Chapter - 6

Geochemical Provenance of the Thar Desert Sand

6.1 Introduction

One of the major sand seas occurs within the Thar Desert of western India and eastern Pakistan (Lancaster, 2009). It is located along the eastern most stretch of the great Sahara-Arabian desert system of the horse latitudes and hosts a variety of aeolian sand dunes, including stabilised fossil dunes. The Desert extends from the foothills of the Aravalli mountain ranges in the east up to the Indus floodplain in the west covering an area over 4000 sq. km (Fig.6.1). Aeolian activity of the Thar Desert began around 150 ka and is majorly controlled by the South-west monsoonal winds (Singhvi and Kar, 2004). One of the major steps towards understanding the development of this vast tract of sandy desert is to determine the source of the accumulated aeolian sediments. Although, many efforts have been made in understanding the dune dynamics and antiquity of the desert, the provenance of the sand deposits of the Thar remains largely speculative. Considering the vastness of the desert, it is natural to assume that there would be variation in sediment sources in different parts of the desert. Earlier workers however, had proposed very different provenance scenarios. Wadia (1960) had hypothesized the Arabian sea coast and the Great Rann of Kachchh to be the primary sediment sources, whereas Singhvi and Kar, (2004) had suggested a local origin due to absence of grain size variation in the down wind direction. On the contrary, Tripathi et al., (2013) had suggested a sub-Himalayan source for the sand based on isotopic fingerprinting. However, their sampling locations were limited to the far north-east corner of the desert, which consisted of stabilised (ancient) dune fields. A contrasting idea has been suggested in a recent detrital zircon based provenance study (East et al., 2015) from the Cholistan Desert that forms a part of the Thar Desert in Pakistan. According to this the desert sand was derived mainly from the trunk Indus, especially the delta region of the river.

In this study, we have strategically collected aeolian sand samples deposited in different parts of the Thar Desert and determined their provenance. Using trace element geochemistry and Sr-Nd isotopic ratios as tracers, we have quantified sediment contributions from plausible sources into the desert.

