

AN EOCENE TIDAL INLET/WASHOVER TYPE BARRIER ISLAND COMPLEX IN THE SOUTH PYRENEAN MARGINAL BASIN, SPAIN¹

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ABSTRACT

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Several barrier island sand bodies are well exposed in the southern Pyrenees, Spain. They belong to the Pano Formation of Lutetian (Upper Eocene) age and were formed in an environment which was strongly influenced by rising sea level. A detailed sedimentological study of a calcarenitic sediment body in this Formation is presented.

The larger part of the barrier system described here is made up of tidal inlet deposits and washover sequences. The sediment body has a lense-shaped geometry. The width of the exposed body is 260 m and its maximum thickness is 20 m. It is made up of thin to thick bedded calcarenites. The tidal inlet part consists of massive, and tabular to lense-shaped beds. Laterally, in a landward direction, massive beds alternate with thinner washover beds, which have a primary landward directed dip. The marl/sand ratio increases in this direction.

In their proximal parts, washover beds are subdivided by horizontal erosional surfaces. The subdivision shows a regular pattern and is attributed to varying storm intensities during one single storm event. Vertical stacking of tidal inlet and washover deposits is ascribed to a balance between the amount of sediment deposited and the rate of relative rise of sea level.

INTRODUCTION

During the Paleogene the central south Pyrenean marginal basin on the flank of the rising axial zone became infilled with mainly siliciclastic sediments. Deposition was strongly influenced by alluvial fan complexes from the north; progradation however was from the east to the west (VAN EDEN, 1970; NIJMAN & NIO, 1975). During the Eocene, progradation was interrupted several times by regional transgressions. One of these, dated Late Lutetian (Biarritzian), flooded a gently north-west sloping coastal plain. In the area northwest of Graus, province of Huesca, Spain (Fig. 1), an embayment was formed that was protected from the open sea in the west by the Mediano High. The bay progressively widened during the continuing transgression (Fig. 2). An onlap sequence developed, consisting of sandy coastal deposits over silty floodplain deposits. The floodplain deposits have been defined as the Capella Formation of Lutetian age (GARRIDO-MEGIAS, 1968). The coastal deposits belong to the Pano Formation of Late

Lutetian (Biarritzian) age. At the place of study, in detail the coastal deposits comprise remnants of drowned barrier islands which are mainly vertically stacked tidal inlet fill deposits. The thicknesses of vertically stacked sequences can be up to 30 m. Within the sandy onlap sequence three subsequent phases of barrier build-up can be recognized which coincide with an established balance between sediment supply and relative sea level rise. Each barrier island sequence is situated higher on the coastal plain than the preceding one (Fig. 2c). The tidal range in the embayment diminished in time due to a partial closing by carbonate sedimentation around the Mediano High (Fig. 2b; PUIGDEFABREGAS, 1974). This decrease of tidal range is reflected in the preserved barrier island deposits as a change from entirely tidal inlet dominated barriers on the lower part of the drowned coastal plain to mixed tidal-inlet/washover type barriers in the higher part, the latter comprising relatively thinner and laterally less extensive tidal inlet fills.

The deposits described in the present paper belong to the stratigraphically highest barrier island complex of the Pano Formation, and include well preserved washover delta deposits. Emphasis is placed on the geometry and internal structures of these deposits. Comparisons are made with modern counterparts.

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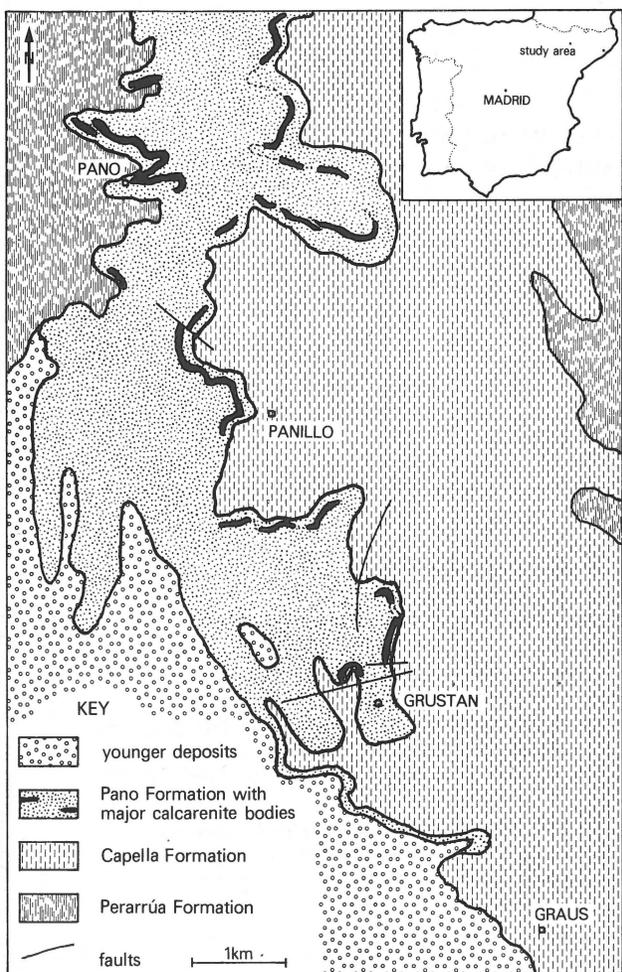


Fig. 1
Geological map of the study area, southern Pyrenees, N. Spain.

PREVIOUS WORK ON BARRIER ISLAND SYSTEMS

Theories about barrier island genesis were already put forward during the nineteenth century (see e.g. HOYT, 1967, who also discussed theories by DE BEAUMONT, 1845 and GILBERT, 1885). During the last two decades studies on barrier island systems have specifically addressed questions such as the response of barrier island systems to conditions of sea level fluctuations – especially in relation with the Holocene rise in sea level – and the resulting sequential development (a.o. SHEPARD ET AL., 1960; DILLON, 1970; KRAFT, 1971; WILKINSON, 1975; KRAFT ET AL., 1979).

Authors agree that landward or seaward migration of barrier islands in time is primarily a function of the ratio between sediment supply and sea level change (DICKINSON ET AL., 1972). For a landward retreating barrier island, the net migration is caused by shoreface ravinement whereby the sediment is transported to the offshore zone (BRUUN, 1962), and/or by processes of overwash, whereby beach sediment is

eroded and transported to the backbarrier flat and lagoon (SWIFT, 1975). In both cases the bulk of sediment displacement takes place during storms.

