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【資料·解説】
(Review)

Morphology and evolution of lagoons on the east coast of India

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Abstract: The few available remote sensing studies on the lagoons along the east coast of India have indicated significant geomorphic features in and around these coastal wetland ecosystems. Lake Chilka, the largest coastal lagoon in India, exhibits rocky erosional features such as headlands, sea cliffs, sea stacks, etc., along its landward margin, suggesting it to be an open coast probably during the late Pleistocene. The 8 km wide beach ridge/barrier spit belt that separates Lake Chilka from the open sea appears to have formed after the Holocene transgression. Lake Kolleru which is sandwiched between the Krishna and Godavari deltas, though being much inland and fresh water lake at present, was in fact a coastal lagoon, presumably formed along the coast during the Holocene transgression. Lake Pulicat, the second largest lagoon, on the other hand, appears to have formed very recently, apparently after the development of the third strandline along the east coast whose age is surmised as 1,500 years B.P. The existence of a number of islands in these lagoons which appear to be the detached portions of the earlier formed beach ridges including those of the third strandline series (the youngest) suggests either the subsidence due to tectonic activity, or sediment compaction, or a slight sea level rise in the recent past. Detailed morpho-stratigraphic studies are necessary for a proper understanding of the evolution of the lagoons along the east coast of India.

Key words: lagoon, beach ridge, former strandline, the east coast of India

インド東海岸におけるラグーンの地形とその発達

日本語摘要

インドの東海岸沿いには，世界有数の面積を持つチルカ湖や，コレルー湖，プリキャット湖などの大型ラグーンが分布する．北部のチルカ湖では，内陸側に現在も海食崖や離れ岩のような浸食地形を持つ一方，数列の浜堤群あるいはバリアーによって，ベンガル湾から隔てられている．広大な流域面積を持つクリシュナデルタと，ゴダバリデルタに挟まれているコレルー湖は，浜堤列の急速な前進により陸封されて，外海から35kmの内陸にあり，僅かに夏季に汽水化するのみである．プリキャット湖は，1,500年前以降に形成されたバリアーおよび浜堤によって成立した新しいラグーンである．いずれのラグーンの形成も，完新世海進頂期以降の，大きく分けて三帯の浜堤群形成と関係するとともに，地盤運動や堆積物の圧密も影響していると見られるが，その詳細は，今後の研究に待つところが大きい．

キーワード：ラグーン，浜堤，旧期海岸線，インド東海岸

1. INTRODUCTION

The east coast of India is characterized by the existence of a number of lagoons some of which include the largest of that type in the world. Of all, Lake Chilka in the state of Orissa is the largest, covering an area of about 860 sq.km (Fig.1). The second largest is Lake Pulicat, in the state of Andhra Pradesh, with an area extent of 360 sp.km. Another one, also in the same state, is Lake Kolleru Located about 35 km inland from the coasts. Though Lake Kolleru is at present a shallow fresh water body, itwas in fact a coastal lagoon at the time of its origin in the geological past. Apart from these larger

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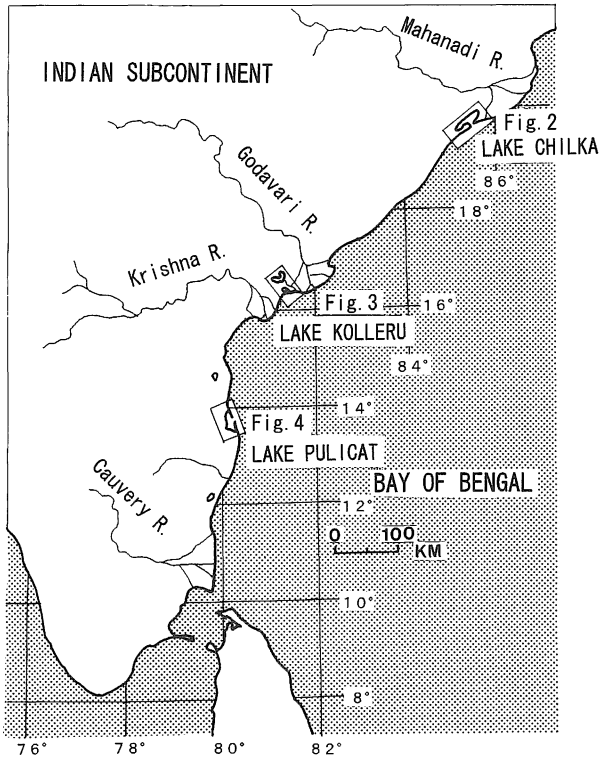

