14. Douglas, L. A. and Bremner, J. M., Extraction and colorimetric determination of urea in soils. *Soil Sci. Soc. Am. Proc.*, 1970, **34**, 859–862.
15. Mulvaney, R. L. and Bremner, J. M., A modified diacetyl monoxide method for colorimetric determination of urea in soil extracts. *Commun. Soil Sci. Plant Anal.*, 1979, **10**, 1163–1170.
16. Junejo, N., Khanif, M. Y., Dharejo, K. A., Hazandy Abdul-Hamid and Arifin Abdu, Evaluation of coated urea for ammonia volatilization loss, nitrogen mineralization and microsite pH in selected soil series. *Afr. J. Biotechnol.*, 2012, **11**, 366–378.
17. Junejo, N., Khanif, M. Y., Hanfi, M. M., Dharejo, K. A. and Wan, Z. W. Y., Reduced loss of NH_3 by coating urea with biodegradable polymers, palm stearin and selected micronutrients. *Afr. J. Biotechnol.*, 2011, **10**, 10618–10625.
18. Singh, B. and Singh, L., Studies on urea hydrolysis in Typic Ustochrepts of Punjab. *J. Indian Soc. Soil Sci.*, 1996, **44**, 638–643.
19. Saini, P., Bajwa, M. S. and Khind, C. S., Effect of decomposition period of added organic matter on urease activity and urea hydrolysis in a flooded alkaline soil. *J. Indian Soc. Soil Sci.*, 1994, **42**, 471–473.
20. Ghosh, B. N., Chowdhury, H., Kundu, S. and Gupta, H. S., Effect of pine needle (*Pinus roxburghii*) and chinaberry (*Melia azaderach*) seed extracts on urea hydrolysis rate in a sandy soil. *J. Indian Soc. Soil Sci.*, 2002, **50**, 309–311.

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Subsurface sediment characteristics of the Great Rann of Kachchh, western India based on preliminary evaluation of textural analysis of two continuous sediment cores

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The present communication describes the lithological characteristics of two drill cores raised from the Great Rann of Kachchh based on physical characteristics, grain size distribution, textural characteristics and X-ray radiographs. The two cores were raised from the southern fringe of the salt-encrusted region, one to the north of Dhordo (~ 60 m depth) in the central part of the Great Rann basin and the second from the northeast of Berada (~ 51 m depth) in the southern Banni plain from the southern marginal part of the basin. Based on textural characteristics, the Dhordo core is subdivided into 16 litho units and the Berada core is subdivided into 13 litho units. Based on the AMS date of 17,700 ± 86 cal years BP obtained from Dhordo core at a depth of 60.13 m and 9,515 ± 61 cal years BP obtained from the basal part of the marine sequence in the Berada core at 38.88 m depth, we infer that the central part of the Great Rann basin was submerged by a shallow sea by ~ 18 ka BP, whereas the marginal parts, including the Banni plain were completely submerged by ~ 10 ka BP.

Keywords: Great Rann, Kachchh, lithological characteristics, textural analysis, sediment cores, subsurface stratigraphy.

THE Great Rann of Kachchh is an E–W trending sub-basin which is bounded by the Nagar Parkar Fault (NPF) in the north and the Kachchh Mainland Fault (KMF) in the south[1] and comprises almost half of the area of the seismically active Kachchh palaeorift basin (Figure 1). Geomorphologically, the rann (meaning saline wasteland in local dialect) comprises a flat hyper saline terrain that opens up to the Arabian Sea in the west. Previous workers have described it as ‘intriguing’ to ‘without any counterpart in the world’[2,3]. Based on geomorphological characteristics, it is generally believed that the inherently saline sediments of the Great Rann basin were deposited during the Holocene in an embayed gulf with the surrounding raised land masses forming the source of the sediments[3–5]. Historical accounts suggest that the rann was occupied by a shallow navigable sea[6], which is confirmed by the presence of several archaeological sites belonging to the Harrapan civilization, including the port town of Dholavira located on the Khadir Island[5–8]. Presently also, a large part of the Rann surface gets inundated by storm tides from the west and the rest by annual monsoon precipitation[3]. The Great Rann comprises four geomorphic units – the Bet zone, linear trench zone, Banni plain and the Great Barren zone[3]. Amongst these, the Banni plain by virtue of its higher elevation is not affected by marine inundation[9,10]. Recent studies have documented raised marine terraces along the margins of the rocky islands of Khadir, Bhanjada and Kuar bet that suggest uninterrupted deposition in the Rann up to ~ 500 years BP (refs 11, 12). The Rann has also been studied in terms of the geomorphic changes attributed to recurrent seismic activity, including the 1819 Allah bund and the 2001 Bhuj earthquakes[13,14]. However, no precise information exists about the subsurface stratigraphy and geological evolution of the Great Rann, which can be attributed to the harsh, inhospitable conditions, difficult terrain and lack of exposure.

