12 Incipient Faulting near Lake Pillsbury, CA

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12.1 Anomalous Seismic Activity

In March of 2000, a swarm of earthquake activity lasting approximately six months and culminating in an \( M_w \) 4.4 earthquake occurred along the eastern edge of the Middle Mountain block (Hayes et al., 2006), between the Ma’acama and Bartlett Springs faults in Northern California. The swarm began with a month-long period of intense microseismicity that preceded the shallow \( M_w \) 4.4 event which occurred on May 17, 2000. Over the course of the next three months, microseismicity at depths of 3 to 8 km propagated to the southeast and eventually a second large \( M_w \) 4.0 earthquake occurred at the southeast end of the seismic lineament. The area sustained elevated earthquake activity for the next 6 years and between 2006 and 2007 another intense swarm culminated in a \( M_w \) 4.8 earthquake. This event was similarly preceded by very energetic microseismicity.

Precise earthquake locations (Waldhauser et al., 2008) from both swarms illuminate discontinuous, geometrically complex structures that roughly parallel the strike of faults within the San Andreas fault (SAF) system. In the south, a small fraction of the seismicity occurs shallowly around 2 km, however the majority of hypocenters are aftershocks of the \( M_w \) 4.0 event and cluster between 5 and 8 km depth on a plane dipping 70°NE. Continuing northwest along strike, seismicity shallows and localizes onto a near vertical structure extending from 1 to 6 km depth, near the hypocenter of the \( M_w \) 4.4. Further north, shallow, diffuse seismicity extends between the surface and 3km depth and hypocenters are located as much as 3 km off fault. In this same area deeper events, which mostly consist of aftershocks from the \( M_w \) 4.8 event, delineate a N-S striking plane dipping 70°NE.

To further constrain the geometry and structural maturity of the lineament we compute double-couple focal mechanisms for all events with 25 or more first motion observations and full-waveform moment tensors for the three largest events (Hardebeck and Shearer, 2002; Dreger et al., 2000). First motion solutions generally have large uncertainties in strike, rake, and dip, which are primarily due to gaps in the takeoff angle particularly before the installation of the Transportable Array stations prior to the 2006-7 swarm. However, the similarity of nearby first motion solutions and agreement with the independent analyses of McLaren et al. (2007) and Hayes et al. (2006) suggests that solutions may be useful in constraining lineament geometry. Figure 1 compares the moment tensor solutions for the 2000 \( M_w \) 4.4, 2000 \( M_w \) 4.0, and 2007 \( M_w \) 4.8 earthquakes, populations of fault plane solutions of nearby earthquakes, and the geometry defined by the earthquake hypocenters. In the southern swarm, focal mechanism and moment tensor solutions indicate that nearly all events are right-lateral strike-slip earthquakes that occur on structures striking parallel to the Ma’acama and Bartlett Springs faults. Some of these events, particularly those associated with the \( M_w \) 4.4, occur on vertically dipping fault planes, however others, including the \( M_w \) 4.0, slip on more shallowly dipping structures that are not optimally oriented. In the northern swarm, mechanisms are highly variable and consist of predominantly right-lateral strike-slip and normal faulting events. Both the first motions and hypocenter locations indicate faulting below 2 km depth occurs along a N10°W trending plane that dips 70°E. The moment tensor solution for the \( M_w \) 4.8 has a similar strike but dips 79° which differs by 9° from the dip inferred from the hypocenters. The 90% confidence interval on the dip angle of \( M_w \) 4.8 solution spans a dip range that includes 70°, however the 80% confidence intervals do not, suggesting this event may have slipped on a plane with a different orientation than that delineated by the hypocenters. While uncertainties in the best-fit geometries were not considered we note this discrepancy because it suggests that the \( M_w \) 4.8 may have involved the fracture of intact rock.

12.2 Comparison to Incipient Faulting in the Field

Earthquake swarms are a relatively common occurrence and have been linked to aseismic slip, pore fluid migration, and volcanic activity (see Roland and McGuire, 2009 and references therein). The geometric complexity, earthquake hypocenters, and focal mechanisms of the seismic lineament suggest that it may be an incipient fault (Bauden et al., 1999). Similar fault geometries have been documented extensively in field studies of the initial stages of shear zone development (Martel, 1988). Structural complexity arises for two reasons. First, faults take advantage of preexisting weaknesses, which may have developed in either an earlier tectonic event or in the same tectonic event (Crider and Peacock, 2004). These zones of weakness typically have poor connectivity and are generally neither coplanar nor optimally oriented. Second, to form a through-going fault while still exploiting these weaknesses, secondary fractures are generated in response to the stress fields surrounding en echelon cracks (Martel et al., 1988; Martel, 1990; Crider and Peacock, 2004). Similarly, the seismic lineament is
structurally segmented with abrupt changes in geometry between the south and north and a general lack of any geometric definition in the shallow events in the north. The colocation of the lineament and the Bucknell Creek fault in the south and with relic dipping structures in the north suggests the lineament may be exploiting pre-existing structure as it propagates northward. Additionally, many of the normal events have strikes coincident with the ~N-S direction of the maximum compressive stress suggesting that small-scale extensional faulting occurs between the two structures.

Focal mechanisms and deformation style also vary markedly along strike. In the south first motion mechanisms are mostly right-lateral strike-slip events that have strikes and dips consistent with the structure delineated by the seismicity. In the north, both the variety of mechanisms and the inconsistency between the geometry delineated by the seismicity and that of the moment tensor for the \( M_w \) 4.8 event argue for immature faulting. In a survey of northern California focal mechanisms, Castillo and Ellsworth (1993) find that right-lateral transform motion between the North American and Pacific Plates often occurs on structures dipping between 50° and 75°. They suggest these structures may have formed as reverse faults in the forearc of the Cascadia subduction zone and furthermore, due to the way in which this deformation is accommodated, will eventually evolve to a more energetically favorable, vertical strike-slip geometry common to the majority of faults within the SAF system (Castillo and Ellsworth, 1993). If their interpretation is correct, then the \( M_w \) 4.8 earthquake likely reflects the transition between these two styles of deformation because it occurred as a strike-slip event on a 70° dipping structure about 10 km north of the more mature southern section of the Bucknell Creek lineament. Focal mechanisms on the Bartlett Springs fault at roughly the same latitude exhibit a similar transition between deformation on dipping planes to near-vertical geometries (Castillo and Ellsworth, 1993). This suggests that pre-existing zones of weakness localize deformation which concentrates stresses and facilitates the development of a new fault zone in a mechanically favorable orientation.

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12.4 References


