Chapter – 7

Summary and Conclusions

In my Ph.D. work I have studied the late Quaternary sedimentary deposits of the western India using field, geochronological, geochemical and isotopic methods to understand the origin and evolution of the major landscapes of this region by understanding the sources and depositional pathways of the siliciclastic sediments. Apart from stratigraphic principles, the geochronological methods included radiocarbon and OSL datings. Geochemical methods included trace element studies, whereas the Sr-Nd isotopic compositions were utilized for source fingerprinting. Ar-Ar dating of detrital mica was also used as a technique to study the sediment provenance. The results and findings from each studied geomorphic feature are discussed in the concluding section of respective chapters. Here I summarize the major conclusions of my work and discuss the scope for future works.

7.1 Region specific conclusions

7.1.1 The Ghaggar river alluvium

The present work draws a conclusion to the long standing debate regarding the palaeo condition of the Ghaggar river of NW India and its influence on the evolution of the Bronze age Harappan civilization. Following findings are the major contributions of my thesis work to this issue:

- The presently ephemeral Ghaggar-Hakra river system had a strong fluvial past. During 70 – 20 ka the river was receiving water from glacier sources through its tributaries, probably the Sutlej and the Yamuna. The Yamuna probably left the Ghaggar channel and moved eastward sometime around 45ka. However, the Ghaggar river still used to flow in its vigour due to contributions from its other tributaries.
- The hydrological conditions of the river first got severely affected during the onset of the last glacial maxima (LGM). Discharges from the glacier sources got drastically reduced.
- In the aftermath of the LGM with the Indian Monsoon returning to its original intensity and with increase in the glacial water input most of the Himalayan rivers got rejuvinated. These changes in the hydrological conditions rejuvenated the Ghaggar channel once again and the distributaries from the Sutlej river flooded the main Ghaggar channel.

- With this reactivated phase of the Ghaggar another interesting development occurred in the Ghaggar valley. The first agro-pastoral community of pre-Harappan people started settling down at the Ghaggar floodplains.
- The settlements gradually flourished further to wide geographical localities which would eventually give rise to the Harappan Civilization.
- The human settlements along the Ghaggar valley enjoyed the vigour of the river until the mid-Holocene when the last of the glacial tributary of the river shifted away. However, it appears that the absence of glacial melt water did not affect the Harappan settlement possibly because the rain water was sufficient for their survival.
- The terminal blow to this system was delivered by the reduction of ISM around 4.2 ka (Enzel et al., 1999; Staubwasser et al., 2003). During this period the discharge in the Ghaggar got severely affected. The situation became detrimental for the Harappan settlements.
- Whereas the demise of the glacial phase of the river might not be the main reason for the decline of the Harappans, its rejuvenated phase appears to have triggered the beginning of the pre-Harappan settlements.

7.1.2 The Great Rann of Kachchh

In the present study, I have quantified the sediment provenance of the Great Rann of Kachchh for the first time. This on the other hand helped in the understanding of the palaeo-drainages active in and around the GRK. The major findings of the present work are as follows:

- There was probably no independent glacier-fed river flowing into the GRK during mid-Holocene. However, a continuous Ghaggar-Hakra-Nara channel was active during 5.5 to 1ka.
- Apart from the local sediment sources the western part of the GRK was receiving recycled detritus of the Ghaggar alluvium through the Ghaggar-Hakra-Nara channel mainly during the monsoonal floods.
- Considering that the Ghaggar-Hakra-Nara system was mainly ephemeral during the mature Harappan period and sedimentation persisted long after the decline of the Harappan civilization, changes in the fluvial conditions might not be the main reason for the demise of the Harappans.

- The sedimentation in the eastern part of the GRK was dominated by local sources during the Holocene. The Mesozoic rocks exposed surrounding this part of the basin was the main source of sediments.
- The eastern GRK, especially the area around the Khadir island was probably estuarine in condition during the period when the Harappan acropolis of Dholavira was occupied. The sea had already started receding by mid-Holocene exposing the eastern GRK.

7.1.3 The Luni river alluvium

The Luni river system, being the only major drainage of the Thar Desert is an important window to the weathering and sediment transport processes in a desert environment. The major outcomes from the present work are as follows:

- The REE geochemistry of the Luni river sediments are controlled mainly by weathering intensity and sediment sorting. Due to incipient weathering, the source rock compositions are not reflected in the sediment characteristics.
- Although the major lithology exposed in the Luni river catchment is the post-Delhi orogenic granites and rhyolites, their contributions to the sedimentary budget are meagre.
- The major sediment contribution to the Luni alluvium was from the pockets of mafic/ultrmafic rocks exposed along the suture zone in the western flank of the Aravalli mountain ranges.

7.1.4 The Thar Desert

The provenance of the Thar Desert sands is one of the most complex and highly debated issues amongst the Quaternary deposits of the western India. The present geochemical work has helped us quantify the complex provenance of the aeolian sands deposited over the Thar Desert. Followings are the major outcomes of our effort:

- The sands in the Thar Desert are derived from multiple provenances. Contrary to the earlier proposal of distant sources (Indus delta and shelf), we find that the sands are dominantly derived from local sources.

