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Umhoefer et al., 2018, Breaching of strike-slip faults and successive flooding of pull-apart basins to form the Gulf of California seaway from ca. 8–6 Ma: Geology, https://doi.org/10.1130/G40242.1.

Supplemental File

TECTONIC RECONSTRUCTION METHODOLOGY

The foundation of our model for sequential breaching of pull-apart basins in the Gulf of California is a series of GIS-based palinspastic reconstruction maps of the Gulf of California-Salton Trough (GCAST) oblique rift. This GCAST reconstruction model is based on a synthesis of numerous datasets for crustal deformation over the past 11 Myr along a ~2,000 km-long, 400–500 km-wide swath of the Pacific–North America plate boundary, from San Bernardino, California (United States) to Puerto Vallarta, Jalisco (México). The study region is divided into discrete tectonic blocks (n=310) based on geologic, fault, geophysical, bathymetric, and topographic data. Spreading center and fault slip rates were acquired from available geologic data, cross-Gulf tie points, GPS studies, and seafloor magnetic data. These data serve as inputs for our GIS-based tectonic reconstruction, which sequentially restores crustal deformation between tectonic blocks in 1 Myr increments.

Regional Model Constraints

The GCAST reconstruction incorporates fundamental constraints on the magnitude and direction of Pacific–North America relative dextral-oblique motion provided by an updated global plate-circuit model (Atwater and Stock, 1998, 2013). Modern geodetic studies indicate that ~93% of modern-day Pacific-North America (PAC-NAM) plate motion is localized between the Baja California microplate (BCM) and NAM (Plattner et al., 2007) and suggest that the Baja California microplate (BCM) has never been completely coupled to the Pacific plate (Dixon et al., 2000). BCM-NAM geodetic rates also agree with the rates derived from documented offsets of late Miocene geologic tie points across the Gulf of California (e.g., Oskin et al, 2001; Oskin and Stock, 2003) and are incorporated in GCAST reconstruction steps back to 6 Ma. Thus, our preferred GCAST reconstruction uses 93% BCM-PAC coupling from the present back to 6 Ma. We assume BCM-PAC coupling of 60% between 6 and 7 Ma, and 25% between 7 and 11 Ma, to avoid unacceptable overlap of continental crustal blocks between Baja California and the Sierra Madre Occidental (on stable NAM). Using these coupling ratios and PAC-NAM stage Euler poles, we determine the azimuth and velocity of individual points on the BCM relative to NAM in 1 million year increments back to 11 Ma. This procedure accounts for minor clockwise rotation of BCM that occurred during oblique rifting, and shows how total BCM-NAM relative motion increases from north to south due to greater distance from the Euler pole.

Local Model Constraints

At a more local scale, the GCAST model attempts to incorporate all published information about the geometry, timing, and magnitude of late Miocene to present crustal deformation, including contemporary deformation rates from GPS studies (e.g., Meade and Hager, 2005; Plattner et al., 2007), the location, timing, style, and magnitude of late Cenozoic faulting from geologic and marine geophysical studies (e.g., Howard and Miller, 1992; Richard, 1993; Umhoefer et al., 2002; Aragon-Arreola and Martin-Barajas, 2007; Guest et al., 2007; Lease et al., 2009; Kluesner, 2011; Bennett et al., 2016), information about crustal structure from magnetic and gravity studies (e.g., Sandwell and Smith, 2009), estimates of the age and width of new oceanic crust in the Gulf of California (e.g., Lizarralde et al., 2007; Martín-Barajas et al., 2013), and unique geologic formations that serve as strain markers across the Pacific–North America plate boundary (e.g., Crowell, 1962; Gastil et al., 1973; Powell, 1993; Matti and Morton, 1993; Oskin et al., 2001; Oskin and Stock, 2003; Darin and Dorsey, 2013). Our 7 Ma reconstruction was compared to the seismic reflection study of the early Guaymas salt basin by Miller and Lizarralde (2013).

Fine-scale restoration of tectonic blocks along significant (>1 km offset) faults, across extensional (e.g. pull-apart and half-graben) basins, and by vertical-axis rotation is accomplished using a custom, open-source "Tectonic Reconstruct" ArcGIS add-in tool (https://astrogeology.usgs.gov/facilities/mrctr/gis-tools). The "Tectonic Reconstruct" tool takes a set of polygons depicting present day locations of tectonic blocks and sequentially restores displacement of their centroids along a vector specific to each time increment. The tool also allowed us to partition strain where appropriate into two components of strike-slip and normal motion. In the northern portion of the GCAST reconstructions in the Salton trough and northern Gulf of California regions, published onshore studies provide constraints for the incremental offset of many tectonic blocks. In the central to southern Gulf of California, most of the tectonic blocks are partially exposed as islands or more commonly fully submerged beneath the Gulf. Only a small number of these blocks have seismic data that constrain offsets between them. Therefore, in that portion of the GCAST reconstructions, we proportioned the total BCM-NAM relative motion with increasing offsets moving from the rift escarpment to the spreading centers as follows: we assigned lesser offset to coastal and near shore blocks, intermediate offset to submerged and island blocks of thinned continental crust, and large offset to ultra-thinned continental crustal blocks near the spreading centers.

EARLIEST MARINE DEPOSITS IN THE GULF OF CALIFORNIA

Numbered references in Figures 2 and 3 refer to the following published studies which provide age constraints for the earliest marine strata in the Gulf of California: 1 – McCloy et al., 1988; 2 – Martínez-Gutiérrez and Sethi, 1997; 3 – Miller and Lizarralde, 2013; 4 – Holt et al., 2000; 5 – Bennett et al., 2015; 6 – Delgado-Argote et al., 2000; 7 – Martín-Barajas et al., 1997; 8 – Boehm, 1984; 9 – Martín-Barajas et al., 2001; 10 – Dorsey et al., 2007; 11 – Dorsey et al., 2018; 12 – McDougall et al., 1999.

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