To understand the geological evolution of the Great Rann and to delineate the palaeoenvironmental changes, two shallow continuous sediment cores were raised (Figure 1). One core of ~ 60 m depth was raised from the

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southern fringe of the salt-encrusted surface occurring to the north of Dhordo. This site falls in the central part of the Great Rann basin, which is frequently inundated by marine waters coming from the west (Figure 1). The second core of ~51 m depth was raised from the Banni plain and is closer to the rocky mainland Kachchh in the south. This site located to the NE of Berada falls in the Banni plain that forms the southern marginal part of the Great Rann basin and is free from present-day marine influence (Figure 1). X-ray images of all cores were obtained to study the sedimentary characteristics in undisturbed conditions. This was followed by splitting of the cores. The split sections of the cores were visually examined for their physical and sedimentary characteristics. One half of both the cores was sampled at 2 cm interval, whereas the other half has been preserved in sub-zero temperature.

Both cores showed the dominance of fine-grained clay and silt-rich lithologies. About 64 samples from Dhordo core and 57 samples from the Berada core were analysed for their textural characteristics. Relative silt–clay–sand content so obtained was used in conjunction with the visual observations of the core to subdivide the cores into various lithological units. Here we describe the preliminary-level data generated on the two cores, mainly based on visual observations and textural analysis. We discuss their possible implications for lithostratigraphic development and palaeoenvironmental conditions in the Great Rann basin.

The Dhordo core is subdivided into 16 litho units (Figure 2). The distinctive characteristics of the units delineated are given in Table 1 and briefly described in the following:

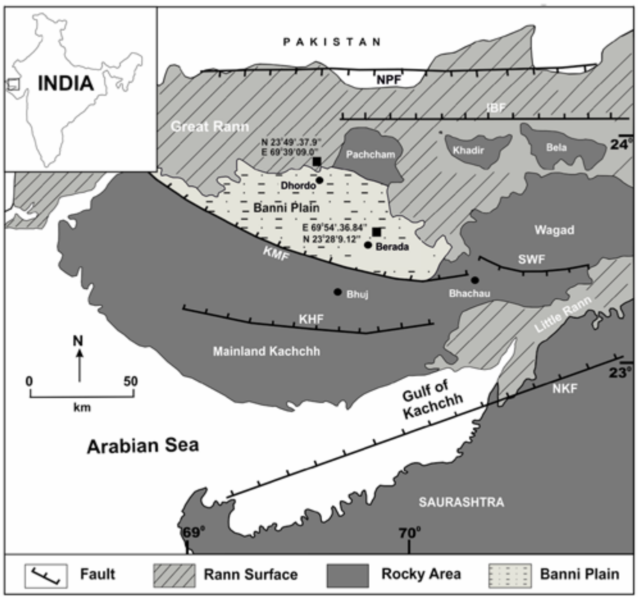

Figure 1. Simplified geomorphological map of Kachchh basin with major faults (based on Biswas[1]). Locations of the two cores obtained are also shown. Note the vast extent of the Great Rann forming the northern part of the basin.

Unit-1 (60.40–53 m depth) comprises a thick sequence of dark greyish colour of clayey silt and is marked by fine laminations of silt-rich sediments. Overall the sediments indicate uniform depositional conditions, wherein fine silty laminae indicate spells of increased flux from the source region. Preliminary micropalaeontological analysis of the samples shows the presence of shallow benthic foraminifera which confirms the deposition of sediments in the marine environment. AMS dating of a sediment sample from 60.13 m depth has yielded an age of 17,700 ± 86 cal years BP. This suggests that marine sedimentation in the Great Rann basin was initiated before ~ 18 ka BP.

Unit-2 (53–43 m depth) is also comprised of finely laminated clayey silt with the absence of sand and the unit is distinguished by the presence of increased frequency of thin silt-rich laminae that alternate with clayey silt layers indicating periodic influx of silt. Overall, the two bottommost units (units 1 and 2) together indicate uninterrupted sedimentation under uniform depositional conditions.