Fig. 1. Location of lagoons described

ones there are many other lagoons of smaller size all along the 2,300 km long east coast which is essentially a progradational coast with a number of major rivers building their deltas at regular intervals. While quite a good number of studies have been made over the last two decades on the geomorphic evolution of the east coast deltas of India, there are hardly any studies on the geomorphology of the lagoons of the region, except a couple of attempts of a preliminary nature. The coastal lagoons are dynamic ecosystems effecting the human activities in and around their location. A thorough knowledge of the landforms and their spatial and temporal variations in the lagoons is essential in understanding not only the evolution of these saline/brackish water bodies but also the changes that are occurring in these fragile wetland environments.

This paper is an attempt to bring together the available information on the geomorphological aspects of the three major lagoons along the Indian east coast, namely, the lakes, Chilka, Kolleru and Puricat, and to interpret the similarities, if any, in the evolution of these landforms highlighting the need for detailed investigations.

2. LAKE CHILKA

Lake Chilka, located at the southern end of Mahanadi delta is the largest coastal lagoon in Asia (Fig.2). The long axis of the pear shaped lagoon is oriented in a northeast-southwest direction, parallel to the coast over a length of about 64 km, while the width is variable with a maximum of about 20 km at its northern side and gradually tapering towards south. The Eastern Ghat hills fringe the western and southern margins of the Lake while on the eastern side, a belt of about 8 km wide sandy beach ridge and barrier spits separate this lagoon

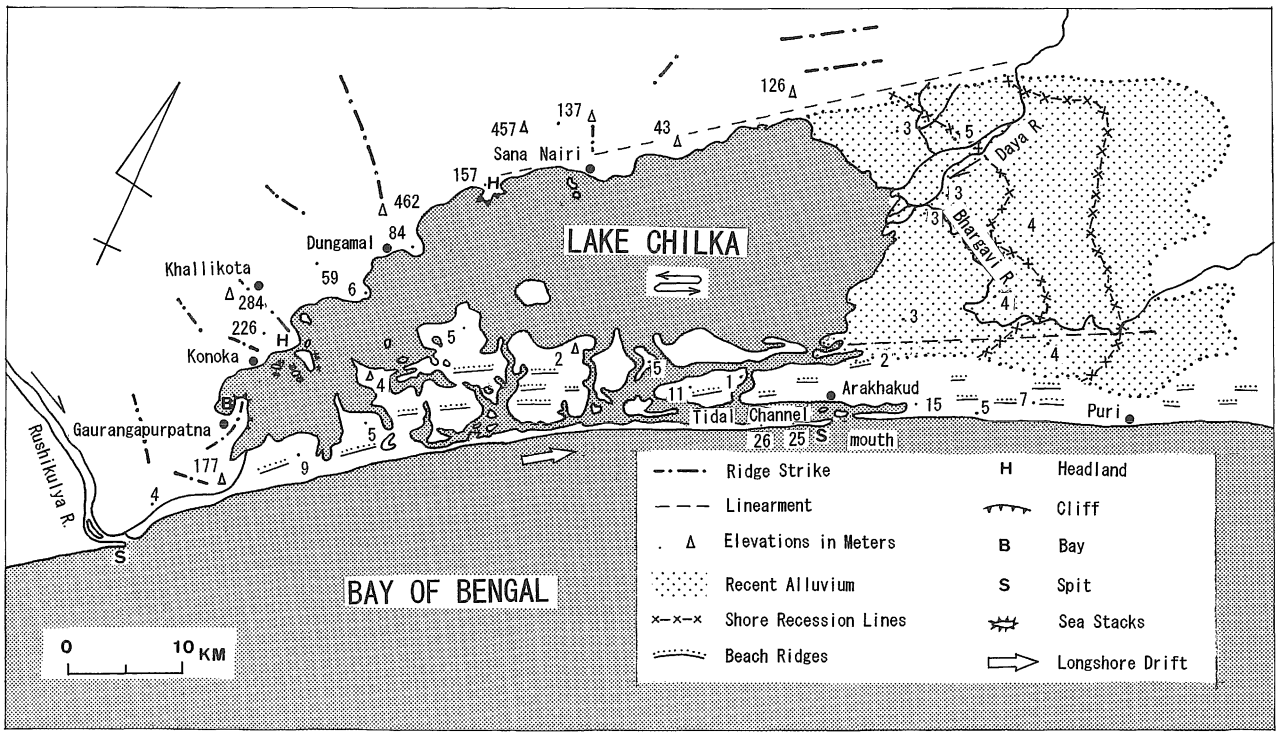

Fig. 2. Landform around Lake Chika

from the Bay of Bengal. Although the area of the Lake is seasonally variable, it spreads over an area of about 860 sq.km, as can be measured from the Survey of India topographic map published in 1929.

