

24.—**Early Concepts of Oceanographic Phenomena of the Indian Ocean.** By N. K. Panikkar and T. M. Srinivasan. History of Sciences Unit of the Indian National Science Academy, National Institute of Oceanography, Panjim, Goa. (With 1 plate)

1. INTRODUCTION

The Indian Ocean has been the scene of varied activities of ancient explorers and maritime traders from the very beginnings of recorded history. Experience of early pioneers has led to much information on the sea pertaining to weather, winds, currents, waves and tides. Although their observations were often correct, the ideas derived from them lacked precision and clarity, but they succeeded in forming a good general picture of the physical conditions prevailing in the northern Indian Ocean. Historically, the subject is of considerable interest, for the ideas concerning the physical aspects of the Indian Ocean have been expressed in the semi-scientific terminology of the times. The principal sources which preserve these early concepts are either of Indian or of Mediterranean origin. The Indian sources are derived mainly from literary (Sanskrit, Pali and Tamil) and archaeological (excavations, numismatics and paintings) records and findings. Of the Mediterranean sources, the Greeks have been the principal contributors through their writings and records pertaining to travel towards Asian and African Coasts.

2. THE WINDS

The Wind and Sail

Right from the time of early civilisations winds have been harnessed to the service of navigation. Although frequently undependable and dangerous they were the main propulsive force for vessels in the open sea. The discovery of the sail for the effective use of winds was initially more by chance than by calculation. But without doubt, however, it conferred an early superiority on those who, independently of one another, discovered its use (Videl de La Blache 1922).

That the sail was employed by the Harappans to harness wind as a source of energy for navigation in the Proto-historic period has been evidenced by the representation of a seagoing vessel on a potsherd unearthed at Mohenjo-daro in the Indus Valley. 'It has a sharply upturned prow and stern and is apparently controlled by a single oar. The mast may probably be a tripod, and one or two yards are shown, or conceivably one only, the second line representing a furled sail' (Mackay 1938, 183). Mackay further observes that 'trade was carried on between the Indus Valley cities and distant Sumer partly by sail rather than solely by caravan across what may have been not wholly friendly territory' (1938, p. 5). The coins of Yajña-Śrī-Sātakarni (A.D. 184-213) of the Andhra dynasty show the representation of a two-masted ship. 'The rigging is crossed between the masts specially for sails and ropes' (Smith 1903, p. 613). Vivid testimony to the use of wind for navigation is given by the Ajanta

wall paintings (cave No. II, ca A.D. 525–650). The painting shows 'a seagoing vessel with high stem and stern, with three oblong sails attached to as many upright masts. Each mast is surmounted by a truck, and carries a lug sail. The jib is filled with wind. A sort of bowsprit, projecting from a kind of gallows on deck, is indicated with an outflying jib, square in form' (Griffith 1896–97, pp. 14, 17 and 30, pl. 34). These are some of the direct evidences.

The indirect evidence that comes from Indian literature throws more light on wind and sail. The *Ṛg Veda* refers to the use of sails in several passages, for example: 'rescued from the mighty surge of the seas (i.e. high seas) in fast going ships equipped with sails' (I, 182–5). The Buddhist *Jātakas* in Pāli contain descriptive accounts of the eastward voyages by Indian merchants as early as the fifth century B.C. The *Saṅkha Jātaka* says that Saṅkha, the merchant who sailed in a ship for the 'Gold Country' (Lower Burma) had three masts, cordage, sails, oars, and rudders (VI, No. 442, pp. 15–17). In the *Samuddavanija Jātaka* it is said that 'They sailed at the wind's will until they reached an island that lay in the midst of the sea' (IV, No. 446, p. 150). The *Milindapañho* or the *Questions of King Milinda* (ca second century A.D.) refers to the functions of the mast thus: 'the one quality of the mast is that the mast carries ropes and braces and sails' (Bk. VII, ch. 2, 13). The Jain canonical literature speaks of ships moving by the force of the wind '*pavanabalasamāhaya*' (Jain 1947, p. 118).

