The Tidal Area in South-Western Jutland and the Process of the Salt Marsh Formation.

By Børge Jakobsen.

The south-western part of Jutland differs in many respects from other Danish coastal areas; one of the main causes of this is the tide water, which is particularly well developed in the area south of Blaavands Huk, but only of very small importance at the northern and eastern shores of Denmark. The tide gives rise to the formation and development of such types of landscapes which are unknown in other parts of Denmark. The landscapes which are especially connected with the tidal area are the tidal flats (wadden) and the salt marshes.

The map, fig. 1, shows the Danish tidal area (wadden sea area) in south-western Jutland and the surrounding landscapes. The moraine landscape from the Riss glacial period reaches the coast at few places; it is only north of Esbjerg and between Ballum and Højer that the moraine landscape follows the coast on long stretches. The outwash plains from the Würm glacial period do not reach the existing coast because their western parts are covered with salt marshes some kilometres broad. The moraine landscape and the outwash plains, which are situated at a higher level than the salt marshes, are called the geest.

The salt marshes, which are situated at a somewhat higher level than the tidal flats, terminate in a low erosion cliff of a height of up to 1 m. The salt marsh plains remind much of the marine forelands which are found at many other Danish coasts — even plains with difficult drainage conditions and temporarily exposed to inundation. Most of the marine forelands in the northern and north-eastern parts of Denmark are principally true raised sea floors due to the post-Littorina emergence of these areas;

consequently, the soil is composed of the material which was originally lying on the bottom of the sea. Other types of forelands are beach ridge plains and barred foreland.

The salt marshes do not take their origin from a normal elevation of the sea floor, but from depositions in a salt marsh vegetation or in a reed-swamp. In the course of time, the sedimentation has caused the level to rise to such a height that practically no overflowings, and consequently no sedimentation of any importance, take place any longer. That is why salt marshes may be formed even at places where a vertical down movement of the land goes on, provided that the deposition takes place faster than the lowering of the land-surface. The big salt marshes alongside the southern part of the North Sea, stretching from Denmark to France, have been formed too in areas which, periodically, have been exposed to lowerings of the surface. Under such circumstances, the salt marsh depositions are apt to become very thick, because lowerings replace the surface at such a level as to permit the deposition to continue. This explains why you can find in the salt marsh areas from fairly ancient times depositions which have a thickness of several metres.

The wadden is the designation of the areas which are dried at low tide and watered again at high tide. The mean high tide level (M.H.T.), which corresponds nearly to the morphological shoreline, is in the northern part of the Danish Wadden Sea about 0,55—0,75 m and in the region at the Rømø dam about 0,80—0,90 m above Danish Zero Level (D.N.N.).[1])

On the western border of the Danish and the Frisian Wadden Sea a series of isles and bars (high sands) of higher level than the ordinary tidal flats are situated. Just like the peninsula of Skallingen, the isles of Rømø and Fanø are dominated by dunes with a fringe of marsh on the east side; Sild, Föhr and Amrum have small geest areas, but are otherwise of a similar structure, and on Mandø, which is situated in the inner part of the tidal area, the regions of dunes are but small, the greater part of this isle consisting of salt marshes. South of Föhr there are several salt marsh isles, partly with dikes such as Nordstrand and Pelworm, partly without dikes: the Halligs. On Danish territory the small isle Jordsand south-east of Rømø must be described as a Hallig.

1) D.N.N. means the average water level for a series of Danish ports and corresponds almost to the morphological shoreline in the areas outside the tidal area.

