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Geophysical constraints on extensional deformation at slow-spreading rate ridges and the evolution of oceanic core complexes

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Oceanic core complexes expose lower crustal and upper mantle rocks on the seafloor by tectonic unroofing in the footwalls of large-slip extensional detachment faults. The common occurrence of these structures in slow and ultra-slow spreading oceanic crust suggests they accommodate a significant component of plate divergence. However, the sub-surface geometry of oceanic detachment faults remains unclear. Competing models involve either: (a) displacement on planar, low-angle faults with little tectonic rotation; or (b) progressive shallowing by rotation of initially steeply dipping faults as a result of flexural unloading (the "rolling-hinge" model). We address this debate using paleomagnetic remanences to test for tectonic rotation of a unique 1.4 km long footwall section of gabbroic rocks recovered by Integrated Ocean Drilling Program (IODP) Expedition 304/305 to Atlantis Massif oceanic core complex on the Mid Atlantic Ridge (MAR). This forms an inside-corner bathymetric high at the intersection of the Atlantis Transform Fault and the MAR. The central dome of the massif exposes the corrugated detachment fault surface, which has tectonically unroofed a faulted and complexly layered footwall section dominated by gabbroic lithologies with minor ultramafic rocks. The core (IODP Hole U1309D) reflects the interplay between magmatism and deformation prior to, during, and subsequent to a period of footwall displacement and denudation associated with slip on the detachment fault.

Palaeomagnetic remanence directions are routinely used as markers for tectonic rotation in a variety of tectonic settings, However, in ODP and IODP hard rock core materials their utility is limited by the lack of azimuthal control on the orientation of core samples. Individual core pieces are free to rotate within the core barrel, effectively randomising remanence declinations and allowing only the inclination of the magnetic vector to be used in tectonic analyses. In these circumstances, tectonic rotation may be inferred from differences between observed and reference inclinations, but the amount of rotation and the orientation of the rotation axis cannot be constrained directly. Robust, quantitative constraints on tectonic rotation parameters can only be obtained from fully oriented palaeomagnetic data (i.e. both remanence declination and inclination), yet current IODP hard rock drilling technologies do not permit collection of oriented drill core samples.

For the first time we have overcome this limitation by independently reorienting core pieces to a true geographic reference frame by correlating structures within individual pieces with those identified from oriented geophysical imagery of the borehole wall. This allows reorientation of paleomagnetic data and subsequent tectonic interpretation without the need for a priori assumptions on the azimuth of the rotation axis. The resulting dataset from Atlantis Massif indicates a 46°±6° counterclockwise rotation of the footwall around a MAR-parallel horizontal axis trending 011°±6°. This provides unequivocal confirmation of the key prediction of flexural, rolling-hinge models for oceanic core complexes. The data demonstrate that the Atlantis Massif detachment fault initiated at a dip of at least 50° and subsequently rotated to its present day low angle geometry during extensional deformation and unroofing.