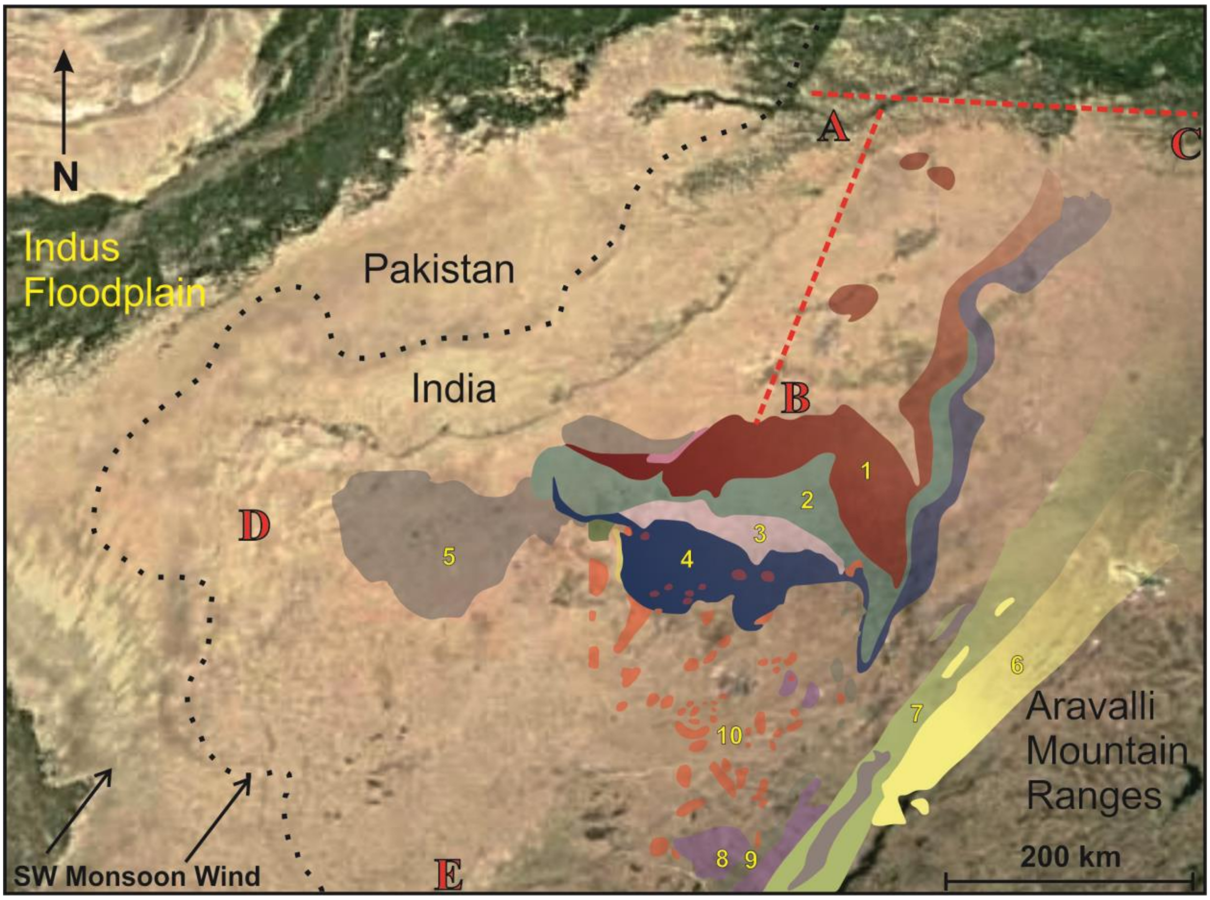

Figure 6.1: Google earth image of the Thar Desert with superimposed lithological map showing the major possible sediment contributors to the basin. Samples had been collected along the AB and AC transects D and E regions on the map. Lithology legends: 1. Nagaur Group, 2. Bilara Group, 3. Girbhankar Formation, 4. Sonia Formation, 5. Mesozoic and Tertiary rocks of Jaisalmer basin, 6. Banded Gneissic Complex-II, 7. Delhi Supergroup, 8. Erinpura Granite, 9. Sirohi Group, 10. Malani Rhyolite. The lithological map is modified from George and Ray, (2017).

6.2 Geology and Geomorphology of the Thar Desert

In last two decades, a significant progress has been made in our understanding of the geological history and antiquity of the Thar Desert. The most important findings of the earlier research are listed below.

- The Quaternary deposits of the Thar Desert are not unequivocally aeolian in character. They are a complex deposit of fluvial, fluvio-lacustrine and aeolian sediments (Dhir et al., 1992; Singhvi and Kar, 2004).
- Neogene tectonic movements had generated a series of NE-SW trending horst-graben structures which acted as the sinks where the Quaternary sediments of the desert got deposited (Dhir et al., 1992). The basement of these basins range from the Proterozoic Delhi ranges in the east, Pre-Cambrian Marwar Supergroup of rocks in the central part and Mesozoic-Tertiary rocks of Jaisalmer basin in the west (Fig.6.1).
- The antiquity of aeolian activities in the desert can be traced back to 200 ka (Dhir and Singhvi, 2012).
- The Desert at present is in a shrinking stage with its most active part limited to the western margin. The paleo desert, however, had a larger active region (Singhvi and Kar, 2004).
- The Thar Desert houses different kinds of dunes such as - transverse, longitudinal, star, parabolic etc. (Wasson et al., 1983). Amongst these, the parabolic dune field is the most dominant geomorphic feature of this desert.
- The orientations of the parabolic dunes (both active and stabilised) suggests that the aeolian activities of the desert is primarily controlled by the SW monsoonal winds (Kar, 1996).

6.3 Results and Discussion

6.3.1 Trace element geochemistry

The trace element composition of the aeolian sediments of the Thar Desert are presented in table 6.1 and are plotted in different tectonic discrimination diagrams and binary plots of elemental ratios in the figure 6.2. Based on these I have made the following observations and discussed their implications:

- From the tectonic discrimination diagrams (Fig. 6.2A and 6.2B) it appears that both passive continental margin and continental island arc types of sources could have contributed to the sediment budget of the desert. Contribution from the passive margin sources are very much expected as the basin is in the vicinity of Archean cratons of western India.