Knowledge of Winds

As already mentioned, the Harappans were the earliest people in India to utilise wind in navigation. But the exact knowledge of winds, as held by them, still remains to be clearly understood. The *Vedic* Aryans had an idea for transforming all their observations on natural phenomena—solar, atmospheric, and terrestrial—into mythological figures, into gods and goddesses. The chief deities of the atmospheric phenomena are *Vāyu* or *Vāta* (the wind Gods) or the gentle breeze, the *Maruts* (storm Gods) or the rain-bearing wind, *Rudra* (the howling God of storm and lightning) or the stormy wind, and *Parjanya* (the God of rain). The attributes of *Vāta* are 'the first-born, order-loving friend of waters; His sound is heard, his form is never looked on' (*Ṛg Veda*, X, 168, 2–3). The rain-bearing winds, the *Maruts*, 'carry long broad and inexhaustible clouds which they spread in the sky' (*Ṛg Veda*, I, 19, 7). *Maruts* are further subdivided into eastern *Maruts* and western *Maruts*, probably referring to the north-east and south-west monsoon winds in India. Reference is made to the winds blowing from the ocean thus: 'Two several winds are blowing here, from Sindhu, from a distant land'; here the term 'Sindhu' stands for ocean.

The *Satapatha Brāhmaṇa* uses five epithets to indicate five types of winds: ocean, flood, unassailable, irresistible, favourable and ogress-ridder (part V, xiv, 2–2–2–5). Similarly, the *Mahābhārata* describes in detail eight types of winds—*pravaha*, *āvaha*, *uttaraha*, *samvaha*, *valahagha*, *vivaha*, *parivaha* and *parāvaha* (XII, 329, 36–51). Different types of winds as known to the ancients of the later period have been arranged chronologically by Tripathi (1969, pp. 106–130) based on various sources; but it requires special study to unravel their climatological and meteorological implications.

The Śāṅgam literature in Tamil, belonging to the early centuries of the Christian era, describes four types of winds with definite appellations referring to the direction. They are *koṅtal* (east wind), *kōtai* (west wind), *vātai* (north wind) and *teṅral* (south

wind). The east wind is referred to mostly in the verses describing the sea coast. The west wind which blows in *mutuvēṇil* (late summer) is said to be very hot and expressed by phrases like '*aḷaleri kōṭai*' (the fiery west wind) and '*erivāykkōṭai*' (the fire-month west wind) (*Aganānūru*, lines 219 and 353). The south wind which is said to blow in *iḷavēṇil* (early summer) makes the rain-clouds roar like thunder (*Narriṇai*, line 129). The north wind is said to blow in the seasons of *kūṭirkālam* (late summer) and *munpaṇi* (early dew) and a full account of this wind is found in the *Nedunālvātai*.

Monsoon Winds

Monsoons, the seasonal winds of the Indian Ocean accompanied by heavy rainfall, derived this name from the Arabic term '*mausim*', meaning seasons. There are two monsoons and they divide the year into equal parts. The north-east or the dry, monsoon begins in November and ends in March. After some weeks of calm weather the south-west or the wet monsoon begins in the month of May and continues to the end of October.

There is adequate archaeological evidence (Wheeler 1954, p. 5) supported by modern meteorological investigations that the Harappans had experienced monsoons during the period between 2500 and 1700 B.C.* (Ramaswamy 1968, pp. 628-629). Although there is no clear reference in the *Vedas* to the monsoons, the *Marut* hymns give clear identification of the monsoon phenomena. One of the main functions of the *Maruts* is to shed rain. 'They (the *Maruts*) are tumultuous, the sons of *Rudra* clothed in rain, hot spirited like lions, giver of rain' (*Rg Veda*, III, 26, 5) 'Let the troops of *Maruts* sing unto thee, O *Parjanya* noisy here and there; let gushes of raining rain, rain along the earth' (*Atharva Veda*, IV, 15, 4). In the later Vedic texts the monsoon is referred to as '*salilavada*' (Macdonell and Keith 1912). The Buddhist texts refer to the monsoon clouds and rain-clouds as '*kālamegha*' and '*Varshavalshaga*' respectively (Tripathi 1969, pp. 129-130).

