Tectonic history of the Los Angeles Basin: Understanding what formed and deforms the city of Los Angeles

Anne Rosett

The Los Angeles (LA) Basin is located in a tectonically complex region which has led to many, varying interpretations of its tectonic history. Current literature indicates that processes from rifting and extensional volcanism to pure dextral strike-slip displacement created the LA Basin. It appears that the best interpretation falls somewhere in between these two end-member explanations, with processes taking place simultaneously, including transtensional pull-apart faulting and clockwise rotation of large crustal blocks. With a comprehensive literature review, and paleomagnetic, seismic refraction, and low-fold reflection survey data, I intend to clarify what tectonic processes actually occurred in the LA Basin, and how that information can provide insight for other research in the region, as well as predicting future seismic hazards in the highly-populated, economically significant, and culturally rich city of Los Angeles.

Introduction

The Los Angeles Basin sits in a tectonically-active region, and thus, a large amount of research exists regarding its formation and tectonic history. However, due to several different fault systems, complex structures, and angles of slip currently affecting the area, the history of the LA Basin is not decisive; there are some discrepancies in the current literature regarding the tectonic and subsidence histories of the LA Basin. These include basin formation due to extensional rifting and basaltic volcanism (Crouch and Suppe, 1993; McCulloh and Beyer, 2003), transtensional pull-apart processes (Schneider et al., 1996), and dextral strike-slip faulting (Howard, 1996). My research question attempts to conduct an extensive literature review to address which interpretation best describes which processes actually happened to which fault systems in the region and led to the LA Basin as we know it today. Beyond that, I will use that information to conduct productive research for predicting potential tectonic-related hazards in the future. Even incremental contributions to understanding the activity and history of this region are important due to the very large, dense population and value of infrastructure and property that currently exists in Los Angeles.

Also, answering this question is essential for understanding aspects of the LA Basin that contribute to other research, such as sediment provenance. This is particularly important given the uncertainty surrounding paleo-currents and paleo-deltas of the Colorado River, which is geographically extensive and carved out the Grand Canyon. Howard (1996) used chronostratigraphic and palinspastic data to suggest that the Colorado River delta prior to 12 Ma was in what is now the LA Basin, but 300 km to the left of its current location. This study indicates that a large portion of the basin fill from this time, particularly in the Sespe Formation, is composed of sediments deposited by the Colorado River. This is opposed by Bright et al. (2016), which states that Colorado River gravels only appeared west of the Grand Canyon after 6 Ma, with a current and delta forming in the Gulf of California region south of the LA Basin. Understanding the tectonic history of this time could help provide some insight into this much-debated question regarding a major waterway in America.

This question can also make contributions to understanding the presence of the La Brea Tar Pits. The Tar Pits are paleontologically fascinating; over 3 million late Pleistocene plant and animal fossils have been found there (Friscia et al., 2008). Understanding the tectonic activity that formed and still allows these tar pits to remain in the LA Basin today is important for other research, and contributes to the culture of LA because the Tar Pits are a major tourist attraction.

To better understand the interpretations and discrepancies in the LA Basin literature, it is essential to study basin classification and each basin's associated characteristics.

Extensional Rifting and Basaltic Volcanism

Active rift systems occur in regions with high surface heat flow, crustal thinning, volcanic activity, relatively high earthquake activity, and gravity anomalies (Allen and Allen, 2013). Earthquake activity is typically due to normal faulting which indicates that the direction of extensional rifting is orthogonal to the fault. However, rift systems can also be attributed to strike-slip faulting given the correct orientation to the direction of extension.

Both Crouch and Suppe (1993) and McCulloh and Beyer (2003) assert that the rifting process that formed the LA Basin began during the early Miocene as a result of 70-90° clockwise rotation of the western Transverse Ranges, which are directly north of the LA Basin. The timing and magnitude of the Transverse Ranges' rotation is supported by paleomagnetic declination data from Oligocene through Miocene aged rocks, all of which indicate clockwise rotation (Luyendyk, Kamerling, and Terres, 1980).

Transtensional Pull-Apart Processes

Basins that form due to strike-slip faulting have low surface heat flow, abundant seismic activity, are relatively small, and structurally complex due to oblique movement creating areas of contraction and other areas of extension within the same basin (Allen and Allen, 2013). Crustal blocks of a basin in strike-slip regimes also may undergo rotation, such as described above for the Transverse Ranges. Allen and Allen (2013) also reference the clockwise rotation of the Transverse Ranges due to displacement along the San Andreas Fault. This model contradicts Luyendyk, Kamerling, and Terres (1980), who found that the San Andreas became active in the late Miocene and probably ended the clockwise rotation of the Transverse Ranges. This would suggest that if strike-slip processes contributed to the initial formation of the LA Basin, it was not due to the San Andreas Fault. Regardless, strike-slip basins that form as a result of rotation about a vertical axis are classified as “transrotational,” (Busby and Azor, 2012).