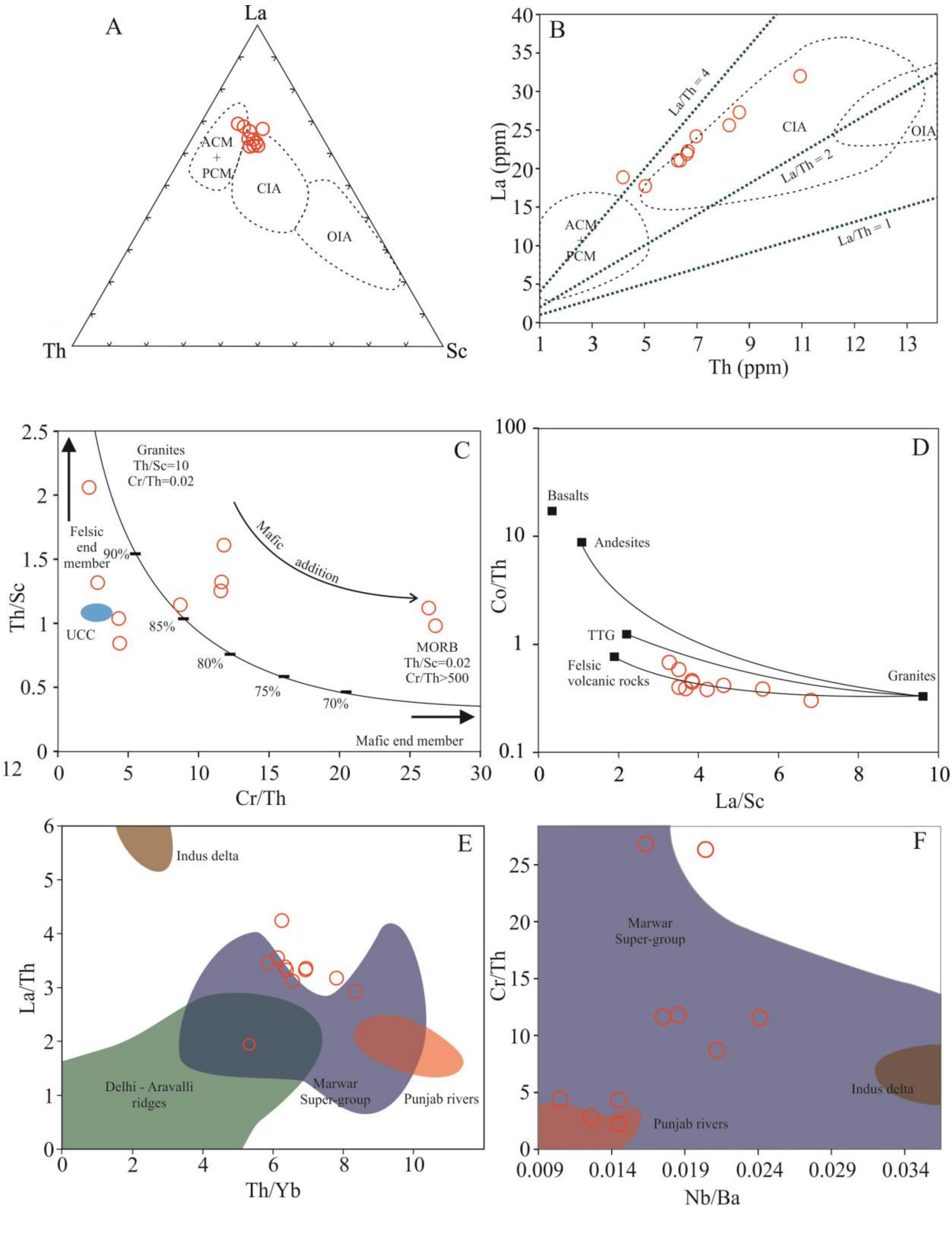

Figure 6.2: (A) & (B) Tectonic discrimination diagrams (After Bhatia and Crook, 1986) for the Thar Desert. ACM: Active Continental Margin; PCM: Passive Continental Margin; CIA: Continental Island Arc; OIA: Ocean Island Arc (C) Th/Sc vs. Cr/Th diagram after Totten et al., (2000), (D) Co/Th vs. La/Sc diagram after Gu et al., (2002), (E) & (F) bivariate plots of different elemental ratios for discriminating the sediment provenance of the Thar Desert sand.

