THREE

HYPOTHESES ON MUDBANKS

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ABSTRACT

The report gives a critical appraisal of the various hypotheses on the formation and the characteristic calmness of the mudbanks, in the ligt of the auther's findings, with special reference to the Alleppey mudbank. A detailed account on various types of mudbanks along the southwest coast of India is also presented.

INTRODUCTION

The mudbanks, though confined to the near-shore waters, is a phenomenon still not fully explained. The formation of mudbanks at the vicinity of river mouths, such as Korapuzha, Bharathapuzha, Chetwai and Azhikode, and Cochin bar mouths, where clay and vegetable debris brought down by the rivers are deposited on the downward side of the littoral currents, is easy to understand. But, the mudbanks at places where there are no river discharges, as at Alleppey, are rather difficult to explain. There are many hypotheses put forward to explain specific aspects, such as the source of the mud and its role in calming down the waves. These hypotheses are briefly discussed here in the light of the present observations.

SOURCE OF MUD

Sir Robert C. Bristow, former Administrator-cum-Chief Engineer of Cochin Harbour, who was also the chief architect of the Willingdon Island, compiled "The History of Mudbanks" from the then available records, which was published in 1938. It details the views held by the earlier authors on the formation and other aspects, mainly of the Alleppey and Narakkal mudbanks, and a hypothesis of Bristow himself. The following is a discussion on the various theories, advanced before and after Bristow, weighing the merits and demerits of each one of them.

1. Subterranean Passage Hypothesis

Crawford (1860; in: Bristow 1938) was the first to advance a hypothesis — the Subterranean Passage Hypothesis — to explain the source of the mud of the Alleppey mudbank. He observed the formation of mud cones on the beaches and in the roads of Alleppey in 1855. This led him to suggest the existence of a subterranean passage, or stream, or a succession of them, that becomes more active during heavy rains, particularly in the commencement of the monsoon, carrying off the accumulating water and with it vast quantities of soft mud from some of the inland rivers and backwater to the sea.

Later Capt. Drury (In: Bristow 1938), observing the deposition of so large a quantity of mud in the open sea, about 2 or 3 miles from the shore and many miles from any bar mouth or outlet from the backwater, suggested that it is not improbable that there exists a subterranean channel through which large quantity of mud is carried off into the sea, where it is thrown up in the form of a bank. He stated that the mud thus formed gradually floated southward with the littoral currents and fresh banks are formed whenever the hydraulic pressure of the inland backwater increases sufficiently to overcome the subterranean resistance of the stratum of fluid mud which is formed at certain places.

According to King (1881), the mudbank may be entirely due to the discharge of mud from under the lands of Alleppey, Purakkad and Narakkal, being effected by the percolation or underground passage of lagoon water into the sea

Philip Lake (1889; in: Bristow 1938) differed from the views held by the previous odservers on the source of mud for the Alleppey mudbank. He opined that the Alleppey mudbank is formed not from the backwater mud, but from an older river deposit found only at particular points along the coast. He further stated that, with regard to the existence of subterranean channels, it might well be doubted whether any could exist in such unstable deposit as found there.

John Rhode (1886; in: Bristow 1938) former Master of Alleppey Port, suggested that a fluid mud strata exists below Alleppey.

The consensus of opinions stated above leads to the conclusion that there is an underground discharge of water, at any rate, into the sea from the lagoon and river system behind the Alleppey-Purakkad coast during flood time, the inland water being at a higher level. This passage of underground water must, more particularly during heavy rains, pour out with it large quantity of the mud.

2. *Hypothesis of water bearing stratum*

Bristow (1938) ruled out the prossibility of the existence of an underground river at Alleppey. His argument is that it is impossible for the backwater to rise more than a foot without flooding the lower parts of the neck of land separating the backwater from the sea, at many points between Cochin and Alleppey. Besides, a head of 5 ft., the maximum possible, would give a pressure of only about 21 lbs/sq. inch, which is not enough to overcome the frictional resistance set up by solids in suspension, According to him, what is more likely is that a water-bearing stratum exists at a good depth, which brings down water from the hills and crops out under the sea at varying distances from the shore, thereby lifting the bottom mud above it and anything sufficiently buoyant that lies buried in the mud.

3. *River deposition hypothesis*

According to Ducane et al (1938), the chemical analysis of the backwater mud and the mudbank mud reveals different characteristics. The mud of the mudbank is greenish, very oily, but mixable with water, whereas the mud of the backwater is black and is full of vegetable debris and is immiscible with water. This difference led Ducane's team to conclude that the mud of the mudbank might be from an older source. They held the view that the laterite/alluvial sediments from the land are run down by the rivers and are deposited on the seabed close to the shore in a regular process of river discharge and the sediment deposit thus accumulated near the coast is churned up by monsoon waves, and thus the mudbank is formed.

