CHAPTER 48

Sand Transport and Coastal Stability, Lancashire, U.K.

by

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Abstract

The stability of an alluvial coast depends upon the localsediment budget. Along the shore, changes from erosion to accretion may reflect changing sediment fluxes, sediment residence times and patterns of sediment movement. Processes influencing these parameters, such as mud sedimentation or migration of intertidal channels will, through their influence on beach gradients and sediment transport patterns, affect the processes and rates of coastal dune erosion and the safety of the dune protected hinterland.

A qualitative description of some of the various processes and phenomena linking foreshore and dune stability with sediment circulation and coastal evolution is presented.

Introduction

Formby Point lies on the eastern side of the Irish Sea, 17 km north of Liverpool, between the estuaries of the Mersey and Ribble, Fig. 1. To the south west is the complex of sandbanks and channels of Liverpool Bay. The floor of the eastern Irish sea slopes gently west from the long sandy foreshore and sand dune systems leading north to the Ribble estuary.

The area has a high tidal range (Mean Spring Range 8.2m) and is subject to large meteorological surge contributions to high waters (Lennon 1963 [a,b]). Maximum local wave conditions occur with strong winds from the south west, west or north west (Darbyshire 1958, Murthy and Cooke 1962). Waves are fully developed except from the

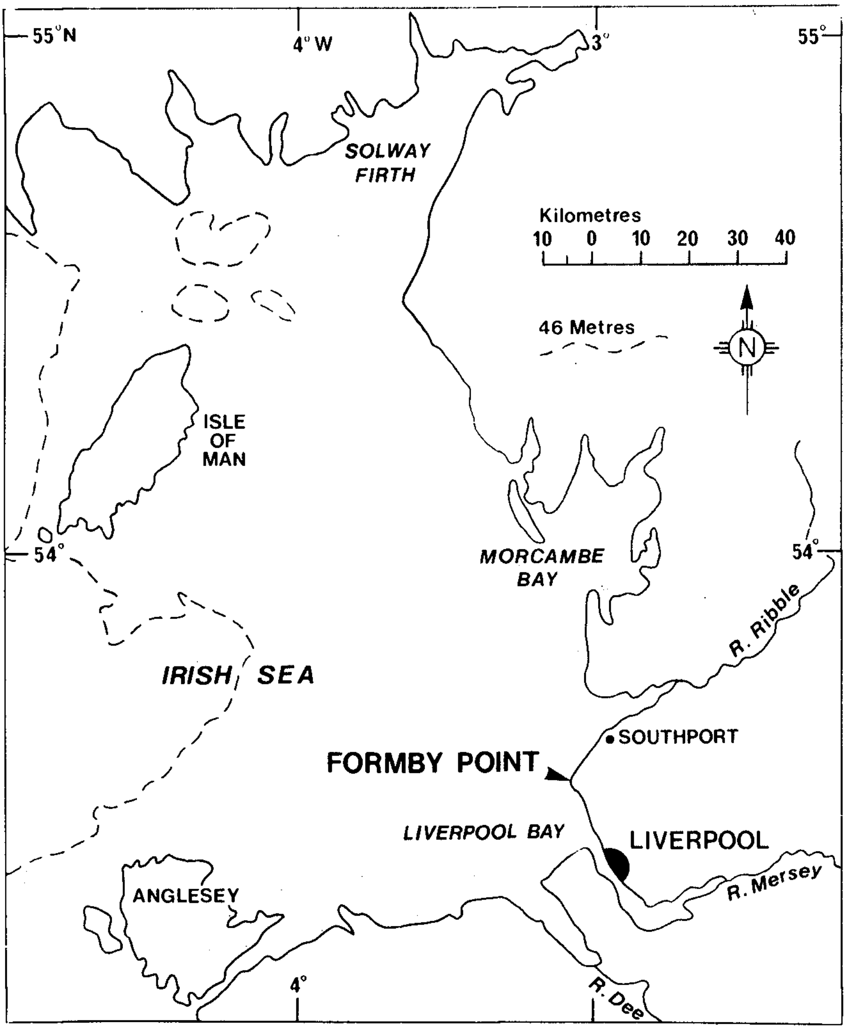
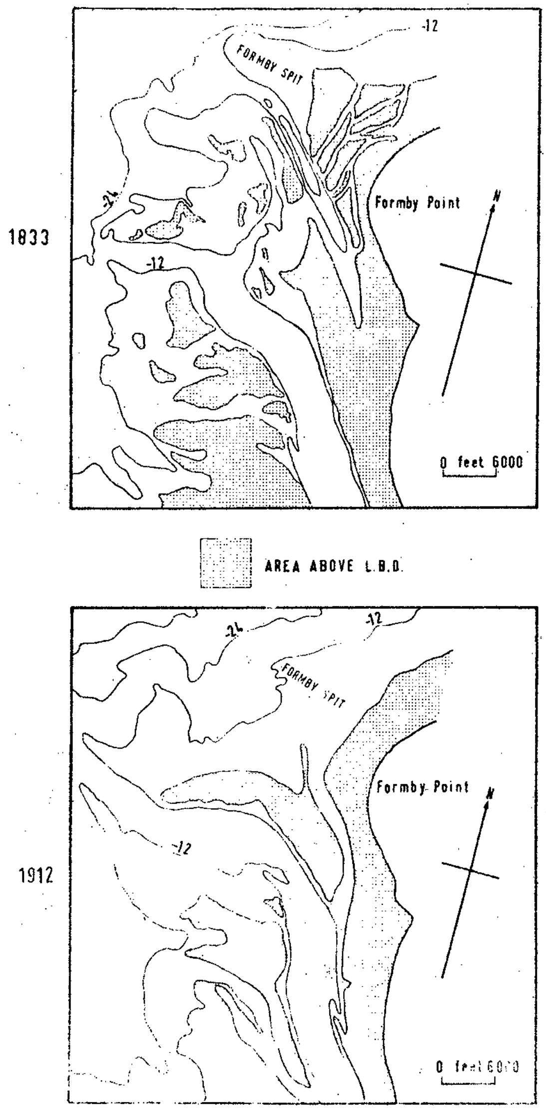


