Monitoring of tectonic deformation in the Gulf of California (Mexico) using GPS measurements

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Abstract. The Gulf of California, Mexico, was formed by the separation of the peninsular Baja California from North America between 12 and 6 Ma. Its transtensional fault system is composed of an *en échelon* array of long right-lateral transform fault segments that alternate with short extensional basins and spreading ridges. This tectonic setting provides a unique opportunity to study deformation associated with the transition of a continental strike-slip fault (the San Andreas Fault) to seafloor spreading (East Pacific Rise) along a rapidly moving fault system. The studied area is composed of the peninsular Baja California and the continental area of the Sonora and Sinaloa states of Mexico. We present the deformation field in the Gulf of California using GPS data observed between 2010 and 2015 and processed using the GAMIT/GLOBK software. The GPS stations used belong to the different networks namely SOPAC, CORS and the Mexican National red (*Red Geodésica Activa de Instituto Nacional de Estadística y Geografía*). A preliminary analysis of the deformation field will be related to the seismic events in the studied area.

Keywords. Baja California, GPS, tectonics

1 Introduction

The area of our investigation is the Gulf of California, extending 1400 km approx. from the fast spreading mid-oceanic ridge system of the East Pacific Rise to San Andreas Transform Fault. The continental rift is extensively exposed in the conjugate margin present in the Mexican states of Sonora and Sinaloa, where there is a zone of active basin-and-range type extension. Crustal deformation within the Gulf itself ranges from ridge transform structures in the south to minimal deformation in the north.

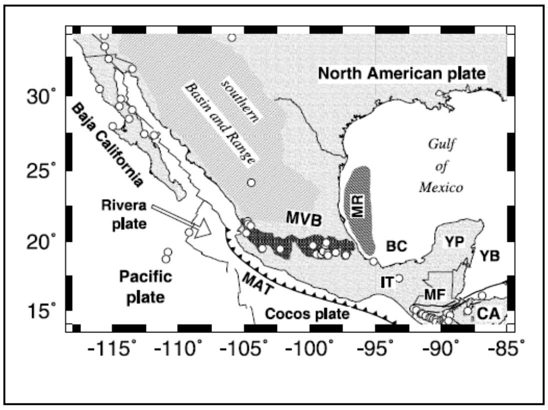

Fig. 1 Volcanic and tectonic setting of Mexico. Circles show locations of Quaternary volcanic eruptions. BC, Bay of Campeche; CA, Caribbean plate; IT, Isthmus of Tehuantepec; MAT, Middle America trench; MR, Mexican Ridges; MF, Motagua fault; MVB, Mexican Volcanic Belt; YB, Yucatan basin; YP, Yucatan Peninsula. (after Marquez-Azua and DeMets, 2003).

GPS technology provides a method to study the kinematics of crustal deformation of the Earth on an unprecedented scale and precision allowing to identify tectonically active faults an evaluate velocity of displacement.

The country of Mexico exhibits remarkable tectonic settings. Mexico incorporates parts of the Pacific, North American, and Caribbean plates (Figures 1 and 2) and accommodates northeastward subduction of the Rivera and Cocos plates beneath a 1500-km-long stretch of its Pacific coast.

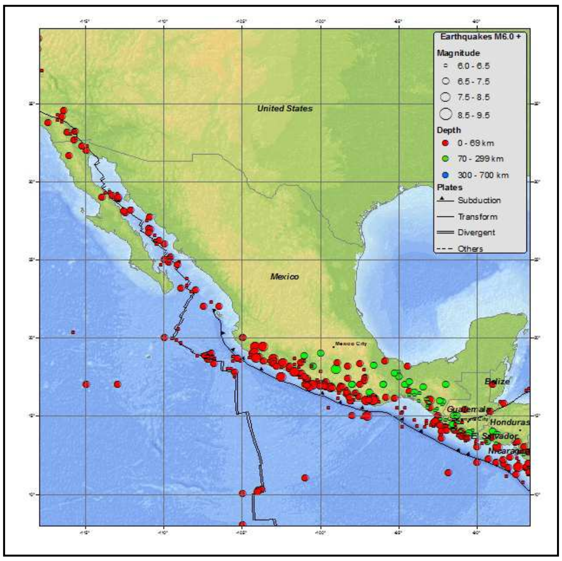

Fig. 2 Earthquakes of at least M6.0 in Mexico since 1900 (USGS report)

In addition, the country is bisected by the Mexican Volcanic Belt, which extends east-southeastward across Mexico for more than 1000 km above the 80–100 km depth contour of the subducting Rivera and Cocos plates (Pardo and Suarez, 1995).

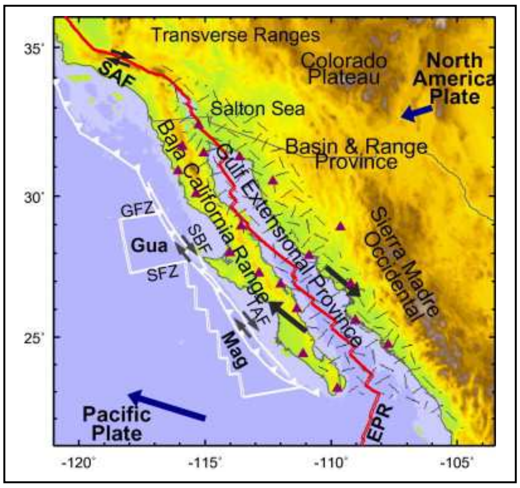

Fig. 3 Tectonic setting of the Gulf of California (after Zhang et Paulssen, 2012); SAF: San Andreas fault; EPR: East Pacific rise.

