THE CONCEPT OF TIDES IN ANCIENT INDIA

N. K. PANIKKAR
National Institute of Oceanography, Miramar, Panjim, Goa
and
T. M. SRINIVASAN*
National Commission for the Compilation of History of Sciences in India, Marine Sciences Unit, Indian National Science Academy, New Delhi

(*Received 12 January 1971*)

Since the beginning of the Proto-historic period, the 'ebb and flow' of the coastal waters of Kathiawar were observed by the Harappans and they were the first to utilize 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 cosmic explanations to explain tidal phenomena.

The cumulative evidence from the *Vedas, Upaniṣads, Saṃhitās*, epics, *Purāṇas* and early literary works in Tamil and later works in Sanskrit show that the ancients had not only observed this physical phenomenon but also evolved a causal concept by linking it with the moon. The *Matsya Purāṇa*, particularly, gives detailed descriptions.

Classical Greek authors and travellers have commented on tides. Arrian, while narrating the exploits of Alexander the Great in India, makes distinct mention of the 'ebb and flow' at the Gulf of the Indus as observed by Alexander. The most absorbing account is found in the *Periplus Maris Erithrei* (A.D. 65) written by an anonymous Egyptian or Greek navigator. His personal observation about the place of occurrence of tides and the exact causes and effects of the phenomenon taking place in the Gulf of Barygaza (the modern Broach) are fairly accurate descriptions. The subject in relation to all these observations is discussed.

1. INTRODUCTION

The ocean and the varied physical phenomena associated with it have attracted the attention of the ancients from the earliest times. Among the many natural phenomena of the oceans, the occurrence of tides and their characteristic effects were of particular interest. In the Proto-historic period, the Harappans appear to have had a considerable knowledge of coastal and tidal features which were of special importance to navigation; but their observations were not recorded for posterity. Historically, the subject is of considerable interest, for, in the succeeding periods, the ideas concerning the tides have been expressed in the philosophical and semi-scientific terminology of the times. The words are as expressive, precise and consistent as those of descriptions of natural phenomena of other ancient civilizations.

* *Present Address:* National Institute of Oceanography, Panjim, Goa.

The literature on tides is not very large; however, there exist sufficient source materials dealing with this topic, partly in the form of theoretical studies and partly in the form of observations. The principal works which preserve the concept of this physical phenomenon are the *Vedas, Upaniṣads, Saṃhitās,* epics, *Purāṇas,* and some early literary works in Tamiḻ and later works in Sanskrit and, lastly, the classical Greek authors' accounts pertaining to India.

Tides result from the periodic rise and fall of the sea produced by the differential gravitational effect of the sun and the moon on the ocean. The character of the tide is very complicated, because any tide can be shown to consist of a number of *partial tides,* each of which is related to the motion of the earth relative to the sun and the moon. The rising tide is known as *flood-tide* and similarly the falling tide as *ebb-tide.* In order to ascertain the ancients' knowledge of these tides in the past it is necessary to examine their observations and interpret them in the light of archaeological discoveries and literary evidence. Hence, an attempt has been made to present here an account of the best established tidal concepts and observations and the range of tides, their effects and usefulness in navigation in ancient India.

2. Observations without the Concept

2.1. *The Proto-historic Period*

The Indus Valley in those days had intimate commercial contacts with Sumer and Elam, both by land and sea, and this has been substantiated by the discovery of a seal and a pot-sherd portraying a ship. It is further corroborated by the discovery of a dockyard at Lothal, a Harappan site, in Saragwala village of Dholka taluka in Ahmedabad district of Gujarat by the Archaeological Survey of India. In the Proto-historic period, the coast of Kathiawar provided excellent harbour facilities to the Harappans for developing coastal trade. The construction of a dock for berthing and servicing ships near the mouth of the River Sabarmati, whose course has shifted in later years, points to the fact that the Harappans had possessed a high degree of knowledge relating to ebb- and flow-tides. This structure, probably the earliest and only one of its kind in the world so far discovered, also 'presupposes a sound knowledge of hydrography and maritime engineering'[1] possessed by the users of the Lothal Port. It is likely that they must have constructed the dock after observing the tidal phenomenon and the effects thereof. Their study of tides did not stop with the observation alone, but included the effect of tidal water on brick-built structures; since the four walls of the dock are found to be built up of kiln-burnt bricks.

Ships were sluiced into the dock through the river estuary flooded by an inlet-channel at high tide from the Gulf of Cambay. Similarly, the ships had

to leave the basin at high tide when the water level was maintained sufficiently high above the inlet-channel. Likewise, precautionary measures were taken against erosion and scouring of the tidal waters by the construction of buttress walls on either side of the inlet in the eastern embankment. The location and inferred performance of the Lothal dock testifies that the Harappans had not only observed the phenomenon of tides but also the tidal effects on man-made structures like the dockyard.

