# PALAOENVIRONMENTAL CONTROLS ON TERRIGENOUS SEDIMENT IN THE MARGNAL MARINE BASIN OF GREAT RANN OF KACHCHH, WESTERN INDIA

**Synopsis**

of the thesis

to be

submitted

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## Introduction

Kachchh basin on the western continental margin of India is known for its semi-arid climate and active tectonics in the form of co-seismic deformations and devastating. The Kachchh basin can be divided into two broad parts i.e., 1) Mainland Kachchh that comprises of mainly rocky land part and 2) the Great and Little Rann of Kachchh sub basins forming marshy lowlands. The Quaternary landscape changes in Kachchh basin are mostly investigated from the rocky mainland part with respect to structure and tectonic activity in the region. The Great Rann of Kachchh (GRK) and Little Rann of Kachchh (LRK) cover almost half of the Kachchh rift basin which has accumulated huge sediments throughout the Quaternary period. In fact, GRK and LRK were forming gulfs of the Arabian Sea till past 500 to 2000 years before present. However, very less information is available in the literature about the evolution of coastal part of the Kachchh basin. The present study explores the overall palaeoenvironmental implications in the evolution of the GRK under varied depositional environmental conditions.

## Regional Geology

The GRK sub basin is structurally bounded by roughly E-W trending Nagar Parkar Fault (NPF) in the north and Island Belt Fault (IBF), Kachchh Mainland Fault (KMF), Banni Fault (BF) to its south. There are several NE-SW and NW-SE trending faults along the major islands of the GRK sub basin that further divide GRK into several tectonic blocks for example: Pachchham, Khadir, Bela islands. Geomorphologically, the GRK is bounded by one of the largest delta- Indus delta to its west, the Thar Desert on north; whereas to its south and east the mainland Kachchh and little Rann of Kachchh marks the basin margin. It is believed that the GRK has received majority of sediments from its north through the eastern Indus distributaries, Saraswati, Luni draining through the margins of the Thar and via local small river/streams originating through mainland Kachchh from its south.

The landscape of the GRK sub basin is monotonous, flat and mostly lacks the exposures; however, there are few raised rann sediment sequences along the margins of the islands and erosional signatures of the past sea (Chowksey et al. 2010; Khonde et al. 2011). Seismically, the GRK has a long historic record of devastating earthquakes, for example- 893 AD, 1668 AD, 1819 that lead significant amount of landscape changes in the form of subsidence, drainage disruptions and upliftment in some parts (Rajendran and Rajendran, 2001; Bilham, 1999). It is also believed that the massive 7.9 magnitude earthquake in 1819 formed a ~90 km NW-SE trending Allah bund fault scarp that modified the land-sea configuration in the western GRK basin (Oldham, 1926; Padmalal et al. 2019). The southern mainland hill ranges comprise of limestones, sandstones, shales, marls and igneous intrusions of Cainozoic age (Biswas, 1993). The Kachchh mainland hill range, Kas hill range marks the southern structural boundary of GRK sub basin and separates the Banni plain surface and rann surface by a slight elevation difference between 2-4 m.

## Objectives and Methods

1. Delineate Holocene palaeoenvironmental changes vis-a-vis terrigenous flux in the Great Rann of Kachchh.
2. Reconstruct Holocene evolutionary history of the Great Rann of Kachchh.
3. Available geological and subsurface data on the Rann of Kachchh is critically evaluated to delineate the deep seated subsurface structural feature and infer the nature of basement configuration.
4. Satellite data combined with field checks were used to understand the emergence pattern of the Great Rann.
5. Multi-proxy data was generated on Sedigraph (grain size parameter, depositional environment, depositional process), mineral magnetic studies (concentration, grain size, mineralogical).
6. Chronology of the cores by AMS dating were established for the present study.

## Geomorphic characteristics of Great Rann of Kachchh

The modern GRK is known for its unique annual inundation cycle through dragging of sea water into the basin for ~100 km inland and with less monsoon precipitation in this region baffled earth scientists for long time to understand inundation pattern (Gleinne and Evans, 1976; Roy and Merh, 1981; Merh, 2005). The flat, gradient less surface of GRK and its slight elevation from sea allows extensive inundation from the Arabian Sea under the strong summer monsoon winds and through the rivers from the northeast by precipitation (Roy and Merh, 1981). The water does not percolate much into subsurface and gets locked for several months in to GRK until the increasing summer temperatures dries it up which leaves thick salt crust across hundreds of square kilometres area (Gleinne and Evans, 1976). Overall, the alternate wet and dry condition in the Great Rann of Kachchh results in a unique and hostile terrain whose environmental condition fluctuates between extremes. There are several known zones where the slummy regions swallow large animals, vehicles and field parties which therefore warrants enough information to carry field activities. Usually, local help is prerequisite to visit before the interior parts.

