Comparison of Sediments and Sedimentary Structures from Cores Taken on the Outer, Middle and Inner Part of Tidal Flat off Büsum, North Sea Germany

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USA • 2010

ISBN-10: 1-59942-325-1
ISBN-13: 978-1-59942-325-8

1. Introduction

1.1 Motivation and Objective

It is known that different environmental conditions, such as availability of sediments, wave climate and current patterns will lead to different deposition processes and therefore to different types of sediment composition and bedding structures.

Based on the analysis of bathymetric data it is known that at some differently exposed tidal flat locations within the investigation area, a pronounced deposition has taken place over the last one or two decades. On this basis it follows that the analysis of sediment cores can be used to describe the deposition processes, which took place at different locations of the tidal flats. This hypothesis additionally includes that it should be possible to distinguish between periodic and aperiodic sedimentation events.

From the analyses of cores taken in these areas it is expected to gain knowledge about the vertical and horizontal spatial distribution of sediments and to formulate a kind of facies model, which allows to describe the driving forces which are more involved in the deposition of sediments in the investigation area.

1.2 Support and Interconnection with other Projects

This investigation was supported by *Forschung-und Technologiezentrum-Westküste* and CORELAB of Kiel University, Germany. It was carried out within the research project *Predictions of Medium Scale Morphodynamics-PROMORPH* and included in the PhD dissertation project of *Nils Asp*.

1.3 Structure and Organization of the Study

The results of the study are meant to fill out the requirements for the completion of the degree of Master of Sciences in Coastal Geosciences and Engineering of Kiel University, Germany. In maintaining the results, it was done in several steps within 8 months as briefly described in the following table (1-1) below.

Table 1-1. The time table which is planned in this study.

Work Description	Time / duration
Literature study	1 month
Vibrocore sampling	3 days, during September and November 2001.
Data preparation and analysis	4 months
Writing of the master thesis (final report)	3 months

2. General Aspects

2.1 Tidal Flat Characteristics

Tidal flats develop along the gently dipping sea coasts with marked tidal rhythms, where enough sediment is available and wave action may influence occasionally. Tidal flats facing the open sea may also develop, if wave activity is being reduced by presence of long subtidal zones extended towards the sea (e.g sand) (Reineck and Singh, 1980).

According to Reineck and Singh (1980), tidal flats are subdivided into three parts from land to the sea ward;

- *supratida*l zone is the zone landward and rarely covered by water due to evenly conditions such during spring or storm tides. This zone is rarely cut by tidal channels. Deposition takes place only at low current velocities. In warm and temperate climatic, this zone is vegetated by halophytic plants.
- *intertidal* zone, as the main tidal flats. It lies between normal low and high tides and is exposed once or twice a day depending on its tidal regime. The intertidal zone is occupied by smaller distributary tidal channel than those on subtidal zone. Sediment distribution on this zone is according to its depth. When it is getting shallower the current energy is also getting lower then only finer grain size can be transported further up. Thus the coarser sediment grain sizes are commonly found on the deeper part of intertidal zone. This intertidal zone can be vegetated on its upper part by mangrove in humid warm climates.
- and below the low water line is the *subtidal* zone. This zone is occupied by channels and subtidal sand bars and shoals with coarser sand size sediments due to high tidal current velocities.

The evolution of coastal morphology is influenced by the tidal amplitude. Three subdivision of tidal ranges and their relationship with the coastal morphology are distinguished (Reineck and Singh, 1980):

- microtidal < 2m, characterized by long barrier islands with few inlets.
- mesotidal 2-4m, short barrier islands, ebb and flood tidal deltas.
- macrotidal > 4m, small or missing islands.

But those morphological subdivision are also depending on the wave energy. Current velocity also has relationship with the sedimentary structure on the sediment surface and at the internal structure. On sandy tidal flats with current velocities of the tidal currents ranging from 30 to 50cm/sec, small-current ripples are abundantly formed. Megaripples or even giant ripples may evolve in gullies and channel when the current velocity exceeds 1.5m/sec (Reineck and Singh 1980).

Herringbone cross-bedding in channel sediment is abundant when the tidal current is bipolar, but on the tidal flats surface both currents and waves are rather complex in their direction. Water level differences play an important role in controlling the current direction as long as no area is subareally exposed. But, when the tidal flats are emerged, it is controlled by morphological slope. The influence of strong wind in current direction is also not negligible. The changing of current and waves direction is expressed in direction of current and waves ripples. Thus, from the direction of ripples the paleo-current can be recognized.

Intertidal flats sediments are mostly fine-grained usually mud (silt and clay) and fine sand. Gravels are rare. But in some special condition such as storm surges causing strong erosion, shell concentration may also occur. There is a tendency in grain size distribution on intertidal flats, fining in grain size towards the high water line and vice versa towards low water line. This tendency caused by the energy and partly the transport mechanism. Near the low water line the energy is high, thus the coarser grains are enriched here. Near high water line, the energy is already reduced, though only finer grains can remain in the water column, transported up to there and deposited.

2.2 Sedimentological Characteristics of Tidal Flats

2.2.1 Types of Bedding

Here we are going to describe only the type of bedding which commonly evolve in the main tidal flats, but none of these types of bedding only is restricted to the tidal flats.

2.2.1.1 Cross Bedding

A cross bed can be defined as a single layer, or a single sedimentation unit consisting of internal laminae (foreset laminae) inclined to the principal surface of sedimentation. There are several processes that can form cross bedding; infilling of channels, scours or by migration of dunes and ripples. Since the thickness of cross-bedding units vary from few millimeters to tens of meters, it is differentiated as (Reineck and Singh, 1980):

- ***small scale cross-bedding***, originated to the migration of current ripple. Small scale cross bedding is the most common on sand flats. The thickness of an individual unit is not more than 4 cm. Units are usually trough-shaped and sometimes show herringbone structure when it cuts perpendicular to the crest axis.
- ***large-scale cross-bedding***, the individual unit is usually more than 4 cm in thickness and may be as thick as 1 or 2 m.