In this connection a pertinent question is whether the Harappans had tried to correlate their observation of the rise and fall of the sea waters to the gravity of the sun and the moon. The question cannot satisfactorily be answered because of the non-existence of written records of the period. One supposition is that when the Harappans had observed the occurrence of the rise and fall of sea water and their effects, they would have found out the cause by linking the phenomenon with the phases of the moon and the sun. Another hypothetical view is that since the tidal effect on the coast of Kathiawar was a regular feature they would have observed only the phenomenon and utilized the effects of it for the purposes of navigation; in other words, they would not have attempted to theorize a causal concept behind the phenomenon. But the views are merely based on presumption and hence the acceptable view is that the Harappans had, indeed, observed the occurrence of tides on the coast of Kathiawar and utilized their observations suitably. The selection of the site as judged by local geography has been cleverly done because of the very high tidal range observed—a feature for which the Gulf of Cambay is well known. Even now the places with the highest tidal range in India are on the coasts adjoining the Cambay region of the Arabian Sea.

3. Observation and Concept

3.1. *Concept in the Vedic Period*

The *Ṛgveda*, the earliest extant work in Sanskrit, does not contain any reference to the tides. But the understanding of tides by the Vedic Aryans comes from the *Saṃhitās* of the *Sāmaveda* which speak of the swelling of the mighty oceans or seas. These references appear to be positively about the tides, and not to any kind of flooding of oceans, as a class of interpreters is prone to believe.[2] In the same work it is clearly expressed that the phenomenon of tides is due mainly to the moon, *Soma . . . vardhā samudramukyam.*[3] It is the earliest reference to the phenomenon of tides and the concept of linking the effect with the cause.

The *Taittirīya* recension, which preserves the *Saṃhitā* of Black *Yajurveda*, clearly refers to the phenomenon of tides thus: *samudramabhita : pinvamānam*,[4] the term *abhita* here implying 'either sides' signifies the action of tides at the mouth of the river or estuary. And the term *pinva* means

'cause to swell' or 'overflow'. These scientific terminologies stand to testify the later Vedic Aryans' knowledge of tides. Likewise, the *Vājasaneyi Saṃhitā* mentions the occurrence of tides as 'the gathered flood of oceans'.[5]

The second class of Vedic texts known by the name of *Brāhmaṇas* contains certain allusions to tides and their actions. Specifically speaking, the *Śatapatha Brāhmaṇa* speaks of the action of tides thus: 'Around the swelling ocean, for the ocean indeed swells round this earth.'[6] Similar to the *Taittirīya Saṃhitā*, the text of this *Brāhmaṇa* also uses the term *pinvama* or *pinvate*, to denote specifically the 'action of tides'. The *Maitrāyanī Upaniṣad* which is later in date than the classical *Upaniṣads* quotes freely of tides in the following line: *samudra velava durnivāryam asya mṛtyorāgamaṇam*, meaning 'like the tide of the ocean, the approach of one's death is hard to keep back'.[7] Here the term *velava* stands for tides, and probably it is only in this *Upaniṣad* that we come across a specific term for denoting the tides. The suggestive meaning of the above-mentioned line is that the force of the ocean tide, as observed by the ancients, was something which cannot be stopped.

3.2. *The Epic Period*

The *Rāmāyaṇa* and the *Mahābhārata*, the twin epics of the Hindus, are replete with references about the tidal phenomenon and its cause. Particularly, the *Rāmāyaṇa*, the first of the two epics, contains several references to them.[8] Vālmīki, the author of the work, seems to have possessed a clear understanding of the whole phenomenon. For he states that due to the influence of the moon in the *parva* the tides were caused: *vivardhamāno viryana samudraparvaṇi*.[9] To the 'rise and fall' of the sea water during the *parva*, he says, *parvasudhirṇavegasya sāgarasyeva nisvana*, meaning 'the roaring of the heaving ocean during the fullness of the moon'.[10] In all these instances the term *parva* is used to imply the new moon or the full moon. It is now understood that *parva* is the time at which the moon at its conjunction or opposition passes through the node, with the result the waters of the sea swell and become restless.

