Types of sedimentation in a drowned delta region

Examples from the salt-marsh area at Tønder

By N. Kingo Jacobsen

Abstract

Four longitudinal sections are given through the post-glacial deposits of the Tønder salt-marshes. They are all departing from about the same point of the geest border. By means of these lines the differentiation in sediment covers and facies types is given in relation to the relative rise of the sea level in this area throughout the Holocene.

Studies related to the post-glacial genesis along the southern part of the North Sea coast i.e. the Wadden Sea and the salt-marsh areas have been going on for more than a generation. Among Danish works should be mentioned those by *Axel Jessen* (1916, 1925) and *V. Nordmann* (1935, 1943) and the researches carried out by the *Skalling-Laboratoriet* and by *De Danske Vade- og Marskundersøgelser, Niels Nielsen* (1960). These three series of investigations cover as many epochs with their totally different basic points of view: *Axel Jessen* worked at a hypothesis of a maximum subsidence in the Bronze Age, *V. Nordmann* at tectonic block movements; at present the conclusions are based on the presumption of a continuous rise of the sea level *(N. Kingo Jacobsen,* 1956) and further on examinations of the sedimentation in the area to-day and the totally new perspectives which they open up *(Børge Jakobsen,* 1954, 1956). The borings in the North Sea salt-marsh conclude in the typical profile already given by *Wildvang* (1938). Above the pleistocene landscape (the geest) is found a basis peat superposed by old marine facies. On top of these layers a younger peat follows and, uppermost, the young marine deposits. Without discussing the factors involved and their interchanges the result is a relative rise of the sea level during the last 10.000 years of about 20 m. An outline on the factors influencing this retreat of the shoreline has previously been given (1956). The object of this article is to state the results of to-day in the

Tønder area; further to describe the multiple variations in the topography of the present surface inclusive of the latest sediments as a result of variations of the geest surface and, consequently, of the holocene deposits too, i.e. to determine the type of the salt-marsh. This is demonstrated by means of four longitudinal sections, all departing from about the same point of the geest border and orientated towards: S, SW, W and NW. From pl. II it appears how easy it is to arrive at very different conclusions about the genesis of the Tønder salt-marsh drawn from single profiles, not to speak of single borings. What further complicates the judgment is that even roughly datings of old facies are difficult; so is the determination of exact levels, at least at the time of sedimentation; this deplorable drawback has made it extremely hard to give a reasonable valuation and interpretation of existing material. As a final contributing factor should be mentioned the activity of man, which in the course of the last thousand years has exercised an influence of vital importance on the processes just mentioned. By the endikements a damming of the sea-waters has taken place especially in rough weather. In the course of time these dikes have been strengthened (both from a point of view of profile and of height). In case of dike-bursts strong erosive effects have appeared locally and consequently wide-spread layers of sand and silt have been deposited further inland. Besides the activity of man, such as ditching, construction of sluices and other drainage measures, has conditioned a rather considerable shrinkage in loose, watery deposits and in sediments of an organic character.

The Tønder salt-marsh is situated just south of the Fenno-Scandian rising block, the outer limit of which stretches from the Esbjerg region through Ærø and the Fehmarn Belt. Epirogenetic subsidence in the southern part of the North Sea has been estimated by *W. Dechend* (1954) at about 2-3 cm. per century; this small size excludes such forces from being of greater importance in this relation. What remains to be considered are the eustatic movements which, on the whole, must be regarded as the principal causes of the abovementioned relative subsidence of about 17 m. since the beginning of Atlanticum, i.e. for the last 7.500 years. Of course, this relative rise of the sea level has been subjected to fluctuations caused by climatical changes and changes of the local meteorological and hydrographical conditions.

The course of the sedimentation along the west coast of Jutland has been extremely varying in the different regions, depending, among other factors, on the topography of the pleistocene landscape.

This appears in details within the Tønder area, as previously described (1959). Considering the evolution in outline, the distribution of outwash plains and older moraines, ranges of terminal moraines and tertiary knots has been decisive in combination with the configuration of the coastal profile. The Danish Wadden Sea in its existing structure is thus conditioned by the presence of two knots: Blåvandshuk and Sild, on which the holocene sedimentation is fixed. Within this line is found a large bay which is being filled with sediments, protected against the North Sea by a festoon of beach deposits: peninsulas, isles, high-sands and sand-bars with interjacent deeps and channels through which the tide spreads across the extensive tidal flats and vast salt-marsh areas of different character on the lee-side of the islands and along the mainland. The original gradient of the coastal profile in this region down to the contours — 10 m. DNN and — 20 m. DNN, (Danish Ordnance Datum) has been decisive too for the result: a Wadden Sea area.