The GRK comprises overall vast, flat, monotonous terrain; however, there are rocky islands, small islets (locally called as bets), raised rann sediments and other peculiar geomorphic characteristics which clarify the overall geomorphic assemblage of the basin. The GRK surface shows considerable variation in elevation from north to south and west to east which clearly gets reflected on its submergence pattern. Gleinne and Evans (1976) described modern GRK environments as a coastal sabkha to supra tidal environments. Roy and Merh (1981) described GRK into four zones based on the submergence pattern namely into- Bet Zone, Linear Trench Zone, Banni plain and Great Barren Zone. The rann (local, informal name for GRK and LRK) surface is dotted with several large to small islands such as- Pachham, Khadir, Bela, Chorar and small rocky islands like the Bhanjada bet, Kuar bet, Mori bet and the Gainda bet (Fig. 2). All these islands show rocky, hilly topography and expose Mesozoic and Tertiary rocks. In addition to this, there are several smaller islands rising up to 1-5 m above the rann surface, especially in the northern part of the Great Rann and consist of sediments similar to the rann surface raised to a higher level (Fig. 2). The top cover of these islands is usually made up of aeolian sediment blown from the wind- swept surface of the rann that is underlined by rann sediments.

## Stratigraphy of cores and Age model

Sediment coring-drilling was performed in 2010 at the central and south marginal part of the GRK basin. The central Dhordo core is ~60 long and south marginal Berada core is ~50 m long (Maurya et al. 2013). Dhordo core suggests the changes took place from the middle of the basin whereas Berada suggest the changes from the southern margin of the basin. The cores were spitted and sub-sampled at every 2 cm and half part of every pipe is preserved in low temperature environment at Baroda.

The basin accumulated sediments throughout Quaternary period (Biswas 1987, 1993). Coring was carried out in order to study the overall evolution in GRK and to understand depositional pattern which acted during the infilling of the basin. The correlation of both cores would suggest overall picture of evolution and changes that took place from the basin.

The age model is based on radiocarbon ages acquired from the different depths in both cores. To convert the radiocarbon dates to calendar year it was calibrated according to (Reimer et al., 2009), and the reservoir effect correction values were calculated and incorporated from (Dutta et al., 2006). The carbon ages are based on the inorganic and organic material from both the cores. The carbon ages are plotted against the representative depth of both cores respectively. The dhordo age model suggests high sedimentation rate (8.57 mm/year) during the early Holocene period whereas relatively suppressed sedimentation rate is noted from berada during the same period. However, high sedimentation rate (10.81 mm/year) is encountered during the mid- Holocene period from the berada core with dhordo showing little decreased sedimentation rate of 6.27 mm/year. Both the cores close with extremely low rate of sedimentation where it reaches as low as 1.46 mm/year in dhordo and 2.65 mm/year in berada.

## Sedimentary Analysis (Grain size analysis)

All the processed samples were run on sedigraph and the data was processed and compiled using Gradistat program in Microsoft Excel (Blott and Pye, 2001). The data on mean grain size, type of sorting and skewness for all 181 samples from both the cores was generated using Gradistat software. The bivariant plot was computed using mean grain size versus sorting of sediments from both the cores showing different energy and depositional environmental conditions (modified after Tanner, 1991). The bivariate plot was computed using grain-size distribution parameters of sorting and skewness for energy of depositional environment (after Bjorlykke, 2010). Total 6 textural classes were recognised from both the cores.

### Dhordo core

### Textural classification

To distinguish and categorize texture based on grain size variation, data of particle distribution were generated at an interval of ~60 cm depth. The core shows consistent presence of silt in entire core with an average of 70% from the entire core. The presence of clay is marked with an average of ~19 %. The presence of sand particle is negligible to very little. Texturally, the Dhordo core sediments show four textural classes that include-slightly sandy slightly clayey silt (52%), very slightly sandy slightly clayey silt (42%), slightly clayey silt (5%) and slightly clayey sandy silt (1%) as per the scheme given by Blott and Pye (2012). The core is mainly dominated by slightly sandy slightly clayey silt (52%). The maximum presence of slightly sandy slightly clayey silt texture is encountered from 55m (5500 cm) to 45m (4500 cm) depth. The sand dominated texture slightly clayey sandy silt (1%) is present at the depth of ~25 m (2500 cm).

**Depositional environments**

The core shows transition from terrestrial to closed basin environment. The skewness vs sorting graph reflects the process acted during the deposition of the sediments. The data reflects dominant of turbidite process during deposition of the core. This type of depositional setting is in consistent with GRK's geomorphic settings. The mean Phi vs sorting Phi value shows the core is mainly deposited during low energy conditions.