However, considering that the arc related sources are limited to the trans-Himalayan suture zone, contribution from these would most likely have been from the floodplains of the Indus river which is draining through those rocks. Another likely arc provenance could be the Luni river alluvium which derives its sediment from the mafic/ultramafic rocks exposed along the Proterozoic Delhi-Aravalli suture zone.

- As can be inferred from figures 6.2C and 6.2D, the Thar sands have, apart from a strong basement component, a significant component of juvenile mafic and felsic rocks.
- To further discriminate the differential provenances, we made use of various bivariate plots of trace element ratios (Fig. 6.2E and 6.2F). However, it was observed that discrimination of sources/provenances is difficult solely on the basis of trace element contents. This could simply because contribution from multiple sediment sources having widely varying compositions.

6.3.2 Sr-Nd isotopic compositions

In the previous chapters it has already been demonstrated that the Sr and Nd istopic ratios are robust proxies for determining the sediment provenance of the Quaternary deposits of western India. Given the fact that the possible source regions are isotopically well constrained, in the present study attempts have been made to quantify different sources which might have contributed into the sedimentary deposits of the Thar Desert. The Sr-Nd isotopic compositions of the Thar Desert sands are presented in the table 6.2. It is expected that there will be differential sediment contribution from various provenances in various parts of the desert. This is further confirmed by the observed variation in Sr-Nd isotopic compositions of the dune sands along two transects: NNW-SSE (AB transect in Fig. 6.1) and W-E (AC transect in Fig.6.1). The variation in Sr-Nd isotopic compositions have been plotted in the figure 6.3. I have made the following observations from the data and discussed their implications:

- Along the AB transect $^{87}Sr/^{86}Sr$ gradually becomes more radiogenic (increasing) towards south. Complimentary variation is seen (i.e. decreasing) in ε_{Nd} (Fig. 6.3A).
- Similar observation can be made along the AC transect too. $^{87}Sr/^{86}Sr$ shows an increasing trend and ε_{Nd} shows a decreasing trend eastward. However, a reversal is observed towards the furthest end of the desert (Fig 6.3B).

These trends simply indicate that there are gradual but consistent mixing of two different source derived sediments along the AB and AC transects on the map.