The Tønder salt-marsh and the Wadden Sea immediately to the west are to be considered as a delta region for the Vidå (å = river) with its tributaries, which have been drowned through the abovementioned rise of the sea level. However, the latter has taken place slowly enough to be balanced by the sedimentation through the formation of the island arc, the Wadden Sea and a fringe of marine foreland along the mainland. Owing to this, belts of salt-marshes are mainly found in the estuaries of the rivers, separated by knots of older moraines which are facing the Wadden Sea with steep erosion cliffs. Højer (pl. III) is situated on a small, isolated knot, and immediately to the north is found the older moraine Hjerpsted with an erosion cliff towards west, 11 km. long.

The following text deals with the stratification and the levels in the four longitudinal profiles mentioned and, further, with the nature and approximate age of the sedimentation covers. Next this location will in outline be placed in the general problems; before doing so, however, it is urgent once more to stress the necessity of exact datings (by pollen analysis, C_{14} determinations and by archaeological excavations of mounds) and determinations of levels. Further it is important to map the layers in order to put them in relation to the factors influencing the sedimentation, cf. the four totally different profiles in pl. II.

The location of the four longitudinal profiles appears from pl. III. Line A may be considered as a typical section starting at the geest border direct facing the rising sea level. *The geest surface* comprises

three morphological types: a) the western half forms part of the outwash plain gently sloping towards west; formerly it was intersected in the middle by a channel (the former Vidå), which is filled now with marine sand. In this area the gradient of the outwash plain is ¾ m. per km., and the mean levels are ranging from about — 5 m. DNN to — 8 m. DNN; b) to the east of this area is found a higher lying terrace characterized by dune topography. The mean level of this undulating surface is — 1 m. DNN. It stands with a cliff facing the outwash plain to the west and with a big blow-out to the east towards c) the older moraine of Møgeltønder, where the salt-marsh area ends with an escarpment. *The morphology of the present surface.* To the west we find the tidal flat with a gully, which, to northwest, leads direct into the Lister Dyb (dyb = deep) between the isles Sild and Rømø. In this region the tidal range is about 1.80 m. The two levels: mean low tide (Lv - L, pl. II) ab. — 0.85 m. DNN and the mean high tide (Hv - L, pl. II) ab. + 0.95 m. DNN have been lead through the whole profile together with DNN (pl.II) in order to give an impression of the surface level in the different polders in relation to these important water levels. At the mean high tide is found a small erosion cliff: the foreland border, which sharply marks the transition from sea to land. To the east of this erosion cliff the foreland is seen and the two westernmost polders: Ny Frederikskog, endiked 1861, and Gl. Frederikskog, endiked 1692. The process of salt-marsh formation to-day (foreland-type) acts through immigrated vegetation on sand-bars moving from west. On the seaward side of the new marsh-isles the wave-action forms an erosional cliff and a new gully (landpriel) (*B. Jakobsen,* 1954): this is clearly demonstrated in the profile pl.II. Two such systems are found on the foreland, two in Ny Frederikskog and three in Gl. Frederikskog. The dikes and the two mounds in Gl. Frederikskog have all been built on the western, highest lying part of such »cliffs«. The eastern part of Gl. Frederikskog is situated at a lower level and is gently sloping towards the Vidå. The decline continues into the middle of Rudbøl Kog (endiked 1715), where a previous branch of the Vidå has been running. To the east of this locality, situated above the western border of the previously mentioned terrace of the geest, is found a high projecting salt-marsh area, a »hallig« (undiked salt-marsh island). At the western side of this hallig the oldest sea-dike of the region has been built (1556). Further, in this region we find a number of big farms on mounds; in total there are three big hallig-islands in this area and about ten big farms and several villages, the