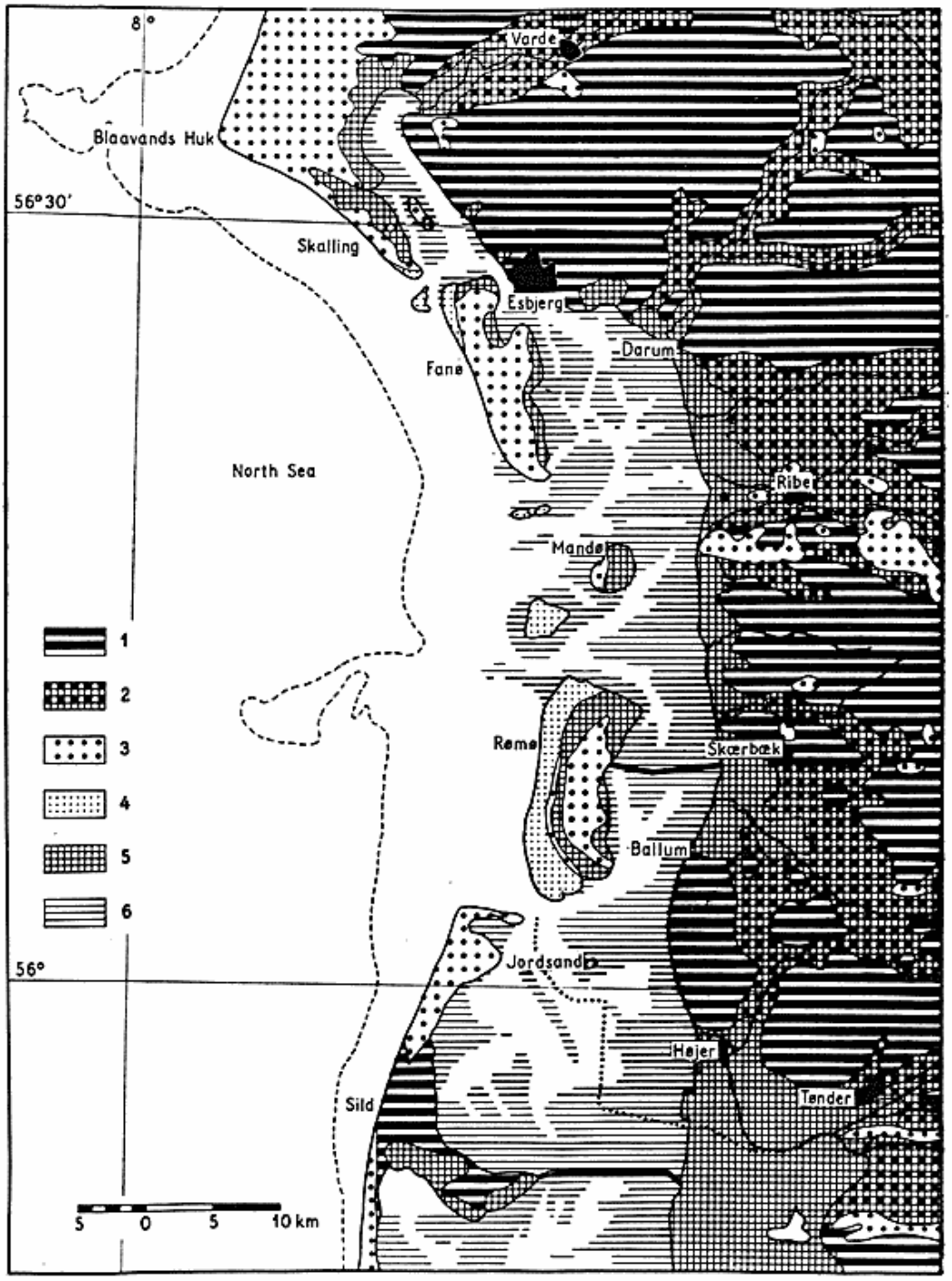

Fig. 1. Geomorphological map of south-western Jutland. 1. Moraine landscapes from the Riss glacial period. 2. Outwash plains. 3. Dune landscapes. 4. Foreshore-plains and "high-sands". 5. Salt marshes. 6. Tidal flats (wadden). (Map partly from: Axel Schou: Atlas of Denmark. I. The landscapes).

The tide, which is the predominant factor of the wadden sea, is a periodical alteration of the water level which goes on twice in the course of about 24 hours. From this results that during rising tide, "flood", large quantities of water flow in between the isles and at falling tide, "ebb", flow out again; by this procedure, considerable areas of the sea floor are covered, respectively uncovered. In the Danish Wadden Sea the wadden amounts to about 60 % of the area.

