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SUBDUCTION OF OCEANIC PLATE IRREGULARITIES IN SOUTH-CENTRAL MEXICO AND THE INFLUENCE ON SUBDUCTION SEISMICITY.

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Abstract: It is known that oceanic plates morphology is not a simple one, but rather complicated by a series of irregularities as seamounts, fracture zones and mid-ocean ridges. These features present on the oceanic floor form part of the fabric of oceanic crust, and once formed they move together with the oceanic plates until eventually enter a subduction zone. Some improvements have been done in the last decades in understanding the influence of seamount subduction on the forearc morphology and also on occurrence of large subduction earthquakes. Although the Cocos plate offshore Mexico present a series of multiple small height seamount chains that enter into subduction well as large fracture zones (i.e. Tehuantepec fracture zone), the understanding of the influence of these oceanic features that might play in geohazards (i.e the generation of large earthquakes) in Mexico is not yet well studied. Previous studies along the Mexican trench reveal that only a small portion of the oceanic sedimentary blanket is accreted and this margin seems to be marked by erosional processes. In the particular case of seamounts, it is not well understood for example whether the Cocos plate seamount chains are accreted to the forearc or carried down into the subduction zone, and how the forearc morphology is affected.

In this study we present some preliminary results where we investigate the morphology of medium-size to large seamounts and fracture zones in the vicinity of the trench in south-central Mexico, and examine the possible links that might exist between these features and subduction seismicity in particular the rupture history of large subduction zone earthquakes along the Mexican margin.

Key words: Mexican Subduction Zone, Seamounts, Fracture zones, Seismicity and Seismic Gapes.

1. INTRODUCTION

The relatively young Cocos plate subducts along the Middle America Trench (MAT) beneath both the North American and Caribbean Plates, causing along trench variation is seismicity distribution, slow slip events, and also non-volcanic tremors (Kostoglodov et al., 2003; Pardo and Suárez, 1995; Payero et al., 2008). The Cocos plate seafloor is irregularly littered with small and medium-size seamounts in the northern half part delimited by the Tehuantepec fracture zone which divides the Cocos plate in two tectonically distinct areas (Manea et al., 2005). These seamounts are created in the vicinity of East Pacific Rise (EPR) and once they become inactive, they are being carried along by the Cocos plate and will be subducted beneath Mexico (Figure 1). There are well known present-day examples of large seamounts that are close of being subducted in different subduction systems as Erimo and Daiichi-Kashima in the Japan Trench, Niue Seamount in the Southwest Pacific Ocean, and Christmas Seamount in the Indian Ocean (Nishizawa et al., 2009, DuBois et al., 1975, Woodroffe et al., 1990). Apart of seamounts, oceanic plates also composed of large fracture zones that are characterized by uplifted edges of normal ocean floor (Sandwell and Schubert, 1982). Independent or not of their size, as soon as these seamounts and fracture zones (often called asperities) enter a subduction zone they alter the morphology and structure of the trench and the forearc. Additionally these asperities may also profoundly influence the distribution of seismicity, and probably the size and frequency of large megathrust earthquakes (Kelleher and McCann, 1976; Watts et al., 2010; Muller and Landgrebe, 2012). The Cocos plate is characterized by small and medium-size seamounts, but their impact with the overriding plate along the MAT offshore Costa Rica and Nicaragua (Ranero and Huene, 2000) revealed an intense process of subduction erosion.

