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Geography

THE DISPERSAL OF COASTAL MUD BALLS IN SUSNI & CHUKSAR ISLANDS, HUGLI ESTUARY: A COMPARATIVE STUDY

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ABSTRACT Coastal mud balls and its dispersal are described from the coastal stretches of Susni Island and Chuksar Island, Hugli Estuary. A comparative analysis has been evaluated by the statistical techniques to get the exact knowledge and enrichment about the dispersal of coastal mud balls in these coastal environments. To get the better knowledge about the dispersal and the orientation of mud balls, geomorphic as well as the sedimentological determinants are analyzed by the regression analysis based on the both coastal environments. This discussion reveals that geomorphic as well as the depositional factors or determinants help to consider the shape and orientation of mud balls. This interrelationship helps to signify the mutuality of determinants to get the clear picture about the shape and orientation of mud balls and might help to put constraints on the depositional features of mud balls by helping the reconstruction of a high resolution depositional model for similar paleo-environment.

KEYWORDS : Mud pebble; Desiccation; Armoured mud ball; Mud clast; Feret Diameter.

1. INTRODUCTION

Mud balls are nearly spherical clasts of cohesive sediment which generally have a diameter of a few centimetres (*Bell, 1940*), also called as rip-up clasts (*Allen*, 1982), clay pebbles (*Trefethen and Dow 1960; Nossi*n 1961) clay balls (*Haas, 1927*) and intra-formational clasts (*Smith, 1972)* are commonly concentrated in marine to non marine settings. Basically mud balls are the distinct sedimentary features from various depositional as well as erosional environments. The present study is centrally focused on the dispersal of the mud balls and the spatio-temporal distribution over the selected coastal stretches by the proper statistical methods for illuminating correlation between the geomorphologic determinants and the basic size data analysis, orientations of the mud balls respective to the coastal strandline position. The main objectives of this paper are:

- To suggest possible pathways and the major controls on distribution of coastal mud balls under similar coastal set up
- To document the spatio-temporal distribution of coastal mud balls of selected study areas

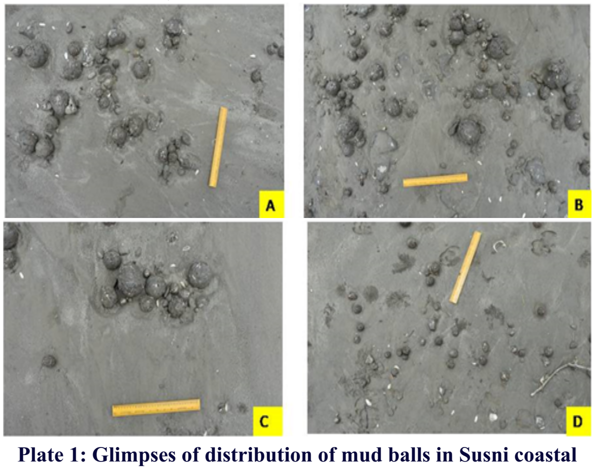

Plate 1: Glimpses of distribution of mud balls in Susni coastal stretch

2. FUNDAMENTAL GEOMORPHOLOGY SET UP OF SUSNI AND CHUKSAR ISLANDS

This present study is focused on the comparative assessment of dispersal of coastal mud balls of two selected coastal stretches one is, *Susni Island* being located along the NNW side of Bakkhali Island (3.4km away from Bakkhali sea beach) having exposed mud banks with desiccation cracks and extensive bioturbation. Apart from that, the beach shows the variations in slop condition, tidal submergence, wave impact and depositional energy which are perhaps responsible factors for the distribution and orientation of mud balls. Additional observations on mud ball distribution in *Chuksar island* (88^0 $01'$ E and 21^0 35' N) being located in the outermost part of the Hugli estuary is also included in the present study (Data source: *A.Chakraborty*, Pers. Communication) to extend observation on mud ball distribution at spatio-temporal scale comparatively.