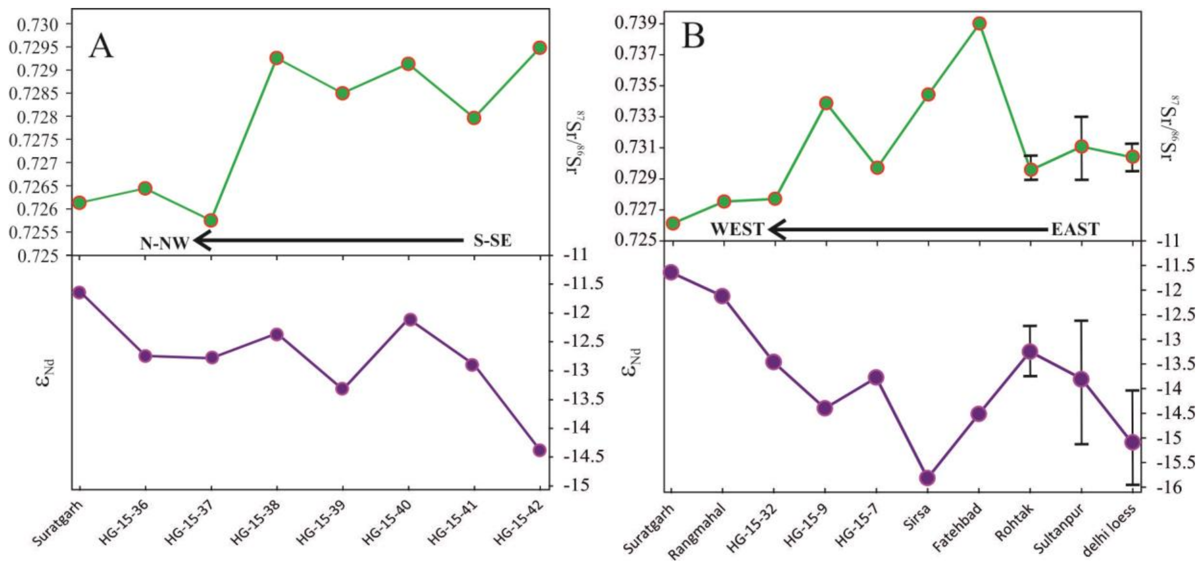

Figure 6.3: (A) Variation of $^{87}Sr/^{86}Sr$ and ε_{Nd} of dune sands along the AB transect of Fig. 6.1. (B) Variation of $^{87}Sr/^{86}Sr$ and ε_{Nd} of dune sands along the AC transect of Fig. 6.1.

The Sr-Nd isotopic composition of the desert sands collected from different locations are compared with that of various probable source rocks in the ε_{Nd} vs. $^{87}Sr/^{86}Sr$ bivariate plot (Fig. 6.4). A three component mixing grid is also presented in the figure for quantifying the differential sediment contributions. A map of the Thar Desert and its various sediment sources along with their differential contribution have been presented in the figure 6.5. From the figures following inferences can be drawn.

- Maximum contribution of the Indus river sediments is observed along the western margin of the desert near Jaisalmer (the region D in Fig 6.4A and Fig. 6.5). The contribution from the Indus floodplain is ~50% of the total (Fig. 6.4A). Given the fact that the SW monsoon winds control the aeolian activity of the Thar and that the Indus floodplain lies at the upwind direction, it is expected that the Indus borne detritus will be a major sediment source. The rest of the sediment contributions are from the rocks of the Marwar Supegroup (Nagaur and Jodhpur Groups) which are located at the heart of the desert (Fig. 6.5).

