Nat Hazards (2011) 58:859–864
DOI 10.1007/s11069-011-9871-z

SHORT COMMUNICATION

Field survey report on the 11th March 2011 tsunami in Pacific coast of Mexico

M. P. Jonathan · P. D. Roy · J. L. Sánchez-Zavala · S. Srinivasalu · M. C. Macías-Romo · C. Lakshumanan

Received: 10 May 2011 / Accepted: 28 May 2011 / Published online: 15 June 2011

On March 11 of 2011, an earthquake of magnitude 9.0 at 05:46:23 UTC triggered a basin-wide tsunami in the Pacific Ocean with a wave height of 10 m or more. The maximum inundation limit was approximately 6 km or more in the east coast of Japan causing the death of more than 10,000 people. This mega earthquake mechanism was caused in the reverse fault region with WNW-ESE compressional axis, and it characterized by an inverse fault with slip of 30–40 m. Its epicenter was located at a distance of 129 km east of Sendai (Honshu, Japan) at a depth of 32 km (http://earthquake.usgs.gov/earthquakes/eqinthenews/2011/usc001xgp/#details). Subsequently, after the earthquake, the tsunami hit the east coast of Japan and a worldwide alert was issued to more than 24 countries all along the Pacific coast.

The tsunami waves travelled a distance of more than 10,000 km to reach west coast of Mexico in Pacific Ocean. The tidal gauge monitors of Institute of Geophysics, National Autonomous University of Mexico (UNAM) reported that the tsunami waves arrived at 19:12 h GMT at Mazatlan (Sinaloa state), 19:41 h GMT at La Paz (Baja California Sur state), 19:58 h GMT at Zihuatanejo (Guerrero state), and 20:12 h GMT at Acapulco (Guerrero state). The maximum wave amplitude identified from the tidal gauge monitors were 0.5 m at La Paz, 0.4 m at Mazatlan, 3.2 m at Zihuatanejo, and 1.8 m at Acapulco.

M. P. Jonathan (✉)
Centro Interdisciplinario de Investigaciones y Estudios sobre Medio Ambiente y Desarrollo (CIIEMAD), Instituto Politécnico Nacional (IPN), Calle 30 de Junio de 1520, Barrio la Laguna Ticomán, Del. Gustavo A. Madero, 07340 Mexico, DF, Mexico
e-mail: mpjonathan7@yahoo.com

P. D. Roy · J. L. Sánchez-Zavala · M. C. Macías-Romo
Instituto de Geología, Universidad Nacional Autónoma de México (UNAM), Ciudad Universitaria, Coyoacán, 04510 Mexico, DF, Mexico
e-mail: roy@geologia.unam.mx

S. Srinivasalu
Department of Geology, Anna University, Chennai 600025, India

C. Lakshumanan
Centre for Remote Sensing, Bharathidasan University, Khajamalai Campus, Thiruchirappalli 620023, India

The tsunami waves reached a maximum height of 1.4 and 1 m than the normal forecast in Zihuatanejo and Acapulco (http://www.mareografico.unam.mx/mareografico/). The present study was carried out in order to characterize the twigs and trails deposited from the mega Japan tsunami that reached the west coast of Mexico and also to assess the maximum inundation limit in the coastal state of Guerrero.

A field visit was carried out from 20th of March, 2011 onwards, and it was mainly concentrated in the low-lying areas along the coast (i.e., lagoons and beaches). The visit was utilized to have a first-hand view of the recent tsunami deposits that will be useful for future studies to identify paleo-tsunamis. A total of 15 locations were surveyed, and we are reporting the information collected from 11 different sites (Fig. 1; Locations 1–11). The survey was carried out at Boca del Río, El Dorado, Barra Vieja, Puerto Marquez, Pie de la Cuesta, Playa el Carrizal, Playa San Jeronomino, La Barrita, Laguna de Potosi, and Barra de Potosi (Fig. 1). The information obtained in the field visit was corroborated with interviews performed with locals (above 30 years of age) living in the region. Eye witness from locations close to Zihuatanejo suggests that the sea retreated more than 20 m for numerous times from the normal tidal line during the afternoon when the approximate arrival time was reported. We relate this phenomenon to various strong aftershocks (magnitudes of 5.5–6.5) that had epicenters close to the original earthquake (e.g., 2004 Indian Ocean tsunami, Srinivasalu et al. 2007), and the duration of withdrawal period varied along the study area. The varying bathymetry and topography of the continental shelf in this region might have influenced the duration of sea retreating in different places