Fig. 1 LOCATION OF FORMBY POINT

Fig 2

CHANGES IN AREA ABOVE BAY DATUM 1833 1912



(from M D h.B charts)

southerly or easterly quadrants and show little seasonal variation in either period or spectral characteristics although waves are generally higher in the autumn and winter months. The most common wave conditions are those with a significant wave height of between 0.5 and 1.0 m and a zero-crossing period of between 4.0 and 4.5 seconds (6.1% of the time) (Draper and Blakey 1969).

The local estuary waters have a mean salinity of 32.00‰ (Bowden 1955, 1960) but inshore, large tidal variations in salinity may occur in some channels with freshwater input. Outside the main channel of the estuary flows are only weakly stratified especially in the near-shore areas. Studies of residual regional water movements (Bowden 1960, Best 1973, Halliwell 1973, Sharaf El Din 1970) show that near bed residual water flow is, over a wide area, south or south east into Liverpool Bay.

The floor of the eastern Irish Sea is covered with fine or medium sand with varying amounts of mud and some areas of gravel (Wright et. al.. 1971, Cronan 1969). The regional pattern of residual sand movement is virtually unknown. Evidence from sandwaves and hydrological measurements (Belderson and Stride 1969, Sly 1966) suggest sediment transport towards the south east.

Coastal Evolution and Morphology

The nearshore regions of south west Lancashire have been subject to considerably bathymetric changes during the recent past (Fig. 2). The sand dune system on this coastline (Fig. 3) have a history of cyclical development related to periods of coast erosion and accretion (Blanchard 1953, Greswell 1953, Parker 1971, 1975). The most recent dune sequence has grown north westwards and the angle of 16° between it and the present eroding coast indicates the extent of reorientation of the coast as does the exposure and erosion of Holocene sediments underlying the foreshire.

Plate 1

From 450' south just north of Dale Slack Gutter (Fig. 4) Note beach ridges, wet (white) patches on upper foreshore in middle centre of plate. Photograph by John Mills Ltd., Liverpool.

Plate 2

Beach in eroding sector of coast. North west mark (Fig. 4) and Victoria Road (caravan site) in left middle ground. Holocene sediments in runnels near left.. Photograph by John Mills Ltd., Liverpool