most important of which is Rudbøl. The hallig is intersected by a small creek and a big creek (Danish: lo). To the east the surface is sloping towards the parish boundary separating: Rudbøl-Gaden and Møgeltønder Kog; this boundary is identical with the upper reaches of the above-mentioned big creek, which in the period immediately before the building of the sea-dike in 1556 acted as a tidal creek for the eastern basin situated close to the geest border. To the west of this basin, still in Møgeltønder Kog, is found a higher part of the salt-marsh, an »isle«, which ows its existence to a corresponding dune-top in the sub-surface of the geest. Such localities have been utilized for building of mounds. As far as the levels are concerned, the various polders show great differences. The foreland, Ny Frederikskog and the western part of Gl. Frederikskog, up to and including the easternmost mound, are situated above mean high tide, parts of Ny Frederikskog even above + 2 m. DNN. To the east of this area are found low-lying regions with the exception of the hallig-area which together with the salt-marsh deposited on the west side of the dunes in the sub-surface reach levels considerably higher than the mean high tide. Apart from this the eastern region is situated below mean high tide, parts of Rudbøl Kog below DNN. The easternmost basin too is situated at a very low level; especially the region in the western part of Møgeltønder Kog, where large areas are situated only a few centimetres above DNN.

After this outline on the topography of the geest and the present surface a view on *the stratification of the alluvial layers* and their variations will be given, passing from the tidal flat, where the formations have a thickness of at least 8 m., via the outer polders with a sedimentation cover of 5-6 m., till the inner polders, which present great variations until the point where the two surfaces unite, i.e. where only the geest is projecting. This inner, eastern borderline of the transgression is varying a lot as far as the levels are concerned. This is quite reasonable as local conditions regarding the geest topography and the exposition to sea and wind have been decisive; in the present case the borderline is found at about + 1 m. DNN.

The sedimentation discussed presupposes the above-mentioned transgression spread via Lister Dyb and the Vidå valley and flooding the outwash plain which is slightly declining towards west. The Tønder region must have had its coastline at about — 7 m. DNN (corresponding to the western part of the profile, pl.II) at about 3.500 years B.C. (1956). In the greater part of the profile the geest is covered by a peat-layer (basis peat). This is found at varying levels and

must be considered as the land-facies which corresponds to the sedimentation in the sea existing at that time at corresponding or somewhat lower levels to the west; the lower the position of the peat-layers, the greater their age: at any rate, this must be the consequence of the hypothesis just put forward: only a single transgression even if it is constantly decreasing. *J. Bennema* (1954) and *J. P. Bakker* (1954) have suggested flooding periods with a certain periodicity. Owing to variations in the rate of transgression assisted by the formation of sand-bars etc. an alternation of the following two systems takes place: 1): Quiet periods with a state of equilibrium, during which the individual facies were formed and gradually passed into each other. 2): Powerful and short interventions of extraordinarily high storm-surges creating new conditions to which, however, the whole system rapidly adapted itself.

If the layers deposited immediately on top of the basis peat are considered, irrespective of their age and their level, this corresponds to following the borderline throughout the ages between the sediments of the land (deposited in fresh water or in slightly brackish water), and the marine sediments (deposited in salt water or typically brackish); thus it is possible on the profile pl.II,A, to make a distinction between two types:

1. The western, exposed marine region, where the basis peat is superposed by a layer of gytja about 1 m. thick. This stratification comes to an end on top of the geest terrace. The depth of the basis peat is varying depending on the relief of the geest surface. The depth of gytja is almost the same all over this area (½ — 1 m.), apart from the eastern, highest lying part, where they have been heavily eroded, cf. the corresponding effects in the profiles C and D demonstrating the conditions in more exposed areas to the north. The gytja-layers represent the brackwater facies of each level. To the west of it we find marine sand-facies and silt-facies and, to the east extensive land-facies: peat bogs in all low-lying parts of the geest. The regular picture indicates quiet conditions, i.e. the retreat of the shoreline has developed gradually, at any rate up to the level ab. — 2 m. DNN.

2. In the protected, eastern basins the transgression has not taken place until very late standing out as a clear-cut from peat to fat basin clay. This corresponds to a catastrophe resulting in a change of facies. However, further examinations of the peat show minor

forerunners as marine ingressions in the peat. Thus, we find immediately on top of the geest a reddish-brown fresh-water peat, dominated by *Alnus* with *Menyanthes* seeds and *Phragmites;* a clay-layer, 1 mm. thick (level ab. — ¾ m. DNN.), separates this peat from a superior, brown *Phragmites* peat with roots of *Alnus* and *Betula*. By a thin clay-layer (level ab. — ½ to — ¼ m. DNN), this peat is separated from a topmost grey to black *Phragmites* peat, superposed by the fat, marine clay. In the latter may be found a single strip of sand originating from a storm-surge; in the northern region too we often find superior layers deposited during storm-surges and dike-bursts.

