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The Tethyan Himalayan detrital record shows that India–Asia terminal collision occurred by 54 Ma in the Western Himalaya

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ABSTRACT

The Himalayan orogen is a type example of continent–continent collision. Knowledge of the timing of India–Asia collision is critical to the calculation of the amount of convergence that must have been accommodated and thus to models of crustal deformation. Sedimentary rocks on the Indian plate near the suture zone can be used to constrain the time of collision by determining first evidence of Asian-derived material deposited on the Indian plate. However, in the Himalaya, for this approach to be applied successfully, it is necessary to be able to distinguish between Asian detritus and detritus from oceanic island arcs that may have collided with India prior to India–Asia collision. Zircons from the Indian plate, Asian plate and Kohistan–Ladakh Island arc can be distinguished based on their U–Pb ages combined with Hf signatures. We undertook a provenance study of the youngest detrital sedimentary rocks of the Tethyan Himalaya of the Indian plate, in the Western Himalaya. We show that zircons of Asian affinity were deposited on the Indian plate at 54 Ma. We thus constrain terminal India–Asia collision, when both sutures north and south of the Kohistan–Ladakh Island arc were closed, to have occurred in the Western Himalaya by 54 Ma.

1. Introduction

Knowledge of the timing of India–Asia collision is critical to models of Himalayan orogenesis, in particular to the determination of the amount of plate convergence that must have been accommodated. Whilst the most commonly quoted age of collision lies within the range of ca. 60 to 50 Ma (e.g. Hu et al., 2016 and references therein), a more recent suggestion has been proposed whereby the above quoted age actually represents a collision between India and an intra-oceanic island arc or Tethyan microcontinent, with later terminal suturing between India and Asia perhaps as late 40 Ma (Bouilhol et al., 2013), 34 Ma (Aitchison et al., 2007) or 23 Ma (van Hinsbergen et al., 2012). Such a degree of difference in the time of final suturing of India with Asia results in differences of >1000 km in the calculation of the amount of continental crust that needs to be accommodated during convergence.

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The NW Himalaya, where the Kohistan–Ladakh intra-oceanic island arc (KLIA; labelled as K and L in Fig. 1) is wedged between the Indian and Asian plates, provides the ideal location to study the relative timings of arc and continent collisions due to the excellent preservation and exposure of the arc. Using data from this region, a number of workers have proposed a ca. 60–50 Ma age for collision between India and the KLIA, with the KLIA already sutured to, and representing the southern margin of, Asia to the north. This is based on various factors including the time of elimination of marine facies in the Tethyan Himalaya and intervening Indus suture that provides a minimum age of collision (e.g. Green et al., 2008), age of eclogites indicative of onset of Indian continental subduction (e.g. Donaldson et al., 2013), and first evidence of detritus from north of the suture zone deposited on the Indian plate (e.g. Clift et al., 2002 but see also; Henderson et al., 2011) or sedimentary rocks containing both Indian and Asian provenance (Tripathy-Lang et al., 2013).

The above evidence can be interpreted as documenting the age of India–Asia collision if one takes the KLIA to have collided with the Asian plate prior to its collision with India (e.g.

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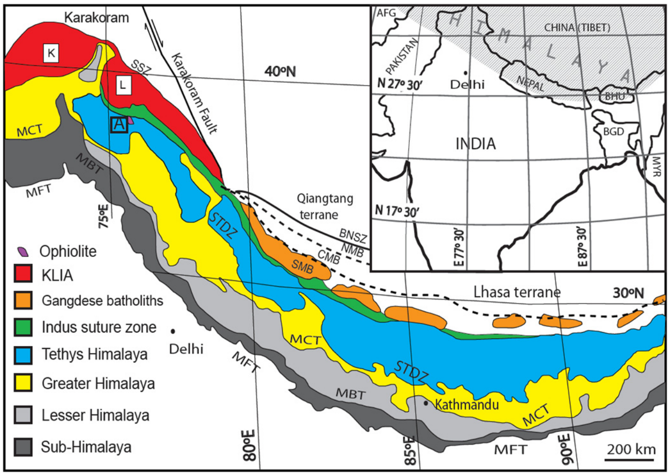

Fig. 1. Geological map of the Himalaya and sampling location (A), with location of Lhasa terrane magmatic belts adapted from Zhu et al. (2011). KLIA – Kohistan (K) and Ladakh (L) oceanic island arc; BNSZ = Bangong–Nujiang Suture Zone; SSZ = Shyok Suture Zone; STDZ = South Tibetan Detachment Zone; MCT = Main Central Thrust; MBT = Main Boundary Thrust; MFT = Main Frontal Thrust. "Ophiolite" refers to the Spongtang ophiolite. Magmatic belts of the Lhasa terrane (e.g. Chu et al., 2006) correspond to the Lhasa subterranes of Zhu et al. (2011): SMB = Southern Magmatic Belt of the Lhasa Terrane; CMB = Central Magmatic Belt of the Lhasa Terrane; NMB = Northern Magmatic belt of the Lhasa Terrane. Inset: location of the region in its wider geographical context: AFG = Afghanistan; BHU = Bhutan; BGD = Bangladesh; MYR = Myanmar.

