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REVIEWS

Imaging, Mapping and Modelling Continental Lithosphere Extension and Breakup

Edited by G.D. Karner, G. Manatschal and L.M. Pinheiro
The Geological Society of London
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The Geological Society has been producing Special Publications for 40 years, with the series gaining clear identity in 1981. The Society currently publishes about 20 new volumes in the series each year. The intention is to provide state-of-the-science reviews of geological topics, where the guest editors are expected to provide a balanced coverage. Based on the success of the series, this is what many geoscientists want: a collection of papers that takes the non-expert up the learning curve of background and currency of a theme of interest. Many of the publications are based on presentations made at scientific meetings, and that is true of the Special Publication under review here, which is based on a one-week workshop held in Pontresina, Switzerland in July 2004. Given that the workshop took place in 2004, the Special Publication was published in 2007 and I am reviewing it in 2008, one might ask if the content is too dated. I attended a session on *Continental Rifting andBreakup* at the European Geosciences Union meeting in Vienna in April 2008. Several authors presented papers that offered incremental enhancements to their contributions to the Special Publication, but no radically new ideas (at least so far as I could determine!). So this Special Publication, based on a workshop held four years ago, is still of great value today to those wanting to get close to the cutting edge of modern research in continental rifting processes.

The notion that rifted continental margins consist of thinned, extended continental crust abutting normal oceanic crust was dispelled years ago, nowhere more emphatically than in studies of the Iberian margin, where serpentinized peridotite was discovered intervening between extended continental crust and oceanic crust. Thus, the continent–ocean transition is more complex than previously thought, and depth-dependent stretching and/or simple shear have been invoked to explain how mantle could be exhumed during the rifting process, and lead to asymmetrical conjugate margins. Recent seismic work followed by Leg 210 of the Ocean Drilling Program on the Newfoundland margin, conjugate to Iberia, resulted in the discovery of an equally complex continent?ocean transition there, where serpentinized peridotite is again present in a zone that exhibits magnetic strip anomalies, previously interpreted as arising from normal oceanic crust. Thus many questions about the nature of the rifting process are posed by these recent studies of the Iberia–Newfoundland conjugate pair.

The Pontresina workshop was held to discuss the recent findings from the Newfoundland margin, how they relate to the conjugate margin, and the rifting processes that led to the present margin configurations. The focus of the workshop, and the Special Publication, was on this conjugate pair, including details of the structure, and models of the processes involved. In addition, a number of papers were presented, for comparative purposes, on other margins and analogues from older rifted margins now exposed on land.

A virtue of the Special Publications is that they usually start with pieces written by the guest editors that set the context and summarize the content. This is particularly valuable for the non-expert who might otherwise get lost quickly in some of the individual contributions. This book is no exception, and the editors provide an excellent summary, explaining the volume's six sections. The full list of contents of the volume can be found at [http://sp.lyellcollection.org/content/vol282/issue1/].

The first section provides geological and geophysical insights from four papers that describe the structure of the Iberia–Newfoundland conjugate pair. A comprehensive review of the Newfoundland–Iberia rift, incorporating the results from the ODP Leg 210 drilled in 2003 in the Newfoundland Basin, is provided by Tucholke et al. Other interesting papers (Hopper et al.; Sibuet et al.) address the peculiarity of the Flemish Cap (e.g. its motions and its margin) at the northern end of the Newfoundland Basin, whereas a contrast with the Iberian margin is presented by Reston. A general conclusion from these papers is that continent–ocean transition zones (made up of a complex mix of highly-extended continental crust, exhumed sub-continental mantle, and abnormal oceanic crust) can be over 100 km wide, are found on both conjugate margins, and are subject to continuing debate as to their genesis.

The second section presents three papers on geodynamic modelling that focus on the strain response to specific stresses applied to defined rheology, with reference to the Iberia–Newfoundland conjugate pair. Huismans and Beaumont present some vividly illustrated examples of the variety of both symmetrical and asymmetrical responses to variable lithosphere rheology and rifting velocity, and transformation from one form to the other during deformation. Other papers address the role of density inversions in the rifting process (Burov), and of pre-existing weaknesses in the rifting history of the Flemish Cap–Galicia Bank conjugate margins (Harry and Grandell).

The third section includes two papers on kinematic modelling, in which the overall subsidence of basins is calculated from lithosphere stretching, optionally with depth dependence and consequent isostatic/flexural response, and including an interpreted thermal history. A Black Sea study by Egan and Meredith shows that crustal thinning, rather than fault displacements, gives a better fit to observed subsidence. Healy and Kusznir provide an example of how upward divergent flow of asthenosphere can provide admissible models of margin evolution, exemplified by the Goban Spur margin of NW Europe, a little to the north of the Iberia–Newfoundland conjugate margin.

Two comparative papers, one examining the Woodlark Basin, Papua-New Guinea (Goodliffe and Taylor), and the other the southern Australian margin (Direen et al.), are presented in the fourth section. The Woodlark Basin displays asymmetry in structure, characterized by distinctly different amounts of faulting that is interpreted as a consequence of contrasting lithospheric deformation; i.e. removal of lower crust through ductile flow on one margin, and brittle faulting of the upper crust on the other. The wide continent–ocean transition zone on the South Australian margin exhibits magnetic signatures which, like those in the Newfoundland Basin, might earlier have been interpreted as indicative of oceanic crust, but are now interpreted to have formed during exhumation of serpentinized peridotite mantle.

In the fifth section, three examples of "non-Atlantic" extensional systems follow. Two of the papers deal with the evolution of passive margins now exposed on land. Manatschal et al. describe the similarities between the Iberia–Newfoundland margin and the Tethyan margins exposed in the Alps. Robertson discusses the roles of asthenospheric shear, inherited lithospheric weaknesses, and slab pull from a neighbouring subduction zone as causative agents for Tethyan rift sequences now exposed in Oman. These rift sequences are devoid of exhumed mantle, unlike the Iberia–Newfoundland margin. A third paper (Cochran and Karner) discusses the transition from rifting to drifting in the Red Sea, concluding that rift systems that are characterized by large rotated fault blocks rarely lead to seafloor spreading, but may be left stranded alongside adjacent margins or survive as failed rifts.

The final section revisits some fundamental concepts, in four contributions. Kusznir and Karner discuss the upward-divergent mantle flow kinematic model and apply it to the Woodlark Basin and the Iberia–Newfoundland conjugates. Christie-Blick et al. reinterpret faults in the Basin and Range Province of the western United States as having much smaller displacements than previously claimed, thus demanding more careful review of models of extreme thinning associated with low-angle normal faults. Dyksterhuis et al. investigate the effects of pre-existing weaknesses on rift architecture with numerical experiments that confirm rotation of normal faults to low angles, and stress how such weaknesses can be dominating factors in determining the mode of deformation. Moresi et al. use a yield criterion developed for incompressible viscous layers and show how it can be manipulated to produce effects similar to those of the Mohr-Coulomb criterion used in brittle failure models.

This is a book with a lot to digest, but very much worth reading for anyone interested in how the details of rifted margins may fit with theories of their genesis. There are some residual questions. Is the thoroughly-studied Iberia–Newfoundland margin the best example for learning about rifting processes that lead to seafloor spreading? The complex along-margin variations, related, in part, to the step-wise northern migration of extension, suggest that this area might not be the best place to isolate a 2D cross section to characterize the process. But then we live in a 3D world, as is confirmed by the variety of passive margin features described in this volume.