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RESEARCH ARTICLE

Morphological Reconstruction of Southern Mahanadi Delta and Chilika Lagoon, India – a critical study

Siba Prasad Mishra [1], Joygopal Jena[2]

1. Assistant Professor (Civil Engineering Department), Research Scholar, Centurion University of Technology, and Management, Bhubaneswar

2. Professor, Institute of technical Education and Research (ITER) SOA University, Bhubaneswar

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Corresponding Author

Siba Prasad Mishra

Abstract

Rivers in Odisha are ephemeral and east flowing. Among six major deltas Mahanadi is the largest. This delta has undergone a number of paleo-climatic changes from pre-Cambrian age till date. It has coastal length of 150km and spread an area of 9500 km^2. The distributaries of Mahanadi have developed number of anabranches and anastomised in its costal stretch. Chilika lagoon, attached to the delta, covers an average area 1045sqkm is the largest lagoon in Asia. The tarn is presently under environmental strategies for required flushing flow. 61% of inflow of the lagoon is received from Mahanadi system through its southern branches, Daya and Bhargovi. The Lagoon is a river estuary and act as a balancing reservoir for Daya and Bhargovi. The deltas are shrinking in mother earth but extension of south delta of Mahanadi is observed.. Investigation has been made here about evolution, manifestation, topography, shape and landform of the southern delta and lagoon. Origin, extension and development of drainage system.in the area is being searched. Extension of Mahanadi delta towards south is scrutinized. The gradual conversion of coastal landform, a sub-bay, then. a gulf and finally to a lagoon is examined.

INTRODUCTION

Deltas are geologically young landforms, but today they are shrinking and under subsidence. Deltas began forming within 7,000 years, when sea levels stopped rising after the last post ice age. The third largest delta of East coast of India, that of river the Mahanadi (Lat. 18°51' N and 21°49' N and Long. 85°00' E and 87°25' E.), is a peninsular river delta of tropical climate is claimed as shrinking. The River is a complex morphologic and hydrodyanmic system. It's 140^0 arcuate shaped delta is an amalgamation of three river deltas (the rivers Brhamani, Baitarani and Mahanadi). The Mahanadi delta extends about 150km coast covering 9500sqkm area and nearly 80- 100km spread in hinterland. The coastal stretch of its southern delta is 100km and area 1777sqkm. The landform is broken by a number of natural drains big or small. Some are active, few branches have been dead, defunct and abondoned. Avulsion,anastomising, meandering, splitting and bypassing are the processes that can be negociated for such morphological changes. At apex of delta, a place named Naraj, the river throws its first limb as Kathajodi. Further, the river avulse to branches Kuakhai, Kushabhadra, Daya and Bhargovi. The flow of Daya and part discharge of Bhargovi terminate at a lagoon named Chilika and balance flow is discharged directly or via cuts to Bay of Bengal.[Fig 1] Chilika lagoon lies in extreme south-west corner, is a swallow, brackish, shore parallel, pear shapped wetland of maximum area 1165 sqkm. The geographical formation of the area are due to different prebreak up reconstructional tectonic activities. They exhibit different geological settings also. The hydrology, morphology, ecology of the area has altered significantly from its

period of origin to present. Least records are available in black and white except some modern scientific techniques used to find the ages of such changes. However historians, geographers and geomorphologists have discussed about most prominent changes that have occurred in the area for the last five millenium.

1. Study area:

The Study area is from Naraj (Lat. 20°29' N and Long. 85° 47' E), the apex of the delta to offshore region of Chilika lagoon (Lat. 19°28' N and 19° 44' N and Long. 85° 07' E and 87° 40' E.). Changes in freshwater inflow of Mahanadi River system through Daya-Bhargovi Doab (Upland between the two rivers) to the brackish water enviornment within the lagoon of the Chilika lake is being investigated. The geology, morphology, Liminology, hydrology of the area and their changes with age is studied.

2. Climate

The climate, enviornment and ecology of the area is governed by tropical SW Monsoon, extreme meteorological events of Bay of Bengal and geomorphology of Eastern Ghats Belt (EGB) hills. The area is hot, humid and touches maximum temperature ranging 29^0 C – 45^0 C and receives average rainfall of 1500mm annually. 80% of rainfall occur in JJASO months. The 100km coastal shore line slams 10% of storms that originate in Bay of Bengal. South Mahanadi delta including barrier spits of Chilika has coastline 137km. The river mouths are in low to medium zone of acretion except Kushabhadra under low erosion zone. The barrier spit of Chilika and river mouths are unstable and moving north. The southern part of spit have low acretion in south for 35 km.

3. Previous studies:

The Chilika lake had the maritime glory of the busiest harbor in anicient past conecting east and west. Chilka was a fine inland sea reported by **Andrew Sterling 1846[1].** It was adorned with a cluster of ports around Chilika harbour were Ganja, Kantiagarh, Palur, Prayagi, Manikpatna, Sanapatna, Badapatna, Arakhkuda, Banjiapatna, Boitkud where the south East Asian navigators had activities with voyage, naval architecture (Golabai and Manikpatna) **Tripathy B (2008) [31]** Since last 400 years, the Harbour has become shallow enough for port activities and the lake is under ecological, biological and hydrological degradation.The grater Chilika in past, as named (area 1500 sqkm) has silted up and reduced in maximum size to 1165 sqkm and even less today **(CDA Report 2012[7l]).** The degradation in the size, volume, topography, extension, depth and stratification of the area was due to local mean sea level changes, anthropogenic interventions, denudation of forests, excess minining in the upstream, convertion and excessive land use pattern and industrialisation etc.