The marine facies in the western region consist of sand of a uniform, rather fine grain size (50— 80μ) which is, as stated in certain localities replaced by more fine-grained material: fine-sand (20 — 50 μ) or silt (2—20 μ). These layers are often rather waterfilled. The westernmost boring in Ny Frederikskog is rather illustrative of the conditions in this region: On top of the outwash plain (— 6.60 m. DNN) is found a layer of gytja, depth 85 cm. (— 5.75 m. DNN). This layer has been superposed by marine, fine-grained, loose sediments, silt and fine-grained sand, constantly alternating. No shells are found, which seems to indicate a sedimentation even enough for the fauna to follow upwards; therefore, no catastrophe is supposed to have taken place. The fine-grained and loose sediments point to the fact that the sedimentation has taken place behind minor offshore-bars. This state of things continues with variations, until the level ab. — 2.80 m. DNN where a shell-layer of common mussels *(Mytilus edulis)* is found, superposed by loose layers of fine sediments and, next, by more compact layers of somewhat coarser sand up to ab. + 60 cm. DNN, where the salt-marsh, foreland type, starts.

The rise of the sea level shows itself in the drifting towards east of the above-mentioned sand-bars; this drifting meets its first real obstacle at the western slope of the geest terrace mentioned above. Undoubtedly offshore-bars have been formed at the places of the flooded outwash plain exposed to surf; however, all indications known locate all such bars to the west of this region corresponding to the rather fine-grained size of the marine sand found within the area. The easternmost drifting of marine sand as bars: an extent to the east of the tidal-flat area and consequently, of exposed, marine sedimentation, are found below Rudbøl Kog at the level — 2 m. DNN.

No doubt, this is a turning point of great importance. It is true that up to this point and to this level a sedimentation has taken place caused by the transgression; however, until then the rise of the sea level has been dominating. Consequently, during this period unceasing losses of land have taken place. Later the situation changes. The sedimentation has now the predominance over the subsidence, and the conditions are present for the displacement towards west of the frontier line between sea and land. However, the subsequent period is still marked by the relative rise of the sea level, and the influence of the sea extends to even larger areas towards east, cf. the above-mentioned profile from the eastern basins close to the geest border. The heavier sedimentation is consequently reflected in an extension of the marine foreland. This is reasonable as it is necessary to take the effects of the storm-surges and the range of the tide into account too. At the same time, this development conditions the formation of halliger (salt-marsh islands), beach ridges (offshore-bars), and behind these lower areas are found to the east which, as lagoons, are filled with fine-grained sediments, fat basin clay with up to 85% of material below 2μ. Parallel to the establishment of a broader marine foreland the conditions are prevalent for a far richer differentiation of all the facies, a differentiation which is continued until man's intervention by the construction of dikes. It is perhaps the most important result of man's cultivation measures: exclusion of the formation of lagoons and of the special types of sedimentation which are found in such regions. The sedimentation to-day in the Wadden Sea almost exclusively comprises tidal flat sand and salt-marshes of the foreland type.

Most probably, the bed of the Vidå has been forced eastward by the intruding sand-masses, i.e. the wide-spread tidal flats. The halligarea must be regarded as levee formations on the eastern bank of the Vidå, characteristically situated a little to the west of the geest terrace, comparable to a damming effect. The same effect is seen in the mound-carrying salt-marsh »island« in the westernmost part of Møgeltønder Kog. The whole interjacent region (Rudbøl-Gaden) is dominated by erosion and sedimentation of a different nature; a general feature is that the fat basin clay is superposed by facies deposited under more exposed conditions; however, they must all be ascribed to the effect of high flooding during rough weather; it is not likely to think of »cliff«-systems of the same nature as those found in the outer polders. Finally, the attention is drawn to the damming effect at the sedimentation of the basin clay in the eastern-

most basin, which is clearly seen in the levels of the transition from peat to basin clay in this area.

A closer examination of the genesis of the topmost layers (above — 2 m. DNN) is far beyond the scope of this article, as the stratification is rather complicated; however, the erosion channels and the formations of basin clay which are clearly outstanding in all the profiles seem to indicate alternations of the two sedimentation cycles mentioned in page 83 accompanied by alternations in the balance between »subsidence« and sedimentation.