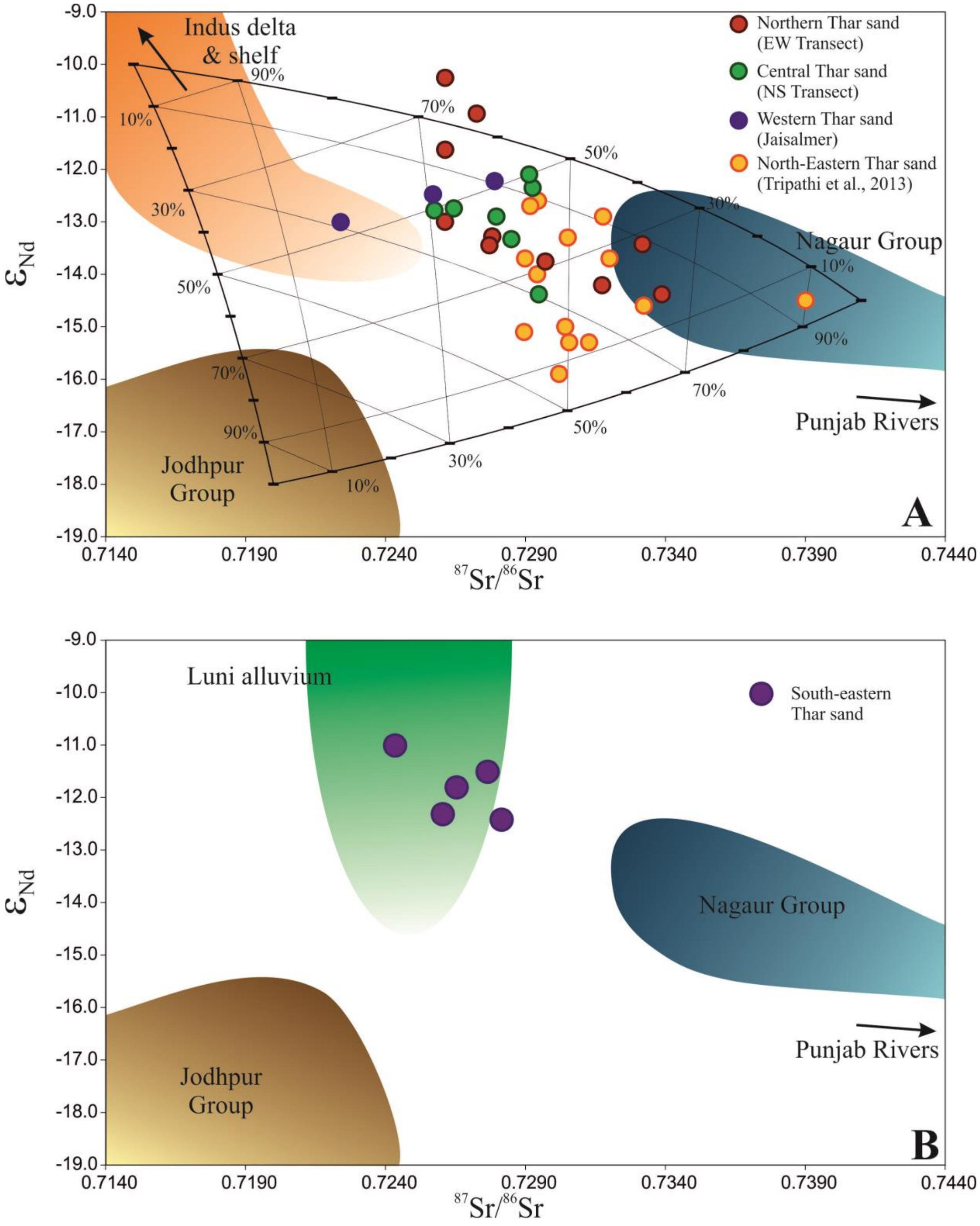

Figure 6.4: (A) and (B) ε_{Nd} vs. $^{87}Sr/^{86}Sr$ diagram showing the composition of the Thar Desert sand compared to the probable sediment sources. End members: Indus delta & shelf: (Clift et al., 2010; Limmer et al., 2012); Nagaur and Jodhpur Group: (George and Ray, 2017); Luni alluvium: Present study.

- The influence of the Indus sediments, however, decreases gradually towards the east and central part of the desert (Fig. 6.5).
- The sands at the northern and north-eastern region of the desert have variable contributions from multiple sources. Towards east, contribution of the Nagaur Group increases (up to ~60%). The contribution from the Jodhpur Group is nearly constant (~20%). Remaining sediments were derived from the Indus river alluvium.
- Similar observation can be made for sediments along the NNW-SSE oriented AC transect. The influence of the Nagaur group increases in the desert sediments towards the central part of the basin.
- The sands in the southern parts (the region E in Fig. 6.5) of the desert have a clearly different provenance. The Luni alluvium becomes the major source for the sediments at this margin. The influence of Indus river is not indiscernible in this part of the desert.

These observations clearly suggest that the Thar Desert is not homogeneous in term of sediment composition. In contrast to the previous observations by East et al., (2013), our data indicate that the composition of the desert sand is highly controlled by the local sources. Maximum contribution of distant source (Indus delta) has been observed to be ~50% and that too restricted to the western margin of the desert.

6.4 Conclusions

The main conclusions inferred from the present work are listed below:

- The Thar Desert sand is derived from multiple sources and not from the Indus alluvium only as suggested by East et al., (2013).
- The maximum influence of the Indus sediments has been observed only at the western margin of the desert (~50%).
- The contribution from the Indus alluvium decreases significantly towards east.
- Towards the central and eastern part of the basin, contributions of sediment derived from the Marwar Supergroup dominate.
- The south eastern part of the desert is heavily influenced by the Luni river alluvium, which masks any contribution from the Indus delta.