The hydrologic, hydrodynamic and Sediment studies commenced in the area was on track as a aftermyth of very high flood (1834 and 1857) and severe drought in Mahanadi catchment area during 1866 **(Harish J. C., 1860)[12].** The geo-morphologic changes of the Mahanadi delta have been studied previously by different investigators **(Mahalik, N. K. et al, 1996[15], Mohanti M. 2005 et al)[20]**. Heavy deltaic sedimentation occurred during late Paleocene period in the Daya- Bhargovi doab and Kushabhadra - Bhargovi doab. The sedimentation process continued till Miocene period as per Remote Sensing Technique for Regional Development reported by **Banerjee R**. **K. et al 2008[3]**. The beach ridges in the deltas of river Mahanadi are poorly preserved due to superseding flood flows. The innermost beach ridge of height 0.3m to 1.5m, exist in the southern part of the delta, near village Ghoradia, Bhubaneswar. Mahanadi Delta has three strand lines with 11 abandoned delta lobes. **(Mallick et al 1972**)[17] . The Holocene period landform of this delta is associated with the nature of beach ridges and abandoned distributary channels. The process of deposition of the spit and the ridges along and off Chilika Coast was initiated from paleocene period. But during last sea level rise before 3750 ± 200 BP (Mid Holocene period) the barrier spit development was active. **(Venkatratnam, K 1970 [33] and Subramanian V et al 2008 [30])**. **Royer J. Y. et al (1989[27] ,1992[26]) [Fig 3].** The rivers in the lower deltaic zone is branched and form anastomosis **(Bart Makaske, 2000[4]).** The tectonic reconstruction of the study area tentamounts to plate tectonics of Indian ocean from Jurassic to Eocene period. **Wanner H., et al (2008)[34]** has reported colder climate caused stronger bottom currents and vice versa which is related to the coastal processes of the area. The delta-building activity is being studied for the northern delta between Chandbali and Paradip by **Subramanyan V et al 2008[30].**

The chilika lake is a distinct block other than Mahanadi delta and EGB hills due to mesozoic tectonic reconstruction. The lake and the delta was attached to EGB-Rayner block during Rodania assembly, moving south, collided with Western Australia was a part of EGB-Rayner Block gave rise to Chilika Lagoon **(Chaterjee N. 2008) [6].** [**Fig 4**].The presence of sub-horizontal stretching of lineation, prominent lineament pattern, distribution of Mesozoic faults along and off Mahanadi river delta and existence of two opposite sets of sheer fabrics in the Chilika

domain establishes the artifact**. (Dutta Kausik et al 2012)[11].** The shoreline changes, 12.42 hours lunar tidal cycles and 24hours solar tidal cycle have been studied by **Ramchandran R et al 2011[25].** Poolean grain analysis and palynological records reveal that the barrier spit formation of the lagoon was due to small variation in local MSL between 5000 to 2500 BP .Since 2000 years BP, the barrier spit formation became active and sand ridges resulted formation of Chilika lagoon by reducing marine influence and enhancing fresh water impact **(Asha Khandelwal and Mohanty M 2007 [13]).** The sea floor fabric near offshore of the Chilika lagoon was studied by **Richa Arya et al 2006 [2].** The decadal changes in land form of the lake has been reported by **Samal et al, CDA 2013[28]**. Landscape and process of evolution of Mahanadi delta is studied by **Mishra H. S. 2014. [18]**

4. The basin

The Mahanadi basin is the direct outcrop of rifting and breaks up of Gandawana land and subsequent shifting of Indian plate in pre-Cambrian age **(Nayak Satyabrata et al 2012[24]).** Rajmahal trap which is the basement of Mahanadi basin, exhibit volcanism in the entire Gandwana Land. **(Mukhopadhyay G. et al 2010 [22]).** During late Jurassic to pre-cretaceous era volcanic activities in the Rajmahal trap adjacent to the basin was vigorous. Late cretaceous period reveal eastward tilting of the Indian plate along the continental slope. Enlargement of the basin was due to deltaic sedimentation between Eastern Ghats and Central Indian cartons during Paleocene period. Eocene period notify collision of Asian Plate with Indian plate, breaking of shelf slope and tilting of the basin. Oligocene period informs shaping of the delta due to normal activities of deposition and erosion. Pro-gradation, subsidence of clastic sediments and gradient provides outline to drainage channel activities during Mio-pliocene period in the basin (**Das P. K. et al 2012)[9].** The Eastern Indian Tectonic Zone (EITZ), North Singhbhum Mobile Belt (NSMB), Eastern fringe of Chhotanagpur Gnesis of (CGC) has formed the Mahanadi basin in past..

But the southern part of the Mahanadi basin is analogous to the characteristics of the 85^0 E ridge, the EGB hills with a shallow offshore. The Geo-periodcal changes and formation of the delta and lagoon is given in **Table 2 and Fig-3.**

4.1. Mahanadi delta

Evolution of East coast of India is due to pre-break up and reconstruction of Gandawana land, Ender bay Land and Mac Robertson land of Antarctica. The Mahanadi Basin is contiguous with Gandwana land. Chilika Lake is in semblance with Cape Darnley of Antarctica. **(Lal N. K. et al 2009[14]).** The Mahanadi delta is the composite tri-delta with other **sub-deltas of rivers Mahanadi, Brahmani and Baitarani**. The composite delta of River Mahanadi sretches 200km along coast and cover an area of 12500sqkm (W. R. Dept Govt of Odisha). The bathymetry, magnetic and gravity data onshore and offshore of the delta of the river Mahanadi show two lineaments, Dhamara offshore lineaments (DOL) and Chilika offshore lineaments (COL). The onshore of the Mahanadi delta exhibits three depressions, Chandbali depression, Paradip depression and Konark-Puri depressions with boundary ridges.at the northern and southern boundary of the delta. (**Subramanian V et al, 2008[30]).[Fig 5]** The off shore region of the lagoon is touching the upper edge of 85^0 E ridge. Major geophysical changes occurred for geological anomalies, like diastrophic, (deformation of earth crust by faulting and folding) tectonic and volcanic activities along onshore and offshore of the study area. The Mahandi tridelta lies beween Subarnarekha delta and the Rushikulya delta of Odisha coast. The characteristics and details of all deltas are in **Table 1**.

4.2. The Lagoon

This EITZ evolved 1800km long Eastern Ghats (Gondwana block). The EITZ Block collided with Rayner complex of Eastern Antarctica in Paleozoic period (119 Ma). Gradually the Rayner block shifted east wards and the Chilika gulf/Sub-bay was created which is datable to 89-66 Ma Cretaceous Period (Mesozoic Era) **(Chatterjee N. 2008[14]).[Fig 4]** The gulf/sub bay Chilika was connected landward to the southern distributaries between the river Daya and river Bhargovi. The extended boundary of the greater Chilika was including Golabai, Samang lake and Sar Lake, the total area was more than 1500sq.km which can be referred as "**Greater Chilika**" **(Sarangi, Mohapatra, Murthy, 1998 as reported CDA Report 2012[7]).** Present days the lagoon is shallow and acts as a balancing reservoir for two southerly distributaries of River Daya and Bhargovi.

