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Short Note

Evidence for Great Tsunamigenic Earthquakes (M 8.6) along the Mexican Subduction Zone

by Gerardo Suárez and Paola Albini

Abstract A very large earthquake took place on 28 March 1787 along the Mexican subduction zone. A unique characteristic of the 1787 event is the large tsunami reported at various coastal locations in southern Mexico. The segment of the coast affected by the strong tsunami coincides with locations where high felt intensities (modified Mercalli intensity [MMI] > VIII) were reported. Assuming, as is generally the case for large and great earthquakes in Mexico, that the fault rupture of the 1787 earthquake encompasses the areas where intensities greater than VIII were reported and where a strong tsunami invaded land, the estimated length of the rupture is approximately 450 km long. This fault length would correspond to an earthquake of approximately M_w 8.6. In the instrumental record there is no evidence of earthquakes of this magnitude in the Middle American subduction zone. This evidence indicates that the rupture area of the 1787 earthquake was at least three times longer that those normally observed for earthquakes that take place in the Mexican subduction zone. The 1787 earthquake appears to have ruptured a long fault segment that more recently broke in earthquakes of more moderate magnitude (M_w 7–8) and relatively short recurrence times of about 30 to 40 yr. Examples of this mode of variable rupture length where great but infrequent earthquakes rupture the fault areas of relatively smaller and more frequent earthquakes have been observed in the Sumatra–Andaman and Colombia–Ecuador plate boundaries, among others.

Introduction

The seismicity along southern Mexico and Central America is dominated by the subduction of the Cocos and Rivera plates beneath the North American and Caribbean plates. The instrumental record of the last 100 yr shows that the magnitude (M_w) of the largest subduction events generated along this plate boundary, range from about 7.3 to 8.2 (e.g., Singh *et al.*, 1981; Kostoglodov and Pacheco, 1999). The two largest earthquakes recorded instrumentally in the region are the Jalisco earthquake of 1932 (M_w 8.2) (Singh *et al.*, 1985) and the 1985 event on the coast of Michoacán (M_w 8.1) (Universidad Nacional Autónoma de México [UNAM] Seismology Group, 1986).

One of the interpretations for the prevalence of earthquakes with magnitudes ranging from 7.3 to 7.7 along the Mexican subduction zone is the size of the asperities presumably responsible for these subduction earthquakes. A second reason may be the shallow depth (~20 km) of the seismogenic plate contact, which is only 80 km wide (Suárez *et al.*, 1990; Suárez and Sánchez, 1996; Melbourne *et al.*, 1997). The coast of Oaxaca in southern Mexico is a good example of a segment of the Mexican subduction zone where earthquakes occur with relatively short recurrence times ranging in magnitudes from 7.3 to 7.7. It has been suggested that the large earthquakes that took place along the coast of Oaxaca in 1965, 1968, 1978, and 1996 are the repeat of events of similar size earthquakes that occurred in the same region in 1928, yielding a repeat time of approximately 40 yr (Singh *et al.*, 1981; Núñez-Cornú and Ponce, 1989; Núñez-Cornú, 1996).

On 28 March 1787 a very large event occurred along the southern coast of the state of Guerrero and Oaxaca. Based on historical reports (Orozco y Berra, 1887–1888; García Acosta and Suárez, 1996), this earthquake appears to be one of the larger events to have occurred along the Mexican subduction zone during the last 500 yr. The damage and felt reports of this earthquake and the coastal extent of the associated tsunami, both suggest a magnitude and rupture length that is much larger than the typical thrust events on the Middle American subduction zone observed in the twentieth century.

Description of Damage

The sequence of earthquakes that occurred in 1787 in Oaxaca was widely felt in southern Mexico and presents some unique characteristics that have not been observed in other coastal earthquakes (Orozco y Berra, 1887–1888; García Acosta and Suárez, 1996). The sequence initiated with a very large earthquake on 28 March, which we interpret here to be the main event. It was followed by three large shocks on 29 March, 30 March, and 3 April. These three large aftershocks also produced damage in the city of Oaxaca. The observed intensities in Oaxaca City suggest that the three largest aftershocks are all greater than a magnitude of 7. In particular, the event of 3 April was felt very strongly in the city of Oaxaca, causing additional damage to the buildings already in poor condition after the damage caused by the mainshock.

Historically, the population density has been sparse along the Mexican Pacific coast. Thus, damage and felt reports of the 1787 sequence of earthquakes come from the coastal towns that existed at the time and from some cities farther inland. It is illustrating to compare the damage in Oaxaca City produced by the subduction earthquakes that occurred in 1965, 1968, 1978, and 1996 with that caused by the earthquake of 28 March 1787 (Table 1).