This lake is connected to the Bay of Bengal through a tidal inlet whose mouth, located southeast of Arakhakud village, is about 130 meters at its widest. The tidal channel branches into a number of distributary creeks which cuts across the 8 km wide beach ridge/barrier belt at several points, and flow in their characteristic winding courses into the lagoon. As a result, the sandy beach ridge/barrier plain between the lagoon and the sea is cut into a number of islands surrounded by tidal creeks and the lagoon waters. Apart from these islands, there are a few more smaller islands within the main water body of the lagoon, most of which are rocky, especially along its western and southern margins, while some of them are of emerging type.

Lake Chilka is very shallow with an average depth of about 1.5 meters in its northern sector and about 2.5 to 3.0 meters in its southern part with an overall seasonal increment of about 1 meter (Sinha, 1990). A number of inland streams drain into this lagoon of which two distributary courses of the Mahanadi river, namely, Daya and Bhargavi are the major ones, while the rest of them are very small, by and large, originating on the Eastern Ghat hillslopes facing the lake. Owing to these streams decanting into it, the lagoon turns seasonally into a fresh water body, as indicated by its highly variable salinity levels from 0.2 parts per thousand in August to 34 parts per thousand in May (Misra, 1990).

Geomorphic Features: Interpretation of topographic maps and satellite imagery, coupled with field checks, has revealed a variety of erosional as well as depositional landforms along Lake Chilka margins. The most prominent erosional landforms found are headlands and bays, sea-cliffs and sea-stacks, while the conspicuous depositional features are alluvial plains, beach ridges, and spits.

Several strike ridges of the Eastern Ghats splay almost at right angles to their general NE-SW trend and run into the lake. For instance, the 20 km long ridge running in a NW-SW direction immediately north of Dungamal village, and another 8 km long ridge striking in a WNW-ESE direction located immediately south of Khallikota, are protruding into the lagoon. Apart from these two prominent ones, there are other smaller ridges in the area running into the lake as headlands with, more or less, similar trends. The headlands are separated by crescentic bays.

The slopes of most of the headlands facing the lake are very steep giving rise to cliffs at different places. The cliffs located at the lakeward side of the Khallikota ridge northeast of Konaka, southwest of Sana Nairi and to the east of Gaurangapurpatna in the extreme southern portion of the lake are some of fine examples of typical sea cliffs. Numerous rocky islands with different sizes are present all along the western and southern margins of the lake, close to its shore. The position of these rocky islands vis-a-vis the headlands suggests that these rocky islands were perhaps the continuation of the headlands, which must have separated from the mainland by marine erosion. Extensive alluvial plains are fringing the Lake, especially on its northern side. Daya and Bhargavi rivers which are the southern most distributaries of the Mahanadi river join the lake from this side, in addition to several other ephemeral streams that drain the nearby hillslopes.

A large alluvial plain covering an area of 640 sq.km is fringing the lake on its northern side. This low lying monotonous plain which is around 4-5 meters above the sea level is obviously built by the Recent sediments. It is interesting to note that Bhargavi river exhibits not only intricate meandering but also turns westwards from its general southeast direction and flows almost in an opposite direction for about 11 km, and takes a further turn at right angles before joining the lake. This aspect of the river flow here may indicate the extremely gentle gradient of the area. Moreover, the two distinctly discernible shore terraces in this plain not only parallel each other, but also prallel to the present shorelines of the Lake. This perhaps marks the shoreline recession due to continuous deposition and consequent emergence of the lagoon floor.

A number of sandy beach ridges are present along the eastern margin of the lake over a width of 8 km separating it from the open sea. There are several individual ridges lying parallel to one another and running over a length of about 75 km from south of Puri town till almost up to the southern part of the lagoon all along its length. Each ridge represents a former shoreline that has stranded inland with the progradation of the coast. Some of these ridges rise up to 5-6 meters above the sea level and each is separated from its adjacent ones by characteristic swales which in turn are occupied by tidal creeks

and /or salt marshes.