4.3. The southerly deltaic stratigraphy

The rivers Daya and Bhargovi and its delta formation started after a major degeneration during Early Middle Miocene and continuing till date **(Bharali et al., 1991[5], Nayak G K 2006[23]).**The delta is a part of North east corner of

Eastern Ghats Belt and aligned as hillocks of NE-SW and ENE-WSW trend. As per strandline movement of Bay of Bengal, the land moved sea ward gradually and have formed a series of shore parallel channel. The impression of such channels still exists today. The prominent geomorphologic changes in southern Mahanadi basin and Chilika have been observed from late Holocene period (4000years BP) to present. River Daya tear the EGB hills for first 15km. and then with its branches directly discharge to the lagoon from its NE edge of the lagoon. **[Fig 9]** The River Bhargovi had shown a number of meander, flowing through deltaic sedimentary zone and finally join river Daya. There are a series of shore perpendicular drainage channels emerging from the left embankment of the river Bhargovi and falling to another shore parallel rivulet Sunamunhi which is almost dead and defunct today. **(Singh S. B. 2011[29])** The rivers Daya is of length 60km, flowing in Southerly direction. The river Bhargovi (85.5 km) flows easterly for first 10kms and balance either S-ly or SW-ly direction and finally join Daya. This anomaly of the course of River Bhargovi may be due to existence of steep gradient from Delang to north of Puri. Ratnachira rivulet was an active river in past. The river Bhargovi and Ratnachira combined with river Sunamunhi and the outer channelof the lagoon were falling in Bay of Bengal even in 18th century **(Sterling 1846**[1]). **C**arbon dating results at different places in Kathjodi River system tells about the age of formation of some channels in southern mahanadi delta.(Table 3)

4.4. From gulf to a lagoon

The U. S. Geologic Survey Report 2004-1043 **(Morton and Miller 2004 [21])** has provided standard land form of a coastal gulf. **(Fig. 6)** The lagoon under study is prototype with the gulf model. The river Rushikulya at South, Barrier Islands on shore, tidal inlets, the outer channel in the NE region of the lake establishes the fact that the lagoon was a gulf in past. Depletion of local mean sea level at Chilika coast affected on the base levels of the debouching rivers, Daya and Bhargovi. During late Holocene period there were abnormal fluctuations of the local MSL which has created new islands within the lagoon and there is extension of the delta towards south. The constructive wave action and the northward drift were the main barrier spit formation processes from southern part of the Lagoon where there is an abrupt curvature along the East Coast line. The orientation of the spit had changed due to difference in self gradient of the coast. Absence or presence of strong tidal current and the wave refraction pattern, constructive wave action, current, storm surges and wind wave are responsible for construction of the barrier spit**. (Venkatratnam, K 1970[33])** The 85^0 E does not allow to spread out more sediment in deep sea and litoral current returns back the off shore sediment with the spring tides to the lagoon is one of the cause sedimentation of the Lagoon.

4.5. Morphology of Hinter land

The hinterland between Naraj to the lagoon comprises of fluvial land form, deltaic land form, coastal land form and Aeolian land form. The fluvial landform starts from Naraj to head of Kuakhai River adjacent to Athagarh sand stone area and lateritic beds of khordha district. The upper fluvial plains accomodate both old and new Kathajodi River, the river Prachi, the river Kuakhai and its system The valley is filled with fertile channel deposits, marginal deposits from Cuttack to Bhubaneswar. The deltaic land form is extended from Bhubaneswar to Chandanpur with alluvial terrains, tidal flats, shallow lakes, flood plains, the rivers Bhargovi and Daya, and a number of abandoned channels. The Samang Lake and the Sar Lake in the area were developed as a result of drop in sea level. Hydrologically the distributaries within the deltaic land form are inefficient to discharge the quantum of flood received at their head, enabling the channels for avulsion and anabranching. The coastal land of 20km from shore comprises of large marsh land and swamps of Kanas and Sakhigopal. This area aggravtes the drainage congesion due to flat terrain with slope 1:4800 for river Daya and 1:4800 to 1:6000 for the river Bhargovi. Between the aeiolean land form and the coastal landform, the brackish water, Chilika lagoon spreads up. The Aeolian landform consists of sand dunes, beach ridges and estuaries. Geological studies reveals that the river Daya has N-S trending lineament in the offshore region of the delta which touches the extension of 85^0 E ridges and flows SW-ly direction. **(Nayak G. K. 2006 [23])**

Morphologically, the upper fluvial plains posseses a number of abandoned/buried distributary channels and natural levees, while the lower coastal strand plains are characterized by a series of beach/dune ridges and swales, mudflats, lagoons, mangrove swamps, tidal channels, spits and barriers. These strand plains are overlapped in certain sections by subsequent fluvial deposits – thus creating fluvio-marine plains. Considering the orientation of the relict beach ridges that lie even up to 30-35 km inland indicating the former shoreline positions. Attempts were made to reconstruct the various stages in the evolution of the deltas subsequent to the Holocene maximum transgression which is believed to be marked by the innermost beach ridge. About 3 to 4 strandlines were surmised, each representing a major change in the coastal configuration either due to shifts in river mouth positions or changes in sea levels.

4.6. Morphology offshore zone

The 85^0 E ridge is adjacent to the Chilika lagoon in its offshore zone. Bathymetry contour of offshore designate long and broad channel like features with sickle shape features of varying width 62 to 92m and depth 60 to 700m depth are observed within Rushikulya River and Devi River. The sediment flow occur in a semi circular manner and bounce back to shore forming some step like terraces in the area **(Arya and lakhotia 2006[2]). [Fig 7]** The northern sector receive direct sediment without being egressed to the offshore reflected back to the shore for 85^0 E ridge . The area gets silted up and made the large area of the lagoon shallow in its NE corner.

