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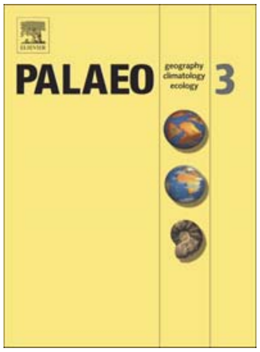

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Abstract

In the comment on our paper (this issue), Clift et al. (2016) compared our recently reported radiogenic Nd–isotopic record in two drill cores (Singh et al., 2016) with those from the Hakra floodplain sediments and Indus Delta sediments. While they agree with the concept of erosion patterns in the western Himalayan sources being climatically modulated, they offer an alternative interpretation for our reported variability in the radiogenic Nd-isotopic values. Here, we show that the Nd-isotopic values for the Holocene succession instead can be explained by the bedrock geology of the source region of these sediments. Moreover, we note that whereas our paper considers a ~ 75 ka fluvial depositional record, their comment is only based on the post–Last Glacial Maximum (LGM) record. When considering the longer record, their arguments do not negate the main conclusions of our original paper.

Keywords: Provenance; Paleoclimate; Isotopic composition; Buried sediment; Ghaggar river

We thank Clift et al. (2016) for initiating a discussion on understanding the coupling of climate and erosion in the western Himalaya as derived from sedimentary records. This arises from our recent publication on this topic (Singh et al., 2016). Clift et al. (2016) have compared our recently reported radiogenic Nd-isotopic record (temporal ε_{Nd} variability, see Fig. 10 in Singh et al., 2016) in two drill cores (GS-10 and GS-11) from alluvial sediments in the Ghaggar Plains of NW India, with those from the Hakra floodplain sediments in the greater Ghaggar region (Alizai et al., 2011; East et al., 2015) and Indus Delta sediments (Clift et al., 2008). This comparison is shown in Fig. 1 of Clift et al. (2016). Whilst Clift et al. (2016) agree with the concept of climate–modulated erosion in the Himalayan sources of these fluvial sediments, they offer an alternative explanation for our reported radiogenic Nd- isotopic record. We note that their comment only focuses on the post–Last Glacial Maximum (LGM) record whereas our paper documents the depositional record for the past ~75 ka. Below we discuss the specific details of their comment and examine the broader implications of our data.

Before continuing the discussion, we correct one data point shown in Fig. 1 of Clift et al. (2016). This data point from the Indus Delta sediment record is plotted at ~15 ka and shows a ε_{Nd} = −10.8 in Clift et al. (2016). However, the same sample is identified as KB–40–5 (see Supplementary Table DR2, Clift et al., 2008) with a date of 28.7 ka. Presuming the published record to be correct, we have plotted this data point in our Fig. 1 taking into account the correct age for that sample. We have also performed Kernel Density Estimates (KDE) of ε_{Nd} values for the modern day Sutlej, Yamuna, and Ghaggar river sediments, and the Thar Desert sediments (Tripathi et al., 2013 and Alizai et al., 2011). This shows that the variation of ε_{Nd} values in the GS-10 core falls within the range of the modern Ghaggar river (Fig. 1) though there is an overlap in the KDE plots of data from the modern Ghaggar and the Thar Desert (1.8 to 9.1 ka) sediments. We do not agree with the argument of Clift et al. (2016) that the ε_{Nd} temporal evolution in the Ghaggar and Indus basins should show a similar trend because they are adjacent to each other. Rather, we posit that isotopic values of (fluvial) sediment mixtures are most likely related to the relative contributions of end-member sources, which in turn is strongly dependent on the catchment lithology. While the Indus basin includes the Karakoram (ε_{Nd}:

−12 to −8) and Trans-Himalayan (ε_{Nd}: −1 to +8; see Fig. DR2 in Clift et al., 2008) sources along with the Higher and Lesser Himalaya (HH and LH) sources, the Sutlej catchment predominantly drains the HH and LH sources, and the Ghaggar river drains the Sub-Himalaya. This is reflected in the more positive ε_{Nd} values for the Indus Delta sediments compared to those of the Ghaggar sediments.

