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Overview of Recent Coastal Tectonic Deformation in the Mexican Subduction Zone

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Abstract—Holocene and Pleistocene tectonic deformation of the coast in the Mexico subudction margin is recorded by geomorphic and stratigraphic markers. We document the spatial and temporal variability of active deformation on the coastal Mexican subduction margin. Pleistocene uplift rates are estimated using wave-cut platforms at ca. 0.7–0.9 m/ka on the Jalisco block coast, Rivera-North America tectonic plate boundary. We examine reported measurements from marine notches and shoreline angle elevations in conjunction with their radiocarbon ages that indicate surface uplift rates increasing during the Holocene up to ca. 3 ± 0.5 m/ka. In contrast, steady rates of uplift (ca. 0.5–1.0 m/ka) in the Pleistocene and Holocene characterize the Michoacan coastal sector, south of El Gordo graben and north of the Orozco Fracture Zone (OFZ), incorporated within the Cocos-North America plate boundary. Significantly higher rates of surface uplift (ca. 7 m/ka) across the OFZ subduction may reflect the roughness of subducting plate. Absence of preserved marine terraces on the coastal sector across El Gordo graben likely reflects slow uplift or coastal subsidence. Stratigraphic markers and their radiocarbon ages show late Holocene (ca. last 6 ka BP) coastal subsidence on the Guerrero gap sector in agreement with a landscape barren of marine terraces and with archeological evidence of coastal subsidence. Temporal and spatial variability in recent deformation rates on the Mexican Pacific coast may be due to differences in tectonic regimes and to localized processes related to subduction, such as crustal faults, subduction erosion and underplating of subducted materials under the southern Mexico continental margin.

Key words: Subduction zone, uplift, subsidence, marine terrace, holocene, pleistocene, southern Mexico.

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1. Introduction

Coastal uplift and subsidence are crucial phenomena along subduction margins. Emergent coasts are commonly characterized by differential uplift within distinct segments that might be sustained as morphotectonic units on time scales of tens of thousands to millions of years (Melnick *et al.*, 2006). These areas seem to be controlling and acting as quasi-independent rupture zones that drive deformation (Ota and Yamaguchi, 2004). Some examples of subduction zones indicate that crustal faults have controlled coastal deformation patterns and their subdivisions appear to rule seismotectonic segmentation, rupture propagation and local earthquake hazard (Briggs *et al.*, 2006; Melnick *et al.*, 2006). This review focuses on the coastal sector of the Pacific subduction margin of Mexico, which is composed of distinct coastal segments. However, it is not known how tectonic deformation (uplift/subsidence) rates vary spatially and temporally, or how this long-term differential uplift and subsidence are manifested in an array of coastal landforms on the active Mexican Pacific margin coastal areas. Recent Pleistocene-Holocene interseismic and historic coseismic deformation along the Mexico subduction margin, considering changes in upper plate structures and Mexican subduction zone dynamics, is analyzed in this paper. We integrate reported geomorphic and stratigraphic markers indicative of tectonic deformation to constrain the spatial and temporal variability of the Mexican subduction margin deformation rates. Data analyzed integrate uplift rate over a 100-ka time scale (Pleistocene), periodicity of marine terrace formation, and the younger time scale (Holocene). Abandoned shorelines are reflected on the landscape as uplifted marine terraces, wave-cut surfaces, beach ridges and tidal notches (e.g., Bradley and Griggs, 1976; Merritts and Bull, 1989; Anderson *et al*., 1999; Muhs *et al*., 1990; Lajoie *et al*., 1991. Landscape response to active tectonics has been observed in numerous parts of the world. The study of locations, rates and styles of Quaternary tectonic deformation using geomorphic markers on coastal areas has proved effective in providing information for patterns of tectonic deformation (e.g., Chappell, 1983; Lajoie *et al*., 1986; Hanson *et al*., 1994; Ota and Chapell, 1996; Chapell *et al*. 1996; Burbank *et al*., 2001).

The Mexican Pacific margin has mainly developed by subduction of the Rivera and Cocos plates along the Middle America trench (MAT). The study area extends from the northwestern end of the MAT where it intersects with the Tamayo fracture zone to the Tehuantepec isthmus in the southeast at the intersection with the Tehuantepec ridge (Fig. 1). We revise studies on morphotectonics of the southern Mexican Pacific coast (Ramirez-Herrera and Urrutia-Fucugauchi, 1999; Ramirez-Herrera *et al*., 1999), integrate studies of geomorphic, geodetic, seismologic and geochronologic data, and evaluate uplift/subsidence rate calculations over various time ranges. We present data on variability in space and time of coastal deformation rates and deliberate on plausible explanations for those changes.

2. Tectonic Setting and Seismicity

2.1. Tectonics

The area presently incorporating the Mexican subduction zone has experienced two major plate reorganizations over the past 25 Ma (Klitgord and Mammerickx, 1982). Large Farallon plate, which initially subducted eastward beneath the North American plate, first evolved into the Cocos plate, which was split off, leaving the reduced Farallon plate to be renamed the Nazca plate, and initiating the Cocos-Nazca spreading at 23 Ma (Lonsdale, 2005); the Rivera plate fragmented from the Cocos plate at 10 Ma (DeMets and Traylen, 2000); they are now subducting along the Middle America. The MAT is a continuous feature off the southern Pacific margin of Mexico and Central America over a distance of more than 3,000 km (Fig. 1). MAT extends from the Gulf of California at the intersection with the Tamayo fracture zone to the Osa Peninsula of Costa Rica in Central America. The MAT can be separated into two main zones, to the northwest and southeast of the intersection zone with the Tehuantepec ridge (Fisher, 1961; Molnar, 1977; Auboin *et al*., 1981). MAT maximum depths of about 6,000 m occur immediately southeast of the intersection zone with the Tehuantepec ridge. The Central America trench sector is characterized by an extended margin with a well-developed forearc basin. The Central American volcanic arc front develops some 150 km away from the trench. The Mexican segment shows a narrow, relatively steep trench inner wall and non- or incipiently developed forearc. The Trans-Mexican volcanic arc lies oblique to the trench axis (Molnar and Sykes, 1969; Urrutia-Fucugauchi and Del Castillo, 1977; Ferrari and Rosas-Elguera, 2000; Ruiz-Martinez *et al*., 2010). Maximum trench depths in the Mexican segment exceed 4,400 m, except off Manzanillo and Zihuatanejo, and where submarine seamounts arise within the trench. Northwest of Acapulco, the trench is generally U-shaped in cross section, with a steeper inboard flank and a flat floor suggesting the presence of a sedimentary fill (Manea *et al*., 2003). From Acapulco southeast to the western side of the Gulf of Tehuantepec, the trench deepens to 5,000 m in a series of basins. The southeast segment has an asymmetric V-shaped form in cross section with an irregular floor. A northeast-trending band of ridge-and-trough topography 111 km wide separates the ocean floor at a depth of 3,276–3,458 m adjacent to the trench off southern Mexico from the somewhat deeper (3,822–4,004 m depth) Guatemala Basin. This ridge-and-trough zone (Tehuantepec ridge) has been traced from an area several hundred kilometers offshore to an intersection with the MAT near the western side of the Gulf of Tehuantepec (Fisher, 1961). Cores recovered from eight sites along transects across the MAT off southwestern Mexico (Fig. 1) have revealed trench sediments ranging in age from Pleistocene to Miocene, indicating that the trench was in existence by the early Miocene (23–20 Ma). The sediments have been uplifted by as much as 2 to 3 km above the present-day trench floor by a combination of accretion and underplating (Shipley *et al*., 1980; Moore *et al*., 1982; Watkins *et al*., 1982).