Earthquakes associated with the faults that separate these five tectonic plates, as well as earthquakes and volcanism within the volcanic belt constitute significant natural hazards to much of central and southern Mexico. The Gulf of California presents a moderate seismic hazard (Figure 2) whereas a M7.2 occurred in 2010.

3 Previous GPS monitoring in Mexico and Baja California

Marquez-Azua and DeMets (2003) combine velocities for 14 continuous GPS stations spanning Mexico and 173 additional continuous GPS sites on the North American and Pacific plates to study the large-scale deformation of Mexico on the period 1993 to June 2001.

These station velocities, which are derived from more than 6000 days of previously unused GPS data, provide the first view of the crustal velocity field of Mexico. Their key results are as follows: (1) Areas north of the Mexican Volcanic Belt, not including Baja California, move with the North American plate interior within the 1–2 mm/yr station velocity uncertainties. Station velocities for the Mexican Basin and Range are consistent with no present-day extension and yield an upper 95% limit of 1–3 mm/yr for any regional extension. (2) South of the Mexican Volcanic Belt, five of the six sites move significantly relative to the North American plate. All sites in the Yucatan Peninsula move toward the east at 3–4 mm/yr, possibly defining an independent Yucatan block. (3) Site velocities are consistent with limits of 0–4 mm/yr for present slip across the Mexican Volcanic Belt. (4) Tampico, on the gulf coast, exhibits eastward motion consistent with gravity sliding known to occur in the adjacent Mexican Ridges fold belt. (5) Southeastward motion of La Paz relative to the Pacific plate is consistent with the hypothesis that the Baja Peninsula is not fully attached to the Pacific plate. (6) Residual velocities for 160 North American plate GPS stations outside of Mexico exhibit no coherent regional patterns indicative of internal plate deformation.

Plattner et al. (2007) compute poles of rotation for the Pacific Plate and the Baja California microplates. For the Pacific plate, Plattner et al. (2007) use only continuous GPS (CGPS) with time-series longer than 3 years, giving time-series durations from 3 to 10 years.

Plattner et al. (2007) use also 32 episodic GPS (EGPS) measurements at sites in Baja California. These EGPS data vary from sites with at least three occupation episodes of two and more 24 hour days and a minimum total time span of 6 years since 1993.

Plattner et al. (2007) show that about ~90% of the full North America-Pacific plate relative motion rate (approximately 43–47mm/yr) is accommodated along the Gulf of California.

3 GPS network analyzed

Several permanent GPS stations exist in the studied area. The SOPAC network of continuous GPS sites exists throughout the field area, but CORS network and GPS sites operated for INEGI (Mexico), are concentred in Sonora, Sinaloa, Colima and Baja California states. We delimit our study region as described above to complement survey networks operated by other Institutions (USGS Geological Survey, TLALOC network, Universidad Autónoma de Mexico).

4 GPS Data processing

We analyze the data using the GAMIT software (King and Bock 2010) with standard procedures (Feigl et al. 1993). For each signal, the linear combination (LC) that removes first-order ionospheric phase delays is formed from the two GPS frequencies (Bock et al 1986).

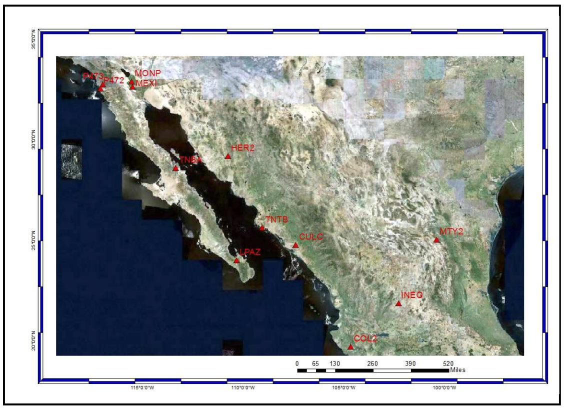

Fig. 4 Selection of 12 permanent GPS stations in Mexico and United States of America

Double difference LC phase residuals are inspected manually for cycle slips in the phase data, although virtually all cycle slips can be detected and corrected by automatic algorithms.

The GPS data are grouped as daily network solutions, with about 6 to 12 stations in each solution, holding fixed the coordinates of the IGS stations and the satellite ephemerides calculated at the IGS.

4 Preliminary results

We use the tsview is a Matlab script for plotting and editing time series. With tsview display the 3 components of site position, along with a list time series, and analyze time series of positions (Herring, 2003).

The La Paz station (LPAZ in Figure 3) shows a co-seismic in relation to the Mayor-Cucapah earthquake (in April 2010 M7.2), south of the U.S.-Mexico border.

5 Conclusion

In order to monitor the tectonic deformation of the Gulf of California, we use GPS measurements over a short period 2010-2015. Further processing of long period of GPS measurements will be performed. Moreover, episodic GPS campaigns should be planned in the states of Baja California, Sonora and Sinaloa (Mexico).

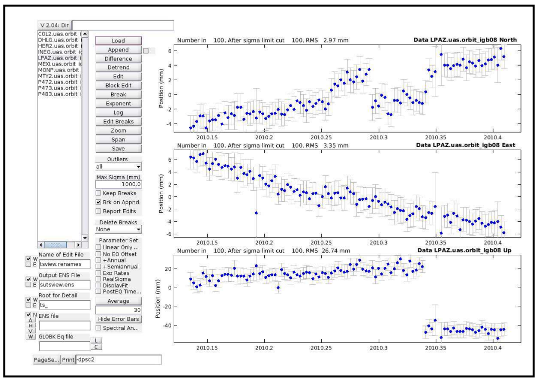

Fig. 3 Example of time series of positions at LPAZ as shown by the tsview program.

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