Is River Ghaggar, Saraswati? Geochemical constraints

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The identity of the river along which the famous Harappan Civilization developed and the causes of the demise of this culture are topics of considerable debate. Many of the Harappan sites are located along the ephemeral Ghaggar river within the Thar Desert in the northwestern India and adjacent Pakistan. The Ghaggar was also thought to be the mythical river Saraswati, which was described as glacial-fed river. Sr and Nd isotopic composition of the Ghaggar alluvium as well as Thar Desert sediments suggests a Sub-Himalayan sediment source, with no contribution from the glaciated regions. The development of extensive Harappan Civilization all along the Ghaggar suggests a catchment with high monsoon rainfall. It is likely that with the changes in the monsoon scenario after 3500 BC could have gradually dried up the Ghaggar river and resulted in the migration and/or extinction of the Harappan Civilization on this river.

THE largest and the oldest urban civilization of the world was the Indus Valley (Harappan) Civilization of northwest India and Pakistan[1]. Almost two-thirds of nearly 1500 archaeological sites of this civilization occur on the dried banks of the Ghaggar river[2] (Figure 1). The River Ghaggar originating in the Sub-Himalayas flows through the northern part of the Thar today as an ephemeral river mainly during the SW monsoon season and disappears in the desert. However, the river seems to have played a key role in the development of the Harappans[2,3]. The Ghaggar river has been identified with the mighty glacial-fed river Saraswati[4–6], which is described in the oldest religious document written in Sanskrit, the *Rig-Veda* (1500 BC)[7,8]. Based on geomorphological studies and identification of clasts in the river channels of outer Himalayas, it has been suggested that the palaeo-Ghaggar (alias Saraswati) had its catchment in the glaciated Higher Himalayas[9,10]. Another prevalent hypothesis is that the ancestral channels of Yamuna and Satluj once fed the Saraswati[9,11]. The antecedent Yamuna and Satluj rivers originate from the glaciated Higher and Tibetan Himalayas respectively, and limit the expansion of the Thar Desert in the east and north. If water availability is the key climate determinant for life[12] and the region was already experiencing aridity[13], the palaeo-Ghaggar must have been perennial for the Harappans to flourish. To identify the source (glaciated or non-glaciated terrains) and the nature (perennial or ephemeral) of the palaeo-Ghaggar and, therefore, to understand the likely cause of the social collapse of the Harappans, we have studied Sr and Nd isotopic characteristics of the sediments deposited by desert-forming processes and by the River Ghaggar in the Thar Desert region of northwestern India and compared these with the values of other Himalayan rivers in the region and with those of various Himalayan lithotectonic units.

Recycled sediments formed due to cannibalistic processes of erosion and subsequent deposition pose difficulties for the identification of their sources. However, in the Himalayan orogen, Sr and Nd isotopes have been successfully used to identify different lithostratigraphic zones[14] and to locate the source areas of sediments of the Tertiary foreland basins[15,16], Bengal fan[17] and those of the present-day Himalayan rivers[18]. Identification of sediment