- Only in the western and north-western margins of the desert the influence of the Indus derived detritus is maximum (up to ~60%).
- Towards the eastern side and the central parts of the Thar, influence of the Indus derived sediment gradually decreases. The sedimentary rocks of the Marwar Supergroup which sits at the heart of the desert contributes the most to the sediment budget of these parts of the desert.
- The south-eastern part of the desert, however, has sands derived from a completely different provenance. This part of the desert sands are mainly sourced from the Luni river alluvium.

7.2 Quaternary sediments and landscape evolution of NW India

The Quaternary sedimentary deposits of the north-western Indian sub-continent are distributed across a wide range of geomorphic landscapes and exchanged sediments with each other through different geological processes (Fig. 7.1). Landscape evolution of this part of the sub-continent is a direct outcome of the interactions between these geomorphic environments. The oldest sedimentary deposits (>200 ka) were encountered in the Luni alluvium. The pre-dominant sources for the sediments were the mafic-ultramafic units exposed along the western flank of the Aravalli Mountains and the meta-sedimentary rocks of the Delhi Super-group (Fig. 7.1). The granitoid rocks exposed in this area have minimum contribution to the sedimentary budget. The sediment provenance in the Luni alluvium remained unchanged during the Quaternary period and the major alluvium deposition ceased when progressing desert dunes covered the alluviuim at ~8ka. At present, Aravalli derived sediments are restricted mainly at the piedmont zone. In the lower reaches, the river reworks local sediments and older alluvium deposits mainly during the monsoonal rains. A part of Luni river sediments get reworked into the eastern Great Rann of Kachchh. The Kachchh basin on the other hand has several other sediment contributors. The eastern part of the basin received sediments from the Luni River as well as Mesozoic rocks exposed around the basin (Fig 7.1). On the other hand, the western part of the basin received a significant amount of sediments from the Indus River. However, the western GRK also received recycled sediments derived from older alluvium deposits, episodically through a continuous Ghaggar-Hakra-Nara in the past (up to ~1 ka). The Ghaggar-Hakra alluvium however, had a very strong fluvial past. From ~70 ka onwards up to ~15 ka it was a strong glacier fed river system which