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**Berada core**

The Textural classification was based on the variation in the grain size data which was computed based on the classification scheme proposed after Blott and Pye., (2012). The data was generated at an interval of ~60 cm depth. Berada core is entirely dominated by the presence of silt fraction with an average of 78%. Lowest presence of silt fraction is marked at 3m depth. Sand remains low in the entire core with an average of ~10%. Highest sand fraction is encountered from the upper part of the core at 3m (300 cm) depth which reaches up to 40%. Presence of clay is marked with an average of ~12 %. The core is entirely dominated by very slightly sandy slightly clayey silt (~54%). Sand rich texture is mainly at 3 m depth. Very slightly sandy slightly clayey silt and slightly sandy slightly clayey silt is present in alteration to each other from 40 m to 17 m. Sand filled fluvial section is present from 50 m to 40 m.

**Depositional environments**

The core was divided into six textural units based on grain size variation namely slightly sandy slightly clayey silt (42%), very slightly sandy slightly clayey silt (32%), slightly clayey silt (15%), very slightly clayey sandy silt (5%), slightly clayey sandy silt (2%) and slightly sandy slightly clayey silt (1%) as per the scheme given by Blott and Pye (2012). The bivariant plot of mean Phi vs sorting Phi value shows the core is mainly deposited during high to low energy conditions. The core shows the deposition from terrestrial to closed basin environment. The skewness vs sorting graph reflects the process acting during the deposition of the sediments. The data reflects dominant of turbidite process during deposition of the core. The lower part of the core fluvial dominated 50 m is separated by marine dominated layer at 40 m. The upper part is mainly dominated by sand enriched texture which is in account of high energy condition of deposition. The presence of texture like slightly silty clay and v. sl. sandy silty clay at 25m to

20m advocates deposition during tidal condition. The consistent presence of slightly silty clay ~80% from the Berada core suggests the deposition in the closed type of environment.

## Mineral magnetic studies

Around 474 samples at ~20 cm interval throughout the Dhordo core were taken for mineral magnetic measurements using standard techniques (Walden, 1999a). ~10 g of air dried sample was filled in non magnetic sample holders for analysis. Magnetic susceptibility ($\chi$lf) at low frequency (0.47 kHz) was determined on Bartington Susceptibility Meter (Model MS2) (noise level ~$3x10^{-9}m^3$ $kg^{-1}$ for a 10 g sample). Anhysteric remanent magnetization (ARM) was induced in the samples using a Molspin AF demagnetizer (with an ARM attachment) in a constant biasing field of 0.1 mT superimposed on a decaying alternating field (a.f.) with a peak of 100mT at the decay rate of 0.001 mT per cycle. The susceptibility of ARM ($\chi$ARM) was calculated by dividing the mass specific ARM by size of the biasing field (0.1mT= 79.6A/m; Walden 1999b). Isothermal remnant magnetization (IRM) was induced in the samples at different field strengths of 20, 50, 70, 100, 200, 300 up to 800 mT and back fields up to -300 mT using ASC Scientific IM 10-30 Impulse Magnetizer. The remenance were measured in a Minispin magnetometer of Molspin Ltd (sensitivity ~$10^{-7}Am^2$ $kg^{-1}$ for a 10 g sample). The interparametric ratios that were used are S-ratio, SIRM/$\chi$lf and $\chi$ARM /SIRM, ARM/ $\chi$lf, Soft IRM and Hard IRM. The isothermal remenance induced at 800mT was considered as the saturation isothermal remanent magnetization (SIRM). S-ratio was calculated by the expression (-IRM-300mT/SIRM2500mT). $\chi$ARM/SIRM, SIRM/$\chi$lf were calculated to determine magnetic grain size. For magnetic mineralogy, the IRM acquisition was performed on all samples.

### Dhordo core

Mineral magnetic parameters show significant variations throughout the Dhordo core section. Magnetic susceptibility ($\chi$lf) varies between 9.8 and 33.6 (avg. 21.7×10−8 m3kg−1), $\chi$ARM ranges between 107.03 and 11.70 (avg: 68.37×10−8 m3 kg−1), SIRM ranges between 257.45 and 54.80 (avg. 198.3×10−5 $Am^2kg^{-1}$) and S-ratio varies between ∼0.5 and 9 (avg. 0.7) throughout the Dhordo core record. Decrease/increase in $\chi$lf values points out reduction/increase in magnetic mineral abundance suggests changing in sediment flux or in-situ formation of magnetic minerals. $\chi$lf and S-ratio shows dominance of magnetic mineral mainly low coercivity minerals like magnetite upto 23 m (2300 cm) whereas the upper part of the core from 23m to 1 m (2300 to 100 cm) reflects high coercivity minerals like Hematite.