Unit-3 (43–41 m depth) consists of laminated silty clay with thin silt-rich layers; increase in silt proportion is up to 80%, which indicates increased sediment flux. The all-pervasive presence of laminations through the base of the core to the present unit indicates turbulence-free conditions within the overall realm of shallow marine environment as suggested by the presence of benthic foraminifera.

Unit-4 (41–35 m depth) consists of massive brownish to greyish coloured clayey silts with silt lamina and marginal increase in sand content.

Unit-5 (35–33 m depth) is characterized by green silty clay with negligible amount of sand (< 5%). This unit is also characterized by the presence of shallow marine micro fauna.

Unit-6 (33–30 m depth) comprises massive greenish coloured clayey silt which is distinguished from the lower unit on the basis of significant increase in silt content to > 80% and decrease in clay content up to < 20%. The sand continues to remain insignificant (< 5%). However, the high content of silt may be indicative of slightly shallower conditions during deposition of the sediments of this unit.

Unit-7 (30–29 m depth) is texturally classified as sandy silty clay with slight increase in clay and anomalous decrease in silt up to 30%. A consequent increase of sand content to ~ 25% is seen and based on sand content, the unit is distinguishable from other units. On a tentative basis the increased sand content may be suggestive of further shallowing of the basin.

Unit-8 (29–27 m depth) comprises massive clayey silt and is characterized by a sharp increase in silt content to ~ 70% with a corresponding decrease in clay content. The nature of the sediments suggests a relative deepening of the basin after the shallowing phase indicated by the

