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Continental collision zones are primary sites for net continental crust growth — A testable hypothesis

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ABSTRACT

The significance of the continental crust (CC) on which we live is self-evident. However, our knowledge remains limited on its origin, its way and rate of growth, and how it has acquired the "andesitic" composition from mantle derived magmas. Compared to rocks formed from mantle derived magmas in all geological environments, volcanic arc rocks associated with seafloor subduction share some common features with the CC; both are relatively depleted in "fluid-insoluble" elements (e.g., Nb, Ta and Ti), but enriched in "fluid-soluble" elements (e.g., U, K and Pb). These chemical characteristics are referred to as the "arc-like signature", and point to a possible link between subduction-zone magmatism and CC formation, thus leading to the "island arc" model widely accepted for the origin of the CC over the past 45 years. However, this "island–arc" model has many difficulties: e.g., (1) the bulk arc crust (AC) is basaltic whereas the bulk CC is andesitic; (2) the AC has variably large Sr excess whereas the CC is weakly Sr deficient; and (3) AC production is mass-balanced by subduction erosion and sediment recycling, thus contributing no net mass to the CC growth, at least in the Phanerozoic. Our recent and ongoing studies on granitoid rocks (both volcanic and intrusive) formed in response to the India–Asia continental collision (~55 ± 10 Ma) show remarkable compositional similarity to the bulk CC with the typical "arc-like signature". Also, these syncollisional granitoid rocks exhibit strong mantle isotopic signatures, meaning that they were recently derived from a mantle source. The petrology and geochemistry of these syncollisional granitoid rocks are most consistent with an origin via partial melting of the upper ocean crust (i.e., last fragments of underthrusting ocean crust upon collision) under amphibolite facies conditions, adding net mantle-derived materials to form juvenile CC mass. This leads to the logical and testable hypothesis that continental collision produces and preserves the juvenile crust, and hence maintains net CC growth.

Importantly, the history of the Greater Tibetan Plateau from the Early Paleozoic to present manifests the history of "super" continent amalgamation through a series of continental collision events with production and preservation of abundant syncollisional granitoids. Plate tectonics in terms of seafloor spreading and subduction is a continuous process on a global scale since its inception (in the early Archean?), whereas continental collision on regional scales and super-continental formation on a global scale are episodic (vs. continuous). Hence, continental collision with juvenile crust formation/preservation and super-continent amalgamation explains the episodic growth of the CC. We are continuing testing and refining this hypothesis by detailed petrological, geochemical and geochronological studies of syncollisional granitoids along older collision zones in central-west China, especially on the northern Tibetan Plateau in a global context.

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> “A fact is a simple statement that everyone believes. It is innocent unless found guilty. A hypothesis is a novel suggestion that no one wants to believe. It is guilty until found effective.”
>
> [Edward Teller (1908–2003).]

1. Introduction

The significance of the continental crust on which we live is self-evident, yet our knowledge remains limited on its origin, its way and rate of growth, and how it has acquired the “andesitic” composition from mantle derived magmas. The first-order complementarity in incompatible element abundances between continental crust and ocean crust is consistent with the view that the incompatible-element enriched bulk continental crust represents the extract of a small amount of very low-degree (~1.5% melting) melt from the primitive mantle in Earth's early history (e.g., Hofmann, 1988), which also resulted in an incompatible-element-depleted residue in the upper mantle that became the source of the present-day mid-ocean ridge basalts (MORB; e.g., Gast, 1968; O'Nions et al., 1979; Allègre et al., 1983). This depleted upper mantle has been termed depleted MORB mantle or DMM (Zindler and Hart, 1986). However, in what kind of geological setting and how such very low-degree melting took place in Earth's early history remains unknown, i.e., a hypothesis that cannot yet be tested.

When on Earth the first continental crust (CC) formed/appeared is also uncertain because of the likely preservation problem. The oldest preserved crustal rocks are the Hadean age ~4.0–4.2 Ga tonalitic Acasta Gneiss (Bowring and Housh, 1995; Iizuka et al., 2007) in northern Canada, and granitoid rocks may have actually existed even earlier at ~4.35 Ga as inferred from “granitic” zircons from Jack Hills in western Australia (Cavosie et al., 2004; Harrison et al., 2005). Hadean rocks are rare and the more abundant are Archean age TTG–granite–greenstone belt complexes (see Condie and Aster, 2009; Ernst, 2009). The TTG (tonalite–trondhjemite–granodiorite) assemblages are considered as primary architecture of the continental crust (e.g., Rollinson, 2008; Condie and Aster, 2009). The origin of the TTGs has been extensively studied and discussed over the last decades with ideas including shallow mantle melting and fractional crystallization, partial melting of eclogite/amphibolite, and incipient melting of hydrous, and fertile upper mantle peridotite (see Ernst, 2009 for review). However, the compositional similarity (Fig. 1) between TTGs and the Phanerozoic subduction-related adakites (e.g., Defant and Drummond, 1990; Castillo, 2006), sanukitoids (e.g., Tatsumi, 2008) or high-Mg andesites (e.g., Kelemen, 1995) has led to the popular acceptance that the TTGs must have formed in Archean-type subduction settings (e.g., Condie, 2005; Martin et al., 2005).

It has long been recognized that the CC is generated through subduction-zone magmatism, i.e., the “island–arc model” proposed by Taylor (1967, 1977), who recognized with wisdom that compared with mantle-derived melts from all tectonic settings, island–arc magmas show remarkable similarity to the bulk CC in incompatible element patterns (Fig. 2), and both must be genetically related. This “island arc model” has been widely accepted as the “standard model” for the origin of the CC. Most studies agreed that the CC continued to grow since the Archean (Fig. 3; see Condie, 2005), while also recognizing that such continuum represents a cumulative growth of a number of magmatic episodes (Fig. 3; McCulloch and Bennett,

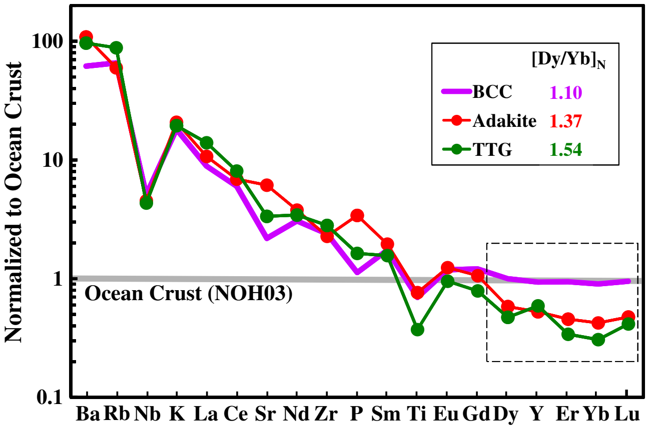

Fig. 1. Multi-element diagram normalized to the mean composition of the ocean crust (Niu and O'Hara, 2003) to show the compositional similarity of the Archean TTGs and the Phanerozoic adakites (data from Martin et al., 2005), both show remarkable depletion of Y and other heavy rare earth elements (HREEs), consistent with the presence of garnet as a residual phase during melting (“garnet signature”). Model bulk continental crust (BCC; Rudnick and Gao, 2003) is also plotted for comparison. Note that the bulk CC shows the same Y and HREE abundances as the ocean crust without the “garnet signature”.