This explanation is, however, convincing with regard to the mudbanks forming near river mouths and bar mouths. But the mudbank near Alleppey cannot be explained by this hypothesis, because there is no river or backwater emptying in the nearby area.

4. *The Upwelling hypothesis*

Ramasastry and Myrland (1959) associated the formation of mudbanks with the upwelling along the west coast of India during the southwest monsoon, the upward movement of water lifting the bottom mud.

The presence of upwelling according to them is only at about 20-30 m bathymetric lines of the coastal waters. It is worthwhile to mention here that the presence of upwelling at such depths, however, does not help to explain the formation ot mudbank from shore to 10 m depth, unless there is some other mechanism in the region of the bathymetric difference of the locations of the two processes. Secondly, unless upwelling extends down to the bottom, which is unlikely, the mechanism would not be able to lift the bottom mud. Thirdly, why the mud banks are limited to only certain regions when upwelling is there all along the southwest coast (Ramamirtham and Rao 1973) is not explainable.

FORMATION OF MUD SUSPENSION AND THE CALMNESS ASSOCIATED WITH THE MUDBANK.

1. *The Deflocculation hypothesis*

Flocculalion is the process in which fine particles are brought together and clustered to become heavier masses so that they would be pulled down by gravity. Keen and Russel (Ducane et al 1938) found in their experiment that the mud of the mudbank completely settled (flocculated) when salinity was greater than 20‰ and it remained suspended (doflocculated) at salinity lower than 2.5‰. This hypothesis was adopted by Kurup (1969) and Padmanabhan and Eswaran Pillai (1971) to explain the calmness of mudbank.

As low as 17.04‰ salinity was reported by Damodaran and Hridayanathan (1966) during August 1966 from the surface waters of Cochin mudbank. Nevertheless, the bottom waters always recorded high values and never went below 33‰ (Iyer and Moni, 1972).

Periodical observations at Alleppey mudbank, which extended from Valanjavazhi in the north to Purakkad in the south during the mudbanks of 1971 and 1972 indicated salinity values as shown in Table 1. It would be seen from the table that the mudbank, both at surface and bottom, maintained well above the upper limit for deflocculation.

Table 1. *Salinity values (‰) at surface and bottom at the mudbank during 1971-72.*

(S=Surface, B=Bottom).

	Valanjavazhi east	Valanjavazai west	Ambalapuzha	Purakkad
1971 S	32.22	32.26	30.89	30.74
B	33.70	32.12	31.81	30.89
1972 S	29.28	30.34	29.82	30.02
B	27.76	29.05	29.50	31.47

Even admitting that surface water is diluted by freshwater influx to the optimum level at some places, bottom water at no place recorded the required low salinity for deflocculation, showing that the water immediately in contact with the mud itself is not in favour of deflocculation.

2. *The Hypothesis of oil in water as an agent to cause calmness*

King (1881) suggested, based on the analysis made by F. R. Mallet, that some brownish-yellow oily matter was present in the mud collected from the Alleppey bank, which he thought, when released into the water, to be the main agent responsible for bringing about calmness over the Alleppey mudbank. Lake (1880), however, discredited this hypothesis. Later the analysis of Keen and Russel showed that there was no such oily matter in the mud at Alleppey.

3. *Hypothesis of elastic nature of mud and its role in producing calmness*

Another suggestion was that the mud is of springy or elastic nature and hence is able, by alternate contractions and expansions, as the wave passed over it, to absorb the wave energy, so bringing them to rest. Keen and Russel (1983; in: Ducane et al) discarded this view. According to them the primary characteristic of any mud is that it is plastic not elastic, i e., it will alter its shape or configuration under external forces, but will not resume its original shape when the deforming force is withdrawn.

4. *Thixotropic hypothesis*

From the known principles of hydrodynamics and from the results of experiments Keen and Russel (in: Ducane et al 1938) concluded that the calming effect is due to the kinematic viscosity and thixotropic properties of the muddy suspensions produced in the monsoon. They are of the opinion that, when the heavy waves and swells of the monsoon reach the shoal bottom at the seaward fringe of the mudbank, the alternation of stresses associated with ridge and trough of the waves brings mud into suspension. The suspended mud increases the kinematic viscosity of the medium. This factor will tend to dampen the motion of the waves on the surface and in subsurface depths. As the stress thus falls, the properties of the mud suspension resemble those of a jelly which will absorb the wave energy completely. Thus, according to Keen and Russel, the effect of thixotropic suspension on wave motion is a cumulative one. In mud-suspended water, at high stresses, e.g., violent wave motion, the kinematic viscosity of the agitated mud suspension produces a higher rate of damping than in mud-free water and the stresses are reduced. Then the thixotropic effect comes into play, and the remaining stress is rapidly dissipated by the jelly-like behaviour of the suspension.

