PALAEOENVIRONMENTAL CONTROLS ON TERREGINOUS SEDIMENT FLUX IN THE MARGINAL MARINE BASIN OF GREAT RANN OF KACHCHH, WESTERN INDIA

Executive Summary
of the thesis submitted by

By

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INTRODUCTION

Kachchh is a pericratonic palaeo-rift graben located on the western continental margin of the Indian plate, which is seismically active suggesting active nature of the various faults. The voluminous literature that exists on the area mainly deals with the pre-Quaternary tectonic and sedimentary evolution of Kachchh. The Quaternary stratigraphy and neotectonic history of Kachchh is not fully understood and remains incomplete. The Great Rann of Kachchh (GRK) is a crucial Quaternary terrain of western India, which has witnessed some of the best-known earthquakes in the Indian subcontinent. However, very little information exists on the sedimentologic, stratigraphic and neotectonic aspects of the Rann sediments. Earlier studies carried out on a very limited scale indicate that the Ranns comprise Holocene marine sediments which possibly merge downward into fluvio-marine and fluvial Pleistocene sediments and have witnessed continuous sedimentation until very recent times. The evolution of the Great Rann of Kachchh has been linked to tectonic activity in recent times. The basin was filled up by sediments supplied from the Indus drainage basin while the surface has been smoothened by the frequent earthquakes. However, no information as yet exists on the sediments comprising the Ranns of Kachchh and its Quaternary evolutionary history.

Understanding the geological evolution of the Rann of Kachchh essentially requires a chronologically well constrained subsurface stratigraphy and delineation of buried structural features within the sediments comprising the Ranns of Kachchh. The present study is an attempt at reconstruction of geological evolution of the Rann basin through a comprehensive approach involving delineation of subsurface stratigraphy and palaeoenvironmental conditions existing in the Ranns during Quaternary.

METHEDOLOGY

Two continuous sediment cores were raised to investigate the subsurface sediment of the Great Rann basin. The Dhordo core of ~60m depth was raised from the southern fringe of the salt encrusted surface occurring to the north of Dhordo village near Pachham island. This site falls in the central part of the Great Rann basin which is frequently inundated by marine waters coming from the east. The Berada core of ~51m depth was raised from the Banni plain and is closer to the rocky mainland Kachchh in the south. The site located to the NE of Berada village that falls in the Banni plain which forms the southern marginal part of the Great Rann basin and is free of present-day marine influence. The cores were raised by rotary drilling in sealed PVC pipes. X-ray images of all cores were obtained to study the sedimentary characteristics of the sediments in undisturbed conditions. This was followed by splitting of cores. The split sections of cores were visually examined for their physical and sedimentary characteristics. One half of both the cores were sampled at 2cm interval while the other half has been preserved in sub-zero temperatures at Department of Geology, The M. S. University of Baroda, Vadodara.

The sediment samples of the cores raised from the Rann of Kachchh were analysed for the multi proxy studies which included physical grain size analysis, sedimentology, environmental magnetism and palynological studies to delineate the palaeoenvironmental condition and deposition in GRK basin. Discussion of multi proxy studies for palaeoenvironmental condition during the Holocene period in GRK are individually mentioned below.

GRAIN SIZE AND TEXTURAL STUDIES IN GRK

The lithological similarity of the Dhordo and Berada cores is very striking even though they are located more than 50 km apart. Both cores are dominantly composed of fine-grained lithology ranging from fine clay to fine sand. The persistence of the fine-grained lithology in both the cores is remarkable. The depositional condition majorly reflected/carried by the change in percentage of silt/clay whereas the relatively higher percentage of fine sand in both cores, conclusive of relatively higher energy of depositional condition. The Dhordo core reveals the subsurface lithological characteristics of the Rann sediments upto ~60m depth. The sediment cores comprise dominantly slightly sandy slightly clayey silt followed by very slightly sandy slightly clayey silt. In fact, about major part of the total length of the core consists of slightly sandy slightly clayey silt. However, some sand dominated lithologies are encountered in this core at around 19 m depth which quantifies sandy nature of the core at this depth. The core also suggests that the thickness of the marine sediments is more than 60m in the central part of the Rann basin. The central basin core covers signature from late Pleistocene to recent. The higher magnitude of silt/clay from Greenlandian Stage signifies moderate to low condition of deposition with the ratio of silt/clay dominating more than 90% throughout this stage. The variation in grain size is noted during Greenlandian Stage at (44-40 m & 23-26m) reflects higher fine sand values i.e, more than the average value of sand 11%. This reflect that the Greenlandian Stage has experienced good monsoonal precipitation leading to enhanced weathering. Northgrippian

Stage of the core also shows a gradual increase in intensity of depositional energy conditions indicative of high monsoonal precipitation. With increase in silt and clay gradually towards the upper part of the core presuming the monsoon to be more of less consistently high throughout this period. Relatively higher energy condition of depositions prevailed in Northgrippian Stage, high intensity of precipitation can be assumed as the fine sand percentage shows increased/high participation.