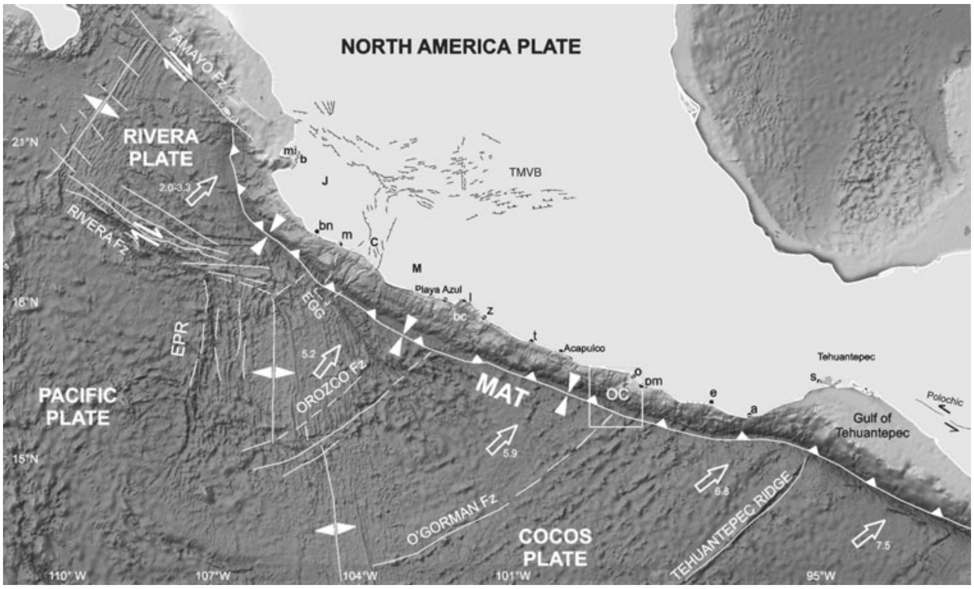

Figure 1

Simplified morphotectonic map and sectors of active tectonic deformation along the coast of the Mexican Pacific active margin. Symbols: *MAT* Middle American Trench; *EPR* East Pacific Rise; *EGG* El Gordo Graben; *Fz* fault zone; *J* Jalisco block; *C* Colima graben; *M* Michoacan; *TMVB* Trans-Mexican volcanic belt; *bc* balsas submarine canyon; *oc* ometepec submarine canyon. *Numbers* indicate convergence rate in cm/year (DeMets and Stein, 1990). *Square* shows location of Deep Sea Drilling project Leg 66 transects (Moore *et al.*, 1982; Watkins *et al.*, 1982). Site names: *mi* Punta Mita; *b* Bahia de Banderas; *bn* Barra de Navidad; *m* Manzanillo; *l* Lagunillas; *z* Zihuatanejo-Ixtapa; *t* Tecpan; *o* Ometepec; *pm* Punta Maldonado; *e* Puerto Escondido; *a* Puerto Angel; *s* Salina Cruz

The Rivera plate is bounded by the Rivera fracture zone, the East Pacific Rise (EPR), the Tamayo fracture zone, and the MAT (Fig. 1). The Rivera-Cocos plate boundary comprises three distinct morphotectonic units: an eastern zone characterized by lithospheric extension and delineated by the El Gordo graben; a structurally complex western zone marked by a regional bathymetric high and formed as a result of rift propagation and convergence between the Rivera and Cocos plates; and a central zone of undisturbed lithosphere, characterized by well-defined magnetic lineations, normal ocean depths and continuous seafloor spreading (Bandy *et al.*, 1995). The Rivera plate moves to the N-NE with respect to the Rivera-North America plate boundary (Bandy *et al.*, 1997; DeMets *et al.*, 1994). Two types of models have been proposed for the convergence rate between the Rivera and North American plates. The first predicts convergence rates varying 2.0 and 5.0 cm/year (Bandy *et al.*, 1995; Kostoglodov and Bandy, 1995). The second model bears out the lower convergence rates of between 2.0 and 3.3 cm/year near the southern end of the Rivera-North America subduction zone and between 0.6 and 1.7 cm/year at its northern termination (e.g., DeMets *et al.*, 1994). Rivera plate subduction is characterized by a steeper angle and more northerly trajectory than the adjacent Cocos plate, with dip angle increasing at depths around 100 km. Yang *et al.* (2009) have proposed that the Rivera plate and westernmost Cocos plate have recently rolled back toward the trench. The Rivera plate at the trench is of late Miocene age (~9 Ma) (Klitgord and Mammerickx, 1982).

Motion of the Cocos plate relative to the North America plate is directed north-northeastwards, slightly counterclockwise to a line normal to the MAT. Convergence rate increases eastward from 4.8 cm/year at 104.5°W to 7.5 cm/year at 94°W (DeMets *et al.*, 1994). Age of the Cocos plate being subducted varies along the MAT, with some discontinuities across the fracture zones that extend eastwards from the flank of the East Pacific Rise (Fig. 1). The most prominent of these are the Orozco (OFZ) and O'Gorman fracture zones (OGFZ). The OFZ is a broad topographic feature consisting of several deep parallel troughs and large ridges, whereas the OGFZ, the largest of the fracture zones in the region that does not offset the EPR, consists of a deep trough (Klitgord and Mammerickx, 1982). To the southeast of the OGFZ the Tehuantepec ridge is a major topographic feature intersecting the MAT at ~95°W, which represents a transpressional structure along the former transform fault on the Guadalupe plate (Manea *et al*., 2005) separating oceanic lithosphere of significantly different ages. The oldest Cocos plate in the region lies adjacent to the trench to the southeast of the Tehuantepec ridge and ranges in age from 28 to 24 Ma (Late Oligocene). To the west and northwest the age of the Cocos plate is 16 to 12 Ma (Middle Miocene), while elsewhere in the region, i.e., along the trench, it is of late Miocene-Pliocene age (Klitgord and Mammerickx, 1982; Ponce *et al*., 1992; Manea *et al*., 2005).

A significant change in the dip of the subducting Cocos plate lithosphere and an associated increase in the maximum depth of the Benioff zone occur near the intersection of the Tehuantepec ridge with the MAT at about longitude 96° west (Ponce *et al*., 1992; Manea *et al*., 2005). The subduction angle is subhorizontal (~15°) west of the Tehuantepec ridge, but ~45° to the east. In the region of subhorizontal subduction (Guerrero-Oaxaca) the earthquake hypocenters are shallower than 80 km, whereas earthquakes with foci as deep as 200 km occur beneath Chiapas and Central America where the subducted slab dips much more steeply to the east. In the Guerrero area, Cocos plate presents subhorizontal subduction for about 250 km, and then the dip increases just before the TMVB front with an angle of ~75°. The plate is truncated at depths of 500 km, probably associated with an E-W propagating tear in the subducted slab (Husker and Davis, 2009). A change in subduction angle also occurs to the northwest from being subhorizontal in the region of Guerrero to ~30° at depths greater than 40 km at the western extremity of the Cocos plate.

2.2. Seismicity

Large magnitude ($M_w > 7.5$), shallow thrust earthquakes occurring along the Mexican subduction zone rupture a low-angle (10–15°) plane dipping to the north-northeast (Fig. 2). Coseismic rebound of the continental lithosphere is reversed to the relative motion between the Cocos plate and the overriding North American plate (Astiz and Kanamori, 1984; Pardo and Suárez, 1995). The area of strong seismogenic coupling in Central Mexico is shallow (maximum rupture depth of the subduction thrust earthquakes is ~25 km) and narrow (width < ~60 km) in comparison with subduction zones elsewhere. For example, the dip of the seismogenic zone in Mexico (~12°) is only half that in Chile, and the distance between the trench and the coast (~70 km) and the thickness of the continental crust in Mexico (35–40 km) are about half of those in Chile. Width of the seismogenic locked interplate area may be the controlling factor that defines the magnitude of the largest earthquakes in the Mexican subduction zone (Suárez and Sánchez, 1996).

During the past two centuries, large shallow earthquakes ($M_w > 7.5$) with recurrence intervals of 30–50 years have been occurring along the Mexican part of the Middle America Trench (MAT) in discrete segments of 100–200 km (Fig. 2). Four possible seismic gaps were identified along the MAT: the Jalisco, Guerrero, Michoacan and Tehuantepec (Astiz and Kanamori, 1984).

In Jalisco the largest subduction earthquake of the last century, the 3 June 1932 ($M_w = 8.2$) was followed by the smaller, $M_w = 7.8$, 18 June 1932 event (Singh *et al*., 1981, 1985; Astiz and Kanamori, 1984). The 9 October 1995 earthquake ($M_w = 7.8$) occurred near Manzanillo and ruptured part of the Rivera-North America plate boundary (Melbourne *et al*., 1997; Bandy *et al*., 1997). This possibly indicates that the recurrence interval of 77 years for 7.5 magnitude earthquakes estimated by Singh *et al*. (1985) is generally correct. However, no large magnitude ($M_w > 8$) earthquake has occurred since 1932.