5. Anastomosis in lower delta

The river Kuakhai, a sub-branch of the river Kathajodi is 2 to 2.5m higher in bed level at its emanating point near Cuttack. This rise in bed does allow flood flow of Mahanadi system when flood in Kathjodi river reaches 2500 to 3000 cumec. Kuakhai further throws three limbs Kushabhadra, Daya and Bhargovi. Gravity contour profile of steep gradient from Delang to Puri indicates that there is steep gradient between the two ranges of NE hills of EGB range allows Daya River to flow almost straight and remain active (**Mahalik 2006[16] and Singh S. B. 2011[29]**). **(Fig 5 and Fig-8)** Whereas the River Bhargovi is changing its course with time as it flows in aluvium, meandering by coping with fluvial sedimentary deposits. New alluvial plains have developed towards south which indicates the delta is growing to south. Geo technical studies are done which tells the soil characteristics beyond Daya river right embankment showing plains of alluvium **Mishra et al 2013[20]**. A green belt of cultivation developed towards west of Daya. The drainage channels that become active and responsible for extension of Daya River system are due to formation of Rajua, Makara and weikhia channels beyond southern territory of the delta. Development of Bhubaneswar city, new channels named Gangua drain adding substantial water as urbanflooding to river Daya directly. Towards the tail end of the southern coastal deltaic zone the rivers has been anastomised**.** The rivesr Daya and Bhargovi have been converted to multi Channel Rivers in alluvial plains. They are formed due to processes of avulsion and branched to a number of drainage channels due to formation of bypass or splitting. **(Fig 8 and Fig 9)**

6. Discussion

Four stages of the delta progradation were identified based on the strandlines and palaeo-deltaic lobes of River Mahanadi. It is due to major changes in the amphitheater of coastal design either due to shift in course of distributaries or changes in sea levels. The coastline regression along the River Mahanadi coast started during Pleistocene (25 km) followed by transgression (5 km) till Late-Up-Pleistocene. During the end of Pleistocene, the regression was found to be vigorous to the extent of 10 km away from the present shoreline. This aggressive regression was followed by a period of slow transgression till early Holocene and continuing during tertiary period also**. (Ramachandran R. 2009[25])**

Similarly four stages of delta building process of the distributaries have been advocated by **Mahalik N. K 1996[15]**. First Stage relates to deltaic evolution and formation of old Kathajodi and Mahanadi system near Cuttack. The second stage is connected with formation of Sukhabhadra and Burdha system towards north of the delta. But during the period of third stage, the rivers Prachi, Alaka and Ratnachira system evolved. The Ratnachira river formed in southern delta from old Kathajodi river. The final development is the present growth which is the New Kathajodi-kuakhai-Birupa (Daya and Bhargovi) systems. In this stage, Kuakhai river system developed and bypassed the old Prachi and Ratnachira rivers.

The nature of the present delta progradation of river mouths of Mahanadi and Devi are different from that of the river Daya. Southern Mahanadi system has a number of geriatric channels, the Ratnachira, river Sunamunhi and river Bhargovi from its 36km to tail. A new sub-system is building up towards south of the delta taking Daya as a major active river**.[Fig 11]** The enlargement of river Daya is due development of Bhubaneswar City resulting more water in Gangua drain during monsoon as urban flood. Creation of the anabranch river Rajua, rise of bed of the river Malaguni and diversion of major flow of river Daya through the river Makara is expanding the delta southward. Peeping of the River Rana from upstream of Naraj to join the river Malaguni during high floods via Daltola earth mass near Khordha has been observed since last 50years. The expected future expansion of Mahanadi delta to south is given in **fig 10**.

The presence of abandoned deltaic channels suggests more than one major stage of delta-building activity controlled by the palaeo-strandlines. The tectonic depressions control the sedimentation pattern in the southern lower deltaic plain. The shifts in the distributaries for base level variations from time to time have been marked in the delta. The rise in base level at confluence points of river Daya and Bhargovi is observed. Formation of lobes, ana-branching, sand dunes and abandoned ridges advocates about the enlargement of the delta. Existence of swamps, mud flats, sand

dunes near the meandered channels also confirm about the delta propagation and abandonment of the old Channels. In the south west corner of the delta the process is very active as the bed level at the confluence point of the river Daya is at higher level of 1.5mtr than the bed of Chilika lagoon. The sedimentation processes within the doab is continuously developing by raising its land form. [Fig 8 and fig 9]

The upper fluvial region, river Mahanadi can accommodate only 50% of discharge only. The balance flood encroaches the flood plain and cause breaches in the embankments during high floods. Now Government is attempting for raising and strengthening the embankments only. The beds of rivers are being raised by silting and deteriorating the capacity and competency of the distributaries. The escapes for flood discharges in the doab are adding to the strategy. The doab has become flood prone to flood vulnerable.

Further human interventions in the last century, the construction of Hirakud Reservoir, Mahanadi, Birupa, Naraj, Gobardhanpur barrages on different distributaries have changed the geomorphology of the delta. The expansion of Mahanadi Delta Stage II, infrastructural development, industrial growth, denudation of hills and excess land use has altered the nature and the environment. The cut at 36km in left bank of River Bhargovi with a barrage Gabakunda village is diverting about 50-55% of the flood flow direct to Bay of Bengal. The river Bhargovi is tending to be defunct downstream thereafter. The moderation of flood by upstream hydraulic structures has increased the flood duration in the lower delta and the lagoon which is augmenting sedimentation. As a result the primitive natural delta dynamics has been disturbed. The southern delta is now undergoing subsidence after the operation of dams and barrages. The sediment concentration has been reducing day by day. The delta formation is under subsidence for reduction in sediment load to the Mahanadi delta.

7. Morphologic Changes:

The head reach of the Daya and Bhargovi river are quite narrow to receive and accommodate their flood share of the River Mahanadi (beyond 34000cumec) whereas the lower reaches are shrunk, can smoothly pass only a fraction of the flood volume. This condition aggravates the drainage congestion of the Daya-Bhargovi doab. The balance of retained flood deposits it sediment in the low lying areas of the western shore of the lagoon which helps in enlargement of the delta.