The range of the tide, i.e. the difference between high-water level and low-water level, decreases in the direction from south to north. At the estuary of the Elbe this difference amounts to about 3 m, at the Danish-German frontier to about 1,9 m and at Esbjerg to about 1,5 m. The range of the tide is subject to certain periodical variations; it is at its highest at spring tide, which arrives at the hours of full moon and new moon, and at its lowest at neap tide, at first and last quarters. Furthermore, the water level, as in other waters, is subject to temporary alterations, caused by air pressure and winds.

The profile, fig. 2, shows a schematical cut through a coastal area in South-West Jutland with the various types of landscapes and their position in relation to D.N.N. and the range of the tide in the southern part of the Danish Wadden Sea.

As already mentioned, the surface of the salt marshes is at a somewhat higher level than the waddens. As it appears from fig. 2, the surface of the salt marsh is situated at between 0,7 m and 1,5 m above M.H.T. or, on an average, about 2 m above D.N.N. At places where no dikes are found a salt marsh with the level conditions mentioned, which are normal to a salt marsh whose formation has practically come to an end, will be overflown with water almost ten times a year, but apart from the outer part of the marshes no deposition of any importance will take place.

At the western side of the isles the beach ridges are formed nearly to the 2 m curve, which also marks the transition from the foreshore plain to the dunes.

Rising of water to an even higher level occurs less frequently and is often described as floods; however, it is only at a height of about 3 m above D.N.N. or more than 2 m above M.H.T. that inundations may have the destructive effect which is generally considered characteristic of floods.

The low dikes in the salt marshes, the so-called summerdikes, which have existed since before the time when the high sea-walls

were built, reach a height of about 3 m above D.N.N.; they offer protection against floods of rather small force, but are not considered as a rampart sufficiently safe for allowing permanent habitation.

It is difficult to indicate any definite height to which floods may arise. Reports which have been given on flood-desasters in old times, for instance in 1634 and in 1825, tend to show that the water has reached a considerable height; however, the actual level can hardly be determined. In this century water risings have been observed at several occasions of a height of between 3 and 4 m above D.N.N. or about 3 m above normal high tide. Among the rural settlements which date from the time before the sea-walls were erected those situated at the lowest level are lying in the Ballum area at a height of 3,5—4 m above D.N.N.; you can find similar conditions at Rømø. The height of the oldest dwelling-mounds (verfs) in the Ballum area, artificial hillocks, on which was situated the village Misthusum, destroyed in 1634, is on an average about 4 m; later on, some of the verfs have been augmented to about 5 m above D.N.N.

This seems to indicate that from experience it has been considered that in the Danish salt marsh areas a level of about 4 m offers a fairly safe protection against the floods alongside the inner margin of the salt marshes, and a little more than 4 m as fa̧ as the isolated verfs are concerned. The existing sea-walls, which apart from the Tønder Salt Marsh have been built in this century, have a height of more than 6 m above D.N.N.

The proportion between the level of the salt marshes and that of the tidal flats has previously given rise to the supposition that formerly the marshes had been subjected to an upheaval, this supposition being based on the idea that the salt marshes were identical with raised tidal flats. Recent investigations have brought to light that the soil in the salt marshes differs to a large degree from the depositions which are found in the tidal flat, and that the formation of salt marshes may commence at a level which corresponds to the tidal flats that are situated at a level about M.H.T. and will then continue to a level which is determined by the frequency of the inundations and the supplies of sediments.

The condition for the formation of salt marshes is a dense vegetation of salt marsh plants or reed-swamp on plains which are situated at such a low level that they are comparatively often overflown at high tide, thereby causing the materials conveyed by the

water to be deposited between the plants. Under the existing natural conditions in the Wadden Sea the formation of salt marshes may, roughly speaking, take place on three different types of locality.

At places which are sheltered against the wave action and where there is a supply of fresh water, for instance at the estuary of Varde river and in bays on the east sides of the isles, formation of salt marshes in reed-swamps (phragmites) can be found.