The Guerrero seismic gap stands out as a region of the highest seismic potential because major seismic events are known to have occurred in this area in the beginning of the last century. In the NW Guerrro gap just one $M_w > 6.0$ earthquake has occurred since the previous large $M_w = 7.5$ event of 1911. This $M_w = 6.7$ shallow subduction thrust earthquake occurred on 18 April 2002 (Iglesias *et al*., 2003), but its rupture area was not large enough to fill

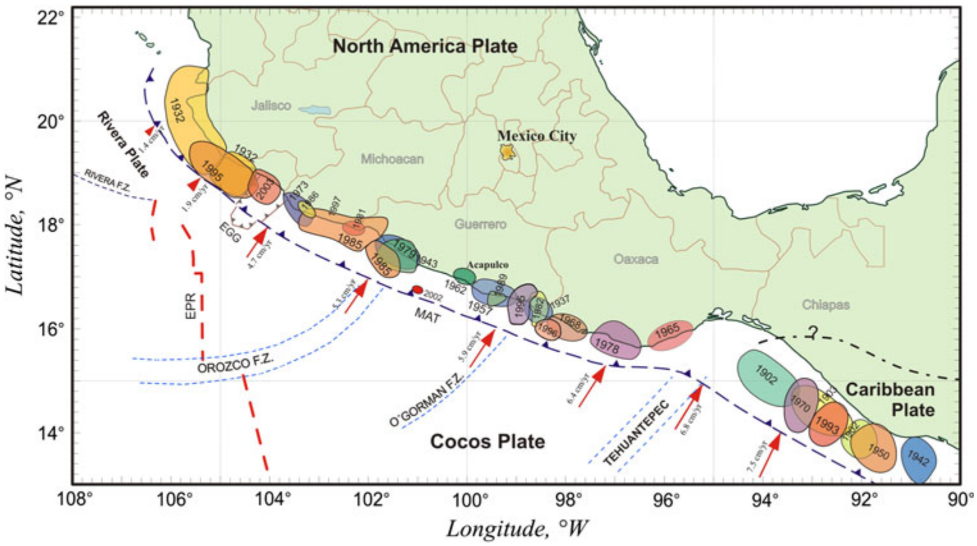

Figure 2

Seismicity along the Middle America Trench. *Map* shows the most important subduction thrust events of this century. *Shaded circles* show rupture zones, and numbers indicate the year of the event

the NW Guerrero seismic gap (Fig. 2). Significant thrust earthquakes on the SE Guerrero coast happened in 1957 ($M_w = 7.8$, Costa Chica) and in 1962 ($M_w = 7.0$, 7.1, Acapulco); thus, the SE Guerrero subduction zone should have accumulated a large amount of strain in the last $\sim$50 years. Recently observed slow slip events (SSE) or "silent earthquakes" occurring within the Guerrero gap region (Larson *et al.*, 2004) do not preclude this area from having a large subduction thrust event. Consequently, almost all the Guerrero coast is currently considered the most likely to experience a large severe earthquake or several smaller seismic events eventually (Anderson *et al.*, 1989; Song *et al.*, 2009).

The area of the former Michoacan seismic gap is flanked on both sides by active seismic segments, and the OFZ intersects the MAT to the southeast of the gap. This gap was filled by a rupture area of a large ($M_w = 8.0$) earthquake on 19 September 1985. The region of maximum uplift during this earthquake is marked by elevated marine terraces, and these are often associated with a long-term coastal uplift resulting from periodic large magnitude earthquakes (McNally and Minster, 1981; Bodin and Klinger, 1986).

In the Tehuantepec sector of the subduction zone no significant shallow thrust earthquake has occurred over the past 180 years (Fig. 2), and therefore it is considered to be either aseismic or seismic with anomalously long recurrence intervals for major earthquakes (Astiz and Kanamori, 1984). The possibility that the Tehuantepec gap may be aseismic for large earthquakes has been explained by an influence of the subducting Tehuantepec ridge. This gap is located near the triple junction and is a transition zone with respect to the geometry of the Benioff zone (Ponce *et al.*, 1992; Manea *et al.*, 2005).

3. *Cenozoic Continental Margin Uplift*

The western margin of North America has been the subject of a dominant process—plate convergence. Arc magmatism and plate tectonic paleoreconstructions provide evidence for long-term plate convergence in southern Mexico. The narrow forearc region and relatively small offscraped deep-sea sedimentary prism suggest removal of the forearc and accretionary prism (Karig *et al.*, 1978). Calc-alkaline plutons are located at the margin close to the trench, and continental basement rocks extend to within some 35 km of the trench in the DSDP Leg 66 study area (e.g., Lundberg and Moore, 1981). Structural trends in the continental basement display abrupt termination at the seaward edge, resulting in close juxtaposition of oceanic and continental crusts (Shipley, 1981). Continuous sediment accretion processes can be traced from the Middle Miocene to the present, which brackets initiation of subduction of the Cocos plate beneath the southwestern Mexican margin.

Continental margin uplift has been an important tectonic process during the Cenozoic. This is indicated by the occurrence of mylonitic belts and metamorphic amphibolite-facies middle crustal rocks along the continental margin within the Xolapa tectonostratigraphic terrane. Clear evidence for Neogene differential uplift of the continental margin of southwestern Mexico is given by the widespread exposure of Oligocene batholiths, which contrast with the presence of coeval volcanic rocks landward into the continental interior (Morán-Zenteno *et al.*, 1996). The location of the Balsas river basin (second largest river in Mexico), which is oriented east-west parallel to the margin following the shape of the igneous and metamorphic bodies of the Xolapa terrane, may reflect the tectonic and uplift processes along the continental margin. Margin uplift and erosional processes have resulted in removal of a significant portion of the upper crust exposing the roots of the Xolapa complex magmatic arc.

Margin uplift and growth of the sedimentary accretionary prism along the southern Mexico continental margin have been attributed to underplating of material removed by subduction erosion (e.g., Shipley *et al.*, 1980; Watkins *et al.*, 1982). Morán-Zenteno *et al.* (1996) propose that progressive uplift along the continental margin was the result of thickening of the subducted slab at the junction of cylindrical flexures at the (trench-trench-transform) triple junction associated with the Chortis block, which was migrating towards the southeast. The left-lateral movement, according to paleogeographic reconstructions, led to progressive migration of the triple junction (e.g., Morán-Zenteno *et al.*, 1996; Meschede *et al.*, 1997).

Isostatic anomalies in central and southern Mexico feature continental margin characteristics (De la Fuente *et al.*, 1994). The trench is characterized by an elongated negative isostatic anomaly (−45 to −55, up to <−75 mgals) associated with bending and subduction of the oceanic plate. The continental margin is characterized by a belt of positive isostatic anomalies, which is marked in the margin south of the Colima area to the south of El Gordo graben. The anomalies show larger amplitudes (45–60 mgals and >65 mgal) in the margin associated with subduction of the Cocos plate. The trend of isostatic anomalies is interrupted at the zones of intersection along the trench with the oceanic fracture zones. These features in the isostaic anomaly pattern can be observed associated with subduction of the Orozco fracture zone and the Tehuantepec ridge. The continental margin and volcanic arc are characterized by small isostatic anomalies. Crustal thickness increases from the coast to the continental interior, with thicker crust under the volcanic arc in the central and eastern TMVB segments (Urrutia-Fucugauchi and Flores-Ruiz, 1996; Urrutia-Fucugauchi *et al.*, 1999). There is also a correlation with the characteristics of the trench shape and sediment infilling. The anomalies can be related to the dense subducted slab of oceanic lithosphere (e.g., Molnar, 1977; Bandy *et al.*, 1999). Gravity models for areas studied along the margin such as the Tehuantepec Isthmus and the Jalisco and Colima sectors indicate that the subducted slab is responsible for the strong high-amplitude positive anomalies.