5. *Rip current hypothesis*

Varma and Kurup (1969) sought to explain the localised formation of the mudbank by attributing it to the rip currents. They said the rip flow, carrying finer offshore sediments, prevents the onshore transport of sediments by waves. Hence localisation of suspended sediments takes place at the rip head.

Although the rip currents are not fully understood (Sverdrup et al 1942), we may believe that these currents are probably associated with the surface transport of water against the beach by the waves (Shepard et al 1941). The rip flow may thus be a concentrated backlash of the waves at the beach and hence its area of action is narrow. On the other hand, the postulated mechanism requires rip flow from behind the mudbank (in between the mudbank and the beach). But backlash of waves from this hind zone is unlikely as the area is calm. The backlash of waves might be possible only if the mudbank is far off from the coast, allowing wave action to take place in the hind zone, which is usually not the case. Therefore, the rip flow cannot be a component of the working mechanism of the mudbank formation.

RESULTS OF THE PRESENT INVESTIGATIONS

The following is an account on the various more probable physico-chemical factors responsible for the formation, maintenance and dissipation of the mudbanks, as revealed by the investigations carried out by the authors from 1971 onwards.

Before dealing with the actual mechanism of the mudbank formation, we may have to consider the geographical features of the areas surrounding the Alleppey mudbank, including the Vembanad lake and also the rivers emptying into it. Vembanad lake is a vast water body lying almost parallel to the coast from Alleppey in the south to Cochin in the north. Its opening to the sea is at Cochin. The lake is separated from the sea by a narrow strip of land of only about 10-13 km width. Five rivers, namely, the Muvattupuzha, the Meenachil, the Pamba, the Manimala and the Achankoil, discharge their waters into the lake. These rivers originate from the Western Ghats in the east and flow towards the west.

There are evidences to believe that, in the past, the area, presently covered by Vembanad lake and the land strip in between the lake and the sea, was under the sea. During that period, the rivers, now flowing into the lake, might have been directly discharging their water into the sea. Later on, owing to some natural causes, such as cyclones, seismic sea waves and earth quakes, huge masses of sand and sediments might have got deposited in between the present lake and the sea to make the Vembanad lake. Boring experiments conducted at various places (Brown; in: Bristow 1938) on the west coast give supporting evidence to this. In one of the borings at Cochin (Brown 1928), the bed rock was found at 395 ft, while in another the hard bottom was felt at 650 ft.

The admirality charts and the recent echo surveys (Silas 1969) indicate that there is rocky substratum at about 75 m depth off the Kerala coast. Thus it seems that the entire vast area between the foot of the hills and at about 75 m depth off the coast was almost a deep basin, got subsequently filled up with mud and sand, over which a sandy crust was formed at some places. The presence of marine shells below 40 m at place like Kaduthuruthy near Vaikom, where the low-lying areas are all under paddy cultivation, gives a positive evidence to this (there is a view that the name Kaduthuruthy is derived from *Kadal thuruthu*; "Sea-island"). The foregoing account suggests that, below the lake and the narrow strip of land, at least between Thottappally and Narakkal, there exists a thick layer of unconsolidated mud, which extends into the sea.