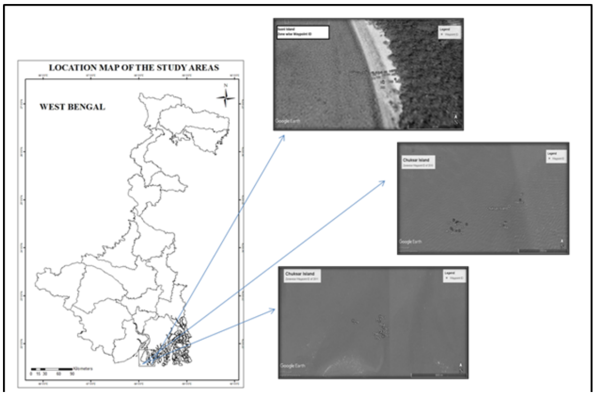

Figure 1: Location Map along with Google Earth Images of the study areas

The Indo-Gangetic is the biggest tract of the world and this alluvial fill is essential of Quaternary age, the Indo-Gangetic plain, more precisely the Bengal plain in its NNW part of Bakkhali area named Susni Island is characterized by the presence of extensive coastal belt with exposed mud banks and concentration of mud balls. On the other part, Chuksar Island being very dynamic in nature geomorphologically for strong wave action and eroding nature, continuously its area is changing and remained in 0.56% in 2009.

3. LITERATURE REVIEW ON MUD BALL FORMATION

Many researchers already defined mud balls as several names and analyzed their basic size data for elaborating that different agents with their specific conditions affect the orientation and distribution of mud balls. *Gardner (1908)* described that mud balls are formed by the cohesion of the fine clay particles. After nearly 20 years in 1927, *Hass* renamed mud balls as the *"pudding balls"* are formed by the accretion around a clay nucleus between the dessication cracks that are referenced and caught by the stream flow in the muddy bed or the mud flat region.

In the coast of Scotland, mud balls were observed as the *"Clay Boulders"* that were formed by glacial clays and well outlined sorted mud boulders had been rolled by the waves (*Grabau, 1932)*.The relationship between the diameter of balls and the stream velocity had been demonstrated for the formation of armoured mud ball sized of fraction of one inch to 20 inches in California *(Hugh Stevens Bell, 1940). G.W Leney & A.T Leney (1957)* observed armoured mud balls sized averaging 2 inches in a sand pit on the edge of the moraine near Michigan.

Pettijohn and Potter (1964) observed mud balls as subspherical balls of 5-30 cm in diameter (pudding balls) coated with coarse sand and fine gravel in fluvial environment. Mud balls, as the elongated and bladed shape in intertidal zone of megatidal coast had the relationship with distance from the high tide mark and had a certain orientation parallel to the *(Thompson and Stanley, 1968-1969)*.

Kugler and Saunders (1959), Dickas and Linking (1968), Fritz and Harrison (1983) observed coastal mud balls as elliptical to spherical ball were composed of coarser lithic fragments including chert, quartz and heavy minerals together with biogenic clasts such as shell and bone fragments. Mud balls were the products of coastal and marshy environments as there was the existence of biogenic materials in the core of the mud balls, suggesting bioturbation process *(Hall and Fritz, 1984)*.

Goldschmidt (1994) reviewed mud balls as poorly sorted coarse grained frozen material up to 5cm in diameter formed in a fluvial or near shore environment mainly in Greenland or Siberia and then transported by sea ice-rafting to their present location. Mud balls were also demonstrated as the glacio-fluvial fossil till ball, armoured mud ball (3-14cm) and unarmoured spherical mud balls composed of coarse materials *(D.P Sen, SK Sit, 1998)*

Ojakangas and Thompson (1977), Faimon and Nehyba (2004), Faimon (2005) observed mud balls or mud pebbles from different aspect of view as they belong to artificial (urban/ quarry) environment as sperical, subspherical, cylindrical and elliptical shapes (10 to 23mm). Armoured mud balls were generated from the accumulation of sediment derived from the fluvial catchments and these got its proper spherical shape due to the motion of the turbulent flows and get sorted by the flow hydraulics *(Anne Mather et.al 2008)*.

