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Zaherite – the key mineral in Alleppey mudbank formation and on the possibility of creating mudbanks artificially

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X-ray diffraction and chemical analysis of Alleppey mudbank sediments have shown the presence of zaherite ($Al_{12}(SO_4)_5(OH)_{26}·20H_2O$), which has not been reported from this area so far. Mudbank sediments are characterized by abnormally high water content. Clay particles are randomly oriented due to the presence of zaherite, making them extremely porous. The porous mud at the top and consolidated mud at the bottom with transitional boundary in between is collectively called as 'dispersed mud', which is responsible for wave damping and mudbank formation. If zaherite or similar type of mineral can be introduced in the required proportion into the clay, it may be possible to create mudbanks artificially.

Keywords: Damping, dispersed mud, mudbanks, zaherite.

MUDBANKS are calm patches of water within an agitated sea, formed due to wave damping, and appear close to the shoreline of Kerala during the southwest monsoon. They are known fishing grounds and help in protecting the coast from erosion. Contrary to earlier views that mudbanks appear during the southwest monsoon and disappear during the northeast monsoon[1,2], recent studies[3] have proposed the persistent nature of Alleppey mudbanks. Detailed physical, chemical and oceanographic studies have been carried out in Alleppey mudbanks[1–15], which has brought out most of their characteristics. However, explanations for the possible mode of formation are not free from ambiguity.

A review on the formation of mudbanks by earlier workers is summarized here. Converging littoral currents and associated offshore flow are responsible for the formation of large quantity of suspended sediments, resulting in the formation of a mudbank[2]. Due to some natural forces the mud accumulated at water depths greater than 20 m moves to near-shore areas where other forces combine to stir the mud up and develop a suitable periphery around the suspended mud; thus a mudbank would come into existence[4]. Transportation of mud from offshore towards the mudbank areas is another cause for mudbank formation[10]. The fall in salinity during the southwest monsoon was also suggested as another reason for inducing the mud in suspension, which in turn results in the formation of mudbanks[2,13]. Sub-terraneous injection or seepage of water/loose mud from lagoons due to differential hydrostatic pressure could also be the cause for mudbank formation[1,14,15]. The monsoonal seabed displays greatly reduced bulk density which could be due to the presence of methane gas which is forced into the surficial sediments either by wave pumping or by seaward flowing sub-bottom freshwater[5]. The infra-gravity waves and far infra-gravity waves coupled with strong shoreline reflections and undertow play an important role in the dynamics associated with the mudbanks off Kerala during the monsoon season[6]. Differences in stress rate of strain relationships exist between the semi-consolidated bottom mud and dense suspensions generated from the natural bottom[7]. Due to the convergence of wave energy, fluid mud is deposited at specific near-shore sites resulting in the occurrence of localized mudbanks[8].

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If converging littoral currents or wave energy and associated offshore flow[2] are responsible for the formation of mudbanks, they have to be found wherever persistent converging littoral currents or wave energy are reported. The studies undertaken by the Geological Survey of India (GSI) show the presence of mud deposits of several meters thickness at many places within water depths of 10–30 m both along the west and east coasts of India. But mudbanks are not formed in all these areas due to 'shifting of mud to near-shore areas by some natural forces'[4]. Salinity values observed at 10 m water depth off Alleppey during monsoon and post-monsoon months are 32‰ and 35‰ respectively, and such small changes in salinity may not have much effect on flocculation[4]. If sub-terrigenous injection or seepage could be the cause for mudbank formation, the area where they are formed would have markedly lower salinity due to continuous dilution. The content of organic carbon in the mudbank sediments is too moderate to form large quantity of methane gas and the concept of wave pumping or seaward flowing sub-bottom freshwater forcing methane into the surficial sediments is hypothetical.

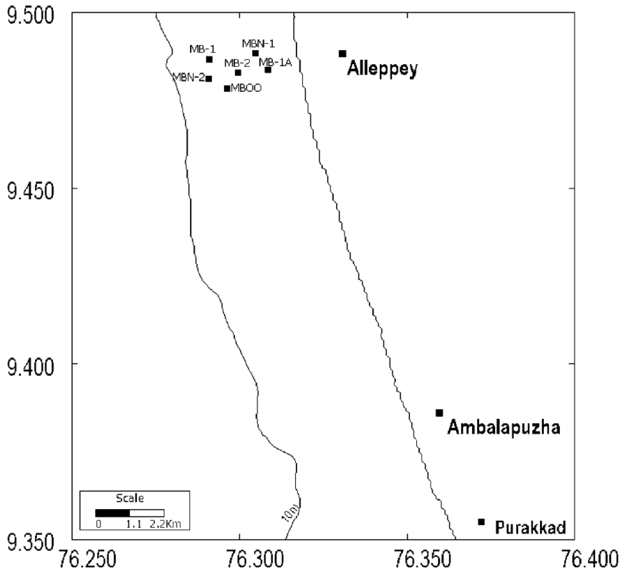

Figure 1. Sample location map.