4. *Coastal Uplift*

An overview of field measurements coupled with the analysis of landforms, geology, stratigraphy and radiometric dating reveals significant variations in morphology, tectonic styles and rates of deformation along the coast of the Mexican subduction margin. Distinct areas experiencing short- and long-term deformation (Holocene and Pleistocene), and coseismic deformation have been identified in the region on the basis of their characteristic coastal morphology and modern geodetic measurements of tectonic deformation.

The coastal area presently incorporating the Jalisco block (Bourgois and Michaud, 1991) shows evidence of recent tectonic uplift (Fig. 1). The continental shelf here is relatively narrow, locally <1 km but reaching up to 2 km. The distance from the trench to the coast averages ~73.4 km (standard deviation

9.6), and the predominant value is 55 km, but increases to about 126 km near Bahia de Banderas (Fig. 1). Bahia de Banderas shows evidence of active faulting. A submarine canyon has a half-graben structure where the associated Banderas fault extends westwards down to the MAT. Inland, the Banderas valley is identified as the extension of this active structure (Alvarez 2002, 2007; Ferrari and Rosas-Elguera, 2000; Urrutia-Fucugauchi and Gonzalez-Moran, 2006). The coastal landscape here is characterized by cliffs and rocky promontories alternating with beaches, a wide alluvial plain at Bahia de Banderas and a small number of lagoons with narrow barriers further south. The inland landscape is typified by low plains with Pleistocene (?) marine terrace remnants, dissected hills and fault-block mountains. Clear evidence of recent tectonic uplift is provided by extensive marine terraces at 46 m (field measured with Abney level) and about 60 and 100 m (topographic map estimates; Fig. 3). Exposures within the lowest (46 m), seaward-dipping terrace (21°) uncover conglomerates overlain by carbonate rocks. The two higher terraces, which are the more extensive, are formed in tuff, volcanic breccia, and other volcanic rocks and conglomerates. No littoral deposits are found on the terrace surfaces (Ramirez-Herrera and Urrutia-Fucugauchi, 1999). Correlations with eustatic sea-level curves (Sidall *et al*., 2006) suggest that the higher terraces may correspond with oxygen isotope stage 3 and 5c highstands (60–100 ka).

Using wave cut platform shoreline angle averaged elevation correlated with sea-level highstand ages, plotted with an eustatic curve following Lajoie (1986), Siddall *et al*. (2006) and Saillard *et al*. (2009), longer term uplift rates are estimated at ca. 0.7–0.9 m/ka (Fig. 4). We can preclude that our estimated rates are in the range of those of other similar subduction margins.

Field observations at Punta Mita, northern flank of the Jalisco block, reveal the presence of emerged beachrock and marine terraces at ca. 4 to 19 m above mean sea level (high precision geodetic survey). Marine terraces extend discontinuously along the coast from north of Puerto Vallarta to Punta de Mita, Nayarit, and their elevations can be correlated along 35 km of the coast. This stretch of coastline coincides with the northernmost sector of the 3 June 1932 earthquake rupture (Fig. 2). Marine terraces show a thin layer of beach deposits. Mollusc shells from marine terrace deposits and beach rock were sampled and dated. The taxonomic analysis of these species (ex. *Chione* sp., *Anomalocardia* sp., *Trigoniocardia* sp. and *Trachycardium* sp.) indicate a moderately shallow water environment. Radiocarbon ages of marine shells collected from beach deposits at the marine terrace platforms provided dates of progressive emergence of these Holocene features. The radiocarbon ages ranging from 1 to 3 ka BP (G. Harper and A. Lefton, personal communication) for the lower terraces (ca. 4 m) indicate that these elevated landforms developed when sea level had reached or was close to its present level. Apparently, subsequent tectonic uplift raised these ancient shorelines above the present sea level. Marine terrace elevations following Antonioli *et al*. (2009) were compared with the predicted value for sea level using the Lambeck model (Lambeck *et al*., 2004) indicating ca. 0 to −0.5 m position and a corrected terrace elevation at ca. 3.5 to 4 m. Marine terrace elevation and the cosmogenic ^{14}C dates (1–3 ka BP) indicate an early Holocene age for these marine terraces and an estimated coastal uplift rate of ca. 0.8 to 3.3 ± 0.5 m/ka, which is in agreement with rates at active margins. It is however difficult to discriminate the coseseismic, if there is such, from the post- and interseismic component. It is inferred that the coast has been rising by interseismic uplift. In the light of historic coseimic subsidence and postseismic recovery reported for the southern part of Jalisco coast (Cumming, 1933; Melbourne *et al*., 1997), the interseismic component could be of most importantance in tectonic uplift and evolution of this coast.

The occurrence of a number of raised marine notches and wave-cut platforms indicate uplift of the Jalisco coast. Most of the notches are in volcanic breccia, some with wave cut platforms, and no deposits are present on the surface (Ramirez-Herrera *et al*., 2004). These abrasion notches developed near high-tide level (the local tide level range is 1.3 m). Their heights range from ca. 1 to 4.5 m (−0.5 for the predicted sea level point using Lambeck model) above mean sea level. In situ intertidal organism (red algae and barnacles) radiocarbon dates of 1,262 ± 51 ^{14}C years BP (cal. AD 660–940; Table 1) indicate

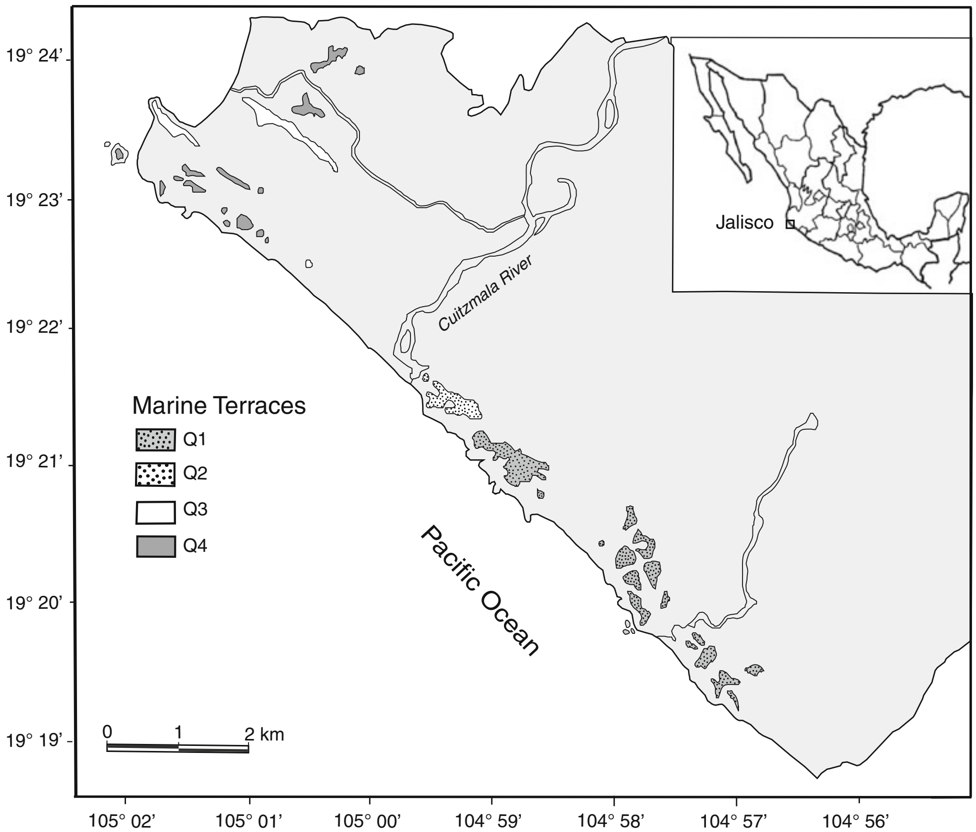

Figure 3
Map of the southern Jalisco coast showing the distribution of marine terraces. Shoreline angle elevations are estimated from topographic maps: Q1: 100–80 m, Q2: 60 m, Q3: 40 m, Q4: 20 m. Insert shows site location