In the wadden sea are found some areas which are higher than the proper tidal flats, but which, nevertheless, are situated at such a low level that they are overflown many times in the course of a year; that is true for instance of the foreshore-plains on the isles and on the high-sands, i. e. sandbars in the outer part of the Wadden Sea, either isolated or in connection with the isles. The conditions on these sandflats are, among other things on account of sand-drift and floods, unfavourable to the establishment of a permanent vegetation. However, there have been cases where such plains have been transformed into salt marshes. The high-sands on the east side of the peninsula Skallingen, which are situated above M.H.T., but, nevertheless, are often submerged, have during this century been covered with a dense salt marsh vegetation, where fine-grained materials are now deposited; parts of the salt marshes on the north side of Fanø and Rømø have been formed in a similar manner.

A considerable part of the big salt marsh areas on the mainland, for instance at Darum, Ribe, Ballum and Højer, have been formed by upward growth of a salt marsh on the very wadden. It is this formation of land which in the following passages is submitted to a further description.

As indicated on the profile fig. 2, in the eastern part of the Wadden Sea, close to the coast, some tidal flats are situated at a high level. As a rule, the highest level can be found at a distance of a few hundred metres from the coast, whereas the area next to the border of the foreland[1]) is situated at a somewhat lower level. This part, the so-called landpriel (off-shore channel) is as a rule water-conveying also at low water, owing to the fact that the drainage conditions are bad and because there is a constant flow of water from the tidal flats. Furthermore, at places the landpriel acts as outlet for the water-courses which flow into the Wadden Sea.

[1]) Danish term for the part of the salt marshes in front of the embanked areas.

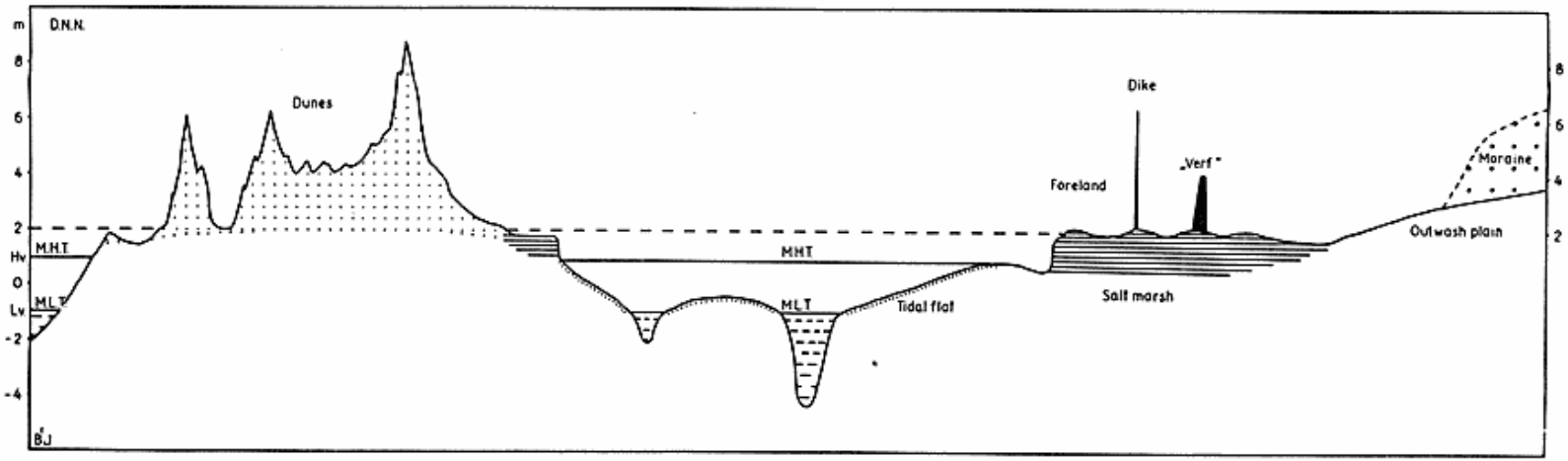

Fig. 2. Idealized cut through a tidal area in the south-western part of Jutland. The various types of landscapes are shown with the right position from a level point of view in relation to Danish Zero Level (D. N. N.) and the tide water. The height is much exaggerated in comparison to the length. M. H. T. and M. L. T.: Mean high tide level and mean low tide level. Stippled line indicates the level which the high tide generally reaches about ten times a year.