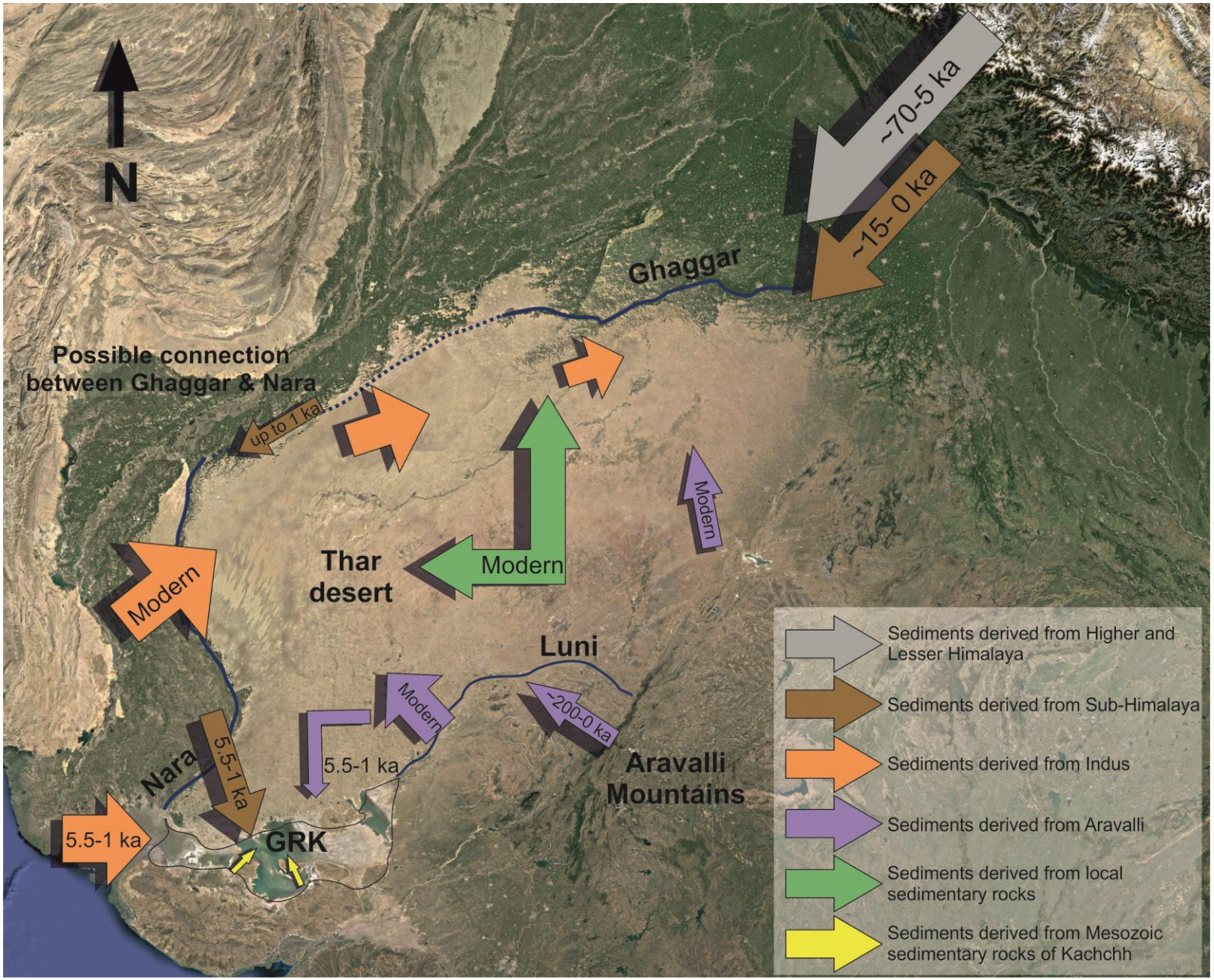

Figure 7.Graphical representation of sediment provenance and transportation pathways in various geomorphic terrains of NW Indian Sub-continent. The sizes of the arrows represent their relative contribution to different sedimentary sinks. The period of deposition are mentioned along the arrows. As the provenance study for the desert was done on recent sub-surface sand, the period is presented as modern.

derived its sediments from the higher and lesser Himalayas after which it received sediments maily from the Sub-Himalayas and local reworking (Fig 7.1). All these landforms surrounding the Thar Desert delivered sediment into it (Fig. 7.1). Unlike the recent conclusions derived from detrital zircon provenance studies, we have shown that the Thar Desert sand composition is controlled by local sources mainly. The sediment contribution from the Indus delta region reduces significantly towards inland. The sand in the central and northern part of the desert are derived mainly from the sedimentary rocks (from Marwar Supergroup) exposed along the heart of the desert. On the other hand the south-eastern part of the desert received its sediments mainly from the older alluvium deposits of the Luni river.

7.3 Summary of the thesis work

The western part of the Indian sub-continent is a natural laboratory of various Quaternary geomorphological terrains. Also the development of one of the earliest human civilization was closely linked to the evolution of these terrains. The present study sheds some light on the long standing debates on the evolution of these terrains. This work establishes that mega glacier fed river system did exist along the palaeo channels of the presently ephemeral Ghaggar-Hakra river of the NW India, however, it was in its full force much before the Mature Harappan period. The river used to be a glacier-fed until at least ~ 5 ka, albeit its flow was much reduced during the Holocene than its pre-LGM condition. Even after the river became ephemeral during the mid-Holocene, the channel was present and used to deliver sediments into the Great Rann of Kachchh, as late as ~1 ka. Therefore, the demise of the river was never the main reason for the decline of the Harappan Civilization around 3.9 ka. Rather the present work opens up a new understanding regarding the River-Culture interrelationship in this region. The rejuvenated phase of the Ghaggar river during the early Holocene helped the earliest agro-pastoral communities to build their settlements along the river bank. They flourished for a few millennia and developed into an urban civilization. It is the gradual decrease in the river discharge associated with severe decrease in monsoonal rain and its associated effects which became detrimental for the mature Harappans.

Our study offers new insights into the evolution of the Thar Desert also. Contradicting the recent propositions that the desert sand was mainly derived from the Indus river detritus, our study confirms that the Thar Desert sands are dominantly originated from local sources from sedimentary rocks of the Marwar Supergroup. The SE part of the desert

receives its sediments mainly from the Luni river alluvium which itself derives its sediments from the Proterozoic rocks of Delhi-Aravalli suture zone.

7.4 Recommendations for Future Studies

Although the present work reveals many interesting aspects regarding the evolution of the Late Quaternary continental deposits of western India and its connection with the development of the Harappan Civilization, there still exist several gaps in our knowledge. The present work is more like a reconnaissance study which gives us a platform to further explore these landscapes. I recommend the following important aspects which should be taken up for study to further advance the hypotheses proposed in this thesis and resolve all the outstanding issues in Quaternary evolution of the western India.

- Even though the palaeo-Ghaggar river has been traced between Sirsa and Anupgarh, its downstream extension is yet to be worked out. The fact that researchers working downstream of the river in the Pakistan region could not trace the river activity during the Holocene, suggests that the river was probably flowing along a different track further downstream than its present day course or that proposed earlier. This aspect needs to be investigated.
- The fluvial deposits studied in the Great Rann of Kachchh date back to the mid-Holocene only. Therefore, the older deposits of the GRK only can reveal what was the discharge condition of the rivers draining into the GRK during the early Holocene and whether any higher-Himalayan river was discharging into the GRK during that period.
- More sections of Thar Desert need to be sampled covering the entire extent of the desert for a rigorous geochemical provenance study. In addition, the temporal evolution of the desert needs to be constrained well.