Mud pebbles were influenced by the tidal wave and environment as they were wave induced broken lumps of clay*(Lawrence H. Tanner*, *1995).* The origin of the armoured mud balls was in early Pleistocene channel fill directly beneath the soil and alluvium complex *(R.F Diffendal, 1984)*.

Seung Soo Chun et al., (2002) described that the retrogressive failures of sub marine channel formed the armoured mud balls that were rolling over the sub marine channel floor, finally deposited on the mud banks in the lower slope. According to *Shunli Li et al., (2017)* mud clasts belonged to fluvial-deltatic, tide dominated shoreline and shelf, and wave dominated shoreline and shelf, deep water environments. They also classified the mud clasts into nine types on the distinct basis of abundance of clasts, sorting and roundness. They mentioned the *Newtonian flow* that forms the well sorted mud clasts and well rounded but originated from *Non- Newtonian flow* mud clasts are mainly based on poorly sorted, angular and matrix supported.

Major researchers studied the spatio-temporal distribution and formation of mud balls in the coastal environment and fluvial environment and lesser studied in the artificial environment (Urban/quarry), glacial and glacio-fluvial environment, intertidal environment which shows the major differentiation between physical characteristics of mud balls and geomorphic signatures on mud balls.

Despite varied modes of origin suggested for mud clasts or mud balls by several researchers; their spatio-temporal analysis is little documented. Present work attempts to document the distribution and dispersal of mud balls emplaced in coastal environments based on available field data, to seek possible explanations about the dispersal of the coastal mud balls.

4. METHODOLOGY

4.1 Pre-field:

Study of relevant research articles and journals on origin of mud pebbles, sediment analysis and coastal processes and coastal morphodynamics of the study areas.

4.2 Field work:

Lica TC-407 total station was used along with a GARMIN E-TREX GPS receiver (Sl #1) to study elevation of the distinct zones of mud balls concentration.

Proper zones (zone 1-8) were made parallel to the shoreline and their positions (Easting and Northing) in the Susni Island received by another GARMIN E-TREX GPS receiver in 2019.

Several pictures were taken in the different zones of mud pebble concentration so that the rapid changes in the distribution of mud balls as well as their geomorphic nature can be observed clearly in the Susni coastal stretch.

4.3 Post field:

Distinct Surface Topography maps of the studied regions have been prepared in SURFER version 16 on the basis of total station survey. GPS data and total station data of the studied areas were plotted together in Google Earth Pro then exported as grid files in SURFER version 16.

Statistical analysis of the size data of mud pebbles according to their distinct zones using software like (Corel draw, Image J, Past) is measured to get knowledge about the basic size data of mud pebbles along with their spatial distribution over the coastal stretches. The Master file on mud ball size data of study areas are in custody of present author of the dissertation work.

Relief profiles based on Total station survey are represented in Microsoft Excel version 2007 to analyse the relief as well as the elevation variations of the distinct zones. Mud ball orientation analysis as per the distinct zones has been represented by the Rose diagram in Past software version 6. Correlation between physical characteristics (Relief or Z values, Distance from strandline, Slope, Cumulative distance) and mud balls characteristics (Mean size, Mode size, Circularity, Orientation, Mud ball concentration per unit area) are analysed by the regression method in Microsoft Excel version 2007 to light up the proper controls on the dispersal of mud balls comparatively in the study areas.

5. RESULTS AND DISCUSSIONS

Several outcomes have been outlined based on the proper methodology that clearly proves the significance of geomorphologic phenomenon on the dispersal of mud balls over the selected coastal stretches.