Those explained above are the cross bedding according the scale based. They also can be divided based on their genesis:

- ***Current-ripple Bedding.*** Cross-bedded units composed of foreset laminae formed as a result of a migration of current ripples are called current-ripple bedding. According to the size, the units are divided into megacurrent ripple and small-current ripple bedding. Megacurrent-ripple bedding is common in the tidal channels (high current energy). It has a similar form and genesis with small-ripple bedding but differs in the thickness of individual units, sometimes more than 4 cm. Megacurrent ripple and megaripple bedding is sometimes developed in the intertidal zone of sand bars and shoals (Klein 1970a in Reineck and Singh 1980). ***Small-ripple bedding*** is formed under the condition of less sediment availability and the reworking is stronger. Each is bounded by planes of erosion (upper and lower bounding surface). Both, small and mega-current ripple type of bedding are bordered by *basal lamina* as the *bottom set*. In tidal flats environment, this type of bedding is mainly present in sandy intertidal flats and shoals.
- ***Wave-ripple Bedding,*** ripples which are produced by wave activity and migrate on the sediment surface. Sometimes it is difficult to differ the ripple of wave origin to current origin (small-current ripple bedding) when the wave-ripple is asymmetric. Boersma (1970) in Reineck and Singh (1980) distinguished the main features of a wave-ripple cross-bedding as followed; (by editing, only the most characteristics features for wave-ripple bedding are described).
  a. the lower bounding surfaces of wave-ripple bedding units are rather irregular or caternary arcuate.
  b. Chevron structures are shown by foresets.
  c. Wave ripple cross-bedded units generally show cross-stratal off-shoots. That is, in case of wave-formed cross-bedding foreset laminae are lofty, wavy in configuration.

The inclined foreset laminae generally pass the trough and peak up again on the other flank of the adjacent ripple, sometimes even reaching the top of it.

- ***longitudinal cross-bedding,*** very common in intertidal flat zones, due to the development of channels and gullies. The bed dip of longitudinal cross-bedding is perpendicular to the current direction as it is formed as a point bar deposit of a channel or a gully. Important features which always occur with this bedding in intertidal zones are curved slip planes, which are gravity fault planes (Reineck 1958a in Reineck and Singh 1980). Another characteristic of this bedding type is the occurrence of shell layer at the base of the bed and this can be recognized as a result of a migrating channel. This shell layer is normal to the dip of longitudinal cross-bedding. The layers which compound this bedding are not laminae, but are composed of different type of bedding of tidal origin, such as flaser bedding, lenticular bedding, wavy bedding, lenticular bedding and finely interlayered sand/mud bedding (Häntzschel 1963a; Reineck 1960a,b in Reineck and Singh 1980).

2.2.1.2 Flaser and Lenticular Bedding

When the deposition of sand and mud take places in the same area, formed a ripple bedding then flaser and lenticular bedding can be developed. The difference between these two bedding types is the composition sand/mud. Flaser bedding shows a little amount of isolated mud deposit between the sand ripple trough. Cross-laminated sands are deposited by tidal currents. As the current wanes, mud is deposited and drapes these sand laminae. Wavy bedding shows horizontally continuous mud and sand.

Lenticular bedding shows the sand lenses between muddy layers or discontinuous mud layers separated by continuous sand layers. The genesis of these bedding due to the energy fluctuation of tidal activity, the sandy layer deposited during periods of current activity that create ripples and muddy layer during slack water periods. These bedding are common developed on mixed flats of the intertidal zone.

2.2.1.3 Graded Bedding

This type of bedding is characterized by grain size gradation fining upward from the bottom to the top part in a unit and may reverse. It can be recognized from the underlying beds by a sharp contact at the base. The development of this bedding type is due to the settling velocity of the grain size available in the suspension of turbidity current. Commonly this bed formed as current turbidity deposit during normal deposition. The origin of *reverse graded bedding* is due to the rapid deposition of mud during the low peak of tidal range of low bed shear followed by deposition of coarser grain size during the high peak afterward.

2.2.1.4 Interlayered Bedding

Interlayered bedding is characterized by the bed unit of alternating layers that can be different in their composition, texture and color. This type of bedding is subdivided by the unit thickness and the grain size composition. They are *coarsely interlayered bedding* and *thinly interlayered bedding (rhytmites).*

a. ***Coarsely interlayered bedding*** is composed of alternating coarser and finer-grained layers which are several millimeters to several centimeters thick (Reineck and Singh 1980). The composition of fine and coarse grain size may differ according to the rate of energy, but definitely the energy is higher than the energy needed to form thinly interlayered bedding. During storm surges, interlayered bedding of various thickness of finer (silt and/or clay) and coarser-grained (sand) layers may occur in the same sequence. It is commonly present in mixed intertidal flats.
b. ***Thinly interlayered bedding (rhythmites)*****,** differs from coarsely interlayered bedding in its thickness of the layers composing the bed. The thickness of individual laminae is usually less than 3 or 4 mm. Sometimes the "rhythmites" term is used when layers composed of two or more different kinds of material which alternatingly repeat, as a result of regular changes in transport or supply of materials which typical in a tidal-influenced environment. Thus the availability of sediment (sand or mud) plays important role in this process. The duration of these regular changes can be for shorter of longer period Winter or summer deposit can be the example of seasonal changes of longer period duration, and the tide dominated deposit as the result of shorter period duration..

2.2.2 Bioturbation

Bioturbation is a reworking done by organisms in the sediment. Bioturbation shows trace of animals or their burrows in sediments. This process is common in tidal flats composed of mud and getting weaker as the grain size coarsen. The abundance of bioturbation features on the mud flats because the fine-grained sediment appears to serve a suitable substrate for local infauna, and because of elevation and longer exposure, many of the organisms burrow fairly deeply (Rhoads, 1967 in Davis, 1982).

One characteristic of the organisms in the tidal flats is that the abundance organisms which belong from little kinds of species. Those organisms are widely distributed on tidal flats due to their survival capability. Escape traces of animals as bioturbation sometimes are found in the point bar and channel bottom deposit of gullies and channels, this is due to sudden rapid rate of sedimentation.