HAYES (1967) was the first to describe in detail recent storm washover processes and their deposits. Later detailed studies on recent washovers focused on geometry, internal structures and textures (e.g. ANDREWS, 1970; MCGOWEN & SCOTT, 1975; SCHWARTZ, 1975; LEATHERMAN ET AL., 1976; LEATHERMAN & WILLIAMS, 1977) as well as on quantification of the washover sediment accumulations (FISHER & STAUBLE, 1977; FISHER & SIMPSON, 1979). Descriptions of washover deposits in the fossil record, however, are few. Among the scarce reports are descriptions by BRIDGES (1976) and HOBDAV & TANKARD (1978).

THE LITHOFACIES UNITS

The deposits of the stratigraphically highest sediment body of the Pano Formation are exposed near the hamlet of Grustan, some 8 km NW of Graus (Figs. 2, 4). Fig. 3 gives a correlation of the measured sections across the sediment body described in this paper. Within the body three lithofacies units can be recognized:

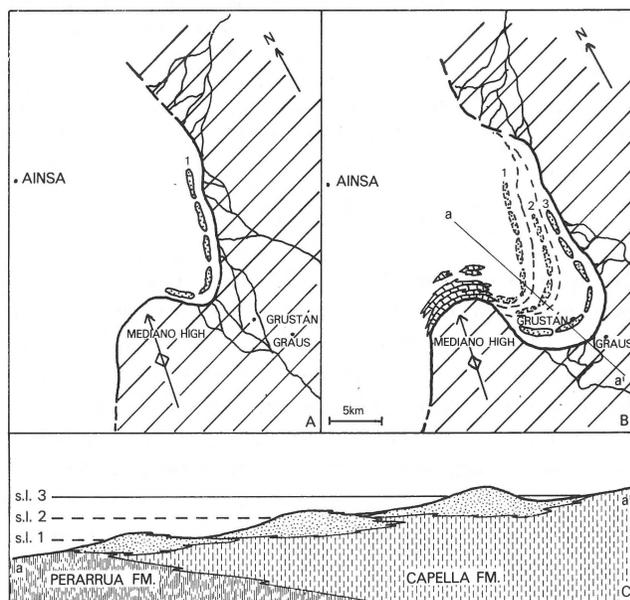


Fig. 2
Paleogeographical sketch of the area at the time of the Late Lutetian transgression.

A. Initial phase: barrier islands (1) fringing a NW – sloping coastal plain (alluvial deposits of the Capella Fm.). Sediment supply from SW and N.

B. Maximum transgressive phase: barrier island chain (3) on submerged coastal plain. Previous barrier chains (1 & 2) drowned and partly preserved. Carbonate sedimentation around the Mediano High.

C. NW -SE cross-section of the studied sequence. Barrier island deposits of the Pano Fm. (dotted) onlap over alluvial deposits of the Capella Fm.

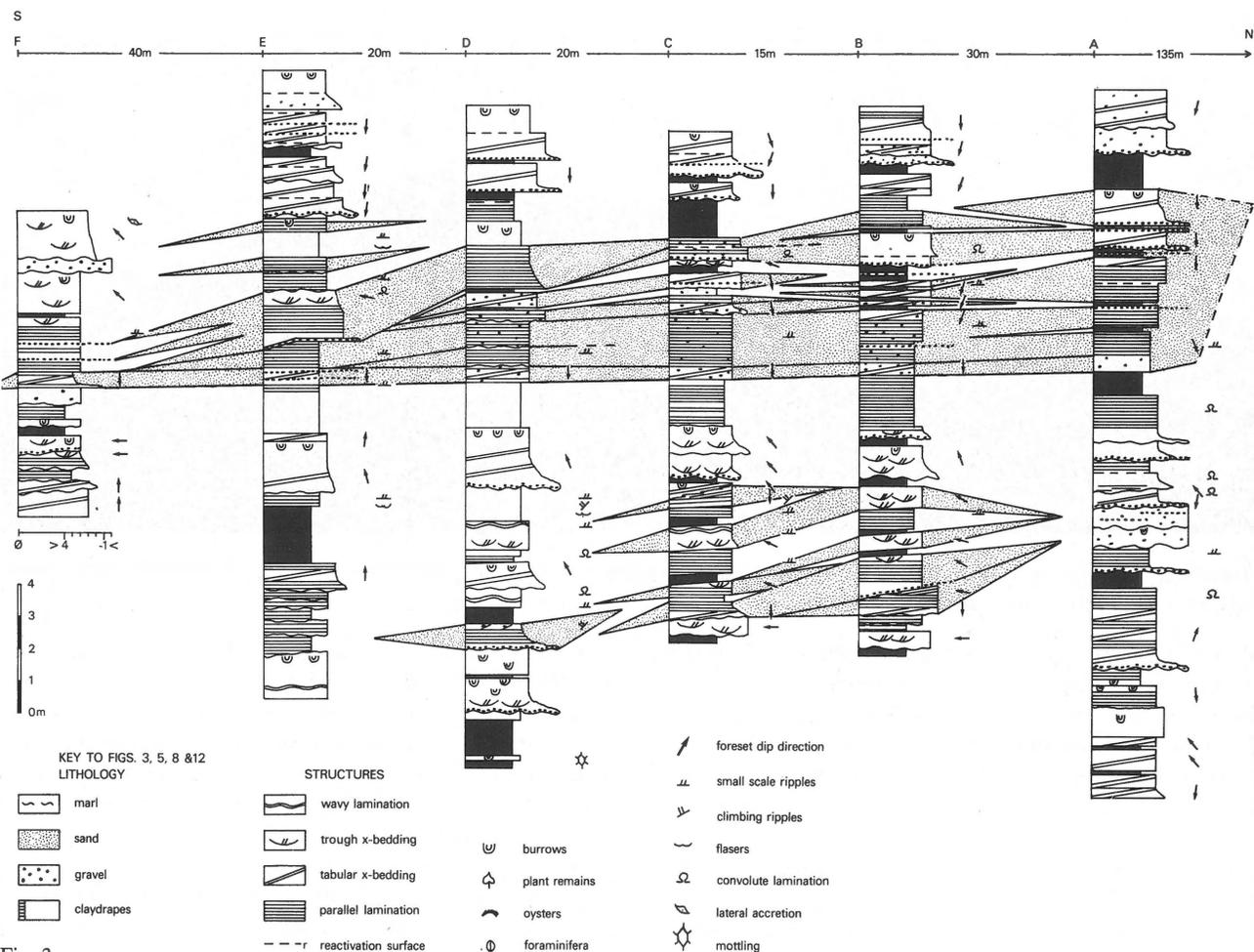


Fig. 3
Correlation of columnar sections A-F. For location see Fig. 4. Lithofacies unit 1: lower 12.5 m of section A. Dotted: lithofacies unit 3. Rest: lithofacies unit 2.