$\chi$ARM/ $\chi$lf and $\chi$ARM/SIRM (fine-grained magnetic minerals) shows high values from 52 m (5200 cm) onward more than its total average value. From 36 m (3600 cm) depth onwards, ratio deciphers transition from dry to wetter environmental condition.

**Berada core**

Magnetic susceptibility ($\chi$lf) varies between 8.1 and 24.6 (avg. $19.7\times10^{-8}$ $m^3kg^{-1}$), $\chi$ARM ranges between 80.03 and 10.70 (avg: $42.37\times10^{-8}$ $m^3$ $kg^{-1}$), SIRM ranges between 250.45 and 50.60 (avg. $99.4\times10^{-5}$ $Am^2kg^{-1}$) and S-ratio varies between ~0.5 and .85 (avg. 0.6) throughout the Berada core record. Abundance in magnetic mineral concentration noted in peak of $\chi$lf at 21 m (2100 cm) and 3 m (300 cm) which in turn matches with the data of SIRM. The S-ratio in Berada core shows dominance of high coercivity minerals like Hematite upto 15 m (1500 cm) whereas the upper part of the core from 15 m to 1 m (1500 to 100 cm) reflects low coercivity minerals like magnetite. At around 21m (2100 cm), sudden peak noted in $\chi$lf and S- ratio reflecting the input of ferrimagnetic minerals with highest peak noted from Soft IRM. $\chi$ARM and SIRM/ $\chi$lf remain above the average value mark and high $\chi$ARM/SIRM from 27- 20 m (2700 – 2000 cm) shows high raise in values indicating enrichment in weathering and high sediment flux.

**Correlation with Holocene eustatic sea level changes**

Sedimentation in dhordo during the post glacial rising sea level during ~10.6 to 9.3 kyr BP occurred under very high sedimentation rate (8.71 cm/y to 2.37 cm/y) during this period which is also seen in other parts of the globe in marginal marine settings. Whereas at berada it experienced moderated sedimentation rate ~1.38 cm/year during this period due to sedimentation in closed type of environment. Sedimentation in the GRK basin during this time could have occurred under – post glacial rapidly rising transgressive sea with ample sediment accumulation space. After 9.3 towards 6.5 kyr, the rate of sedimentation comparatively decreased in dhordo core which mismatches with the other sea level data from the western part of Indian Sub-continent which could be due to tectonically control factors. In fact the rise in sedimentation rate in berada clearly indicates it continued receiving sediment from the upraised surface present on the southern periphery of the basin. The drastic decrease in the sedimentation rate is encountered from both the cores during late Holocene which matches with the global and sub-continent sea level data. The exposer of both cores occurred at around ~2kya suggesting withdrawal of sea from the core site.

## Holocene palaeoenvironmental changes

Temporal variability of the magnetic and sedimentological studies revealed that the SW monsoon strengthening started at ∼9 kyr BP and Northgrippian climate Optima observed at ∼6.5 kyr BP. Consistent aridity signatures in GRK basin revealed at ∼4 kyr BP interrupted by slightly wetter phase around 1500-1000 years under otherwise weaker monsoon (arid environment). Lowest sedimentation rate is marked within past 1500 to present (0.14cm/yr) during the withdrawal of sea on account of filling of the basin and/or tectonic uplift. Due to this, the Dhordo core site was transformed from sub-tidal-intertidal to present day supra-tidal conditions. Banni received marine sediments since Greanlandian time (~9.3 kyr B.P.). Banni plain experienced warm to arid condition during Greanlandian along with marine transgression which suppresses the fluvial activity from the area. The transformation from arid – sub arid condition to humid condition took place during Northgrippian. Grain size data and magnetic analysis suggests wetter phase and enhancement of humid condition from the Banni plain during Meghalayan.

## Inferences

1. The study documents signatures of early-mid Holocene Optima during ~10 kyr - ~5 kyr in the form of increase in various sediment grain size or particle size and magnetic proxies.
2. The data based on magnetic measurement and grain size analysis indicate arid/dry events at ~8 kyr and <5 kyr.
3. The area experienced pulsating withdrawal of sea post mid Holocene under low to high energy conditions with fast infilling of sediments.
4. The major shift in regional monsoon condition reflected in silt and clay percentage with sand influx along with variation in magnetic susceptibility pertaining to increase precipitation of the region at ~ 7 to 6.5 kyr.
5. The GRK basin documents sedimentation to be of sallow marine deposition since ~10 kyr from central basin and marginal basin documents around ~9 kyr.