The fertile flood plain of Puri district is having a poor yield today due to saltation and salinity ingress. The flow obstruction through the infested weeds growth in the lower reaches, tide, wind and depth exercise a great influence especially on the salinity changes of the lake. Tidal influence is prominent in the outer channel gradually dwindling lake ward and opening of more numbers of new tidal inlets. It has affected the salinity circulation within the lake. Negligible tidal effect is felt in the bulk of the main area of the lake. Wind plays a vital role in affecting local and transient changes in the salinity and depth of the lake especially in the shallow northern sector**.**

The small streamlets in the delta and joining the Lagoon have been renovated and increased flow. The lateritic upland and EGB Hills and back swamps formed in northern sector of Chilika Lake accelerate growth of southern delta. The attributes are difference in density of sediment laden flood water and the saline water entering the lake which results in poor mixing. The proliferation of phyto-planktons arrests sediment at the head of entry to the lake. There is development of young mud flat of 48.3 sqkm with younger paleo channels of 11.4 sqkm between the western catchment of lagoon and the delta. This development is mostly in the right flank of the River Daya.

The formation the river Rajua as an anabranch at 28km further rejoining at 48km during 1857 flood of the River Mahanadi towards the southern side of the delta beyond Daya Right embankment is a proof for enlargement of Mahanadi Delta in its southern side**.** The meandering character of the river Kuakhai and the river Daya after that devastating flood has widened the southernmost river Kuakhai of Mahanadi Delta. Further the River Makara developed at the expense of main River Daya, which is draining its 55% flow today. **(Mishra and Jena 2012[19])** Another lobe has been formed at 49km distance and now it is named as Kalapadar Gherry having mudflat in second half of 19th Century. The southern boundary of the Delta has been extended and new deltaic lobes formed is a proof for extension of the south Mahanadi delta**.[fig 11]**

Prognosis of Paleo strand lines indicates high ridges and slopes with supporting vegetation and development of network of drainage channels. A vast area of 14000 ha GCA and 4100 ha of water logged area has been developed to the south of the delta and with a network of drainage channels with main drainage channel, Gangua drain of the tertiary age. This Land cover have extended between the river Daya and the river Rajua encroaching Daya – Salia Doab emphasizes the reconstruction of Mahanadi delta to south.

8. Conclusion

The Chilika gulf was extending deep inland 30km upstream. Formation of barrier spit started from the southern corner of Rambha hills due to heavy sediment transport.

The process of sedimentation and enlargement of the delta in southern sector is still in progress. Due to sediment imbalance in the Lagoon, continuous deposition of sediment in the mouth of Daya branch is in the NW periphery of the lagoon. Development of southern Mahanadi delta is due to formation of river Rajua, the river Makara.

Cuts at Gobakunda cut and Mangala near Puri has resulted in weakening Bhargovi and Ratnachira system. The paleo channels of the Daya-Bhargovi upland have been silted up and overloaded with phytoplanktons like Ipomea and water Hyacinth which is aggravating sedimentation and avulsion processes.

Though Mahanadi delta is shrinking and under subsidence, the high ridges and slopes, the vegetative cover, the formation of new distributaries channels since last two hundred years indicate the delta of the river Mahanadi is extending towards south and covered Daya-Rajua Doab (Doab VIII). The southern boundary may propagate and encroach a portion of the catchment of Malagumi River. The right embankment of river Daya is no longer the southern boundary of Mahanadi delta.

Delta building process is a long term mesoscale natural activity and a continuous process. The Aeolian activity along the shore or barier spit is more rapid and change of river or drainage channel course is long term whereas the deltaic changes are geospatial. The metamorphosis of distributaries

Fig 1: Index map of south Mahanadi delta and Chilika lake

Fig 2: Beach ridge excavated near Ghoradia, Bhubaneswar

of Mahanadi delta is in a process of reconstruction and abandonment with age affected by subsidence, submergence and emergence of coastal land due to change in local mean sea level.

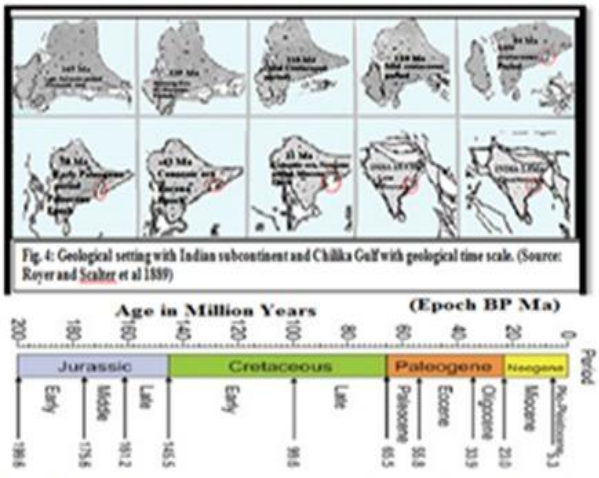

Fig 3: Geologic reconstruction of Mahanadi and Chilika

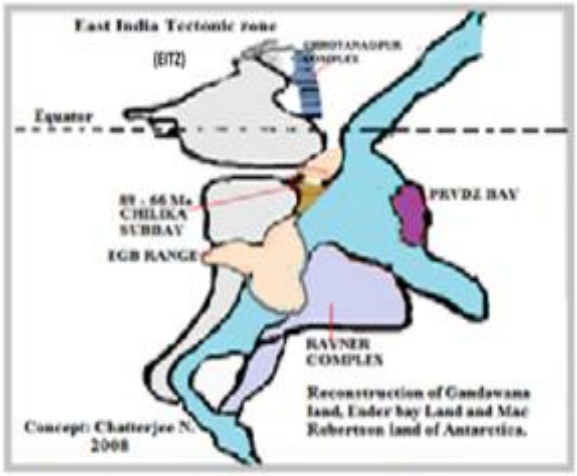

Fig 4:Reconstruction tectonics of Chilika lagoon

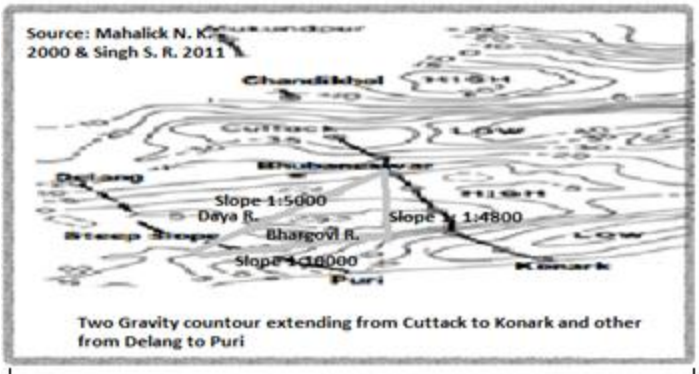

Fig:5: Gravity contour gradient profiles along southern Mahanadi delta (Mahalik 2004)