1. medium bedded to very-thick bedded (cf. BLATT ET AL., 1972) calcarenites with erosive lower surfaces, alternating with marl and clay (Fig. 3, section A). To the north the calcarenites grade into sandy marls while to the south they become thinner and interfinger with,
2. bioturbated marls containing thin calcarenite beds, and,
3. discontinuous, medium to thick bedded lense-shaped calcarenites with sharp erosive lower surfaces with a flat to undulating appearance (Units 2 and 3: Fig. 3, columnar sections A through F).

LITHOFACIES UNIT 1

Description

Fig. 5 gives a detailed section through the 12.5 m thick sequence of lithofacies unit 1. The bulk of the deposits is made up of medium bedded to very thick-bedded calcarenites (mean bed thickness 80 cm) with erosive lower surfaces. The grain size of the well sorted beds is mainly fine sand.

Coarse-grained lags consisting of clay pebbles, gravel, benthonic foraminifera, and coarse to very coarse sand are present. Dominant structures are parallel lamination and high- and low-angle wedge-shaped sets (dips up to 26° and 10° resp.; set height between 10-30 cm) with bipolar dip directions (Fig. 6) between 305° - 35° and 185° - 190° ; NW directions dominate. Subordinate structures are convolute laminations (Fig. 5, beds k, p, q and r) and wave ripples; within various beds discontinuity surfaces are recognized. Bioturbation is weak but may increase towards the upper part of a bed. The calcarenite beds contain plant remains, foraminifera (*Nummulites*) and scarce oyster fragments.

Beds n, o and p (Fig. 5) are exceptions in the general picture. They are made up of badly sorted, very coarse grained calcarenites with strongly scouring bases. The 50 cm to 60 cm thick beds pinch out to the south and consist of calcareous pebbles and cobbles (up to 10 cm in diameter), clay pebbles, a considerable quantity of nummulites, oyster- and plant fragments in a fine to coarse sandy matrix; bed p is cross-bedded with bipolar (NW: 320° and S: 190°) foreset dip directions. To the south (sections B-D) on the same level, lenticular beds of the third lithofacies unit are exposed.

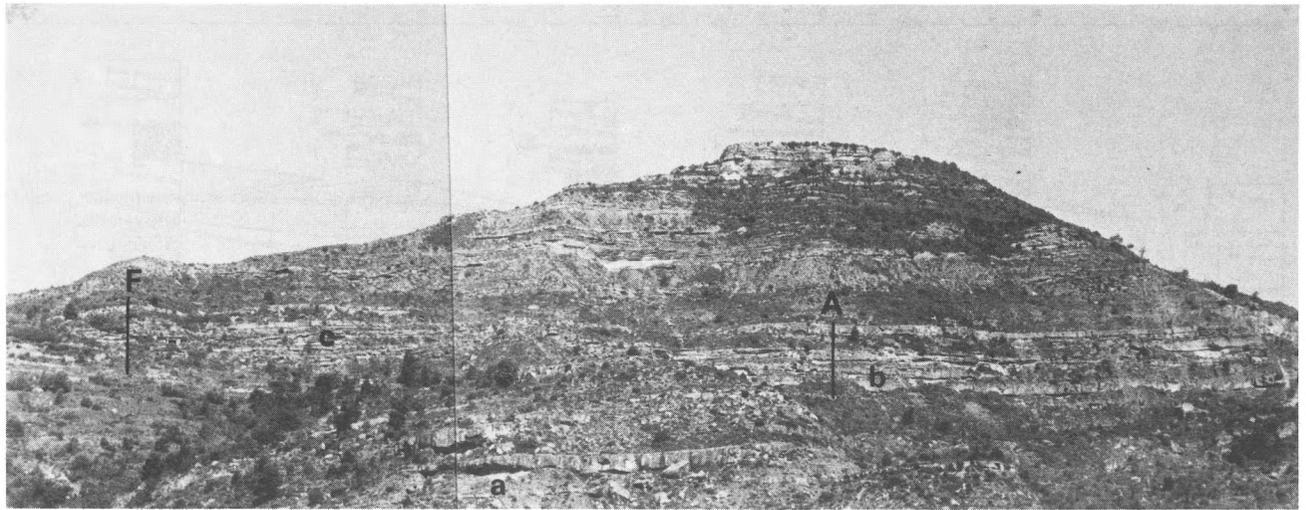


Fig. 4
Panorama-view of Grustan mountain. a. Fine-grained deposits of the alluvial Capella Fm. b. Thick bedded deposits of lithofacies unit 1. c. Deposits of lithofacies units 2 and 3. Columnar sections of Fig. 3 are situated between A and F.

Moderately to strong bioturbated marl layers, 5-75 cm thick and rich in plant remains, intercalate with the calcarenites. To the south (Fig. 4, cross sections B-F) these fine-grained deposits gain in number and/or thickness.

Within lithofacies unit 1 four distinct sequences are recognized:

1. fining-upward sequences with related increase of rate of bioturbation (Fig. 5, beds a -i; k -l; m; r -s)
2. a change from high angle (beds a -i) to low angle (beds k; p) crossbedded sets
3. a transition within one bed from parallel lamination below to wave ripple lamination above (bed m) or from cross bedding to parallel lamination (bed k): the latter sequence also is present within the series of beds a -j (Fig. 5).
4. a vertical increase in nummulites content and a decrease of the number of plant remains.

Interpretation

The feature described from the calcarenites of lithofacies unit 1, are typical for tidal inlet deposits. Descriptions of comparable deposits from recent environments are given by KUMAR & SANDERS (1974) and by HAYES & KANA (1976). KUMAR & SANDERS (1974) showed a vertical sequence of modern tidal inlet deposits of Fire Island Inlet, New York (Fig. 7), which consist of a basal lag of shells and pebbles overlain by steeply dipping planar cross-beds (deep channel), parallel laminated and low-angle cross-bedded sands with ripple lamination (shallow channel) overlain in turn by a cross-bedded spit platform and spit sequence. HAYES & KANA (1976) described similar sequences from recent Massachusetts tidal inlets, comprising bipolar large- to medium scale cross-bedded coarse sand and shells followed by small- to medium scale cross-bedded medium grained sands, overlain by flat laminated sands and fine grained cross-bedded eolian deposits.