In the time of the later epic, the *Mahābhārata*, the ancients were fully acquainted with tides. Their constant observations had led them to reach a firm conclusion that the moon was its cause and that the new moon and the full moon were special occasions when it intensified.[11] The *Mahābhārata*, like the *Maitrāyanī Upaniṣad*, uses the same appellation *vela* to denote the tides.[12]

3.3. *Period of Buddhist Works*

The evidences drawn from the Vedic texts and epics regarding the phenomenon and causation of tides find corroboration in the Buddhist works, particularly the *Jātakas* or rebirth stories. The *Samudravaṇika Jātaka*

points out that the causation of tides was frequently due to the pull of the moon.[13] The term *vela* is frequently used in the Buddhist texts to mean tides.

3.4. *Purāṇic Period*

With the expansion of geographical knowledge due to military expeditions and commercial contacts across the seas, the ancients' understanding of tides, their causation and other characteristic effects increased to a great extent. We find their ideas being incorporated appropriately in the compositions of the later Sanskrit works like the *Purāṇas*. Although the *Purāṇas* have freely utilized the geographical material of the *Rāmāyaṇa* and the *Mahābhārata*, they, however, present certain details about the study of tides that were based on factual observations and experience rather than on speculation and presupposed notions. Of all the *Purāṇas*, the *Viṣṇu, Matsya, Agni, Brahmāṇḍa, Brahma* and *Vāyu* are of special importance and the details gleaned from them on the subject of tides are found almost in the same stereotyped phrases.[14] However, it is necessary to present the relevant passages from the *Viṣṇu* and *Matsya Purāṇas*, for they are of particular interest in this context.

In the *Viṣṇu Purāṇa* it is said: 'In all the oceans the water remains at all times the same in quantity and never increases and diminishes; but like the water in a cauldron, which in consequence of its combination with heat expands, so the waters of the oceans swell with the increase of the moon. The waters, although really neither more nor less, dilate or contract as the moon increases or wanes in the light and dark fortnights.'[15] The comparison of the swelling of the waters of the ocean to the expansion of water in a kettle or boiler due to heat is interesting.

3.5. *A Modern Parallel*

Still more interesting is the information found in the *Matsya Purāṇa*. The account in this work runs thus: '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 loose any water). On the rising of the moon, the sea increases as if its waters have really increased. During the bright and dark fortnights, 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 the phases of the moon.'[16] This is a very important and interesting statement which is a parallel of the fundamental concepts 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.

3.6. *The Works of Kālidāsa*

Kālidāsa's *Raghuvaṃśa*, which excels not only in poetic beauty but provides a good deal of accurate observations, makes a reference to tides. While making a note on tides, the Sanskrit poet tries to give reasons for their causation thus: *mahodadhe: pur ivendu darśanāta*;[17] likewise in the fifth canto of the *Kumārasambhavam* he says: *harstukiñcita pariluptadhauryas candrodayārambha ivāmburāśi*.[18] These references point unmistakably to the author's personal knowledge of the ocean and its tidal phenomenon.

The causation of tides, as mentioned in the *Kāmandakiya Nītisāra*, is as follows: 'even as the moon affords delight into the mighty ocean.'[19]

3.7. *Period of Saṅgam Literary Works*

There are also certain passages in the Tamiḻ *Saṅgam* literature which specify the disturbance of the sea on the occasion of full moon by the term *uvavu*. The author of the *Aganānūru*, while indulging in the descriptive study of the *pālai* (dry or desert) tracts, observes: *urukeḻu peruṅgkadal uvavu-k-kiḻarnthāṅgu*, that is, 'the great sea (*peruṅgkadal*), which causes fear in the minds of people, rises (swells) with tumultuous noise on the full moon (*uvavu*) day'.[20] Similarly, the works like the *Puranānūru*, *Pattupāṭṭu* and *Silappadikāram* refer singularly to the day of disturbance of the sea by the term *uvavu*, the full moon day.[21]

The above-stated references from Sanskrit, Pāli and Tamiḻ literatures show that they are a mixture of observed facts, imagination and fancy. Nevertheless, they help us to get a grasp of the ancients' knowledge of tides. But the most disappointing factor is that none of the literary citations tend to mention the places of occurrence of the phenomenon.

3.8. *Observational Notices from the Foreign Accounts*

The evidences drawn from the writings of the Greek authors are much more precise than the passages cited from ancient Indian literary works. For they have recorded their observations on the basis of the places of occurrence of the phenomenon. The earliest, probably, is that of Herodotus (450 B.C.), the Father of History, whose reference to the phenomenon is very interesting. Because he recounts[22] the regular occurrence of tides in the Arabian Gulf (what we now term as the Red Sea); a phenomenon which always attracted the attention of the Greeks, to which they were unfamiliar due to the absence of easily perceptible tides in the Mediterranean. Since Herodotus has not recorded the cause for it, it is presumable that he might have obtained this correct information from the Egyptian informants. Further, we do not find in his work any information about this noteworthy phenomenon occurring in the waters of the Erythraean Sea (Indian Ocean). It is, therefore, quite evident that he had a vague or no idea at all about the open sea beyond the

Red Sea. But the significant point in his evidence is that he specifies the place of occurrence of the phenomenon.