Schneider et al. (1996) indicates that the LA Basin is likely classified as transtensional, which includes strike-slip, pull-apart basins. Busby and Azor (2012) define transtensional basins as ones that form associated with releasing bends. This indicates that while transform faulting is occurring, there are areas that are undergoing extension, lithospheric thinning, and subsidence.

Dextral Strike-Slip Faulting

The characteristics of a basin due to strike-slip faulting are similar to the ones described above for transtensional pull-apart processes. However, pure dextral slip would indicate a pure shear environment in which originally perpendicular principal strain axes would remain perpendicular after deformation. This situation describes plane strain, in which there is no strain in the vertical direction (Allen and Allen, 2013).

Howard (1996) found that all sediments older than 8 to 10 Ma in the LA Basin are dextrally offset by about 300 km, and thus supports a model of basin formation that includes substantial right-lateral displacement. Howard (1996) uses this interpretation to show that the Colorado River flowed out to the Pacific Ocean through the region that is now in LA Basin, but, at the time, would have been 300 km to the left. This scenario of pure dextral slip seems unlikely in the case of the LA Basin given the known transrotational and orogenic events that occurred since the beginning of the Miocene.

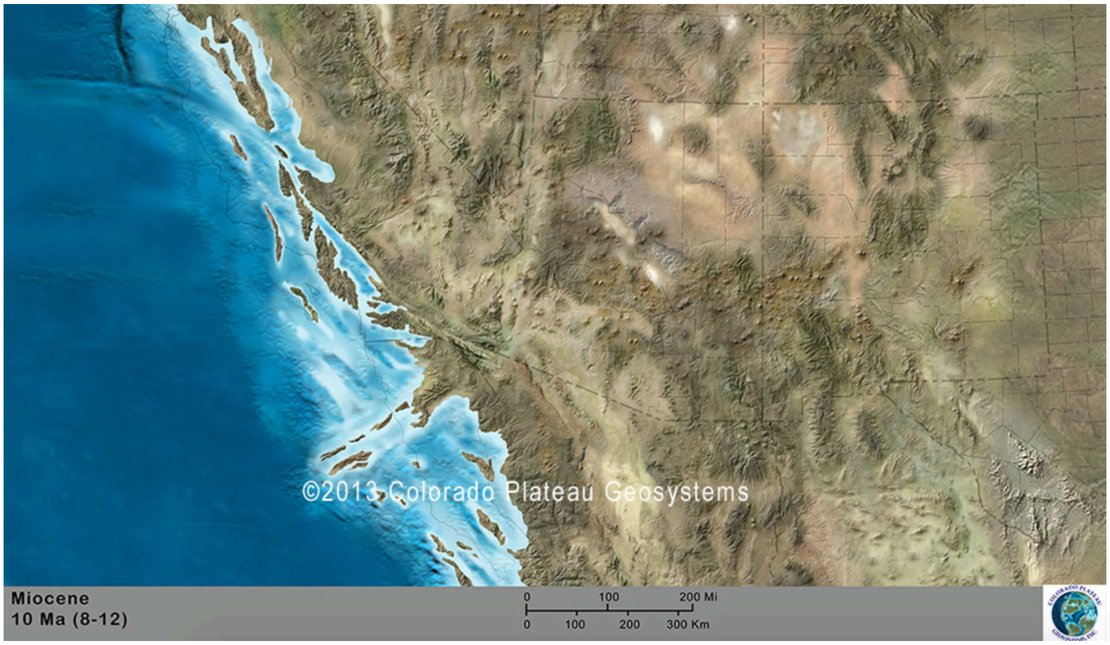

Figure 1. A "Deep Time Maps™: maps of ancient Earth" showing CA around 10 Ma (roughly 7.4 years after subsidence and extension began). Transverse Ranges seen sticking out into the Pacific Ocean like a small peninsula, south of the modern US – Mexico border superimposed on the map. This supports Sawyer, Hsui, and Toksoz's (1987) and Howard's (1996) findings that indicate substantial dextral offset of the LA Basin since the Miocene (map; modified from Blakey, 2013).

Based on these varying analyses and their implications to research, it is essential to dig further into the extensive work that addresses these questions of tectonic history in the LA Basin. An in-depth literature review would provide a concise report of what interpretations still hold and what research needs to be done or redone.