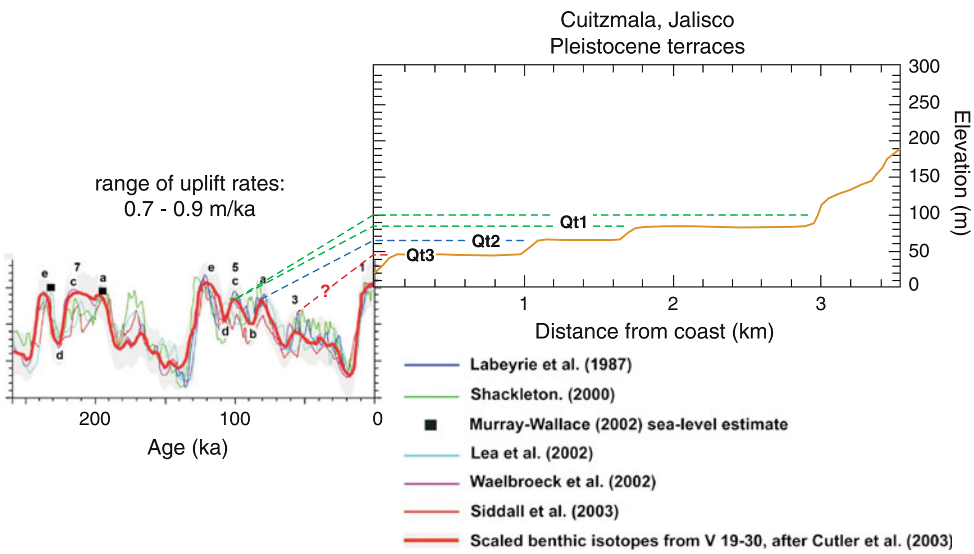

Figure 4
Pleistocene tectonic rates were computed from wave cut platform shoreline angle averaged elevations versus last sea-level highstand ages, plotted with eustatic curve from Siddall *et al.* (2006) and modified *curve* from Saillard *et al*. (2009)

tectonic uplift during at least the past 1,300 years BP at an average rate of about 3 ± 0.5 mm/year (Ramirez-Herrera *et al*., 2004). This supports a model in which coseismic subsidence produced by offshore earthquakes is rapidly recovered during the postseismic and interseismic periods. There is no evidence of coastal interseismic and long-term subsidence along this sector of the Mexican Pacific active margin (Ramirez-Herrera *et al*., 2004).

Further evidence of tectonic uplift is found on the coastal zone incorporated south of the El Gordo-Colima graben to where the onshore projection of the OFZ meets the coast in the vicinity of the Balsas submarine canyon (Fig. 1), incorporated in the Michoacan morphotectonic zone (Ramirez-Herrera and Urrutia-Fucugauchi *et al*., 1999). The distance from the coast to the trench is greater towards the boundaries of the zone marked by the El Gordo graben and the OFZ to about 95 km, with an average distance of 79 km (standard deviation 9.6; Fig. 1). Here high (>600 m) fault-block mountains reach the sea and give rise to a coastal landscape characterized by steep cliffs and rocky promontories alternating with narrow pocket beaches. Inland the high fault-block and folded mountains have been deeply incised by coastal streams, suggesting the rivers response to tectonic uplift. Landforms provide evidence of uplift on this sector of the Mexican Pacific margin. A number of marine terraces, elevated wave-cut notches and river terraces are intermittently present between the Playa Azul and south of the Colima graben to the north (Fig. 1). At least two well-preserved marine and fluvial terraces are prominent and rise discontinuously through this coastline at elevations ranging from 15 to 120 m (the lowest measured with precise leveling). Gravels supporting well-developed clay-rich soils up to several meters thick are present on these terraces suggesting that they pre-date the Holocene. Correlations with eustatic sea-level curves (Sidall *et al*., 2006) suggest that the terraces may correspond with oxygen isotope stage 3 and 5e highstands (60–120 ka) and support this interpretation. This indicates longer term uplift rates of 0.5–1.0 m/ka, following Lajoie *et al.* (1986) and Saillard *et al*. (2009), within the central Michoacan coast (Ramirez-Herrera *et al*., 1998). At the southern flank of the Michoacan morphotectonic zone (Ramirez-Herrera and Urrutia-Fucugauchi, 1999) and close to the OFZ, marine terraces range from 5–6 m to 8 m above mean sea level. Beach ridge deposits containing datable marine shells and pottery shards record progressive emergence during the Holocene. Cosmogenic date, 6.5 ± 0.5 ^{14}C ka (G. Harper and A. Lefton, personal communication), for uplifted, 3.5 ± 1-m-elevation beach ridges near the southern border of the Michoacan coast indicate an estimated uplift rate, using the Lambeck model, of 0.08 m/ka.

South of OFZ and in the area that incorporates the Guerrero morphotectonic zone (Ramirez-Herrera and Urrutia-Fucugauchi, 1999; Ramirez-Herrera *et al*., 1999), recent uplift is indicated by both marine and river terraces. Clear evidence comes from the area to the southeast of OFZ to about the Ometepec canyon. At least three extensive marine surfaces are present near Lagunillas (Fig. 1). The lowest is ca. 10 m above mean sea level, while the elevation of the intermediate terrace is ca. 20 m. This terrace, which is mantled by unconsolidated sands interbedded with pebble sand units, is the most extensive terrace along this sector of the coast. High river terraces are observed along all the largest rivers in the area, indicating uplift; for instance, the Rio Mezcala shows a series of terraces of up to 100 m above the present river level.

Evidence of uplift is more sporadic south of Lagunillas (Fig. 1). Two distinct surfaces are the only marine terraces observed and measured in this area, approximately 3 km north of Zihuatanejo-Ixtapa. The upper terrace, which is a little over 10 m high above the present mean sea level, is the most extensive, being approximately 2 km long and 1 km wide. It is formed of granite with a 2–3-m-thick mantle of gravel. The lower marine terrace is ca. 6 m above high tide. Scattered remnants of what appears to be an older higher marine terrace are present inland from the two lower terrace. OSL dating indicates a late Pleistocene age for the higher terraces (G. Harper and A. Lefton, personal communication). U-series dates of corals on the lowest uplifted beach ridge at La Saladita, north Guerrero, 4.5 m above mean sea level (compared with Lambeck model), ranging from ca. 584 ± 34 to 895 ± 29 year BP (G. Harper and A. Lefton, personal communication), suggest that uplift rates could be as high as 6.6 ± 2 m/ka. A notch

Table 1

Radiocarbon dates from cores one (ACA-04-01) and three (ACA-04-06), Laguna Mitla site

Sample lab ID[d,e]	Site	Core	Sample depth cm	Averaged elevations (m)[a]	Elevation amsl (m)	Material dated	^{14}C age year BP	Calibrated age (2 sigma range)	$^{14}C/^{13}C$	Reference
AA03760	Barra de Navidad notch	–	–	0.46 to 0.6[b]	0.6 to 0.9	Shell	Post 0[c]	ca. 1959 AD[c]	–	Ramirez-Herrera *et al.* (2004)
AA22193	Cuitzmala notch	–	–	4.5 to 4.7	4.5. to 4.7	Coralline algae	1,262 ± 51	660–940 AD	−25	Ramirez-Herrera *et al.* (2004)
AA59462	Laguna Mitla, Guerrero	ACA-04-01	155	–	–	Wood	3,166 ± 34	3,336–3,456	−27.15	Ramirez-Herrera *et al.* (2007)
AA59469	Laguna Mitla, Guerrero	ACA-04-06	394		–	Charcoal/ wood	4,630 ± 37	5,297–5,467	−30.173	Ramirez-Herrera *et al.* (2007)
AA59470	Laguna Mitla, Guerrero	ACA-04-06	387	–	–	Wood	4,547 ± 36	5,051–5,317	−24.991	Ramirez-Herrera *et al.* (2007)
AA59471	Laguna Mitla, Guerrero	ACA-04-06	377	–	–	Wood	4,559 ± 36	5,053–5,437	−27.77	Ramirez-Herrera *et al.* (2007)
AA59472	Laguna Mitla, Guerrero	ACA-04-06	371	–	–	Wood	4,626 ± 37	5,294–5,468	−28.26	Ramirez-Herrera *et al.* (2007)
AA59474	Laguna Mitla, Guerrero	ACA-04-06	234	–	–	Wood	2,836 ± 34	2,859–3,063	−27.412	Ramirez-Herrera *et al.* (2007)
AA54043[e]	Laguna Mitla, Guerrero	ACA-03-02	299–300	–	–	Charcoal	2,818 ± 42	2,842–3,043 Cal BP	–	Ramirez-Herrera *et al.* (2009)
AA54044[e]	Laguna Mitla, Guerrero	ACA-03-02	560–564	–	–	Wood	6,161 ± 53	6,901–7,176 Cal BP	–	Ramirez-Herrera *et al.* (2009)

