Continental–marine interaction in the vicinity of the Nara River during the last 1400 years, Great Rann of Kachchh, Western India

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In the near-coastal environment, river channels respond to changing land–sea configuration by spatial and temporal changes in the sedimentation pattern, which in turn can be used to reconstruct the past climate and tectonic history. We studied a shallow sedimentary sequence on the relict Nara River bed in the western Great Rann of Kachchh for sedimentological, geochemical and chronological studies in order to ascertain past climate and tectonic history. It was found that the present-day relict Nara River course was active after 2200 years BP. During 2200–1000 years BP, sedimentation was dominated by both marine and continental processes. The study indicates that after 1000 years BP, both marine and fluvial processes diminished, which implies withdrawal of the sea and decline in the hydrological condition that persists till today.

Keywords: Carbon–nitrogen ratio, continental–marine interaction, Great Rann of Kachchh, Nara River, river channels.

THE western Great Rann of Kachchh is currently an extensive saline mudflats and salt encrustation area; part of it is inundated due to storm-induced tidal surges during the monsoon, particularly the narrow trench zone[1,2]. Fluvial processes are virtually absent, except during the occasional major floods in the Indus River to the northwestern Great Rann. The western Great Rann opens into the Arabian Sea through a macrotidal-dominated Kori creek, which serves as a conduit for sea water to seasonally enter inland which results in the flooding of the Great Rann of Kachchh during monsoon[3–5]. Geomorphologically the western Great Rann is divided into two major landforms; these are the raised micaceous sandy bets and the low-lying silty clay-dominated bets[3,6]. A recent study by Tyagi *et al.*[6] suggested that the micaceous sand dominated bets were deposited by southern draining streams, whereas the silty-clay-dominated bets are the outcome of tidal flat sedimentation. Further based on the geochemical characteristics, it was argued that the Indus River was a major contributor of sediments into the western Great Rann, which was largely routed through the Kori creek during the mid-Holocene minor contributions through rivers and streams from the western part[6].

It has been suggested that the present course of the Nara River was attained sometime after 2200 years BP caused due to a major earthquake-induced westward migration of the river. The earthquake, which was bracketed between 2200 and 1400 years BP, not only shifted the river course to the west but also raised appreciably the Rann sediments, which led to the withdrawal of marginally high sea. As a result, tidal flat sedimentation ceased in the western Great Rann of Kachchh[6].

The existing chronometric data suggest that although the tidal flat sedimentation terminated from the major part of the western Great Rann in the narrow confined Nara River channel, sedimentation continued until around 1000 years BP. However, the nature of sedimentation remained speculative[6]. The present study is therefore aimed at reconstructing the history of sedimentation in the Nara River bed after 2200 years BP. Towards this, we studied a shallow pit (1.20 m) that was dug proximal to the Allah Bund scarp (24°07′36.7″N and 69°07′15.1″E; Figure 1). We used total organic carbon (TOC) and carbon and nitrogen (C/N) ratio supported by the radiocarbon and optical ages.

Field stratigraphy and sedimentology of the succession show that sedimentation pattern frequently changed from sand to silty-clay lenticles and a few horizons containing turritella shells. From bottom upwards the sediment succession starts with a turritella-rich silty-clay horizon. This is overlain by a 10 cm thick sandy-silt layer containing broken turritella shells. Overlying this is 20 cm thick crudely laminated micaceous sand containing impersistent clay streaks. This is followed by a 30 cm thick cherry-brown silty-clay containing a millimetre thick broken shell laminae which is overlain by a 30 cm thick planar and ripple laminated light to dark grey sand. This is succeeded by a 20 cm thick crudely laminated cherry-brown silty-clay with a millimetre thick sandy lenticles. Finally, the sequence is terminated with 20 cm thick sand–clay alteration (Figure 2).

The lowermost unbroken turritella shell-rich silty-clay horizon indicates deposition proximal to the intertidal environment[6]. The unbroken nature of the shell indicates that they were not transported much subsequent to their deposition. We suggest that the freshwater flux was reduced and that facilitated saline water ingression through the Nara River channel, while during high tides it led to the deposition of the silty-clay facies in the proximity of the Allah Bund scarp. The overlying broken shell and micaceous-rich sand can be interpreted as the reworking of the underlying sediment by fluvial process and transportation of the micaceous sand by the stream from the locally available parabolic dunes in the north (Figure 1) during short-lived enhanced fluvial activity.

