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Dating the India–Eurasia collision through arc magmatic records

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ABSTRACT

The Himalayan orogeny, a result of the collision of India and Eurasia, provides direct evidence of strain accommodation and large-scale rheological behavior of the continental lithosphere. Knowledge of the timing of the India–Eurasia collision is essential to understand the physical processes involved in collisional systems. Here we present a geochronological and multi-isotopic study on rocks from the upper crust of the Kohistan Paleo-Island Arc that formed in the equatorial part of the Neo-Tethys Ocean. In situ U–Pb geochronology and Hf isotopes in zircon, and whole-rock Nd and Sr isotopic data of plutonic rocks from the Kohistan-Ladakh Batholith, are used to construct a continuous record of the isotopic evolution of the source region of these granitoids that are related to both the subduction of the oceanic lithosphere and subsequent arc–continent collisions. We demonstrate that profound changes in the source region of these rocks correspond to collisional events. Our dataset constrains that the Kohistan–Ladakh Island Arc initially collided along the Indus suture zone with India at 50.2 ± 1.5 Ma, an age generally attributed to the final India–Eurasia collision for the entire Himalayan belt. In the western Himalaya, the final collision between the assembled India/Arc and Eurasia however, occurred $\sim$10 Ma later at 40.4 ± 1.3 Ma along the so-called Shyok suture zone. We present evidence indicating that a similar dual collision scenario can be extended to the east and conclude that a final India/Arc–Eurasia collision at $\sim$40 Ma integrates crucial aspects of the magmatic, tectonic, and sedimentary record of the whole Himalayan mountain belt.

1. Introduction

The continent–continent collision of India with Eurasia has significantly shaped the surface of the Earth by producing one of the largest known orogenic systems. To understand the importance of the physical processes controlling crustal deformation and the influence of this mountain building event on the climatic system (Le Pichon et al., 1992; Molnar et al., 1993; Molnar and Tapponnier, 1975; Royden et al., 2008; Tapponnier et al., 1982), an accurate knowledge of the plate convergence and the kinematic history of the collision is essential. Key boundary parameters include the timing of collision and plate reconstructions, which together constrain the absolute amount of plate convergence accommodated. Whereas modern paleomagnetic studies agree on plate reconstruction within a few hundred kilometers (e.g., van Hinsbergen et al., 2012), the timing of the final India–Eurasia collision is debated. Estimates range from $\sim$70 to $\sim$25 Ma (e.g., van Hinsbergen et al., 2012; Yin and Harrison, 2000) with most workers preferring a $\sim$52–50 Ma collision age (e.g., Najman et al., 2010). Recent paleomagnetic data suggest a complex collision scenario that invoked multiple continental or arc fragments and increasingly casts doubt that the $\sim$50 Ma events constrains the final India–Eurasia collision (Aitchison et al., 2007; Khan et al., 2009; van Hinsbergen et al., 2012). This uncertainty on the collision age translates to up to $\sim$3000 km differences in estimates on the convergence accommodated in the system, which strongly hampers our understanding of the formation of the India–Asia collisional system.

In this paper we present new results that constrain the timing of collision in the western Himalaya (Fig. 1). Our approach is derived from our understanding of currently active continent–island arc collision zones (see Section 3). In these systems, the subduction of continental lithosphere below the arc can be tracked by the differences in isotopic compositions between pre- and post-collisional arc magmas if significant isotopic differences exist between the subducting continental lithosphere and the obducting arc crust. Along the Himalayan belt, only the Kohistan–Ladakh Paleo-Island Arc (KLA) that is exposed in the western Himalaya offers such an opportunity.

The main objective of this paper is to construct a continuous spatial and temporal record of the isotopic composition of the KLA related rocks, spanning from the intra-oceanic subduction in the early Cretaceous to the Miocene, thus covering all proposed collision times. Kohistan–Ladakh Arc magmas that formed prior

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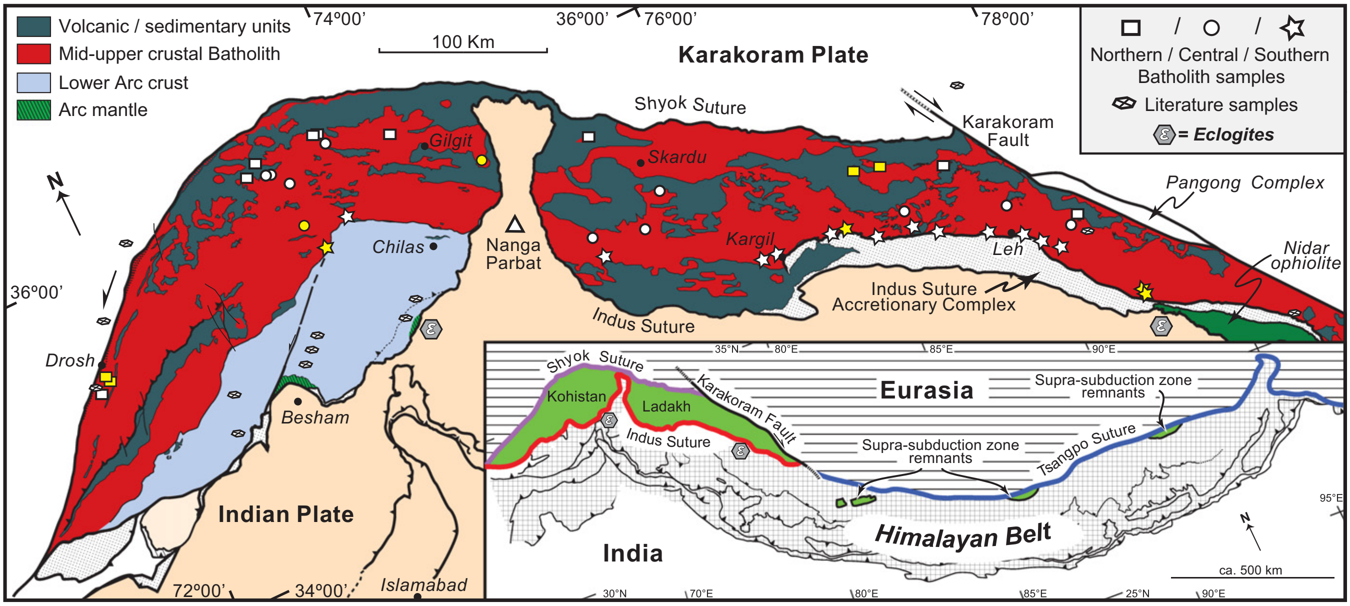