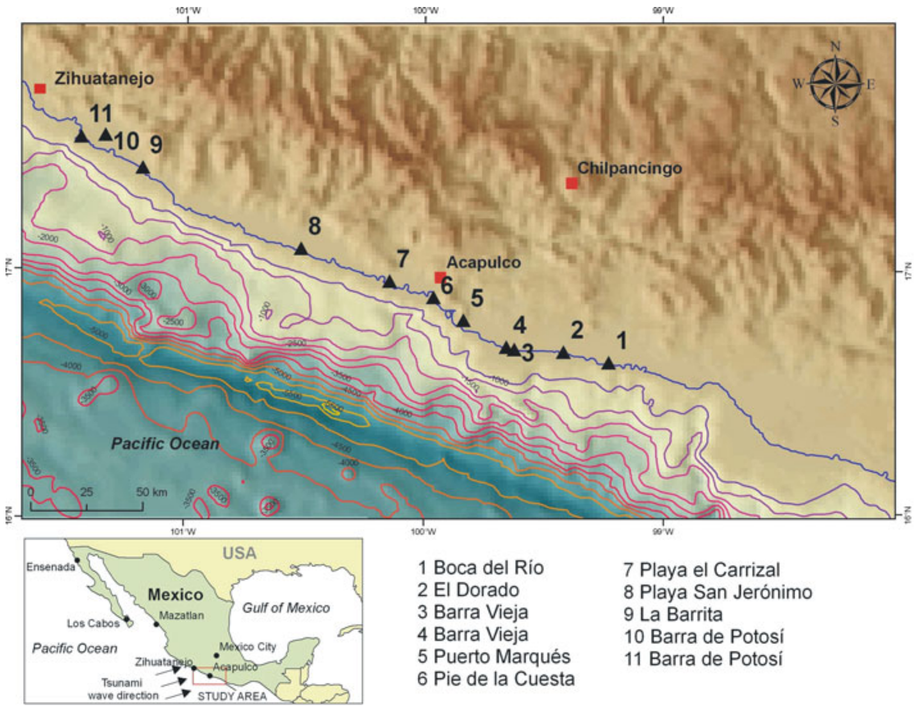

Fig. 1 Study area map indicating the sites visited to survey the tsunami deposits due to the Japanese earthquake and subsequent tsunami. (Source data for contour map: Vectorial data, INEGI 2010, Mexico. Scale: 1: 1,000,000)

along the coast of Guerrero. The bathymetry contours generated for this region indicate that the deeper regions (more than 1,000 m) are very close to the low-lying regions (coastal lagoons), where inundation is also higher than other sites.

Our observations along the coastal regions indicate that the present tsunami waves had left less than 1 cm thick salt that is encrusted with heavy mineral and recent sand deposits (Fig. 2) (e.g. Kelletat et al. 2007). The heavy minerals identified from the collected samples consists of amphiboles, pyroxenes, sphene, epidote, rutile, ilmenite, zircon, apatite, tourmaline, garnet, chlorite, and similar types of heavy mineral increase is also reported from earlier events (e.g., Babu et al. 2007; Leatherman et al. 1977; Nanayama et al. 2000). The presence of these heavy minerals is supported by the fact that the gneiss and granite-granodiorites are exposed along the western coast and continental shelf (Mittlefhldt et al. 1996; Ducea et al. 2004; Morán Centeno et al. 2005). The heavy mineral deposits were identified at a distance of 15–40 m from the normal high-tide line, and this distance increased in the coastal lagoons. In Barra Vieja (4) and Laguna de Potosi (10), heavy mineral deposits were found at a distance of 160 and 320 m, respectively, from the normal high-tide limit. The preservation of the heavy mineral layer was favored mostly by the higher salt content (precipitated from the evaporation of seawater). The higher salt content in the sediments acted as an adhesive to keep them together for some time, and it did not allow their reworking by wind activities. The sediments were also preserved due to the absence of rainfall in the study area during, after the tsunami, and till this field survey was completed. Moreover, we also affirm that as the full moon day had passed on 4th of March, we could confirm that the heavy mineral sheet is from the tsunami and not from any other high-tide event prior to the mega tsunami.

