Gondwana Research 40 (2016) 184–198

Contents lists available at ScienceDirect

Gondwana Research

journal homepage: www.elsevier.com/locate/gr

GR focus review

Subduction erosion, and the de-construction of continental crust: The Central America case and its global implications

Paola Vannucchi [a,b,*], Jason P. Morgan [a], Maria Laura Balestrieri [c]

[a] Earth Sciences Department, Royal Holloway, University of London, Egham TW20 0EX, UK
[b] Dipartimento di Scienze della Terra, Università degli Studi di Firenze, 50121 Firenze, Italy
[c] Istituto di Geoscienze e Georisorse, CNR, 50121 Firenze, Italy

A R T I C L E I N F O

Article history:
Received 21 May 2016
Received in revised form 26 September 2016
Accepted 1 October 2016
Available online 11 October 2016

Handling Editor: M. Santosh

Keywords:
Subduction erosion
Ocean drilling
Apatite fission track
Central America

A B S T R A C T

The relative rates of creation and destruction of continental crust at subduction zones are a key factor shaping the evolution of continental crust through time. Central America, arguably the best studied place where subduction erosion has been documented, is used here to assess past rates and modes of forearc recycling. Drilling from Guatemala to Costa Rica indicates that subduction erosion has been active since at least the early Miocene. Drilling also shows that the rates of subduction erosion have varied significantly both along strike and through time. The Integrated Ocean Drilling Program (IODP) Expedition 334 to southern Costa Rica documents unprecedented subduction erosion there — at rates larger than the fastest known rates of forearc accretion. In southern Costa Rica, accelerated subduction erosion of the upper plate initiated when the Panama Fracture Zone/Cocos Ridge, the latter being an over thickened aseismic ridge, arrived at the Middle America Trench. The forearc records this event with an unconformity at 2.2 ± 0.2 Ma. The recovered shelf sequence overlying the unconformity constrains a short (<2 Myr) interval of extreme subsidence (~1200 m) with a rapid pulse occurring during the first ~0.3 Myr. This event removed an estimated 1.2×10^6 km^3 of forearc material at a rate of ~1125 km^3/Myr/km of trench during a time of rapid (~1035 m/Myr) contemporaneous shelf sediment accumulation. Detrital apatite fission-track thermochronology on the sediments above the unconformity indicates the pattern of surficial sediment transport during this subduction erosion event. The fission track data show that sediments from the extinct and exhumed volcanic arc – the Cordillera de Talamanca – were able to immediately access the growing forearc basin after the onset of the 2.2 Ma subduction erosion event. The onset of subduction of an aseismic ridge as occurred at 2.2 Ma in southern Costa Rica is a fairly common tectonic event along a subduction margin. We suggest that similar rapid pulses of subduction erosion may punctuate the evolution of many margins, contributing disproportionately to crustal recycling at subduction zones. The (poorly) preserved geologic record of paleoforearcs needs to be reassessed with this mechanism in mind. It also implies that continental forearc material may be significantly consumed during short local bursts along a subduction margin, and furthermore, that margins abutting regions of frequent subduction of aseismic ridges, like the regions in the Western Pacific where the Darwin Rise currently subducts, should face disproportionate pulses of future subduction erosion and forearc recycling.

Contents

* Corresponding author at: Earth Sciences Department, Royal Holloway, University of London, Egham TW20 0EX, UK.
E-mail address: paola.vannucchi@rhul.ac.uk (P. Vannucchi).

http://dx.doi.org/10.1016/j.gr.2016.10.001
1342-937X/

1. Introduction

The quantification of the growth, destruction and recycling of continental crust across the geological eras is critical to understand not only the evolution of key tectonic processes, such as interactions between plates and other lithospheric geomechanics, but also the geochemical evolution of the mantle (Tatsumi and Kogiso, 2003; Tatsumi, 2005). Several authors have produced global models for crustal growth through time (cf. Rino et al., 2004). Most models imply net growth at differing rates through time. Their most significant contrasts lie in stressing the importance of continuous (Hurley and Rand, 1969; O'Nions et al., 1979; Veizer and Jansen, 1979; Allègre, 1982) vs. episodic growth (McCulloch and Bennett, 1994; Condie, 1998), or in arguing for rapid growth in the first 0.6–1 Ga after Earth's origin, followed by a period with nearly constant crustal volume (Brown, 1979; Armstrong, 1981; Dewey and Windley, 1981; McLennan and Taylor, 1982; Reymer and Schubert, 1984) vs. a major phase of early continental crustal growth before ~ 3.8 Ga followed by a slow, steady reduction in the volume of continental crust since (Fyfe, 1978). One of the most-used approaches to address the rate of growth of continental crust through time has been through the compilation of U–Pb zircon ages in detrital and granitoid rocks (Condie et al., 2011). Zircon ages show a relatively small number of high-density age peaks distributed over the ~4.5 Ga of Earth's existence. While these data have often been interpreted to imply phases of episodic crustal growth, they can also be interpreted to imply phases of preferential preservation of crust, orogeny and crustal metamorphism (for example zircon age-resets during Himalayan-style orogeny) (Condie et al., 2011; Cawood et al., 2012; Condie, 2014). The global importance of the destruction and mantle recycling of continental crust at subduction zones has captured the attention of geophysicists (Scholl and von Huene, 2007, 2009; Stern and Scholl, 2010) and, during the last few years, also isotope geochemists (Willbold and Stracke, 2006, 2010). Here we focus on observational evidence for the selective destruction and preservation of continental crust. Is it plausible for there to be periods with net destruction of continental crust? If so, what are reasonable magnitudes and timescales of the processes of net crustal destruction? Providing answers to these questions is the primary goal of this study, which is based on the approach of using constrained present-day rates as a key to better understand plausible past rates.