The city of Oaxaca lies about 100 km inland from the coast. In the last four earthquakes of the twentieth century, Oaxaca City did not sustain major damage due to coastal earthquakes. In all these cases, the maximum intensities (modified Mercalli intensity [MMI]) observed in the city of Oaxaca were V to VI. Similar intensities were observed during the earthquake sequence that occurred in 1928 (Figueroa, 1975; 1987). In contrast, the earthquake of 1787 produced important damage and the collapse of well-constructed buildings and structures, such as churches, convents, government houses, and private dwellings (García Acosta and Suárez, 1996). The observed intensity for the main event in 1787 in Oaxaca City (MMI = IX) has never been observed in the historical record for other events occurring along the subduction zone to the south of the city.

During the 1787 main event, MMI > VIII were observed on coastal locations stretching from Ometepec to the city of Tehuantepec in the Isthmus of the same name (Fig. 1). The isoseismal maps computed for the largest Mexican subduction earthquakes since the nineteenth century show that the rupture zones of earthquakes with magnitudes greater than ~7.0 consistently coincide with observed MMI > VIII along the coast (Figueroa, 1975; 1987). A recent example is the 1985 Michoacan earthquake (M_w 8.1) where the area of high intensities (MMI > VIII) (Figueroa, 1987) is about 160 km long, similar to the rupture zone mapped with aftershocks (UNAM Seismology Group, 1986). Thus, the areas enclosed by population centers reporting intensity greater than VIII are a good estimate of the rupture length of large earthquakes in Mexico.

Table 1

MMIs Observed in the City of Oaxaca for Several Earthquakes along the Subduction Zone

Earthquake Date	M_w	Oaxaca (MMI)
23 August 1965	7.4	VI
2 August 1968	7.3	V
29 November 1978	7.6	VI
25 February 1996	7.1	IV
3 March 1787		IX

The Presence of a Large Tsunami

The most unusual phenomenon observed during the 1787 earthquake, compared with other Mexican subduction events in both the instrumental and historical records, is the report of a very large tsunami that struck the coast of the southern states of Guerrero and Oaxaca. A vivid description of the tsunami was reported by various sources to the south of the city of Ometepec and on the Alotengo Lagoon (today renamed as the Corralero Lagoon) (García Acosta and Suárez, 1996).

The description of the 1787 tsunami stemming from reports in the Alotengo Lagoon conveys the magnitude of the phenomenon: "[the fishermen] after building sandbars to catch fish and when some of them were already mounted on horses, after having collected the nets, watched in awe how the sea retreated about one Spanish league (one Spanish league is approximately 4.18 km) uncovering lands of various colors and submarine rocks and trees. With the same speed as that with which the sea retreated, it came back leaving thousands of fish stranded on land and swept several of the men inland leaving them hanging and stuck among the trees of a mountain that lies about one and a half league (~6 km) from the sea."

To the east, it is reported that along the coast of Pochutla (what is today Puerto Angel) the sea invaded land, leaving behind fish and shellfish (Fig. 1). A similar phenomenon was reported on the coast, south of the city of Tehuantepec, where the sea invaded land "with terrible noises and left fish and shellfish of strange shape stranded on the beach." In Acapulco, about 250 km to the northwest of the Alotengo Lagoon (Fig. 1), seiches were reported where the sea continuously retreated and inundated the pier for about 24 hr.

The 1787 tsunami is not reported in the Japanese catalogs. As Hatori (1995) points out, the coast of Mexico faces the southwest Pacific and a tsunami generated on the Middle American Trench would not radiate energy towards Japan. If the tsunami propagated away from the coast of Mexico, it would have been observed on Easter Island and the Tuamotus; unfortunately, no written records existed on these islands at that time.