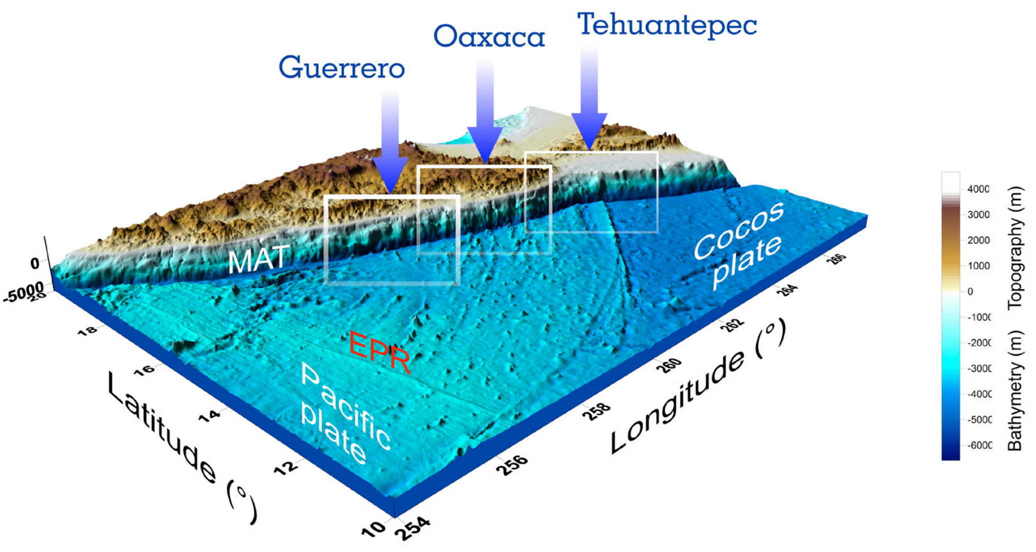

Figure 1. Topographic and bathymetric map of the Mexican subduction zone. White squares delineate the tree regions Guerrero, Oaxaca and Tehuantepec, where we analyze the oceanic plate morphology and its impact on the trench and forearc. MAT – Middle America Trench. EPR – East Pacific Rise.

Although subduction erosion clearly dominates tectonic processes off Costa Rica and Nicaragua, it probably also extends northward along the MAT margin. Using free-air gravity anomalies Manea et al. (2003) proposed that subduction erosion takes place along MAT offshore Mexico only in the northern part delimited by the Tehuantepec fracture zone. South of Tehuantepec fracture zone, the Cocos plate is characterized by a rather smooth morphology and almost lacking seamounts (Figure 1). An interesting aspect of the Mexican subduction zone is the presence of two large seismic gapes, the Guerrero and Tehuantepec seismic gaps, where no significant quake has occurred in more than 100 years or more (Figure 2). However, the origin of these two major seismic gaps has not been elucidated yet and this study might represents one of the first steps in finding the first order cause of these seismic gaps in particular, but in the same time, plays an important role in understanding long-term geodynamical evolution of the Mexican subduction zone. For this purpose we investigate the distribution of seamounts off trench Mexico and their relationship with distribution of shallow seismicity (<30 km depth) along the MAT. Finally, we investigate a potential correlation of the Tehuantepec fracture zone with the presence of a large seismic gap in the region.