2. 3 Sediment Grain Size

Grain size of sedimentary particles is a very important parameter in sedimentation, since it reflects the energy, mechanism and environment of sediment deposition. Grain size can be measured in various techniques, the simples one is by using caliper (tape or ruler) for grain size coarser than sand and sand mostly measured by sieving technique (for grain size larger than 63μ). For silt and clay different measurement techniques are needed, several which commonly used are by pipette or hydrometer analysis and by light-scattering diffraction.

Phi Units*	Size	Wentworth Size Class	Sediment/Rock Name
		Boulders	Sediment: GRAVEL Rock RUDITES: (conglomerates, breccias)
-8	256 mm	Cobbles	
-6	64 mm	Pebbles	
-2	4 mm	Granules	
-1	2 mm	Very Coarse Sand	Sediment: SAND Rocks: SANDSTONES (arenites, wackes)
0	1 mm	Coarse Sand	
1	1/2 mm	Medium Sand	
2	1/4 mm	Fine Sand	
3	1/8 mm	Very Fine Sand	
4	1/16 mm	Silt	Sediment: MUD Rocks: LUTITES (mudrocks)
8	1/256 mm	Clay	

* Udden-Wentworth Scale

Figure 2-1. Udden-Wentworth scale as the grain size scale which the most commonly used. Phi scale as logarithmic transformation proposed by Krumbein (1934) in Selley (1988).

The range of sediment grain size is almost infinite, thus logarithmic scale is needed for size classification. A grain size scale by Udden-Wentworth (1922) in Selley (1988) is the commonly used in grain size analysis (fig. 2-1) and later modified by Krumbein (1934) in Selley (1988) for logarithmic transformation. The phi (ϕ) scale is based on the negative log to the base 2:

$$\phi = -\log_2 d$$

where d is the diameter in millimeter.

2.3.1 Statistical Parameters of Grain Size

After grain size measurement is done, later the presentation of data will be done in several statistical parameter which describe the nature of the population of the grain size. Firstly, a cumulative curve of weight percentage of each grain size class is plotted on a probability (logarithmic) paper. Or by plotting the frequency of each grain size class as histogram to determine the most frequent grain size (fig.2-2). But unfortunately it is difficult to gain some statistical parameters from histogram except the degree of peakedness (kurtosis).

From the cumulative curve, later we can obtain the parameters to describe the grain size distribution (after Folk, 1974 in Davis 1992):

- ***Graphic Mean (M)*** is the average (in ϕ unit) grain size in a sample, can be obtained from formula

$$M = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

where M values are:

Values from	To	Equal
-∞ϕ	-1ϕ	gravel
-1ϕ	0ϕ	very coarse sand
+0ϕ	+1ϕ	coarse sand
+1ϕ	+2ϕ	medium sand
+2ϕ	+3ϕ	fine sand
+3ϕ	+4ϕ	very fine sand
+4ϕ	+8ϕ	silt
+8ϕ	ϕ	clay

- ***Inclusive Graphic Standard Deviation (D)*** is the parameter of grain size uniformity or sorting in a sample. This parameter is a valuable one because sorting reflects conditions during the deposition of sediment.

$$D = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 + \phi 5}{6.6}$$

In frequency curve or histogram (fig.2-2) the steep curve or steep peak reflects good sorting and flat curve or equally high of peaks in histogram reflects poor sorting.

where D values are:

Values from	To	Equal
0.00ϕ	0.35ϕ	very well sorted
0.35ϕ	0.50ϕ	well sorted
0.50ϕ	0.71ϕ	moderately well sorted
0.71ϕ	1.00ϕ	moderately sorted
1.00ϕ	2.00ϕ	poorly sorted
2.00ϕ	4.00ϕ	very poorly sorted
4.00ϕ	∞ϕ	extremely poorly sorted

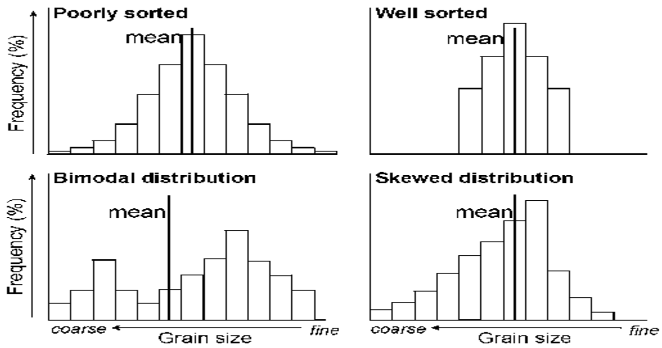

Figure 2-2. The histogram of grain size distribution.

Beside those parameters mentioned above, the median and mode are important value in sediment analysis. The *median* is the grain size in the middle of population and the *mode* is the most frequent grain size in the population.

2.3.2 Sediment Composition on Tidal Flat

Sediment composition at any places always depend on the source of the sediment available. In tidal flats the sediment may from inland and bottom sea sediment (offshore) or minerals as the result of precipitation. Sediment from inland brought by river and mainly contains minerals that characterized from land, i.e., quartz, clay minerals, heavy minerals, light minerals and other minerals depending on the rock type inland. Sediments on siliciclastic tidal flats are composed primarily of mud and sand. Mud predominate in the supratidal and upper intertidal zones, and the deposits of supratidal marshes are further characterized by abundant plant debris, which may eventually form peat. Mixed mud and sand characterized the middle part of intertidal zone, and sand dominates the lower intertidal zone as well as the channel and bar deposits of the shallow subtidal zone. Mud may be deposited between channels in the subtidal zone below wave base. The proportion of mud and sand in modern tidal flats varies considerably (Boggs, 2001).

3. The Investigation Area

3.1 Geographic Location

The investigation area is the tidal flat off Büsum with an extension of about 600^2km, which is located on the West coast of Federal State Schleswig Holstein, German North Sea (fig.3-1). The south and north limits are the Latitudes 54°01’N and 54°12’N. The west and east limits are almost at the 08°30’ and 09°00’ Longitude. In fact the east and west limits are represented by the coastal or dike line of Büsum and the outer intertidal sand banks (D-Steert and Tertius) respectively.