There is also a passage in the *Taittiriya saṁhita* which describes the west wind and the east wind or the rain-bearing monsoon wind thus: 'Stay, O *Maruts*, the speeding falcons, (with these words) he pushes back the west wind, to win the rains. He makes offerings to the names of the wind, the winds rule the rain' (II, 4.9.1). In *Marut* hymns quoted above, though mythologically expressed, the contents obviously refer to the monsoons, particularly the violent character of the south-west monsoon.

Uses of the Monsoons

The antiquity of the use of the monsoons for navigation is uncertain. But the fact that the monsoons appear with regularity in the Indian Ocean and that advantage could be taken of them in navigation was doubtless known to the people of India and Arabia from time immemorial. The evidence drawn from various sources indicates that their seamen steered boldly out of sight of land, before records were written to

* Thick vegetation and marsh jungles inhabited by animals like the tiger, buffalo, rhinoceros and elephant would have characterised the period. The occurrence of intermittent floods at Mohenjo-daro and Harappa has been emphasised by archaeologists. The use of millions of burnt-bricks by the Harappans for their houses would have been good protection against floods. Mud-bricks, if they had been used, would have been rapidly destroyed by rain or flood water. These conclusions, based on archaeological evidence, are also supported by modern meteorological investigations carried out by Ramaswamy over part of the Indo-Pakistan sub-continent.

tell of it. It is likely that the knowledge of winds was a jealously guarded secret used exclusively for their own maritime adventures.

In the early stages of navigation, the sailors from Egypt and the countries of the Mediterranean could not sail out of sight of land, but only hugged the coastline for keeping their direction (stage I). We have conjectural interpretations given by modern scholars to show that the expedition of the Queen Hatshepsut (ca 1495 B.C.) to the land of Punt (Landstörn 1965, p. 11) and the circumnavigation of Africa by the Phoenicians under Necho (610–594 B.C.) were accomplished with the help of the monsoons (Casson 1969, p. 131). The latter voyage has been referred to vaguely by Herodotus (Bk. IV, ch. 42). The same writer who records the exploration of the Indus by Scylax of Caryanda sent by Darius (ca 510 B.C.) does not inform us of the use of the north-east monsoon by Scylax for his return voyage. It is also possible that the Phoenicians and the early Greeks could have used their astronomical knowledge for coastline voyages (Taylor 1956, p. 72).

The existence of the monsoons and the seasonal change during the north-east were common knowledge to the Greeks from the time of Nearchus's return voyage from the Indus to the Euphrates. Nearchus started his voyage in the autumn at the time of the raising of the pleiad in the west. 'Because the mild breezes which then blow steadily by this time with heavy rain, favour coasting voyages, whether made by oar or by sail' (Arrian, *Anabasis*, Bk. VI, ch. xxi). By the end of the second century B.C., Eudoxus of Cyzicus, under the direction of Ptolemy II, took two trips to India. The first voyage was made with the guidance of a shipwrecked Hindu sailor who divulged the secrets of the open sea route to India to the Greeks. In the second voyage, taken between 117 and 108 B.C., Eudoxus was caught by the north-easterly monsoon and blown a fair distance down the east coast of Africa south of Guardafui (Cary and Warmington 1963, pp. 123–124). Since then the Arabs, who were acting as the principal trade intermediaries, could no longer keep the knowledge of the monsoons as a 'trade secret'.

But the much-needed breakthrough came during the reign of Claudius (A.D. 41–54) when a Greek mariner called Hippalus found a short-cut route to reach India (stage II). 'He was the first pilot who by observing the location of the ports and the condition of the sea, first discovered how to lay his course straight across the ocean' (*Periplus* § 57). He boldly ventured one summer to steer a direct course from the Cape of Ras Farak in South Arabia to the western coast of India. From the time of Hippalus to the author of the *Periplus* 'ships start direct from Cana, and some from the Cape of Spices (Guardafui) and those bound for Damirica (Tamil Country) throw the ship's head considerably off the wind; while those bound for Barygaza (Broach) and Scythia keep along shore not more than three days and for the rest of the time hold the same course straight out to sea from that region, with a favourable wind, quite away from the land' (*Periplus* § 57).