1. Source of mud for Alleppey mudbank

The Subterranean passage hypothesis (Crawford 1860) and the Waterbearing stratum hypothesis (Bristow 1938) owe their leverage respectively to the hydrostatic pressure of the backwater and to the hydraulic pressure in the foot of the hills. The boring experiments have revealed the presence of a clayey substratum of varying thickness. Although no mention is found to have been made of the presence of a waterbearing stratum in the reports on borings of Cochin and Alleppey, the same has been reported to exist at 181' and at 312' in the Wellingdon Island boring. Davey's borings (at Alleppey) have shown the presence of mud, of varying composition, down to 316', while Crawford's borings at Alleppey revealed the presence of sandstone till a depth of 50' and then loose mud to a depth of 80', in which "the shaft sunk of its own from 60 to 80''. Waterbearing stratum has been observed to be associated with sandy substratum, but surfacing of the stratum has not been indicated in any of the boring records. In the absence of this, it cannot be believed that water could permeate the overlying mud layers from great depths (to greater heights) to crop up in the sea and on the shore. Further, it is doubtful whether such a massive hydraulic pressure could be developed at the foot of the hills as to feed the waterbearing stratum and to push the overlying layers of clayey mud. Crawford's experience of violent ejection of water and vegetable debris from 12' below, at a place 200 yards from the beach at Alleppey during the construction of the Alleppey canal, observations of 'Linus' in the Chenganur river by him, the presence of deep pot-holes in the water as reported by Logam (1882, in: Bristow 1938) and other available information, all equally suggest that the pressure-head developed at the bed of rivers as well as at the backwater generates a subterranean passage of mud, which crops out at varying distances through weaker points both on land and in the sea.

The present authors have observed, first time since Crawford, and Davey and Lake, mud cropping up in the form of cones for about 9 to 12 days during the monsoon of 1972, on the beach and at the inter-tidal zone at Kakkazham, near Ambalapuzha. Narrow (a few centimeters wide) cracks, 10 to 15 m long along the shoreline, were observed on the sea side of the beach-mud cones, indicating subsidence, while the mud cones at the intertidal zone feeding loose mud, as well as lumps of it, to the water flowing past the mud cones in its to and fro motion across the shoreline (*See* paper on mud cones). These observations too, support the subterranean passage hypothesis for the Alleppey mudbank.

II. Calmness associated with the mudbank

The most striking character of the mudbank is its calmness. The reasons for the prevailing calmness over a restricted region, when all other places are highly wave-beaten, are to be considered. Several views have been put forward to explain this phenomenon. It is generally accepted that the calmness is brought about by the mud in suspension. But, the view that a purely physical process, say, the churning action of the monsoon waves causes the mud into suspension is not satisfactory. The following hypothesis, evolved by the present authors, is offered to explain the whole processes leading to the calmness associated with the mudbank.

A. Wave Propagation

a) Movement of particles of the medium: The waves at the surface of the sea are caused either by wind force or tidal force. Below the wave crest of a progressive wave, the horizontal motion of the particles is in the opposite direction of that under the trough. The particle attains maximum horizontal velocity (speed) when it is just below the centre of the crest or the trough. During the first half of the wavelength, from mid-trough to mid-crest, the particles experience vertically donward velocities. The vertical velocities reverse in the second half of the wave length. The vertical speed is maximum at a point where the wave passes from trough to crest, or vice versa, and it is zero half-way between the crest or the trough (Sverdrup et al 1942). Thus, as the wave form is propagated in the direction of wave motion, the individual water particles involved in propagation of wave form are subjected to harmonic motions from their mean (undisturbed) position.

Jeffrays (in: Sverdrup et al 1942) pointed out that, within surface waves (deep water waves) the individual water particles near the surface move in circular orbits, the radius of which is equal to the amplitude of the wave (a circular motion can be resolved into a simple harmonic motion). But the radii of these orbits, and therefore the velocities, decrease rapidly with depth. According to the results of the classical hydrodynamics, the orbital paths of water particles in surface waves are elliptical, covering within the same time-interval, during which the wave travels over a distance of a wavelength (Dieitrich et al. 1980). The elliptic orbit changes into a circular orbit, if the water depth exceeds half the wave length, when the amplitude is very small compared to the wavelength (Newman 1978). Theoretically, the diameter of orbits at a depth of one-half the wave length is only one-twenty-third of the corresponding diameter at the surface. Regardless of the actual depth, the character of the wave therefore remains unaltered, if the depth to the bottom is greater than that short distance.

b) Summary of motion at surface : In a surface wave, let us assume, the wave motion is in the 'x' direction and let the distance 'x' and the time 't' be reckoned from a point when the wave passes its equilibrium position from trough to crest. Then the functional representations in terms of x and t of the deflection (y) of the sea surface from its position of rest, the horizontal (V_H) and vertical (V_V) velocities of the particles of the fluid medium at the surface may be written (Dietrich et al 1980 and Starling 1947) as

$$y = a \text{ Sin } 2\pi \left(\frac{x}{\lambda} - \frac{t}{T}\right)$$

$$V_H = V_{HO} \text{ Sin } 2\pi \left(\frac{x}{\lambda} - \frac{t}{T}\right)$$

$$V_V = V_{VO} \text{ Sin } 2\pi \left(\frac{x - \frac{\lambda}{4}}{\lambda} - \frac{t}{T}\right)$$

where λ is wavelength, T is the period of wave, a is the maximum value of y (amplitude of the wave), V_{HO} and V_{VO} are maximum values of V_H and V_V respectively. The magnitudes of V_{HO} and V_{VO} are equal for deep water waves but they differ for shallow water waves.