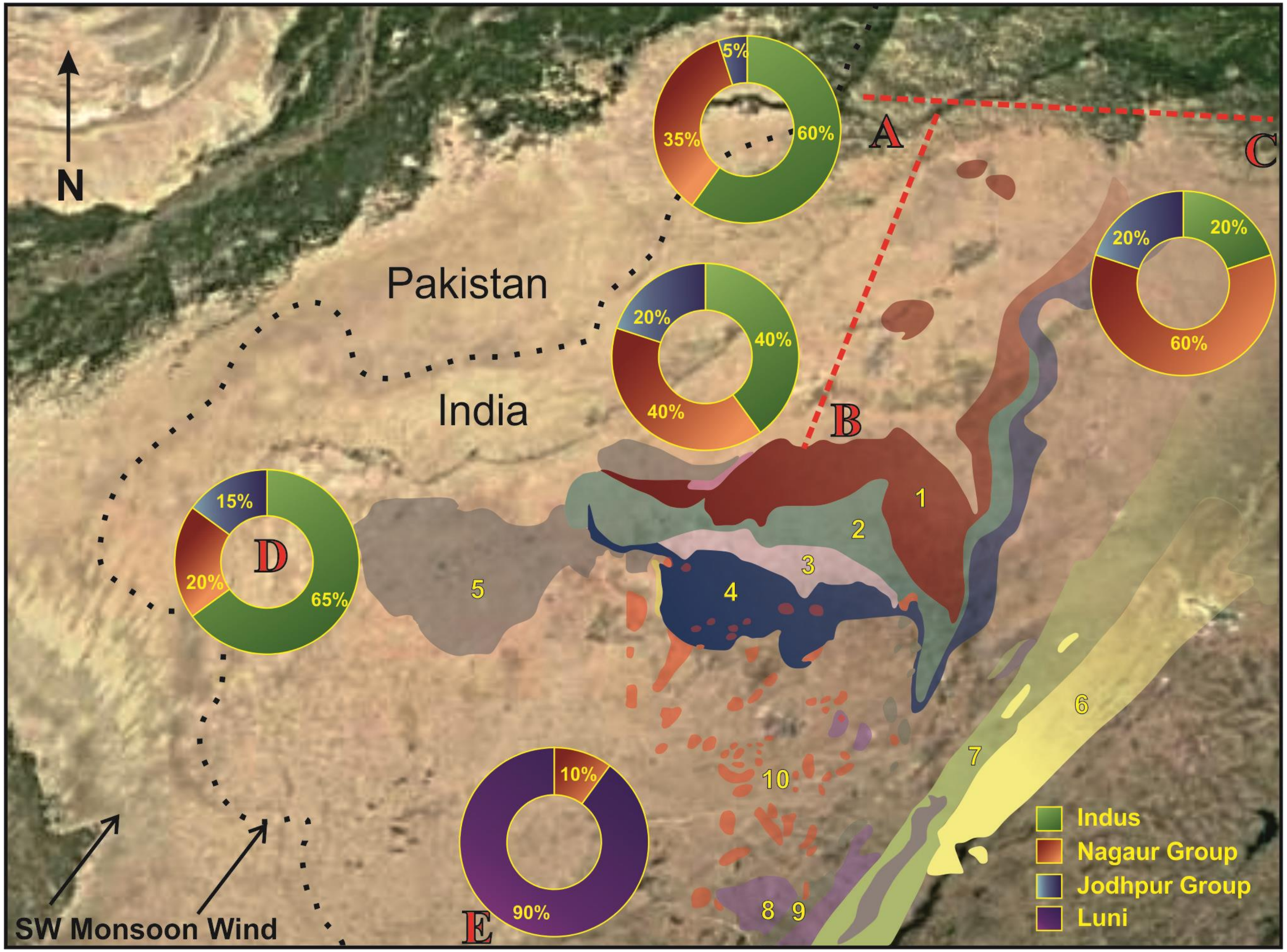

Figure 6.5: Pie diagrams of variation in sediment contribution from different provenances shown over the map of the Thar Desert. Lithology legends: 1. Nagaur Group, 2. Bilara Group, 3. Girbhankar Formation, 4. Sonia Formation, 5. Mesozoic and Tertiary rocks of Jaisalmer basin, 6. Banded Gneissic Complex-II, 7. Delhi Supergroup, 8. Erinpura Granite, 9. Sirohi Group, 10. Malani Rhyolite.

Table 6.1 Trace element concentrations of the sands from different sectors of the Thar Desert. All concentrations are in ppm.