The Berada core also dominantly consists of very slightly sandy slightly clayey silt and slightly sandy slightly clayey silt. Fluvial sands are encountered in the bottom part of the core which are obviously the extension of fluvial deposits from the mainland fault in the south. The sands are coarse grained and comprise about 6m of the total length of the core, however fine-grained texture of marine origin is encountered at ~40 m depth separating the top part core from the fluvial origin sediments. The presence of coarser grained sands represents fluvial sedimentation before the onset of the marine transgression that finally flooded the Rann basin. The overlying finer lithologies comprising silty and clayey dominated textures indicate uninterrupted marine sedimentation under shallow marine conditions. The very slightly sandy slightly clayey silt comprises about 28m (~76%) of the total length of the Berada core while slightly sandy slightly clayey silt forms for about 6 m of the total length of the core. This indicates an overwhelming domination of silt and clay in the sedimentary basin fill of the Rann. The overall lithological composition of the cores appears to be in conformity with the geomorphological setting of the Rann that suggests that it was an embayed shallow gulf in the past. The dominantly fine-grained lithology of the cores suggest that the basin was filled up by sediments that underwent long distance transport from the distant source regions.

ENVIRONMENTAL MAGNETIC IMPLICATIONS IN GRK

The sediment core from the central GRK basin i.e Dhordo records the highest sedimentation rate in response to rapid post glacial sea level rise and the dynamic climatic change during Greenlandian Stage. During this Stage, the susceptibility (χlf) values vary from 21 – 24 $*10^{-8}$ Am^2kg^{-1} (~60 - ~50 m depths) by decreasing values from bottom to upwards. This transition is significant as it denotes the transition from high concentrations magnetic minerals to low concentrations of magnetic minerals. The relative increase in finer sediment flux indicated by increasing trend of χARM/SIRM, which shows the gradual strengthening of monsoonal conditions, The S-Ratio indicating a decrease in the reading pointing toward the presence of Hematite/Goethite at 47- 45 m which concludes that the period ended at lowering of the precipitation. The granulometric magnetic parameter χARM/SIRM and χARM are sensitive towards finer sediments whereas low values of this parameter show the coarsening of the magnetic grain size. In the core χARM/SIRM and χARM shows lower to average values inferring the presence of mixture of MD-SD particles. The southern marginal core during Greenlandian Stage marks moderate to lower value of S-Ratio <0.7, however the χlf $10^{-8}m^3kg^{-1}$ are in contrast with S-Ratio values. This contradiction could further be explained upon the reading of HIRM which has a peak in the reading confirming the presence of antiferromagnetic minerals such as Hematite. The peat sediments show low χARM/SIRM values indicating a large MD component arising from the presence of detrital minerals, mostly its trend follows silt percent curve. The core shows high to low χARM/SIRM value along with S-Ratio showing 6 to 5 values suggesting the moderate influx of finer sediments, this may be in response to gradual build-up of monsoon during 8.5 to 7.5 kyr.

The environmental magnetic data on Dhordo core and Berada core from the Great Rann of Kachchh basin show increasing values in the mineral magnetic concentration (χlf) reading coupled with S-Ratio, SIRM, χARM and SIRM/χlf and high χARM/SIRM from 27-20 m shows a high raise in values value which indicates enrichment in weathering and high sediment flux. The data also collaborates with the findings of pollen evidence from Himalayan region which predicts strong monsoon during mid Holocene. The data also matches with the continental record from the lake sediments of Nal Sarovar, Gujarat which documents a short spell of wet climate during ~ 6.2 kyr. The period is known for enhanced precipitation which documents for the strong monsoon precipitation during Northgrippian Stage.