It has been an acknowledged fact that knowledge of the periodicity of the south-west monsoon reached the later Greeks and Romans only through Hippalus. But it must be mentioned here that he did not 'discover' the existence of the monsoons. What he actually discovered, on the contrary, was 'how to lay his course straight across the ocean' with the help of the south-west monsoon winds. The *Periplus* and Pliny mention in several passages that the favourable season to set sail from Egypt was about the month of July (Epiphi). They not only name the direction of the south-

west or west wind as Hippalus, but the *Periplus* positively states that the 'voyage at this season is attended with danger', a qualification which is applicable only to the south-west monsoon. Next we must record that neither the *Periplus* or Pliny attributes to Hippalus any discovery about the return voyage from India. The return voyage was commenced at the beginning of the Egyptian month of Tybis (December) or at all events before the sixth day of the Egyptian month Mechis (January) with the north-east monsoon which carried ships to the Red Sea (Pliny VI, 26).

But Hippalus's discovery of the new route for direct trade was indeed an achievement because it substantially curtailed the voyage time. Without that knowledge, which, according to Pliny, could reduce the crossing of the Indian Ocean to forty days, the laborious coastal voyage must have prevented the development of regular and direct trade with South India. His achievement, therefore, must be remembered, 'Not for a discovery new to the world, but for freeing the Roman Empire from Arabian monopoly of the Eastern trade by tracing it to its source' (Schoff 1912, p. 228).

Hippalus's findings and the utilisation of the monsoons gave tremendous impetus to trade between Rome and India. And consequently new routes were discovered by stages—one from South Arabia to Sigerus (Jaigarh) (stage III), and the second from Bab-el-Mandeb to Muziris (Cranganore) on the Malabar coast (stage IV) (Pliny, VI, 96-107). With the establishment of direct links between Egypt and India the size of ships increased considerably and, naturally, the Egyptian share in the maritime traffic crippled the trade of the southern Arabs, but it did not paralyse it.

3. CURRENTS

In the early Vedic texts we do not find any reference to the reversal of surface winds and the ocean currents which is a unique feature of the Indian Ocean. But the *Śatapatha Brāhmaṇa*, which belongs to the later Vedic period, gives some ideas about the circulation of ocean waters. It says: 'the ocean flows round this world on all sides'. '(He puts up the stones) by turning to the right (or south), whence the ocean flows round this world (from the east) southwards' (VII.1.1.13). Eggeling's commentary for 'turning to the right (or south)' is 'from east to south, etc., following the course of the Sun' (S.B.E., XLI, p. 301). An examination of the above passage reveals that it may be referring to the south-west monsoon which lasts from May to September. During this period the general flow is easterly towards southwards.

Āryasura in the *Jātakamāla* (ca fourth century A.D.) differentiates waves from currents and terms the latter as '*salila*' (Tripathi 1969, p. 152). It is interesting that these early sources clearly distinguished the three physical phenomena of the ocean, that is, the tides, the currents and the waves.

Clear evidence of the phenomenon of currents is furnished by the author of the *Periplus* (§ 13). He says that beyond Tabae (Ras Chenarif) and Pano (Ras Binna) and 'then after sailing four hundred stadia along a promontory, towards which place the currents also draws you, there is another market town called Opone' which is now known as Ras Hafun, about 144.9 km below the Cape of Guardafui. This is the only early reference to the currents coming out the Gulf of Aden. Cosmos Indicopleustus in his *Christian Topography* (ca sixth century A.D.) mentions in passing the disturbing currents near the mouth of the Gulf of Aden. Details are rather lacking in his account. A more precise idea of the currents of the North Indian Ocean was developed only

during a later Arab period and the Arab geographers' knowledge of this important phenomenon has been well traced and documented by Warren (1966, pp. 167-171) and Aleem (1967, pp. 459-464).