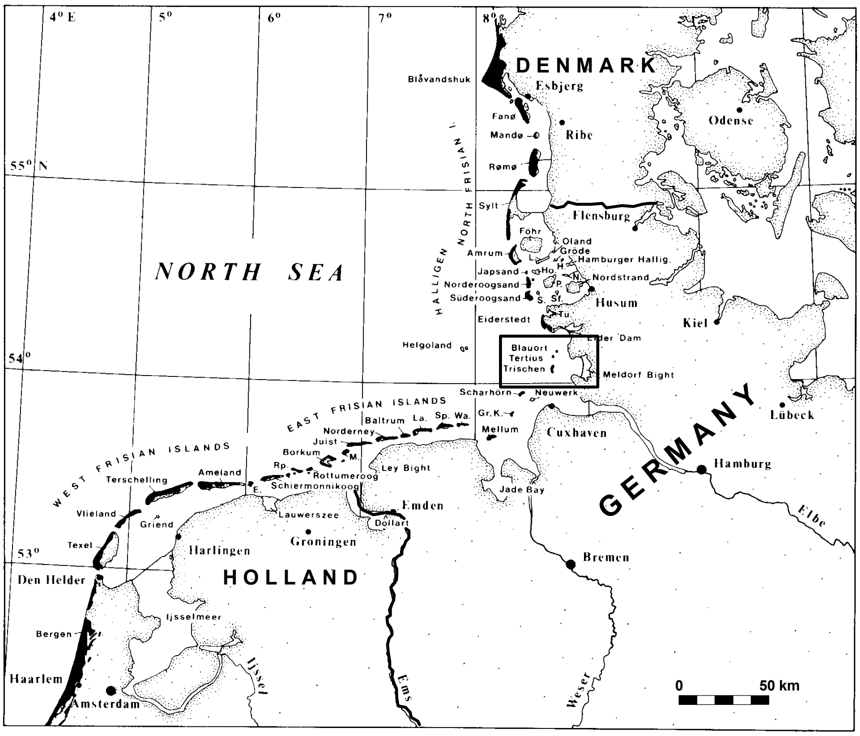

Figure 3-1. The location of investigation area (modified from Ehlers, 1988).

The region comprises two major tidal inlets of Norderpiep and Süderpiep which connect the domain with the open sea and numerous of secondary and third order of tidal channels with a maximum water depth of about 23 m. The intersection of these two major channels within the investigation area is forming the main Piep tidal channel.

The studied tidal flat area is composed of different intertidal sand banks, which are Tertiussand, D-Steert, Bielhövensand, Blauortsand and Buschand. These last two banks include 2 supratidal banks as well which are Blauort and Trischen.

3.2 Climatic Condition

3.2.1 Wind

According to the observation from year 1975 until 1982 taken at the north of the domain, that the most frequently wind direction are from Southwest to Northwest (fig. 3-2). This phenomenon gives locally modification to the relief of the coast and islands in the region.

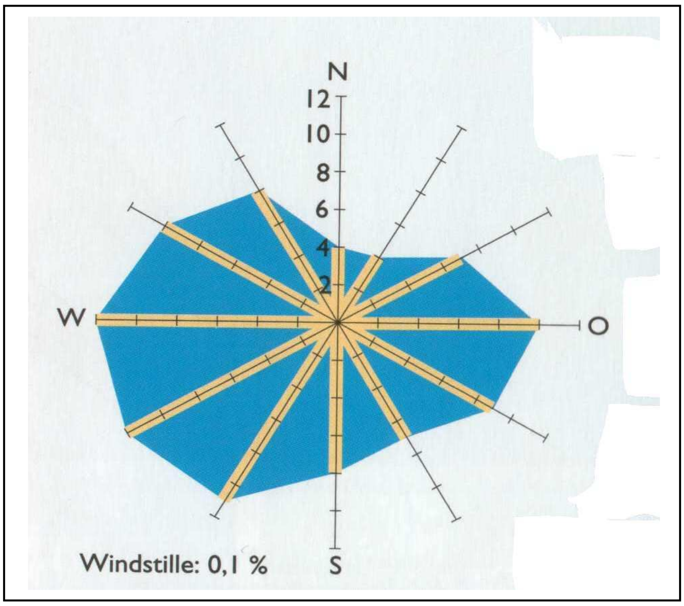

Figure 3-2. The average of wind direction distribution on the north of the investigation area in %-proportions of the time (Umweltatlas Wattenmeer – Band I, 1998).

The highest wind speeds (that 15% of the wind speeds are higher than 10m/s) are recorded generally occurred during November and December which cause the Fall- and winter storms, and the most weak or minimum wind speeds occurred between May and October (summer time).

3.2.2 Temperature

The lowest temperature of the sea water in the North sea lies at freezing point of sea water (-1,5°C to –1,9°C) and the highest one may exceed around 23°C, and at some closed ponds it may reach until around 30°C. From the determination of the of minimal- and maximal water temperatures distribution over ten years in the North sea region, it is found that the tidal flat area is special area. There, the highest and the lowest water temperatures occurred (fig.3-3).

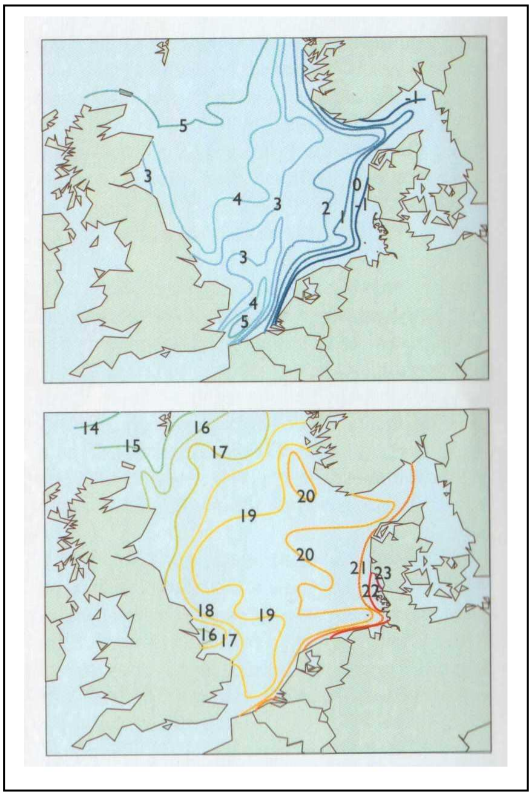

Figure 3-3. Minimum and Maximum surface temperatures in °C at North Sea within period of 1971 until 1980 (Umweltatlas Wattenmeer – Band I, 1998).