As a conclusion of this description of the profile the attention must be drawn to the configuration of the present surface of the tidal flat, stretching from its easternmost limit below the dike between Rudbøl Kog and Gl. Frederikskog, farther out below the two outer polders and the foreland to the mean low-tide level to the west. Looking so a big sand-bar demonstrates itself; a bar which has drifted inwards with small sand-bars as ripples on the surface. These small bars are the basis of salt-marsh formation of the foreland type, mentioned as the »cliff«-system (*Børge Jakobsen,* 1954). To-day the level of the former tidal flat to the east is at 0 m. DNN and that of the tidal flat to-day at the foreland border at + 0.95 m. DNN. As indicated, this level is identical with the mean high-tide level at the time being. No doubt the size is demonstrated of the relative rise of the sea level within this period, i.e. in the course of about 300 years. On the eastern side of the cliff-systems we normally meet old gullies situated at a lower level; therefore, the rise of the sea level during the last 300 years must be estimated at a total of 50 cm. As it has been possible for man within the same period by means of construction of dikes to press the shoreline 3 to 4 km. to the west it is evident that the present is a period where the sedimentation is predominant to the relative subsidence. Further, the damming-effect of the dikes is demonstrated as the low-lying, eastern areas, if not protected by dikes, would be overflooded every time the high tide rises above + 2 m. DNN which normally occurs a few times a year. At such occasions sedimentation would have taken place of rather coarse deposits as well as some erosive effects caused by the activity of the tides.

The other three profiles only serve to show the rich variation of sediment covers of the easternmost part of the salt-marsh between the river Vidå and the geest border. The profile to the south (B) shows the conditions in the protected part of the salt-marsh where basin clay and fluvial marsh of a rather brackish type are met with.

In the previous trunk stream of the Vidå, now abandoned, borings have been carried out to ab. — 10 m. DNN without reaching the geest *(B. Valeur Larsen)*. The present bed of the Vidå is seen to the south. Profile C shows the stratification found towards west. As a new element the hollow in the middle of the Højer Kog (the Søgaard basin) is of particular interest. This hollow is circular, ab. 1 m. deep and, no doubt, formed as a lake by bar closure of the beach-ridge system situated to the west, departing from the Højer knot. Beach-ridge formations at this level (0 - + 2 m. DNN) have already been described by *Axel Jessen* (1916) from the Ribe salt-marsh. They must be interpreted as a period of stagnation either in the »subsidence« or, in the influence of the tide. At any rate, in this period a strong, south-going beach-drift has taken place, resulting, in Højer Kog, in the formation of three beach-ridge systems with corresponding bar closures and lagoon lakes, cf. pl. III. Shrinkage as an explanation is out of the question; this is evident from the substrata which differ in the eastern part and in the western part of the lake. In the latter area is seen a big creek, which has cut through the peat-layers from — 3 m. DNN to — ½ m. DNN. The north-western profile D situated close to Højer presents a very heterogeneous picture with a protruding knot of the geest to the west close to the dike of 1556. Just east of this knot is found a deep channel which has served the Sejersbæk Kog, situated to the north and east of the previously mentioned older moraine of Hjerpsted. To the east of this channel is seen another old channel which has probably functioned in late-glacial time as a trunk stream for the Lindskov Møllestrøm (from the older moraine of Møgeltønder). The transgression in the eastern basins has been less abrupt in this rather exposed area than in the better protected lagoons to the south-east. This is seen in the presence of a gytja-layer between the basis peat and the basin clay. Further, this area has almost reached a state of stagnation after the building of the dikes in 1556 owing to ample supplies of fresh water from the geest. This has resulted in the formation of peat-layers on top of the basin clay. During dike-bursts a supply of sea water has taken place; this is why peat-layers alternate with gytja-like formations.

The available facts, as described above and demonstrated by the four longitudinal sections, point to a detailed mapping of soil types and a determination of exact spot heights with accompanying datings as indispensable for providing a valid picture of the genesis in this region in post-glacial time. Results based on a single profile

