SPECIAL COLLECTION: PERSPECTIVES ON ORIGINS AND EVOLUTION OF CRUSTAL MAGMAS

From the Hadean to the Himalaya: 4.4 Ga of felsic terrestrial magmatism

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ABSTRACT

Detrital zircons as old as nearly 4.4 Ga offer insights into the earliest moments of Earth history. Results of geochemical investigations of these grains have been interpreted to indicate their formation in near-H2O saturated meta- and peraluminous magmas under a relatively low (15–30 °C/km) geotherm. A key feature in pursuing a petrotectonic model that explains the full spectrum of these observations is their seeming contrast to most Phanerozoic magmatic zircons, specifically their low Ti-in-zircon crystallization temperatures and inclusion assemblages. The ~22 Ma Arunachal leucogranites of the eastern Himalaya appear, however, to be a rare exception to this generality. They show large-ion lithophile covariance trends indicative of wet basement melting together with a normal distribution of magmatic crystallization temperatures about an average of 660 °C. In the same fashion as Hadean zircons, Arunachal leucogranite and host gneiss zircons are dominated by muscovite + quartz inclusions that yield formation pressures of 5–15 kbars. We suggest that the Arunachal leucogranites originated in the hanging wall of a megathrust that carried H2O-rich foreland sediments to depths of >20 km whereupon de-watering reactions released fluids that fluxed hanging wall anatexis. Modeling suggests the thermal structure of this continental collision environment may have been broadly similar to a Hadean ocean-continent subduction zone. The similarity of these two environments, separated by over 4 Ga may explain seemingly common features of the Hadean and Arunachal leucogranite zircons. Their key difference is the absence of metaluminous magmas in the continental collision environment, which is shielded from juvenile additions.

Keywords: Early Earth, zircon, geochronology, geochemistry, crustal magmas, Himalaya

INTRODUCTION

Hadean zircon geochemistry

Much of our understanding of the Hadean—the first 500 Ma of Earth history—is gleaned from detrital zircons as old as nearly 4.4 Ga (see review of Harrison 2009). Hadean zircons, most notably those from Jack Hills, Western Australia, have been analyzed by numerous geochemical methods, including oxygen isotopes (e.g., Mojzsis et al. 2001; Peck et al. 2001; Cavosie et al. 2005; Trail et al. 2007; Harrison et al. 2008; Bell and Harrison 2013), Xe isotopes (Turner et al. 2004, 2007), Ti-in-zircon thermometry (Watson and Harrison 2005; Harrison et al. 2007; Harrison and Schmitt 2007; Fu et al. 2008), Lu-Hf (Amelin et al. 1999; Harrison et al. 2005, 2008; Blichert-Toft and Albarède 2008; Bell et al. 2011, 2013), Sm-Nd (Amelin 2004; Caro et al. 2008), Li isotopes (Ushikubo et al. 2008), trace elements (e.g., Maas and McCulloch 1991; Peck et al. 2001; Cavosie et al. 2005), and characterized for mineral inclusions (Maas et al. 1992; Cavosie et al. 2004; Menneken et al. 2007; Hopkins et al. 2008, 2010, 2012; Rasmussen et al. 2011; Bell et al. 2015).

If any generalization can be drawn from these studies, it is that their results appear inconsistent with the long-standing view that the first several hundred million years of Earth history were characterized by a waterless and molten surface (e.g., Kaula 1979; Wetherill 1980; Solomon 1980; Ward and Brownlee 2000). Alternate views, such as their growth in melts derived from mafic crust (e.g., Rollinson 2008; Shirey et al. 2008), invariably focus on the subset of their geochemical constraints that are consistent with the proposed interpretation while ignoring those that are contradictory (e.g., inclusion assemblages, crystallization temperature). Instead, low (~680 °C) crystallization temperatures, hydrous S- and I-type inclusion assemblages, δ18O enrichment in some Hadean zircons, and continental trace element signatures indicate melting of crust protoliths under high-water activities to produce both metaluminous and peraluminous magmas (Harrison 2009). Hopkins et al. (2008, 2010) interpret the relatively low (15–30 °C/km) geotherms obtained from thermobarometry of zircons and their inclusion assemblages to indicate that these magmas formed in plate-boundary-type settings.

Collectively these data suggest that the Hadean world may have been more similar to the present than long thought, raising the question: Is there a modern environment that produces broadly similar geochemical signals?

Himalayan granitoid geochemistry

It is generally agreed that the High-Himalayan leucogranites formed by melting of petelles in the underlying Greater Himalayan Crystallines during Neoalpine ultrametamorphism (LeFort et al. 1987; Harris and Inger 1992; Guillot and LeFort 1995; LeFort 1996; Harrison et al. 1997; Yin and Harrison 2000; Zhang et al. 2004). However, in the eastern Himalaya, four distinctive modes...