3.9. *Alexander and the Erythraean Sea (Indian Ocean)*

Arrian's account of Alexander's military exploits in India in the *Anabasis* of Alexander includes a piece of scientific information which is not only authentic but also valuable from the point of view of our inquiry on the subject of tides. He makes distinct mention about the phenomenon of the *ebb and flow* at the Gulf of the Indus as observed by Alexander the Great.

According to Arrian, Alexander proceeded to explore the Indus up to the mouth after completing his military operation in the north-western part of India. About the end of July (325 B.C.), the invader reached the city of Pattala where the Indus bifurcated into two branches, thus forming a delta. Near Pattala the king constructed a harbour and a dockyard; and when the work had just begun he resolved to explore both the arms of the river down to the sea.

First, he started sailing down the western or right branch of the Indus. At the mouth of this branch where the king and his troops moored their vessels, the phenomenon of the *ebb and flow* of the sea water occurred.[23] His sailors, who were particularly familiar only with the tideless waters of the Mediterranean, were totally terror-stricken by observing the unacquainted and dangerous tidal waves that lashed the mouths of the Indus. Since they were unfamiliar with the tides and their effects, they could not possibly make out the real cause for them. Undaunted by the adverse nature of the sea at the Indus mouth, Alexander swiftly advanced forward with the best sailing ships and reached the 'outer sea' (the Indian Ocean which includes the Arabian Sea of today) of India. From the accounts of Arrian we further learn that the king then returned *via* the same branch of the river to Pattala where he again resolved to sail down the *Great Sea* by the other arm of the Indus to ascertain which branch of the river was easier to navigate. In his exploratory voyage, he with his thirty oared galleys passed beyond the mouth of the Indus, advanced into the open sea and finally confirmed that the outlet of the river on the eastern side was much easier to navigate than the other.[24] Although Arrian has left no information in his account about the phenomenon of tides at the mouth of the eastern arm of the river, it is, however, understandable that the behaviour of tides may have been less forceful than at the western arm. On the whole, Arrian is the first Greek writer who records the exact place of occurrence of tides and their resultant effects in the waters of the Indian Ocean.

3.10. *The Periplus Maris Erithrei*

The *Periplus Maris Erithrei* (the *Periplus of the Erythraean Sea*), written in the first century (A.D. 65) by an anonymous Egyptian or Greek navigator, is a

most remarkable work of that period. Apart from giving details of harbours, marts, anchorages, prevailing winds, local tribes and rulers, exports and imports and other particulars of the coastal regions of the *Erythraean Sea* (the Arabian Sea, a part of the Indian Ocean), the author records his personal observations about tides and the exact causes and effects of the phenomenon taking place in the Gulf of Barygaza (Sanskrit, *Bhrigukachchha*; Prakrit, *Bharukachchha*; and the modern Broach). He says that in India the seas 'ebb and flow' with tides of extraordinary strength, which increase with the moon both when new and full, and for three days after each, but fall off in the intermediate space (days).[25] The continuance of the high tides for three days after the full moon and three days after the new moon, as observed by the author, makes us to arrive at the opinion that what the author had watched carefully 'for three days each' were *spring tides*. For the *spring tides* take place near the time when the moon and the sun are either in opposition or conjunction and occur a day or two after the full moon and a day or two after the new moon. The anonymous author's details about the concept of the phenomenon are, indeed, remarkable and further he is the only Greek writer who gives a complete description of the adverse nature of the phenomenon on the coast of Kathiawar, about which we shall describe in length in the succeeding pages.

4. Tidal Range

Regarding the computation of the amplitude of tides, the Buddhist works commit glaring errors. For example, the *Samudravaṇika Jātaka*[26] speaks of tides of 'seven palm heights'. Likewise, the *Milindapañho* exaggerates the tidal range thus, 'a hundred, two hundred cubits high'.[27] It is curious to note such super exaggerations in the Pāli texts, for they, generally, give a good account of navigation and other allied information. These erroneous accounts are also contradicted by certain passages found in the *Purāṇas*.