In addition to the heavy minerals, the tsunami deposits also contained organic debris and broken shells (Figs. 3, 4). The organic debris was characterized by the presence of light weight timbers and remnants of palm trees. The line of deposition by the organic debris was considered as the maximum limit of inundation during the survey. The offshore areas are often fed by the organic particles transported from the terrestrial materials, and

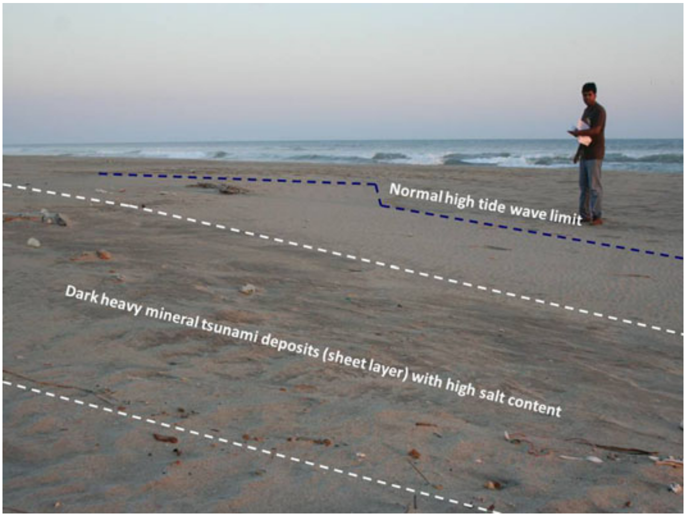

Fig. 2 Wooden timber pieces and dark heavy mineral deposits above the regular tidal line in El Dorado south of Acapulco in Guerrero State, México

Fig. 3 Dark heavy mineral deposits along with coconut leaves and light weight timber pieces deposited near the mouth of Lagoon Barra Vieja south of Acapulco in Guerrero State, México

Fig. 4 Evidences of broken timber pieces (*inside white circle line*), heavy mineral deposits in a single line along with broken shells (*inside blue circled line*) after the organic debris in La Barrita south of Zihuatenejo in Guerrero State, Mexico

many times during these high-energy events, they are churned up and are brought back as a heap, back to the coastal beaches (e.g., Schiff and Bay 2003). The inundation limit measured at different locations in the study area is presented in Table 1. The broken shell deposits were present near to the shore, i.e., between the organic debris and shore (Fig. 4). We could justify that as broken shells are lighter compared to heavy mineral-bearing sediments, and the returning waves have transported them from their original location. The

Table 1 Field observations and the inundation limit in some of the areas surveyed after the 11th March 2011 Japan tsunami in Acapulco—Zihuatanejo in Pacific coast of Mexico

Location numbers	Places surveyed	Inundation limits (in mts)	Field observations
1	Boca del Río	–	No effect observed
2	El Dorado	40	Dark heavy mineral sheet with salt content
3	Barra Vieja	26–160	Dark heavy mineral sheet with salt content, organic debris
4	Barra Vieja	20	Dark heavy mineral sheet with salt content, organic debris
5	Puerto Marquez	–	No effect observed
6	Pie de la Cuesta	15	Broken shells, organic debris, and heavy minerals
7	Playa El Carrizal	15	Organic debris
8	Playa San Jerónimo	–	No effect observed
9	La Barrita	20	Organic debris and broken shells
10	Laguna de Potosí	320	Broken shells and heavy minerals
11	Barra de Potosí	24	Broken shells and heavy minerals

Note The live fish pool and dead fish found in beaches and reported in the article are not mentioned in the table as it is a rare phenomenon and observed only during the event and disappeared immediately afterward

other important rare phenomena not reported during earlier events is that during the expected arrival time of tsunami waves and retraction of sea, huge fish pools were found very close to the shore and this fact was reported by local news papers and the fisher folks in the region (Fig. 5). Additionally, the presence of dead fish was also reported immediately after the tsunami hit the beaches and this supports the direct field evidences observed by the fishermen. This rare phenomenon is attributed to the high-energy tsunami waves