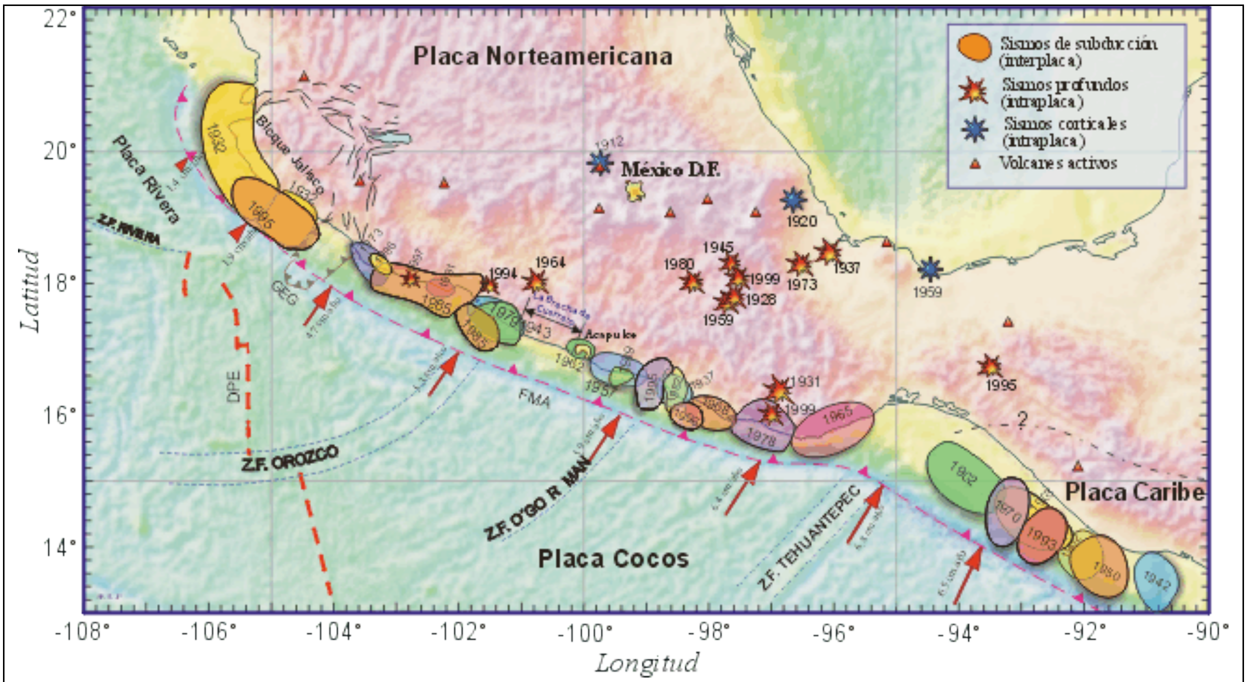

Figure 2. Rupture areas along the Mexican subduction zone for the las century (Kostoglodov and Pacheco, 1999). Note the presence of Guerrero and Tehuantepec seismic gaps.

2. METHODOLOGY

2.1 Study area

The Mexican subduction zone (MSZ) is located where the Cocos plate, and the smaller Rivera Plate, is currently subducting beneath the North America plate (Figure 1). The convergence rate between Cocos and North America plates increases only slightly to the southeast along the MAT (~5 to ~6 cm/yr) (Manea et al., 2016), however the dip of the subducting slab varies strongly, from flat slab beneath Guerrero and Oaxaca to steep slab beneath Chiapas in the south. Although large interplate earthquakes occur actively along the Mexican margin, the flat-slab region beneath Guerrero lacks widespread earthquakes in both the forearc region and within the subducting Cocos slab (Pardo and Suárez, 1995). The flat-slab region beneath Guerrero is also characterized by slow slip phenomena (SSE) that have largest (average slip of ~10 cm) reliably detected events ever (Kostoglodov et al., 2003). It has been estimated that due to these large SSE's there is no large megathrust earthquake ($M \geq 7$) that has occurred in more than 100 yrs creating a seismic gap. In contrast with the Guerrero area, the Oaxaca region is considered more seismically active and also holds regions where large megathrust earthquakes occurred in the last century. On the other hand, the region affected by SSEs is more reduced. To the south, the last region presented in this paper show a sharp bending along the MAT and a large ocean floor depth difference (~1 km) marked by the presence of the Tehuantepec fracture zone. The seismicity in the region where Tehuantepec fracture zone intersect MAT is less seismically active and, similar with the Guerrero region, there is no large megathrust earthquake ($M \geq 7$) in the last century creating a second large seismic gap in Mexico. Further south towards the Central America, the seismic activity resumes with large megathrusts and intense forearc and intraslab earthquakes as well.

2.2 Cocos plate seamounts in front of Guerrero and Oaxaca

In the last two decades, extensive bathymetric studies off Guerrero and Oaxaca revealed a complex subducting morphology. For the Mexican subduction zone we analyze the morphology of the incoming Cocos plate in terms of seamounts for two neighbor regions: Guerrero zone located offshore the Guerrero seismic gap, Oaxaca zone (Figure 1). The first region, Guerrero zone, is characterized by a relatively small number of seamounts with heights of 1 km or more. Several subparallel seamount chains are entering the subduction zone nearly orthogonal to the MAT axis (Figure 3 – insets). These seamount chains are composed of small to medium sized volcanic edifices with size up to a ~20 km diameter and rising >1500 m or more above the ocean floor. These seamount complexes spread over hundreds of kilometers from the trench axis across the outer rise and they reach the East Pacific Rise (EPR).