Other Mexican subduction earthquakes have produced tsunamis. These tsunamis, however, have been of local and limited extent (Farreras and Sánchez, 1990). In Mexico, the largest and most damaging tsunami in the instrumental period took place on 18 June 1932. This tsunami was pro-

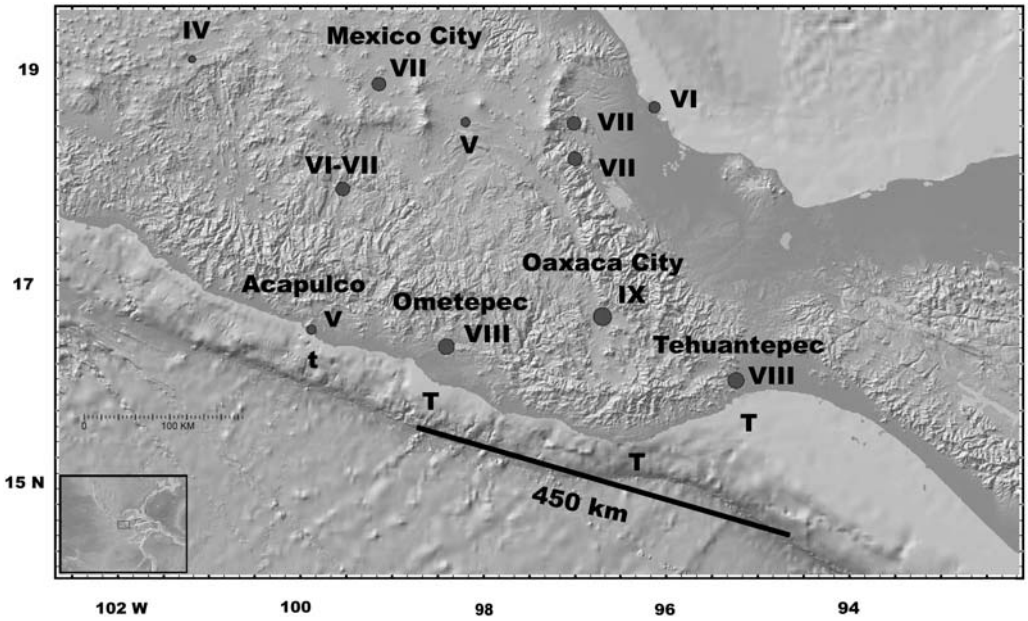

Figure 1. Distribution of intensity data in the MMI scale for the 1787 earthquake. The large *T* indicates locations along the subduction zone where a large tsunami was reported; they are, from west to east, the coast of Ometepec, Pochutla, and Tehuantepec. The small *t* corresponds to the city of Acapulco where seiches were observed during the 1787 earthquake. The estimated fault length of the 28 March 1787 earthquake is about 450 km, which is shown as a solid line along the trench.

duced by the largest aftershock that followed the great Jalisco earthquake of 3 June 1932 (Singh *et al.*, 1985). The 18 June event (M_w 7.8) produced a tsunami that flooded the city of Cuyutlán. This tsunami, as in the other cases reported in Mexico, was of limited extent along the coast and invaded land for only a few hundreds of meters (Farreras and Sánchez, 1990).

Fault Length and Estimated Magnitude of the 1787 Earthquake

As discussed before, there is good coincidence between the locations along the coast where values of MMI $\geq$ VIII were observed during the 1787 earthquake and where reports of a large tsunami hit the coast. Thus, the length of the fault that ruptured during the 1787 earthquake may be inferred assuming that the coast of Ometepec and of the city of Tehuantepec, where intensities larger than VIII and a large tsunami took place, correspond approximately to the edges of the rupture zone (Fig. 1).

The length of the rupture zone inferred in this manner is approximately 450 km long (Fig. 1). Using some of the recently proposed scaling relations of magnitude versus area of dip-slip events (e.g., Wells and Coppersmith, 1994) the resulting magnitude of the 1787 earthquake would be approximately 8.6.

Variable Rupture Length along the Middle American Subduction Zone

The rupture zone inferred for the so-called San Sixto earthquake of 1787 includes the fault areas mapped from the aftershock distributions of the 1965, 1968, 1978, 1982, and 1996 events (Figs. 2 and 3) and from the isoseismal maps of the 1928 sequence. After the 1787 event, this segment of the plate boundary apparently had a long period of quiescence for earthquakes $M > 7$ that lasted 141 yr (Núñez-Cornú, 1996). The 1787 event appears to have broken a long segment of the plate boundary that is at least three times as