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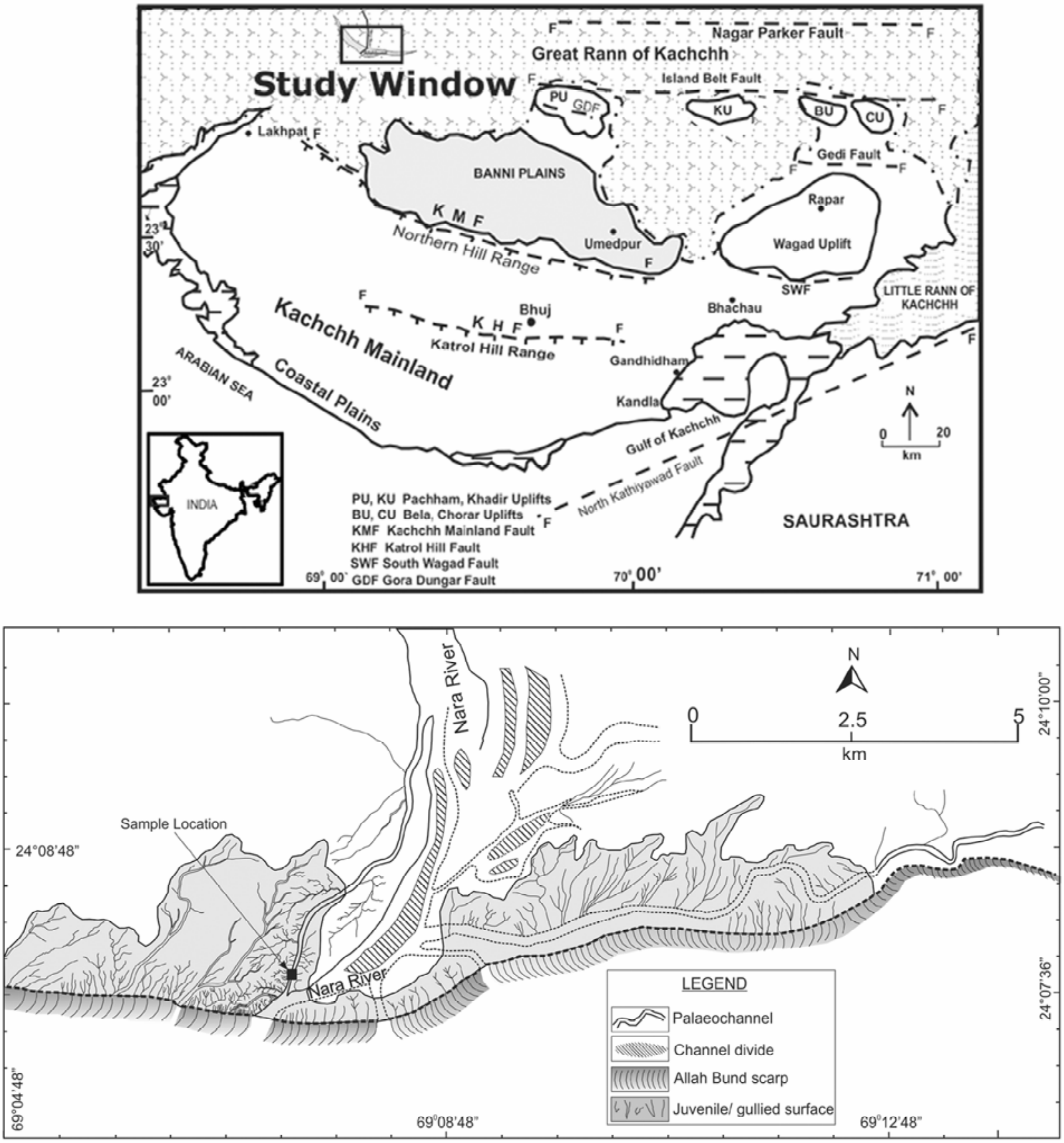

Figure 1. Location map of the study area showing the sample location on the uplifted palaeochannel course of Nara River. Note the sample site is located on the gullied surface of Allahbund.