In lithofacies unit 1 a vertical stacking of five tidal inlet sequences is recognized (Fig. 5, beds a -j, k -l, m, q, and r -s), the base of each sequence is marked by an erosive surface and coarser grain size, the top by finer grain size and/or overlying marls. From the bipolar foreset dip directions a NW -SE tidal channel long axis is inferred, and that corresponds to an NE -SW oriented coastline. The presence of five subsequent tidal inlet sequences indicates a fixed coastline position during the time of formation of these inlets. In an environment with a relative rise in sea level, as is the case here, a fixation of the coastline is caused by an equilibrium between the amount of sediment deposited and the rate of relative sea level rise. In this environment, vertical stacking of tidal inlet deposits is caused by lateral migration. In recent barrier islands, tidal inlet deposits may in fact form the bulk of the barrier island nucleus (KUMAR & SANDERS, 1974). From the features described from beds n, o and p (Fig. 5), and their position with respect to the lenticular beds of lithofacies unit 3 (see Fig. 3) we submit a scour-channel fill origin whereby the channel has been eroded during storms. Recent overwash generated scour-channels are described on the Texas coast by HAYES (1967), who termed them hurricane channels, and by MCGOWEN & SCOTT (1975) and SCHWARTZ (1975).

LITHOFACIES UNIT 2

Description

To the south of and partly overlying the tidal channel deposits, well exposed fine grained deposits of lithofacies unit 2 intercalate with coarser grained, lense-shaped beds of unit 3.

The deposits of lithofacies unit 2 (Fig. 8) consist predominantly of bioturbated marls. They are occasionally parallel laminated and alternate with thin, very fine grained, locally

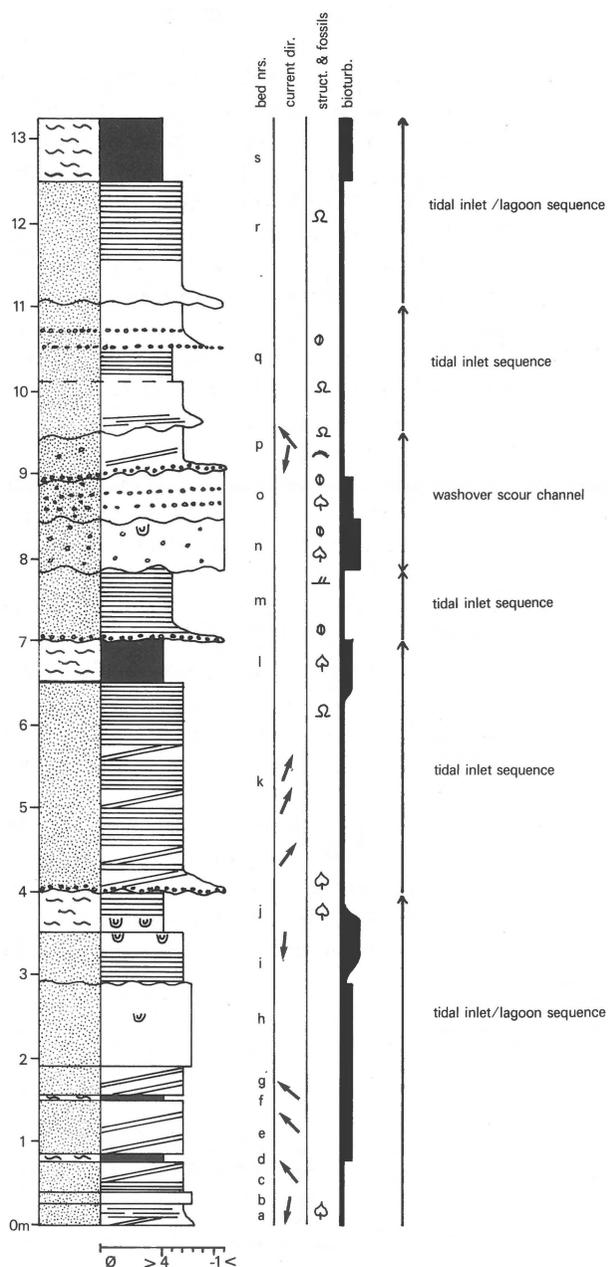


Fig. 5 Description and interpretation of lithofacies unit 1. For legend see Fig. 3.

wave/current rippled calcarenites; flaser and linsen structures are present; plant remains are common. Some thicker bedded elongate calcarenites are present; they have a scouring base, a lag of clay pebbles, wood- and oyster fragments; a fining upward sequence is common and the upper parts of the beds are strongly bioturbated. Dominant structures are trough cross-bedding and low angle tabular sets with sigmoidal shaped foresets (5-35 cm thick). The dip directions of both types are between W and ENE (270°-15°). Discontinuity surfaces and claydrapes on the foresets are present.

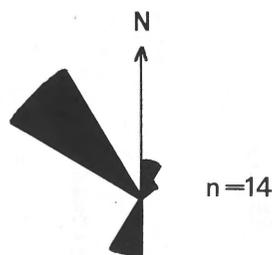


Fig. 6 Foreset dip directions. Lithofacies unit 1.

Interpretation

The bioturbated marl with flaser and linsen and thin calcarenite beds was deposited in a low energy lagoonal environment.

The thicker bedded elongate calcarenites with scouring bases, coarse lags, and fining upward sequences represent deposits of laterally migrating, lagoonal tidal channels. After deposition the upper parts of these tidal channel fills were thoroughly burrowed.

LITHOFACIES UNIT 3

Description

Intercalated with the fine grained sediments of lithofacies unit 2 there are a number of thin to thick bedded, lense-shaped calcarenites. The measurable length of the these beds in the Grustan outcrop varies between 25 m and 260 m. In cross-section the subsequent beds tend to have their southern limits progressively more to the south. The lenticular beds are concentrated into two clusters (Fig. 9); the deposits of this lithofacies unit have in total a southward inclined imbricate geometry (Fig. 9) against which most of the finer grained lagoonal deposits pinch out. Individual beds have a convex-upward form. Based on the geometry of the beds a subdivision is made into two types (Fig. 10):

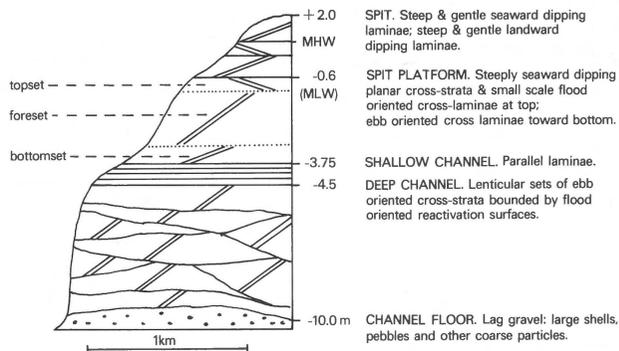


Fig. 7 Vertical sequence of a modern tidal inlet. Fire Island Inlet, USA. After Kumar & Sanders (1974).