Fig 3

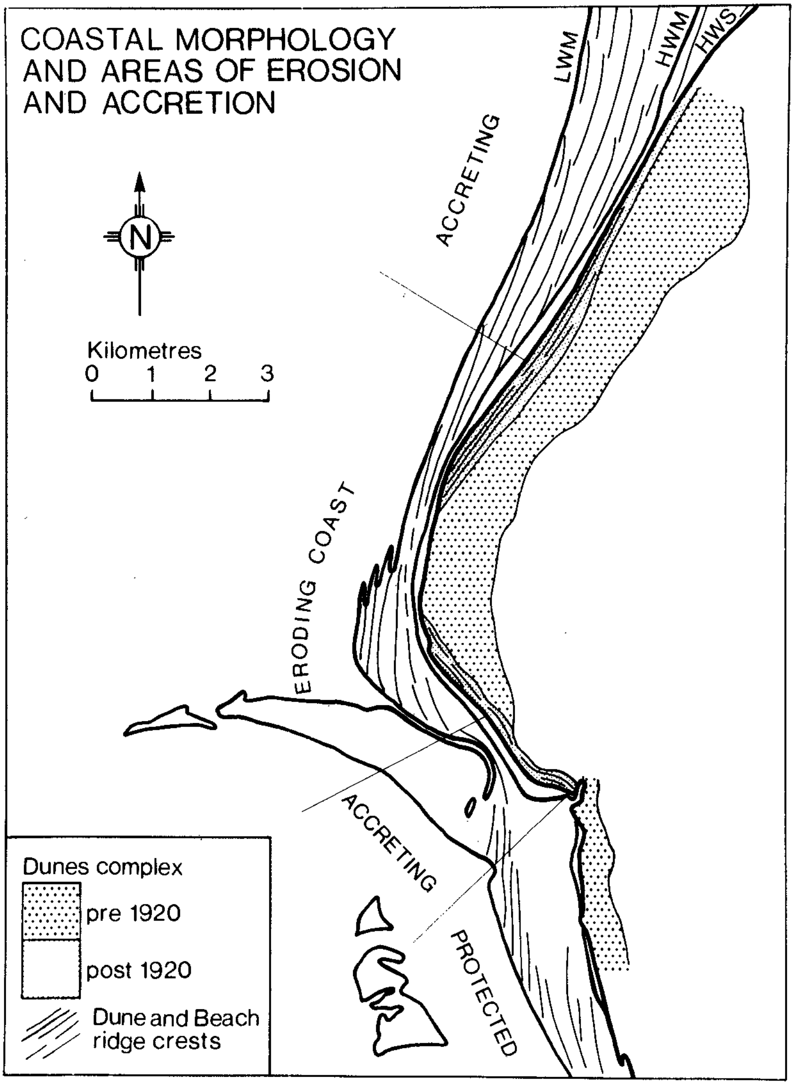
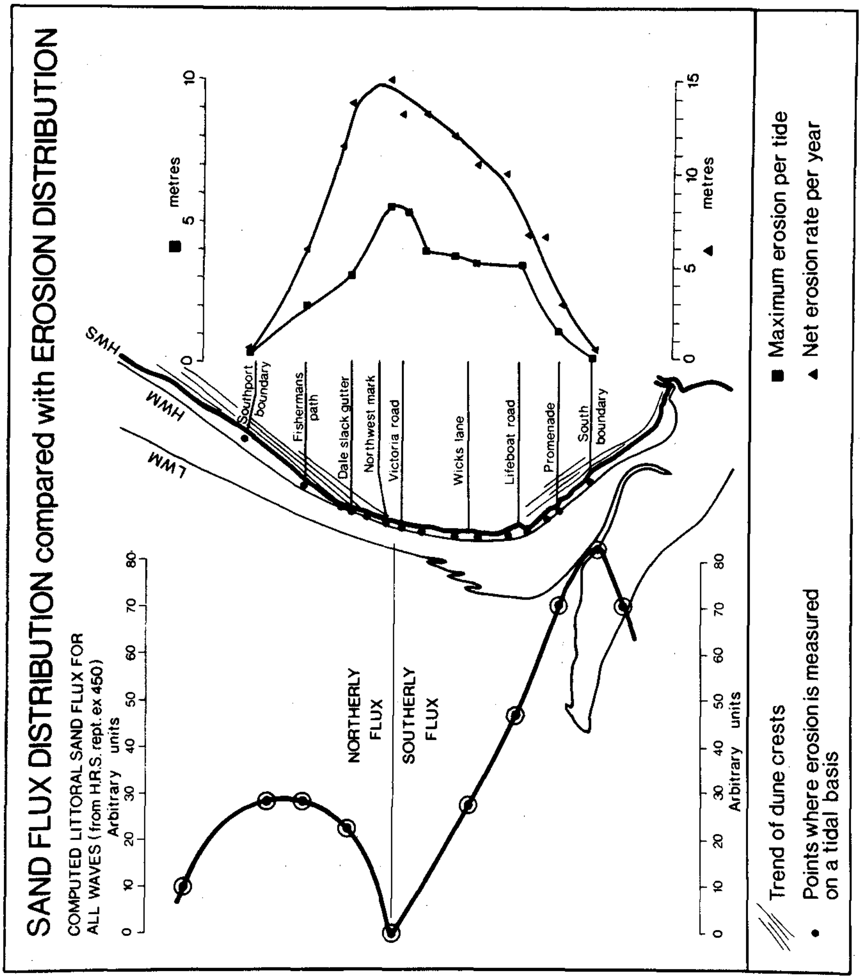

COASTAL MORPHOLOGY
AND AREAS OF EROSION
AND ACCRETION
N
Kilometres
0 1 2 3
LWM
HWM
HWS
ACCRETING
ERODING COAST
ACCRETING
PROTECTED
Dunes complex
pre 1920
post 1920
Dune and Beach
ridge crests

Fig 4



Data on Sand Flux from Hydraulics Research Station, Wallingford. Report No. EX.450. Crown Copyright. Published by permission Controller, H.M.S.O. Courtesy Hydraulics Research Station. Wallingford, England.

Along this coastline a range of conditions of stability exist (Fig. 3). In the north of the area rapid accretion of the coast allows intertidal and high water mark sand extraction to the extent of over 200,000 tons per year. This typical ridge and runnel foreshore shows long continuous runnels with regularly spaced rip channels. Southwards from this area of accretion a change takes place through a retreating, though uncliffed coast, to a retreating sand cliff coastline.