Presence of cherry-brown silty-clay above the sand horizon again suggests the decline in fluvial activity in the region. This was again followed by a rather enhanced fluvial phase which led to the deposition of around 30 cm thick planar and ripple laminated sand. Following this, an absence of distinct sandy facies and dominance of silty-clay indicates overall decline in the fluvial regime.

The depositional environment inferred based on sedimentological characteristics, was further supported by TOC and C/N ratio obtained from 22 samples collected ~ 5 cm interval above the lowermost 20 cm thick turritella-rich horizon. The possible source of sedimentary organic matter in the coastal areas is terrestrial biomass and organic matter derived from *in situ* aquatic sources. The tidal salt marshes (elevated areas in mudflats) are usually covered with vascular plants (high C/N ratio), whereas mudflats (low-lying areas) are dominated by nonvascular plants like algae and tidal-derived organic material[7]. Vascular plants have relatively high C/N ratio (> 12) as they consist chiefly of nitrogen-poor lignin and cellulose[8], whereas marine organic carbon[9] has relatively low C/N ratio (~10). Thus, C/N ratio can be used to differentiate between the land verses marine derived organic carbon in near-coastal environment[8,10–14].

Figure 3 shows the temporal changes in TOC and C/N ratio during the last 1400 years BP in the proximity of Nara River. The TOC variability ranges from 0.06% to 0.9%, whereas C/N ratio shows wide fluctuation from 3.75 to 57.92 (Table 1). The pattern of variability in both the organic proxies shows four distinctly high values between 15 and 35 cm, 45 and 60 cm, 75 and 90 cm and after 100 cm (Figure 3). The most prominent enhancement both in the TOC and C/N ratio is observed between 15 and 35 cm, where TOC increases to ~0.9% and C/N ratio is around 58. These values suggest that sediment organic carbon is derived from continental sources (Figure 3). Similarly, marginal increase in TOC (0.2% to 0.4%) and C/N ratio (>10) between 45 and 60 cm as well as 75 and 90 cm can be attributed to significant continental contributions of the organic carbon, which shows an increasing trend after 100 cm. Combining the TOC and C/N ratio data with those of the sediment succession, the high values (peaks) broadly correlate with the sandy horizons, whereas the low values are associated with the silty-clay horizons. Deposition of sandy horizons in the western Great Rann is attributed to the fluvial processes, whereas the silty-clay-dominated sediments are interpreted as tidal flat sedimentation[6].

Thus translating the observed sedimentological and geochemical variability in terms of sedimentation processes that were in operation after 1400 years BP and till beyond 1000 years BP, it can be suggested that the variation in the grain size and associated TOC and C/N ratio reflects the temporal changes in the fluvial contribution by the Nara River. Pollen and magnetic studies from the peat bog in Central Himalaya[15] indicated two warm and

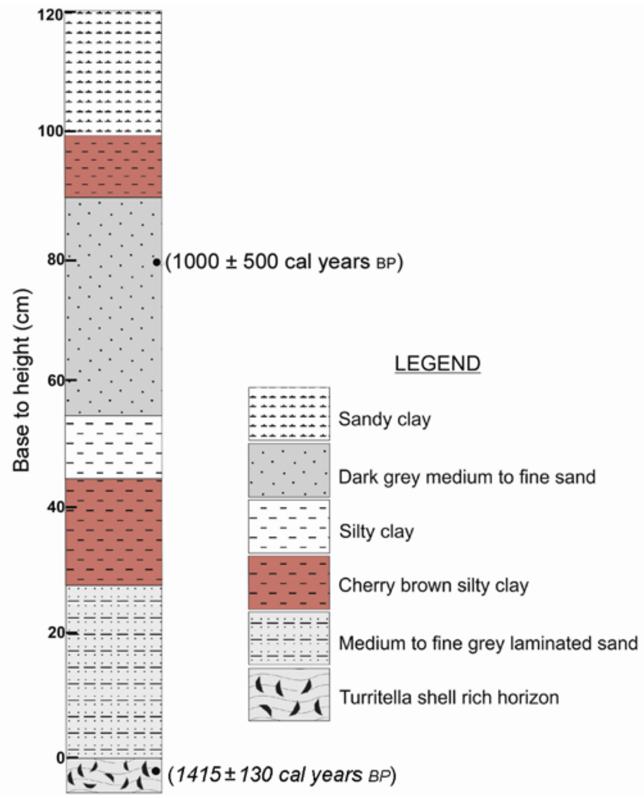

Figure 2. Stratigraphy and optical chronology of the Nara River sediment at the Great Rann of Kachchh. The age shown in italics (turritella horizon) pertains to carbon-14, while the other one is of optically stimulated luminescence.