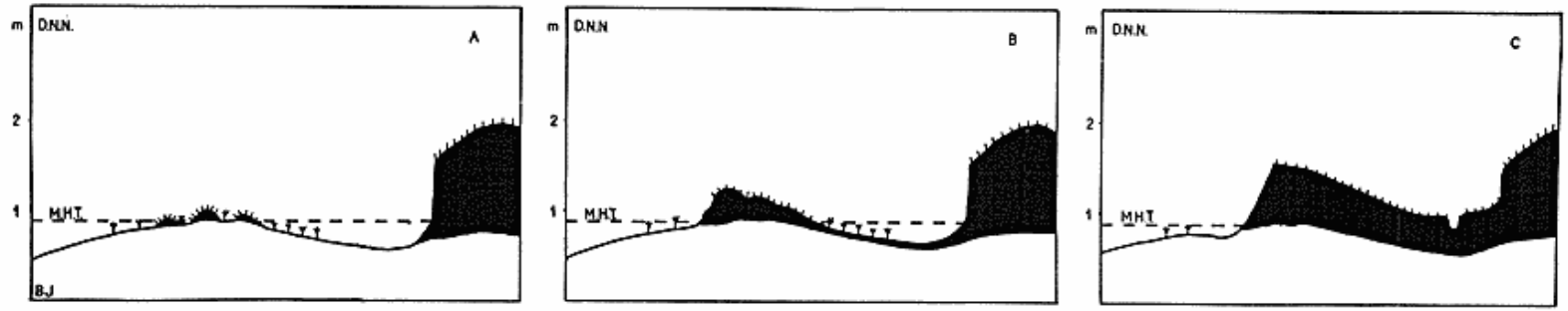

Fig. 3. A. Commencing salt marsh formation on a high-lying tidal flat outside an old salt marsh area. In a Salicornia vegetation, Glyceria recently immigrated has begun to form hummocks. B. In the course of time a new marsh isle is formed. C. The lanpriel between the isle and the old erosion cliff is filled up and transformed into salt marsh. — M. H. T.: Mean high tide level. The height is much exaggerated in comparison to the length.

The tidal flats situated at a high level do not form a continuous off-shore bar outside the coast, but are separated in irregular bars, between which the water from the land-priels searches its way to the depths through shallow inlets or through marked tidal channels. The tidal flats outside the land-priels are generally hard sandy tidal flats. At places, the highest lying parts may be situated at a level which corresponds nearly to M. H. T., so that ordinarily they are only covered with water a short time; at eastern wind and at neap tide they may be dry during one tide-water period or more. On such tidal flats are found the largest growths of *Salicornia herbacea* (Danish: kveller), which is a succulent annual and is able to resist a frequent overflowing of salt water. The quantities and the occurrences of Salicornia change much from one place to another and from year to year, but even the occurrence of dense growths of this plant during several succeeding years does not involve considerable alterations of the level of the tidal area nor of the composition of its soil.

On the lee-side of the tidal sand, facing the landpriel, one will often find some fine-grained material in the surface, and it is there that the growth of Salicornia is normally most dense and most constant. The appearance at this place of the fine, soft, water-filled material (slik) and a vegetation of Salicornia can be ascribed to the same cause: the sheltering effect of the tidal flat. However, such conditions only prevail in small areas and may exist in long periods without giving rise to continuous depositions of any importance. Only in a few localities, for instance in certain bays or at places with special hydrographic conditions, such as on the south side of Rømø dam, permanent, steadily increasing depositions of slik (silt) may be formed. The surface of the greater part of the tidal flats is periodically exposed to current- and wave-actions of such a force that the fine-grained as well as the sandy materials may be torn up and carried away or be redeposited.

Even vegetations of Salicornia only offer a feeble protection against this process and may in some cases, as a result of the formation of eddies around the single plants, cause the surface of the tidal flat to be eroded.

In certain cases the real salt marsh plants, in the first place *Glyceria maritima (Puccinellia maritima.* Danish: annel grass) may suddenly make their appearance on the highest lying parts of the tidal flat outside the landpriel. This happens rather seldom and seems to require a combination of favourable factors.