The amplitude of tides given in the *Purāṇas* is almost mathematically accurate. 'The sea rises and falls according to the phases of the moon and 510 *aṅgulas* (nearly 32 feet) is the measure of its rise and fall on the two *parva* days (that is, the full moon and the new moon respectively).'[28] This *Purāṇic* account in all probability corresponds to the highest tidal range occurring even today at the Gulf of Cambay. 'Spring tides in the Gulf of Cambay rise and fall as much as 33 feet, and run at a velocity of 6 to 7 knots per hour. Ordinary tides reach 25 feet at $4\frac{1}{2}$ to 6 knots.'[29]

5. Effects of Tides

In the preceding pages we have seen the extent of the ancients' knowledge of the phenomenon and concept of tides. Now we shall discuss in detail the effects of the phenomenon and tidal currents in navigation on the

coastal areas of the subcontinent. It so happens that our evidence for studying the effects of tides is particularly plentiful through the works of Arrian, who narrated Alexander's achievements in India and the anonymous writer of the *Periplus of the Erythraean Sea,* which was intended as merchants' practical guide-book for Indian seas.

5.1. *In the Indus Delta*

In the last quarter of the sixth century (*c.* 510 B.C.), Scylax, a Carian of Caryanda, by the order of Darius Hystaspes, had descended towards the Sindhu (Indus) to its mouth, and from thence sailed round to the head of the Arabian Gulf (Red Sea). Unfortunately, Herodotus, who records the epic voyage of Scylax from 'east to west', appears to have possessed no details concerning the effects of tides near the mouths of the Indus. But this was subsequently followed in the next century by Alexander whose observations have been recorded for posterity by Arrian in his *Anabasis.* During his exploratory voyages along the two arms of the river, Alexander could not possibly find out the real cause of the phenomenon. Further, the dangerous tidal waves that lashed the mouths of the Indus caused 'great alarm and confusion among the navigators and considerable damage to the Flotilla'.[30] The effect of tides in the Indus is so great that it is indeed puzzling enough to attract the attention of more experienced modern navigators than those who had accompanied Alexander. The remarks of A. Burnes, the first explorer of the Indus in modern times, would be fitting in this context: 'The tides rise in the mouths of the Indus about nine feet at full moon and "flow and ebb" with great violence, particularly near the sea, where they flood and abandon the banks with equal and incredible velocity. It is dangerous to drop the anchor unless at low waters, as the channel is frequently obscured, and the vessel may be left dry.'[31] And there is no doubt, according to Arrian's account, that the rise and fall in the level of the sea near the Indus delta terrified the troops of Alexander and caused great damage to his fleet of warships.

5.2. *At Barygaza (the Modern Broach)*

The tidal effects on the western coast of India can be best explained by citing from the Periplus. The author's knowledge of tides in the Gulf of Cambay at the mouth of the River Nammados (Narmada) is a factual account, personally observed during his enterprise in the waters of the subcontinent and the general accuracy of his narration of the effect of tides in navigation compels our admiration.

Sailors who intended to reach Barygaza (Broach), which was the most important emporium of eastern trade, had to turn their course east for the mouth of the River Nammados (Narmada), that led to Barygaza, and the

distance from the mouth of the river up to this trading centre was reckoned to 600 stadia.[32] To get an access to the mouth of the Nammados from the sea was always difficult because of its narrow passage. Further, on the right, at the entrance of the river, was situated a narrow strip of shoal called *Herone*, rough and beset with rocks. On the left side of the passage was the promontory of *Papica*, where it was difficult to anchor from the strength of the currents and because the cables (ropes) were cut through by the sharp rocks at the bottom.[33] Even after securing the passage into the gulf, the mouth of the Nammados for Barygaza was not easy to hit. The reason attributed by the author was that the coast was low and there were no identifying marks to make out, apart from the presence of menacing shoals at the mouth of the river. In order to avoid such unfortunate accidents at the entrance of the gulf native fishermen appointed by government were stationed at the mouth of the river with well-manned long boats called *Trappaga* and *Cotymba*. From there they used to go as far as Syrastrene (Saurashtra-Kathiawar Peninsula) to meet ships particularly from West and pilot them up to Barygaza. At the mouth of the river, the pilot, after taking charge of the ship's head to keep her clear of the shoals, towed her from one fixed station to another moving with the beginning of the tide and dropping anchor at certain road-steads and basins when it was at low ebb.[34] Normally such basins occurred at points where the river was deeper than usual.