Table 1. Phosphate and water content in surface sediment samples

Sample no.	Sediment type	Water content (%)	P_2O_5 (ppm)
MB-1	Silty clay	255	7984
MB-1A	Silty clay	232	7588
MB-2	Silty clay	220	6788
MBN-1	Silty clay	246	8200
MBN-2	Silty clay	230	6345
MBOO	Silty clay	223	8123
8965-A (non-mudbank sediment sample)	Silty clay	135	1756

An attempt is made here to understand the factors responsible for the origin of mudbanks. A total of six surface sediment samples of which three were collected during pre-monsoon (MB-1, MB-1A and MB-2) and three after the southwest monsoon (MBN-1, MBN-2 and MBOO) from Alleppey mudbank area have been studied for this purpose (Figure 1). Another sample collected from a non-mudbank area off Ponnani was used for comparison (8965-A).

The mudbank sediments are characterized by abnormally high water content and lack of shear strength (Table 1). The water content in the Alleppy mudbank sediments ranges between 220% and 255%. According to studies conducted by the GSI, non-mudbank sediments all along the west coast on the other hand, have considerably low water content. Laboratory experiments conducted using equal weights of sediments both from mudbank and non-mudbank areas after stirring in settling jars show increase in the volume of the former. No significant change in the water content of mudbank sediment samples was observed with the elapse of time. If the formation of mudbank is due to littoral convergence, sub-terraneaneous seepage or due to other natural forces, with their cessation, the mudbank sediments should have shown a decrease in water content. This has also prompted us to think that mudbank formation is not governed by physical processes alone.

Clay fractions separated from three samples (MB-1, MBN-1 and MBOO) were subjected to X-ray diffraction (XRD) at the Mineral Physics Laboratory, GSI, Kolkata. The results are given in Table 2. XRD studies of sediments from Alleppey mudbank have shown the presence of a mineral, namely zaherite, which has not been reported from this area so far (Figures 2–4). In order to confirm the presence of zaherite, the sediment samples MB-1 and MBN-1 were again subjected to XRD analysis at the GSI laboratory, Bangalore, which also showed the presence of the above mineral. Zaherite ($Al_{12}(SO_4)_5(OH)_{26}\cdot 20H_2O$) is a hydrated aluminium sulphate[16], first reported from the Salt Range of Pakistan (M. A. Zaher, unpublished). It has a density of 2.007 and occurs as extremely fine tubular and fibrous grains. Chemical analysis of four clay fractions carried out in the GSI laboratory, Mangalore is given in Table 3. XRD results have not shown the presence of any other sulphate mineral in the mudbank sediments studied. Hence the concentration of zaherite was calculated using SO_4 content in the mudbank sediments, which varies between 2% and 3%.

Though electrostatically neutral, zaherite is bipolar. The clay minerals such as montmorillonite, illite, etc. are negatively charged while entering the marine environment. But due to adsorption of cations from the sea water, they flocculate and settle down.

Mudbanks, as a rule, occur in shallow waters with their seaward periphery confined to the zone where the wave base confronts the seafloor strongly. Bathymetry has a

Table 2. Mineral phases identified using XRD

Sample no.	Major	Minor	Trace
MB-1	Montmorillonite	Kaolinite, gibbsite, quatz	Illite, zaherite, anatase
MBN-1	Montmorillonite	Kaolinite, gibbsite, quatz	Illite, zaherite, anatase
MBOO	Montmorillonite	Kaolinite, gibbsite, quatz	Illite, zaherite