Fig 6: Comparision between standard Gulf and the Chilika gulf

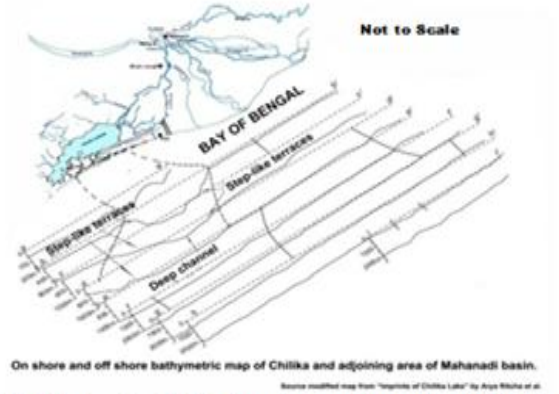

Fig 7: The floor fabric Chilika in onshore zone Source: Arya & Lakhotia

Fig 8 &9:The meandering and anastomising patterns of south Mahanadi delta coastal landform, Source Google satellite imagery

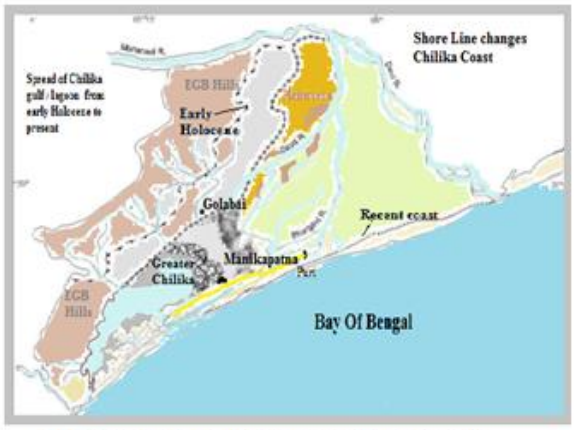

Fig 10: Strand line position in south Mahanadi delta

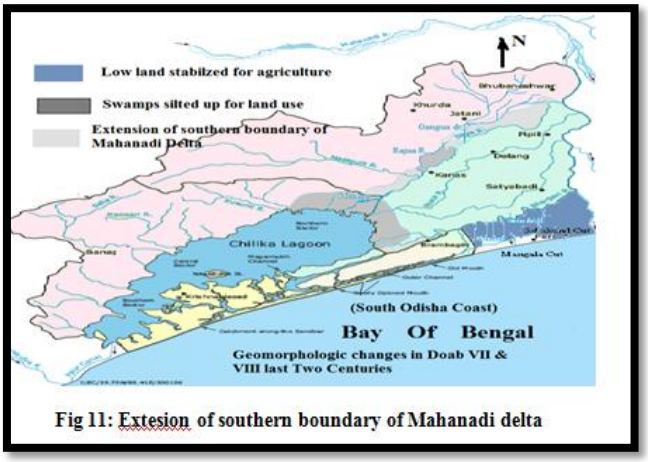

Fig 11: Extesion of southern boundary of Mahanadi delta

Table 2: Geologic setting of Mahanadi delta with Chilika Lake:

Sl	Geological age	Years B. (Ma)	Status of delta formation along with Coastal changes	Reference
1	Pre- Jurassic	200-161	Before pre breakup, East Coast of India was attached wi Gondwana, Ender-Bay and Mac Robertson land of Antarctica.	**Proposal in MN-DWN 98/3 Block. Html, 2010**.
2	Late Jurassic-	144 Ma	Australia and Indian peninsula evolved from Antarctica,by rifting and shifting within Tethys sea. Sediment deposited in the Mahanadi-Godavari grabens.	**Lal N. K. et al, 2009[14]**
3	Early Creta-ceous	122-107 Ma	Vigorous Volcanic activity in Rajmahal trap, formation of Crozet hotspot, Athgarh Sand stone, 85 deg east ridge (117 Ma), Sedimentation in delta, (proto rivers Mahanadi, Brahmani and Devi upto Daya) formed with a narrow stretch. Early cretaceous volcanoes are present in off shore, absent in on shore of delta.	Nayak S. et al 2012,[24]2 L N. K. et al, 2009[14]
4	Late Creta-ceous	107-65 Ma	Rajmahal trap eruption ceased no sediments available in Mahanadi basin, only in off shore due to movement of Indian plate over Crozet Hotspot. Sediments used to uplift the basin with sudden narrowing with southward swing of Mahanadi shelf from south of Chilika Lake. The Grenvillian collision of Rayner complex of east Antarctica &Rodinia Block of Gondwana land evolved Chilika lake.	**Nayak G. K. et al 2006[23] Lal N. K. et al, 2009[14], Chatterjee N. (2008)[6]**
5	Early Paleocene	65.5- 55.8 Ma	Carbonates deposited extended Mahanadi basin south ward present in offshore Basin but not in inland.	Lal N. K. et al, 2009[14] Nayak G. K. et al 2006[23]
6	Eocene	55.8 to 33.9 Ma	Wide spread transgression of East Coast, formation of a long Shelf from Assam to Mahanadi basin.	**Validiya K. S.(1993)** [32]
7	Oligocene, Miocene	33.9-5.332 Ma	The Basin margin formed Khurdha and Bolgarh Formation. No Oligocene formation in both onshore and off shore.	Proposal for declaration, 2010 Nayak G. K. 2006[23]
8	Late Paleisto-cene to early Holocene	5.332Ma 11700 years BP	Lateritic table land of fluvial origin skirted over the Pleistocene boulder conglomerate. The shallow marine estuarine clay in Kaimundi formation in the onshore area, river Sediment deposition of greenish grey and greenish yellow, moorum soil in Belipada formation in the mid deltaic zone.	Current Science, volume 64 June 1993, (Google. Com)
9	Middle Holocen	11700years to 7600 year BP	Banki Basin formation and the river Prachi originated. Sediment accretion in Daltolah ridge.Chilika lake was a gulf associated with river estuary or delta with fresh water vegetation.	Current Science, volume 64 June 1993 by Validiy **K. S, Khandelwal Ash 2008[13]**
10	Late Holocene	7600 years BP to 3000 years BP	Mahanadi river mouth shifted from SW to NE to present position by abandoning paleo-channels,Sukhabhadra, Old kathjodi, Burdha, Alaka, Prachi and Ratnachira. Formation of the Chilika Lagoon as a gulf in the estuary between southern distributaries of the River Mahanadi and the Rambha Hills of EGB.	**Mahalik N. K. et al 1996[15]**
11	Late Holocene Present	3000years BP to present.	Development of barier spit formation of Chilika lagoon. Th Lagoon become extinct due to sedimentation. Ageing of Bhargo system, Prachi system. Ratnachira system. Chandrabhaga riv and Sunamunhi river and they have become defunct.New sets beach ridges have formed near Chandabali depression ar Konark depression. Kadua andDaya system become active**.**	**Validiya K. S 1993,** & WR dept , Odisha[33]