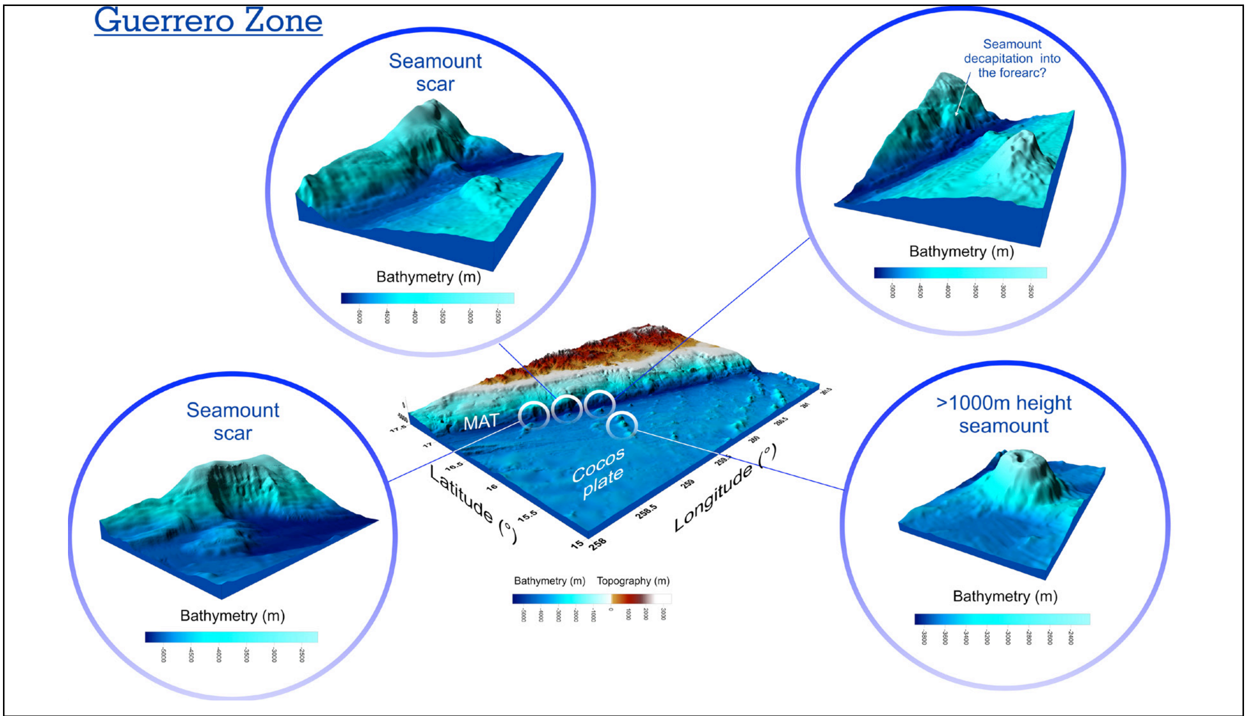

Figure 3. Guerrero zone. The Cocos plate offshore the seismic gap is characterized by a small number of seamounts of 1 km or more in height. Note how the trench morphology is strongly affected by the seamounts currently entering into subduction.

The largest seamounts are probably bordered by small sediment filled moats due to a downward-deflected seafloor surface created by flexural bending of the ocean lithosphere under the volcanic mass. However the smaller volcanic edifices are entirely supported by the Cocos plate elastic resistance. As the Cocos plate approaches the MAT the oceanic crust is affected by the reactivation of the abyssal-hill faulting fabric. However a closer analysis of the larger seamounts that are in the throes of being subducted they show no indication of being affected by the abyssal-hill faulting (Figure 3), but the smaller cones located in the in the outer trench slope may be affected by the faulting system. Once the seamounts enter into subduction most of them appear to remain physically intact at least throughout the shallow subduction process, as several zones with seamount head scars are clearly visible in figure 2. Additionally, further south along the trench, some of the seamounts look like decapitated and incorporated into the forearc.