5.3. *Tidal Behaviour at Barygaza*

We learn from the *Periplus* how the departure from Barygaza (Broach) was made very difficult by the perilous effects of tide near the mouth of the River Nammados (Narmada). In detailing his experience the author has supplemented a study of tidal effects, with observation conducted *in situ* during his voyage to Barygaza as a Greek sailor. He says that in India the seas 'ebb and flow' with tides of extraordinary strength, which increase with the moon both when new and full, and for three days after each, but fall off in the intermediate space (days).[35] At Barygaza the tides were more violent than in any part of the western coast, for all of a sudden one could observe the depth laid bare, and portions of the land nearly turned into sea, and the sea, where the ships were sailing before turned without warning into dry land. The rivers, again, on the access of *flood-tide*, rushing into their channels with the whole body of the sea, were driven upwards against their normal course for a great number of miles with an irresistible force. It was because of this specific reason that ships frequenting this emporium were exposed to great risk, both during arrival and departure, if handled by sailors who were unacquainted with the navigation of the gulf or were visiting it for the first time. Further, ships could not be anchored in safety owing to the swiftness of tides, especially during the higher ranges.[36]

Large vessels, moreover, if caught in the tidal stream were driven away from their course by the rapidity of the current till they were stranded and wrecked, while smaller craft usually capsized. Other vessels, taking refuge in the side channels, were left dry by the receding tide, often turned over on one side. If not set erect on prows the boats turned over, got filled up and sank. During new moon especially when this occurred in conjunction with a night tide, the flood moved into such extraordinary violence that even in a calm sea the tidal roar could be heard sounding like the tumult of battle at some distance by those living near the river mouth.[37] Even now the tidal effect is felt for 40 km above Broach. The spring tides have a height of 7·5 to 9 metres at the mouth and 2·7 metres at Broach.

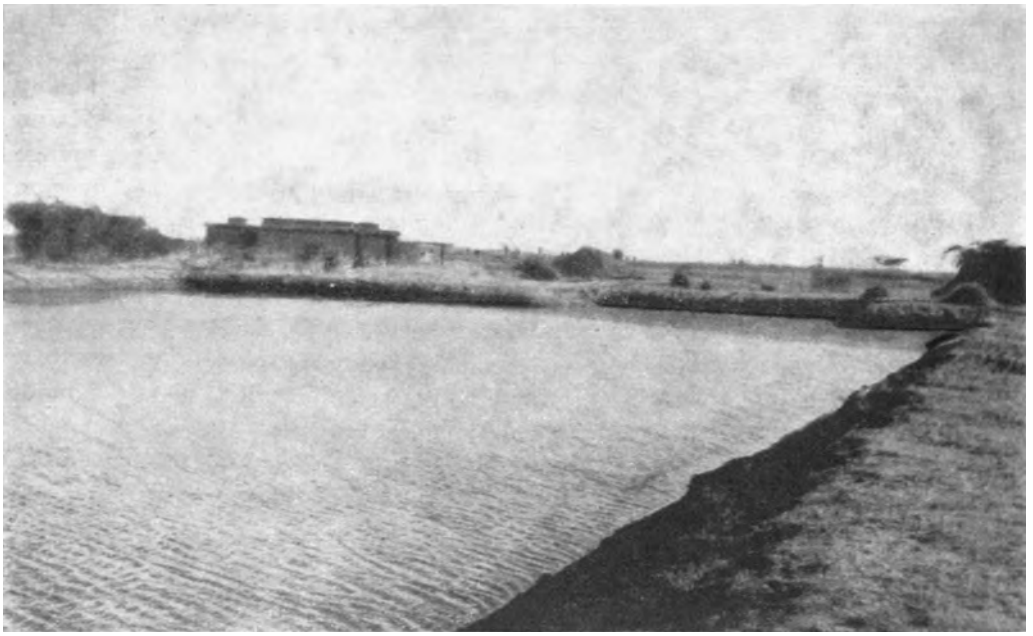
6. Utilization of Tides

6.1. *Lothal Dockyard (Proto-historic Period)*

The tides, notwithstanding all their adverse effects, have a useful application in navigation and shipping. The Lothal dock-builders were some of the successful pioneers in making full use of the tides, an important port which flourished during Harappan times on the coast of Kathiawar, where they had constructed a dockyard for developing coastal as well as overseas trade. At present Lothal is the name of an ancient mount in a site near Saragwala village, Ahmedabad district, and surrounded by the Sabarmati and Bhogava rivers. The site is now silt-laden but excavations carried out by the Archaeological Survey of India have shown five phases of structural activity in a total habitation-deposit of 6·46 metres. 'The first four phases are assigned to period "A" (2450–1900 B.C.) which represents the true or mature Harappa culture and the fifth to period "B" (1900–1400 B.C.) representing the late or degenerate phase of that culture.'[38]

The discovery of a dockyard, roughly trapezoidal in plan, situated at the eastern end of the mound, is the most important structure laid bare at Lothal in 1958–59 by the Lothal excavations project under S. R. Rao. It was built in Phase II and continued to be in use in Phases III and IV. The eastern and western embankments of this artificial enclosure for berthing and handling cargo are each 218·4 metres long; the northern measured 38·1 metres, and the southern 34·1 metres. The four walls are constructed out of kiln-burnt bricks, the maximum extant height of the embankment being 4·3 metres.[39]