would be rather questionable as the point is a pattern of sedimentation types which at each level, i.e. layers from different periods, are built up of a highly differentiated organism of alternating facies. These are varying partly in conformity with the simultaneously existing geest borders of varied topographical configuration, partly in accordance with the rivers and tidal creeks in function. The first type of facies variations might be called the circular variation type, the latter (in relation to the channels) the radial variation type. Adding to this that the balance between »subsidence« and sedimentation during the different periods (different levels) is subjected to systematical fluctuations, impeding the creation of an equilibrium between the hydrographical and sedimentological factors, it is reasonable that these problems still are in question. During the last 50 years where these problems have been discussed neither efforts nor ability have been lacking; however, the complexity of the problems has been overwhelming as to the collected facts. Two-dimensional representations, which can be obtained by single borings or longitudinal sections, are not quite adequate; nor do three-dimensional representations through mapping of soil types suffice as exact datings are necessary too. It is imperative to produce four-dimensional representations of the post-glacial genesis along several localities of the west coast of Jutland to the north and to the south of the outer limit for the Fenno-Scandian rising block before we know any further about the development during this epoch. However, to procure exact levellings and datings supposes hard work. It is therefore necessary to propose the following as a working programme. Through mapping of soil types within a given area (cf. 1956) to get a broad idea about the pattern of facies types at different levels. According to this each epoch and each facies can be investigated just at the place, where it is typically developed, and only in such places it is worth while to go through with detailed and specialized examinations.

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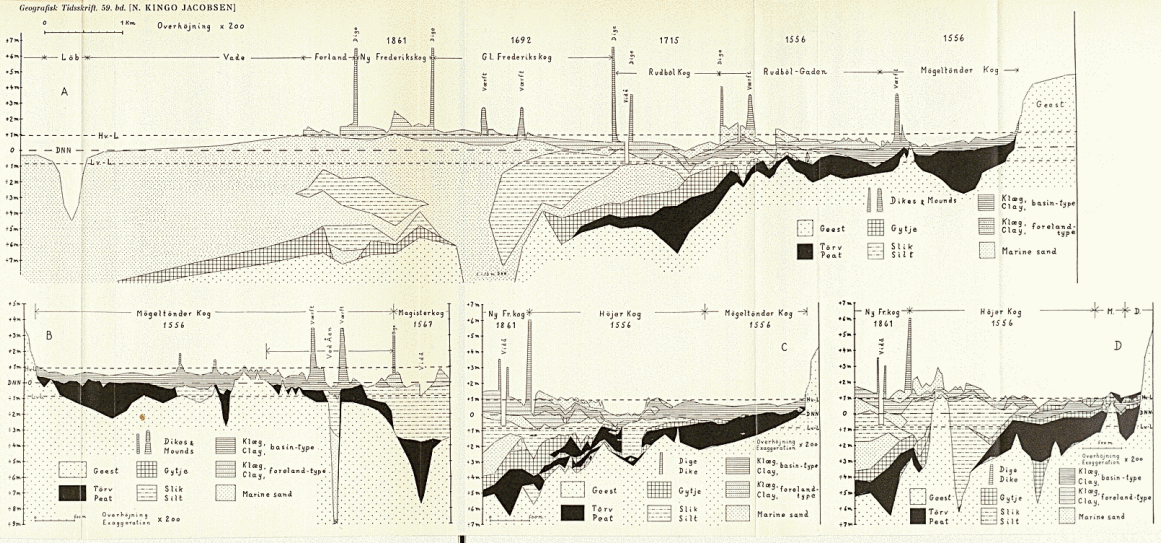
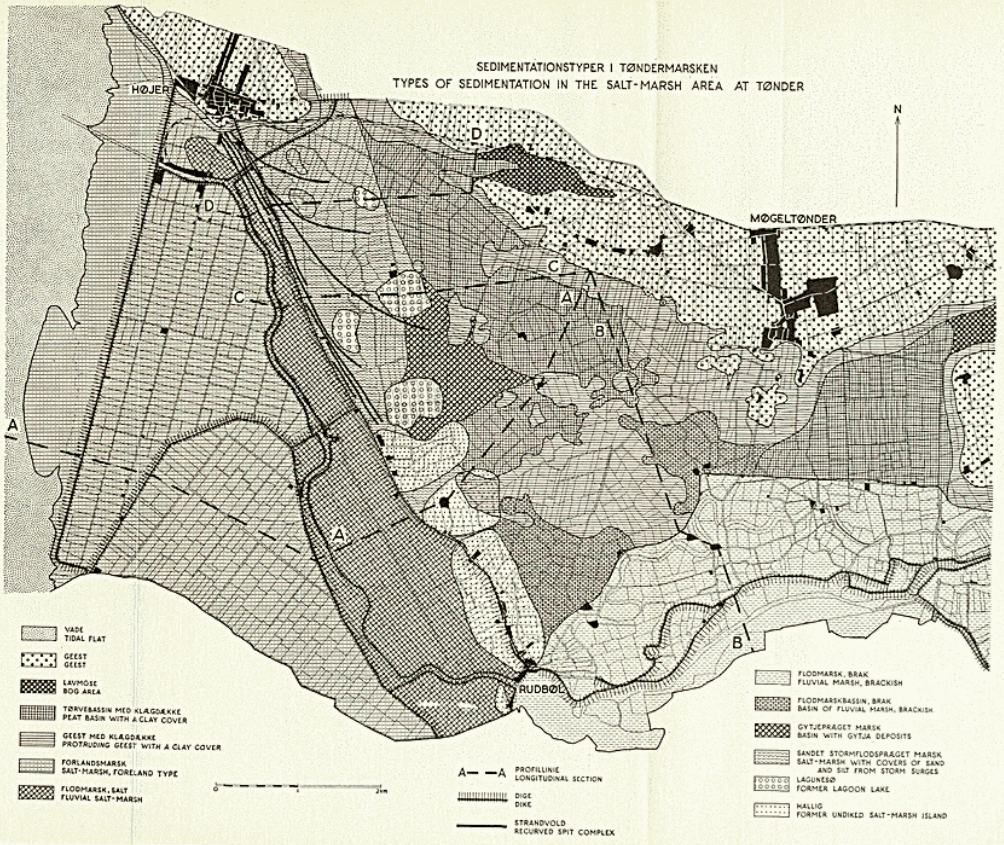