The open coast of Lake Chilka is marked by the presence of a prominent spit connected to the main land at its southern end. The outer margin of the spit facing the open sea is straight, while the lagoonal side is irregular with a number of cuspate projections each representing an earlier hooked head of the growing spit. Sand dunes of varying heights which at places as high as 26 meters dominate the entire length of the spit surface indicating high energy winds in the region. It is obvious, from the orientation of the spit and the traces of the earlier spit heads, that the spit has grown from southwest by the longshore drift of the sediments, perhaps, from the Rushikulya river which is located at the southern end of Lake Chilka. The existence of a longshore component from southwest to northeast in this region is also indicated by the nature of the Rushikulya mouth itself which shows a northerly deflection by the growth of another spit across its width.

The spit while extending towards northeast is deflecting the mouth of the tidal channel in the direction of its growth. The orientation of the spit and the tidal channel parallel to each other indicates this phenomenon. The mouth of the inlet which was about 1.6 km wide in 1780 (Venkataratnam, 1970), has decreased to a mere 90 to 130 meters (Das et al, 1990), obviously due to the growth of the spit.

Evolution: The presence of the headland and bay topography, and especially the sea cliffs and sea stacks along the western and southern margins of Lake Chilka indicates that this part was exposed to open wave action during the geologic past, suggesting it to be the initial coastline. In the absence of any accurate data, it is tentatively surmised that the formation of the erosional features might have taken place during the later stage of the Pleistocene, or, latest, at the time the maximum Holocene transgression, prior to the formation of the beach ridge on the eastern side of the lake (Nageswara Rao and Srinivasa Rao, 1992). A prominent lineament can be seen in a northeast-southwest direction parallel to the long axis of the lake all along its western margin, indicated by from the satellite imagery, suggests possible neotectonic activity. A result of this is that the area to the east of the lineament was floundered, and subsequently occupied by the invading sea.

The deposition of the beach ridges and the spit which enclosed a body of sea water resulting in the formation of Lake Chilka took place much later, perhaps, during the later part of the Holocene. The subsurface data as interpreted by Venkataratnam(1970), based on 12 auger holes from different parts of the eastern and southern margins of the Lake has led to some interesting results. Extensive beds of estuarine molluscan shells composed of *Arca granosa* and *Meretrix casta* are found at about 6 to 8 meters above the present mean sea level on the southern shores of the lagoon, and in the creeks and ridges. These organisms are presently found in the main tidal channel. Further, a shell bed of *Ostrea Virginiana*, Placentata and *Champ sp.*, the types of which at present are only found in the offshore regions, was also observed from the core samples collected at the southern margin of Lake Chilka near Gaurangapurpatna village. The shelly layer is embedded in the sandy sediments which overlie a 60-90 cm thick calcrete layer which in turn rests on the basement rock. C-14 dating of a shell of *Ostrea,* picked up from the core, has indicated an age of 3,750 ± 200 years B.P. In view of evidence elsewhere along the east coast of India, which indicated higher sea levels of about 4 to 5 meters than present about 6,000 years B.P. (Nageswara Rao and Sadakata, 1993), it may be inferred that Lake Chilka region was submerged under the Holocene transgression and has formed a part of the open sea during which period the shell beds as reported by Venkataratnam (1970) were deposited.

However, the elevation of the shell beds at about 6 to 8 meters above the present sea level, may be inferred, as Venkataratnam (1970) opined, to be the consequence of a minor tectonic uplift along the eastern margin of the lake as indicated by the lineament that is identified in this study as running along the inland margin of the beach ridge belt. Perhaps, this tectonic movement has triggered the growth of barriers right across the eastern side of the lagoon, thus separating it from the sea. Subsequent coastal progradation due, perhaps, to the sea level lowering, and/or deposition of sediment by long shore currents has resulted in the widening or the barrier spit/beach ridge belt. The fact that this beach ridge belt is cut across by a number of tidal channels and creeks suggests a much more recent submergence of the area.