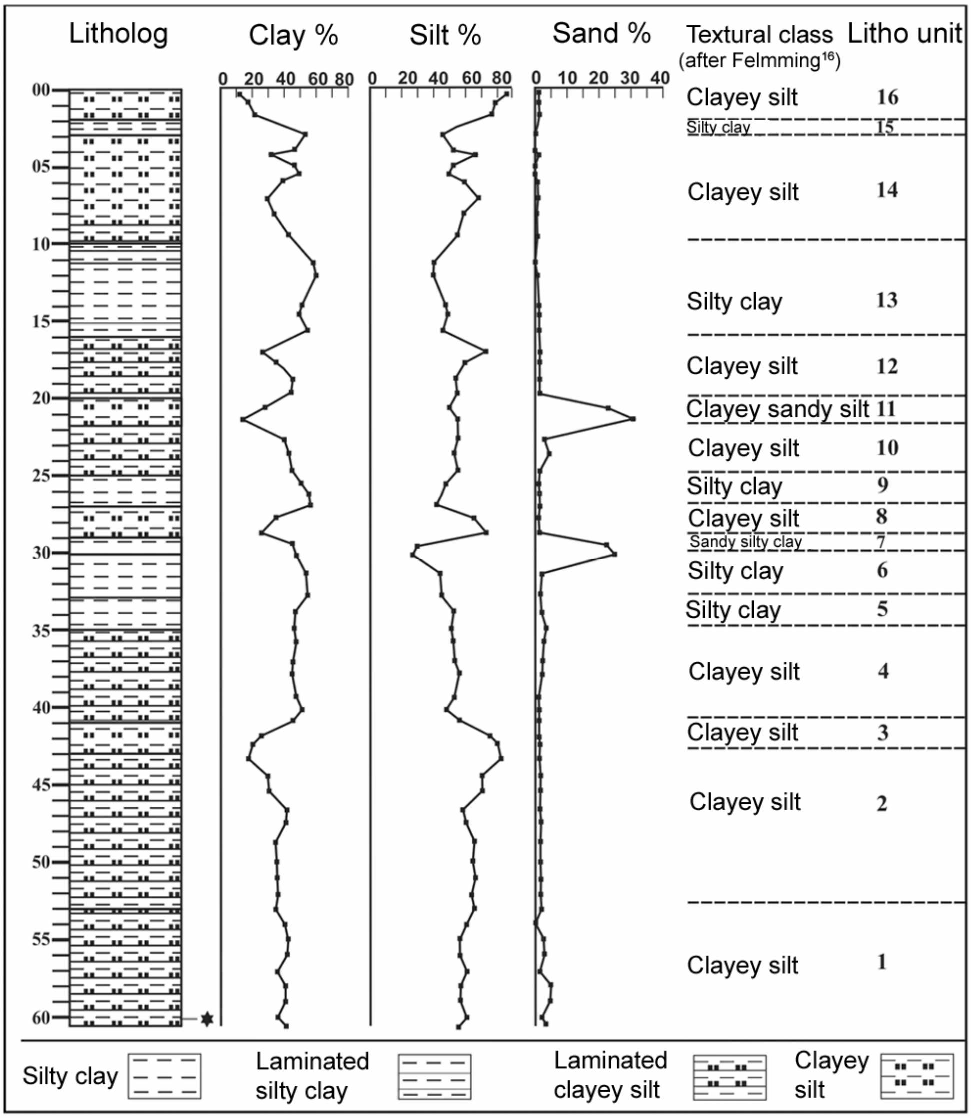

Figure 2. Litholog of the Dhordo core with plots of clay–silt–sand contents. The textural class and litho units identified are also shown. AMS dating of the sample located at the position indicated by star has yielded an age of 17,700 ± 86 cal years BP.

underlying units 7 and 6. Towards the upper part of the unit, few segregated masses of small broken shells of bivalves and gastropods are observed.

Unit-9 (27–25 m depth) consists of massive silty clay with negligible amount of sand. A significant feature of this unit is the presence of broken and complete bivalve and gastropod shells. The complete shells are identified as *Arca* sp. The broken shells suggest turbulent conditions at/or close to the site of the core.

Unit-10 (25–22 m depth) consists of massive clayey silt with silt-rich lamina along with marginal increase of sand at the top. Throughout this unit organic particles are also reported.

Unit-11 (22–20 m depth) consists of massive sandy silt with uniform lithology. The silt content is > 50%, whereas the sand content is > 20%. The reduction of clay content to < 15% is significant. The unit indicates increased influx of sand with dominance of silt into the basin for a relatively short period of time.

Unit-12 (20–16 m depth) comprises bluish-green coloured sticky clayey silt with 70% of silt and 25% of clay. The sand content is reduced to < 1% in contrast to the underlying unit. The sediments suggest relative deepening of the basin during deposition of this unit.

Unit-13 (16–10 m depth) consists of greenish coloured silty clay with thin silt-rich layers and negligible amount of sand. The unit is distinguished by high amount of clay (~ 60%). The gross lithology of the unit suggests a depositional environment comparable to the underlying unit.

Unit-14 (10–3 m depth) consists of clayey silt and is texturally similar throughout the length of the unit. The silt content varies from 50% to 65%, whereas the clay

Table 1. Summary of the major lithological characteristics of the various litho units of the Dhordo core

Lithological unit	Depth (m)	Lithology	Description
16	0–2	Clayey silt	Earthy brown coloured, laminated silts with scattered salt crystals. Gypsum crystals present.
15	2–3	Silty clay	Light brown, massive silty clay with scattered grains of gypsum. Mottling in shades of ash grey colour noted throughout the unit.
14	3–10	Clayey silt	Brown to greyish-green coloured clayey silt. Mottling is also observed in shades of brown and ash colour.
13	10–16	Silty clay	Dark greenish silty clay with fine silt layers.
12	16–20	Clayey silt	Bluish-green sticky clayey silt with silt layers.
11	20–22	Clayey sandy silt	Greenish clayey sandy silt with very fine silt layers.
10	22–25	Clayey silt	Dark grey clayey silt with occasional silty layers. Scattered organic particles present throughout.
9	25–27	Silty clay	Bluish-grey silty clayey sediments. Broken as well as complete bivalve and gastropod shells present.
8	27–29	Clayey silt	Greenish massive clayey silt. Laminations are absent throughout this unit. Broken bivalve shells are present occasionally.
7	29–30	Sandy silty clay	Greenish sandy silty clay. Characterized by relative decrease in silt and increase in sand proportion.
6	30–33	Silty clay	Greenish silty clay.
5	33–35	Silty clay	Greenish clay with silt lamina is seen.
4	35–41	Clayey silt	Massive brownish to greenish clayey silt with occasional silt layers.
3	41–43	Clayey silt	Dark brownish clayey silt with some thin silt lamina. The sediment is massive in nature.
2	43–53	Clayey silt	Dark grey coloured clayey silty sediments. Characterized by high frequency of silt layers throughout this unit.
1	53–60	Clayey silt	Dark grey coloured clayey silty sediments with silt layers.

content varies from 30% to 49%. The sand content remains negligible. Based on colour of the sediments, the unit is divisible into massive green (~3 m thick), alternate bands of ash clay (~ 2 m thick) and bands of brown clay sediments. These changes could be due to alternate shallowing and relative deepening of the basin.