[a] Elevation data corrected for tide level at time of measurement; measurement error estimates ±0.2 m. Mean tide range for locations near Manzanillo, Colima, ca. ±0.5 m, and ±0.8 m for locations near Puerto Vallarta

[b] El Niño correction (1998) +0.14 to 0.32 m

[c] 109% of modern (Beta-119880)

[d] NSF-Arizona AMS facility. Radiocarbon calibrations were performed using the program CALIB 5.0 (Stuiver and Reimer, 1993) and the calibration dataset IntCal04 (Reimer *et al.*, 2004)

[e] NOSAMS AMS laboratory

in bedrock and a highly irregular wave-cut surface are uplifted 5 m above high-tide level near Zihuatanejo-Ixtapa; however, these features are barren of deposits from which the cutting of the surface could be dated. Three river terraces, indicative of tectonic uplift, are present near Petatlan (southeast of Zihuatanejo-Ixtapa). Deposits on the highest, 25-m-elevation terrace and a thick soil cover suggest an old age (Pleistocene?) for this feature.

The Mexican Pacific coast is formed by rising mountains exhibiting triangular facets and V-shaped valleys indicating discrete faulting between the coastal plain and mountains inland, off the OGFZ and southeast of the Ometepec canyon (Fig. 1). The coastal landscape shows uplifted terraces in this area, near Punta Maldonado. A clear flight of marine and fluvial terraces is revealed on the Oaxaca coast along ca. 40 km, from Puerto Escondido to Puerto Angel

(Fig. 1). Two terraces rise at ca. 8 and 19 m elevation. Several streams dissect these terraces showing V-shaped valleys, indicative of active river incision. Moreover, marine terraces show a well-preserved and steep sea cliff. Active river incision and well-preserved sea cliffs on these terraces suggest active tectonic uplift in this area. Further work is required in this sector of the Pacific coast of Mexico to precisely determine rates of uplift.

5. *Coastal Subsidence*

The coastal area incorporated within the El Gordo-Colima graben coastal sector, which corresponds to the boundary between the Rivera and Cocos plates, is marked by the lack of evidence of elevated surfaces. Here the distance from the coast to the trench averages 77.5 km (5.7 km SD) and reaches up to ca. 88 km. The coastal landscape displays a wide low deltaic plain, sand bars, berms, estuaries and large coastal lagoons. Inland, fold mountains and Quaternary active volcanoes fringe the area. Active faults of the Colima graben show triangular facets and a remarkable depression further inland. Active extension has been suggested by other authors (Bandy *et al*., 2000, 2005; Suarez *et al*., 1994). A large, $M_w = 5.3$, normal event recently occurred (7 March 2000) in South-Colima graben (Zobin *et al*., 2000; Pacheco *et al*., 2003a, b). This event conclusively demonstrates that a NW-SE oriented extension is occurring in the South-Colima graben (Bandy *et al*., 2005). Depositional landforms on the coast suggest that the coast is either subsiding or perhaps slowly rising. Evidence of historical coseismic subsidence has been reported on this coast (Cumming, 1933; Melbourne *et al*., 1997). We discuss this further below.

Stratigraphic, morphologic and archeological evidence of Late Holocene coastal subsidence has been reported for the Guerrero central coast (Ramirez-Herrera *et al*., 2007, 2009). The sedimentary record of the Mitla and Coyuca Lagoon indicates a rapid shift from freshwater/brackish, i.e., a marginal lagoon, to marine conditions at ca. 3,400 year BP (Fig. 5). This rapid change in depositional environment is explained by a local earthquake that triggered a tsunami (Ramirez-Herrera *et al*., 2007). The latter is inferred from the presence of discrete sand layers above the brackish mangrove peat and associated with a rapid marine inundation by a tsunami (Ramirez-Herrera *et al*., 2007). The paleoseismic record thus suggests that subsidence of the coast occurred with a large thrust event that triggered a tsunami at the central Guerrero coast near Acapulco. Further indirect evidence for coastal subsidence along this coast is also revealed by local archeological sites, in the form of submerged shell middens at Laguna Coyuca (Kennett *et al*., 2004; Ramirez-Herrera *et al*., 2005) and marine microfossil proxies (pollen, diatoms and marine plankton) at the adjacent Laguna Tetitlan in the central Guerrero coast (Gonzalez-Quintero, 1980).

Recent geodetic observations: leveling from 1995 to 1998 (Kostoglodov *et al*., 2001) and continuous GPS records from 1997 up to 2008 suggest a short-term coastal subsidence of 1.1–1.4 cm/year (Vergnolle *et al*., 2010) at a period of $\sim$4 years between the occurrence of aseismic slow slip events (SSE; Yoshioka *et al*., 2004; Kostoglodov *et al*., 2003; Cotte *et al*., 2009). Tide gauge sea-level records available from 1953 reveal a long-term interseismic subsidence of ca. 0.3–0.4 cm/year on the Guerrero coast near Acapulco (Alva and Kostoglodov, 2007). A large subduction thrust earthquake should release the elastic strain accumulated during the interseismic epoch, which will result in a notable coseismic uplift. For example, an uplift of 22 cm was observed in 1962 during the M_w 7, 7.1 earthquake doublet that ruptured the plate interface right below the Acapulco coast (Ortiz, 2000).

An apparent inconsistency exists between the expected coseismic "uplift" and a notable subsidence of the coastal area derived from the sedimentary record of a large tsunamigenic earthquake by ca. 3,400–3,500 year BP (Table 1) (Ramirez-Herrera *et al*., 2009). A plausible explanation proposed to reconcile this inconsistency is that while the recent (100–150 years) large earthquakes in the central Mexican subduction zone have a limited width and rupture only strongly coupled interplate patches (within only 40-60 km and located below the coast), some prehistoric earthquakes most likely ruptured the entire coupled plate interface almost up to the trench.