3.LAKE KOLLERU

Lake Kolleru is situated in between the large deltas of Krishna and Godavari, occupying a seasonally variable area of about 300 sq.km with a maximum depth of about

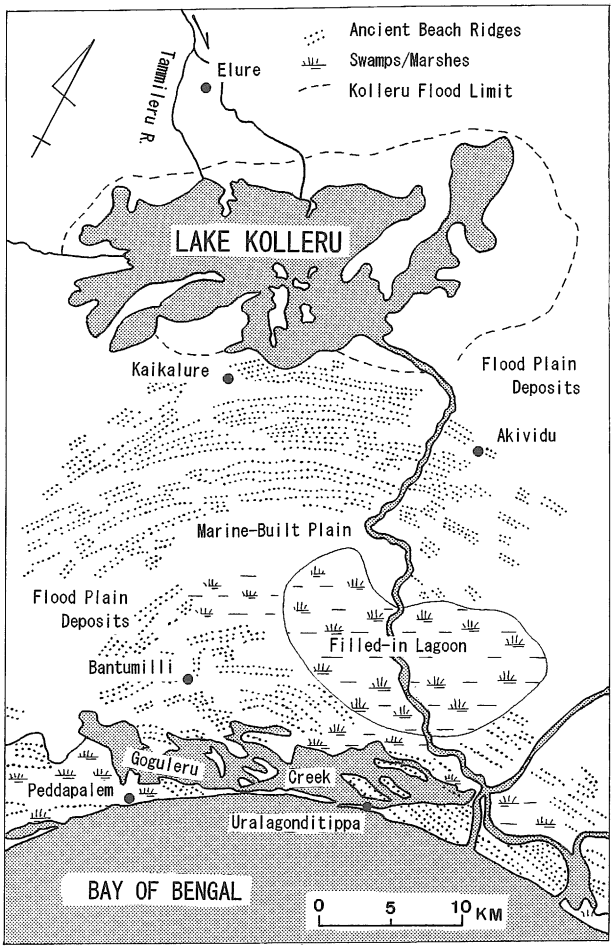

Fig. 3. Landform around Lake Kolleru

3 meters at its center (Fig.3). The seaward (southern) margin of the lake is about 35 km inland from the present coast. Although Lake Kolleru is essentially a fresh water lake, apparently it was initially formed as a coastal lagoon (Nageswara Rao, 1985).

Geomorphic Features: Interpretation of aerial photographs and satellite imagery has revealed a variety of landforms in an area covering about 2,100 sq.km between the Krishna and Godavari deltas which is known as inter-delta area. The most striking feature of all is Lake Kolleru itself, besides a number of relict sandy beach ridges, tidal marshes, and finally lagoons and spits along the present coast. Quite a number of low, narrow, elongated and nearly parallel sets of sandy ridges separated from one another by swales are existing right from the immediate vicinity of the seaward (southern) margin of Lake Kolleru, each representing a former shoreline. Interestingly, the orientation of these ridges especially close to Lake Kolleru is curvilinear, exactly similar to the trend of the present coast far southward. Based on the difference in the orientation of various sets of beach ridges, about three strandlines were surmised in the area (Nageswara Rao, 1985). These strandlines reflect a former periodical coastal change after a long stationary state The set of curvilinear ridges located immediately south of Lake Kolleru over a width of 10 km, belong to the first strandline. North of Bantumilli village, the ridge are not only straight but also vary considerably in their orientation with those of the first strandline. These perhaps belong to the second strandline. Again the ridges are curvilinear south of Bantumilli bending towards Goguleru creek the present lagoon along the coast. These ridges may belong to the third strandline. These ridges may belong to the third strandline. The present coastline appears to have a slightly different orientation as it obliquely cuts the ridges of the third strandline as can be seen to the east of Peddapalem and Uralagonditippa villages.

To the south of Lake Kolleru and the 10 km wide curvilinear set of the beach ridges of first strandline, there is a large tract of low-lying marshy land covering about 135 sq.km area. But for an occasional tidal inundation along the few tidal creeks that traverse some parts of it, most of this area is dry and covered with reed and grass. Sedimentological studies made by Shanmukha Rao (1980) in the inter-delta area has indicated a high concentration of clay (up to about 70% as against 10-20 % in the surrounding areas) and organic matter content (up to 5 % as opposed to the 1-2 % in other areas wherever present), in this marshy area, which is mostly dried up at present. The isolines of clay and the organic matter content percentages form into concentric circles with higher values towards the central parts of the area. This phenomenon is suggestive of the existence of the higher existence of a lagoon in this part sometime in the past which was subsequently filled in and dried up.

Another interesting feature in the inter-delta area is a 70 sq.km spread of sea water body locally called the Goguleru Creek. This elongated lagoon is separated from the open sea by a long narrow spit grown the west. It may be noted that the islands in the Goguleru Creek appear to exhibit a similar trend as that of the beach ridges on both northwestern and southeastern ends of it, indicating that the islands could be detached parts of the same beach ridges.