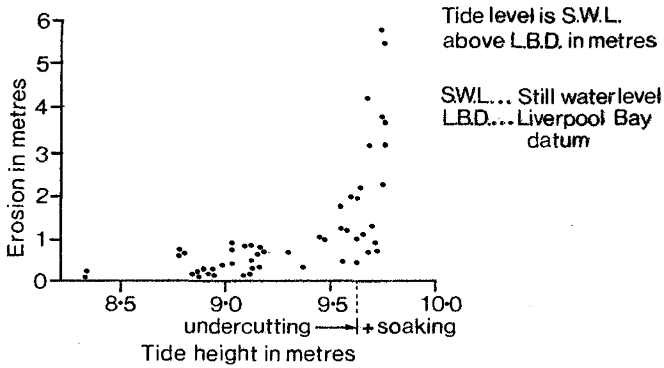
The transition, illustrated in Plate 1, looking south towards the eroding coast, is accompanied by a reorientation of HWM, the exposure on the foreshore of the underlying Holocene sediments, and erosion of the sub-beach Holocene surface (Plate 2). On the eroding sector of coast the beach ridges are less continuous with more closely spaced rip channels (Plate 2).

On the eroding sector of the coast long and short term erosion varies from north to south (Fig. 4). Comparisons between these measured rates and distributions of erosion and theoretical calculations of sand flux (HRS 1969) show interesting correlation. The agreement between the erosion predicted from the sand flux distribution and the distribution of erosion 'on site' is good.

Studies of the processes of cliff erosion (Parker 1971, 1975) and their comparison with model work of Edelman (1968, 1973) and Meulen and Gourlay (1968), indicate that meteorological surge contributions to high water of spring tides are primarily responsible for producing tide levels sufficient for a wide range of rates of erosion (Parker 1971, 1975). A still water level of +9.6m above local chart datum (Liverpool Bay Datum) has been identified beyond which rates of erosion rise dramatically (Fig. 5). The accelerated rates of erosion may lead to serious local threats of flooding (Plates 3 and 4).

Southwards the rate of erosion decreases and inshore of a wider intertidal area the change to accretion takes place (Plate 5).

Fig 5



CLIFF EROSION PER TIDE PLOTTED AGAINST TIDE HEIGHT

TABLE 1

Sequence of sand transport on a Ridge

L.W.	Currents draining runnel move sand along shore.
Flood Tide	Sand swept landward by swash over ridge crest into runnel filling with water Breaker zone over ridge crest.. Sand moved landwards into runnel which is site of long shore current. Development of dune bedforms in runnel. Breaker zone decays. Long shore currents decline. Low sand movement.
High Water	Low currents, little sediment movement
Ebb Tide	Breaker zone develops over ridge. Long shore currents generated. Sand moved along runnel. Sand swept landward over ridge into longshore current. Sand swept landward by swash into runnel draining alongshore. Breaker zone develops over next ridge to seaward. Ridge exposed. Runnel drains. Currents move sand alongshore.
L.W.	

Plate 3

Wave Erosion exploits deflated hollow in frontal dunes protecting nature reserve at Dale Slack Gutter (Fig. 4).

Plate 4

Waves breach deflated remnants of frontal dune protecting large blow-out at Lifeboat Road (Fig.4).

Sediment Transport Patterns and Stability

The aim of this study was to examine the modes and patterns of sand movement on the foreshore as an aid to establishing the mechanisms of balance along this sector of coastline and to guide consideration of remedial action.

If, for a sandy alluvial coastline, a dynamic balance between onshore sand transport and littoral drift is a valid model of the mechanism of coastal stability, then the erosion of the sand dune cliffs is but a sympton of the budgetary relationship of the foreshore and adjacent offshore areas. The model must also include an evaluation of the sand supply across the foreshore to the dunes. That the dunes are being eroded indicates that there is a deficit in supply across the foreshore.

The mechanisms and sequence of sand transport on beaches have been widely studied. Field observations on this multibarred foreshore (reported in Parker 1971 and 1975) suggest that:

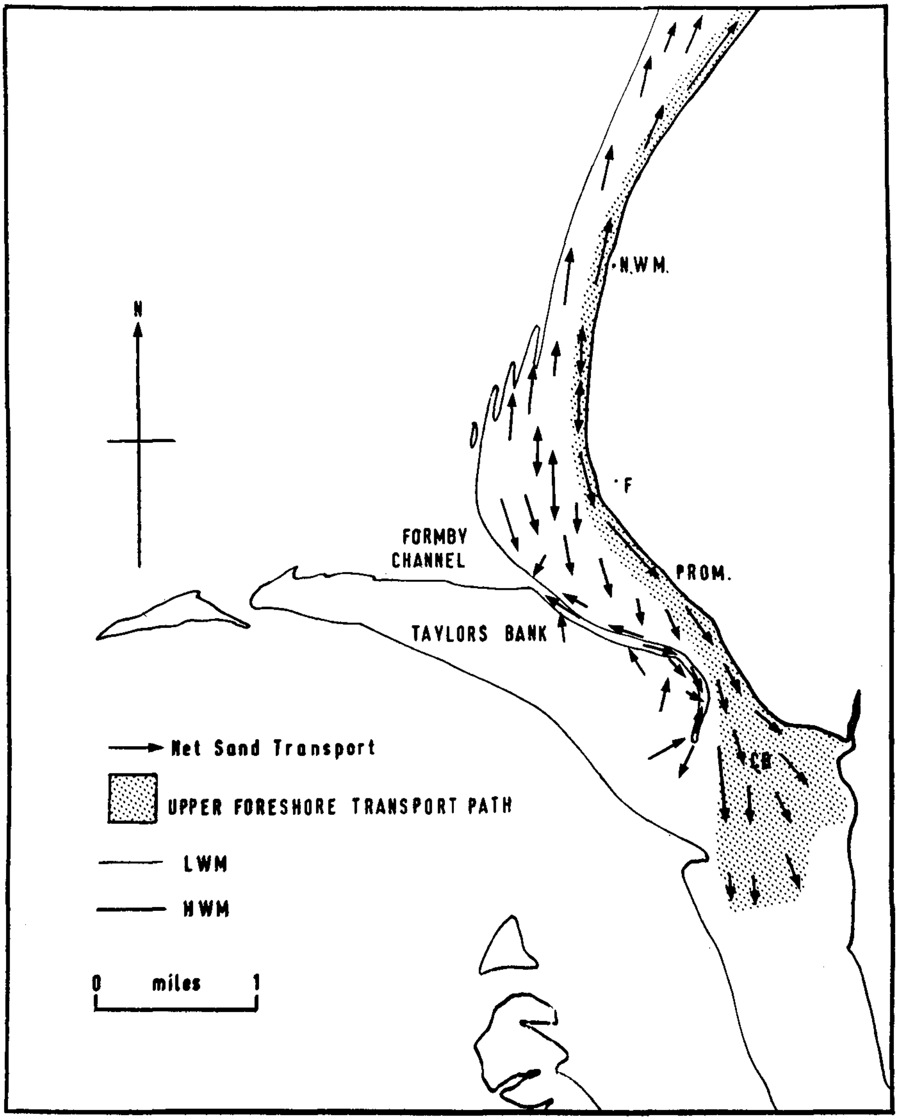
1. Most of the sediment moves as 'bed load', as dunes and ripples;
2. Transport is concentrated into zones. The runnels, and the plane area of the upper foreshore between the most landward runnel and the cliff, are zones dominated by longshore transport. This is particularly true of the runnels. The beach ridges are zones where transport vectors are normal to the shoreline.
3. Beaches of the timing of sand movement on the beach ridges the landward vectors of sand movement are short.

On both the flood and ebb tides the times of most intensive sand transport on the ridges is associated with those times when longshore currents (Bruun 1962, 1963, Chiu and Bruun 1964) are most active. The sand swept landward over the ridge crests into the runnel is thence moved alongshore by the runnel currents. The sequence of events is outlined in Table 1.

It is apparent therefore that the runnels and their associated longshore and rip current systems play an important rôle in the sand circulation pattern of this foreshore. The sand circulation pattern

Fig 6

FORESHORE SEDIMENT TRANSPORT



shown in Fig. 6 is based on field observations of water flow and observation of bed form patterns (Parker 1975).