Fig. 1. Sample location on a simplified geological map of the Kohistan–Ladakh Arc (KLA). White symbols indicate homogenous unradiogenic samples and yellow filled symbols indicate isotopically evolved and/or heterogeneous granitoids. Inset shows the structural position of the KLA with respect to the different Himalayan suture zones. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

to the 50–52 Ma collision of the arc with India have isotopic characteristics comparable to modern intra-oceanic arc volcanics (Figs. 2 and 3). Conversely, the post-collisional, late-Eocene/Oligocene granites are more variable in composition and trend to significantly more radiogenic isotopic compositions (Heuberger et al., 2007) indicating the involvement of old continental lithosphere in their formation.

2. Geological setting

Three suture zones, the Indus, Shyok and Tsangpo, mark the Himalayan collision (Fig. 1). In the NW Himalaya, the ~70,000 km^2 KLA is wedged between India and Karakoram (the former paleo-Eurasian continental margin). The Shyok suture separates the KLA in the north from the Karakoram, whereas in the south the Indus suture divides the KLA from the Indian continent (Fig. 1). The Tsangpo (or Yarlung-Tsangpo) separates India from Eurasia in the central and eastern part of the Himalaya (Burg and Chen, 1984; Gansser, 1980; Yin and Harrison, 2000).

2.1. The KLA and the Karakoram

The KLA (for a recent review see Burg, 2011) formed primarily during the late Mesozoic as an intra-oceanic arc, during the northward directed intra-oceanic subduction of the Neotethys ocean basin (Bard, 1983; Coward et al., 1987; Tahirkheli, 1979). This interpretation is based on the absence of continental basement and continental derived sediments in the KLA (Bard, 1983; Jagoutz et al., 2009; Tahirkheli, 1979), and on paleomagnetic data placing the formation of the KLA near the equator within an oceanic basin (e.g., Khan et al., 2009) much further south than the Eurasian margin during the Mesozoic (Schettino and Scotese, 2005).

To the north of the arc system, at the northern most margin of the Neothethys, a second subduction system was active simultaneously, resulting in the Jurassic to Tertiary Gangdese and Karakoram Batholiths (e.g., Debon et al., 1987; Gaetani, 1997; Heuberger et al., 2007; Searle et al., 2010). These Batholiths were part of an active continental margin due to the northward subduction of Tethyan oceanic lithosphere beneath the southern Eurasian margin (e.g., Le Fort, 1988; Rex et al., 1988; Yin and Harrison, 2000).

2.2. The Indus suture

In contrast to the Tsangpo suture, the Indus suture zone contains eclogites and ultra-high pressure (UHP) assemblages that can be used to reliably constrain the timing of the formation of the Indus suture. The P-T-t path of the eclogites provides evidence for the beginning of the subduction of the Indian margin at ~50 Ma (Kaneko et al., 2003; O'Brien et al., 2001; Parrish et al., 2006). In conjunction with the fact that the sedimentary record places the transition from marine to non-marine sedimentation on the northern Indian Margin at ~50 Ma (e.g., Beck et al., 1995; Garzanti et al., 1987; Green et al., 2008), the timing of the Indus suture, and the collision between India and the KLA, have been accepted to be ~50 Ma.

2.3. The Shyok suture

The Shyok suture has a complex history and its formation is poorly constrained. North verging folds and top-to-the-north directed shear zones within the northern part of the KLA indicate that the KLA was initially overthrusted on top of the Karakoram margin (Coward et al., 1986). During the early Miocene, parts of the Shyok suture were reactivated as a top-to-the-south directed thrust, overprinting the previous suture related structures (Brookfield and Reynolds, 1990; Coward et al., 1986).

Originally, the formation age of the Shyok suture was interpreted to postdate the India–KLA collision (Achache et al., 1984; Andrewsspeed and Brookfield, 1982; Bard, 1983; Brookfield and Reynolds, 1981). Subsequently, based on a proposed systematic relationship between emplacement age of plutonic rocks from the northern KLA (determined by Rb–Sr whole rock and mineral isochrons) and the presence or absence of deformational fabric in the rocks (i.e., younger ones being undeformed, older deformed), the Shyok suture has been inferred to have formed during the