Evolution: Generally lagoons are formed along the progradational coasts by the development of barriers/spits somewhere offshore parallel/sub-parallel to the

existing coast, thereby separating a body of sea water from the main sea. Thus, the initial coastline is expected to be on the landward side of the lagoon. However, lagoons may also be formed due to submergence of land. The presence of beach ridges abutting Lake Kolleru on its seaward side invariably suggests that the lake was along the ancient coast and that it could be a lagoon. However, it is hard to believe that this lagoon has developed due to the progradation of the coast as there is no evidence even sedimentologically (Shanmukha Rao, 1980) of the presence of sandy clasts to suggest the existence of the initial coast on the landward side of the lake (south of Eluru town). Therefore, it should be presumed that Lake Kolleru was formed due to the submergence of land when the coastline was along the Kaikaluru-Akividu, perhaps during the maximum Holocene transgression. The other logoons along deltaic coast in this area are being filled up rather rapidly. Lake Kolleru still continue to exist because of its location in a regional tectonic depression which is severely and repeatedly subjected to faulting (Sastri et al, 1973).

As the coastline was progressively advanced into the sea , the lake became farther and farther inland and hence the deposition in it by marine agents has become negligible. Moreover as the lake is fed by two rivulets namely the Budameru and Tammileru with a combined catchment of 5120 sq.km to the north of the lake, it has turned out to be a fresh water body. However, the lake still maintains its connection with the sea through a single 40 km long tidal channel, Upputeru (meaning, salt stream), a typical lagoonal characteristic. The result being the lake water turns brackish in its southern margin, especially during summer months.

Unlike Lake Kolleru, the second lagoon which formed after the initiation of the second strandline and by the growth of spits and barriers, underwent a natural sequence of evolution and is now completely filled up. The 132 sq.km dried up marshy area south of the 10 km wide curvilinear beach ridges of the first strandline, represents the filled-in-lagoon which, in fact, evolved after Lake Kolleru came into existence. The present lagoon along the inter-delta coast (the Goguleru Creek) is the third of its kind in the region and is separated from the second (filled) one by a set of beach ridges. Like in the case of Lake Kolleru, the third lagoon also appears to be formed by the submergence of land as suggested by the cut off portions of the beach ridges appearing as islands in this lagoon. This suggests a comparatively recent transgression of the sea in this part, just before the development of the spit between Paddapalem and Uralagontippa. On the whole, the area between the Krishna and the Godavari deltas exhibits several sets of beach ridges separated by lagoons, developed as a result of a general progradation of the coast, with intermittent episodes of submergence either due to sea transgression or subsidence or both.

4. LAKE PULICAT

Like Lake Chilka and unlike Lake Kolleru, Lake Pulicat is right on the coast at the southeastern end of the state of Andhra Pradesh. Extending over an area of about 360 sq.km measured up to the high water line, and excluding 18 sq.km area of 10 km long tidal channel that connects the lagoon with the sea and the area occupied by the islands in the lake, Lake Pulicat is the second largest lagoon after Lake Chilka along the east coast of India (Fig.4). The landward margin of the Lake as a whole, including the dried up part, resembles an arc of a circle from Durgarajupatnam in the north through Kalluru, Sulurpet, Tada, Sunnambukulam (progressively westward and southward) and finally up to Pulicat village at its southern end. The lake is separated from the open sea by a narrow elongated strip of land built of sand ridges which, in fact, comprises of two barrier spits. The seaward margin of the northern spit grown from Durgarajupatnam southward is straight, while the other spit grown northward from Pulicat village is smooth and concave. The head of the southern spit which is called "Sriharikota" is very broad, measuring up to 8 km normal to the coast. The combined length of these two spits between durgarajupatnam and Pulicat village is about 63 km. The tidal channel that connects the lagoon with the sea opens into the sea just to the north of Pulicat village. Although the over all area of the lake between the semicircular landward margin and the spits is about 620 sq.km, (excluding the area occupied by the islands) about 260 sq.km of the lake in the northern half is dried up. Quite a number of islands are present in the lake body including the dried up portion occupying a total area of 120 sq.km with about 95 sq.km island area in the abandoned (dried up) part and about 25 sq.km in the active part of the lagoon. Thus, the whole area of Lake Pulicat, including the islands, is about 740 sq.km.

