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Indus Basin sediment provenance constrained using garnet geochemistry

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ABSTRACT

The chemical and mineralogical diversity of western Himalayan rivers is the result of each of them draining different tectonic and lithologic units, whose character is partly transferred to the sediments carried by those rivers. Garnet geochemistry was employed to discriminate provenance in the Indus River system. We characterized the geochemistry of garnet sediment grains from the modern Indus and all its major tributaries, as well as the related but ephemeral Ghaggar-Hakra River and dune sand from the Thar Desert. Garnet geochemistry displays a unique signature for the Himalayan rivers on the east of the Indus drainage compared to those in the western drainage. The trunk Indus remains distinct because of the dominant arc-type pyrope-garnet derived from Kohistan and the Karakoram. The Jhellum, which lies just east of the modern Indus has modest concentrations of arc-type pyrope garnets, which are more depleted in the other eastern tributaries. Their presence in the Jhellum reflects recycling of trunk Indus garnets through the Miocene Siwalik Group foreland sedimentary rocks. The Thar Desert dune sample contains significant numbers of grains similar to those in the trunk Indus, likely reworked by monsoon winds from the SW. Our data further indicate the presence of a Himalayan river channel east of the present Indus, close to the delta, in the Nara River valley during the middle Holocene. Sands from this channel cannot be distinguished from the Indus on the basis of their garnet geochemistry alone but we favour their sedimentation from an Indus channel rather than reworking of desert sands by another stream. The garnet geochemistry shows some potential as a provenance tool, but cannot be used alone to uniquely discriminate Indus Basin provenance.

1. Introduction

The western Himalaya provide an opportunity to study what processes control continental erosion, specifically the relative influence of climate, tectonics and topography. Theoretically the sedimentary/erosional record can provide a detailed archive of past erosion that may be used to test which processes dominate over different time scales. In particular, we test the hypothesis that monsoon intensity is the primary control on rates and patterns of erosion, as proposed by several studies of Himalayan tectonics (Beaumont et al., 2001; Wobus et al., 2003; Clift et al., 2008b). However, in order to decipher these records we need to employ provenance methods to trace sediments back to their sources in order to budget the flux from different contributors.

Single grain analytical methods have been most successful in constraining provenance compared with bulk methods (Gehrels et al., 1995; Mange and Morton, 2007). This approach is based on the principle of finding a diagnostic and distinct property for individual mineral grains using their physical and geochemical properties that can then be used to match with their potential source. This unique property could be complicated because the grains are transported far from their source, allowing physical and chemical modification compared to their original state. However, single-grain techniques can be more powerful than bulk methods in quantifying the erosional flux from any given source because they potentially allow resolution of the flux from individual different parts of the source region provided there is initial heterogeneity in the sources rocks.

Garnet geochemistry is an established method of sediment provenance and is employed here to examine erosion patterns and sediment transport in the modern and Holocene Indus River. In turn this approach can also be used to characterize the source

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terrains of the Indus River system when a given river drains only a single source terrain. This technique was used to constrain the source of the sediment in the modern stream and to compare this with Holocene sand stored on the flood plain in order to see how stable the river has been in the recent geological past. Furthermore, comparison is made between the characteristics of the river and palaeo-river sands and those from the Thar Desert (Fig. 1). This is done to constrain its origin and the role it plays in recycling sediment to the modern and Holocene rivers on the eastern side of the Indus Basin (East et al., 2015).

1.1. Provenance and transport

There are number of factors that can influence the original compositional signal between source and final sediment sink. Chemical weathering during transport and during storage on flood plains can result in breakdown of chemically unstable minerals. However, we do not consider chemical weathering to be a major issue in this study because the sediments in question are either modern or only buried a few meters so that diagenesis can be largely discounted. Nonetheless, chemical weathering during transport and storage in flood plains can cause the breakdown of garnet grains (Ando et al., 2012). Chemical weathering of almandine garnets can be severe in soils and streams, but is modulated based on the chemical environment, such as the development of saprolites (Velbel, 1984). Although garnet can be susceptible to breakdown during transport it has greater durability than might be expected (e.g., compared to olivine) because of the formation of a protective coating during the initial stages of alteration (Velbel, 1999). The relatively arid conditions of the Indus basin means that this is much less of an issue than has been documented in tropical and humid fluvial basins.