4. THE WAVES

The waves, one of the phenomena connected with the wind and water, are termed as 'ūrmi' in the early Sanskrit texts. Similarly the Śaṅgam Tamil classics speak of the waves as *tirai*, *alai*, *punari*, and *ōtham*. These terms are referred to in the texts in context of the action of the waves.

Causation

That the waves are caused by the action of the wind is indicated in one of the hymns of the *Ṛg Veda*: 'They who toss the clouds across the surging sea; with the *Maruts* come hither, O Agni' (I, 19.7). In this context Wilson's commentary is relevant for he says: 'who scatter the clouds and agitate the sea (with waves)'. He further remarks that the influence of the winds upon the sea alluded to in this verse indicates familiarity with the oceans on the part of the early Hindus (1891-97, p. 58). The *Śatapatha Brāhmaṇa* informs us that the wind is all important for causing movement in the ocean waters: 'The way of waters is the wind, for when he (the wind) blows hither and thither, then the water flows' (VII, 5.2.46).

Action of the Waves

The winds generate the waves and they in turn propagate for some distance and finally dissipate in their own waters. This is clearly expressed in the *Aṅgīta* of the *Mahābhārata* thus: 'Whatever is produced from them (the elements) is dissolved in due time in those very five great elements, like billows in the ocean' (ch. xxxvi, p. 388). Waves are changeable according to the strength of the wind. The *Milindapañho* alludes to this thus: 'even in the mighty sea, in the expanse of waters agitated by the crowding of ever-varying waves' (Bk. VII, ch. 2.11). In the Tamil sources of the same period of the early Christian Era the waves are said to attack and fight with the shores: '*poṅgu tirai poruta vārmaṇal aṭaikarai*' (*Narriṇai*, stanza 35). Accretion of sand on the beaches by the waves is subtly mentioned in the *Narriṇai*: '*muḷaṅgu tirai* (the noisy waves) *koḷiyea* (deposit) *mūri ekkar* (large quantities of sand) *tadaṅtāl* (to form a raised sandy patch on the shore) (stanza 203). In the same work it is said that the west wind breaks the rising waves, splits the water and throws the spindrift like soft cotton carded with a bow-like instrument (stanza 299).

The Sanskrit poet and playwright Kālidāśa (ca fourth century A.D.) describes the action of the waves at the mouth of the Tāmraparni in the *Raghuvamśa*: 'The shoals of conch-shells with their heads transfixed at their jutting points, being dashed at once by the force of the billows against the reefs of corals glide away with great difficulty (canto XIII, 13).

Effects of Waves

Ships in the early days were greatly affected by the fury of the waves. The *Milindapañho* says that 'a ship pieced together of all sorts is broken up by the force of the

violence of the waves' (Bk. VII, ch. 2.9). Nearchus, the trusted General of Alexander, had to delay his departure from the mouth of the Indus because of the effects of the waves (Arrian, *Indica*, Bk. VIII, ch. 21). The experience of the author of the *Periplus* at the Gulf of Baraca (Cutch) is fitting in this context. He says (§ 40): 'those who are drawn inside into the Gulf of Baraca are lost; for the waves are high and very violent, and the sea is tumultuous and foul, and has eddies and rushing whirlpools'.

Calming Effect of Oil on Waves

It is interesting to note here that the early Indian seafarers had devised certain ways which they applied when they were beset with the imminent danger of their ships being wrecked by giant waves. We learn from the Buddhist *Jātakas* that the mariners 'ate a mess of powdered sugar with ghee' as much as they could take and anointed all their bodies with oil. (*Sāṅkha Jātaka*, No. 442). These precautions of taking in ghee and sugar and besmearing of the body with oil were very sound psychologically and indicative of a long period of trial and error (Basham 1949, p. 61). While the practice of taking ghee and sugar would have been to stave off hunger in the distressing conditions of shipwreck, the purpose of using oil might have been to smooth the surface of the water they touched, thus reducing the impact of wind and breaking the waves—the real danger in wave motions. Defant (1961, p. 134) admits that 'not all oils have such action and that viscous heavy animal oils, like fish oil, cod liver oil, also rape seed or colza oil are more effective than mineral oils'. It is presumed that they would have equipped themselves with readily available vegetable or animal oils for this purpose.