The problem of sluicing from the estuary into the basin must have engaged the attention of the builders early in the construction of the dockyard. They solved this problem with the help of the original flow-channel of the river washing the western margin of the town and the ancient nullah provided access to ships, through the inlet-channel which is 7 metres wide and



Lothal dock showing the southern embankment with two corners; and the gap in the embankment shows the spillway. The building under construction in the background is the site museum of the Archaeological Survey of India. *Photo : N. K. Panikkar*

Another view of the Lothal dock; the figures on the left are standing near the western embankment. The loading platform on the western side, measuring 240 metres long and 23 metres wide, now submerged in water, was used for hauling goods. The extreme end of the dock shows the northern embankment.
Photo : N. K. Panikkar

2·5 kilometres long. It joins the eastern embankment at the inlet-gap which has the same width as the inlet-channel.

The inlet-channel, according to S. R. Rao, appears to have been built in Phase IV, after the river had suddenly changed its course about a mile west of its original channel at the end of Phase III.[40] Moreover, it has been ascertained on the basis of the extraordinary salinity of the accumulated silt in the basin and occurrence of estuarine shells that an arm of the sea used to reach the dock and the tidal waters entered the basin. The Director of Ports, Ahmedabad, who has carefully examined the structure says: 'It is, therefore, consistent to conclude on the basis of topo sheet and our experience that a sea passage to Lothal, approachable at high tide, existed. This leads to the dockyard.'[41]

Ships entering the Gulf of Cambay were sluiced into the basin at high tide through inlet-channel and similarly they had to leave the basin at high tide when the water level was maintained sufficiently high above the inlet-sill. To take care of likely scouring effect of the tidal waters, they constructed two buttress walls, one on either side of the inlet-gap in the eastern embankment. It is now well known that the Harappans had reached considerable competence in the management of drainage installations as compared with the then existing other civilizations. It would appear that the knowledge of hydraulics and methods of collection and discharge of water from their habitations were useful in developing ideas pertaining to inlets and outlets of tidal water.

The second channel noticed in the southern embankment runs at right angles to it. The vertical grooves on either side of its junction with the embankment were meant for inserting a wooden door with a view to closing the spillway for maintaining the required water level in the basin. The problem of automatic desilting was achieved by allowing excess water to escape through the spillway. And some more grooves provided at regular intervals in the side walls of the spillway must have been weep-holes. To counteract the thrust of water inside the basin the enclosure walls were buttressed on the outer face with 12 to 13 metres wide platform of mud-brick. The problem of ensuring floatation to ships at low tide was solved by the construction of abutments to the wall at the entrance of the dock. Technologically speaking, this arrangement is definitely an advanced one which even the dock-builders of the early historic period had not attained. Because at Ghoga, an early historical port south of Lothal, which is still in use, the ships get stuck up in the mud at low tide.[42] We may, therefore, affirm on the basis of the studies made regarding Lothal that this dock was purely tidal and the Lothal engineers had possessed sound knowledge of the tidal effects like erosion and thrust, apart from competence for receiving ships at high tide and ensuring floatation to ships at low tide inside the dock.

7. Conclusion

The ancients had, indeed, evolved the concept of the tidal phenomenon by connecting it with the moon. But it would be unfair on our part to expect from the ancients a thorough understanding of the phenomenon of gravitational attraction between two heavenly bodies. However, the basic and most important fact in their understanding is that they were able to make intelligent and relevant observations and connect the different tidal phases to the phases of the moon. There is something more than poetic speculation when it is stated that the moon and the oceans are intimately 'connected' in producing the tides. That the ancients failed to ascribe it to gravitational attraction hardly matters in our discussion here, because the concept of gravitation had to wait for several centuries till the appearance of Newton. It was the Harappans who were some of the early users of tidal phenomena and they exploited its effects purposely for sluicing and berthing ships in the dockyard at Lothal.

References

[1] Rao, S. R., Further Excavations at Lothal, *Lalit Kala*, No. 11 (April 1962), Lalit Kala Akademi, p. 17.

[2] Tripathi, Maya Prasad, *Development of Geographic Knowledge in Ancient India* (Varanasi, 1969), p. 135.

[3] *Sāmaveda*, ch. 10, part II, 20 (*Uttaracika*), Eng. trans. by J. Stevenson (London, 1892).

[4] *Taittirīya Saṃhitā*, IV, 2.8.1, Eng. trans. by A. B. Keith, two parts (Cambridge, Massachusetts, 1914).

