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Interactive comment on "Regional Pliocene Exhumation of the Lesser Himalaya in the Indus Drainage" *by* Peter D. Clift et al.

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We agree completely with the reviewer that monsoon rains impact the Lesser Himalaya, including the Lesser Himalaya Crystallines, and indeed all the ranges on the southern side of the Himalaya rain shadow. The monsoon does affect erosion north of the Greater Himalaya too (Jonell et al., 2017), but the volumes of sediment derived are somewhat less. Water supplied to the Karakoram today is more dominated by the Westerlies rather than the monsoon because of the high topography blocking the SW Monsoon. We note that over the last glacial cycle, erosion patterns within the Himalaya are strongly controlled by monsoon intensity, mostly act to cyclically strengthen and weaken the erosion of the Lesser Himalaya. Comparison of the changing erosion patterns with the foreland basin carbon isotope record was intended to show the

possible linkages between erosion and climate. Carbon isotopes reflect the balance between C3 to C4 plants, which in turn is dependent on the aridity of the Indus basin. In contrast, the study of nitrogen isotopes published by Tripathi et al. (2017) does not make a suitable comparison to the erosion because it tracks marine productivity offshore western India and not rainfall in the Himalaya. The fact that this record is at odds with other paleoceanographic monsoon records in the Arabian Sea (Betzler et al., 2016; Gupta et al., 2015) also suggests a need for caution in its application. Nonetheless, we now note the correlation between increased Lesser Himalaya erosion and the change in the nitrogen isotope record after 3 Ma in the revised manuscript. As far as constraining the influence of the Karakoram is concerned, a range of Nd and Sr isotope compositions are considered and are plotted as a field in Figure 4. While a single value for the Karakoram isotopes could be misleading, we note that the average ïĄěNd measured in Karakoram bedrocks is -9.3 compared to -14.7 for the Greater Himalaya. Although the Karakoram bedrocks vary greatly in ïĄěNd values, from -1.5 to -22.8, measurements from rivers draining wide areas of the mountains also imply relatively positive ïĄěNd values for the erosional flux, e.g.,ïĂăïĄěNd = -9.0 for the Karakoram in Nubra Valley, India, and -11.3 for the Braldu River in Pakistan (Clift et al., 2002). However, the influence of the Karakoram to the erosion flux is mostly clearly defined by the zircon U-Pb ages. A simple two-part Nd isotope mixing model of the type suggested may be applicable before the strong influence of the Lesser Himalaya, but also does not account for the influence of Kohistan and other parts of the Transhimalaya. Using the average ïĄěNd values of -14.7 for the Himalaya and -8 for the combined Karakoram and Kohistan, yields a range from only 15.4% Karakoram contribution at 1.13 Ma up to 94.8% at 6.74 Ma. Unfortunately, there is no separate climate record for the Karakoram extending over these tectonic timescales. Erosion in the modern Karakoram is driven by glaciers, with generated sediments then being remobilized in rivers fed by snow melt delivering material largely to the Indus, but also north to the Tarim Basin. Whether erosion in the Indus basin has played a role in controlling global climate is not clear from the data presented in this study, which only tracks the original sources, not the volumes or chemical weathering state of the sediment. Falling ïĄěNd values through time imply less erosion of primitive magmatic rocks of the type favored by Macdonald et al. (2019) and would not be supportive of their enhanced weathering playing a role in driving cooling over the same period. A change in source would not otherwise imply more or less weathering flux. Regional sediment budgets from earlier work show falling sedimentation rates from the Late Miocene to the Pliocene at a time when chemical weathering intensity was also declining (Clift et al., 2008), which argues against surface processes in the Indus Basin playing a role in forcing global climate. Avulsion of the active depositional lobes of the Indus Fan does not explain the changing sediment provenance at the drill site. Sedimentation rates at the drill sites in the Laxmi Basin are controlled by the location of the active lobe and are reported to be just 10 cm/k.y. in the Late Miocene but increasing to 45 cm/k.y. in the Early Pleistocene at IODP Site U1456 (Pandey et al., 2016a). When the active lobe is not directly over the sites then this would allow sediment flux from other non-Indus sources to be seen and not diluted. This may be the explanation for the modest amount of sediment with high ïĄěNd possibly derived from peninsular India. The zircon U-Pb data, however, are conclusive in requiring all sands and silt analyzed to be Indus derived as evidenced by the abundance of zircon grains dated <200 Ma. Eolian sediment is not considered to be important, even in those parts of the section where sedimentation was slow. When sedimentation rates were 10 cm/k.y. then using a dry density of ca. 1.6 g/cm3, equates to a dry mass accumulation rate (MAR) 160 g/cm2/k.y. total sediment. In contrast, the nearest sediment traps from the Arabian Sea showed MARs of 1.05–0.29 g/cm2/k.y. and with a clear reduction away from Arabia (Honjo et al., 1999). It thus seems unlikely that wind-blown material would have contributed much of the sediment in Laxmi Basin.

Regarding the detailed comments

Age Control. It's not clear what extra information the reviewer would like to see in the age model beyond the nannofossil, foraminifers and magnetostratigraphy employed in the existing scheme (Pandey et al., 2016a; Pandey et al., 2016b). Although the age model continues to be refined the overall structure will not change greatly, especially with regard to long-term trends of the type we focus on in this study.

Use of HCl rather than acetic acid is not favored for the decarbonation of the sediment prior to Nd and Sr isotopic analysis because it has been demonstrated that strong HCl can affect the Nd isotope composition of the analysis (Hein et al., 2017). Because Nd was the more critical isotope for provenance work we chose to use acetic acid for this work, which has a good track record of removing the carbonate.

Regarding grain size analysis, we measured grain size for the 11 coarser sediments for which zircon U-Pb data were obtained, not for the Nd-Sr isotope samples. This is now clarified.

The isotopic compositions of the end members that we compare to our sediments have to be assumed to remain constant through time. This is likely to be mostly correct for the bedrock sources in the mountains and in any case because the older rocks have now been eroded there is no way to know if any given source was the same in the past as it is now. As far as the Tapti, Narmada and Mahi Rivers are concerned, these have likely changed as erosion has changed the geology exposed in each catchment. Reconstructing this would require a sediment section from close to the mouths of each river to look at their changing discharge. Most likely ongoing erosion has stripped away Deccan Flood Basalts from over the older Precambrian peninsula rocks. The Tapti is still dominated by basaltic sources, while the Mahi may have been most affected. The effect would have been to have made each peninsula river more ïĄěNd negative through time, i.e., more similar to the Indus River. Sediment supply from these rivers would thus have been easier to see in the past then it is now. However, the major element data from the sands and silts do not favor significant sediment supply from the peninsula at any time because they overlap with compositions from the Quaternary delta and canyon of the Indus on the CN-A-K triangular diagram but are dissimilar to sediments from the modern continental shelf of peninsular India.

As requested, we add the data from the recent Yu et al. (2019) study to the temporal evolution diagram together with some suitable accompanying text.

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