The material transported by the water can easily be deposited in the Glyceria vegetation, where it is sheltered against waves and currents. This is why the immigration of Glyceria involves that the surface of a wadden, hitherto of a rather stationary level begins to change. At first, the material is accumulated in the sparse tufts of Glyceria, which rapidly spread by means of numerous off-shoots, and small hummocks are formed which on account of the depositions rise above the surface of the tidal flat.

In the outer part of the newformed marsh, where during wave-action a deposition, essentially of sand, takes place, the hummocks are pronounced and rapidly rise by several decimetres above the tidal flat. Further inland the hummocks are more flat, and the material deposited is principally silt or fine-grained sand. By and by the hummocks grow together, and in the course of a few years a tidal flat may thus be transformed into a dense Glyceria meadow.

Simultaneously with the creation of the new marsh, the sea commences to erode its outer parts, and in the course of time a distinctly marked cliff is formed facing the tidal flat. In the original landpriel, where the sheltering effect increases, an additional quantity of slik is deposited, and the *Salicornia herbacea* and later on the *Glyceria maritima* spread in the direction of the old foreland. Gradually as the depositions cause the level to rise the number of tidal submersions decreases appreciably, and especially the highest lying parts may in the summer season be dry for long periods.

The above described process continues through depositions and levelling of the surface, in such a manner, however, that the outer parts remain the highest, the level decreasing in the direction of the landpriel, where the deposition of silt becomes more and more prominent. The deposition only takes place during big high-waters, which normally appear in connection with stormy weather. From the wadden, quantities of sand are whirled up, the greater part of which is deposited in the outer area, the thickness of the sand-layers decreasing in the direction of the landpriel. The fine-grained clayey sediment (Danish: klæg), which is produced by diagenesis, in particular dehydration of slik (silt) is in the outer area only found in the form of narrow bands, the thickness of the layers increasing in inward direction, and the clayey sediment is almost homogeneous in the low-lying parts, only mixed with a few thin sand-layers in the previous landpriel.

Outside the new marsh a new coastal profile with a more or

less pronounced landpriel is apt to be formed, and on the tidal flat off this landpriel possibilities may arise for the creation of a new marsh. Sometimes, even before the formation of one area has been accomplished, one or more new marshes are developed outside the first area. The individual "isles" can be traced for a long time in the surface profile and in the distribution of the sand-layers and the clayey sediments. In some cases the erosion is so powerful that a new marsh area will be obliterated, totally or partly, even before its formation has come to an end.

Under the existing tidal conditions the formation of a salt marsh will be almost accomplished at the time when the outer parts have reached a level of about 2 m above D.N.N. or a little more than 1 m above the original wadden. In the previous landpriel, which for a long time retains a swampy character, the level is often ½—¾ m lower than in the outer parts and rises in the direction towards the foreland, where the old erosion cliff can be preserved more or less pronounced.

The above mentioned upward growth of marsh, which may take shape in the course of a few decennaries, is schematically represented in fig. 3.

A continued sedimentation will then take place at a low rate, because the area in question is only submerged a few times a year. The difference of level between the high-lying outer parts and the low-lying inner parts is neutralized to some degree, but is not completely done away with, and in the reclaimed salt marshes, which have partly been formed in the manner described above, one will consequently still be able to find several rows of high, sandy, stratified parts with interjacent, more clayey low-lying parts.

Through upward growth on a tidal flat a salt marsh has thus been formed which, not only as far as the level is concerned, but also with regard to the soil conditions differs greatly from the original tidal flat. This natural formation of land has been observed at some places in the Wadden Sea along the coast of south-western Jutland. The final result is a salt marsh of the same aspect and of practically the same level as in the outer parts of the old marshes. Consequently, the position of the latter from a level point of view need not be contributed to land-uplift.

As already mentioned, the natural formation of land has been observed at various places along the coast, but often the accretion of land has been artificially accelerated by different methods of

reclamation. The method preferably applied is a system of parallel ditches of a depth of about 15—30 cm in the tidal flat or in a new-formed salt marsh meadow. As a rule the ditches (Danish: grøbler) are placed at a right angle to the coast with outlet to the landpriel. The main purpose of the ditches is to promote the drainage of the seawater, thereby furthering the possibilities of growth for the salt marsh plants. Furthermore, the formation of closed, swampy holes and irregular tidal creeks (Danish: loer) is thereby avoided. In the ditches, which are watered principally from the landpriel, fine-grained material is rapidly deposited; this material is afterwards dug up and piled on the interjacent fields. In order to encourage a beginning land formation on high tidal flats they have been planted successfully with *Glyceria maritima*.