In the literature review, to address these questions, I am primarily going to investigate studies that used seismic and paleomagnetic data. Fuis et al. (2001) used seismic refraction and low-fold reflection surveys resulting in one cross section from Seal Beach to the Mojave Desert. In the LA Basin, this cross section strikes northeast from Seal Beach to the northern extent of the Whittier Fault, which is an active dextral strike-slip fault located in the Northeast Block of the LA Basin (Sawyer, Hsui, and Toksoz, 1987). Fuis et al. (2001) addressed questions regarding crustal structure, sediment thickness, and tectonics of southern California that cannot be observed from the surface. In particular, Fuis et al. (2001) identified active crustal décollements and blind thrust faults from the cross section.

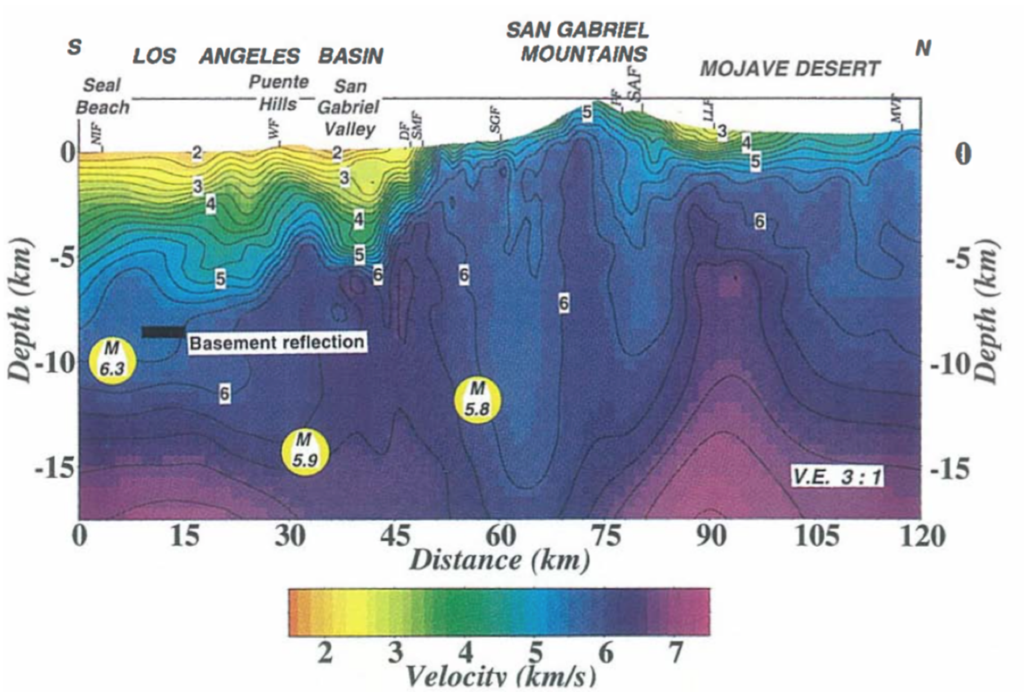

Figure 2. Seismic velocity model along transect line from seismic refraction and low-fold reflection surveys data from Seal Beach to the Mojave Desert resulting from . Hypocenters for 3 earthquakes projected onto the model and sediment-basement depth indicated by black bar (Fuis et al., 2001).

Scott Hornafius et al. (1986) used paleomagnetic data from Neogene rocks in the Santa Ynez Range, the Santa Monica Mountains, the Northern Channel Islands, and the San Gabriel block to show that the clockwise rotation of this region during the early Miocene occurred over large crustal areas. From these data, they suggest that the California coastline underwent about 200 km of dextral displacement, and that large-scale, rapid rotation of crustal blocks was the result of dextral shear between the Pacific and North American plates.

From the literature that I have investigated so far, it is apparent that a combination of different tectonic processes and movement of varying crustal blocks in the southern California region contributed to the formation and subsidence of the LA Basin. It seems that both extensional rifting due to large-scale clockwise rotation of crustal blocks and simultaneous dextral strike-slip faulting led to the formation and substantial displacement of the LA Basin beginning in the early Miocene. What I intend to further discover with this project is more specificity regarding which faults led to this dextral displacement and to what degree did each process contribute to LA Basin formation and subsidence. And again, to better inform efforts for determining potential seismic, tectonically-driven hazards in Los Angeles.

