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Plate Kinematic model of the NW Indian Ocean and derived regional stress history of the East African Margin

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Starting with the break up of Gondwana, the northwest Indian Ocean and its continental margins in Madagascar, East Africa and western India formed by divergence of the African and Indian plates and were shaped by a complicated sequence of plate boundary relocations, ridge propagation events, and the independent movement of the Seychelles microplate. As a result, attempts to reconcile the different plate-tectonic components and processes into a coherent kinematic model have so far been unsatisfactory. A new high-resolution plate kinematic model has been produced in an attempt to solve these problems, using seafloor spreading data and rotation parameters generated by a mixture of visual fitting of magnetic isochron data and iterative joint inversion of magnetic isochron and fracture zone data. Using plate motion vectors and plate boundary geometries derived from this model, the first-order regional stress pattern was modelled for distinct phases of margin formation. The stress pattern is correlated with the tectono-stratigraphic history of related sedimentary basins.

The plate kinematic model identifies three phases of spreading, from the Jurassic to the Paleogene, which resulted in the formation of three main oceanic basins. Prior to these phases, intracontinental 'Karoo' rifting episodes in the late Carboniferous to late Triassic had failed to break up Gondwana, but initiated the formation of sedimentary basins along the East African and West Madagascan margins.

At the start of the first phase of spreading (183 to 133 Ma) predominantly NW – SE extension caused continental rifting that separated Madagascar/India/Antarctica from Africa. Maximum horizontal stresses trended perpendicular to the local plate-kinematic vector, and parallel to the rift axes.

During and after continental break-up and subsequent spreading, the regional stress regime changed drastically. The extensional stress regime became restricted to the active spreading ridges that in turn adopted trends normal to the plate divergence vector. Away from the active ridges, compressional horizontal stresses caused by ridge-push forces were transmitted through the subsiding oceanic lithosphere, with an SH max orientation parallel to plate divergence vectors. These changes are documented by the lower Bajocian continental breakup unconformity, which can be traced throughout East African basins. At 133 Ma, the plate boundary moved from north to south of Madagascar, incorporating it into the African plate and initiating its separation from Antarctica. The orientation of the plate divergence vector however did not change markedly.

The second phase (89 – 61 Ma) led to the separation of India from Madagascar, initiating a new and dramatic change in stress orientation from N-S to ENE-WSW. This led to renewed tectonic activity in the sedimentary basins of western Madagascar.

In the third phase (61 Ma to present) asymmetric spreading of the Carlsberg Ridge separated India from the Seychelles and the Mascarene Plateau via the southward propagation of the Carlsberg Ridge to form the Central Indian Ridge. The anti-clockwise rotation of the independent Seychelles microplate between chrons 28n (64.13 Ma) and 26n (58.38 Ma) and the opening of the short-lived Laxmi Basin (67 Ma to abandonment within chron 28n (64.13 – 63.10 Ma)) have been further constrained by the new plate kinematic model. Along the East African margin, SH max remained in a NE – SW orientation and the sedimentary basins experienced continued thick, deep water sediment deposition.

Contemporaneously, in the sedimentary basins along East African passive margin, ridge-push related maximum horizontal stresses became progressively outweighed by local gravity-driven NE-SW maximum horizontal stresses trending parallel to the margin. These stress regimes are caused by sediment loading and extensional collapse of thick sediment wedges, predominantly controlled by margin geometry.

Our study successfully integrates an interpretation of paleo-stress regimes constrained by the new high resolution plate kinematic and basin history to produce a margin scale tectono-stratigraphic framework that highlights the important interplay of plate boundary forces and basin formation events along the East African margin.