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Preface

Introduction to the special issue on convergent plate margin dynamics

Convergent plate margins are arguably the most complicated and dynamic plate boundaries on Earth and have been the subject of many investigations and discussions since the advent of plate tectonic theory. Due to the varied, heterogeneous and complex structure of convergent plate margins, which arises from the multiple geological, physical and chemical processes operating at these zones, and because the largest portion of the system is hidden deep beneath the surface, much remains enigmatic and unknown about these important plate tectonic features. As such, numerous fundamental problems still need to be addressed. The papers presented in this special issue provide many new insights into a variety of geological, geophysical and geodynamical problems.

Schellart and Rawlinson (2010-this issue) provide a historical background and a review of the development of geological and geodynamic theories on convergent plate margins. Furthermore, the paper discusses some of the recent advances that have been made in the fields of structural geology, geophysics and geodynamics, which are fundamental to our understanding of convergent plate margins. The paper shows that contributions from structural geologists, geophysicists and geodynamic modellers have been crucial for the development of geological theories of large-scale tectonic processes and for the understanding of convergent plate boundaries.

A topic of active research is the initiation of a new subduction zone, which has been suggested to occur at passive margins due to sediment loading (Cloetingh et al., 1982; Regenauer-Lieb et al., 2001), at fracture zones due to far-field compressive stresses thereby forcing convergence across the lithospheric heterogeneity (Hall et al., 2003; Gurnis et al., 2004), or at passive margins due to large buoyancy forces across the passive margin (Mart et al., 2005; Goren et al., 2008). In this special issue, Farrington et al. (2010-this issue) present numerical models that illustrate plate motion-induced edge-driven convection below a lithospheric step at a passive margin. This vigorous convection could facilitate thermal weakening of the passive margin lithosphere and might induce deviatoric stresses across the margin. Such edge-driven convection could thus facilitate and play a role in subduction initiation at passive margins.

After a critical amount of subduction (100–150 km) a self-sustaining subduction zone forms (Gurnis et al., 2004). The subsequent kinematic and dynamic evolution of the system will depend on the different physical parameters that control the system. Various controlling parameters have been proposed, including mantle stratification (Kincaid and Olson, 1987; Christensen, 1996), slab strength (Capitanio et al., 2007; Billen and Hirth, 2007; Di Giuseppe et al., 2008; Schellart, 2008a; Funiciello et al., 2008), slab negative buoyancy (Molnar and Atwater, 1978; Schellart, 2004; Morra et al., 2006; Capitanio et al., 2007), subducting plate velocity (Funiciello et al., 2004; Schellart, 2005), overriding plate velocity (Olbertz et al., 1997; van Hunen et al., 2000; Heuret et al., 2007; Guillaume et al., 2009), and slab width (Dvorkin et al., 1993; Schellart, 2004; Stegman et al., 2006; Morra et al., 2006; Schellart et al., 2007). Stegman et al. (2010-this issue-a) illustrate that the role of the strength of the subducting lithosphere in resisting bending at the trench is critical in determining the subduction kinematics and the geometry of the slab. However, considering that for present day subduction zones the slab/mantle effective viscosity ratio likely falls within a relatively narrow range, it appears that such minor variation of this ratio cannot explain the variety of present-day subduction zone behaviour on Earth, although it might give insight into subduction zone behaviour in the distant geological past. As illustrated in Stegman et al. (2010-this issue-b), it appears that the width (trench-parallel extent) of subduction zones, as well as the trailing plate boundary condition provide a dominant control on the dynamics and kinematics of active subduction zones on Earth.

Subduction zones are limited in trench-parallel extent. At their edges, subduction zones often turn into collision zones or transform plate boundaries. At subduction zone-transform edges, continued subduction requires the downgoing plate to tear at the edge, such that one part of the plate sinks into the mantle, whilst the other part remains at the surface. These faults have recently been referred to as STEP-faults (subduction-transform-edge-propagator-faults) (Govers and Wortel, 2005; Wortel et al., 2009). Hale et al. (2010-this issue) present 3D numerical models of progressive subduction to test how the resistance of the subducting plate to tear at a subduction zone corner influences subduction zone curvature and the kinematics of subduction. The authors find that an increase in tear resistance enhances subduction zone curvature and decreases the trench retreat velocity.

The role of trench-parallel density variations in subducting plates has been argued to have an important impact on subduction kinematics and trench geometry (e.g. Vogt, 1973; Hsui and Youngquist, 1985; Martinod et al., 2005; Morra et al., 2006; Wallace et al., 2009). These density variations have been ascribed to a change in plate age or the presence of buoyant features on the subducting plate, such as oceanic plateaus, aseismic ridges and continental fragments. Mason et al. (2010-this issue) investigate how the presence of a buoyant plateau on the subducting plate affects the trench kinematics and trench geometry using 3D numerical models of progressive free subduction. They find that with increasing plateau buoyancy the trench velocity changes from slow retreat to trench advance, whilst the trench becomes increasingly indented.