The absolute values of the highest air temperatures from the mainland to the coast may reach until around 36°C and vary on the islands. The absolute values of the lowest air temperatures occurred on the mainland are at –30°C until –22°C, at the islands on the tidal flat region will reach until –25°C to –20°C and at Helgoland around –15°C.

The number of frost- and summer days during a year more or less influence the heating and cooling in North Sea. The frost days characterized by minimum temperatures under 0°C and summer days by maximum temperatures at least 25°C. Meanwhile, more to the inland of western part of federal state Schleswig.Holstein, about 70 to 80 of frost days occurred during a year. These numbers fall at the beach and islands on tidal flat region, which only occur for about 55 to 79 days. The fewest frost days occurred in Helgoland which are about 37 days. The same condition for summer days, Helgoland has the fewest summer days that only 1 day per year (average), 5 to 11 days at the beach and islands on the tidal flat region and on inland about 12 to 17 summer days.

3.2.3 Precipitation

The precipitation rates which occurred during a year at Western part of Schleswig Holstein are between 700 mm in the North Frisian islands region and more than 900 mm in small part of Holstein and in area of Schleswig. These high precipitations distribute over the year during around 185 until 215 days with minimum precipitation of 0,1mm which is generally occurred on February (Landesamt für den Nationalpark Schleswig Holstein Wattenmeer Umweltatlas, 1998).

3.3 Hydrographical Condition

In 24 hours, the investigation area experiences two times of low and high water, meaning that the tidal regime is semidiurnal. From measurement taken at the mouth of Elbe Estuary in the South to the Eiderstedt peninsula in the North, it appears that the mean tidal range is about 3,1 to 3,4m. Referred to the German water level datum “NN” the mean high water at Büsum is at +1,6m NN and the mean low water as at –1,6m NN (BSH, 2002). The difference between neap and spring tidal range is approximately 0,9m. Severe onshore storms can result in an upset of the water level of more than +5m NN.

The maximum tidal current recorded in the main tidal channel may reach 2 m/s, where the mean maximum velocities are about 1.2 to 1.5 m/s. In the tidal flats the ebb current velocity is remarkably higher than the flood current velocity (Gierloff-Emden, 1980) within range of 30 cm/s and rarely exceeds 50 cm/s (Ehlers, 1988).

The wave conditions are more or less depending on the exposition and the water depth. In the inlets close to the open sea significant wave heights of 4 m can occur, but due to the bathymetry, this wave height will decrease as the waves move toward the mainland. In this study, the sampling locations were mainly located on the points which protected from the swells.

3.4 Geological Background

3.4.1 Holocene Evolution of the Ditmarschen Tidal Flat

The beginning of post-Pleistocene age in the Ditmarschen tidal flat is marked by a peat layer overlying the Pleistocene glacio-fluviatile sands. But, due to a rapid sea level rise at the beginning of the post-Pleistocene transgression the peat was widely eroded and subsequently silty clay was deposited and later is called as “Dithmarscher Klei” (DITTMER, 1938), which indicating a submarine deposition condition. This silty clay layer reached a thickness of more than 10 m.

Then, in the following period the early Holocene silty clay was partly discordant and partly concordant overlaid by a sequence of sandy sediments with some interlayered cohesive, muddy deposits. This is indicated by a change in the environment from deeper water to intertidal shallow water conditions. The composition if the deposits correspond extensively to that of the recent tidal flat sediments. The thickness of these modern intertidal deposits is around 20 m (fig.3-4).

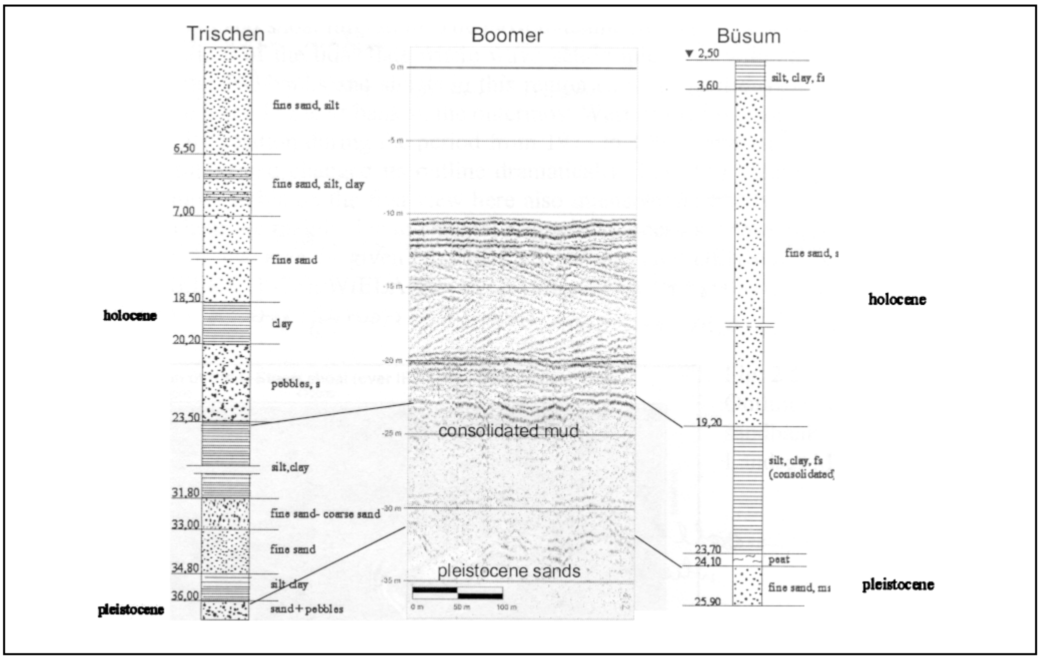

Figure 3-4. Profiles of cores representing the geological structure of the Dithmarschen Wadden Sea:
Left core: supra tidal sand of Trischen (after DITTMER, 1938)
Right core: harbour of Büsum
Boomer: Shallow seismic profile along the Piep channel axes some km off Büsum

3.4.2 Sediments of the Dithmarschen Tidal Flat

Köster (1998) described the three main types of sediments which are distributed in the Dithmarschen Wadden Sea. Those types are classified due to their corresponding unit: sand (from the tidal flat – “Sandwatt” – and from the supra-tidal sands), muddy sand (“Mischwatt”) and mud (“Schlickwatt). The supra-tidal sands composed fractions range from fine to medium sand and the other three classes of sediments are around 40% to 60% composed fine sand whose range from 63μm to 125μm (table 3-1).