Geologic Setting

The LA Basin is located in southern California and has as much as 10 km thick sediment accumulated since the middle Miocene and is underlain by pre-Tertiary metamorphic and plutonic igneous rocks (Yerkes et al., 1965). It is surrounded by mountains, including the western Transverse Ranges, Santa Monica Mountains, Santa Ana Mountains, and San Joaquin Hills, which are included in the Peninsular Ranges. It is divided into 4 sections with one section, the Southwestern Block, extending into the Pacific Ocean. Marine sediment and facies located in sections that are now completely terrestrial indicate that during the LA Basin's development, much of the Los Angeles area was below sea level (Sawyer, Hsui, and Toksoz, 1987).

The LA Basin is characterized by both marine and non-marine, mostly fluvial, facies that, in some areas of the basin, are interbedded (McCulloh and Beyer, 2003). Most of the non-marine facies, including the geographically extensive Sespe Formation, are composed of fluviatile sandstones and gravels. In some locations, the terrestrial facies are interbedded with the fossiliferous shallow marine facies of the Topanga Formation (McCulloh and Beyer, 2003). While a fair amount of the fluvial sediments appears to be locally derived, there are also paleocurrent indicators, including clast size gradations, that indicate that most of the sediment fill in the non-marine facies of the basin was transported from the northeast. (McCulloh and Beyer, 2003). This interpretation, at least when considering the Sespe Formation, is in support of Howard (1996)'s findings described earlier. These terrestrial facies and basin fill indicate a fluvial environment, while the interbedded portions possibly indicate the presence of a delta that experienced regressive and transgressive periods.

The marine facies of the Vaqueros and Topanga Canyon Formations dominate most of the western portion of the basin with easternmost extent reaching the Santa Monica Mountains where it interbeds with the fluvial facies of the Sespe Formation (McCulloh and Beyer, 2003). The marine strata include interbedded sandstones and muds as well as distinctive schist breccia called the San Onofre Breccia (McCulloh and Beyer, 2003). Biofacies reported by McCulloh and Beyer (2003) include foraminifera and the "provincial" mollusk *Turritella ocoyana* which further supports the interpretation of previous marine environment dominating much of the currently terrestrial, western portions of the basin.

Research Plan

My research plan includes reproducing two main types of data in the LA Basin: paleomagnetic (similar to those collected by Scott Hornafius et al. (1986)) and seismic refraction and low-fold reflection surveys (similar to those collected by Fuis et al. (2001)). I intend to use these authors' methods to verify that I am explaining the same phenomena, and then will also apply those methods in other areas within the LA Basin.

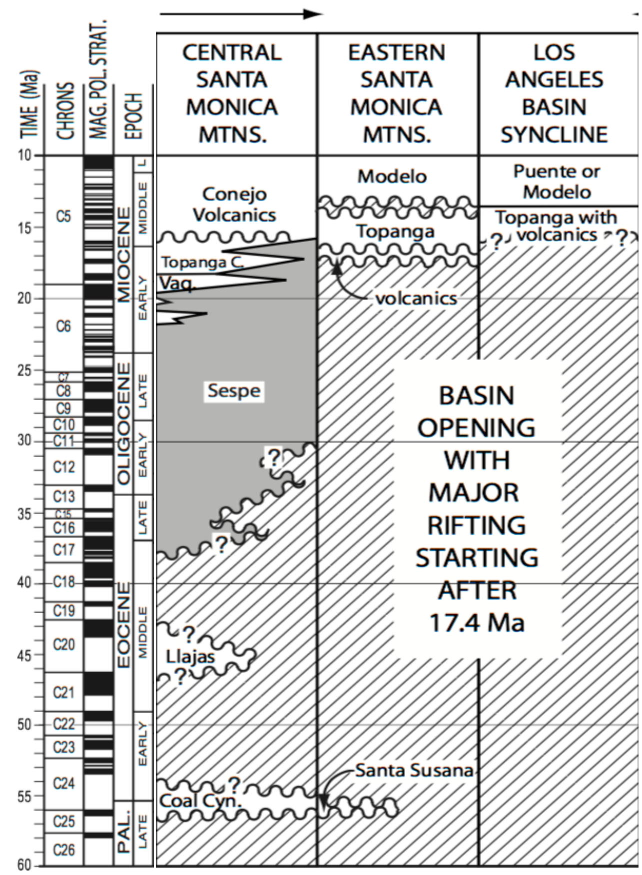

Figure 3. Chronostratigraphic figure depicting facies over time (60 – 10 Ma) in the region that includes the volcanics in the central trough of the LA Basin. Diagonal stripes indicate lacunas (hiatuses in the geologic record). Wavy lines indicate unconformities (modified from McCulloh and Beyer, 2003).