In our paper (Singh et al., 2016), we documented the ε_{Nd} variability in dated sediment cores through alluvial strata spanning a time interval from ~75 ka to the Holocene. We presented a ε_{Nd} record that shows temporal variability that can potentially be linked to Late Quaternary climate–controlled erosion in the Himalayan source areas supplying these sediments. Clift et al. (2016) focus on the post–LGM record. Our data show that the ε_{Nd} of Ghaggar sediments increases by ~2 ε units from MIS2 (>14 ka) to MIS1. This is in contradiction to the observations by Clift et al. (2008) from the Indus Delta sediments where they document a decreasing ε_{Nd} trend of similar magnitude during the same time period. Clift et al. (2016) propose that the shift in ε_{Nd} we observe in our cores from MIS2 to MIS1 does not require a climate–controlled change in the Himalayan source areas but can be explained by admixture of more radiogenic aeolian sediments from the Thar Desert. Whilst this is a plausible hypothesis, we offer here a better explanation for this ε_{Nd} variability. In our paper, we did not explicitly discuss the causes of the ε_{Nd} variability for the post–LGM transition. The sediments in our core GS-10, deposited during MIS1, are very fine–grained sands and silts with a distinctive reddish–brown colour. We interpret these as deposits of the Ghaggar river that has its headwaters in the Sub–Himalaya (Singh, 2014). The older sediments in the GS-10 and GS-11 cores are coarse–grained fluvial sands that are likely deposits of a Himalayan sourced river (Sinha et al., 2013). We have inferred that this transition may record a major river shift (Sinha et al., 2013; Singh et al., 2015; Singh et al. manuscript in prep.). The Ghaggar river sediments are derived from erosion of early Himalayan foreland basin sedimentary rocks that are now exposed in the headwaters of the modern Ghaggar river. These include foreland basin strata of the Dagshai and Kasauli Formations that were derived from erosion of dominantly Higher Himalayan crystalline rocks during the Oligocene–Miocene (Najman et al., 2000; Ravikant et al., 2011). The ε_{Nd} of modern Ghaggar and GS-10 core sediments show similar range as that of the Higher Himalaya as seen in the bivariate plot of Sr and Nd isotopic ratios (Fig. 6 of Singh et al., 2016). Thus the ε_{Nd} transition from MIS2 to MIS1 in our cores is best explained neither by a climatically controlled shift in Himalayan erosional source region, nor by admixture of aeolian sediments from the Thar desert, but by a transition from deposition by a Himalayan-sourced river to deposition by the foothills-sourced Ghaggar river (Sinha et al., 2013; Singh et al., 2015; Singh et al., manuscript under prep.). Because the Hakra floodplain sites documented by Clift et al. (2016) are downstream of the Ghaggar floodplain and likely connected, the ε_{Nd} records for the Holocene Hakra floodplain sediments are also best explained as the deposits of the Ghaggar river– with more positive ε_{Nd} because of their derivation from Sub–Himalayan foreland basin rocks.

However, our older sediment records (e.g., GS-11 core) do show ε_{Nd} variability within the range reported for the HH and LH units in NW Himalaya (Fig. 6 of Singh et al., 2016). The temporal variation in ε_{Nd} shows an increase from less radiogenic ($\varepsilon_{Nd} = -19.0$) during MIS4 to more radiogenic ($\varepsilon_{Nd} = -17.0$) during MIS3. We explain this temporal variability as the result of variable contribution from the LH and HH endmembers in the NW Himalayan source region. In our paper (Singh et al., 2016), we concluded that an increase in sediment contribution from LH (less radiogenic Nd-isotopic ratios) during MIS4 glacial period followed by an increase in sediment contribution from HH (more radiogenic) during MIS3 interglacial can explain the variation of ε_{Nd} in the GS cores. As there is no record available from the Indus Delta for this time period, we cannot compare older isotopic records of GS cores with that of available data on Indus Delta sediments.

Sediment production and evacuation in the NW Himalaya in response to climate change is a topic of much recent debate. We agree with Clift et al. (2016) that interpretation of geochemical records to reconstruct the distribution of erosion in Himalayan catchments requires a thorough understanding of geomorphologic and sedimentary contexts. Moreover, better knowledge of erosional processes in source regions and delivery of sediment from glaciated catchments is also required before establishing a unique model of climate-erosion coupling that also explains the spatial distribution of erosional patterns in Himalayan sources.

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Figure Caption

Figure 1. Kernel density estimation (KDE) plot of ε_{Nd} values in the modern Sutlej, Ghaggar and Yamuna, and Thar Desert sand (Tripathi et al., 2013 and Alizai et al., 2011). Also shown are temporal variabilities in ε_{Nd} of Indus Delta sediments (Clift et al., 2008) and drill core sediments from Ghaggar (Singh et al., 2016) and Hakra floodplains (Alizai et al., 2011 and East et al., 2015).