The profiles shown (A-D) are meant to be considered as pedagogic sections. The profiles of the geest surface and of to-day's surface have been constructed according to contour maps of these surfaces; contour intervals of 25 cm. and 20 cm., respectively. In this way it is possible to arrive at characteristical profiles which could not have been obtained using levels from the number of actual borings applied to besides, cf. the longitudinal profile published in 1956. The next step has been to sketch in the layers with small corrections. At the same time it should be pointed out that only the region to the east of the Højer-Rudbøl dike and that to the north of the road from Rudbøl to Mögeltönder have been subjected to detailled examinations in this respect.



The map showing types of sedimentation in the salt-marsh area at Tønder should only be regarded as a preliminary statement based on the results of 1500 borings. As mentioned (plate II) the map differs in its various parts as to reliability. To the east of the Højer-Rudbøl dike and to the north of the road from Rudbøl to Møgeltønder the reliability is great, in Ny Frederikskog, Gl. Frederikskog and in Rudbøl Kog it is good, whereas it is rather bad in the remaining south-eastern regions. Here the map has only been based on a restricted number of borings. These areas are included (by coarse type-designations) nevertheless in support of the text, and in order to facilitate the general view.

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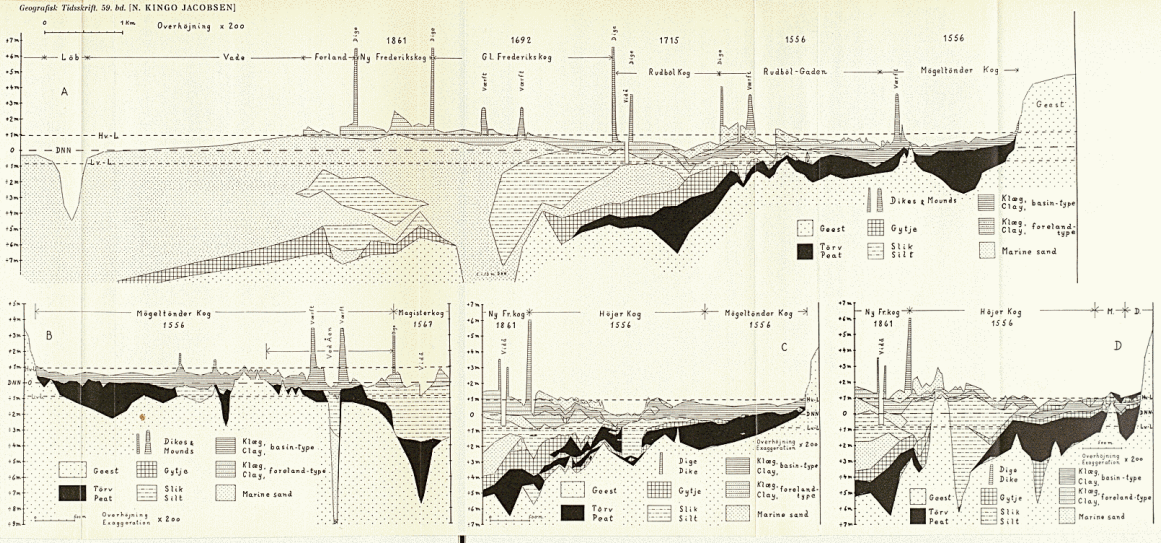