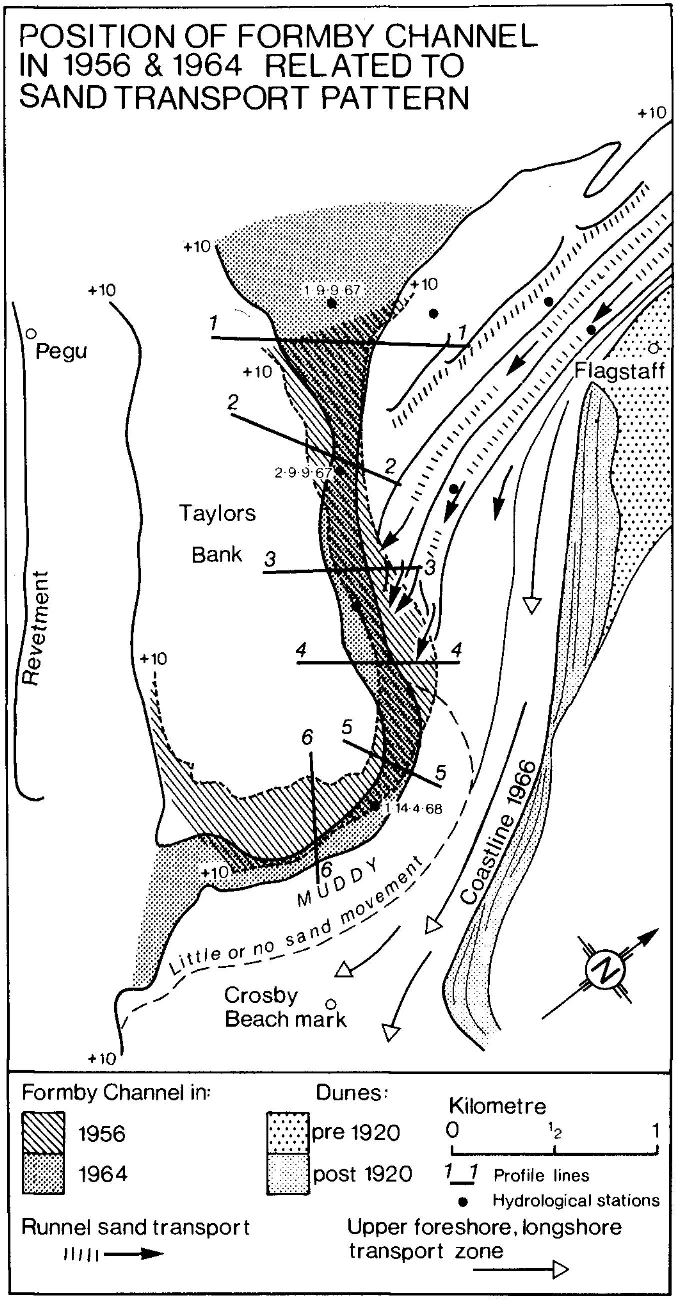
It is suggested that the exchange of sediment between the runnel system and the dunes is low. This is supported by the correspondence between erosion and sand flux computed for high water conditions only. The computations relate to transport in the upper foreshore transport path only and that they reflect field conditions suggests that they describe the principal component of the mechanism.

Because of the orientation of the coast and beach ridges both north and south of the centre of Formby Point, the sand in the runnels moves offshore. Thus within much of the intertidal zone of this multibarred foreshore the topography controlled sand transport pattern moves sand away from high water mark.

Aeolean sand transport is ineffective despite the dominance of onshore westerly winds (Reynolds 1956). The runnels, remaining wet at low water, and the wet areas of the upper foreshore, produced by the water table perched on the underlying Holocene sediments, are effective barriers to the aeolean nourishment of the dunes trapping what little sand is blown onshore. Heavy pedestrian usage of the dunes and an absence of any management policy ensures the destruction of vegetation and severe deflation of the dunes.

The waters of Liverpool Bay are on the whole turbid (Halliwell and O'Connor 1966). Intertidal mud sedimentation is widespread on this foreshore (Parker 1973, 1975) but the survival of the deposited mud is restricted to those areas protected topographically from ebb breakers, e.g. runnels (Parker 1975). The mud layers which develop in the runnels act as a brake on the sediment mobility. The erosion and transfer of the mud into an intertidal channel during low water appears to be significant in the mechanisms of coastal evolution, affecting the

Fig 7


POSITION OF FORMBY CHANNEL
IN 1956 & 1964 RELATED TO
SAND TRANSPORT PATTERN
+10
Pegu
Revetment
Taylors
Bank
Flagstaff
1·9·9·67
2·9·9·67
1·14·4·68
MUDDY
Little or no sand movement
Coastline 1966
Crosby
Beach mark
N
Formby Channel in:
1956
1964
Dunes:
pre 1920
post 1920
Kilometre
0 ½ 1
1 1 Profile lines
Hydrological stations
Runnel sand transport
Upper foreshore, longshore
transport zone

stability of the southerly section of presently accreting coast. Thus within the central section of this stretch of coast all the natural processes appear to act in concert to achieve a high rate of coastal recession.

In the south of the area, the operation of the natural processes in this direction is somewhat more subtle. The change from erosion to accretion in the south of the area (Figs. 3 and 4) takes place inshore of a wide intertidal area bounded to the south by an intertidal channel (Plate 5), Formby Channel. This channel has a history of instability, becomming narrow, shallow, more sinuous and migrating inshore. Previous reports on this area e.g. Price and Kendrick 1963, have suggested the possible importance of this channel as a sand feed route. The shoreward migration of the channel is threatening the stability of the southern sector of coast because the inshore bank of the channel, topped by the frontal dunes (Plate 5) is sliding into the channel.

However, the more far-reaching effects on local coastal stability stem from the interaction of the southerly sand flux (Fig. 4) and the sedimentation processes within the channel. The southerly component of the local littoral sand flux (Fig. 6) may be considered in two parts; that occurring in the intertidal runnels and that occurring on the plane area between the most landward runnel and the cliffs (the 'Upper Foreshore' route).

The juxtaposition of these fluxes and Formby Channel is shown in Fig. 7.