The behaviour of the parameters of the particle motion at the surface as the wave completes a cycle of wavelength is indicated schematically in fig. 1 by dividing the circle into four quadrants corresponding to the four quarters of the wave length. The length of an arrow in each circle represents the magnitude of the parameter for which the circle stands. Anticlockwise direction is treated as positive. The zero point in each circle represents the starting point of the parameter. The rise of the wave is indicated by y which reaches its maximum at $x = \frac{\lambda}{4}$, thereafter it falls to the zero level at $x = \frac{\lambda}{2}$. Afterwards the height of the wave is negative (below the mean level) and it reaches the negative maximum (trough maximum) at $x = \frac{3}{4}\lambda$ from where

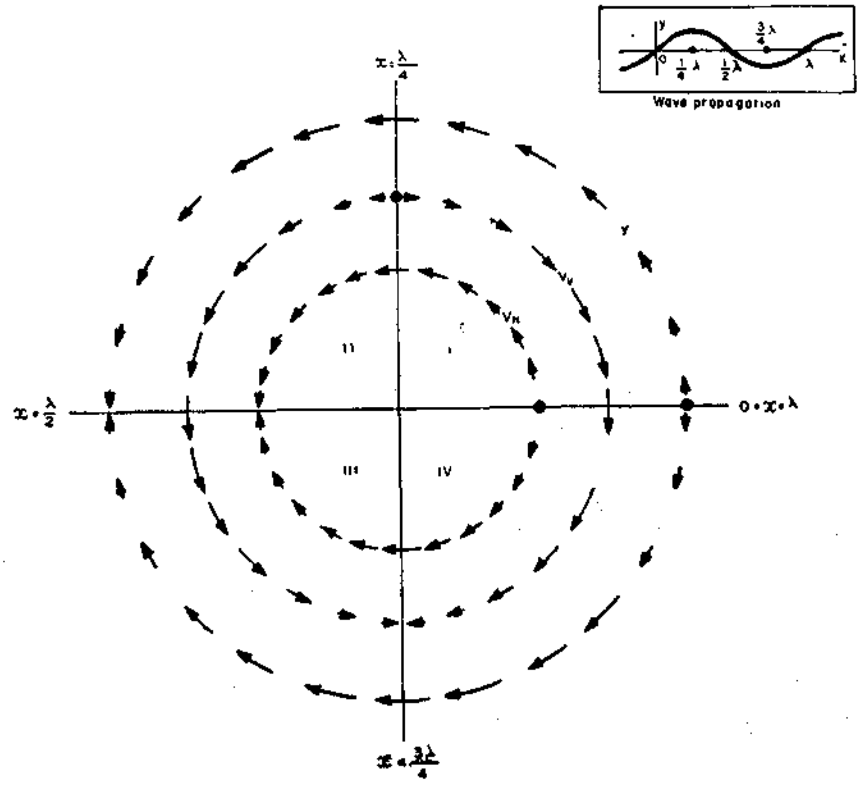

Fig. 1 Schematic representation of motion of a particle at the surface over a wavelegth

its magnitude decreases until it becomes zero at $x = \lambda$.

The horizontal velocity is forward during the crest period and it reverses during the trough period. As it varies in phase with wave height, the magnitude of the horizontal velocity reaches its maximum at $x = \frac{\lambda}{4}$ and at $x = \frac{3}{4}\lambda$.

While the horizontal velocity of the particle varies in phase with the waveheight (particle height), the vertical velocity varies out of phase with it. The vertical velocity leads the wave height by one-fourth of wavelength, therefore it is zero at the peak crest or trough.

Owing to the decrease of velocity with depth, the forward velocity of the particle, when it is above the mean depth, exceeds the backward velocity of it when it is below the mean depth. Therefore over a cycle of one wave-length the particle does not return to its original position but it experiences a net forward motion, resulting in net flow in the direction of progress of the wave. (Sverdrup et al 1942).

In the case of shallow water, the fact that the vertical motion cannot exist at the bottom modifies the character of the waves. At the bottom the motion can be only back and forth, and, if the depth is small compared to the wave length, the motion will remain nearly horizontal at all depths. Actually, the orbits of the individual water particles will be flat ellipses that become more and more narrow when approaching the bottom and at the bottom they degenerate into straight lines. Thus, all the particles involved in wave propogation move in different but systematic ways.