Geomorphic Features: One of the most prominent

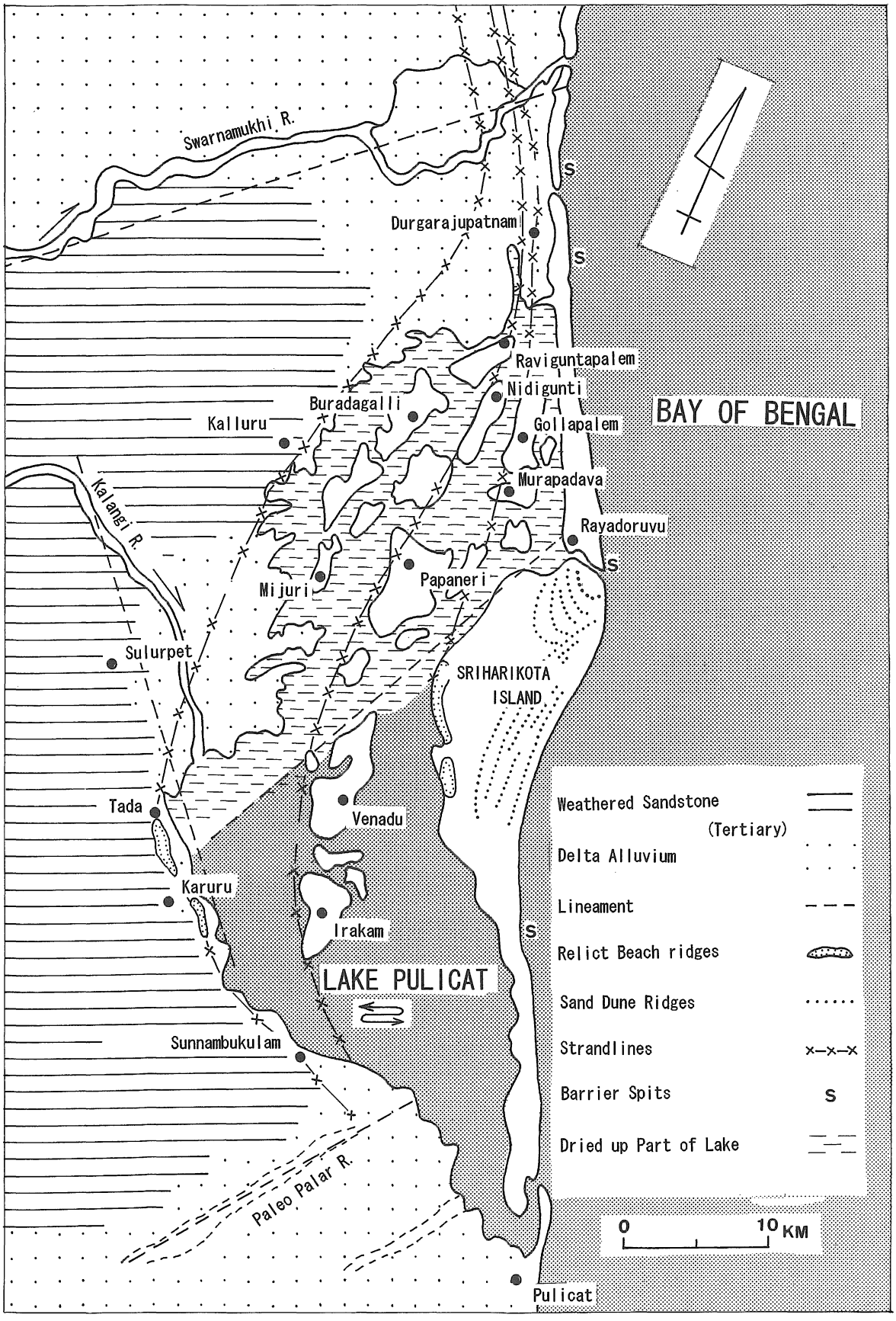

Fig. 4. Landform around Lake Pulicat

features of Lake Pulicat is the existence of many islands. The orientation of these islands, more or less parallel to the coast in several series, suggests that these are the remnants of a number of beach ridges spread all along the width of Lake Pulicat. This inference is also supported by the sedimentological studies of Durgaprasada Rao and Poornachandra Rao (1974), which indicated that the submerged portions around these islands are sandy, meaning that the islands were much larger earlier and perhaps continuous before submergence.