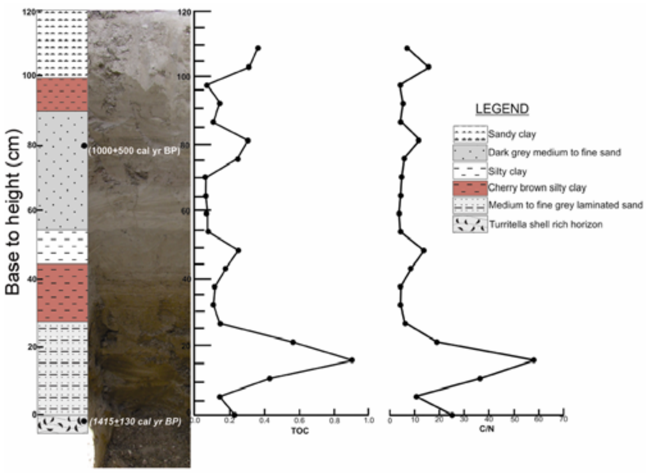

Figure 3. Total organic carbon and carbon and nitrogen ratio plotted against the lithostratigraphy of the Nara River sediment at the Great Rann of Kachchh.

Table 1. Carbon, nitrogen and C/N ratio of 22 samples collected from the Nara river bed

Sample ID	Depth (m)	Nitrogen %	Carbon %	C/N ratio
NRM-23	10	0.052	0.361	6.957
NRM-22	15	0.020	0.309	15.498
NRM-21	20	0.016	0.072	4.419
NRM-20	25	0.026	0.145	5.480
NRM-19	30	0.023	0.108	4.810
NRM-18	35	0.026	0.304	11.764
NRM-17	40	0.042	0.250	5.915
NRM-16	45	0.013	0.064	4.843
NRM-15	50	0.015	0.064	4.360
NRM-14	55	0.019	0.070	3.758
NRM-13	60	0.017	0.079	4.498
NRM-12	65	0.018	0.249	13.595
NRM-11	70	0.021	0.179	8.435
NRM-10	75	0.027	0.118	4.343
NRM-9	80	0.025	0.110	4.438
NRM-8	85	0.024	0.150	6.347
NRM-7	90	0.030	0.563	18.885
NRM-6	95	0.016	0.901	57.925
NRM-5	100	0.012	0.433	36.095
NRM-4	105	0.013	0.147	11.107
NRM-3	110	0.009	0.230	25.226
NRM-2	115	0.011	0.250	23.086

moist climatic events punctuated by cold and dry condition during 1572–200 years BP. According to Chauhan *et al.*[16], Western Himalaya witnessed warm climatic condition during 1500–900 years BP. In marine record, von Rad *et al.*[17] observed enhanced Indus River discharge during 1700–1200 years BP and around 900 years BP. With the limited chronological constrains, it can be hypothesized that the Nara River responded in accordance with the regional climatic pattern during the last 1400 years. The two prominent peaks of TOC and C/N ratio, and their association with the micaceous-rich sandy horizon can be interpreted as deposition under enhanced fluvial discharge. Chronologically these events occurred after 1400 years BP and around 1000 years BP that can be equated with the onset of the Medieval Warm Period.

Therefore based on the above, it can be suggested that during the last 1400 years BP the Nara River experienced at least four relatively high discharge events punctuated by low discharge events. Due to limited chronometric control, we desist from assigning precise timing of each event. However, the data allow us to hypothesize that during periods of high fluvial discharge, the marine influence was restricted proximal to the Kori creek, whereas the periods of reduced fluvial discharge facilitated the northward ingression of the tidal influence. This is being amply demonstrated both in the temporal changes in sediment characteristics (fluvial to tidal flat transition) and in the changes in TOC and C/N ratio. Considering that the man-made bunds (dams) on the Nara River came into existence after AD 1766 (ref. 18), we attribute these fluctuations to the oscillating climatic condition after 1400 years BP. It was preserved in the form of sediment and geochemical record in the Nara River channel till the river bed was uplifted after the 1819 Allah Bund earthquake.

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