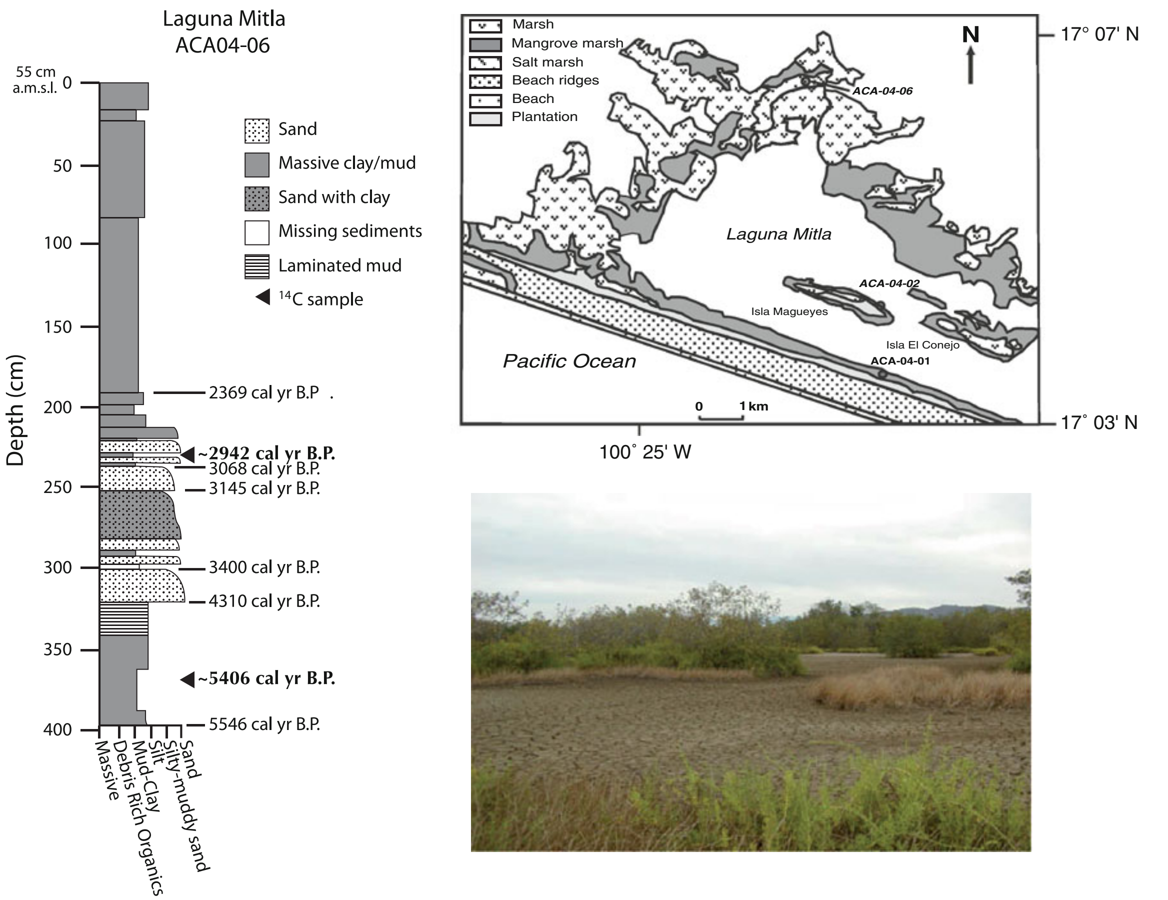

Figure 5

Sediment record from lagoonal marsh at Laguna Mitla, Guerrero. Cored sediments show a buried soil cover by sand (marine incursion) indicative of coastal subsidence. Insert shows location map and photograph of lagoon marshes (modified from Ramírez-Herrera *et al*., 2007)

Such a combined megathrust event should produce a considerable coastal area subsidence (Ramirez-Herrera *et al*., 2009). Figure 6 illustrates possible models to explain the difference in uplift produced by recent subduction earthquakes and a hypothetical mega-event. An example of a near trench event is the M_w 6.7, 18 April 2002 thrust earthquake in front of the Guerrero coast, which ruptured a weakly coupled plate contact close to the trench and generated a small tsunami (Fig. 2; Iglesias *et al.*, 2003). The recurrence period of mega-events such as the one that occurred by ca. 3,400–3,500 years BP (Ramirez-Herrera *et al*., 2009) may be very long (10^2–10^3 years). Nevertheless, more detailed studies on the coseismic deformation of historical and prehistorical earthquakes and modeling is required to resolve this inconsistency between interseismic and expected coseismic coastal deformation on the Guerrero coast.

Further south and southeast of the Tehuantepec ridge offshore, the coastal landscape shows a remarkable change. In this area, low accumulative marine plains with eolian, marine and alluvial deposits, wide beaches, sandbars and lagoons characterize most of the coast. No evidence of elevated surfaces is found on this sector of the Mexican Pacific margin. However, high fault-block mountains border the area inland (Ramirez-Herrera and Urrutia-Fucugauchi, 1999). The coast has been "apparently stable" in recent times. Offshore, there is a dramatic change with the presence of the Tehuantepec ridge and an increase in the width of the continental margin into a well-developed fore-arc basin, and no observed accretion. Here changes in convergence rates, geometry of the subduction and depth of earthquakes mark a seismotectonic transition to a different domain (Shipley *et al.*, 1980; Auboin *et al.*, 1981; Ramirez-Herrera and Urrutia-Fucugauchi, 1999; Manea *et al.*, 2005). The palaeoecology and stratigraphy of the sequence on marsh and lagoonal sediments should help to distinguish evidence of sudden land elevation changes. Beach ridge sequences at this coast, if these exist, may reveal possible coseismic steps. However, further studies should be done to reconcile the Recent (Pleistocene-Holocene) coastal deformation of this region and to check a hypothesis that the coastal deformation here has been driven by a gradual, interseismic process.

5.1. Historic Coseismic Deformation

There is limited evidence of local coseismic deformation measured after the occurrence of large earthquakes on the Pacific Mexican margin. The 1985 earthquake, 8.1 (M_w), produced up to 1.0 m of coastal uplift in the Michoacan coastal segment (Bodin and Klinger, 1986). A survey of the vertical distribution of intertidal organisms documents local deformation through the coastal area enclosed in the 19 and 21 September 1985 earthquake rupture zones. These data however represent a conservative estimate of the actual magnitude of vertical displacement associated with the earthquakes. The region of greatest reported uplift coincides with an area marked by flights of uplifted marine terraces, mentioned above, associated with long-term coastal uplift and may represent residual uplift resulting from episodic large earthquakes on the underlying megathrust (Bodin and Klinger, 1986).

Vertical deformation that produced coastal uplift was recorded by the extent of coralline algae mortality after the M_w 6.3, 2 February 1998 earthquake in Puerto Angel, Oaxaca (Ramirez-Herrera and Zamorano, 2002). The extent of the coastal uplift reached up to 0.5 m near Agua Blanca. Coseismic uplift was recorded for ca. 70 km along the Oaxaca coast (Ramirez-Herrera and Zamorano, 2002). The region of reported maximum coseismic coastal uplift also coincides with an area of clear uplifted marine

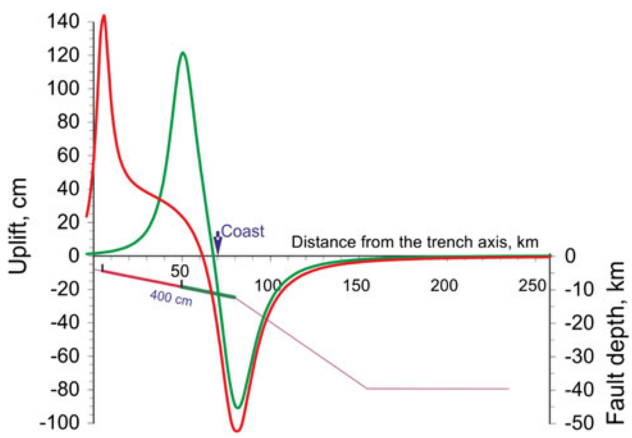

Figure 6

The model of tectonic uplift (dislocation in a homogeneous elastic half-space, Savage, 1983). *Green line* is modeled uplift produced by recent subduction thrust events on the coast of Guerrero (1962 M_w 7.1, 7.0 events). The ruptured patch of the coupled plate interface with a coseismic displacement of 400 cm is shown as a *green line*. *Straight line* segments represent the subduction plate interface geometry (Kostoglodov *et al.*, 1996; Kim *et al.*, 2010). While the tsunamis produced by these seismic events were only ~22 cm (Ortiz *et al.*, 2000), their combined effect was negligible, in particular because the subsidence of the coast was <10 cm. The main subsidence occurred over the area of highland and was not affected by the tsunami at all. *Red line* is the uplift model for the case when the near trench coupled patch rupture together with a downdip coupled plate interface (*red* + *green* patches, with the same fault slip of 400 cm as during the 1962 events. Actually the fault slip for the higher magnitude earthquake may have been about two times larger than that in 1962). The uplift for this hypothetical earthquake (*red curve*) shows that the coastal area will subside noticeably, and the combined effect of tsunami amplitude and its runup should be very large. Later interseismic subsidence of the coast will be produced mostly by a strongly coupled downdip seismogenic patch (*green*). Recurrence period of the "combined" mega-thrust earthquake may be of the order of 10^3 years terraces, mentioned above, and associated to long-term coastal uplift. The area is also enclosed within the rupture area of the 29 November 1978, $M = 7.6$ earthquake. This suggests that it may as well represent residual uplift produced by periodical large earthquakes on the underlying megathrust in southern Mexico.

The June 3 and 18 1932 earthquakes, $M_s = 8.1$ and 7.8, respectively, broke the Rivera-North America Plate boundary (Singh *et al.*, 1985) and produced coastal subsidence estimated at 40–75 cm on the stretch of the coast from Barra de Navidad and south of the Tecoman, southern Jalisco and Colima coasts (Cumming, 1933). Recently, the 9 October 1995 earthquake ($M_w = 8.0$), located near Manzanillo, ruptured part of the Rivera-North America plate boundary (Melbourne *et al.*, 1997; Bandy *et al.*, 1997; Ortiz *et al.*, 1999). Coseismic subsidence of 80 ± 14 mm at Manzanillo, Colima, was estimated from GPS surveys performed before and after the earthquake (Melbourne *et al.*, 1997). Pressured gauge records however indicated subsidence of 44 cm in Barra de Navidad and 11 cm in Manzanillo, Colima (Kostoglodov *et al.*, 1997).

