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Differential preservation in the geologic record of intraoceanic arc sedimentary and tectonic processes

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ABSTRACT

Records of ancient intraoceanic arc activity, now preserved in continental suture zones, are commonly used to reconstruct paleogeography and plate motion, and to understand how continental crust is formed, recycled, and maintained through time. However, interpreting tectonic and sedimentary records from ancient terranes after arc–continent collision is complicated by preferential preservation of evidence for some arc processes and loss of evidence for others. In this synthesis we examine what is lost, and what is preserved, in the translation from modern processes to the ancient record of intraoceanic arcs.

Composition of accreted arc terranes differs as a function of arc–continent collision geometry. 'Forward-facing' collision can accrete an oceanic arc on to either a passive or an active continental margin, with the arc facing the continent and colliding trench- and forearc-side first. In a 'backward-facing' collision, involving two subduction zones with similar polarity, the arc collides backarc-first with an active continental margin. The preservation of evidence for contemporary sedimentary and tectonic arc processes in the geologic record depends greatly on how well the various parts of the arc survive collision and orogeny in each case.

Preservation of arc terranes likely is biased towards those that were in a state of tectonic accretion for tens of millions of years before collision, rather than tectonic erosion. The prevalence of tectonic erosion in modern intraoceanic arcs implies that valuable records of arc processes are commonly destroyed even before the arc collides with a continent. Arc systems are most likely to undergo tectonic accretion shortly before forward-facing collision with a continent, and thus most forearc and accretionary-prism material in ancient arc terranes likely is temporally biased toward the final stages of arc activity, when sediment flux to the trench was greatest and tectonic accretion prevailed. Collision geometry and tectonic erosion vs. accretion are important controls on the ultimate survival of material from the trench, forearc, arc massif, intra-arc basins, and backarc basins, and thus on how well an ancient arc terrane preserves evidence for tectonic processes such as subduction of aseismic ridges and seamounts, oblique plate convergence, and arc rifting. Forward-facing collision involves substantial recycling, melting, and fractionation of continent-derived material during and after collision, and so produces melts rich in silica and incompatible trace elements. As a result, forward-facing collision can drive the composition of accreted arc crust toward that of average continental crust.

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1. Introduction

Geologic records from intraoceanic arcs are commonly used to interpret the tectonic history of convergent margins. Ancient arc terranes preserved in suture zones within continents reveal patterns of plate motion and supercontinent assembly that are significant controls for paleogeographic reconstructions (Cawood and Buchan, 2007; Murphy et al., 2009; van der Meer et al., 2012), and contain rock assemblages that are economically valuable (Cooke et al., 2007; Glen et al., 2011; Herrington et al., 2011; Wainwright et al., 2011). Moreover, intraoceanic arcs have been producing and refining Earth's crust since Archean time (Kimura et al., 1993; Polat and Kerrich, 2002), and are key to understanding the origin and evolution of the continental crust (Rudnick and Fountain, 1995; Suyehiro et al., 1996; Holbrook et al., 1999; Draut et al., 2002; Kelemen et al., 2003a; Davidson and Arculus, 2006; Hawkesworth and Kemp, 2006; Clift et al., 2009; Draut et al., 2009; Stern and Scholl, 2010). Intraoceanic arcs, which comprise 35–40% of active subduction-zone length globally, are most common today in the western Pacific Ocean (Fig. 1). Ancient, accreted oceanic arc terranes occur within orogenic belts on every continent.

Although much of our understanding of Earth's history relies on the geologic record of ancient subduction zones (Scholl and von Huene, 2010; Dilek and Furnes, 2011; Korsch et al., 2011; Murphy et al., 2011), it is likely that the ancient arc terranes now preserved in continental suture zones lack, or represent disproportionately, evidence for sedimentary and tectonic processes that characterized the intraoceanic arc while it was active prior to collision. Such a disparity likely arises because the different tectonic regions of an arc have variable preservation potential following collision with a continent (Scholl and von Huene, 2010; Draut and Clift, 2012). As a result, some tectonic events and processes that commonly affect the development of intraoceanic arcs over millions to tens of millions of years, and that are notable and prominent in the modern oceans, may leave little or no trace in the rock record after the arc accretes onto a continental margin.

In this paper we review and summarize major tectonic, geomorphic, and sedimentary characteristics of active intraoceanic arcs, and discuss the means by which they reflect and record significant tectonic processes that commonly characterize arc development, such as subduction of high bathymetric features (i.e., seamounts, aseismic ridges, and fracture zones), oblique plate convergence, and arc rifting. Different regions of an oceanic arc have variable preservation potential after collision with a continental margin, controlled in part by collision geometry. In light of these complications, we discuss whether and how completely the record of arc sedimentary and tectonic history is preserved through geologic time. We thereby evaluate the benefits and limitations of interpreting ancient arc terranes in the geologic record.

2. Intraoceanic arc morphology and sedimentary processes

Seafloor and sub-bottom mapping of modern, active arc regions, combined with dredging and drill-core sampling, documents their

Fig. 1. Map showing active global subduction zones and the ancient arc systems referenced in the text. Accretionary plate margins are shown with solid triangular marks along the plate boundary, and tectonically erosive margins are indicated by empty triangles.