The Meghayala Stage in Dhordo core is marked from ~20 m. The decline in concentration dependent parameter χlf marks the period of aridity. The topmost part of the core shows the dominant of Hematite reflected by the S-ratio, pointing towards the aridity prevalence during this period. The rapid evolution of central basin under fluctuating withdrawal of the sea and the basin witnessing sediment deposit under regression condition. The southern margin of the basin shows contrast nature related to magnetic signature under climatic variation where it shows high value of χlf along with increase in sediment grain size. The S-Ratio shows decreasing trend along with χARM/SIRM and with increment in HIRM pointing towards the input of hematite/goethite of coarser nature. The presence of gypsum from the top part of Berada and Dhordo cores evident of deposition under arid condition. The sediments show decrease in chemical weathering which implies the sediments to have deposited in oxidizing condition. The particle size analysis shows the increase of fine sand and at the same time decrease in the values of Silt and clay from the top part of the core. The core site witnessed the withdrawal of the sea, which probably opens the accommodation space for the sediments to be deposited. The core location from the southern margin is the location where the many ephemeral rivers (locally controlled) deposit their sediments. The onset of aridity phase (~5 kyr) perhaps resulted in the regression of the sea where the locally derived sediments (coarse to medium coarse) started accumulating at that locality. However, the increase in the sediment coarsing is also linked with the increase in sediment flux but in view of the magnetic data we could not find any signature of increase in the ferrimagnetic minerals as the S-Ratio shifts towards lower side. The marine record shows the evidence of reduced monsoon wind strength from the Arabian Sea. The reduced and dry phase in the topmost sections correlate well with the dry event, recorded globally and in the Indian subcontinent.

SEDIMENTOLOGICAL CHARACTERISTICS OF GRK

Physical examination of the split cores and detailed textural analysis carried out on the samples indicate subtle variations in the lithological composition which have allowed reconstruction of vertical variations in each core and also in establishing the distinctive characteristics of the two cores. To recognize the sedimentary features of the core the recovered pipes were subjected to produce X' ray photographs through radiography before splitting the core pipes. The photographs were taken of each core pipe after splitting it into two halves. With the combination of both taken manually and through x ray the sedimentary features were recognized.

The stratigraphy of both cores was established based on the sedimentary facies described in the sedimentary section. A lithographic comparison between both the cores was established to delineate the depositional changes in and around the cores site during Holocene period. The accumulation rate and the sedimentary facies of both the cores are closely related. Both curves indicate a high accumulation rate during Greenlandian Stage where the average sedimentation rate of Dhordo core is 1.8 cm/y and 1.1 cm/y is shown by Berada core. Low accumulation rate was reflected during Meghalayan Stage from both the cores.

The fluvial facies encountered in Berada core is marked as fluvial deposits characteristic of channel fill sediments. This fluvial channel can be considered as small channel within a channel complex flowing from the southern part of the area. These sediments are deposited to the Berada core site by the northerly flowing river channels from Kachchh Mainland Fault which was inundated during the transgressive phase under sea level rise after LGM (last glacial maximum). The fluvial facies are overlined by the marine influenced estuarine facies. Moreover, the presence of peat layer at 39 m suggest presence of stagnant condition of sediment deposition and increased water column in the Banni plain. These sediments are deposited to the Berada core site by the northerly flowing river channels. The Dhordo core in the central basin shows sub tidal sediment facies at the bottom most part of the core. The sub tidal condition in the central basin was established much prior to the Berada core in the Banni plain.

High sedimentation rate was noted from both the cores during Greenlandian Stage where Dhordo continues to reflect sub tidal condition of deposition whereas Berada core continues receiving sediment under estuarine/marshy condition. The depositional condition in GRK during Greenlandian Stage demonstrates the presence of shallow marine condition in the central part of the basin which approached the Banni plain during high tidal conditions. The Northgippian Stage in the Berada core marked the change in the depositional condition where it accumulated sediments under sub tidal condition which is in conformity with the similar depositional condition established at Dhordo core. The extension of the similar depositional condition points toward the transgressive phase of sea level in GRK where the shoreline remained stagnant and continues to approach towards the south of GRK during high tide conditions. At the end of Northgrippian Stage the transformation of facies from sub tidal to intertidal marked from both cores is evident for the change depositional condition under regressive sea level. The Meghalayan Stage is noted as regressive sea level phase in the GRK basin where the sediment accumulation curve shows a dip in sedimentation rate of both cores which marks the lowest from the entire Dhordo and Berada core. The sea level withdrawal from the GRK is noted at around ~2 kyr which quantifies the cores to be deposited under supra tidal conditions.