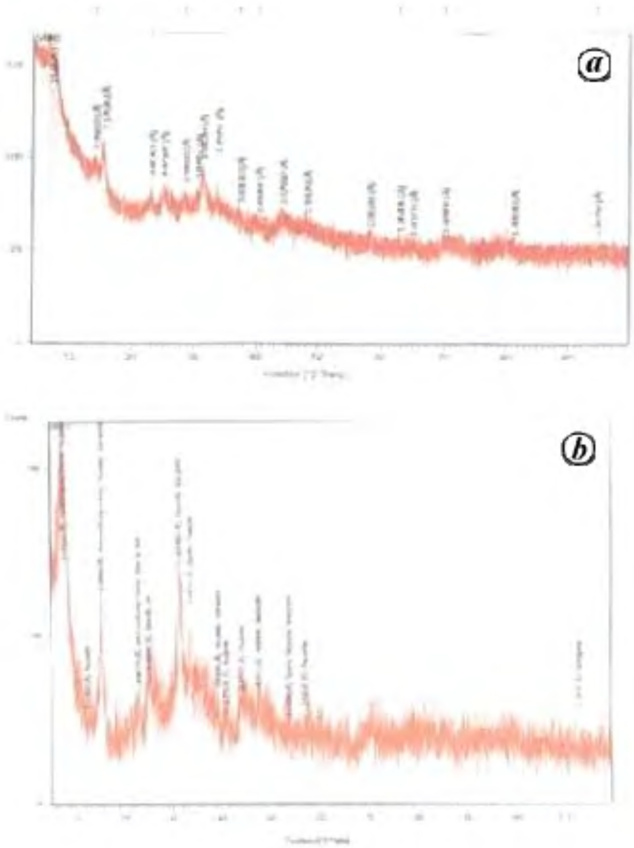

Figure 2. X-ray diffractogram of sample MB-1 analysed at GSI laboratory, Kolkata (***a***) and GSI laboratory, Bangalore (***b***).

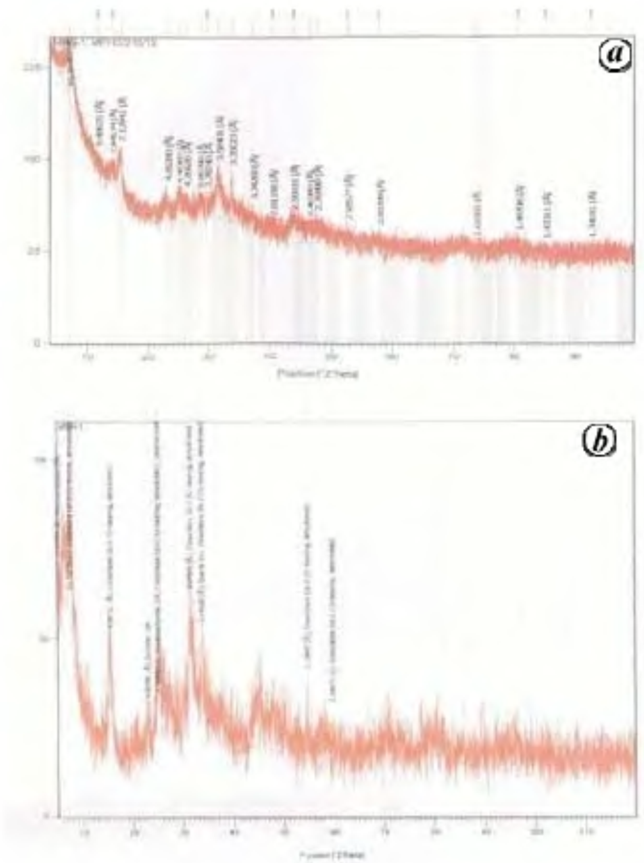

Figure 3. X-ray diffractogram of sample MBN-1 analysed at GSI laboratory, Kolkata (***a***) and GSI laboratory, Bangalore (***b***).

key role in delineating the seaward periphery of mudbanks. In this zone, large quantity of wave energy is transferred to the seafloor, a phenomenon which is maximum during the SW monsoon. Due to this, the bottom sediments undergo intense churning and are brought into re-suspension. During this process, the adsorbed cations are stripped-off from the flocculated clay minerals due to the energy imparted by the waves, making them negatively charged. These charged minerals again flocculate by adsorbing cations from sea water. But when zaherite is present in the sediments, the clay minerals get attracted towards the positive end of zaherite rather than the less active sodium, potassium or magnesium ions available in sea water. In this process, the clay minerals flocculate by randomly sticking to zaherite grains and settle down. Due to this random orientation, the sediments remain loosely packed. In order to understand the textural fabric of the sediments, SEM studies were carried out at GSI Laboratory,