Table 3-1. Sediment type of the Dithmarschen tidal flat, modified from Köster (1998).

Grain Size	Unit/Type of Sediment		
	Sandwatt / Sand	Mischwatt /Muddy sand	Schlickwatt / Mud
< 63 μm	< 10%	10 – 50%	> 50%
63 μm to 125 μm	40 – 60%	40 – 60%	40 – 60%
> 125 μm	> 30%	< 20%	0

3.5 Morphological Evolution in the Investigation Area

The combination of strong tidal currents in the channels and wave action in the outer sand banks, awards the area a changing morphology. These morphological changes are well-related in the historic and scientific literature that date back to the 16th century (Lang, 1975). These changes are influenced by the human activity, especially trough dyke construction.
These morphological changes have been studied since the beginning of the 20th century. With the beginning of the *PROMORPH* project in 1999, the knowledge about the morphological evolution of the area has been noticeable improved. A morphological study based on bathymetric measurements from a 24-years periods (1974 – 1997), collected by BSH (Federal Maritime and Hydrographic Agency of Germany) in the Dithmarschen Bight, is being carried out until now and postulate that, regarding to the sediment volume in the area, no big differences between 1974 and 1997 can be recognized (Asp, 2002).

On the other hand, inside the study area, important morphological changes have taken place, resulting in distinct sediment transfers between different compartments or sub environments. In this aspect, the clearest tendency is the transfer of sediments from sub-tidal areas to the inter-tidal areas, i.e., erosion in channels and deep parts, and deposition in the tidal flats.

Other noticeable points are the well-known migration of the outer banks landwards, the filling up of parts of the channels near the dykes constructed between 1972 and 1979 in the Meldorf Bight and the lateral migration of channels. These processes resulting important deposition in some areas, where were chosen to take cores used in this study.

The northern part of Tertiussand has migrated landwards like 150m/y in the last 24 years according to Rausch (2000), based on satellite images. According to Reimers (2000), based on aerial photographs, this migration was something like 100m/y in the last 10 years. Wieland (1972) related migration rates of 30m/y for the sand banks Blauort and Trischen in this region over a period of more than 100 years. This tendency could be also identified according to the comparison between the bathymetric measurements from BSH.

Although the northern part of Tertius has been migrated clearly, the middle part seems to be stable. Strong ebb-tidal currents seem to erode and control its position. The section of the Süderpiep between two sand shoals, Tertius (southern part) and D-Steert, has experienced a narrowing, as results of the migration or morphological changes in those sand shoals. As a result, the channel was getting deeper as well (Asp, 2002, in preparation).

4. Methodology

4.1 Determination of Sampling Points Locations

Since the aim of this study is to investigate the sediment and sedimentation process based on the vertically in situ sediment on different exposed locations, the determination of sampling locations should be based on the bathymetrical changes that occurred in the investigation area. According to this, the locations where the sedimentation took place can be recognized and later the sampling locations can be determined. A map of sedimentation and erosion sites is shown in the figure 4-1.

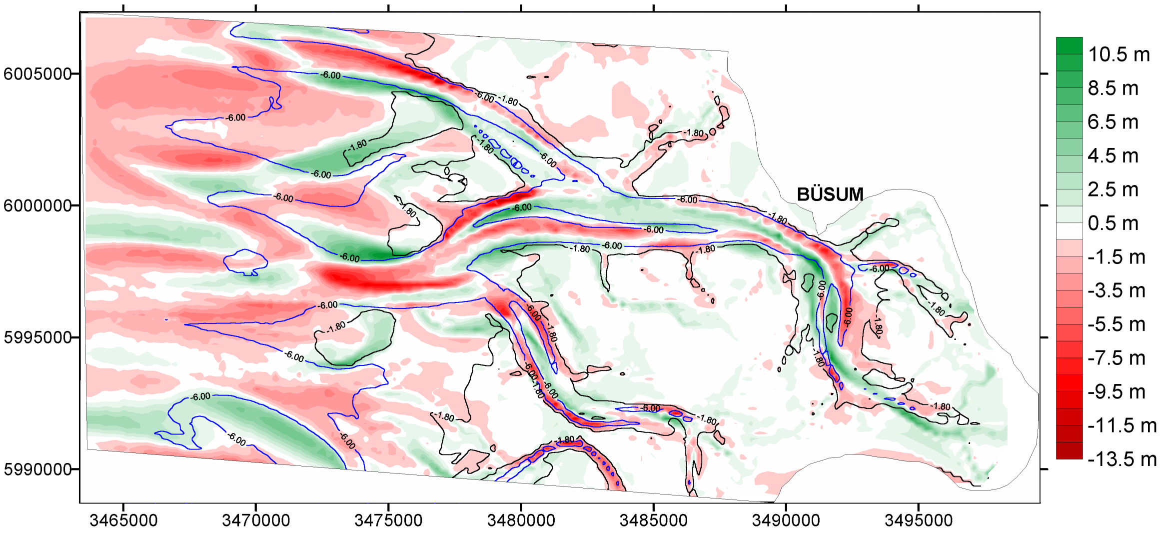

Figure 4.1. Sedimentation and erosion map, a comparison from morphological changes from year 1977-1996 (Asp. 2001, personal communication)