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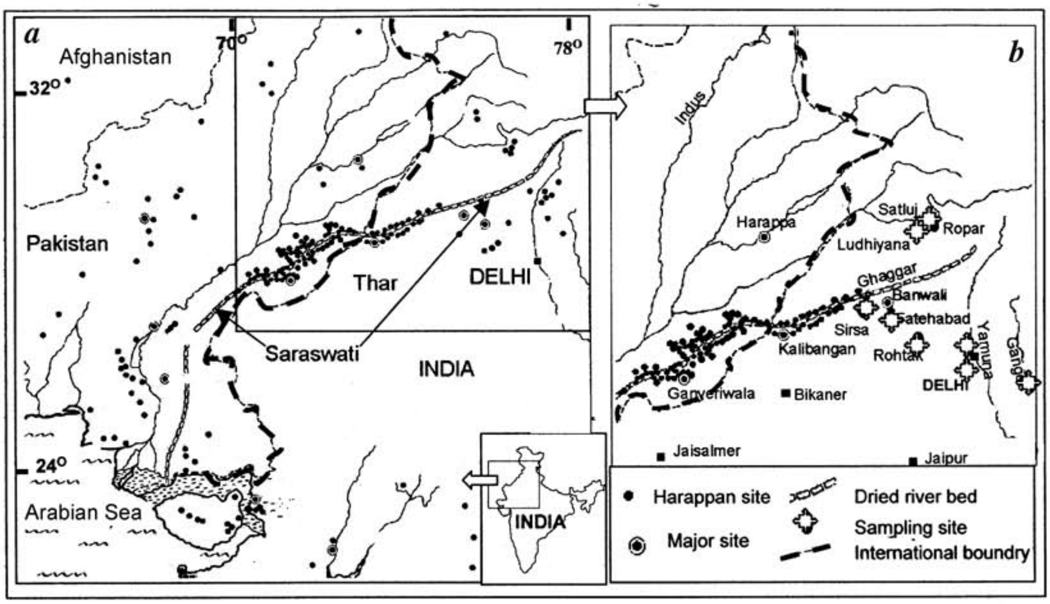

Figure 1. ***a***, Harappan cultural sites in northwestern India and Pakistan. The cultural sites are dispersed over a vast area, but concentrated on the dried course of River Ghaggar. ***b***, Alluvium sampling sites include Ludhiyana and Ropar on Satluj, Sirsa and Fatehabad on Ghaggar, and Baghpat and Garhmukteshwar on Yamuna and Ganga respectively. Sand dunes were sampled from the rest of the sites except for Delhi (for loessic sediments). Note the difference in the source of Ghaggar, shown in (***b***).

sources in turn, has enabled the understanding of the exhumation and erosional history of the Himalayas. Our study was undertaken to evaluate the provenance of the reworked older alluvium (Thar Desert sediments, including its palaeo-desert[19]) in comparison to the alluvium derived from the Himalayas.

For this study, mainly the Quaternary sediments from the western part of the Indo-Gangetic plains were sampled (Figure 1) and analysed for Sr and Nd isotope compositions. The sediment samples were collected from vertical profiles ranging in thickness from 1 to 9 m in the alluvium and sand dunes (lithologs and physical properties to be published elsewhere). These sediment profiles have been deposited between 2 to 20 Ka (S. K. Tandon and A. K. Singhvi, pers. commun.). The sediment samples include alluvium of Yamuna, Satluj and Ghaggar rivers, dune sands and loessic sediments of northeastern part of the Thar Desert (derived from the older flood plains of the dried river[20]) (Figure 1).

Isotopic ratios were determined on Finnigan MAT262-RPQ^{2+} Thermal Ionization Mass Spectrometer (TIMS) and Triton at GEOMAR, Germany. The detailed digestion procedure after leaching the samples with 1.3 N HCl to exclude the carbonates and isotope separation by resin column chemistry are given elsewhere[21]. Sr and Nd isotopes were measured in static and multidynamic modes respectively, and were normalized within run to $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$ and $^{146}\text{Nd}/^{144}\text{Nd} = 0.7219$ respectively; all errors are 2σ. Over the course of this study, NBS 987 gave $^{87}\text{Sr}/^{86}\text{Sr} = 0.710215 \pm 0.000008$ ($n = 11$) and $^{143}\text{Nd}/^{144}\text{Nd} = 0.511709 \pm 0.000006$ ($n = 7$) for an inhouse Nd monitor, Spex. For Triton, NBS 987 gave $^{87}\text{Sr}/^{86}\text{Sr} = 0.710254 \pm 0.000003$ ($n = 35$) and Spex gave $^{143}\text{Nd}/^{144}\text{Nd} = 0.511706 \pm 0.000004$ ($n = 10$). Total chemistry blanks were < 600 pg for Sr and < 200 pg for Nd, and sample-to-blank ratio was very high (>1000); thus blank is negligible. $\varepsilon_{\text{Nd}}(0)$ is calculated at time $t = 0$ for CHUR $^{143}\text{Nd}/^{144}\text{Nd} = 0.512638$.