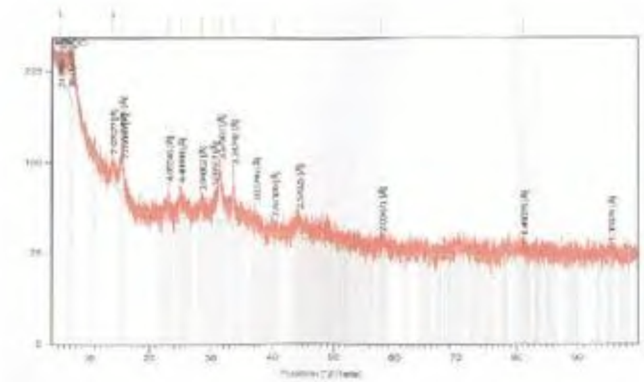

Figure 4. X-ray diffractogram of sample MBOO analysed at GSI laboratory, Kolkata.

Kolkata. Loose packing with edge-to-edge and edge-to-face arrangement as well as grain segregation were noticed in the micrographs of the SEM (Figure 5), which

Table 3. Chemical analysis (%) of clay fractions of surface sediment samples

Sample no.	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	Na_2O	K_2O	CaO	MgO	LOI	SO_4	Total
MB-1	37.90	18.34	11.76	0.80	0.53	1.05	1.94	4.80	20.50	1.51	99.13
MB-2	39.47	18.83	12.30	1.30	0.30	1.00	0.90	3.50	19.50	1.05	98.15
MBOO	38.84	17.66	11.65	1.00	0.40	0.95	1.30	4.90	21.20	1.40	99.30
MBN-1	36.90	18.74	11.39	1.10	1.05	0.80	2.10	3.72	22.60	1.50	99.90

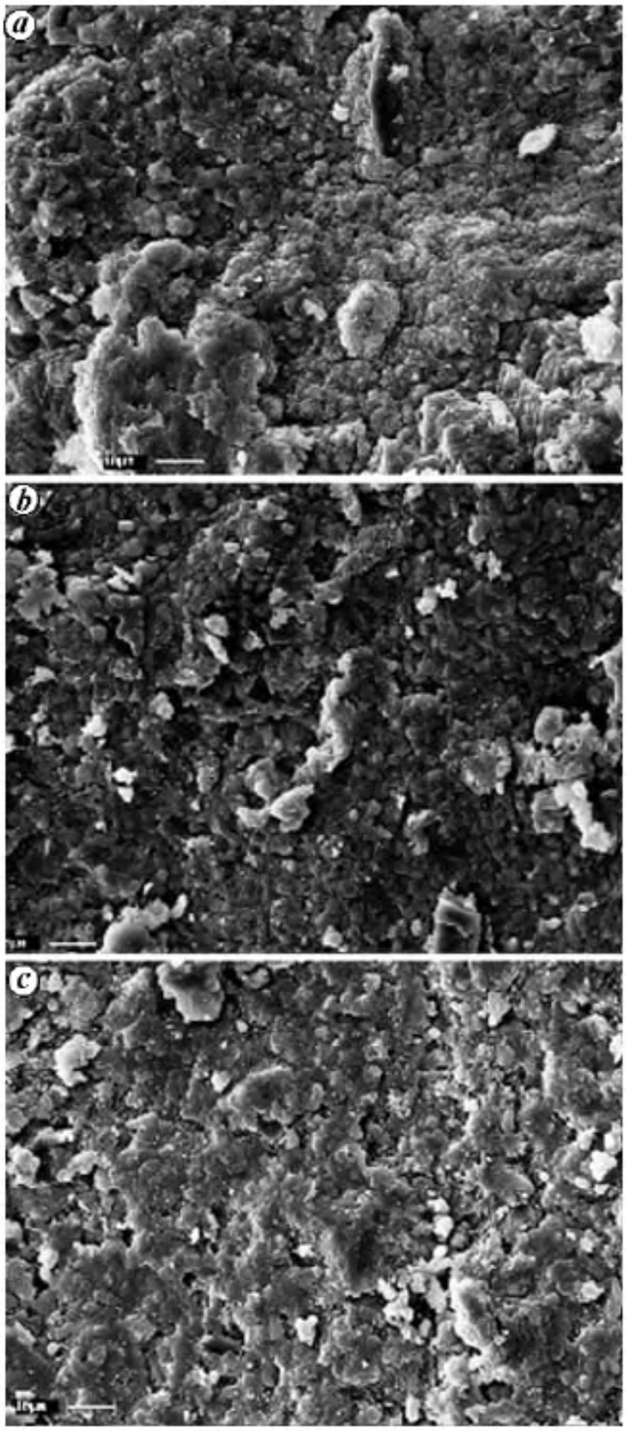

Figure 5. SEM photomicrographs of (***a***) sample MB-1 showing loosely packed texture due to grain segregation, (***b***) sample MBN-1 showing edge-to-edge arrangement of grains resulting in loose packing and (***c***) sample MBOO showing characteristics of both (***a***) and (***b***).