- **Surface Topography Maps**

Surface Topography Maps along with Google Earth Images of the study regions have revealed the fluctuations in height in meter that helps to build the strong base of relief factor in this study. In the Susni Island (2019), the relief value (Z value) ranges from 0 to 3.6 meter. According to the 2010 data of Chuksar Island, the value ranges from 0.6 to 4.8 meter and 1.5 to 7.5 meter in 2011 data.

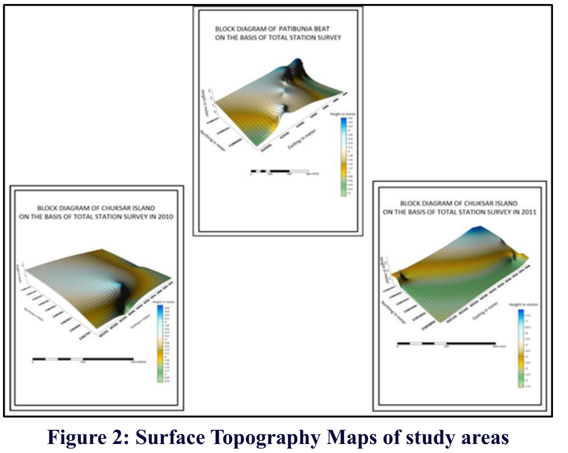

Figure 2: Surface Topography Maps of study areas

- **Relief Profiles of the study areas**

Three consecutive relief profiles have been generated based on the relief values (Z values) derived from the Total station survey that helps to build the relationship between geomorphology and mud ball concentration of the study areas also gives the strong information how the distance from strandline affects the elevation of the study areas.

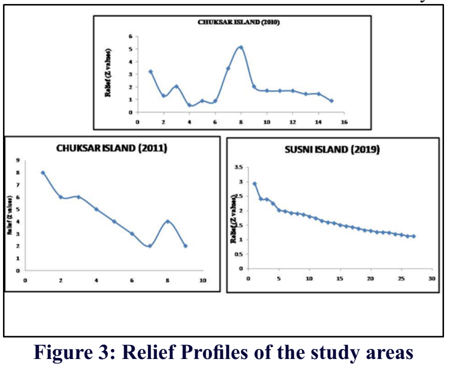

Figure 3: Relief Profiles of the study areas

- **Orientation of Mud balls**

As per the Rose Diagrams of specific zones of mud ball concentration, the average values of Feret Angle have been varied from Susni Island to Chuksar Island that demonstrates the varied orientation of mud balls depended on the strandline variation and slope variation of the particular coastal stretches. In the Susni Island, the value averages between 81.44^0-105.54^0 and in Chuksar Island (2010) 77.80^0 - 103.17^0 and in 2011 data is 81.02^0 - 121.92^0.

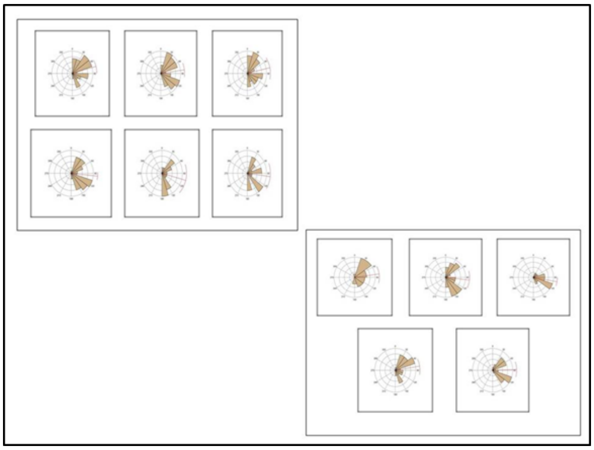

Figure 4: Zone wise orientation of mud balls in Chuksar Island (2010 & 2011)

According to this orientation it had been observed that there is diversification in orientation of mud balls as per the landward and seaward zones of mud ball concentration that triggers the control of relief and slope factors on the mud ball orientation in the Chuksar Island.