	Southern Thar Desert						Northern Thar Desert			
Samples	LUNI-2013-4	BKS-1	BKS-2	BKS-3	BKS-5	KU-Aeolian	HG-14-23	HG-14-24	R-14-1	R-14-3
Sc	4.35	5.84	6.06	3.88	3.12	4.97	8.75	6.53	7.37	6.77
V	30.10	41.28	31.97	26.59	21.82	25.00	49.14	39.68	46.33	42.45
Cr	82.44	58.09	27.24	14.36	14.32	18.48	126.80	100.40	217.10	177.90
Co	2.68	2.99	2.50	2.09	1.92	1.86	4.23	3.28	4.79	4.49
Cs	1.30	1.53	1.73	1.65	1.08	1.78	2.18	1.76	2.14	1.99
Rb	56.0	55.9	64.0	57.0	40.3	64.6	63.2	62.3	66.8	65.6
Ba	289	281	313	280	201	336	331	345	352	366
Th	7.0	6.7	6.3	5.0	6.4	4.2	10.9	8.6	8.2	6.6
U	1.03	0.94	0.72	0.62	0.63	0.58	1.11	0.77	0.90	0.73
Nb	5	6	5	4	3	4	8	6	7	6
Ta	0.48	0.55	0.47	0.30	0.28	0.46	0.66	0.58	0.57	0.47
La	24	23	21	18	21	19	32	28	26	22
Ce	50	45	40	36	41	35	63	53	51	44
Pb	4.9	4.7	5.2	5.9	4.1	5.5	16.7	17.4	18.3	18.2
Pr	5.6	4.9	4.3	4.0	4.4	3.7	7.0	5.9	5.8	5.1
Sr	135	167	168	143	96	158	181	184	172	180
Nd	20	18	15	15	15	13	25	21	21	18
Zr	14	13	16	7	13	12	11	8	0	8
Hf	0.5	0.4	0.5	0.3	0.5	0.3	0.4	0.3	0.4	0.3
Sm	3.7	3.1	2.7	2.6	2.5	2.1	4.5	3.7	3.8	3.4
Eu	0.8	0.7	0.7	0.8	0.6	0.6	0.9	0.8	0.9	0.8
Gd	3.3	2.9	2.5	2.4	2.4	2.0	3.9	3.1	3.3	3.0
Tb	0.40	0.34	0.30	0.28	0.27	0.23	0.49	0.38	0.41	0.37
Dy	2.4	2.0	1.9	1.6	1.5	1.4	2.7	2.1	2.3	2.1
Y	10.0	9.8	9.2	6.0	5.5	6.4	14.6	11.6	11.0	11.3
Ho	0.43	0.36	0.34	0.30	0.29	0.25	0.51	0.41	0.45	0.40
Er	1.3	1.1	1.1	0.9	0.9	0.8	1.5	1.2	1.3	1.1
Tm	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Yb	1.2	1.0	1.0	0.8	0.9	0.7	1.3	1.1	1.2	1.0
Lu	0.17	0.13	0.14	0.11	0.13	0.09	0.18	0.15	0.18	0.15

Table 6.2 Sr-Nd isotopic composition of the Thar Desert sands

Samples	Suratgarh			N. Thar	
Samples	HG-14-23	HG-14-24	Avg.	HG-15-22	HG-15-27
$^{87}Sr/^{86}Sr$	0.726126	0.726132	0.726129	0.731738	0.733181
ε_{Nd}	-13.0	-10.3	-11.6	-14.2	-13.4
	West to East transect (N. Thar Desert)				
Samples	R-14-1	R-14-3	HG-15-32	HG-15-9	HG-15-7
$^{87}Sr/^{86}Sr$	0.727257	0.727815	0.727714	0.733874	0.729716
ε_{Nd}	-10.9	-13.3	-13.4	-14.4	-13.8
	NNW to SSE transect				
Samples	HG-15-36	HG-15-37	HG-15-38	HG-15-39	HG-15-40
$^{87}Sr/^{86}Sr$	0.726441	0.72575	0.729257	0.728496	0.729133
ε_{Nd}	-12.7	-12.8	-12.4	-13.3	-12.1
	NNw to SSE Transect		W. Thar (Jaisalmer)		
Samples	HG-15-41	HG-15-42	JA-16-2	JA-16-3	JA-16-4
$^{87}Sr/^{86}Sr$	0.727963	0.729478	0.727900	0.725700	0.722400
ε_{Nd}	-12.9	-14.4	-12.2	-12.5	-13.0
	SE Thar				
Samples	KU-Aeolian	LUNI-2013-4	BKS2	BKS3	BKS5
$^{87}Sr/^{86}Sr$	0.728100	0.726000	0.726500	0.727600	0.724300
ε_{Nd}	-12.4	-12.3	-11.8	-11.5	-11.0