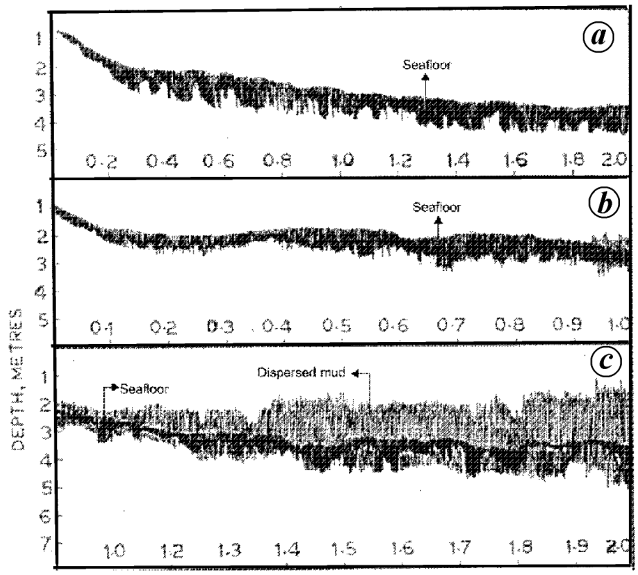

Figure 6. Echogram profiles across Alleppey mudbank during (***a***) pre-monsoon, (***b***) at the onset of monsoon and (***c***) well-developed wedge-shaped mudbank platform formed during peak monsoon (after Gopinathan and Qasim[4]).

corroborates the above view. This observation was also reported from the sediments of Quilandy mudbanks[11].

Due to random orientation of grains, the sediments are loosely packed enabling them to carry large quantity of pore water. Hence the volume of mudbank sediments is relatively higher than that of the adjoining sediments. This increase in volume is responsible for the mudbank area to stand out as an elevated platform above the sea-floor (Figure 6). Since the energy transmitted by the pounding waves is maximum at the seaward periphery of the mudbank, this platform has maximum height in the region. Towards land, the height of the platform gradually reduces imparting a wedge shape to it. Existence of a wedge-shaped profile with increasing seaward thickness along the axis of the Alleppey mudbank, determined using the echogram[4], substantiates the above view.

During our study we observed that the elevated platform forming the mudbank transitionally merges with the consolidated mud below. The degree of compaction of the sediments in this platform progressively increases towards the bottom. This results in the development of a sediment column with loose mud at the top and a strong base of consolidated mud at the bottom. This sediment column can be collectively called as 'dispersed mud', which is different from the suspended mud as there is a strong base of consolidated mud in the former, whereas the latter is devoid of any such base. This dispersed mud, efficiently resorbs the wave energy, resulting in the quelling of waves. Due to the decline in wave energy after monsoon, the dispersed mud particles gradually come closer due to gravity and hydrostatic pressure. This results in the reduction in volume causing the elevated platform to thin out and thus the mudbank becomes passive.

Available data and the present study show high phosphate content in mudbank sediments (Table 1). Though the actual reason for this is yet to be established, we presume that the phosphate may be adsorbed on the surface of bipolar zaherite. During monsoon, due to the heavy pounding of waves, the adsorbed phosphate comes out. The presence of a large number of PO_4^{-3} ions in pore water further enhances mud dispersion. It is a known fact that phosphate compounds are used as dispersing agents in clay.

The prerequisites for the formation of a mudbank, therefore, are zaherite, mud deposit and strong monsoon waves combined with suitable bathymetry. Except zaherite, the other factors required for mudbank formation are available at several places along the west coast of India. Thus, if zaherite or a similar type of mineral is introduced in the required proportion into the clay, it may be possible to create mudbanks artificially.

Even though we could address several important issues pertaining to mudbank formation, there are many other problems such as formation and localization of zaherite, genesis of impersistent mudbanks (non-Alleppey mudbanks) and creating mudbanks artificially, regarding which work is in progress.

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