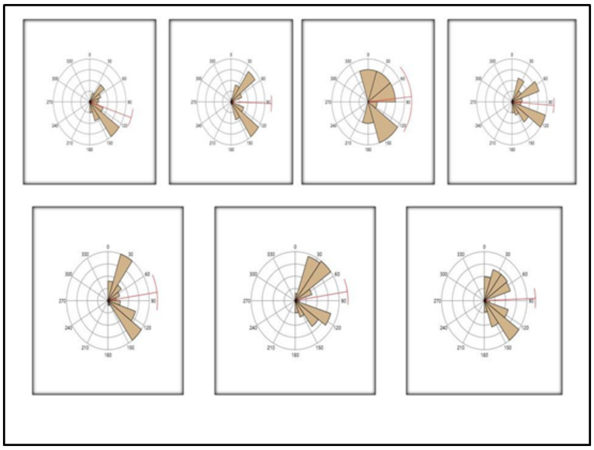

Figure 5: Zone wise orientation of mud balls in Susni Island (2019)

As per the average values of the orientation of mud balls in Susni Island, it had been observed that there is also diversification among the selected eight zones based on the distance from the strandline. Relief and slope factors as the primary ones always control the orientation of mud balls from landward to seaward zones.

- **Scatter Diagrams**

Correlation between the geomorphic variables like *Relief (Z values), slope and cumulative distance from strandline* of the study areas and size and shape variables like *Mean size, Mode size, Circularity, Orientation, Feret diameter, mud ball concentration per area* of the mud balls have been analyzed through the Scatter diagrams that helps to depict the variability and dependency of the mud ball size analysis on the geomorphic attributes.

Susni Island (2019)			
GEOMORPHIC	SIZE & SHAPE VARIABLES	REGRESSION VALUES	
Relief	Mean diameter	0.624	
Relief	Modal diameter	0.146	
Relief	Circularity	0.009	
Relief	Orientation	0.42	
Relief	Mud ball concentration/unit area	0.517	
Slope	Mud ball concentration/unit area	0.142	
Slope	Mean diameter	0.624	
Slope	Modal diameter	0.146	
Slope	Circularity	0.15	
Slope	Orientation	0.02	
Cumulative distance from strandline	Mean diameter	0.409	
Cumulative distance from strandline	Modal diameter	0.059	
Cumulative distance from strandline	Mud ball concentration/unit area	0.47	
Cumulative distance from strandline	Orientation	0.551	
Cumulative distance from strandline	Circularity	0.022	
Chuksar Island		2010	2011
Relief	Mean diameter	0.637	0.284
Relief	Modal diamter	0	0.747
Relief	Circularity	0.069	0.275
Relief	Feret diamter	0.256	0
Relief	Orientation	0.081	0.211
Relief	Mud ball concentration/unit area	0.063	0.096
Slope	Mud ball concentration/unit area	0.148	0.008
Slope	Mean diameter	0.116	0.066
Slope	Circularity	0.002	0.026
Slope	Orientation	0.093	0.066
Cumulative distance from strandline	Mud ball concentration/unit area	0.25	0.023
Cumulative distance from strandline	Mean diameter	0.201	0.088
Cumulative distance from strandline	Circularity	0.013	0.015
Cumulative distance from strandline	Orientation	0.706	0.415

Table 1: Regression Analysis

Several strong outcomes have been derived from this section like:

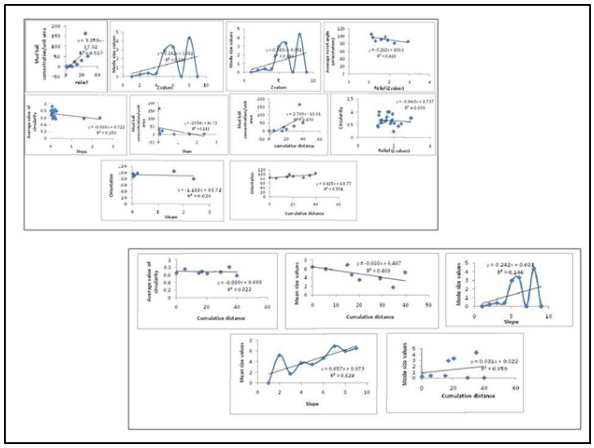

Figure 6: Variation Curves based on field data (2019)