5. THE TIDES

The tides, an important oceanic phenomenon, are of great importance in coastal navigation. The Harappans, who had observed the 'ebb and flow' of the coastal waters of Kathiawar, were the first to utilise the phenomenon effectively for berthing ships in the dockyard which they had constructed at Lothal, Ahmedabad district of Gujarat. But there is no evidence to show that they had any scientific understanding or explanation of the tidal phenomenon. It may be added, however, that no evidence of tide marks as used in the Nile (Schafer, H., 1902—Ein Bruchstück altägyptischer Annalen. *Abh. Preuss. Akad. Wiss.* S. 12–13) has so far been found with reference to ancient India.

Concept

The cumulative evidence from the early literary works in Sanskrit, Pāli, and Tamil proves that the ancients had not only observed this physical phenomenon but also had evolved a casual concept by linking it with the phases of the moon. The earliest evidence comes from the *Sāma Veda* in which the concept of linking the effect with the cause is given: '*soma . . . vardhā samudramukyam*' (ch. 10, pt. II, 20). The *Taittirīya Saṁhitā* refers to the phenomenon thus: '*samudramābhita: pinvamānam*', the term 'ābhita' implying 'eithersides' signifies the action of tides at the mouth of the river; and the term '*pinva*' means 'cause to swell' or 'over flow' (IV, 2.8.1). Vālmiki in the *Rāmāyaṇa* states that due to the influence of the moon in the '*parva*' the tides are caused: '*parvasudhirṇavegasva sāgarasya nisvaṇa*', meaning the roaring of the heaving

ocean during the fullness of the moon. Here the 'parva' is used to mean the new moon or full moon (II, 6.27). The Mahābhārata uses the term *vela* to denote the tides (VII, 159.73).

Out of the eighteen *Purānas*, the *Matsya Purāna* preserves interesting information and the passage is as follows: 'when the moon is in the east, the sea begins to swell. The sea becomes low when the moon wanes. When it swells it does so with its own waters (and not with additional waters), and when it subsides, its swelling is lost in its own waters (that is, does not lose any water). On the rising of the moon, the sea increases as if its waters have really increased. During the bright and dark fortnight, the sea heaves at the waning of the moon and becomes placid at the wane of it, but the store of the water remains the same. The sea rises and falls according to phases of the moon' (120, 30-34). This is a very important and interesting statement which is a parallel of the fundamental concept of 'continuity' in modern hydrodynamics. This is in refreshing contrast with the back-drop of the period and people who were prone to explain away unusual natural phenomenon with myths and divine mystic forces (Panikkar and Srinivasan 1971, p. 40).

Effects of Tides

Among the Greek writers, Herodotus recounts the regular occurrence of tides in the Red Sea (Bk. 2, ch. 11). Arrian in his '*Anabasis*' records the dangerous tidal waves that lashed the mouth of the Indus, as observed by Alexander (Bk. VI, ch. xix). Vivid testimony to the exact causes and effects of the phenomenon that took place in the Gulf of Barygaza (Broach) is gleaned from the *Periplus* (§ 45 and § 46).

Tidal Range

Regarding the amplitude of tides, the Buddhist texts commit glaring errors. But the tidal range given in the *Matsya Purāna* is fairly accurate: 'The sea rises and falls according to the phases of the moon and 510 *āṅgulas* (about 9.75 metres) is the measure of its rise and fall on the 'parva' days (*Matsya Purāna*, *op. cit.*). This corresponds in all probability to the highest tidal range occurring even today at the Gulf of Cambay.

Lothal Dock (2350-2000 B.C.)

