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Partial melting of slab window margins: genesis of adakitic and non-adakitic magmas

Derek J. Thorkelson[a,*], Katrin Breitsprecher[b]

[a]Department of Earth Sciences, Simon Fraser University, Burnaby, British Columbia, Canada, V5A 1S6
[b]Department of Earth and Ocean Sciences, University of British Columbia, Vancouver, British Columbia, Canada, V6T 1Z4

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Abstract

When a mid-ocean spreading ridge subducts, it typically splits apart at depth to form two tapered slab edges separated by asthenospheric mantle within a slab window. We examine the fate of the slab edges using simplified slab window geometries, specific thermal parameters, and assumptions regarding shear stress and slab hydration. Six fundamental zones of slab anatexis are identified and classified according to expected melt and restite compositions. Non-adakitic melts of granodioritic to tonalitic composition are generated along the plate edges at depths of 5–65 km, whereas adakitic melts form proximal to the edges at depths of 25–90 km. As anatexis proceeds, the subducted crust is converted to a migmatite of slab melt and eclogitic restite. Much of the migmatite may shear away from the slab and become incorporated into the mantle. The melts will rise and leave behind fragments of restite within mantle peridotite. If the peridotite is part of the overriding plate, then the restite fragments may become long-term residents of the continental lithospheric mantle. However, if the restite becomes entrained in the asthenosphere, it may undergo upwelling and melting, or flow away as ductile streaks to become long-term mantle heterogeneities. Slab windows are thereby identified as important sites for slab melting and geochemical replenishment of the mantle.

Keywords: Slab window; Ridge subduction; Adakite; Anatexis; Mantle; Restite

1. Introduction

Ridge subduction and concomitant slab window formation are principal causes of igneous, metamorphic and structural variations in active continental margins (Dickinson and Snyder, 1979; Johnson and O'Neil, 1984; Forsythe and Nelson, 1985; Thorkelson and Taylor, 1989; Sisson et al., 1994; Thorkelson, 1996; Sisson et al., 2003). These variations are imposed on the leading edge of an overriding plate which normally consists of an amagmatic forearc, an active volcanic arc, and a back-arc which may or may not be magmatically active. When a ridge is subducted, the forearc tends to become heated, intruded by magmas, and deformed (Marshak and

* Corresponding author. Tel.: +1 604 291 5390; fax: +1 604 291 4198.
E-mail addresses: dthorkel@sfu.ca (D.J. Thorkelson), kbreitsp@eos.ubc.ca (K. Breitsprecher).

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Karig, 1977; DeLong et al., 1979; Sisson and Pavlis, 1993; Groome et al., 2003); the arc tends to be extinguished or invaded by magmas of anomalous composition (Forsythe and Nelson, 1985; Hole et al., 1991; Cole and Basu, 1995; Thorkelson, 1996); and the back-arc may become more magmatically active (Gorring et al., 1997; D'Orazio et al., 2001). These various responses are driven largely by physical, thermal and chemical changes to both the underlying mantle and the subducting oceanic slabs (Delong et al., 1979; Benz et al., 1992; Hole and Larter, 1993; Lewis et al., 1997). For example, the slab is progressively younger and hotter toward the subducting ridge, and the mantle within the slab window will tend to be hotter and less hydrated (Thorkelson, 1996; Sisson et al., 2003). These changes to the subduction environment are, in turn, affected by a range of dynamic processes. For example, upwelling or lateral flowage of asthenosphere will lead to displacement of the mantle wedge with peridotite of different chemical and thermal characteristics (Johnston and Thorkelson, 1997; Murdie and Russo, 1999; Frederiksen et al., 1998); thermal erosion of slab window margins (Severinghaus and Atwater, 1990) will liberate slab-anatectic melts and contaminate the ambient mantle (Thorkelson, 1996); and migration of the ridge–trench intersection will tend to produce diachroneity of the aforementioned effects in the overriding plate (Johnson and O'Neil, 1984; Gorring et al., 1997; Thorkelson and Taylor, 1989; Haeussler et al., 2003). Consequently, the igneous responses to a migrating slab window are both compositionally complex and time-transgressive.

In this paper, we focus on the genesis of slab melts derived from thermal erosion of slab window margins, specifically the anatexis of subducted igneous crust. Our work brings together established phase equilibria, P–T paths of subducting slabs, and physical models of ridge subduction to provide the first detailed identification of slab-melt regions in slab window environments. This investigation is carried out using idealized slab window geometries constructed using the structural principles of Thorkelson (1996). The topics of melt transport and emplacement, and the various factors governing compositional variabilities in arc magmas, remain important issues in the study of slab melts. However, in this paper, we are chiefly concerned with magmagenesis rather than melt migration and modification, and we therefore focus our attention on the physical, thermal and chemical factors which influence anatexis of subducted crust.

A slab window is an asthenosphere-filled gap that forms between a pair of diverging, subducting oceanic plates in response to ridge subduction. As a spreading ridge descends into the mantle, the oceanic slabs on either side continue to diverge but cease to grow, and the ridge progressively unzips to form a gap called a slab window. Typically, ridge systems consist of ridge segments separated by transform faults, and the subduction of these different parts yield two different types of slab window margins (Fig. 1). Ridge segments widen upon subduction to form margins which taper into feather edges, reflecting the lithospheric profile acquired during sea-floor spreading (Stein and Stein, 1996); these edges are the hottest, youngest parts of the subducting slab. Transform faults, on the other hand, continue to be active as the descending plates slide past one another, during which they progressively expose square-ended slab edges. In some cases, such as at a ridge–trench–transform triple junction, only one of the oceanic plates will subduct. Additional geophysical complexities can arise if the edges of the subducting plates break up into microplates (Dickinson, 1997).

The feather edges bounding a slab window (those derived from subducting ridge segments) are more

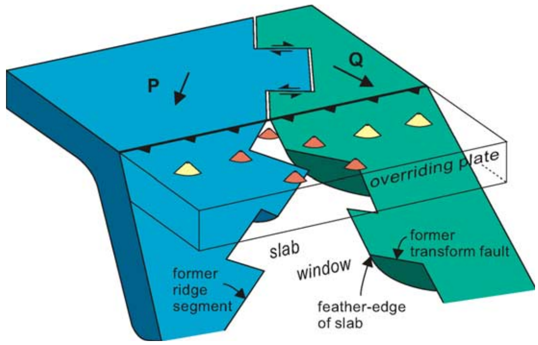

Fig. 1. Simplified slab window caused by subduction of a spreading ridge segmented by transform faults. Overriding plate is shown transparent. Motion vectors of oceanic plates P and Q are relative to the overriding plate (transparent). Slab P dips at 50° whereas slab Q dips at 25°. Volcanic arc (yellow volcanoes) is interrupted by field of anomalous magmatism (orange volcanoes) which includes products of slab anatexis. Note the feather edge morphology of subducted ridge segments. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).