Table 1: Status of Deltas in and around Mahanadi basin

Sl no	Name of the delta	Length(km)/catchment (sq Km) /Av. flow annual	Length (km)	Area delta (km^2)	Sub deltas	Shape	Source
1	Subarnarekha	433km/19277 sq km/2922mcum	113.5	2217	Subarnarekha Burhabalang	Cuspate	orissa.gov.in slusi.dacnet.nic.in
2	Tridelta Mahanadi	Bai :360km/12790km^2 Bra: 799km/39033 km^2 Maha: 851km/141589 sq km/5574 MCM	200	9500	Mahanadi, Devi,daya Brahmani & Dhmara	Arcuate	Wet land International
3	Rushikulya	165km/8963sq km/ 1529mcum	30	----	----	No delta	http://dictionary.sensagent.com

Table 3: **Radio-Carbon data in and around the lake:**

Sl No	Name of Distributaries	Place of origin	Length in km	^{14}C data result in years BP	formation Years BP	Remarks (Formation age)
1	Chilika	South Sector		792 ± 2 Ma		lake anthrosites Study Dobemier C. 2003[10]
1	Prachi	Pratapnagari (Cutack)	73	5880±120 - 4250±210	7000-6000	Middle Holocene, old, mature, active, 9-4m high
2	Devi-Kushabhadra	Balianta (Bhubaneswar)	56	1590±150 - 1220±180	2300 - 750	Young, active, 8 to 2.5m high
3	Bhargovi R.	Uttara (Bhubaneswar)	85.5	1590±150 - 1220±180	2300 - 750	Old, inactive for last 40kms, 8 to 2.5m high
4	Daya R.	Uttara (Bhubaneswar)	60	2300 -750	2300 - 750	Young, active, avulsive 8 to 2.5m high
5	Kadua	Devi- Kushabh-adra doab	48	750-50	750-50	Late Holocene to recent, falling Sea period, 1.5-2m high
6	Golabai Sasan	Malaguni R bank	10km m (west bank	4300	4300	Neolithic1600BC,Chalcooli-thic1400 BC, Iron age 900 BC
7	Chandrabhaga formation	Kaktapur area	15-20	750-50	750-50	Late Holocene to recent Dead and inactive
8	Konarak Formation	Konarak	15-20	2300 -750	2300 - 750	Late Holocen, Young, active . Coast formation
9	Rajua (a loop branch of Daya)	Kanti (Jatni)	16.5	250-0	250-0	Young and active, Daya formed, Makara another branch became active
10	Chilika Lake (S Secdtor)	Near Raghunathpur		3750±200	3750	A part of Gulf shore, . Arya R. 2006[2]
11	Chilika Lake	19° 43' N, 85.37° E	Near Satapada	538 ± 5		Low lying swampy area in N-Sector (K Dutta 2001)[11]