In contrast with the Guerrero zone, the next study region, Oaxaca, is quite abundant of similar seamounts and they are grouped in several chains. There are several linear volcanic ridges intersecting the MAT axis that likely originated off-axis of the EPR. These seamounts are not related with the extension-related abyssal faults currently forming at the trench outer rise because the linearly-organized volcanic chains spread out from the MAT 200 km or more and individual large seamounts can be observed all the way up to the EPR (Figure 1). Also it is important to note the almost perfect round shape of the Mexican seamounts (Figure 1) which points dismiss any potential relationship with elongated tensional state of reactivated abyssal faults off trench Guerrero and Oaxaca.

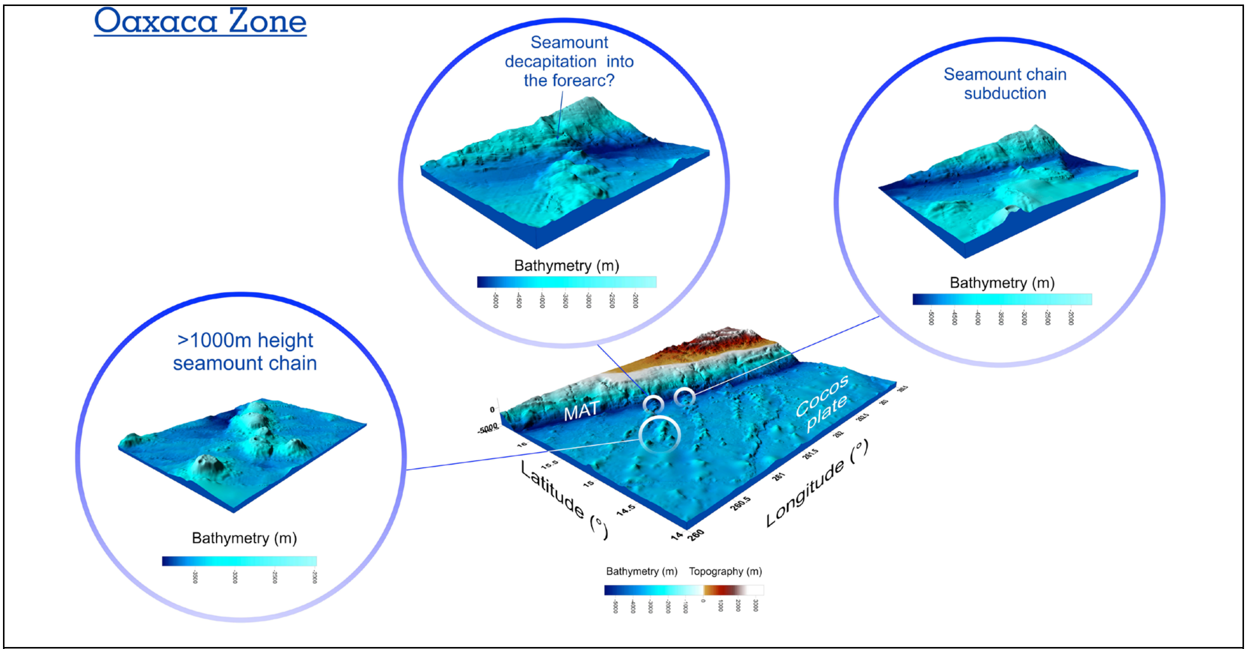

Figure 4. Oaxaca zone. The Cocos plate offshore Oaxaca si characterized by a large number of seamounts and seamount chains. Note how the trench morphology is strongly affected by the seamounts curently enetring into subduction.