Table 4-1. The vibrocores sampling positions

Station Number	Nautical Coordinates		Gauss-Kruger Coordinates		Core Length (m)	Elevation (m. from NN)
	Latitude	Longitude	Latitude	Longitude		
KE 1	54°09.838'	8°39.313'	3477549	6003780	3.59	+0.5
KE 2	54°09.837'	8°39.314'	3476300	5998500	1.81	+0.5
KE 3	54°05.448'	8°37.372'	3475393	5995647	3.51	-0.1
KE 4	54°03.324'	8°57.458'	3497296	5991642	3.65	-0.2
KE 5	54°03.881'	8°54.791'	3494386	5992678	4.62	-0.5
KE 6	54°06.264'	8°51.683'	3491003	5997104	3.12	-0.3
KE 7	54°07.634'	8°54.841'	3494449	5999640	4.56	-0.5
KE 8	54°06.510'	8°44.377'	3483040	5997583	5.5	+1
KE 9	54°06.954'	8°49.974'	3486173	5997589	3.5	-0.1
KE 10	54°06.519'	8°47.251'	3489143	5998388	4.82	+0.6

Positioning of each sampling location was done by using GPS which are later transferred into Gauss-Kruger coordinates (table 4-1), to facilitate the graphic representation, calculations and comparison (table 4-1) and the sampling locations map are shown on the figure 4-2.

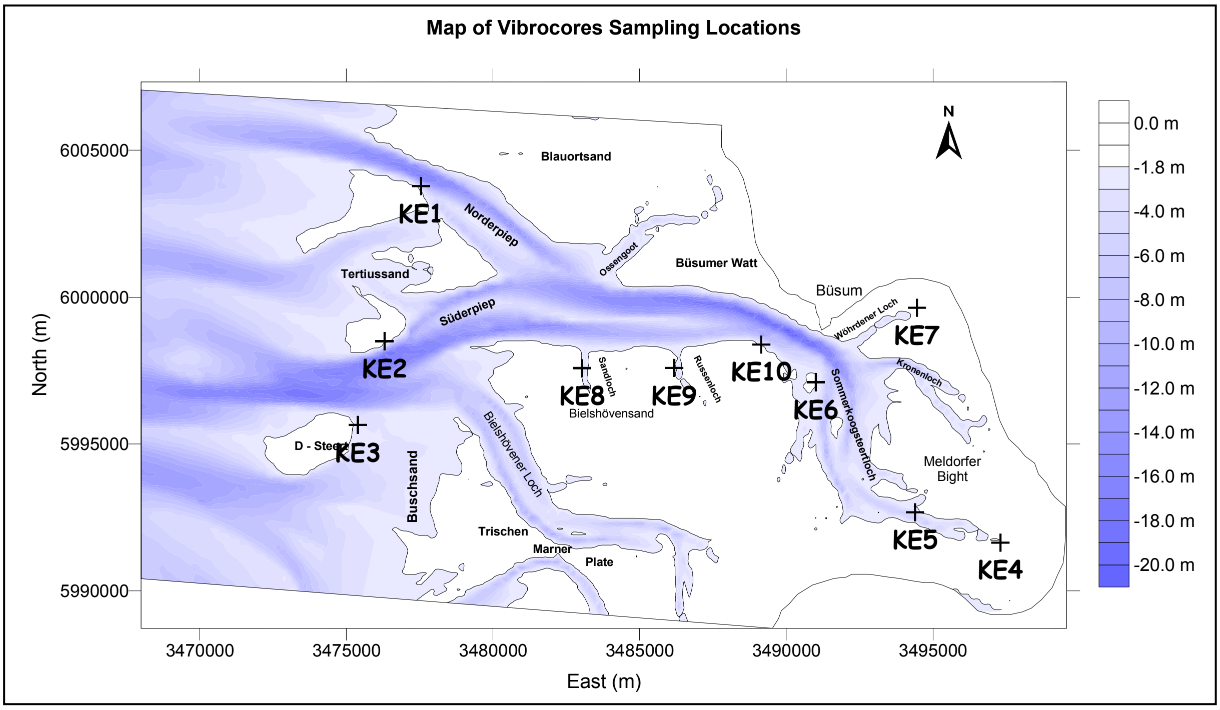

Figure 4-2. The vibrocore sampling positions map in the Gauss-Kruger coordinates.

4.2 Vibrocore Sampling

The method used in vibrocore sampling is based on the method described in LANESKY (1979). The samplings were done during low water with special equipments such as: 6 m long with 8 cm diameter of aluminum core, vibrocorer, tripod with a winch and special designed coring boat owned by FTZ-West Küste, Kiel University.

4.3 Identification of Sedimentary Structures

4.3.1 Handling Over Detailed Section Descriptions of the Sedimentary Structures

Detailed section descriptions were done after the opening of the cores comprised of:

- Detailed descriptions of the sedimentary structures, recorded all the information by rough sketches and written descriptions. Those descriptions include the texture (color, predicted grain size, etc), internal structures, biturbations and compositions.
- Taking static photographs of sediments in the core as they were still fresh (directly after the opening) and after a few days for a visual comparisons.

4.3.2 Computertomography

This method was meant to present a more detailed visual recognition on the thick mud sediments that can give more information about its sedimentation process.

The *computertomography* is a layer record process by using X-ray. Originally it was used as an application for human medical diagnosis. Nevertheless, this procedure can be also used in investigation on the marine sediments. An overview of *computertomography* application in geosciences is described by Abegg, 1988.

The technique of this method is that the cross-formed *computertomograph* lies in a x-ray tube and scans the sample (object) from different sides. In front of this x-ray tube, a detector will measure the x-ray radiations which come out from the sample. Then the measurement result, as values, will be collected in a reconstructions computer in order to build up an image. A method to calibrate a computertomography is described by ORSI (1994).
Digital images can be developed by using software produced by JOBEX/CBBL SRP-Project, Texas A&M University.

4.4 Grain Size Analysis and Statistic Parameter Calculation

The grain size analysis is more focused on the sandy sediments found in the cores and the sieving procedure was carried out based on the procedure described in TUCKER (1991). A brief schematic procedure which is used in this investigation is described in figure 4-3.

The use of *hydrogen peroxide* was meant to disaggregate the sample, stirred and left at least 24 hours and then heated overnight at 90°C to drive off excess *hydrogen peroxide* following oxidation of organic matter. The sample which is being dry sieved through numbers of range from 0,45mm to 38µm with weight range about 80gr to 120gr. There was no separation of carbonate materials within the sieved samples.