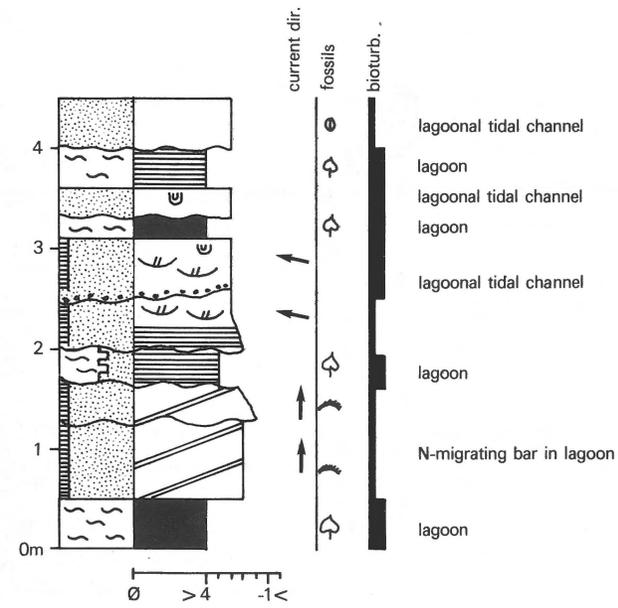


Fig. 8 Description and interpretation of lithofacies unit 2. For legend see Fig. 3.

type I: beds with straight to undulating, slightly ($< 4^\circ$) S-inclined lower surfaces which are erosive in their northern parts (Fig. 10a)

type II: beds with a typically S- inclined flexure-like feature. The dips of the scouring lower surfaces in the inclined part are between 9° and 12° . To the north of this inclined part the lower surfaces are erosive, sub-horizontal and may attain an irregular shape (Fig. 13); to the south, lower surfaces are straight, slightly erosive to non-erosive (Fig. 10b).

Beds of both types wedge out to the south.

A. Lower lenticular unit (Fig. 9) In this lower unit seven medium to thick bedded calcarenites are exposed. The maximum north-south extension of the unit in the exposure is some 40 m. All beds have scouring bases, are S- inclined, and have flat to slightly undulating lower surfaces. Beds have a type I geometry, except for the basal beds (Fig. 9, nrs. 1 and 2), which are of type II and which in their inclined parts dip 12° and 9° southward, respectively. Bed nr. 1 (Fig. 9) erodes part of the underlying lagoonal deposits; to the south the bed typically splits and interfingers with lagoonal marls of lithofacies unit 2.

Generally, the lower lenticular unit shows a fining upward. The lowermost beds are coarse-grained and have lags of gravel, clay pebbles and oyster fragments, while the overlying beds are fine-grained calcarenites without lag deposits.

The dominant sedimentary structure in this unit is lamination parallel to the (inclined) lower surface. This lamination is either present throughout the bed or shows one of the following sequences:

- a. within one bed parallel laminae grade upward into in-phase ripples (Fig. 11),
- b. parallel laminae alternate with minor tabular cross-bedding with S-dipping foresets,
- c. upper parts of the laminated beds are truncated by trough cross-bedding; upper parts contain small-scale current ripple lamination.

Within the beds reactivation surfaces are common and may be accentuated by thin discontinuous marl layers.

The calcarenites of this unit are non-bioturbated; the lowermost beds of the unit contain oyster fragments (bed 3) and plant remains are concentrated in parallel laminae (beds 1 and 2).

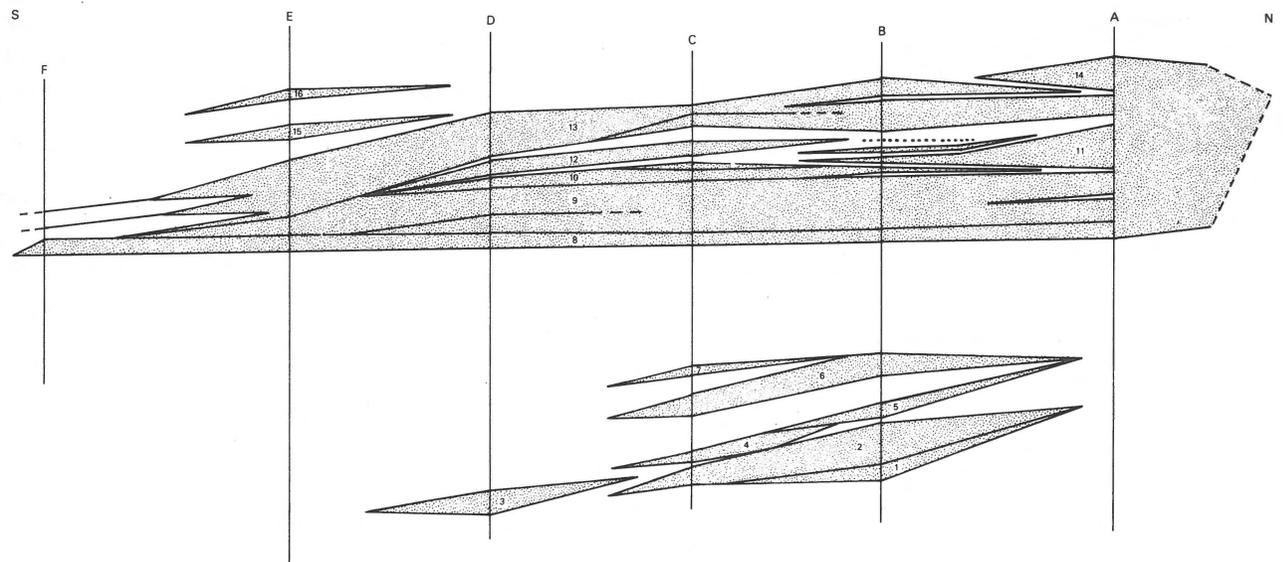


Fig.9 Correlation of the lenticular beds of lithofacies unit 3. For scale see Fig. 3.

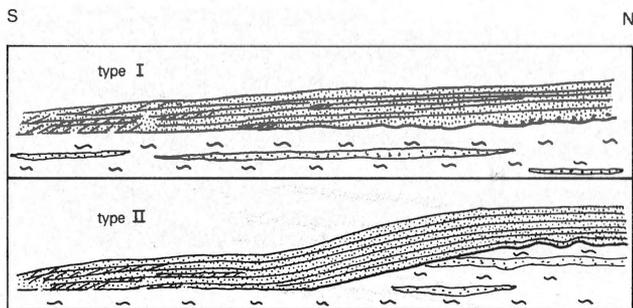


Fig. 10
Geometry of beds of lithofacies unit 3. Type I: lower surface straight to undulating, erosive in northern part. Towards the south parallel lamination may grade into S-directed cross-bedding. Type II: lower surface with S-dipping flexure-like feature (angle 9° - 12°) Northern part with flat to irregular erosive lower surface. Inclined part with erosive lower surface, southern part slightly erosive to non-erosive. Lamination in northern and flexured part parallel to lower surface, towards the south lamination may grade into S-directed cross-bedding.