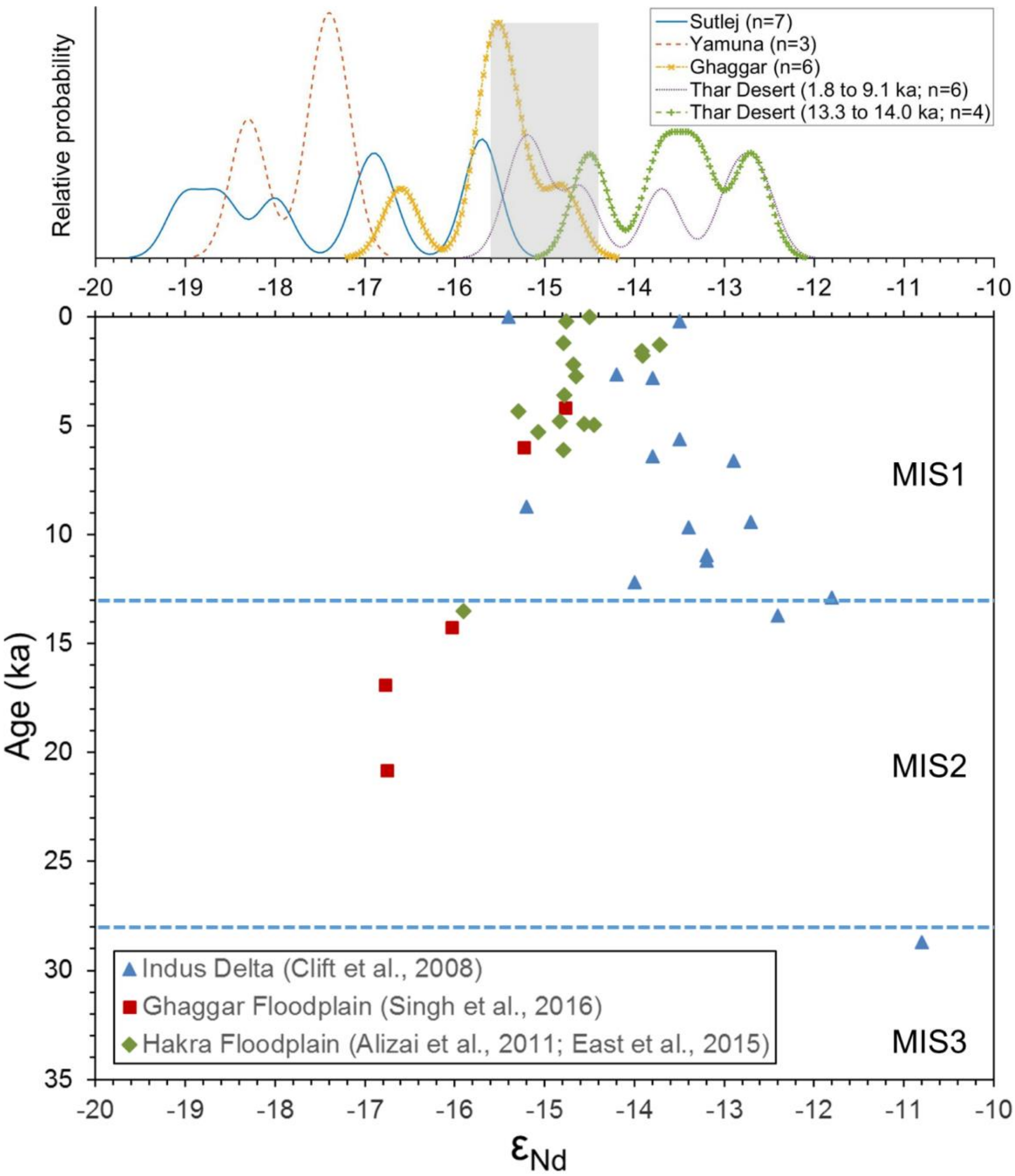
Relative probability
Sutlej (n=7)
Yamuna (n=3)
Ghaggar (n=6)
Thar Desert (1.8 to 9.1 ka; n=6)
Thar Desert (13.3 to 14.0 ka; n=4)
-20
-19
-18
-17
-16
-15
-14
-13
-12
-11
-10
Age (ka)
0
5
10
15
20
25
30
35
MIS1
MIS2
MIS3
Indus Delta (Clift et al., 2008)
Ghaggar Floodplain (Singh et al., 2016)
Hakra Floodplain (Alizai et al., 2011; East et al., 2015)
ε_{Nd}

Figure 1