Unit-15 (3–2 m depth) comprises brown coloured massive silty clay with 55% clay and 45% silt and consistent distinct earthy brown colour similar to the surface sediments of the Rann. The unit contains scattered gypsum crystals, which points to significant shallowing of the basin. This unit may be the equivalent of the gypsum-rich layer reported from the shallow subsurface in the vicinity of the rocky Pachchham Island[3]. However, the size of the foraminifera was found to be significantly reduced. This could be due to stressful conditions that may have been triggered by shallowing of the basin as a consequence of the gradual withdrawal of the sea. The stressful conditions may also have been produced by increasing dominance or mixing of freshwater with the sea water, as is the case in the present-day surface environment of the Rann. Overall, the unit suggests a definite transitional phase from the fully marine conditions to present conditions existing in the Rann.

Unit-16 (1–0 m depth) is characterized by massive, earthy brown clayey silt with increase in silt content up to > 80% and reduction of clay to < 20% and negligible content of sand. In general, the unit may be considered to represent the transition to present-day conditions. Foraminifera with significantly reduced size are observed in a few samples analysed from this unit, indicating stressful conditions comparable to the present conditions.

The 51 m long Berada core is subdivided into 13 litho units (Figure 3). The major lithologic characteristics of the various units delineated are described bottom upwards (Table 2).

Unit-1 (51–47.5 m depth) consists of unconsolidated brown coloured, highly angular and unsorted coarse sand with minor amount of silt. Dominance of quartz and feldspar in the sand suggests fluvial origin and proximal source of the sediments, i.e. sediments from Kachchh mainland which exposes Mesozoic sandstones and limestone. Recent studies have documented dominantly coarse-grained (colluvio-fluvial) Quaternary sediments in front of KMF scarps marking the northern margin of the mainland[15]. The sand deposits in the bottom of the core are possibly the northward extension of these deposits.

Unit-2 (47.5–42.5 m depth) consists of semi-compacted to partially compacted silty clay with decrease in sand content. The clay content varies from 50% to 55%, whereas silt forms the rest of the sediment component. Preliminary analysis of samples for micro fauna has revealed the presence of shallow marine micro fauna, indicating marine origin of this unit. The unit therefore marks the submergence of the basin by a transgressive sea.