Size classification is based on the method proposed by *Udden & Wentworth* (1922) in *Tucker* (1991). The statistics were calculated by using *SEDIVISION 3.0* based on the method of moments by *Folk and Ward* (1957).

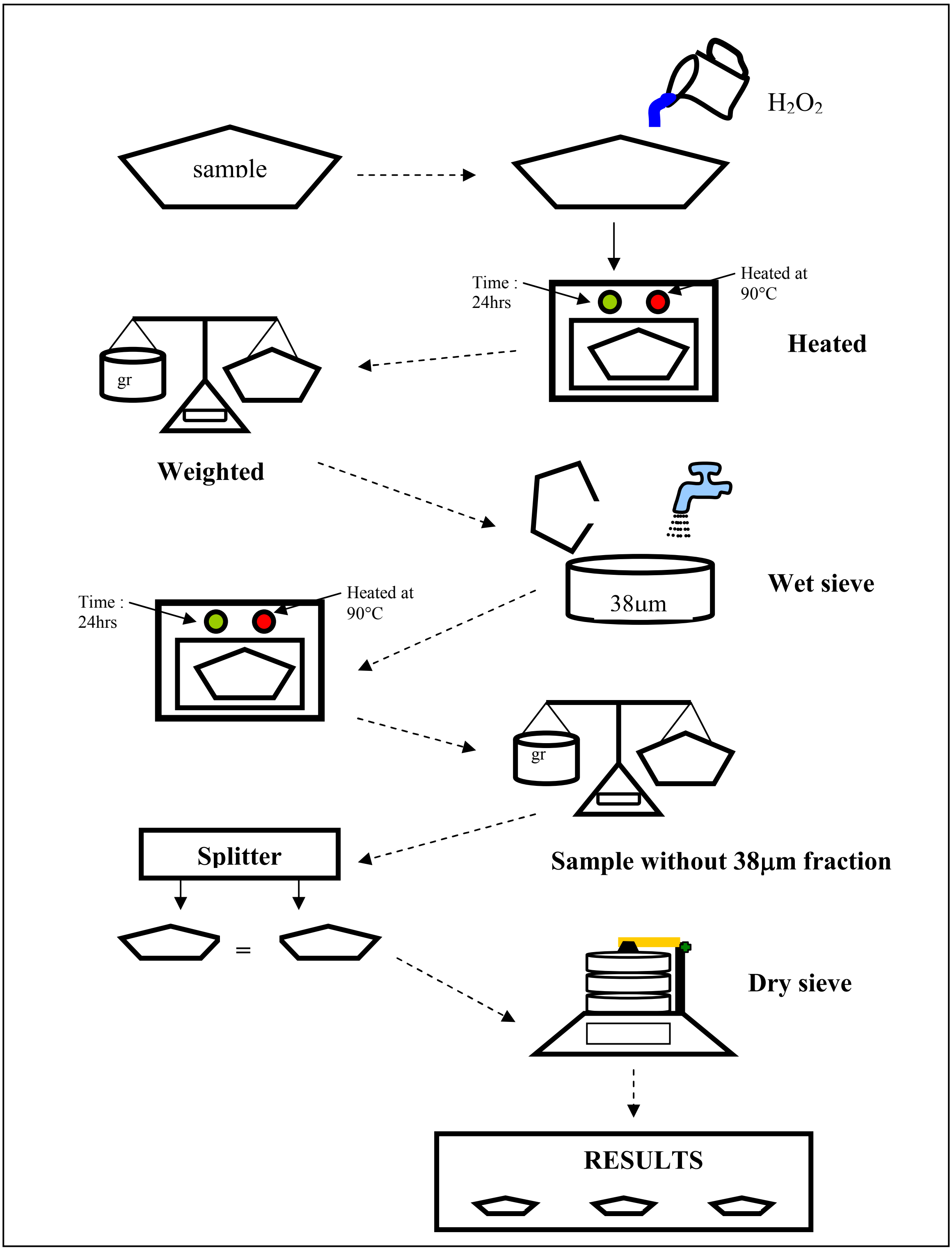

Figure 4-3. The schematic procedure in grain size analysis, the inserting of H_2O_2 was meant to mechanically break the flocculated fine materials.

6. Discussion of Results

The study of sediments and sedimentary structures in the different parts of tidal flats serves several useful functions. Firstly it provides basic information about the sedimentological characteristics of each part and second, it provides information to interpret the sediment distribution over the whole tidal flats area (from the outer part to the inner part), which may indicates the processes responsible for the deposition on each parts.

In the intertidal zone, sediment processes of transport and deposition are zoned in a contour-parallel fashion from high-tide level to low-tide level (Davis, 1985) (figure 6-1).

On the high-tide level, here in this investigation is termed as the inner part, the dominant transport mode is suspension transport. On this part, the submergence only lasts at about one-third of a tidal cycle (Davis, 1985). Suspension transport dominated, time velocity asymmetry of tidal currents (Postma, 1961; Groen, 1967) and a long period of exposure (Van Straaten and Kuenen, 1967) aid the net accumulation of fine-grained sediments on the high-tide level. Therefore, on this part the mud enrichment occurs, and as a matter of fact, this condition is found in the investigation area.

The mid-flat as the central portion of intertidal flats (the middle part of investigation area) inundates for approximately 50% of a tidal cycle. Here, on this part, the periods of both suspension and bedload sedimentation are nearly equal. This nearly equal alternation of bedload and suspension deposition generates a mixed lithology (DeRaaf and Boersma, 1971 *in* Davis, 1985) of interbedded sand and mud. Similar with the condition found in the middle part of investigation area, where the flaser bedding occurred as the dominant sedimentary structures.

Transport and deposition of sediment occurs, obviously, in the intertidal zone only during the periods of submergence. On the low-tide level (or outer part) of investigation area, the submergence lasts for about two-third of a tidal cycle. There, on this part, the highest current velocity occurs and the main sediment transport mode is bedload. Nevertheless, suspension transport by waves is also found, which is reflected by large quantity of laminated sand.