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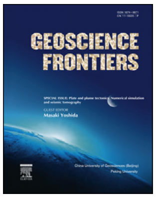

Research paper

Geodynamics of oceanic plateau and plume head accretion and their role in Phanerozoic orogenic systems of China

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ABSTRACT

We present three 3D numerical models of deep subduction where buoyant material from an oceanic plateau and a plume interact with the overriding plate to assess the influence on subduction dynamics, trench geometry, and mechanisms for plateau accretion and continental growth. Transient instabilities of the convergent margin are produced, resulting in: contorted trench geometry; trench migration parallel with the plate margin; folding of the subducting slab and orocline development at the convergent margin; and transfer of the plateau to the overriding plate. The presence of plume material beneath the oceanic plateau causes flat subduction above the plume, resulting in a "bowed" shaped subducting slab. In plateau-only models, plateau accretion at the edge of the overriding plate results in trench migration around the edge of the plateau before subduction is re-established directly behind the trailing edge of the plateau. The plateau shortens and some plateau material subducts. The presence of buoyant plume material beneath the oceanic plateau has a profound influence on the behaviour of the convergent margin. In the plateau + plume model, plateau accretion causes rapid trench advance. Plate convergence is accommodated by shearing at the base of the plateau and shortening in the overriding plate. The trench migrates around the edge of the plateau and subduction is re-established well behind the trailing edge of the plateau, effectively embedding the plateau into the overriding plate. A slab window forms beneath the accreted plateau and plume material is transferred from the subducting plate to the overriding plate through the window. In all of the models, the subduction zone maintains a relatively stable configuration away from the buoyancy anomalies within the downgoing plate. The models provide a dynamic context for plateau and plume accretion in Phanerozoic accretionary orogenic systems such as the East China Orogen and the Central Asian Orogen (Altiads), which are characterised by accreted ophiolite complexes with diverse geochemical affinities, and a protracted evolution of accretion of exotic terranes including oceanic plateau and terranes with plume origins.

1. Introduction

Plume-subduction interactions and oceanic plateau-subduction interactions allow buoyant oceanic lithosphere to engage with convergent margins (Cloos, 1993; Murphy et al., 1998). On the modern Earth the influence and occurrence of upwelling mantle hotspots at downgoing subducting oceanic lithosphere have been imaged in seismic tomographic data (Zhao et al., 2007; Miller and Lee, 2008), and presence of oceanic plateaus, seamounts, and other aseismic ridges occur along most convergent margin (Vogt, 1973), where they are correlate with regions of significant trench and slab modifications (Miller et al., 2004, 2005; Mason et al., 2010). A third scenario exists when a plateau or seamount interacts with the convergent margin whilst a plume is impinging at the base of the oceanic lithosphere. For example, aseismic ridges within the Nazca plate may represent incipient stage of plateau accretion with the plume interacting with the ridges that have not been subducted (Pilger, 1984; O'Connor et al., 2007). Several examples of plume subduction have been proposed for ancient

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convergent margins (Murphy et al., 1998, 2003; Dalziel et al., 2000; Murphy and Keppie, 2005; Betts et al., 2009). These examples show how a plume interacting with a convergent margin can cause the arc to migrate towards the interior of the overriding plate and result in the transition from arc- to plume-related magmatism in the overriding plate (Murphy et al., 1998; Dalziel et al., 2000; Betts et al., 2009). The latter suggests plume material eventually transfers from the downgoing oceanic plate to the overriding plate, although the mechanism responsible for this is not fully understood.

1.1. *Accretionary orogenic systems of Central and Eastern Asia*

The Phanerozoic geological record of convergent margins is dominated by long-lived accretionary orogenic systems characterised by significant crustal growth via lateral accretion of exotic terranes from the oceanic realm (Cawood et al., 2009). Late Neoproterozoic to Phanerozoic crustal growth in Asia is preserved in two long-lived accretionary orogenic systems: the Central Asian Orogen and the East Asian Orogen (Fig. 1). The Central Asian Orogen or Altaids (Windley et al., 2007; Wilhem et al., 2012) records Neoproterozoic to Permian accretion along the southern margin of Eurasia (Safonova et al., 2009; Safonova and Santosh, 2014) (Fig. 1) during the closure of the Paleo-Asian Ocean. The East Asian Orogen records Devonian to present-day accretion along eastern Asia (Zhang et al., 2008; Safonova and Santosh, 2014) (Fig. 1). The geological record of these orogens is complex and involves the accretion of micro-continental fragments, arc terranes (Safonova and Santosh, 2014), ocean plateaus and seamounts, as well as the development of terrane-scale oroclines (Windley et al., 2007; Wilhem et al., 2012).