Another interesting aspect related with the Mexican seamounts is the presence of a uniform thin pelagic sediment cover (Kanjorsky, 2003) similar to surrounding oceanic crust, which points out to a genesis place located close to the EPR. Present day oceanic floor morphology in the vicinity of the fast EPR also supports the hypothesis that present day off-trench seamounts in Mexico are produced at EPR. Since the Cocos plate offshore the Oaxaca trench (Figure 4) is littered with a large number of seamounts arranged in chains almost parallel with the convergence direction, suggests that Cocos-Pacific spreading center had quite strong mantle upwelling 15 Myr ago or more. These seamount chains profoundly affect the morphology of the trench and the forearc, and in several regions we identified seamounts head scars and possible incorporation of seamounts into the forearc. Further south, at the southern limit of the Oaxaca study region, the linear seamount chains disappears and replaced by broad volcanic region made up of many scattered small seamount cones accompanied and lava flows. However their impact on the trench morphology is quite similar, but smaller in magnitude compared with the neighbor region.

2.3 The Tehuantepec fracture zone

The third and last area we analyzed for the Mexican subduction zone corresponds where the Tehuantepec fracture zone that enters into subduction. From this large bathymetric linear structure further south along the MAT we observed a totally different Cocos plate structure with almost no seamounts. However a very clear abyssal fault system can be easily identified (Figure 5). The regular fabric of abyssal horst and graben-like faulting is generated at EPR and it is typical for a fast spreading center. The angle between the abyssal fault system and the trench axis in southern Mexico is quite small ~10-15°. Therefore the faults observed in figure 5 are not newly created faults off-trench axis, but rather old faults reactivated by the tensional stresses within the Cocos plate as it approaches the trench (Masson, 1991).

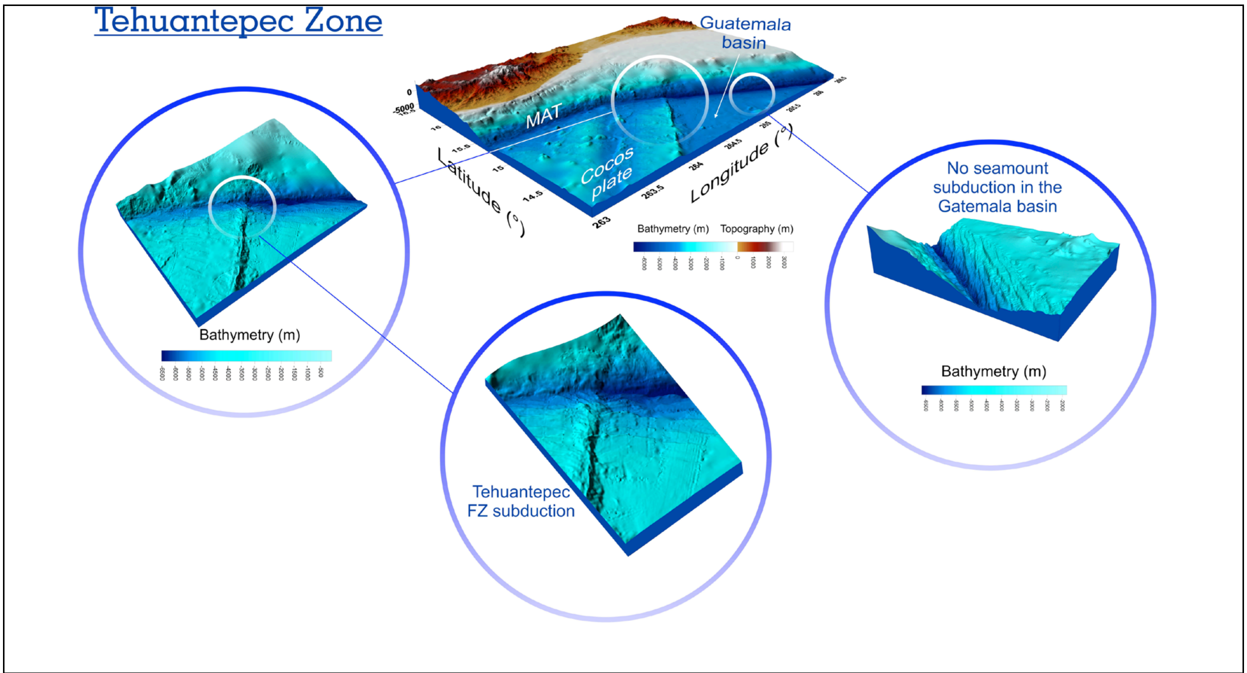

Figure 5. Tehuantepec zone. The Cocos plate offshore Chiapas si characterized by a lack of seamounts or seamount chains. However note the presence of the large Tehuantepec fracture zone and clear pattern of abyssal fault system.