Borneman et al., 2015). However, some workers propose that the KLIA collided with Asia subsequent to its earlier collision with India (e.g. see review in Burg, 2011), and that collision is dated variously as having occurred at 85 Ma (Chatterjee et al., 2013), 61 Ma (Khan et al., 2009) and 50 Ma (Bouilhol et al., 2013). In such a scenario, the criteria quoted above would be dating India–KLIA rather than India–Asia collision, with final collision of India + KLIA with Asia occurring not until later, for example at 40 Ma (Bouilhol et al., 2013). This, plus the questioning by Henderson et al. (2011) of previous work constraining collision by first arrival of material from north of the suture zone on the Indian plate (Clift et al., 2002), suggests that the time is right for a reappraisal of the relative timings of India–arc–Asia collision on the western side of the Himalayan orogen.

The criterion used in this paper to constrain the age of India–Asia collision is that of earliest evidence of Asian detritus deposited within the youngest Tethyan sedimentary rocks on the Indian plate. Differentiation of detritus between ancient passive Indian margin origin vs Mesozoic arcs (of Asian or KLIA origin) is relatively straightforward using petrography and U–Pb dating of detrital zircons. However, dating the timing of terminal India–Asia collision relies critically on the ability to differentiate between Asian- and KLIA-derived detritus. There is large overlap in the field of U–Pb ages of igneous zircons from the KLIA and the southern margin of the Asian plate (the Lhasa terrane), precluding differentiation between these potential sources on the basis of zircon age alone. However, zircons from these two terranes show differences in terms of zircon εHf characteristics, which reflect their juvenile vs more evolved sources. Thus, to assess the provenance of the detrital grains, we carried out Hf analyses on Mesozoic detrital zircons to discriminate between Asian vs KLIA source.

We then applied this provenance approach to the biostratigraphically dated Paleogene sedimentary rocks of the Kong and Chulung La Formations of the Tethyan Himalaya, in Ladakh, India (Fig. 1) to determine first evidence of Asian detrital input onto the Indian plate. Given the recent re-interpretation of syn-orogenic rocks in the suture zone in Ladakh (Henderson et al., 2011), and the inability of previous detrital studies to differentiate between an Asian vs island arc provenance (e.g. Tripathy-Lang et al., 2013) our study of these Tethyan rocks is the first isotopic provenance study used to differentiate between India–Asia and India–KLIA collision in NW India.

2. Geological background

The Himalaya (Fig. 1) resulted from the closure of the Tethyan Ocean and resultant collision between the northern palaeo-Indian passive margin to the south and the Eurasian active margin to the north.

To the south of the Indus–Yarlung suture zone, the northern margin of the Indian plate is composed of the Palaeozoic–Early Cenozoic Tethyan Himalayan passive margin sedimentary rocks, including the Palaeogene Kong and Chulung La Formations (Critelli and Garzanti, 1994; Garzanti et al., 1987), which are the focus of this study. Obducted onto the Tethyan Himalaya in either the Late Cretaceous (Searle et al., 1997) or Eocene (Garzanti et al., 1987), is the Jurassic Spontang ophiolite and arc (Pedersen et al., 2001).

In the NW part of the orogen, our area of study, the Mesozoic–Paleogene Kohistan–Ladakh intra-oceanic island arc is confined between the Indian plate to its south along the Indus Yarlung suture zone and to its north by the Asian plate Karakoram along the Shyok suture zone (e.g. Schaltegger et al., 2002). As noted above, the relative timings of the collisions between India, Asia and the KLIA are debated, with some researchers considering that the KLIA collided with India first (e.g. Khan et al., 2009), and others proposing it collided with Asia first (e.g. Borneman et al., 2015).

The Karakoram represents the continental arc of Asia in the NW part of the orogen. It consists of (i) a southern belt characterised by Late Jurassic–Cretaceous metamorphism related to subduction-related plutonism and later Cenozoic metamorphism associated with the India–Asia collision, (ii) a northern sedimentary belt characterised by Ordovician to Early Cretaceous sedimentary rocks, and (iii) pre-collisional plutons of Late Jurassic and Cretaceous age and post-collisional plutons as young as Miocene (e.g. Searle et al., 1999). To the east the KLIA dies out, and the Karakoram may be correlated with either the Lhasa or Qiangtang terranes of Tibet across the Karakoram Fault (Fig. 1) (Fraser et al., 2001; Robinson et al., 2012 and references therein). Fraser et al. (2001) speculate that the Karakoram and Lhasa terranes may have had similar magmatic and metamorphic histories prior to and during the early stages of India–Asia collision, with later tectonism causing deeper exhumation, to lower crustal levels, in the Karakoram.

The Lhasa terrane, which represents the southernmost extent of the Asian margin east of the Karakoram Fault, is composed of Phanerozoic low grade metamorphic and sedimentary cover overlying Precambrian–Cambrian basement (e.g. Leier et al., 2007). Along its southern rampart are intruded the Gangdese continental arc batholiths (Scharer and Allegre, 1984). Whilst Gangdese intrusions are Mesozoic–Paleogene aged, post-collisional igneous activity continued into Miocene times (e.g. Harrison et al., 2000). Chu et al. (2006) and Zhu et al. (2011) divide the Lhasa terrane into three magmatic belts or subterranes. The Gangdese batholiths represent the Southern Magmatic belt. The Mesozoic Central and Northern magmatic belts may be the result of either 1) the low angle northward subduction of the Neotethyan slab subducting beneath the Lhasa terrane from the south, or 2) the southward subduction of the Bangong Ocean sea floor that separated the Lhasa terrane from the Qiangtang Terrane to its north, prior to their col-