As already mentioned, the Harappans were the successful originators in making full use of the tides at Lothal where they had constructed a dock for developing coastal as well as overseas trade. The basin of the dock, trapezoidal in plan, measures 219 metres north-south and 38 metres east-west (Pl. 1). The four embankment walls are constructed out of kiln-fired bricks, the original height being 4.15 metres. However, the present height is only 3.3 metres. Ships entering the Gulf of Cambay had to be moored along the river on the western side of the town and sluiced into the basin at high tide through the inlet channel which was 12 metres wide. It joins the northern embankment to enable large ships to have easy manoeuvrability. During floods in 2000 B.C. (dating by C¹⁴ method) the mouth of the river silted up and shifted its course to the east of the town, thus necessitating the digging of a new channel, 2 metres deep and 2 km long, to connect the dock with the sea through the river. It joins the eastern embankment at the inlet gap which has the same width as the inlet

channel. A spillway with a 1.5 metres-thick wall was built at right angles to the southern embankment wall to allow excess water to escape.

Ships had to enter and leave the basin at high tide when the water level was maintained sufficiently high above the inlet sill. The easy flow of water at high tide ensured desilting of the basin. The scouring effect of the tidal waters was arrested by the construction of two buttress walls one on either side of the inlet gap. To counteract the thrust of water inside the basin the enclosure walls were buttressed on the outer surface with a 12 to 13 metres wide platform of mud-bricks. The problem of ensuring flotation of ships at low tide was solved by closing the spillway, inserting the wooden shutter in the grooves (Rao 1962, pp. 15-19). Some significant technical details about this dock may be noted here. 'The minimum water-column in the basin was about 2 metres at low tide, the maximum being 3.5 metres at high tide. It is observed that boats of 60 to 75 tons capacity and 20 to 25 metres in length could enter the dock' (Rao 1970, p. 87). Another notable point brought out in the study by Rao is that the Lothal dockyard had features which in terms of height, width and length compare favourably with the modern dockyards of Bombay and Visakhapatnam.

We may affirm, therefore, on the basis of studies made regarding Lothal that this dock was purely tidal and the Lothal engineers had possessed a knowledge of the tidal effects, the amplitude, erosion and thrust. From this knowledge they developed competence at Lothal for receiving ships at high tide and ensuring flotation of ships inside the dock at low tide (Panikkar and Srinivasan 1970).

6. CONCLUSION

This brief survey indicates that within the course of centuries empirical knowledge pertaining to certain oceanographic features of the Indian Ocean had reached a sufficient level to be of practical use even during the time of early civilisations. The coastal communities of India had developed concepts pertaining to the winds, the waves, the tides and the currents. Early maritime adventures in the Indian Ocean seem to indicate that knowledge of monsoon phenomena and the reversal of winds were known to the ancient Hindus from whom the ideas spread to the Greeks and thence to the Romans. At about the same time the Arabs also secured the information relating to the monsoons in the areas of the Northern Arabian Sea. Obviously, navigation was based on winds; knowledge of its seasonal reversal was cleverly utilised for crossing the Arabian Sea. A corresponding knowledge of currents in the Indian Ocean, particularly the reversal of the currents around India, does not appear to have existed. In the subsequent centuries the Arabs seem to have acquired a better knowledge of the currents than either the Indian or the Mediterranean peoples. As regards tides, the influence of the moon had been clearly diagnosed. The Proto-historic Harappan civilisation provides a unique example of a dockyard at Lothal for receiving ships at high tide and berthing them in a basin even during low tide. This is probably the earliest example of knowledge of tidal phenomena being put to a highly practical purpose both in the selection of a site having the highest tidal amplitude and in adopting a method of operation for entry and exit of ships. Concepts of tides and of the monsoons by the ancients have played a key role in the early maritime contacts between India and the Mediterranean countries.

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Lothal Dock. (Foreground) southern embankment with spill-way on the left. (Background) northern embankment. Inlet channel near the person standing on the eastern side. Loading platform on the western side measures 240 metres long and 23 metres wide (now partially submerged under water).