Fig. 5 Abnormal evidences of school of fishes at very low depth in the coastal beaches in Acapulco—Zihuatenejo, Mexico. (*Photo source*: http://www.taringa.net/posts/info/9652756/Increible-Enjambre-de-Peces-en-Costa-de-Acapulco-por-Tsunami.html)

with high amplitude that might have brought them to the beaches and left them stranded after retraction. The tsunami wave dynamics indicate that the waves break on a steeper coast, which is supported in the offshore regions of Acapulco, where nearly 1,000 mts is observed at 5–10 km distance in the offshore (Bryant 2008). Moreover, as the tsunami wave energy gets dissipated, they could have pushed the fish pools to the beaches.

Based on the field evidences and instrumental registers, we report that the maximum run up of the tsunami of 11th March 2011 was observed close to Zihuatanejo and had inundated a maximum distance of 40 m in various beaches in the state of Guerrero. The wave height could be higher than 1.5 m in the low-lying areas and likewise, the limit of inundation was also higher in the coastal lagoons reaching up to 320 m. The tsunami deposits were characterized by the presence of <1 m thick heavy mineral deposits, broken shells, and the maximum inundation limit was identified from the organic debris left by the waves. The register of this mega Japan tsunami is poor from the Pacific coast of Mexico, especially with reference to the historical and geological time scales. However, information obtained from this field survey should be useful to identify paleo-tsunami deposits in the west coast of Mexico and extend the register beyond the instrumental record.

Acknowledgments MPJ and PDR wish to thank SNI-CONACYT and acknowledges financial support from the Bilateral project Mexico-India (CONACYT-DST). MPJ thanks COFAA and EDI, Instituto Politécnico Nacional, México and PDR thanks CTIC-UNAM. Special thanks for G. Muthusankar for his help in generating the study area map. This article is 54th contribution from Earth System Sciences Group (ESSG), Chennai, India.

References

Babu N, Suresh-Babu DS, Mohan-Das PN (2007) Impact of tsunami on texture and mineralogy of a major placer deposit in southwest coast of India. Env Geol 52(1):71–80

Bryant E (2008) Tsunami: The underrated Hazard. Part 1.2 Tsunami dynamics. Spriner Verlag Publs, UK, pp 27–47

Ducea MN, Gehrels GE, Shoemaker S, Ruiz J, Valencia VA (2004) Geologic evolution of the Xolapa Complex, southern Mexico: Evidence from U-Pb zircon geochronology. Geol Soc Am Bull 116: 1016–1025

Kelletat D, Schefflers SR, Scheffers A (2007) Field signatures of the SE Asian mega tsunami along the west coast of Thailand compared to Holocene Paleotsunami from the Atlantic region. Puer & Appl Geophy 164:413–431

Leatherman SP, Allan WT, John FS (1977) Overwash sedimentation associated with a large-scale northeaster. Mar Geol 24:109–121

Mittlefhldt DW, Lindstrom MM, Bogard DD, Garrison DH, Field SW (1996) Acapulco- and Lodran-like achondrites: Petrology, geochemistry, chronology and origin. Geochim Cosmochim Acta 60(5): 867–882

Morán Centeno DJ, Cerca M, Keppie JD (2005) La evolución tectónica y magmática cenozoica del suroeste de México: avances y problemas de interpretación. Boletin de la Sociedad Geológica Mexicana 57:319–341

Nanayama F, Shigeno K, Satake K, Shimokawa K, Koitabashi S, Miyasaka S, Ishii M (2000) Sedimentary differences between the 1993 Hokkaido-nansei-oki tsunami and the 1959 Miyakojima typhoon at Taisei, southwestern Hokkaido, northern Japan. Sed Geol 135:255–264

Schiff K, Bay S (2003) Impacts of storm water discharges on the near shore benthic environment of Santa Monica bay. Mar Env Res 56:225–243

Srinivasalu S, Thangadurai N, Switzer AD, Ram-Mohan V, Ayyamperumal T (2007) Erosion and sedimentation in Kalpakkam (N Tamil Nadu, India) from the 26th December 2004 tsunami. Mar Geol 240:65–75