spot. Fortunately the same spot was surveyed two weeks before the earthquake, so, the survey should provide evidence of changes in coastal elevation.

Taken together these observations suggest that:

- the earthquake of 19 September, 1985 was a tsunamigenetic event, a multiple rupture which probably broke the plate boundary from the trench inland. This would agree with the direction of collapse of filler walls, suggesting one or several lurches of the ground in the ocean-ward direction.

The director of International Tsunami Center in Honolulu, Hawaii attributes the relatively small size of the tsunami to the shallow angle of this subduction on the small vertical motion of the crust during the earthquake.

8. RISK OF FUTURE EARTHQUAKES IN MEXICO

The September 19 earthquake of 1985 caused unprecedented damage in Mexico. None of the earthquakes along the Mexican Subduction Zone since the 1932 Jalisco earthquake (**UNAM**, 1986) exceeded rupture lengths of about 100 km. Therefore the unusually large rupture length of the 1985 shock, complied with the explosive growth of earthquakes in the last 30-40 years,and may be particularly responsible for the damage.

Scientists have observed that the seismic gap theory is based upon the stress built up at a relatively constant rate along the zones of plate boundary interaction, so that a section of a given fault might be expected to generate earthquakes at regular intervals.

Sections of a fault that have been unusually quiet for a long time are termed "Seismic Gaps". The identification of these gaps provides the basis for many modern systems of predictions of where earthquakes are most likely to occur next. However, it is much more difficult to predict when the earthquake will actually take place.

Repeat times of large earthquakes along the Central American trench, in the south of the Michoacan Seismic Gaps lies the Guerrero Seismic Gaps, are usually between 30-70 years (Fig.22). This shows that the sections of the fault that generated the 1985 earthquake had been quiet for a much longer period than this, and it had not experienced a mayor seismic event for over two centuries and formed part of a quiet zone termed the Michoacan Seismic Gap.

The likelihood of an earthquake along this section of the fault therefore remains high, and may have been not seriously increased following the transfer or stress from the rupture in the Michoacan Gap. Still further to the south are other seismic gap that also, have the potential to produce large earthquakes in the near future. Most notable of these sections is the fault of Acapulco. In other words, the risk of other large earthquakes in Mexico in the future, might continue to be considered high. The event of 1985 has not reduced the risk of another large earthquake in Mexico, in fact, it may well have increased it.

Another factor is that the ground vibrations were amplified more or less, five times, because Mexico City is situated on an old lake sediments beds, that resonate with the seismic waves. The thickness of the beds is such that they most amplify the low frequency signals, which can do the most damage to taller buildings. This will occur during other earthquakes with the lake beds motions at least as intense as those in September 1985. This must be considered as being a strong possibility in the near future.

The September 1985 disaster suggests that conformance to the seismic provisions in the Uniform building code is not sufficient to prevent the collapse of buildings in a major earthquake in Mexico City.

Engineers recognize that earthquakes cause structures to vibrate, introducing dynamic loads. With a dynamic analysis, they find that in a major earthquake the structural loads greatly exceed the building code seismic design loads and will cause cracking of the concrete and masonry and yielding of the steel. But for major earthquake loads, reliance is placed on the capacity of structures.

At present, ductility and energy absorption in a structure during an earthquake are difficult to quantify. It is also believed that the ground motion will subside before a major earthquake can collapse a building that has been designed according to code provisions. In other words, the safety factors will be revised for a new code, considering the a city's soils and the magnitude of the earthquake. Geologic and geophysical properties of the soils tests are being made in Mexico. Every city in the world has unique geological and soil conditions, and the codes must reflect this.

Singh et al. (1987) show an empirical prediction of ground motion in Mexico City from earthquakes in the Mexican Subduction Zone. They analyzed strong motion data from coastal earthquakes recorded at a single firm site, in the Caudad Universitaria located in the hill zone of Mexico City, because there are more there than at any other in the City.

They used a functional form to express peak horizontal ground motion employed the acceleration, velocity and magnitude in the surface waves.

The attenatuation relations derived in their paper can provide reliable estimations of peak ground motion from future critical earthquakes along the Mexican Subduction Zone, thus is necessary for more data so that solution will be representative.

Also, in a study of the Mexicali-Imperial Valley (**Anderson and Bodin**, 1987) identified six overlapping fault segments of inferred rupture history and they suggest plausible occurrence times for future events in the six segments. They compared the historical data with predictions of the time-predictable and slip-predictable models, and they suggest the possibility of an earthquake there in the near future.

9. CONCLUSIONS

The 1985 Mexico earthquake, occurred as a result of slipping in the subduction process between the Cocos and American plates. This event ruptured a Seismic gap where unusual Oceanic Lithosphere is subducting beneath Mexico.

There are many lessons to be learned from this event in the context of the earthquake engineering, it is important to understand the causes of structural failure. In the seismological context, it is an important event in both a global and regional sense. Those had been a global hiatus in the occurrence of large earthquakes from 1980 until 1985 when two large earthquakes occurred; the March 3 Chilean (Ms=8.0) and September 19 Mexican (Ms=8.1) earthquakes.

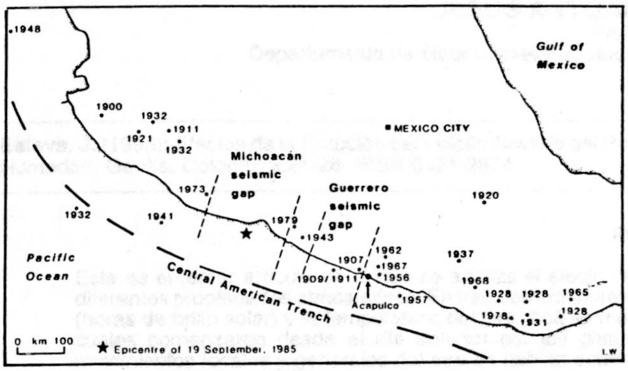

Figure 22. Epicentres of twentieth century Mexican earthquakes (From Degg, 1987).

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