6. Discussion

6.1. How Tectonic Deformation (Uplift/Subsidence) Rates Vary Spatially and Temporally on the Active Mexican Pacific Margin Coastal Areas

The Mexican Pacific margin shows spatial and temporal variability in the style and rates of tectonic deformation along-strike the subduction zone (Fig. 7). Non-steady long-term uplift rates are recorded from wave-cut platforms resulting from marine erosion during sea-level highstands, from beach ridges and tidal notches. Pleistocene uplift rates are estimated at ca. 0.7–0.9 m/ka on the Jalisco block active margin, within the Rivera-North America tectonic plate boundary, while uplift rates show an increase in the Holocene up to ca. 3 ± 0.5 m/ka. On the contrary, steady rates of uplift (ca. 0.5–1.0 m/ka), in the Pleistocene and Holocene, characterize the coastal sector south of El Gordo graben to the OFZ, Michoacan coast, which is incorporated within the Cocos-North America plate boundary. Considerable high rates of uplift were measured in the margin sector across the OFZ subduction. Long-term, late Holocene subsidence was recorded in the Guerrero coastal sector near Acapulco, where the geometry of the subduction is very shallow. This is in agreement with a landscape and archeological evidence of coastal subsidence.

The difference in the deformation records from the Jalisco coastal sector and those from the Michoacan coast, particularly at the OFZ coastal sector, suggests that the uplift rate varies not only temporally (non-steady rates in Jalisco), but also spatially along-strike. The possible causes of uplift rate variability, temporal and spatial, are likely due to localized coastal tectonic processes linked to subduction. Marine terraces in the studied areas were developed indifferently on a heterogeneous substratum (i.e., volcanic breccia, granite). Therefore, lithologic variations in bedrock do not play a major role in the morphology of these terraces. Faulting in the Punta de Mita coastal area, Jalisco block, possibly the "Marieta-Punta de Mita Fault" (Alvarez, 2007), might have occurred after the formation of the Holocene marine terrace, which might explain the accelerated rates during the Holocene. Another plausible explanation for those changes in coastal morphology and surface deformation rates, i.e., uplift (Jalisco and Michoacan) and subsidence (Guerrero), is that slab subduction processes strongly influence the forearc tectonic deformation. The roughness of the subducted plate, such as irregularities, seamounts and ridges, can certainly lead to subduction erosion and underplating of material (e.g. Hsu, 1992; Hampel *et al.*, 2004; Cliff and Hartley, 2007; Sack *et al.*, 2009). These processes are even more evident on the coastal sector where the OFZ produces topographic irregularities on the subducting plate or material in the trench leading to rapid and episodic uplift rates. Thus, it is probable that the Mexican Pacific margin similarly to the Chilean forearc has experienced periods of lower uplift rates that might alternate with periods of accelerated uplift rates over time scales $<<$ 1 Ma (Saillard *et al.*, 2009), and also may be due to active faulting. Another plausible explanation for the variability of uplift rates of marine terraces above different tectonic settings along the coast of the

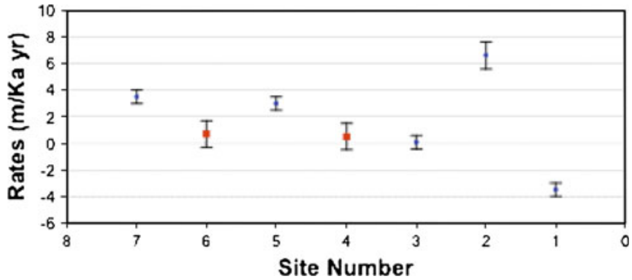

Figure 7
Tectonic rates with *error bars*. Temporal and spatial variability of coastal deformation rates on the Mexican Pacific margin. *Circles* with *error bars* in *black* show Holocene rates, *squares* with *error bars* in *gray* show Pleistocene rates. Sites: *1* Guerrero (Mitla), *2* Guerrero (Saladita), *3* Michoacan (Bufadero), *4* Michoacan (Neixpa), *5* Jalisco (Cuitzmala), *6* Jalisco (Farallon), *7* Jalisco-Nayarit (Punta Mita). Distance between sites is not to scale

Mexican Pacific margin could be related to the change in downdip position of the locked zone along the plate interface with respect to the continental forearc. Nevertheless, further data are required to determine which mechanism is responsible for the strong variation in uplift rates and style of deformation (uplift vs. subsidence).

6.2. *Interseismic and Coseismic Deformation*

Coseismic deformation produced during large thrust events results in coastal uplift and coastal subsidence along the Mexican Pacific margin. Coseismic deformation rates show that considerable deformation accompanies large thrust events ($M_w > 6.0$) on the Mexican Pacific margin. Coseismic uplift was measured after the 1985 event on the Michoacan coast reaching up to 1 m. Coastal uplift was also produced by the 1998 event on the Oaxaca coast that reached up to 0.5 m. These two sectors of the coast, Michoacan and Oaxaca, show marine terraces that indicate that uplift also takes place during interseismic periods. However, south of the Jalisco block, coastal coseismic subsidence of up to 0.4–0.75 m was measured after the 1932 earthquake at El Gordo-Colima graben coastal sector. Similarly, the Colima 1995 earthquake produced coastal subsidence of up to 0.08 m (measured with GPS) and 0.11–0.44 cm (tide gauge records) in the Manzanillo, Colima coast. The coastal landscape of this sector of Mexican Pacific margin is barren of morphologic evidence of long-term tectonic uplift, suggesting that either these coastal features have been eroded and/or this coast is subject to interseismic slow uplift or to slow subsidence. Further work is required to support this hypothesis.

Coastal Holocene subsidence has occurred on the central Guerrero coast during great earthquakes that have ruptured the entire coupled plate interface almost up to the trench (Ramirez-Herrera *et al.*, 2009). Based on models from registered seismic events, the expected coseismic coastal response is coseismic uplift in this coastal sector during events with limited width of the rupture area (within only 60 km and located below the coast).

Coastal rate estimates might have large uncertainties but show a consistent pattern of uplift in the Michoacán and Oaxaca coastal sectors, and subsidence in the Colima-south Jalisco coastal sectors, respectively. Elastic dislocation models constrained by interseismic geodetic or/and thermal data used to predict the coseismic pattern of deformation for the likely strain accumulation periods of plate convergence and for uniform megathrust slip are scarce for the Mexican megathrust fault. These models would provide a better understanding and help determine if predicted uplift/subsidence is in broad agreement with observed coseismic deformation.

7. *Conclusions*

Systematic measurements of marine wave-cut platforms, marine terraces, beach ridges and tidal notches suggest a pattern of non-steady uplift in the northwestern segment of the Mexican Pacific margin

(Jalisco block). Accelerated uplift rates in the late Holocene on the coastal stretch of the Jalisco block and Rivera plate boundary might be related to local faulting. The coastal segment incorporated in the Jalisco block-Rivera plate boundary has been rising by interseismic non-steady tectonic uplift. In light of historic coseismic subsidence and rapid postseismic recovery reported for the southern part of Jalisco coast (Cumming, 1933; Melbourne *et al*., 1997), the interseismic component must be the most important process for tectonic uplift and the evolution of this coast. This supports a model in which coseismic subsidence produced by offshore earthquakes is rapidly recovered during the postseismic and interseismic periods. We show that recent uplift/subsidence rates in the Mexican Pacific coast have been highly variable, spatially and temporally, during the last 120 ka year, at time scales intermediate between those obtained using geodetic methods ($\sim$10 year) and those based on geological data (10^6 year). Variation in the uplift/subsidence rates is likely due to differences in tectonic regimes and to localized processes related to subduction, such as crustal faults, subduction erosion and underplating of subducted materials under the coastal zone (e.g., coast across the OFZ). This highlights the importance of identifying several datable geomorphic markers over the time-scale of interest when attempting to assess regional or local uplift/subsidence rates. This is of most importance on the Mexican Pacific margin in light of the scarcity of such data and of elastic dislocation models.

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