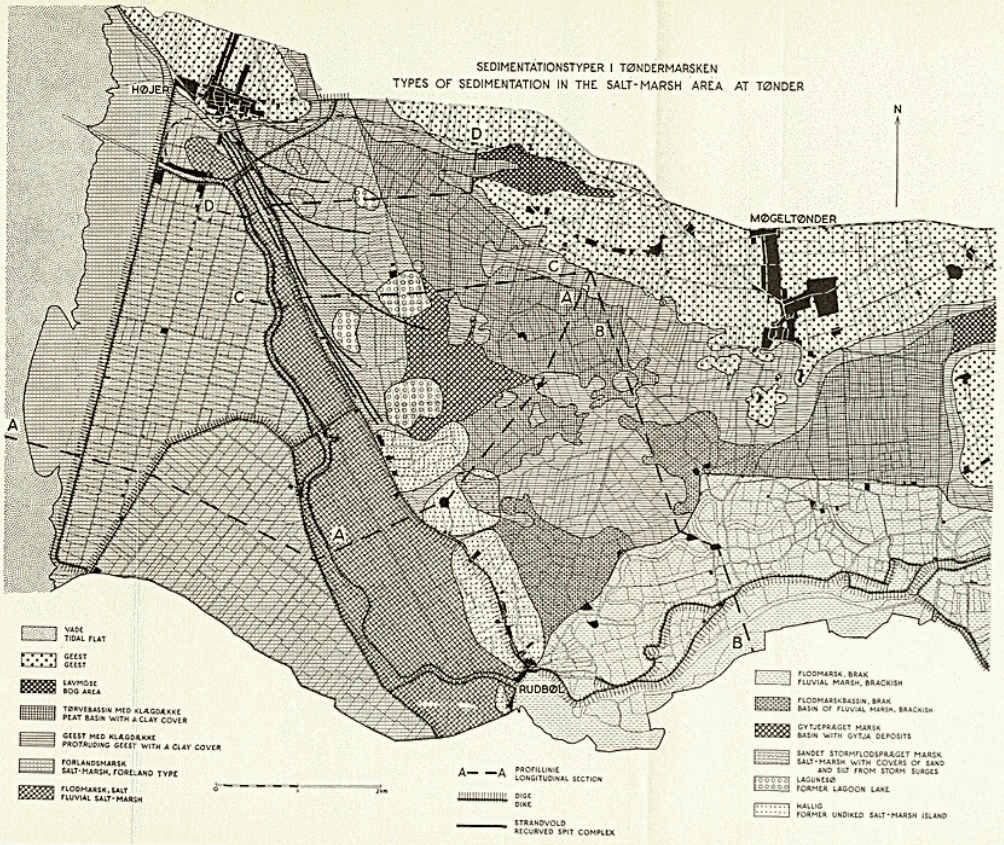


The profiles shown (A-D) are meant to be considered as pedagogic sections. The profiles of the geest surface and of to-day's surface have been constructed according to contour maps of these surfaces; contour intervals of 25 cm. and 20 cm., respectively. In this way it is possible to arrive at characteristical profiles which could not have been obtained using levels from the number of actual borings applied to besides, cf. the longitudinal profile published in 1956. The next step has been to sketch in the layers with small corrections. At the same time it should be pointed out that only the region to the east of the Højer-Rudbøl dike and that to the north of the road from Rudbøl to Mögeltönder have been subjected to detailled examinations in this respect.



The map showing types of sedimentation in the salt-marsh area at Tønder should only be regarded as a preliminary statement based on the results of 1500 borings. As mentioned (plate II) the map differs in its various parts as to reliability. To the east of the Højer-Rudbøl dike and to the north of the road from Rudbøl to Møgeltønder the reliability is great, in Ny Frederikskog, Gl. Frederikskog and in Rudbøl Kog it is good, whereas it is rather bad in the remaining south-eastern regions. Here the map has only been based on a restricted number of borings. These areas are included (by coarse type-designations) nevertheless in support of the text, and in order to facilitate the general view.