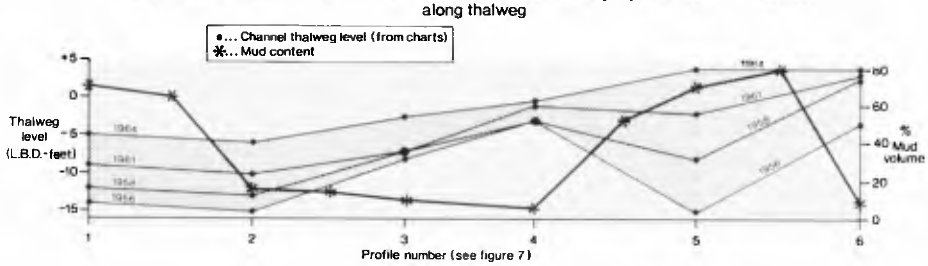
The runnels discharge sand, during the ebb tide and over low water, into Formby Channel. The affected sector of channel bank has prograded rapidly. Reference to Figs. 7 and 8 reveals that the sector of the channel where the banks are prograding rapidly (Sector 2-4) is not where the channel is filling. The rapid filling of the channel is on either side (Sectors 1-2 and 4-6).

Plate 5

From 450 feet oblique view south over Formby Channel showing beach ridges (nearground) approaching the Channel and frontal dunes protecting housing and farmland (left). Compare with channel sectors on Fig. 7.

Fig 8

Longitudinal profiles of Formby Channel : Levels of channel thalweg at profile lines and mud content along thalweg



Sedimentation within the Channel

In view of the apparent importance of this channel in past studies, and because no previous examination of conditions within the channel had been made, two lines of investigation were followed.

A series of hydrological experiments were carried out to examine the flow patterns within the channel, calculate water and solids discharge and residual transport, try to measure peak boundary stress values and sediment movement, whence, using information on the distribution of mud and sand in the channel sediments, some approach could be made to rationalising the more recent channel history. A number of interesting relationships emerge.

The rate of thalweg accretion is most rapid in the areas of high mud content in the sediment (Fig. 8).

Residual water flow suggests ebb dominance between sections 1 and 4 but no distinct drift around section 5 (Fig. 9). Examination of temporal variation of U_* (as a measure of boundary shear stress) suggests a separation of sediment movement, ebbwise in Sections 1-3 floodwise at Section 5. Combination of these hydrological data with visual observations of the processes operating during the ebbtide and over low water leads to a closer understanding of the mechanisms operating within the channel, particularly the influence of mud sedimention.

Sedimentation Sequence within the Channel

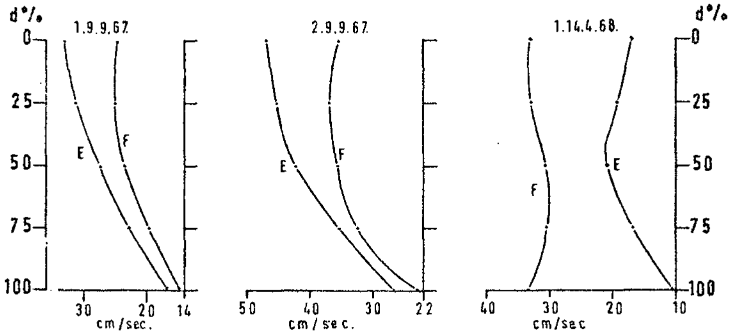
During low watersand and soft mud, eroded from the floors of the runnels, is discharged into the channel between sections 2 and 4 by the runnel currents (see Fig. 7). Currents draining from the channel carry the sediment to feed the muddy area at the northwest (outer) end of the channel between sections 1 and 3.

During the flood tide some mud and sand is swept into the channel from the northwest, but much of the mud deposited between sections 2 and

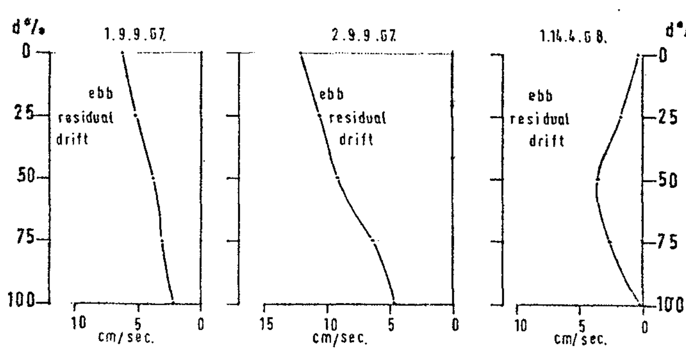
Fig 9

COMPUTED MEAN VELOCITIES AND C.R.W.D. FOR STATIONS

1.9.9.67. 2.9.9.67. 1.14.4.68.