$^{87}\text{Sr}/^{86}\text{Sr}$ and $\varepsilon_{\text{Nd}}(0)$ values of different lithotectonic units of the Himalayan orogen are shown in Figure 2. The most radiogenic lithologies with respect to Sr isotopes are from the Lesser Himalayas as they include equivalents of older granites of the Indian subcontinent such as the Aravallis and the Bundelkhand[22,23]. Although the Tibetan Sedimentary Series (TSS) and the High Himalayan Crystallines (HHC) show little difference in $\varepsilon_{\text{Nd}}(0)$ values, they can be distinguished by a difference in $^{87}\text{Sr}/^{86}\text{Sr}$ values. This difference is due to several episodes of high-grade metamorphism of HHC resulting in the mobilization of Sr and Rb[24]. Therefore, the HHC rocks have more radiogenic Sr isotopic composition than the TSS. The Indus Tsangpo Suture Zone (ITSZ) includes young juvenile rocks and carries the most unevolved Sr and Nd isotope compositions[15]. Figure 2 also shows the isotope composition of the Sub-Himalayan Tertiary marine (Subathu Formation) and fluvial (Dagshai, Kasauli formations and Siwalik Group) sediments derived from various Himalayan lithotectonic units[15,16].

$^{87}\text{Sr}/^{86}\text{Sr}$ and $\varepsilon_{\text{Nd}}(0)$ values of the Thar Desert sediments, including Ghaggar and those of Ganga, Yamuna, Satluj

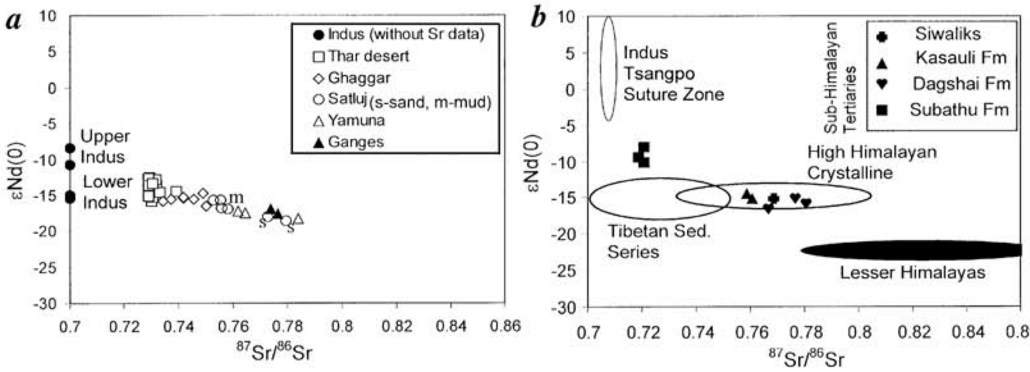

Figure 2. ***a***, Nd–Sr isotopic composition of the sediments of northwestern India. Geochemically, the Ghaggar and Thar sediments are distinct for their lesser radiogenic Sr and more radiogenic Nd isotopes. These sediments show more affinity to the marine Subathu Formation containing juvenile ITSZ components, present in the Ghaggar catchment. The present isotopic composition of the Thar is explained by mixing of the HHC-dominated Dagshai, Kasauli and Siwalik sediments with the Subathu sediments, all present at the Ghaggar catchment. An analogous case is the Nd of lower Indus sediment, which is explained by mixing of ITSZ-dominated upper Indus with the HHC-dominated Satluj sediments. ***b***, Nd–Sr isotopic distribution for different tectonic units of Himalayas (15, 16). $\varepsilon_{Nd}(0)$ calculated at time $t = 0$ for CHUR $^{143}Nd/^{144}Nd = 0.512638$.

