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Dip analysis as a tool for estimating regional kinematics in extensional terranes: Reply

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We welcome the opportunity to explore further the usefulness and limitations of applying a fundamental structural concept to the plethora of geophysical data that structural geologists are increasingly incorporating into their interpretations. Ring and Betzler's Discussion of our use of dip analysis (Scott *et al.* 1994) in a rifted terrane with which they are familiar, expanded on many of the limitations and/or pitfalls that were listed in the original manuscript. We agree wholeheartedly that all relevant geological factors must be considered in any interpretation of dip data, including multiple phase deformation, pre-existing topography, depositional dips, etc. Nonetheless, the method of dip analysis in the interpretation of geophysical data is nothing more than converting standard geological practice to the interpretation of these data (i.e. computing a true dip from two apparent dips where they are measurable). This is an *observable, quantifiable* geometric parameter that must be consistent with any structural evaluation of the available data. The advantage of dip measurements thus derived is that they are not 'qualified' by contouring or 'smoothed' by gridding of irregularly spaced profile data, both processes that can give misleading information about the dip at a point where we can actually measure it.

The interpretation of the consistency of empirical dip data in the Tanganyika and Malawi rift zones did not lead so much to an 'inaccurate interpretation' of the extension direction, but rather to a more accurate measurement and interpretation of the *net extension* during the rift forming deformation event(s). Rose diagrams of the entire data set and various sub-sets clearly support an overall west-northwest *net extension*. Other prominent dip azimuths are nearly east–west and northwest–southeast (fig. 5, Scott *et al.* 1992). A dip analysis of a series of different time horizons (whose ages were determined from well data) on reflection seismic data from the Rukwa rift zone (Scott 1994) confirms the timing, structural relationship and *kinematics* of two Tertiary extensional events as proposed by others for other segments of the rift system (e.g. Strecker *et al.* 1990, Ring *et al.* 1992). The multiphase Tertiary deformation in the rift zone was discernible in the Rukwa data, *despite* a clearly recognizable Permo-Triassic basin-forming event. Further, rotation of dips through time is consistent with rotation of these infra-rift blocks about vertical axes as predicted by onshore kinematic analysis of exposed fault surfaces which indicate an early nearly east–west (280°–290°) extensional and later NW–SE strike-slip deformation event in the Rukwa area (Chorowicz *et al.* 1987, Daly *et al.* 1989). Unfortunately, research results are not always communicated to the community in a logical order, but it seems clear that as the measurable, quantifiable geological observables from the East African Rift System are disseminated by various teams, we are arriving at an increasingly consistent tectonic history for this classical intra-cratonic rift system.

Ring & Betzler (this issue) point out that pre-existing Karroo (Permo-Triassic) rifts underlie portions of the Cenozoic Tanganyika and Malawi rift zones (their fig. 1) and thus acoustic basement is not everywhere the same within the rift zone. The Karroo rift zones generally cross-cut the Malawi rift zone at a high angle, and thus they should underly only small distinct portions of the younger rift. One might predict that measured dips through these zones may be 'anomalous' with respect to the rest of the lakes. However, the compartmentalization of dips into domains, is, in fact, not coincident with these intersections.

Conversely, dip analysis in the Townsville rift zone offshore of the northeastern Australian margin demonstrated that no consistent intra-rift block rotation could be interpreted (Struckmeyer *et al.* 1994) and thus, traditional extensional models were inadequate to explain the basin-forming structures. On the basis of clearly defined dip domains and the seismic data, lineament mapping was undertaken to define basement blocks or terranes. The non-unique interpretation of gravity and magnetic data in the area was thus constrained. The interpretation allowed extension of several of the onshore basement terrane boundaries into the offshore continental crust. The deepest depocenters are located where these lineaments intersect and the dips are locally consistent with fault geometries predicted by reactivation at these nucleation intersections. Thus, a reasonable tectonic history for trough formation, which was consistent with all of the observable data and revealed something about the basement geology was derived. In other areas where basement geology structural relationships are notoriously difficult to discern (e.g. plutonic and metamorphic terranes) dip data derived from paleomagnetic data have been used successfully to identify previously unknown structures (e.g. Wingate & Irving 1994).

The use of dip data and our method of dip domain analysis is like many tools we use in geological interpretations. An objective understanding of what is data and what is interpretation of the data must be maintained. The interpretation must be consistent with other observables and possible alternative interpretations must be pursued vigorously. In each area where we have applied this standard structural method to geophysical data, invaluable information regarding the geometries of deformed zones has been obtained.

REFERENCES

Chorowicz, J., LeFournier, J. & Vidal, G. 1987. A model for rift development in Eastern Africa. *J. Geol.* **22**, 495–513.

Daly, M. C., Chorowicz, J. & Fairhead, J. D. 1989. Rift basin evolution in Africa: the influence of reactivated steep basement shear zones. In: *Inversion Tectonics* (edited by Cooper, M. A. & Williams, G. D.). *Publ. Spec. geol. Soc.* 309–334.

Ring, U., Betzler, C. & Delvaux, D. 1992. Normal vs strike-slip faulting during rift development in East Africa: the Malawi rift. *Geology* **20**, 1015–1018.

Scott, D. L. 1994. Oblique Lithospheric Extension: a comparative analysis of the East African Rift System and some Australian Passive Margins. Unpublished Ph.D. thesis, Australian National University.

Scott, D. L., Braun, J. & Etheridge, M. A. 1994. Dip analysis as a tool for estimating regional kinematics in extensional terranes. *J. Struct. Geol.* **16**, 393–401.

Scott, D. L., Etheridge, M. A. & Rosendahl, B. R. 1992. Oblique-slip deformation in extensional terrains: a case study from the Lakes Tanganyika and Malawi rift zones, East Africa. *Tectonics* **11**, 998–1009.

Strecker, M. R., Blisniuk, P. M. & Eisbacher, G. H. 1990. Rotation of extension direction on the central Kenya Rift. *Geology*, **18**, 299–302.

Struckmeyer, H. I. M., Symonds, P. A., Fellows, M. & Scott, D. L. 1994. Townsville Basin, Northeast Australia: Structural and stratigraphic evolution. Record #49, Australian Geological Survey Organization.

Wingate, M. T. D. & Irving, E. 1994. Extension in high-grade terranes of the southern Omineca Basin, British Columbia: evidence from paleomagnetism. *Tectonics* **13**, 686–711.