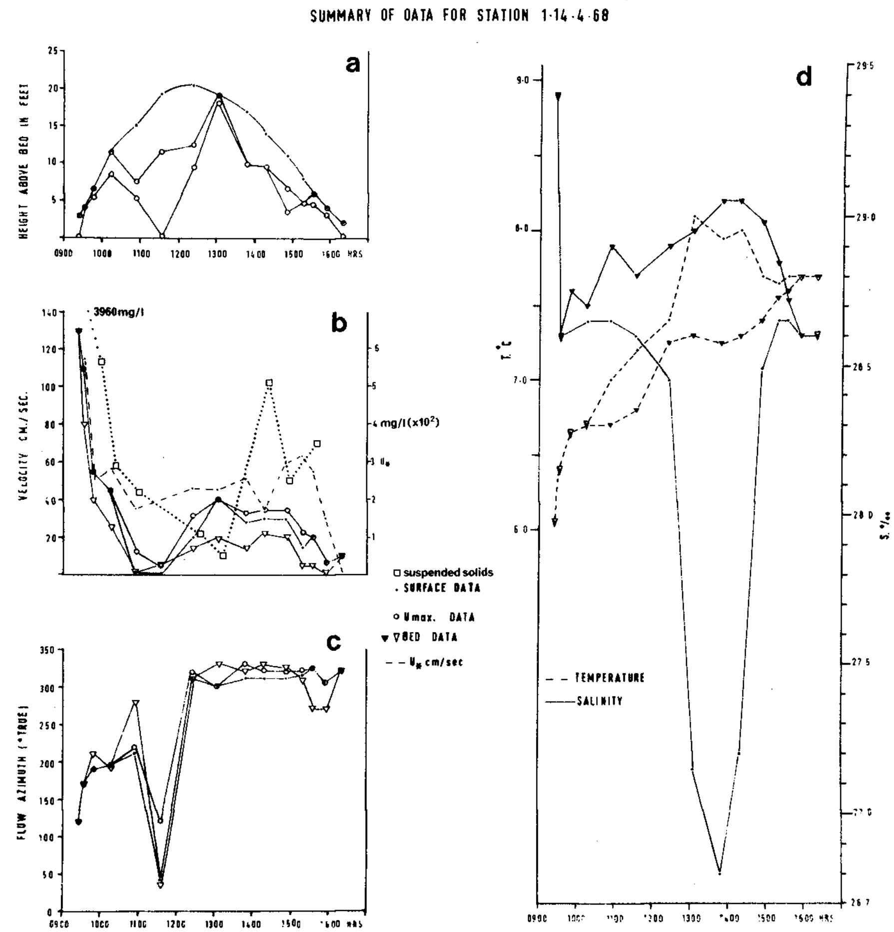
Computed Mean Flood(F) and Ebb(E) Velocity Profiles



C.R.W.D. - Computed Residual Water Drift, computed by Liverpool University, Department of Civil Eningeering Hydrological Research Group programme. Courtesy A. R. Halliwell and B.A. O'Connor.

d% = depth as % of total flow depth

Fig 10



Surface data refers to data on water surface elevation (a), veldcity (b), direction of flow (c) and temperature and salinity (d).

Umax data refers to elevation of the velocity maximum in the flow profiles (a).

Suspended solids refers to mean concentration in profiles (b).

4 at slack of low water is re-eroded and swept into the inner part of the channel, sections 4 to 6. The long stand of high water in this section of the channel (Fig. 10) allows mud to settle over the inter-tidal area between the channel and the frontal dunes (Fig. 7) as well as in the floor of the channel and the slow drainage on the ebb, coupled with protection from breakers, ensures its survival to be exposed and dessicate over low water. The ebb accelerates out of the channel, scouring the mud and sand from the central section of the channel (profile 3 and 4) sweeping this sand and mud northwest towards sections 1 and 2. During this time, as the intertidal area drains, more sand and mud is fed from the foreshore via the runnels into the channel which continues to drain northwest over low water.

These studies indicate a number of effects operating within and aound the channel:

a) The divergence of residual sediment transport from the"central" feeder from the foreshore.

b) The supply of sediment to the channel and the location of the areas of rapid filling, influenced by the hydrological control on mud sedimentation, lead to the changes in shape and migration of the channel.

c) The hydrological conditions in the inshore bend of the channel is allowing mud to spread over the foreshore thus influencing the mobility of the sand there and its availability for contributing to the local longshore and onshore flux.

d) The migration of the channel and its associated sedimentation pattern is restricting the width of the upper foreshore longshore transport route (Fig. 7) and this is resulting in the starvation of a bank to the south which protects an area of large housing development.

Conclusion

This research was an attempt to relate qualitatively the structure of interaction of some of the various sedimentary processes operating in an area of variable coastal stability. In the complex situation which exists in the real sea it is the essential first step towards identifying those components which might appropriately be quantified.

It is apparent that sediment transport on the foreshore is one part of an interacting system whereby, in this particular case, the processes in one area affect coastal stability in another area through their interaction with an inbetween component, the tidal channel. The individual mechanisms are relatively simple but their grouping into interacting groups produces the complexity of the natural sedimentary situation which provide the practising engineer with his decisive problems.

Acknowledgment

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