B. Viscosity

As the particles involved in wave propagation experience relative motion, either horizontal or vertical or both, here comes the effect of the internal friction (viscosity) of the medium in which the waves are propagated.

a) Newtonian viscosity : If relative motion occurs, viscosity or internal friction is experienced by the fluid. It was assumed by Sir Isac Newton that, for a fluid moving in parallel layers, the shearing stress at any point—where the velocity gradient is perpendicular to the direction of motion, $\frac{du}{dz}$ — is directly proportional to the value of the gradient, so that the frictional stress, f, per unit area is given by:

$$f = \eta \frac{du}{dz}$$

where η, a characteristic constant for the fluid, is called the coefficient of velocity. Newton's assumption was found true as long as the motion is laminar (non-turbulent), (Newman and Searle 1951). The values of viscosity (in 10^3 times c.g.s. units) of pure water and of seawater of 35‰ salinity at different temperatures are given in the following table (from Sverdrup et al 1942.)

Temperature °C

	0	5	10	15	20	25	30
Pure water	17.9	15.2	13.1	11.4	10.1	8.9	8.0
Seawater	18.9	16.1	13.9	12.2	10.9	9.6	8.7

Viscosity decreases with increasing temperature. Viscosity of seawater is correspondingly higher than that of pure water at all temperatures. The effect of pressure on the viscosity in the case of seawater is found to be insignificant.

b) Viscosity of the medium of mudbank : Let us study how the waves are damped once they enter into the region of mudbank. The mud particles present in a vertical column of the mudbank is treated to exist in three different phases.

i. Phase I (Thixotropic phase) : As early as 1923,A. Szegvari and E. Schalek (in Glasstone 195) found that when concentrated pasty mass of ferric oxide is mixed with suitable quantities of electrolyte in aqueous solution, on shaking, formed colloidal solution. This phenomenon has been called 'thixotropy' by Petrifi (1927). Subsequently, this was also observed in other colloidal systems such as alumina, silicic acid, vanadium pentoxide, zirconium dioxide, stannic oxide and even with suspension of fine clays. The analysis of the mud collected from the mud cones showed that it contained ferric oxide in finest clayey form.

The mud particles in this phase are very fine, ultramicroscopic, and they are subject to liquifaction by agitation (thixotropy).

ii Phase II (Sol phase) : The mud particles which are to be treated under this phase are microscopic. However, they do not enter into liquifaction but remain as sols or suspensoids. The viscosity of the medium is tremendously increased by the presence of such suspensoids for which state of solution Albert Einstein derived the formula

$$\eta_c = \eta_o \ (1 + 2.5\ \Phi)$$

where η_o = viscosity of solvent,
η_c = viscosity of solution
Φ - volumetric concentration of soils.

According to Einstein the volumetric concentration of particles (sols), i. e., the aggregate volume of the suspensoids, not their size, come into picture. Thus the presence of sols in the medium increases its viscosity by 2.5 times the volumetric concentration of the sols. For higher concentration a term in Φ^2 has to be added (Encyclopaedia Britannica, 1973).

iii Phase III (Gravity-influenced phase): The mud particles encountered in the third phase are so big in size that they are subjected to gravity where Stokes' theory is applicable. Assuming the mud particle in the third phase be spherical, according to Stoke's law, its rate of fall will be inversely proportional to the viscosity of the liquid and directly proportional to the relative density of the particle with respect to the density of the liquid. According to this law, the terminal velocity v, which is steady, is given by

$$v = \frac{2}{9} g \ \frac{(\rho - \sigma)\ r^2}{\eta}$$

where v is the rate of fall of the particle, η is viscosity of the liquid, σ is the density of the liquid, ρ is the density of the particle and r is its radius, and g is acceleration due to gravity.

Therefore, the fraction of the mud that has entered into the thixotropic phase with seawater increases the viscosity of the latter. Seawater and the thixotropically liquified mud fraction form the medium for the suspensoids which are constituted by the fraction of mud under the second phase (sole phase). Now the sols, thixotropic particles and seawater all together constitute the liquid medium for the suspended mud particles that are accounted under the last fraction which is influenced by gravity. Thus at every stage the viscosity of the medium is stepped up with the result that the particles categorised under the last fraction will experience tremendous amount of resistance to their fall due to the viscosity of the medium. Thus the effective viscosity of the medium depends upon the relative fractions of the mud entering into the first two phases. In case mud is present in seawater only in the gravity-infleuced state, the vis, cosity of the medium in that case remains the same as that of seawater at its corresponding salinity and temperature only.