Hydraulic sorting also plays a major role in determining the relative abundance of minerals in any given sample and can cause anomalous results if this produces samples with very high or low concentrations of heavy minerals. We do not have bulk petrographic data for the samples considered here, but bulk sediment geochemistry for the major tributaries was published by Alizai et al. (2011a). In Fig. 2 we show how these compositions compare with one another and with the bulk upper continental crust of Rudnick and Fountain (1995) using the Multidimensional Scalar diagram of Vermeesch et al. (2016). This figure shows that the modern sands generally cluster together, albeit not with the upper crust average, reflecting their sandy, more quartz-rich composition compared to the average. The anomalous sediment is the Ghaggar River, which is richer in SiO_2 and depleted in MgO, Fe_2O_3 and Al_2O_3 compared to the other samples, indicative of preferentially sorting out of heavy mafic minerals. Thus while the compositions of

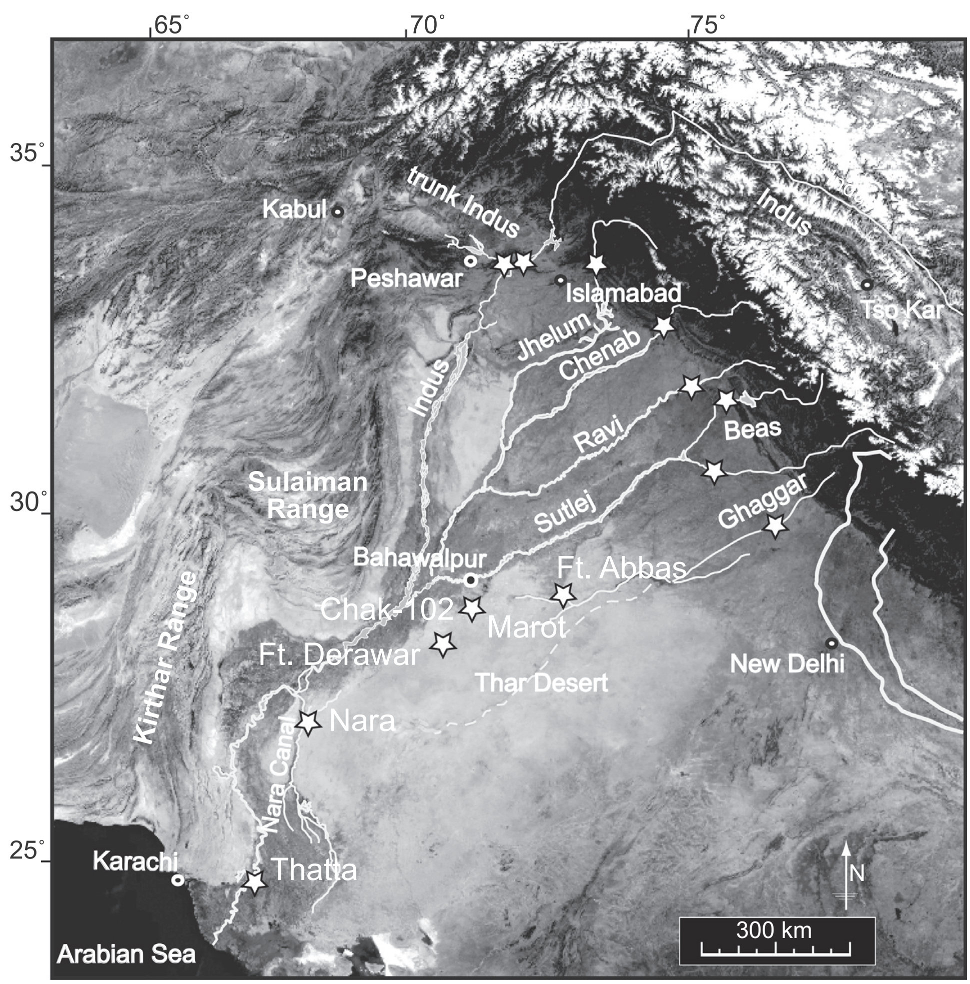

Fig. 1. Map showing sample locations for the trunk Indus and all its tributaries and the locations from the upper eastern floodplain, Nara region and downstream Indus near Thatta.