All beds pinch out to the north between sections A and B (Fig. 3); to the north of these beds, at the same level, the very coarse grained scour-channel beds (see lithofacies unit 1) are exposed.

B. Upper lenticular unit (Figs. 9, 12 and 13) Separated from the lower unit by 3,5 m of lagoonal deposits, the upper lenticular unit is exposed. Beds of this unit have a larger north-south extent than those of the lower unit: single bed lengths are of the order of some 100 m with a maximum of 260 m. A maximum thickness of 6 m for this unit is reached at the site of section A (Fig. 9). The unit is made up of nine major beds (beds 8-16), all with bedding features comparable to those of the lower unit: beds nr. 13 and 15 have a type II (Fig. 10) geometry, the other beds a type I geometry. This unit lacks the overall fining upward sequence of the lower lenticular unit, but the thin to thick bedded calcarenites show some typical grainsize- and sedimentary structure configuration types, namely:

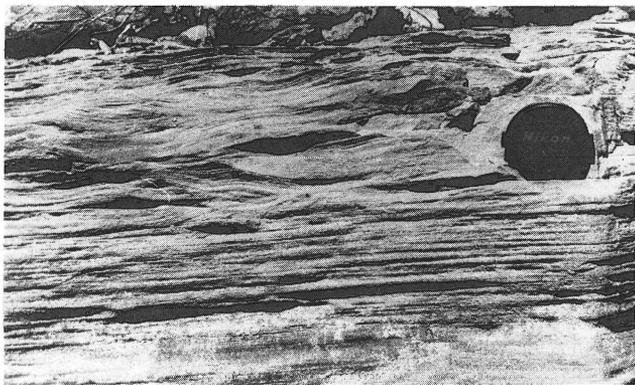


Fig. 11
Upward grading of parallel laminae into in-phase ripples. Lithofacies unit 3. Lense-hood (diameter 5 cm) for scale.

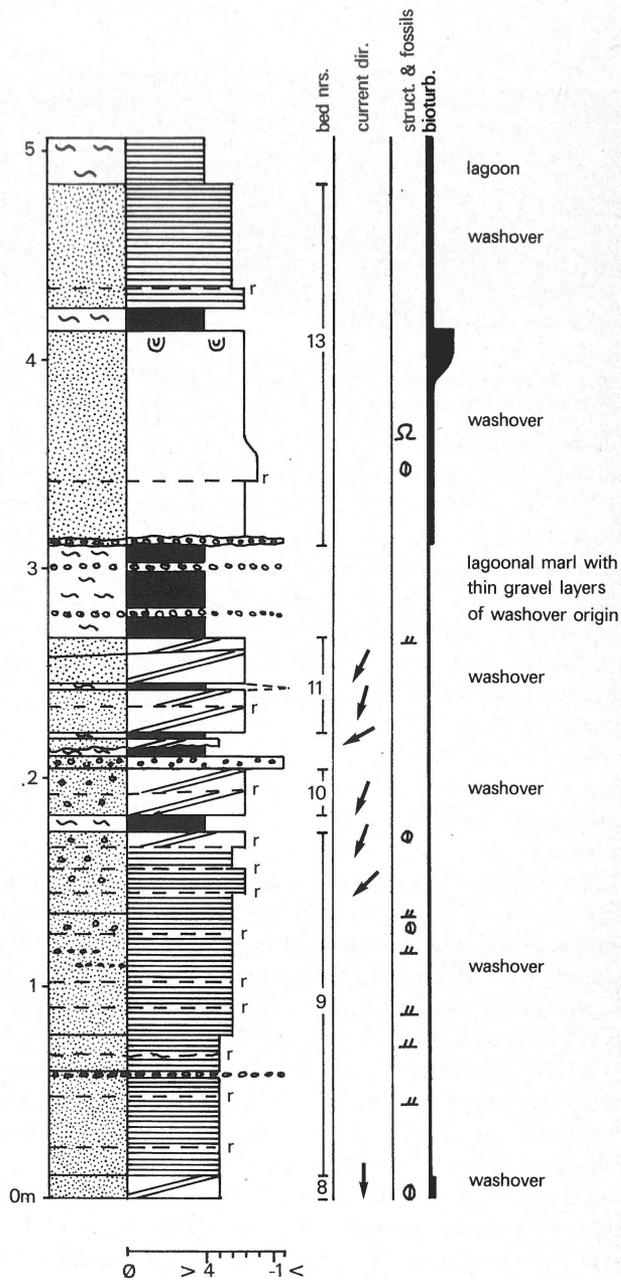


Fig. 12
Detailed section (Fig. 3, upper part of section B) through part of the deposits of lithofacies unit 3. For legend, see Fig. 3.

- well sorted very fine to medium grained, parallel laminated calcarenite beds, containing dispersed calcareous pebbles and thin gravel bands (Fig. 12, bed nrs. 8 and 9),
- well sorted fine to very fine grained, parallel laminated calcarenite beds that lack gravel bands or dispersed pebbles; instead the upper parts of the beds show wave ripples,
- medium-grained cross-bedded calcarenites (foreset dip directions of the tabular cross-sets: S-SW (170° - 215°)) with dispersed or layered gravel (bed nr. 10),
- beds with a clay pebble lag in a coarse to medium grained matrix, fining upward to well sorted fine to medium grained calcarenite (bed nr. 13),

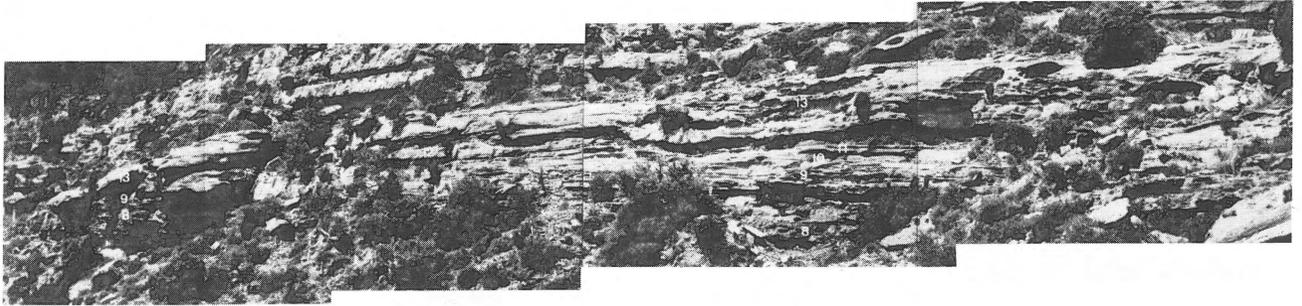


Fig. 13
Panorama of the upper lenticular unit, lithofacies unit 3. Towards the south (left) the unit pinches out. Bed numbers correspond to Fig. 9. Note irregular lower surface of bed nr. 13.

e. within a number of beds lateral grading is recognizable: to the south a decrease in grainsize takes place; for example, bed nr. 8 (Fig. 12) in its northern part consists of calcareous pebbles of 5 cm max. diameter, wood fragments and large quantities of *Nummulites* in a very fine sand matrix, towards the south wood fragments gradually disappear and the amount and size of pebbles and nummulites tests decreases drastically. South of section F pebbles and nummulites tests are absent. Similar features were recorded in beds nr. 9 and 13 (gravel to very-fine sand; Figs 3 and 12).