The recent synthesis of Ocean Island Basalts (OIB) in the Central Asian and East Asian orogens by Safonova and Santosh (2014) show 35 occurrences OIB terranes entrained within these orogenic systems (Fig. 1), suggesting they are significant contributors to crustal growth along these orogenic belts. Several of the mapped OIB terranes are suggested to have formed during super plume activity (Li and Zhong, 2009). For example, Neoproterozoic OIB rocks within the Central Asian Orogen are associated with the super plume linked with Rodinia break-up (Safonova et al., 2009; Safonova and Santosh, 2014). Cretaceous OIB rocks of the East Asian Orogen are associated with the Pacific super plume (Safonova et al., 2009; Safonova and Santosh, 2014). These OIB terranes are interpreted as far-travelled oceanic plateaus. However, in the central Asian Orogen, there are several Devonian to Permian ophiolite complexes characterised by diverse geochemical associations that include calc-alkaline, OIB, MORB, bonnanite and adakite terranes (e.g., Wong et al., 2010; Yang et al., 2012). Several of these terrane contain ophiolites that are similar in age to, or slightly older than, their inferred timing of accretion.

1.2. *Subduction modelling*

Flat slab subduction occurs when the subducting lithosphere dip is shallow ($<30°$) beneath the overriding plate. Shallow subduction can extend for hundreds to a few thousand kilometres beneath the overriding plate. Numerical models have illustrated several phenomena that can influence the dip of a subduction including: subduction driven flow in the mantle wedge or "suction" (Stevenson and Turner, 1977); corner flow in the mantle wedge (Billen and Hirth, 2007); temperature of the overriding plate (Rodríguez-González et al., 2012); the thickness and trench-ward motion of the overriding plate (Manea et al., 2012); variation in the slab thickness as a function of age (Molnar and Atwater, 1978; Capitanio et al., 2011); and the presence of buoyancy anomalies entrained in the subducting slab (e.g. Gutscher et al., 2000; van Hunen et al., 2002). Cloos (1993) explored the role these buoyancy anomalies played on the dynamics of the subducting plate and showed the size and density of the anomaly determined if subduction "locked-up" or became entrained within the subducting slab, causing localised and transient isostatic uplift.

Two-dimensional numerical simulations of accretionary processes have focussed on different aspects of subduction and accretion of buoyant anomalies at convergent margins. Arrial and Billen (2013) illustrated that eclogitization of an ocean plateau inhibits accretion by increasing slab negative buoyancy, although in some dynamic models, slab break-off leads to vertical accretion of the buoyant plateau beneath the overriding plate. Tetreault and Buiter (2012) suggested that buoyancy alone was not a barrier to subduction and showed accretion of a buoyant ocean plateau was partially dependent on the development of a basal detachment fault and the depth of this detachment. van Hunen et al. (2002) showed that collision with buoyant continental masses in a subduction zone leads to slab break-off and stalling of convergence. More recently, Vogt and Gerya (2014) proposed three modes of oceanic plateau accretion. These include scenarios where plateau subduction occurs resulting in forearc uplift; frontal plateau accretion where the plateau docks onto the continental margin, resulting in intense deformation in the overriding plate and slab break-off and; basal plateau accretion where the oceanic plateau is scraped from the subducting slab and a new subduction zone developing behind the accreted terrane.

3D geodynamic modelling of subducting slabs have provided insight into the 3D slab geometries (e.g., Stegman et al., 2006, 2010; van Hunen and Allen, 2011; Li et al., 2013), the motion of a trench along a convergent margin (Schellart et al., 2007; Capitanio et al., 2011), mantle dynamics (OzBench et al., 2008; Schellart, 2008), and more recently the dynamics of an overriding plate (Yamato et al., 2009; Capitanio et al., 2011; Capitanio and Replumaz, 2013; Magni et al., 2014; Moresi et al., 2014). Recent 3D numerical modelling with *Underworld* (Moresi et al., 2007), which we use in the models presented here, have addressed accretion of entrained buoyant material in 3D slab subduction models. Mason et al. (2010) undertook 3D viscoplastic subduction modelling with a buoyant plateau entrained in the oceanic lithosphere, showing the potential for large plateaus to cause significant modification to trench geometry and creation of a large slab window. Betts et al. (2012) showed how plume-heads, and their associated buoyancy, interact with a convergent margin markedly modify trench geometry, change trench velocity, shorten the overriding plate, as well damage the subducting slab by creating slab windows. Moresi et al. (2014) included an overriding plate in their models and undertook 3D simulations of buoyant micro-continental ribbon accretion and showed that subduction re-established behind the accreted ribbon via margin parallel migration of a highly arcuate trench and as a consequence the ribbon was embedded into the overriding plate.

In this paper we present the results of 3D numerical simulations of thick oceanic plateau crust and the buoyant plume material to examine how these exotic oceanic terranes contribute to lateral continental growth of long-lived convergent margins. Our models illustrate how accretion of oceanic plateaus and associated plume material at convergent margins influence trench geometry and architecture of the subducting slab. The model results will serve as a geodynamic context to interpret complex convergent margin interaction characterised by ophiolite complexes with diverse and mixed geochemical responses in long-lived accretionary belts.