However in the vicinity of the Tehuantepec fracture zone can be observed a wedge shape like fractures at an angle of ~45° with the Tehuantepec fracture zone direction (Figure 5). They are likely to be newly created faults by the interaction between the fracture zone and the trench. Although the quality of bathymetry data is not very good in the forearc, the influence of Tehuantepec fracture zone is still visible, and the forearc seems to be uplifted locally. However, more high quality data (i.e. multibeam surveys) is needed in order to quantify the impact of Tehuantepec fracture zone on the forearc.

3. Seismicity along MAT and distribution of Cocos plate irregularities

It has been demonstrated that major oceanic plate irregularities (i.e. seamounts) are able to control the rupture extent of large megathrusts (Nishizawa et al., 2009; Das and Watts, 2009). They can even act as a low or high friction barrier that limits the lateral extent of a rupture area. Therefore since it is accepted that oceanic plate irregularities influence the degree of coupling between the overriding and subducting plates (Watts et al., 2010), we plot the crustal seismicity (< 40 km depth) along MAT in Mexico and analyze it in terms of its relationship with the oceanic plate irregularities discussed in the previous chapters (Figure 6). We identified two small size clusters of high seismic activity in the Guerrero gap and one rather large spot corresponding to the Oaxaca region.

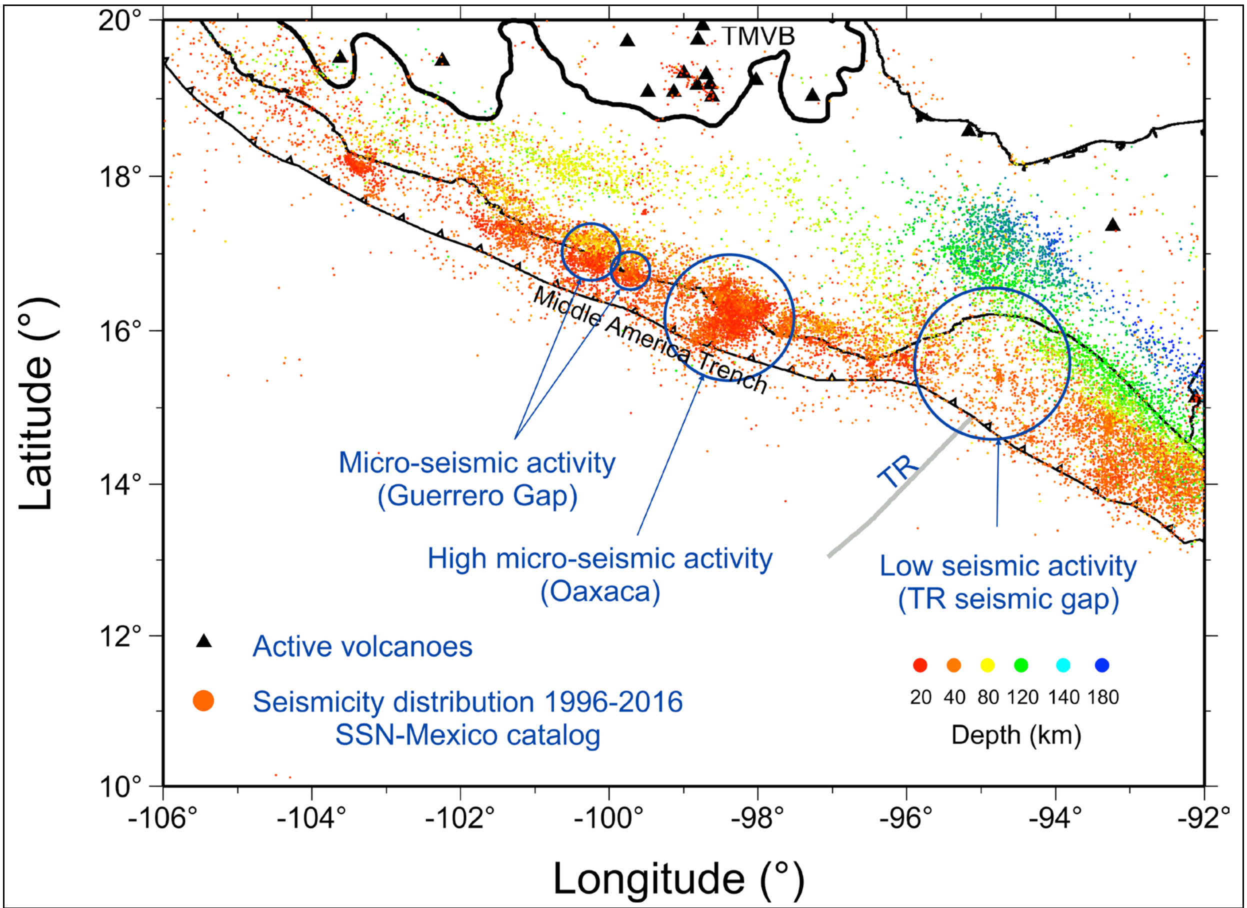

Figure 6. Crustal seismicity (depth <40 km) distribution along the Mexican subduction zone. Note the presence of several clusters of high micro-seismic activity in front of Guerrero and Oaxaca, and a fairly reduced seismic activity corresponding to the intersection between the Tehuantepec fracture zone and the MAT.

This might suggest an intrinsic relationship between the presence of seamounts and their relative distribution on the Cocos plate, with more seamounts corresponding to an area of increased seismic activity. Additionally earthquakes recorded on local broadband seismic networks show that the region marked by a high density of seamounts appear to be seismically active. This increase in seismicity does not linearly increase along the MAT following the plate age increase, but rather is characteristic only for the area off-Oaxaca with seamount chains. This pattern indicates some direct relationship between the seamount chains, abyssal faulting and increased seismic activity. Kanjorsky (2003) suggested the increased seismicity is due to the presence of a secondary normal fault system perpendicular to the parallel to the trench abyssal fault system. A similar dual normal fault pattern in the vicinity of trench was observed in Japan (Minamino and Fujii, 1981) and is generated by the convex shape of the trench, similar with the MAT geometry in Mexico.