With the understanding of three-stage (fold) increase of viscosity—seawater, thixotropic solution and sol phase state—of the medium, where large-size mud particles are suspended, let us go back to the propagtion of waves in such a liquid medium.

The wave propagation involved horizontal and vertical oscillations of the particles of the liquid medium as well as the suspended gravity-influenced mud particles. The particles of the liquid medium are equipped with high viscosity, resisting their relative motion, while the movement of the gravity-influenced mud particles is subjected to the influence of gravity and viscosity of the medium together

As a consequence of this, the particles of the medium, as well as the gravity-influenced suspsnded mud particles in it, suffer a loss of vertical and horizontal velocities. Hence it results in reduction in amplitude of the wave. The more the fraction of mud identifying itself with the medium under the first two phases- the more would be the viscosity of the medium, and the greater would be the reduction of amplitude of the waves. Thus, as the wave damping occurs, the mudbank enters into tranquillity, while the neighbouring region is wave-beaten.

The relative fractions of the mud entering into the three stages, namely, the thixotropic phase, the sol phase and the gravity-influenced suspended stage, explain other characters of the mudbank region, such as stability and longevity of a mudbank. In case the first two fractions are sufficiently high, which identify themselves with seawater in constituting the medium, they remain for long in the medium supporting the longevity, intensity of calmness and stability of mud bank. If the entire mud remains solely in the gravity-influenced suspended particle state, as the viscosity of the medium in that case reduces merely to that of seawater at its own temperature and salinity, the system cannot offer any calmness to the mudbank. Such a situation is experienced many times at mudbank regions and elsewhere where the water was apparently muddy, but the waves are found lashing within such areas even under calm wind conditions.

The Alleppey mudbank, where calmness is of higher grade and which remains for months together when compared to other mudbanks, which remain only for a few days, speaks about its richness in the first two fractions of the mud.

One is tempted to solely attribute the wave damping in the mudbank region to the bottom mud. It is interpreted that the mud acts as a semisolid jelly to absorb the wave energy. This concept ignores the physical state of the liquid column standing above the bottom mud. Moreover, as the wind-waves are caused at the sea surface, the origin of wave propagation rests primarily at the surface waters buf not at the bottom mud. McPherson and Kurup (1981) developed an interesting mathematical model for the wave damping at the mudbank region. Their model is in fact based on the mathematical model developed by Gade (1958). In the above mathematical model a two-layer system, the lower layer representing the sediment and the upper layer representing the water above, is considered. In this two-layer model, the bottom layer is assumed to be homogenous and the top layer frictionless. It is the experience of the authors that the mud is more and more concentrated towards the bottom. Setting aside the question of homogeneity of bottom layer, what is more important is the frictional character of the top layer (water column), which offers resistance to the motion set in it. Therefore, the physical conditions assumed in that mathematical model are not identical with the mudbank conditions prevailing here.

DISSIPATION OF MUDBANKS

Towards the end of monsoon, as the rain decreases, the water level in the backwater gets reduced to the normal, leading to reduction in hydraulic pressure in the subterranean strata which finally results in the cessation of supply of fresh mud. As the monsoon gets weakened, the turbulance of the water column also gets reduced and mud in the bank settles down causing dissipation of the banks.

During the mudbank season, the littoral currents are observed to be always southerly and the local tides have no influence on the direction of current. Toward the end of August the currents start reversing, thereby setting in offshore and northerly components (refer Chapter 10). The suspended and loose mud of the bank is gradually taken off by these veering currents.

Thus, towards the end of monsoon, in the absence of fresh supply of mud into the water column, the already available mud fraction which increases viscosity, gradually diminishes and the mudbank dissipatas. This leads to the fading of calmness over the mudbank. Then the rough conditions set in irrespective of the presence or not of gravity-influenced mud particles in the water.

MOVEMENT OF MUDBANKS

It has been observed that the mudbanks exhibit slow movement (in course of time), usually in a southward direction. In the case of the permanent mudbank of Alleppey, the investigations carried out by the authors showed that the mudbank moved from the place of incidence by about 0.5 to 2 km year to year southward. The table given below shows the pattern of movement of this mudbank during 1972 to 1981.