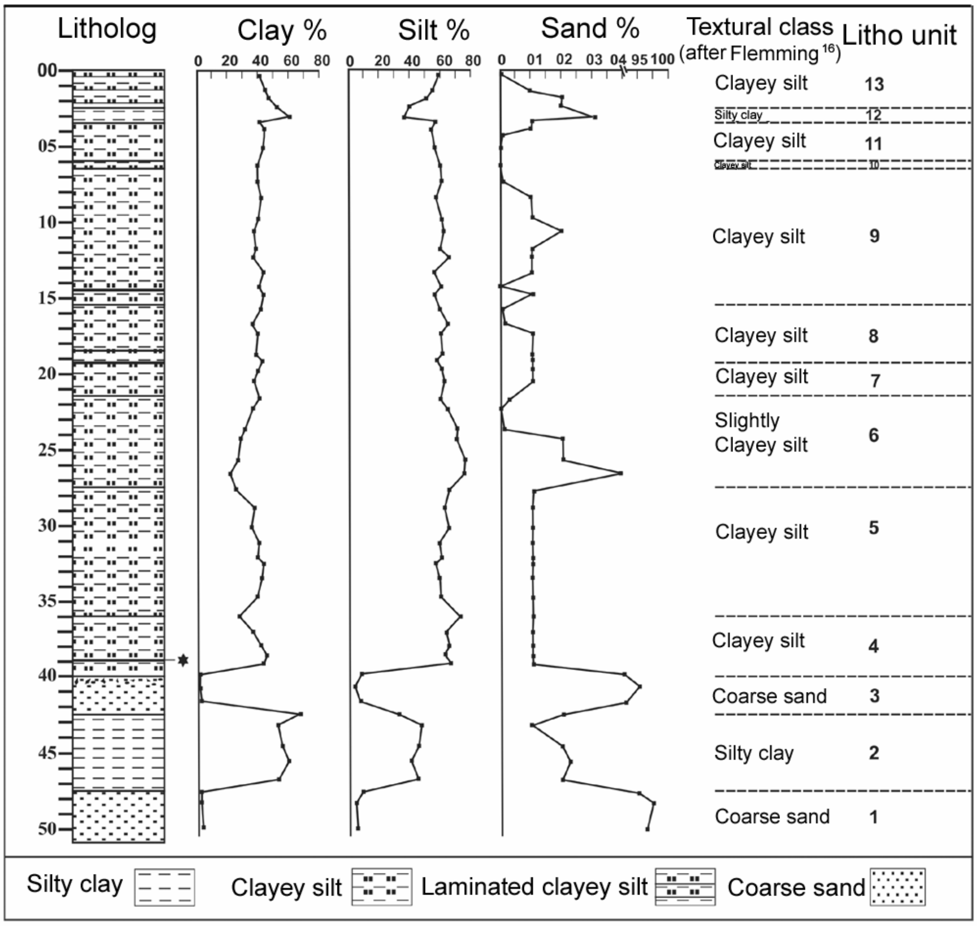

Figure 3. Litholog of the Berada core with plots of clay–silt–sand content. The textural class and litho units identified are also shown. AMS dating of the sample located at the position indicated by star has yielded an age of 9515 ± 61 cal years BP.

Unit-3 (42.5–40 m depth) consists of unconsolidated brownish-white coloured coarse sands with pebbly sand in the uppermost part, which is mineralogically and texturally similar to unit-1. This unit probably marks a brief phase of regression of the sea with a consequent extension of the fluvial deposition from the mainland towards north into the Rann basin.

Unit-4 (40–36 m depth) consists of massive clayey silt with > 70% silt, 29% clay and negligible amount of sand (< 1%). The unit marks a sharp lithological contrast with the underlying unit that consists of fluvial sand. The occurrence of complete and broken bivalve and gastropod shells is observed with significant thick organic-rich layer (1.5 cm). The layer appears to be of peat and indicates a marginal near-coastal environment. This unit, therefore, marks a renewed phase of marine transgression into the Rann basin that overlapped the underlying fluvial deposits. AMS dating of the peat sample from 38.88 m depth has yielded an age of 9,515 ± 61 cal years BP. This suggests that by ~ 10 ka BP, the marginal parts of the Great Rann, including the Banni region, were submerged by the sea.

Unit-5 (36–27.5 m depth) comprises a monotonous sequence of greyish-green clayey silt (65% silt, 40% clay) and negligible sand content with scattered gastropod shells throughout the unit. The uniform character of sediments suggests continuous sedimentation for a prolonged period and also a relatively deeper basin.

Unit-6 (27.5–21.5 m depth) consists of dark greenish-grey uniform clayey silt with increased silt (65%) and reduction in clay content up to 35%, where again sand content is low. Presence of mud clast in the upper part can be correlated with the increased influx of clay, suggesting shallowing up of the basin. Organic particles are also present and overall the unit shows a uniform depositional environment.

Unit-7 (21.5–18.5 m depth) comprises massive grey coloured clayey silt with some organic particles and a thick organic-rich layer, where significant broken bivalve shells are also noticed. An overall similar depositional condition with increased input of organic matter is inferred during the deposition of this unit.

Unit-8 (18.5–15.5 m depth) consists of massive light green coloured clayey silt with few thin silt-rich layers.

Table 2. Summary of the major lithological characteristics of the various litho units of the Berada core

Lithological unit	Depth (m)	Lithology	Description
13	0–2.5	Clayey silt	Brown coloured laminated silt with clay sediments with scattered gypsum crystals in the lower part.
12	2.5–3.5	Silty clay	Light brown coloured silty clay sediments with high mica content.
11	3.5–6	Clayey silt	Light brown coloured massive, loose silt with less clay proportion.
10	6–6.5	Clayey silt	Greenish colour clayey silt with increased mica content.
9	6.5–15.5	Clayey silt	Bluish-green clayey silt with scattered black organic particles. Two centimetre thick organic rich layer at ~ 15 m depth.
8	15.5–18.5	Clayey silt	Massive light greenish-grey coloured clayey silt. Scattered broken shells of bivalves present throughout.
7	18.5–21.5	Clayey silt	Greenish-grey massive clayey silt with scattered organic particles. A thick organic-rich layer noted at ~ 19 m depth.
6	21.5–27.5	Slightly clayey silt	Massive dark greenish-grey coloured silt-rich sediments with low clay proportion. Scattered organic particles present throughout.
5	27.5–36	Clayey silt	Light greyish-green coloured massive clayey silty sediments. Scattered occurrence of bivalve and gastropod shells with organic particles. Cerithids abundant.
4	36–40	Clayey silt	Massive dark brownish to grey coloured clayey silt with broken shells.
3	40–42.5	Coarse sand	Yellow coloured loose, angular, unsorted, coarse sand. Upper portion of the unit is marked by pebbles.
2	42.5–47.5	Silty clay	Semi-compacted silty clayey sediments. Topmost thin layer is of moderately sorted ferruginous semicompacted sand followed by intercalations of ash coloured and yellowish coloured silty layers.
1	47.5–51.11	Coarse sand	Brown coloured loose, angular, unsorted coarse sand.