[5] *Vājasaneyi Saṃhitā*, VIII, 28, Eng. trans. by R. T. H. Griffith (Banares, 1899).

[6] *Śatapatha Brāhmaṇa*, IX, 1.2.3, Eng. trans. by J. Eggeling, in five parts, Sacred Books of the East (Oxford, 1882–1900).

[7] Radhakrishnan, S., *The Principal Upaniṣads*, IV, 2 (London, 1953), p. 809, George, Allen and Unwin Ltd.

[8] *Rāmāyaṇa*, I, 55.20; II, 6.27; V, 1.10; VII, 29.12.

[9] *Ibid.*, I, 55.20.

[10] *Ibid.*, II, 6.27.

[11] *Mahābhārata*, I, 2.11 and V, 151.56.

[12] *Ibid.*, VII, 159.73.

[13] *Jātaka*, No. 466, Eng. trans. by E. B. Cowell, 7 vols. (1897–1917).

[14] *Viṣṇu*, ansa II, sec. 4, verses 87–91; *Matsya*, 123.30–34; *Sacred Books of Hindus*, 2 vols. (Allahabad, 1916–17); *Agni*, 119.25–26; *Brahmāṇḍa*, XIX, 131–36; *Brahma*, XX, 91–94; *Vāyu*, 49.127–31.

[15] *Viṣṇu Purāṇa*, Eng. trans. by H. H. Wilson, ch. IV, in five vols. (London, 1864–70), p. 201.

[16] *Matsya*, op. cit.

[17] *Raghuvaṃśa*, III, 7; XVI, 27, Eng. trans. by Sir William Jones (Calcutta, 1901).

[18] *Kumārasaṃbhavam*, III, 267.

[19] *Kāmandakīya Nītisāra*, ed. by R. Mitra, *Bibliotheca Indica* (Calcutta, 1884); Eng. trans. by M. N. Datta (Calcutta, 1896), p. 4, Tripathi, Maya Prasad, *op. cit.*, p. 142.

[20] *Aganānūru*, verse 201, line 9, ed. by N. M. Venkataswami Nattar (Madras).

[21] *Puranānūru*, verse 65, lines 6; *Paṭṭinapālai*, lines 101–102, one of the Ten Tamil Idylls (*Pattupāṭṭu*), Eng. trans. by J. V. Chelliah, Colombo; *Śilappadikāram*, IV, 111, Eng. trans. by V. R. Ramachandra Dikshitar (Oxford University Press, Madras, 1939).

[22] Herodotus, Book II, 11.

[23] Arrian, *The Anabasis of Alexander*, VI, ch. xix; Eng. trans. by J. W. McCrindle, *The Invasion of India by Alexander the Great.*

[24] Arrian, *op. cit.*

[25] *The Periplus of the Erythraean Sea*, ch. 45, Eng. trans. with notes by Wilfred H. Schoff (New York, 1912).

[26] *Jātaka*, No. 466, *op. cit.*

[27] *Milindapañho*, Eng. trans. by Rhys Davids, Vol. II, iv, 6.57.

[28] *Matsya Purāṇa*, op. cit.

[29] *Imperial Gazetteer of India*, first edition, IX, p. 297.

[30] Arrian, *op. cit.*

[31] *Travels*, Vol. I, p. 217; *Journal of Geographical Society*, III, p. 120; and *The History of Ancient Geography*, by E. H. Bunbury, Vol. I, p. 448.

[32] *Periplus*, ch. 44.

[33] *Ibid.*, ch. 43.

[34] *Ibid.*, ch. 44.

[35] *Ibid.*, ch. 45.

[36] *Ibid.*

[37] *Ibid.*, ch. 46.

[38] Rao, S. R., with contributions by B. B. Lal, Bholanath, S. S. Ghosh, and Krishna Lal, Excavations at Rangpur and other Exploration in Gujarat, *Ancient India*, Nos. 18 and 19 1962–63 (1963), *Bulletin of the Archaeological Survey of India*, pp. 178 and 180. The dates of Lothal 'A' (2450–1900 B.C.) and 'B' (1900–1400 B.C.) have been determined on the basis of Carbon-14 method.

[39] ———— Further Excavations at Lothal, *op. cit.*, p. 17.

[40] ———— with contributions by B. B. Lal, Bholanath, S. S. Ghosh, and Krishna Lal, *op. cit.*, p. 179.

[41] ———— *op. cit.*, p. 18; Also U. P. Shah in the *Journal of the Oriental Institute, Baroda*, IX, pp. 310–20.

[42] ———— *op. cit.*, p. 28.