Year	Place of occurrence		Distance from Alleppey to the northern limit of mudbank (km)
	Northern limit	Southern limit	
1971	Kakkazham	Ambalapuzha	13
1972	Kakkazham	Karoor	13
1973	Karoor	Purakkad	15
1974	Purakkad	Chennankara	18
1971-80	Chennankara	Thottappally	20
1981 (1)	Chennankara	Pallana	20
1981 (2)	Paravoor	S. Punnapra	5

The table indicates that the period of rapid shift of mudbank was from 1972-75, during which period it moved a distance of 8 km from Kakkazham to Thottappally. Afterwards the rate of movement was slowed down or became rather nil. However, in 1981 the limit of the mudbank was extended up to Pallana, south of Thottappally spillway. The possibility of fresh discharge of mud in the nearshore areas at Pallana in 1981 or anywhere north of this place during the previous years also cannot be ruled out. In this year a fresh mudbank of approximately 4 km long was formed at Punnapra (Paravoor-south Punnapra), about 14 km north of Chennakara.

The mud from the place of discharge gradually moved southward due to the then southerly flow of the water. This movement was continued till the beginning of the northeast monsoon winds, and the subsequent reversal of the southerly drift, when conditions had already set in for the dissipation of the mudbank.

During the process of the movement, it has been found that the finer particles of mud at the bottom were always deposited at the down-drift side, while coarser particles are left out near the source. A series of mud samples collected from the mudbank and the surrounding places fully support this view.

DIFFERENT TYPES OF MUDBANKS

The mudbanks can be classified into four major categories based on the source of mud:

1. *Mudbanks formed by subterranean mud:* e.g., Alleppey mudbank, described above.

2. *Mudbanks formed by the aggregation of coastal mud:* e.g., Parappanangadi-Tanur mudbank.

In this case, the mudbank is very extensive, stretching over several kilometres along the shore, but is very temporary. There is no calmness as the nongravity-influenced mud particles in the medium do not absorb all the wave energy. By the effect of the southwest monsoon, the mud present in the coastal mud belt is churned up and, at this time, if the prevailing environmental conditions are favourable to the formation of the mudbank, the mud will be brought very near to the shore and thus a mudbank will be formed. Once such favourable conditions cease to exist, these mudbanks disappear suddenly.

3. *Mudbanks formed by the sediments and organic debris discharged from rivers and estuaries :* e. g., Chellanam-Manassery (Cochin bar mouth), Narakkal (The Azhikode bar mouth), Valapad-Nattika (The Chetwai river mouth), Elathur (The Korapuzha river mouth), Quilandy (The Kuttiyadi river mouth), Muzhippilangadi(The Dharmadam river mouth), Kottikulam-Ajanur-N-Bella-Adakathubail (The Chandragiri river mouth), Kumbala (The Kumbala river mouth), Uppala (The Uppala river mouth) and Ullal (The Netravati river mouth).

The flood waters coming down from rivers and lakes during the heay rains of the southwest monsoon bring huge quantities of sediments and other organic matters, which are dumped at the estuary and bar mouths. These sediments are always aggregated on the southern side and are held up there for a while by the southerly flow and the local eddy currents. Once the water force from the lakes and esturies is reduced, and the current reversed, the mud is spread out and the mudbank gradually disappears.

4. *Mudbanks formed by the accumulation of mud resulting from dredging operations :* eg., mudbank at Vypeen, Cochin.

At Vypeen, north of Cochin bar mouth, accumulation of mud is observable right from the shore. This mud is the result of periodical dredging operations done for deepening the navigational channel. Here the water over a wide area is calm due to this mud accumulation.

MUDBANKS AND COASTAL EROSION

It was observed that the silt-clay fraction was more on the southern side of the mudbank, while its northern side is sandy (see Chapter five). The southerly gradient of finer size of grain is due to the effect of littoral currents which are southerly. Occurrence of erosion along the coast during the southwest monsoon period is not uncommon. One may expect that the beach material eroded by the inshore waves and littoral currents may be deposited down stream at a place south of the erosion area. Occasionally erosion is taking place on the down-stream side of the mudbank The mudbanks are ahead of erosion areas with respect to the littoral currents.

Padmanabhan and Eswara Pillai (1971) explained the infleunce of mudbank on erosion process as follows:

"Most of the movement of materials is caused by waves approaching the shore at an angle. As the material so transported reaches the mudbank areas, its further movement is arrested as a result of the absence of waves in this area. This material thus got trapped within the mudbank cannot reach the down-drift side. The shore immediately on the down-drift side suffers from a lack of supply of littoral material, and the coast is eroded to make up the deficiency."

It is difficult to comprehend, unless some eddy currents are thought of, how the coast on the hind side of the mudbank gets eroded, due to the simple reason that the shore immediatley on the down-drift side suffers from the lack of supply of littoral material.