The interaction between subducting plate, overriding plate and ambient mantle has been investigated with kinematically driven laboratory models of progressive subduction (e.g. Shemenda, 1993, 1994; Faccenna et al., 1999; Boutelier and Cruden, 2008) and with dynamic 3D numerical models (Clark et al., 2008; Yamato et al., 2009). It has also been investigated with statistical methods, leading to

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contrasting conceptual models for trench migration and overriding plate deformation (e.g. Jarrard, 1986; Heuret and Lallemand, 2005; Schellart, 2008b). Capitanio et al. (2010-this issue) investigate the interaction between subducting plate, overriding plate and ambient mantle in fully dynamic 2D numerical models of progressive subduction, demonstrating the control of overriding plate strength on subduction kinematics. These authors find that trench retreat generally corresponds with overriding plate extension while trench advance generally corresponds with overriding plate shortening. This is in agreement with the statistical findings from Schellart (2008b) and would suggest that slab dynamics controls trench migration and the style of overriding plate deformation (extension or shortening) rather than overriding plate motion controlling trench migration and overriding plate deformation.

After consumption of an entire ocean basin, the converging plates may collide during arc–continent collision or continent–continent collision. Keep and Haig (2010-this issue) and Ely and Sandiford (2010-this issue) discuss the active arc–continent collision between the Banda arc and the northwest Australian continental margin. Keep and Haig (2010-this issue) investigate the geology in East Timor, suggesting that collision started at 9.8–5.5 Ma, much earlier than previously thought; that Timor emerged above sea-level at 3.1 Ma; and that the collisional phase is characterized by three distinct orogenic phases. Ely and Sandiford (2010-this issue) investigate the state of stress in the eastern Sunda-Banda slab segment. The authors show that in eastern Sunda subduction of normal oceanic lithosphere results in down-dip tension at 70–300 km depth, whilst towards the east subduction of the buoyant Scott plateau results in down-dip compression. Even further to the east, below East Timor, a seismic gap is present implying that the slab has detached in this region. Replumaz et al. (2010-this issue) discuss the continent–continent collision between India and Eurasia using plate reconstructions and mantle tomography. The research points to considerable lateral and vertical variation in mantle structure below and south of the Himalayas. The authors identify a large pre-collisional detached slab in the lower mantle, syn-collisional detached slab segments below the centre and east and a narrow slab segment below the western Himalayas that reaches 600 km depth and is continuous with the surface lithosphere. The authors propose a different tectonic evolutionary scenario for the western Himalayas compared to the eastern Himalayas.

After slabs detach from their surface plates, they continue to play a role in shaping the geological history of our planet through dynamic topography (Gurnis et al., 1997; Gurnis and Müller, 2003; Müller et al., 2008). Heine et al. (2010-this issue) demonstrate that fossil slabs that were subducting below the Gondwana margin of Australia in the Mesozoic have produced dynamic topography at the surface, leading to periods of inundation of various parts of the Australian continent at times of a global sea-level low and surface exposure of the Gulf of Carpentaria at times of a global sea-level high.

An intensive debate regards the start of plate tectonics on Earth, and as such, the start of subduction zone processes. Some have argued in favour of initiation as early as the Archean (e.g. Cawood et al., 2006; Davies, 2006), whilst others have argued in favour of the Late Proterozoic (e.g. Stern, 2005). Stewart and Betts (2010-this issue) demonstrate that Middle Proterozoic structures observed in the Gawler Craton in South Australia can be interpreted in a plate tectonic framework. In particular, extensional and shortening structures are interpreted to have formed in an upper plate backarc setting resulting from subduction, slab rollback and flat-slab subduction processes.

Geodynamic modelling of large-scale tectonic processes has a long history in which laboratory (analogue) and numerical modelling techniques have been used. Laboratory models are mostly mechanical, and sometimes thermo-mechanical, and a major advantage is that they are ideally suited to model progressive large-strain deformation as well as investigate complex three-dimensional geodynamic problems (Koyi, 1997; Schellart, 2002). Most numerical modelling has been done in 2D space, although the last few years have seen an increase in 3D numerical modelling. An advantage of numerical models is that they can readily incorporate both thermal and mechanical processes. Poulet et al. (2010-this issue) present a thermo-chemo-mechanical modelling technique that includes chemical feedbacks, thereby allowing for the development of numerical models that have the potential to more accurately represent geodynamic processes.

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