In contrast with the area of Oaxaca, and at some extent with Guerrero zone, the region where the Tehuantepec fracture zone enters into subduction is characterized by an extremely low seismic activity and the absence of a megathrust in the last century (a seismic gap). This is consistent with recent studies that proposed the presence of a serpentinized lithospheric root beneath the Tehuantepec fracture zone (Manea and Manea, 2008), which during subduction in entrained into the forearc due to its high buoyancy and low mechanical strength (Manea et. al, 2014). The deficiency of stress in the vicinity of Tehuantepec fracture zone subduction might results in an obstacle for large earthquake lateral propagation, resulting in a long-term, or even permanent, seismic gap. Additionally, the increased presence of serpentinite beneath the Tehuantepec fracture zone fluids may also act to locally reduce the normal stress on the main subduction fault.

4. CONCLUSIONS

Our preliminary study shows that there is clear relationship between the subduction of a large number of seamounts distributed in chains on the Cocos plate and the crustal seismic activity associated with subduction. There are several clusters of intense seismic activity, particularly in front of Oaxaca that correlate well with the location of seamounts on the incoming Cocos plate. We also found an inverse correlation between the subduction of the Tehuantepec fracture zone and the low seismic activity in the region including the presence os a long-term (100 yr or more) seismic gap. However our understanding of the interaction of seamounts and fracture zones with subduction systems is still limited and we will use this study as a starting base for our future advanced thermomechanical numeric models that will investigate the interaction between seamounts and subduction zones.This is an initial effort to understand the long-term effect of seamount and fracture zone subduction along MAT in particular, but also serve for further advancing our understanding of oceanic plate irregularities impact on other active subduction zones.

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