Thin gravel layers, belonging to this unit and intercalating with lagoonal marl, are restricted to the northern part of the outcrop.

Just as in the lower lenticular unit, parallel lamination is the dominant sedimentary structure. In general this lamination persists throughout the whole lateral extent of the bed, but towards the southern limits of beds nr. 10 and 11 (Fig. 3) parallel lamination changes to tabular- and trough cross-bedding, both with SW-dipping (195° - 215°) foresets. In beds nr. 13 and 16 parallel laminae locally have been deformed to convolute laminae. Convolutions have narrow crests and broad troughs (Fig. 14). The upper parts of the parallel laminated beds may contain wave ripples (Fig. 15).

Second in importance is tabular cross-bedding, in which the foresets dip unidirectional to the south. Trough cross-bedding is restricted to the southern part of the unit, foreset 'dip

directions are oblique with respect to those of the tabular cross-bedding: dip directions vary between 285° and 300° . Fig. 16 gives the distribution of forest dip directions in the third lithofacies unit (both upper and lower lenticular units), in which westward directions represent both trough cross-bedding of the upper lenticular unit and trough cross-bedding that is present in the upper parts of the lower unit beds.

In more detail, the beds of the upper lenticular unit are characterized by the occurrence of horizontally oriented discontinuity surfaces, accentuated by topped-off wave ripples or slight jumps in grainsize; beds are thus divided into 3.0-72.5 cm thick sub-beds (c.f. process of washover deposit formation and Fig. 17). Bioturbation is minor to absent in the lower part of this unit and increases upward. The lenticular beds contain oyster- and plant fragments and *Nummulites* tests (in bed nr. 8, northern part, in large quantities).

Interpretation

The parallel laminated deposits with dispersed pebbles and gravel bands, which locally grade upward into in-phase ripple lamination (Fig. 11), were clearly formed under upper-flow conditions. An important feature is the vertical and southward decrease of current energy as shown by the repeated upward fining and change from parallel lamination to current and wave ripples as well as by the southward decrease of erosive features (see Fig. 10), the change from upper flow

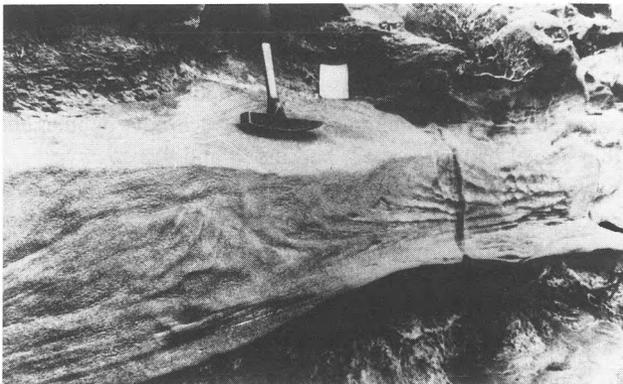


Fig. 14
Convolute lamination in bed nr. 13. Lithofacies unit 3.



Fig. 15
Wave ripples in the upper part of bed nr. 9 of lithofacies unit 3.

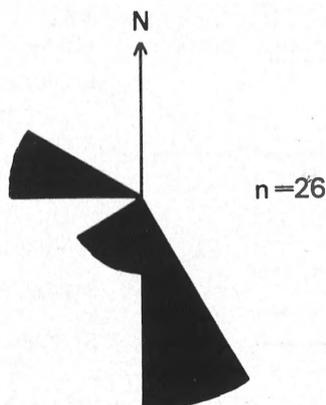


Fig. 16
Foreset dip directions of lithofacies unit 3.

parallel lamination to lower flow cross-bedding, and the fining grain size of sequences in this same direction. These features, combined with the influx of marine fauna and the dominant S-directed foreset dips (Fig. 16) are diagnostic for washover deposits.

The washovers described here have many features in common with modern counterparts: ANDREWS (1970) reported the scouring of lower surfaces as typical for the washover sands of St. Josephs Island, Texas; HAYES (1967), ANDREWS (1970) and SCHWARTZ (1975) noted the introduction of marine fauna into the lagoon and back-barrier flats by wash-over processes.

Parallel lamination is the characteristic feature of both modern and ancient washover deposits: SCHWARTZ (1975) and LEATHERMAN & WILLIAMS (1977) described the abundance of this feature in recent washover deposits on the Atlantic coast of the USA and Presque Isle Peninsula, Pennsylvania; BRIDGES (1976) described horizontally laminated washover sandstones from Lower Silurian Marloes Sands, SW Wales.

The downdip transition of parallel lamination into cross-bedding, as encountered in beds nr. 10 and 11 of the washover deposits described in this paper, can be compared with observations made by KUMAR & SANDERS (1974) and SCHWARTZ (1975) on crossbedded washover lobe terminae of modern washover deposits. The downcurrent fining is also described by ANDREWS (1970) and LEATHERMAN & WILLIAMS (1977) as a clear trend in modern washover deposits on St. Joseph- and Assateague Islands, USA.

Because of the presence of wave/current-rippled and trough-reworked washover tops, the interbedding with lagoonal marls and flaser and linsen beds, and the occurrence of convolute laminations (Fig. 14) the deposits could be defined as subaqueously formed washover deltas (terminology SHEPARD & WANLESS, 1971). The convolutions result from pore fluid escape (LOWE, 1975) of the rapidly deposited and poorly packed washovers. Whereas in subaerial deposited washover fans water is lost easily by percolation through the porous substratum (SCHWARTZ, 1975), which prevents liquefaction,

the rapid subaqueous sedimentation of a water-saturated washover delta flux over an also water-saturated lagoonal mud will cause loading consolidation of the latter and the pore fluids that are expelled by the mud can trigger liquefaction of the overlying washover sand.