The unit is distinguished by its light colour and broken bivalve shells in a thin layer in the upper part. Presence of broken shells indicates relatively shallow conditions with some turbulence.

Unit-9 (15.5–6.5 m depth) is characterized by a thick monotonous sequence of massive bluish-green clayey silt with 60% silt and 40% clay. The unit shows scattered occurrence of black coloured particles of organic matter.

Unit-10 (6.5–6 m depth) consists of massive clayey silt with a distinctive green colour. However, its distinctive colour may be indicative of a brief change in depositional conditions or in the nature of sediment influx.

Unit-11 (6–3.5 m depth) comprises clayey silt and compositionally is similar to the underlying units 10 and 9. The unit shows a marginal increase in clay content.

Unit-12 (3.5–2.5 m depth) is characterized by silty clay, where clay content is > 60% and silt content is < 40%. The sand content marginally increases to about 3%.

Unit-13 (2.5–0 m depth) consists of laminated brown coloured clayey silt with increasing silt content in the upper part. The lower part of the unit shows dispersed grains of gypsum, which correlates with similar characteristics in the upper part (unit-15) of the Dhordo core and also the gypsum layer observed in the shallow subsurface in the vicinity of Pachchham Island[3]. However, the marine micro fauna are absent in the top ~ 1 m of the unit. The unit represents transition phase from marine to the present non-marine conditions.

The lithological similarity of the Dhordo and Berada cores is striking even though they are located more than 50 km apart. The Dhordo core reveals the subsurface lithological characteristics of the Rann sediments up to ~ 60 m depth (Figure 2). The sediment cores comprise dominantly clayey silt followed by silty clay (Table 1). In fact, about 46 m (~ 75%) of the total length of the core consists of clayey silt, and silty clay forms the rest of the core. The Berada core also dominantly consists of clayey silt and silty clay (Figure 3). However, fluvial sands are encountered in the bottom part of the core, which is obviously the extension of fluvial deposits from the mainland in the south (Table 2). The sands are coarse-grained and comprise about 6 m of the total length of the core, However, they form two litho units (unit 1 and 3) separated by a marine silty clay unit. The sands represent fluvial sedimentation before the onset of the marine transgression that finally flooded the Rann basin. The overall lithological composition of the cores appears to be consistent with the geomorphological setting of the Rann, which suggests that it was an embayed shallow gulf in the past.

The other distinguishing characteristics of the cores are the presence of shallow marine foraminifera throughout, presence of organic-rich carbonaceous material in the form of dispersed/scattered particles and as thin layers in various litho units (Tables 1 and 2). Occurrence of small, broken shells in layers and dispersed form is also significant. In general, the shell remains are found in the units which have relatively higher sand content. Overall, both cores suggest continuous sedimentation for a long period of time in shallow marine conditions, with minor variations in depositional conditions.

Based on the AMS date of $17,700 \pm 86$ cal years BP obtained from Dhordo core at a depth of 60.13 m, we infer that the central part of the Great Rann basin corresponding to the present-day linear trench zone, was submerged by a shallow sea by ~ 18 ka. However, submergence of the entire basin appears to have taken place gradually. The AMS date of 9515 ± 61 cal years BP obtained from the Berada core at 38.88 m depth suggests that marginal parts, including the present-day Banni plain were submerged by ~ 10 ka BP. Since then, continuous marine sedimentation took place through the Holocene under shallow marine conditions.