and Indus rivers[25] are plotted in Figure 2 (data available on request). Analysed sediments (sands) of the Ganga, Yamuna and Satluj have the most radiogenic Sr and the least radiogenic Nd isotope composition (Figure 2), suggesting a HHC-dominated Himalayan provenance for the sediments. The HHC units mark the highest peaks in the Himalayas that are covered by glaciers today. Unlike the sands, the mud samples of the Satluj river have less radiogenic Sr, suggesting relatively a greater contribution from the TSS to the fine-grained sediment budget of the Satluj. However, the differences in the Nd isotopic composition are less pronounced between sand and mud samples of Satluj, as required by their probable sources.

The differences in Nd isotopes are less pronounced among the various sediments, as expected from the isotope compositions of the possible source areas. If the alluvium of the Ghaggar was also derived from the Himalayan orogen, then the Tertiary lithologies together have the appropriate isotope characteristics to have supplied the sediments (Figure 2 *a* and *b*). The Early Palaeogene Subathu Formation has Sr and Nd isotope compositions intermediate between ITSZ and TSS[15]. However, the Late Palaeogene and Neogene formations are dominated by HHC isotopic signatures[16]. Interestingly, the deeper part of Ghaggar alluvium and sands of the Thar Desert have less radiogenic Sr (0.73–0.74) and similar spread in the Nd isotope composition ($\varepsilon_{Nd}(0) = -12.7$ to -15.1). These isotopic characteristics require a sediment provenance that has components of ITSZ and TSS just as the Early Palaeogene Subathu Formation in the Sub-Himalayas. The deeper samples within the profiles of the Ghaggar alluvium have more of Subathu component relative to the shallower samples and the change appear to be due to increasing Siwalik, Dagshai and Kasauli sediment components from the frontal part of the Sub-Himalayas. Although antecedent Yamuna, Ganga and Satluj rivers pass through the Sub-Himalayas, they mainly derive their sediments from the Higher Himalayas unlike the Ghaggar, which originates and derives its sediments from the Sub-Himalayas only. It has been found that the sediment composition of a river is largely determined by the lithologies present in its high elevation and high-relief catchment areas[26]. Therefore, the contribution from Subathu component is minimal in the sediments of antecedent rivers originating in the Higher Himalayas. However, recycling of the HHC sediments through the Tertiary sediments in the Sub-Himalayas could not mask the Subathu signatures in the Ghaggar-derived sediments.

Interestingly, the modern aerosols originating from the Thar Desert (sampled at Bikaner, Jhunjhunu and Delhi)[27] and the dust deposits (loessic sediments)[20] also are isotopically similar to the Ghaggar and Thar sediments. Because of long transport and recycling of sediment, loess deposits are often homogeneous and represent the average composition of source areas[28]. The isotopic homogeneity of Thar Desert sands, aerosols, deposited loessic sediments and older Ghaggar alluvium indicates their consanguinity. Therefore, the Ghaggar alluvium is most likely the proximal source to the Thar sediments and this older alluvium especially derived mostly from the non-glaciated Sub-Himalayan Tertiary sediments.

Among the other possible sources for the Thar sediments the Aravalli rocks occurring east of the Thar Desert are the least likely contributors, as they have high radiogenic Sr and low radiogenic Nd isotope signatures, similar to the rocks of the Lesser Himalayas[22,23] (Figure 2 *b*). Unlike the present-day Ganga sediments, the Ghaggar and therefore the Thar sediments lack contribution from the LHS or local cratonic lithologies. Although the lower Indus sediments have similar $\varepsilon_{Nd}(0)$ values[25] (Figure 2 *a*), the Indus river draining through this region is unlikely. Thus, a Himalayan distal source, dominated by the Subathu Formation and Sub-Himalayas is required for the Thar sediments.

