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Role of Structural Inheritance on the Evolution of Rift-Scale Segmented Normal Faults: Examples From Northern California and the East African Rift

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ABSTRACT

Oil and gas reservoirs in extensional environments are commonly associated with segmented normal faults that create permeability barriers and result in compartmentalized systems. For example, producing fields on the North Slope of Alaska are structurally controlled and reflect the end-result of multiple phases of extensional deformation dating back to the Devonian and culminating in Early Cretaceous break-up and opening of the Canada Basin. In response to this polyphase history, structural inheritance was likely an important component of the ultimate reservoir architectures that developed. Analog field studies of structural inheritance in normal faulting environments provide insights into the role of pre-existing structures during polyphase deformation events. We examine two examples from active extensional systems in predominantly volcanic rocks, in which fault architectures and fault evolutionary evidence is well preserved: (1) The Hat Creek fault is the most prominent normal fault within the broadly extending region of the Modoc plateau in Northern California. The fault dissects Late Pleistocene lavas, the oldest of which (~925 ka; maximum cumulative throw of ~570 m) indicates that the Hat Creek fault developed in <1 Myr. Despite this young age, the fault experienced a multi-stage growth history that resulted in three systems of segmented scarps with different ages, throws, and orientations. Our field analysis unraveled the relative timing of fault segments and control on localization by structural inheritance. A polyphase fault history that responded to a progressive ~45[sup]o[/sup]Â clockwise rotation of the horizontal principal stresses resulted in significant fault geometric complexity as older structures were reactivated during consecutive fault growth stages over a relatively short time frame (~1 Myr). (2) Normal faults dissect volcanic rocks of an active rift system in the ~7 Ma southern Kenya (Magadi) portion of the East African Rift Valley. Stress rotations occurred over similar time scales to those at the Hat Creek fault in response to migrating magma systems and rift segment interactions during the early stages of continental rifting. Evolving fault systems in the Magadi rift were strongly influenced by structural inheritance associated with tectonic fabrics within underlying Proterozoic rocks of the Mozambique orogenic belt. This inheritance is manifested in the segmentation of the primary rift border fault, the Nguruman fault, which exhibits a ~1600-m-high surface scarp but has likely accrued ~5 km of cumulative throw. Younger faults at the rift center, such as the <1.4 Ma Kordjya fault, have developed prominent fault scarps (up to 350 m high) oblique to the dominant rift-fault fabric and parallel to the inherited basement fabric. At the surface, this fault has also cannibalized Pliocene rift faults in an en echelon pattern in response to temporal changes in the horizontal principal stress orientations. The Hat Creek fault and East Africa Rift examples reveal the importance of evolving fault complexity in extending basins influenced by polyphase faulting episodes that resulted from changes in both regional-scale (e.g., plate boundary forces) and basin-scale (e.g., rift-axial magmatism) rift processes. Such changes strongly impact rift basin evolution, the distribution of depositional sequences, fluid pathways, and reservoir compartmentalization.