A SEDIMENTATION MODEL FOR WASHOVER DEPOSITS AS DEDUCED FROM THE STUDIED SEQUENCE.

Sediment displacement occurred under high energy storm conditions; in the subaerial part of the barrier scour-channels were eroded by the high energy flow. The coarsest washover material lagged behind in the scour-channels (beds nr. n-p, Fig. 5) or was transported over small distances only, thus forming thin pebble & cobble layers in the northern (proximal) sector of the washover deposits (Fig. 12, 11.0-12.2 m). The finer material with dispersed gravel was transported further by the upper flow regime washover flux. On entering the lagoon, the standing body of lagoon water decelerated the flux, whereupon deposition started of parallel laminated (lower part upper flow regime) sands with thin gravel bands and dispersed pebbles. In their proximal parts the washovers are erosive, downflow they rest conformable upon undisturbed lagoonal marl.

The flexure-like feature of type II washover fluxes is primarily caused by a pre-existing convex-upward surface morphology such as an older washover delta rim or lagoonal channel edge, and is accentuated by the erosive power of the washover flux that descended down this inclined surface. Notable is the consistency of the parallel laminae within the inclined part of the washover bed. In absence of such a relief the washover deposits have a flat, sheet-like geometry with an original lagoonward dip ($<3^\circ$). SCHWARTZ (1975) in his study on modern washovers of Pea Island and Caffey Inlet, N. Carolina and Presque Isle, Pennsylvania posed the question 'whether the alternation of texturally and compositionally different layers is the result of some sorting process that occurs during a single washover 'injection' or whether differently textured layers are deposited by different washover injections of varying hydraulic parameters'. In the case of his (SCHWARTZ, 1975) subaerial washover fans the vertical alternation of finer and coarser layers is plausibly explained by the sorting process during grainflow transport, where a fine-coarse couple is deposited during one event, although the exact position of the scour truncation in the fine-coarse-fine-coarse sequence (see SCHWARTZ, 1975, p. 15) is not specified. However, in the subaqueous washover delta deposits described in this paper no regular fine-coarse sequences occur. In their proximal parts, washover beds are internally subdivided by subhorizontal, slightly scouring surfaces. Here the question rises whether the subhorizontal scouring surfaces represent discontinuity surfaces that separate the deposits of

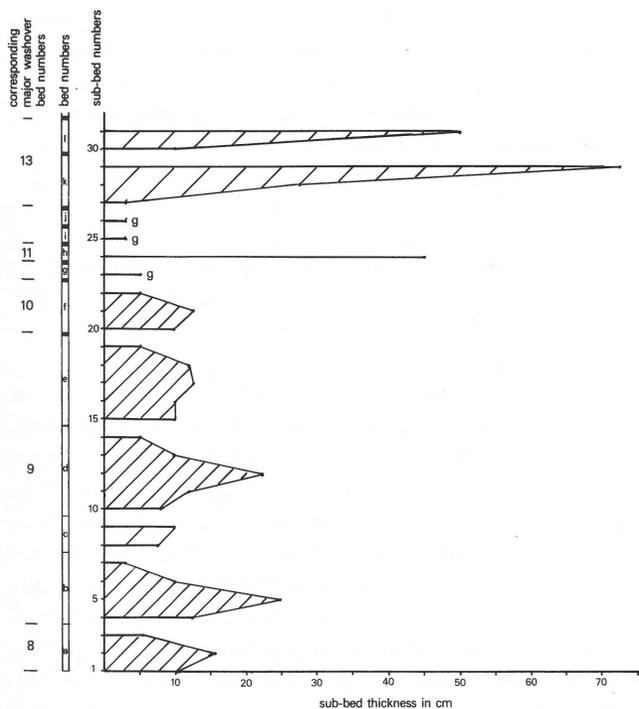


Fig. 17 Proximal parts of washover beds a-f and k-l are internally subdivided into sub-beds. Thickness division of the sub-beds shows thickening upward (wide-spaced lines) and thickening-thinning sequences (close-spaced lines). g = 3-5 cm thick gravel layers. In bed h no clear reactivation surfaces could be recognized. Bed numbers 8-11 and 13 correspond to Fig. 9.

subsequent storm events, or whether the complete beds were deposited during one single storm event and the horizontal scouring surfaces separate subsequent stages of the same storm.

Fig. 17 enumerates the thickness division of the sub-beds bounded by the subhorizontal scouring surfaces within the proximal washover beds. The thickness division shown is clearly regular (Fig. 17): the sub-beds within the washover bed either show a thickening upward or a thickening-thinning sequence. These thickness variations can be considered a reflection of differential sedimentation rates caused by variation in stream power during one single storm event. As to the thickness division in the washover beds we suggest that the thickening upward sequences reflect increasing storm, with maximum deposition related to storm peak, in some cases followed by a thinner sub-bed deposited during waning storm (Fig. 18). This means that the different sub-beds, united in one bed, are deposited during one storm event.

CONCLUSIONS

The sediment body described here represent a well preserved mixed tidal inlet/washover type barrier island complex. The balance between sediment supply and relative rise in sea level resulted in a stable position of the barrier coastline. In the

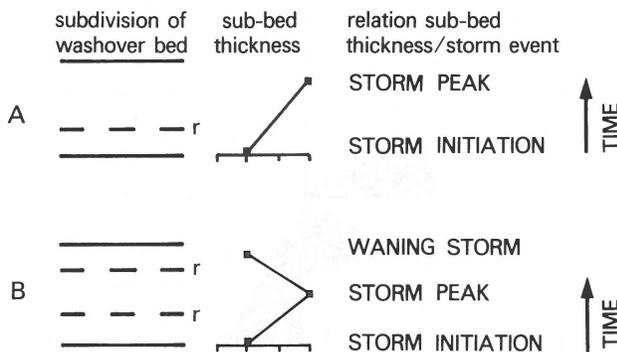


Fig 18

A. Reactivation surface (r) divides a washover bed into sub-beds. The thickening upward sequence is related to the increase in storm intensity during one storm period.

B. Subdivision of the washover beds produces a thickening - thinning sequence: thick sub-beds related to a storm peak are overlain by thinner sub-beds formed during the waning of the storm.

environment of stable coastline position under conditions of a relative rise in sea level (i.e. rise in wave base), the preservation potential of both tidal-inlet and washover delta deposits is high.

Lateral migration of barrier islands in this setting resulted in vertical stacking of tidal-inlets. Both deep channel and shallow channel parts of the tidal-inlet sequence are preserved.

During storms washover deltas developed in the lagoon behind the barrier island. The upper parts of the washover deposits are reworked by wave action and lagoonal currents. Subsequently the washover deltas were buried by fine grained lagoonal deposits.

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