A research area of interest that seems to be relatively untouched by paleomagnetic methods is around the perimeter of the central trough in the LA Basin. This section of the Basin has partly submarine, middle Miocene volcanic rocks and has two faults on either side: the Las Cienegas and the Newport-Inglewood zone (McCulloh and Beyer, 2003). This suggests that during the crustal rotation, rifting, and dextral slip in the area, there was localized volcanic upwellings in the LA Basin. I intend to collect samples with accurate orientation from the central trough area, and follow the methods used by Scott Hornafius et al. (1986) to find paleomagnetic declination of those volcanic rocks.

I also plan to recreate the seismic refraction and low-fold reflection surveys that Scott Hornafius et al. (1986) used in their study. However, I intend to expand upon this and focus on other major faults in the LA Basin. These include the active strike-slip Newport-Inglewood and Elsinore-Whittier faults. The Newport-Inglewood fault slips about 1 mm/yr and the Elsinore-Whittier fault slip about 5 mm/yr due to interactions between the North America and Pacific plates (Sleep, 2015). I also plan to create a cross-section in the region where the La Brea Tar Pits are located. The additional information collected on these previously unexamined faults should help clarify the tectonic history of the LA Basin.

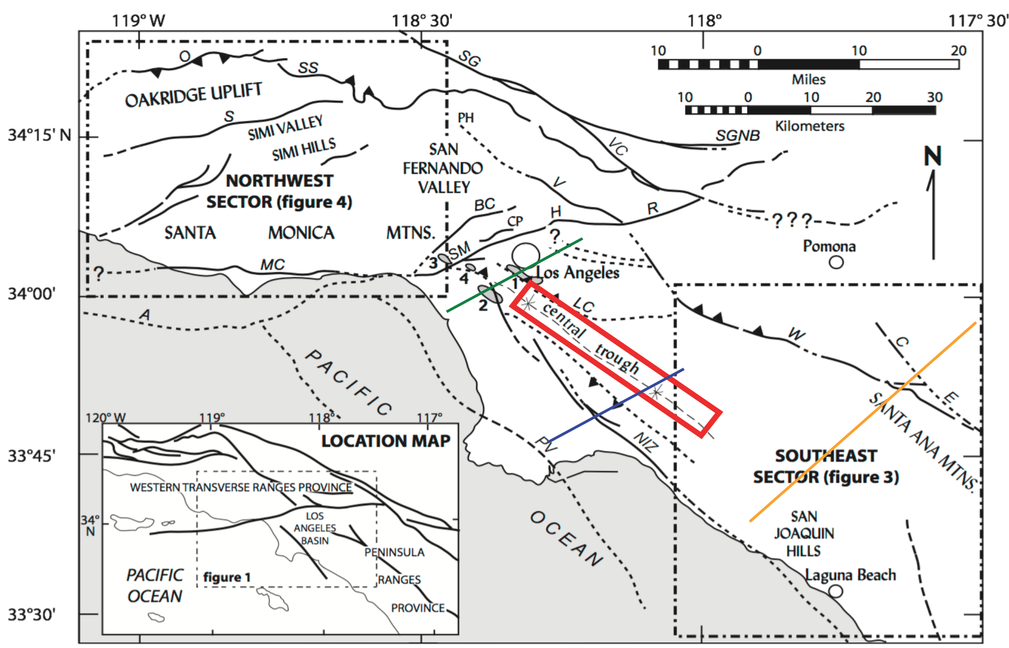

Figure 4. Map view of the LA Basin with fault systems and other structural features. Faults of interest for cross-sections (blue and orange lines) include: E—Elsinore, NIZ—Newport-Inglewood zone, and W—Whittier. Green line indicates location for La Brea Tar Pits cross-section. Red box indicates location of central trough (map; modified from McCulloh and Beyer, 2003).

Outcome

The results of the literature review and data collection will result in a more concise understanding of what tectonic processes actually formed the LA Basin. I will also create updated palinspastic reconstructions from these data to make the findings more accessible. In particular, the paleomagnetic data will help inform how much rotation occurred in the LA Basin contemporaneously to rotation of large crustal blocks that affected the western Transverse Ranges. The cross-sections from the seismic refraction and low-fold reflection surveys will provide information regarding subsurface structures of and around major strike-slip faults in the LA Basin. From these, I hope to provide a better understanding of the faults in the region that contributed to the substantial dextral displacement during the Miocene, the formation of the La Brea Tar Pits, and effect Los Angeles today as possible sources of earthquakes.

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