2. Subduction erosion and its controlling factors

Subduction erosion, i.e. the basal removal of upper plate material induced by subduction (von Huene and Scholl, 1991) is at present the largest-scale geological process destroying continental crust, with sediment subduction and continental delamination playing a lesser role (e.g. Clift et al., 2009a, 2009b). In this paper we assess the rates of subduction erosion and the net volume increase or decrease of continental crust where it is best measured offshore Central America, during the ~ 25 Ma time frame within which we can confidently track subduction erosion. We focus on Central America because this is the region that provides the biggest regional constraints to calculate a rate-time budget for this process of crustal destruction.

Several factors appear to shape subduction erosion. The topographic relief of seamounts on the subducting plate is one. This leads to directly observable effects on the forearc slope of the overriding plate. In the southeast part of the Central America Trench offshore Costa Rica, the slope is punctuated by elongate depressions of roughly the same width as seamounts that are traceable up to 55 km inland, and parallel to the subduction vector (von Huene et al., 2000) (Fig. 1). At a bigger scale, still in Central America, the trench strike changes abruptly between Nicaragua and Costa Rica, describing a retreat that culminates at the axis of the subducting Cocos Ridge (Ranero et al., 2008) (Fig. 1). However, subduction erosion across Central America is not limited to areas where volcanic seafloor relief is subducting. Erosion is also measured for Guatemala (Vannucchi et al., 2004) and northern Costa Rica offshore Nicoya Peninsula (Vannucchi et al., 2001, 2003) where the seafloor is relatively smooth and seamount-poor. More generally, the controlling factors on the occurrence of subduction erosion or accretion appear to be primarily linked with the thickness of trench sediments and the subduction rate (Clift and Vannucchi, 2004). In particular, subduction erosion is favored by fast subduction – >8 cm/yr – and thin – <1 km – trench sediment fill.

In addition to the traces – 'topographic shadows' – that incoming plate relief can induce on the upper plate slope shortly after its subduction, in general subduction erosion can be directly detected by geologic observations in the forearc. Such observations include upper plate "basement" units – e.g. crystalline, ophiolitic, and fossil accretionary prisms – cropping out and forming the outer forearc (e.g. Straub et al., 2015), or the presence of a plate boundary shear zone that cuts through upper plate material (Vannucchi et al., 2008). Indirect evidence for subduction erosion involves a basal cut of imbricate thrusts and/or extensional faulting across the forearc that can be visible in reflection seismic images (Ranero and von Huene, 2000; Laursen et al., 2002), the progressive landward migration of the volcanic arc(Rutland, 1971; Bloomer et al., 1994; Vannucchi et al., 2001; Kay et al., 2005), and the subsidence of the forearc (von Huene et al., 1985; von Huene and Lallemand, 1990; Clift and MacLeod, 1999; Vannucchi et al., 2001, 2003). The latter can be detected through forearc drilling of unconformities with deposition of progressively deeper marine sediments on top of continental to shallow marine coastal facies, and sedimentary and paleo-ecological proxies. It is important to notice that subsidence in the forearc – in particular close to the trench – implies upper plate thinning, i.e. local removal of forearc material.

3. Subduction erosion in Central America

The Central America Trench was dredged offshore Nicaragua (Silver et al., 2000) and Mexico (de Lepinay et al., 1997). In both sites, upper plate basement was recovered from submarine outcrops located just a few km from the trench axis (Fig. 1). From Mexico to southern Costa Rica eight DSDP/ODP/IODP expeditions have recovered material from the forearc of the Central America Trench (Fig. 1). Here we concentrate on the temporal variability of subduction erosion along the margin that is shown by DSDP Leg 84 offshore Guatemala, ODP Leg 170 offshore Northern Costa Rica, and IODP Exp. 334 offshore southern Costa Rica (Fig. 2). These three areas also correspond to different "smoothnesses" of the subducting Cocos plate. Therefore, here they are considered type examples of what happens in smooth, seamount-dominated, and ridge-dominated subduction examples.