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References

1. Andrew Sterling, (1846), Orissa: its geography, statistics, history, religion and antiquities, late personal secretary to Bengal Government, Burton-on-Trent, Staffordshire.
2. Arya, R. and Lakhotia, S.C.,(2006), Imprints of Chilika lake in the offshore region – a geomorphic evidence, Current science, Vol. 90, No.9,pp- 1180-1182
3. Banerjee R. K, Banerjee B., (2000) , "Remote sensing technique for regional development, Concept publishing company, A 15/16, Commercial block, Mohan garden, New delhi.
4. Bart Makaske, (2000), Anastomosing rivers: a review of their classification, origin and sedimentary products, Elsevier, Earth-Science Reviews 53 Ž200, pp- 149–196
5. Bharali, B., Rath, S., Sarma, R., (1991) , A Brief review of Mahanadi delta and the deltaic sediments in Mahanadi basin. Memoirs Geol. Soc. Ind. No.22, 31-49.
6. Chatterjee N., James L. Crowley,Mukherjee A. B. and Das S.,(2008),Geochronology of 983-Ma Chilika Lake Anorthosite, Eastern Ghats Belt, India: Implications for Pre-Gondwana Tectonics, The Journal of Geology, Vol. 116, No 2, P. 105-118.
7. Chilika Development Authority, (2012), Draft final report,Project context Section I, Strengthening of Wetland Research &Training Centre and Bio-diversity Conservation on Chilika Lagoon", [Online] Available: iczmpodisha.org/.../Chilika.
8. Das K., Bose S. Karmakar S. and Chakraborty S., (2012), Petrotectonic frame work of granulites from northern part of Chilika Lake area, Eastern Ghats belt, India: Compressional vis-à-vis transpressional tectonics, Journal earth Syst. Science, 121, No 1 pp 1-17.
9. Das P. K. and Dutta S., (2012), Paleogene low stand deepwater canyon fill deposits in Mahanadi Offshore Basin: can it prove to be the elusive major hydrocarbon discovery?, 9th Biennial conference and exposition on Petroleum geophysics, Hyderabad 2012
10. Dobemeir C., and Raith M. M. M Yosida, B. F. Windely, and Dasgupta S., (2003), Crustal architecture and evolution of eastern Ghats belt and adjacent regions of India, Jour. Of geological society India, Vol 73,pp- 145-168, 2009.
11. Dutta Koushik , Ravi Bhushan, Somayajulu B. L. K., (2001), Δ**R** correction values for the northern Indian ocean, Proceedings of the 17th International 14C Conference, edited by I Carmi and E Boaretto, RADIOCARBON, Vol 43, Nr 2A, 2001, p 483–488
12. Harrish; J. C., Young C.B. ,(1860), Captain Harrish report on Mahanadi Flood protection survey works, correspondences between the Chief engineer and superintending Engineer and Executive engineer , lower provinces 1858 to 1860, source Water Resources Dept. Library Odisha.
13. Khandelwal, Asha and Mohanty, M, (2007),Vegetation history and sea level variation during the last 13,500 years inferred from a pollen record at chilika Lake, Orissa, India, Vegt hist Archaeobot(2008) 17 335-344 DOI 10. 1007/s00334-007-0127-5. Springer verlag 2007.
14. Lal, N.K., Siawal, A., Kaul, A.K., (2009), Evolution of East Coast of India – a plate tectonic reconstruction", Journal Geological Society of India, Volume 73, pp 249-260.
15. Mahalik; N. K., Das, C., and Maejima Wataru (1996): "Geomorphology and evolution of Mahanadi Delta, India",Jour. of Geosciences, Osaka City University, Vol. 39, Article. 6, p. 111 – 122 (March,1996).
16. Mahalik N. K.(2006):"A Study of the morphological features and bore hole cuttings in understanding the evolution and geological processes in Mahanadi Delta in East Coast of India
17. Mallick S.K., Bhattacharya, A. and Niyogi, D. (1972), A comparative study of Quaternary formations in the Baitarani valley, Orissa with those of the Damodar-Ajay delta area, Lower Ganga, Basin. Proc. Seminar on Geom. Geohydr. Geotech of Ganga Basin, 91-104
18. Mishra H. S. , 2014, Landscape pattern and process of Mahanadi delta, Estonian University of Life Sciences, Acadima edu.
19. Mishra S. P. and Jena J. G. (2012):"Characteristics of western catchment and their inflow contribution to Chilika Lagoon, Odisha (India)"International Journal of Lakes and Rivers, Vol. (6), No 2, PP 119-129
20. Mohanti M., Swain M. R., (2005), Mahanadi river delta, east coast of india : an overview on evolution and dynamic processes, Department of Geology, Utakal university, Vani vihar, [Online] Available: http://www. megadelta .ecnu. edu.cn.
21. Morton, R.A., Miller, T.L., Moore, L.J.,(2004), National assessment of shoreline change; Part 1, Historical shoreline changes and associated coastal land loss along the U.S. Gulf of Mexico: U. S. Geological Survey Open-File Report 2004-1043, 42 p., [Online] Available::http://pubs. usgs.gov/ of/ 2004 /1043.

22. Mukhopadhyay G., Mukhopadhyay S K., Roychowdhury M., and Parui P. K., (2010), Stratigraphic correlation between different Gandwana basins of India, Journal Geological society of India, Volume 76, Sept 2010, Page 251 -266.
23. Nayak G. K.,Ch. Rama Rao, and H. V. Rambabu (2006), Aeromagnetic evidences for the arcuate shape of Mahanadi delta, Earth Planet space, Vol -58, pp 1093-98.
24. Nayak S., Das S., Bastia R., Kar B., (2012),Lava delta below 85 ^{0} ridge, Mahanadi offshore basin, identification characterization and implication of hydrocarbon prospectively, Petroleum Business (E&P), Reliance Industries limited, India.
25. Ramachandran R. Purvaja R,. Ahana laxmi, (2009), Deltas, Coastal vulnerability and management, Inst. for Ocean Management, Anna University Chennai, Chennai - 600025. INDIA
26. Royer, J. Y. and Coffin, M. F., (1992). Jurassic to Eocene plate tectonic reconstructions in the Kerguelen plateau region, in Proc. ODP, Sci. Results, 120, 917 – 928, eds Wise, Jr. S. W., Schlich, R., et al., Ocean Drilling Program, College Station, TX.
27. Royer, J-Y., Sclater, J. G. and Sandwell, D. T., (1989): A preliminary tectonic fabric chart of the Indian Ocean, Proc. Ind. Acad. Sci., Earth Planet. Sci., 98, 7 - 24.
28. Samal, R., N., Rout J. and Ojha A., (2013), Monitoring lagoon coast dynamics with g-tech, Geospatial communication network, Earth Science, Sediments in Mahanadi Basin. Memoirs Geological Society of India, No. 22, Bangalore, India
29. Singh, S., B., Veeraiah, B., Dhar, R., L., Prakash, (2011), Deep resistivity sounding studies for probing deep fresh aquifers in the coastal areas of Orissa, India, Hydrology Journal Vol. 19 pp-355-366.
30. Subramanyam, V., Subramanyam, A., S., Murthy, G., P., S.. Murthy, K., S., R., 2008, Morphology and tectonics of Mahanadi basin, north eastern continental margin of India from geophysical studies, Marine Geology, 253, pp 63-72.
31. Tripathy, B, (2008), Maritime heritage of Orissa, Orissa Review, Government of Orissa
32. Valdiya, K., S., (1993), Tertiary period in India, Current Science, Volume 64, No 11 & 12, Publisher : Current Science Association, Banglore, Source Google.
33. Venkatrathnam, K., (1970), Formation of the Barrier spit and other sand ridges near Chilika Lake on the east coast of India, Marine Geology, Elsivier, Vol.9, Issue 2, P 101-106
34. Wanner, H., Beer J., (2008), Mid to late Holocene climate change: an over view" Elsivier, quarterly science reviews, 27, 2008, pp-1791-1828