PALYNOLOGICAL IMPLICATIONS IN GRK

The palynological studies mainly focused on the evolution of the vegetation pattern record from the GRK basin. The palynological study carried out on the two raised cores from the basin reveled the dominance of core mangrove taxa, such as *Rhizophora* spp., *Bruguiera* sp., *Sonneratia* sp., *Avicennia* sp., as well as the peripheral mangrove taxon (*Nypa*). The core mangroves were found well distributed in both the cores, much to the surprise the abundance of the cultural taxa was also noted to be present throughout the length of the cores. The study pointed towards the establishment of the marshy and mangrove condition in Berada core during Greenlandian Stage. Whereas frequency of core mangrove taxa was noted to decline in the same period from the Dhordo core which points toward the presence of comparatively high-water coulomb at the Dhordo core site. The enhanced monsoonal rainfall and humid condition resulted in the establishment of mangrove forest at Dhordo core site. The presence of pollen such as Cerealia and other cultural plant pollen taxa, like Amaranthaceae, Brassicaceae, Caryophyllaceae, *Artemisia* sp., *Alternanthera sessilis* and *Cannabis sativa* suggests that incipient cereal-based agricultural practice and other anthropogenic (human) activities around the Dhordo core site. The same was noted from the Berada core which also confirms the cereal-based agricultural practice around the Banni plane.

A reduction in the core mangrove taxa and a simultaneous presence of a few midland taxa, such as *Casuarina, Syzygium,* and *Holoptelea*, as well as comparative increase in Poaceae, suggesting a relatively lesser monsoonal condition (relatively less warm-humid conditions) during Northgrippian Stage in GRK basin. The record of pollen of *Pinus* sp., *Cedrus* sp., and *Ephedra* sp. from both the cores indicates long-distance air and/or transport from the far-off Himalaya.

The overall decreasing pollen assemblage from ~5 kyr therefore, marks the initiation of the aridity that established by ~4kyr which correlates well with the other records from the NW Indian archives. Moreover, the simultaneous record of comparative increased values of aridity-tolerant herbs, such as Amaranthaceae and *Artemisia* sp. (growing in arid and semi-arid climates), followed by Poaceae, Asteroideae, Malvaceae and *Cannabis sativa* (although in lesser values) suggest decrease in both vegetation cover and monsoonal rainfall, as well as drier climate. Negligible abundance in the pollen during past ~2 kyr suggests the degradation of mangrove forest, swampy-marshy land that probably also marks the phase of drying in GRK basin, the supra tidal setting was established since then.

CONCLUSIONS

The present thesis deals with reconstruction of palaeoenvironmental conditions and variability in the depositional condition inferred from the multi proxy study carried out on the two raised sedimentary cores. Such studies are important to understand the evolution of the basin and role of the interplay between palaeoenvironments and sea level variations over a period. The attempts made in the study therefore sheds lights on better understanding of palaeo-conditions of environmental fluctuations and deposition of sediments.

The present study provides conclusive evidence in respect of the uninterrupted marine sedimentation in the tectonically formed basins of the Ranns of Kachchh since ~10 kyr. Based on the AMS date of ~10 kyr obtained from Dhordo core at a depth of ~59 m and ~10 kyr obtained from the basal part of the marine sequence in Berada core at ~39.88 m depth, it is inferred that the central part of the Great Rann basin was submerged by a shallow sea by ~10 kyr while the marginal parts including the Banni plain were completely submerged by ~10 kyr. Overall, both cores together, suggest continuous sedimentation in shallow marine conditions for a long period of time, with variations in depositional conditions.

Sedimentation in Dhordo core during the post glacial rising sea level during ~10.6 to 9.3 kyr 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.

The palynological studies from the GRK basin revels the past vegetation and its evolution during the Holocene period. The Banni plains appear to have evolved from originally a fluvial landscape during LGM that was occupied by shallow marine sea ingression which enabled rapid growth of mangrove swamps during ~10-8 kyr in the region peaking at ~8 kyr. Whereas no such condition developed in the central part of the basin. The strengthening of SW monsoon enhanced the warm-wet conditions in the GRK basin during the Northgrippian Stage. The deterioration in the monsoonal condition initiated at around ~5 kyr in the basin. The present grassland of Banni plan was established after the withdrawal of the sea in the past ~2 kyr.

Temporal variability of the magnetic and sedimentological studies revealed that the SW monsoon strengthening started at ∼9 kyr and Northgrippian climate Optima observed at ∼6.5 kyr. Consistent aridity signatures in GRK basin revealed at ∼4 kyr 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). Banni plain experienced warm to arid condition during Greanlandian Stage 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 Stage.

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