- According to table 1 (figure 6), there is a positive relationship among these factors such as relief vs mean diameter, slope vs mean diameter of mud balls, relief vs mud ball concentration per unit area and cumulative distance vs. orientation. It had been observed that relief and slope factors affect the size and distribution of mud balls whereas; cumulative distance from strandline affects the orientation factor in Susni Island (2019).

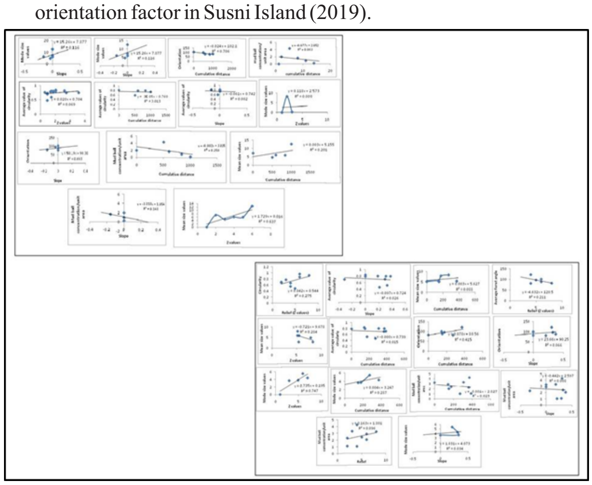

Figure 7: Variation Curves based on Chuksar Island data (2010 & 2011)

- In Chuksar 2010 data (table 1), strong correlation has been found in relief vs. mean diameter and cumulative distance from strandline vs orientation which implies that only relief factor dominates the mean size diameter of the mud balls and cumulative distance from strandline also dominates the orientation of mud balls that are significant result from this analysis based on the Chuksar data of 2010.

- Chuksar 2011 data (table 1) reveals that there is significant relation between relief and modal diameter of the mud balls belonging to distinct zones that implies that relief of the particular coastal stretch always dominates the size and shape factors of the mud balls.

6. CONCLUSION AND IMPLICATIONS

Present study on the dispersal of mud balls in the coastal fringes of Susni (2019) and Chuksar Islands (2010, 2011) reveals varied controls of geomorphic attributes (slope, relief and distance from strandline) and depositional attributes (coastal processes: waves or currents, aeolian) vis-à-vis size, shape and orientation of mud balls. Mud balls are characteristically distributed in coastline parallel zones.

In Susni coast

Relief and Slope play a definitive control on mean size.

Cumulative distance has a subtle correlation with the orientation of mud balls.

In Chuksar Island

Modal size or mean size show good correlation with relief.

Orientation of mud balls of different zones show better correlation with cumulative distance from strandline.

Present observations do not support the predicted correlation between cumulative distances with mean or modal size of the mud balls. This is perhaps due to storm mixing of the size populations of the mud balls and subsequent readjustment of mud balls along the slope of the substrate, with time.

Another interesting observation on shape of the mud balls revealed broadly three shape populations- near spherical, ellipsoidal and angular. Basic control appears to be the fragmentation of source mud layers (through desiccation and transportation in bottom load) producing near spherical and elliptical clasts and bottom eddies (producing depressions/ potholes) producing dominant spherical clasts. Apparent lack of correlation between circularity with any geomorphic parameters (slope, relief and distance from strandline) is perhaps due to near source contribution of spherical clasts through bottom turbulence.

Present observations on mud ball distribution might help to put constraints on the depositional attributes and help reconstruction of a high resolution depositional model for similar paleo-environment.

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