The top parts of the cores (1–3 m) appear to indicate a definite transition phase which turned the Rann from a fully marine basin to the present sub-aerially exposed land with peculiar characteristics. We believe that the emergence of the Rann surface may have occurred gradually in the recent past, which led to the formation of the distinct morphologic units, viz. the Banni plain, the Bet zone and the linear trench zone. The Banni plain astrides the subsurface median high and is separated from the rest of the Rann basin by the Banni Fault to the north[1]. Similarly, the Bet zone is delimited by the Allah bund Fault to its south[3]. The close association of these units with faults suggest that differential tectonic activity along subsurface faults within the Great Rann basin may have played a major role in the emergence of various morphologic units at different times. Based on elevation and present-day submergence characteristics, the Banni plain appears to be the first to emerge followed by the Bet zone and the linear trench zone, which still gets submerged by marine waters regularly. However, a critical study of the cores through multidisciplinary approach, including micropalaeontology, mineralogy, geochemistry and chronology is essential to establish a palaeoenvironmental record and neotectonic history from the marginal marine basin of the Great Rann.

1. Biswas, S. K., Landscape of Kutch – a morphotectonic analysis. *Indian J. Earth Sci*., 1974, **1**, 177–190.
2. Burnes, A., A memoir on the eastern branch of the River Indus giving an account of the alterations produced on them by an earthquake in 1819, also a theory of the Runn, and some conjectures on the route of Alexander the Great, drawn up in the years 1827–28. *Royal Asiatic Soc*., 1835, **3**, 550–588.
3. Roy, B. and Merh, S. S., The Great Rann of Kutch – an intriguing Quaternary terrains. In *Recent Researches in Geology*, Hindustan Pub. Corporation, 1981, vol. 9, pp. 100–108.
4. Glennie, K. W. and Evans, G., A reconnaissance of the recent sediments of the Ranns of Kutch, India. *Sedimentology*, 1976, **23**, 625–647.
5. Maurya, D. M., Thakkar, M. G., Khonde, N. and Chamyal, L. S., Geomorphology of Little Rann of Kachchh, western India: implication for basin architecture and Holocene palaeo-oceanographic conditions. *Z. Geomorphol.*, 2009, **53**, 69–80.
6. Merh, S. S., The Great Rann of Kachchh: perceptions of a field geologist. *J. Geol. Soc. India*, 2005, **65**, 9–25.
7. Gaur, A. S. and Vora, K. H., Ancient shorelines of Gujarat, India, during the Indus civilization (Late Mid-Holocene): a study based on archeological evidences. *Curr. Sci.*, 1999, **77**, 180–185.
8. A. R. (Indian Archaeology: A review). Bulletin of Archeological Survey of India, Archaeological Survey of India, New Delhi, 1994–99.
9. Kar, A., Geomorphology of the western India. *Mem. Geol. Soc. India*, 1995, **32**, 168–190.
10. Singh, N. and Kar, A., Characteristics of major soils of Banni mudflat in arid western India and their relationship with topography. *J. Arid Environ.*, 2001, **58**, 509–520.
11. Chowksey, V., Maurya, D. M., Khonde, N. and Chamyal, L. S., Tectonic geomorphology and evidence for active tilting of the Bela, Khadir and Bhanjada islands in the seismically active Kachchh palaeorift graben, western India. *Z. Geomorphol.*, 2010, **54**, 467–490.
12. Khonde, N., Maurya, D. M., Sing, A. D., Chowksey, V. and Chamyal, L. S., Environmental significance of raised rann sediments along the margins of Khadir, Bhanjada and Kuar Bet islands in Great Rann of Kachchh, Western India. *Curr. Sci*., 2011, **101**, 1429–1434.
13. Bilham, R., Slip parameters for the Rann of Kachchh, India, 16 June 1819 earthquake quantified from contemporary accounts. In *Coastal Tectonics* (eds Stewart, S. and Vita Finzi, C.), Geological Society of London, Special Publication, 1998, vol. 146, pp. 295–318.
14. Maurya, D. M., Goyal, B., Patidar, A. K., Mulchandani, N., Thakkar, M. G. and Chamyal, L. S., Ground penetrating radar imaging of two large sand blow craters related to the 2001 Bhuj earthquake, Kachchh. Western India. *J. Appl. Geophys.*, 2006, **60**, 142–152.
15. Chowksey, V., Maurya, D. M., Joshi, P., Khonde, N., Das, A. and Chamyal, L. S., Lithostratigraphic development and neotectonic significance of the Quaternary sediments along the Kachchh Mainland Fault (KMF) zone, western India. *J. Earth Syst. Sci*., 2011, **120**, 979–999.
16. Flemming, B. W., A revised textural classification of gravel-free muddy sediments on the basis of ternary diagrams. *Cont. Shelf Res.*, 2000, **20**, 1125–1137.

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