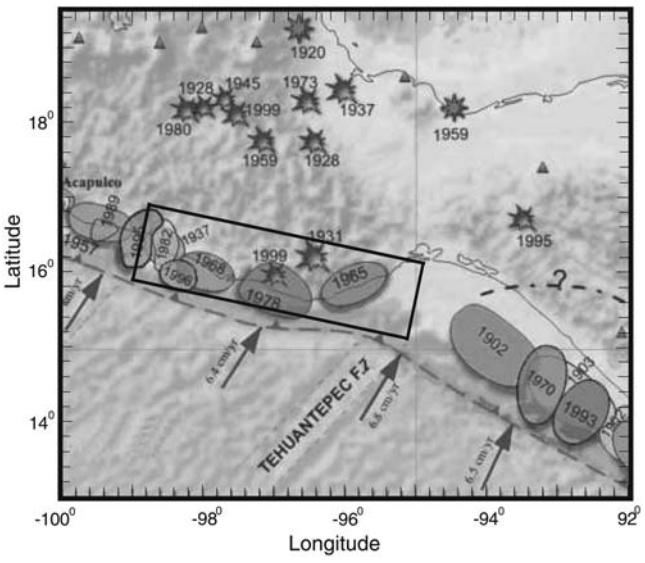

Figure 2. Rupture zones of the 1965, 1968, 1978, 1982, and 1996 earthquakes along the coast of Oaxaca. Stars indicate events occurring within the downgoing Cocos plate. The rectangle shows the estimated rupture length of the 28 March 1787 earthquake inferred from intensity data and tsunami reports along the coast. Triangles are Quaternary volcanoes.

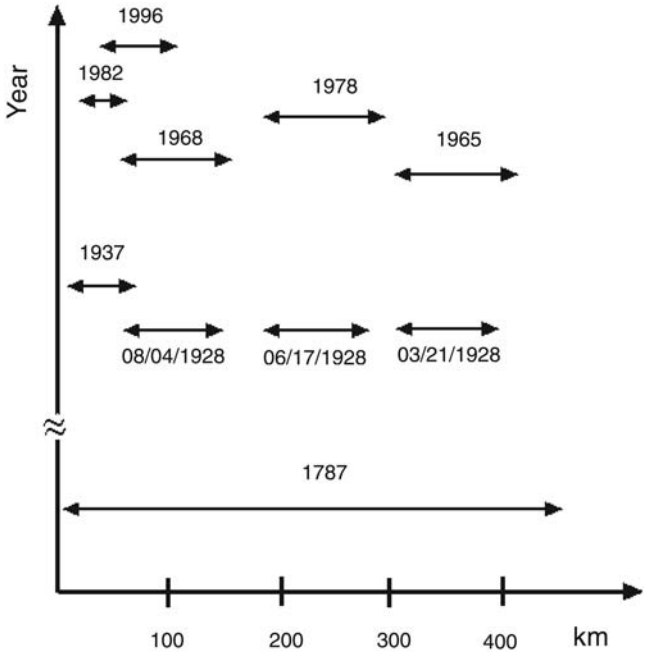

Figure 3. Rupture lengths of the largest events on the southern coast of Guerrero and Oaxaca states in Mexico. The rupture length of the 1787 event is inferred from population centers along the coast reporting MMI > VIII. The fault lengths of the 1928 earthquakes are inferred from the isoseismal maps of Figueroa (1975; 1987). For all other earthquakes rupture lengths are taken from Kostoglodov and Pacheco (1999).

long as the fault zones observed during the more recent earthquakes of smaller magnitude (M_w ~7.3; Fig. 3).

Such variation in the rupture length of earthquakes is well established from the geological and historical records in several subduction zones. Recent geological studies indicate that this variation in rupture mode is a common feature along the Pacific Rim (e.g., Cisternas *et al.*, 2005; Satake and Atwater, 2007). The variation in rupture length observed in Oaxaca is reminiscent of the variability of earthquake size observed in the Colombia–Ecuador subduction zone. Here, three earthquakes that occurred in 1942 (M_w 7.9), 1958 (M_w 7.8), and 1979 (M_w 7.7) broke patches within the rupture zone of a much larger earthquake that slipped during the M_w 8.8 event of 1906 (Kanamori and McNally, 1982).

The recent Sumatra–Andaman megathrust earthquake is a more recent example of a variable rupture length process in a subduction zone. There is no evidence, neither instrumental nor historical, that would lead one to expect an earthquake of this magnitude in an area where the documented earthquake activity was dominated by events of magnitudes 7.5–8.0 (e.g., Bilham *et al.*, 2005; Kanamori, 2006; Subarya *et al.*, 2006). The Sumatra–Andaman earthquake produced slip on a fault over 1400 km in length that includes the smaller rupture areas of all previously known large events in the area.

The inferred rupture length of the 28 March 1787 earthquake suggests that great earthquakes with magnitudes of about 8.6 with very long recurrence times may take place along the coast of Mexico and Central America even though the seismic slip on the plate contact observed during the last 100 yr has been dominated by earthquakes in the magnitude range of 7.3 to 8.2.

Data and Resources

All data used in this article are taken from the articles and books listed in the references.

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