Lake Pulicat is bound by two prominent faults-one to the north along which the Swarnamukhi river is flowing, and the other to the south along which the paleo course of the Palar river used to flow (Narasimhan, 1990; and Ravi Kumar et al , 1994). Besides these two, a third lineament is inferred as running along the western margin of the Lake, through Sururpet, Tada and further south. Perhaps the abrupt bending of the Kalangi river at right angles towards south and straight course thereafter till it joins the calm lagoonal waters of the Puricat Lake, coupled with the straight segment of the western margin of the lake itself from Tada southward, suggests neotectonic activity along this line. Another linearment is also inferred as running in a northeast-southwest direction right across the lake between Tada on the landward margin to Rayadoruvu on the coast. Interestingly, the linearment separates the dried up part of the lake from that of the present water body.

The landward margin of the Lake Pulicat exhibits varied geology. While the northern portion is marked by the deltaic alluvium of Swarnamukhi river, the paleo Palar delta alluvium bounds the southern side. Deeply weathered Tertiary sandstones fringe the western margin of the lake except in the central part just north of Tada where Kalangi river joins the lake and builds a small bird foot delta bisecting the territories. Further, in a narrow zone between the sandstone terrain and the landward shore of the lake, lies a strip of low sandy ridges in patches, which are discerned as the remnants of the beach ridges (Ravi Kumar et al, 1994). The predominance of sand in the lake bottom sediments in a narrow strip along its western margin (Durgaprasada Rao and Poornachandra Rao, 1974) corroborates the existence of beach ridges which are submerged at present.

Evolution: Lake Pulicat seemingly owes its origin to tectonics. Based on the available information, it is presumed that the Holocene transgression of the sea occupied a preexisting regional depression bound by faults and thus a bay has resulted. Continuous supply of sediments by the Palar river in the south and Swarnamukhi in the north into the bay, by seasonally variable longshore drift, has filled the bay in the form of a series of beach ridges. A result being that the coast has advanced into the sea like most of the east coast region. This inference is also supported by the heavy mineral analysis of the lake floor sediments by Durgaprasada Rao and Poornachandra Rao (1973).

Based on the orientation of the beach ridges, three strandline are surmised in the area, similar to other part of the east coast of India, each representing a major change in the coastal configuration mainly due to lowering of sea level as inferred elsewhere along the coast (Nageswara Rao and Sadakata, 1993). Thus, the islands of Raviguntapalem, Buradagalli and Mijuri including the sand ridge patches on the landward side of the lake near Tada and Karuru form the first strandline. The second strandline runs along the islands of Nidigunti, Papaneri, Venadu and Irakam, while the third one is inferred along the Gollapalem, Mulapadava and the western part of the Sriharikota Island. Thus, at some point of time (late Holocene?), after the formation of the third strandline, the bay must have been almost filled up and emerged as land, may be with intermittent marshy areas between strandlines. Lake Pulicat came into existence only later, probably by the invasion of the sea, perhaps due to subsidence (tectonic) along the western margin of the Lake. This is indicated by the linearment that might have also guided the Kalangi river, which till then was perhaps a tributary of Swarnamukhi, to turn abruptly southward and flow in a straight course as an independent river into the lake. If the age of the third strandline along the east coast as inferred by Nageswara Rao and Sadakata (1993) as around 1,500 years B.P. is any indication, the formation of Lake Pulicat must be younger than that period.

Thus, when the lake was formed, it was occupying an area of about 620 sq.km submerging the beach ridges while some portions of them remain as islands. Subsequently, there must have been another minor tectonic activity along the Tada-Rayadaruvu linearment as a result of which the northern part of Lake Pulicat emerged and therefore dried up. The tidal channel south of Rayadaruru that separates the two spits, probably used to carry sea water back and forth into the northern portion of the lagoon also got filled up. The fact that the submerged portion of the sandy beach ridges have still

remained sandy without much of a clay/silt cover over them, which normally constitutes the floors of lagoons, indicates the recency of the submergence.

5. CONCLUSION

The preliminary geomorphic analysis of some of the lagoons along the eastern seaboard of India has indicated a Holocene origin for these coastal sedimentary depo-centers. The existence of a partially submerged former beach ridges as islands in Lake Chilka, Goguleru Creek between the Krishna and the Godavari deltas, and Lake Pulicat suggests a definite possibility of a recent trans-gression of sea either by subsidence of land due to tectonic activity or a slight rise in the sea level. Probably detailed morpho-stratigraphic studies, supplemented by dating, would lead to a better understanding of the evolution of the lagoons on the east coast of India.

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