The Palaeo-Ghaggar must have been a mighty river with broad channels once flowing through the Thar region, when the climate favoured abundant monsoon precipitation in the Sub-Himalayan region. Presently, the River Ghaggar is too small to have contributed significantly to the Thar sediments. The suggestion of glacial sources[9,10] and the Yamuna and Satluj rivers draining to the River Saraswati through Ghaggar before they were pirated by the Ganga and Indus respectively[9,11], are not supported by our isotopic data. If these hypotheses were correct, we would expect to find sediments derived from the Higher Himalayas in the Thar. Our data also do not support the idea that there was a change in the source area for the Ghaggar from a glaciated region to rainfall region. Although the isotopic data cannot distinguish between HHC and Neogene Siwalik sediments for the present-day Ghaggar, geographically the Ghaggar catchment is only in the Sub-Himalayan region. It appears that the River Ghaggar has always been sourced in the non-glaciated Sub-Himalayan region. If the snowline did not drop to the Sub-Himalayan ranges even during glaciation[10] and the glaciers continuously occurred only in the HHC, a higher rainfall for the huge erosion of Sub-Himalayan lithologies and to sustain the rivers was essential. Our isotope data provide a scientific basis for the absence of a glacial-fed, perennial Himalayan river in the Harappan domain, i.e. the River Ghaggar is not the Saraswati as far as its origin in the glaciated Himalayas is concerned. Alternatively, River Saraswati had its origin in the Sub-Himalayas.

Our results on the Thar sediments provide important clues to the demise of the Harappan Civilization on the Ghaggar river. The Thar region has been arid since 3500 BC, as shown by the lake records of the Thar[13]. However, during this arid phase in the Thar region, studies of Indus fan sediments indicate relatively a better summer monsoon run-off in the rivers[29,30]. Pollen records from alpine peat in the Himalayas also show higher amount of rainfall in the Himalayas during the same period[31]. Therefore, it is likely that the Himalayan region received greater rainfall than the Thar region and was connected to the Indian Ocean through the Indus. It is well known that the summer monsoon rainfall decreases from east to west as well as from frontal to interior ranges in the Himalayas. Persistent spatial variations of rainfall distribution on the Indian land mass, like today, seem to have been occurring since the Holocene[32]. Because the Ghaggar catchment lies to the east of the Indus and in the southern part of the Himalayas, we suggest that the Ghaggar could have received a higher rainfall due to intense monsoon spells of Holocene and therefore flowed further downstream into the Thar.

The latest increase in monsoon activity in this region was reported[13] around 8000–3500 BC and its waning period also coincides with the Harappans (3500–1900 BC). Since the drying was gradual[29] in terms of time and space from circa 3500 BC, the run-off of the river shrank towards the north gradually. The retreat of the run-off limit point upstream (and the encroachment of active dunes on the river beds[33]) had caused the migration of the cultures northeastward. This is revealed by the occurrences of younger Late Harappan and Painted Grey Ware settlements (1900–400 BC) in the northeastern parts of the Thar and adjoining Ganga–Yamuna plains[8,34]. As long as the river was flowing in the lower reaches, although the region was witnessing aridity, the Harappans would have been occupying the Ghaggar basin.

The cultural collapse of Harappans during 1700–1900 BC has been thought to be due to desiccation in the Thar[35]. However, others suggested that the river became ephemeral due to tectonically induced river piracy[9–11]. Here, we suggest, unlike these theories, that the Ghaggar-Harappan Civilization was a 'true river valley civilization' supported by monsoonal rainfall in the Sub-Himalayan catchment, the reduction of which was responsible for the extinction of the river and the associated civilization. The Ghaggar's Harappan culture presents a unique example unlike the other cultures of the world. Most of the cultural collapses in the world have been attributed to the occurrence of droughts in the region[12], while the Ghaggar-Harappan culture survived aridity, which was already being experienced since 3500 BC in this region. They survived because of Ghaggar's connection to a wetter source area, a feature similar to some of the peninsular rivers today.

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