Sedimentation basins, partly closed, which are constructed in the tidal flats from rows of piles and fascines, are used with greatest profit at places where on account of special hydrographic conditions considerable supplies of finegrained material are deposited, but where it is difficult for a dense, protecting salt marsh vegetation on account of the low level to grain foothold, for instance on the south side of the Rømø dam.

In the innermost parts of the big salt marsh areas, at Darum, Ribe, Ballum and Tønder, the surface is more smooth than in the outer parts, and the soil consists chiefly of a homogeneous fat, clayey sediment, which is formed under other conditions than those existing in the outer marshes, this clayey sediment being to a great extent deposited in reed vegetation (Phragmites swamp).

The level conditions mentioned above refer to the salt marshes which have not, or have only recently, been embanked. In areas where embankments have taken place in fairly ancient times, possibly already in the Middle Ages, it appears as a rule that the oldest of the areas diked-in (Danish: kog. Dutch: polder) are situated considerably lower than those which have been embanked at a more recent date. This is particularly known from the Netherlands; however, similar examples are found in all salt marshes of an ancient date. On Danish territory only parts of the Tønder salt marsh have been embanked for any long period. The dike from Højer to Rudbøl and further on to Tønder was built in 1553—55, and the marsh outside this dike was not embanked until later on. The existing sea-wall at Højer was built in 1860. While the level conditions in the area just inside this sea-wall at Ny Fre-

deriks Kog correspond to those that are found in the salt marshes at Ribe and Ballum, the surface of the older "kog"s at Rudbøl, Højer and Møgeltønder is generally lower and at several places near 0,0 m D.N.N. or considerably below M.H.T. In the "Magister" kog around the Vidaa river levels below 0,0 m are found.

These facts are often difficult to explain, and without determining the causes of the low situation of the Tønder salt marsh, some factors will here be mentioned which may have contributed to this state of affairs.

When a salt marsh area has been embanked the submersion ceases and, consequently, the possibilities of deposition vanish. In some cases salt marshes have been embanked before maturity; if only for that reason, such a kog is situated at a lower level than the kogs which have not been diked-in until the formation of the salt marsh had practically finished.

If, after the embankment, a lowering of the land-surface in proportion to the surface of the sea goes on, this cannot be compensated by a continued deposition, and it is also due to these circumstances that the oldest "kog"s are those lying at the lowest level.

In the sediments of the salt marshes, in particular those which are very clayey, a shrinking takes place which is presumably at its highest in the period just after the deposition, when the slik is transformed into a clayey sediment (klæg), but which possibly lasts very long. In an embanked area a drainage and a removal normally takes place of the superfluous water, with which a certain quantity of dissolved and suspended material is carried away. If the drainage also touches layers of peat, which in many localities are found below the salt marshes, this involves a considerable desintegration and shrinking in the peat layer.

In areas with peat layers lying immediately below a relatively thin clay layer the peat has in old days been dug up to serve as fuel and as object for the extraction of salt, and the clayey layer was afterwards redeposited. Considerable areas have been dug up in this way and lowered in the Netherlands, on the Halligs and in the old Nordstrand.

The lowering of the surface of the old salt marsh "kog"s gives as an immediate result that the removal of the superfluous water is rendered difficult. If the down movement is considerable it may induce infiltration of ground water, which in these regions is often salt. The greatest danger to which low-lying salt marsh "kog"s

are exposed arises if during floods the sea destroys the dikes; if so, the depth of the water in the "kog" becomes particularly great; furthermore, of the surface of the "kog" is lower than M.H.T. the sea continues under normal tide water conditions to penetrate through the openings in the dikes, thereby forming deep tidal channels, and the surface is damaged. The reconstruction of the "kog"s is in such cases more difficult than when it is a question of high-lying "kog"s where, the flood finished, the water disappears again.

Especially in ancient times it has been difficult or impossible to reestablish submerged, low-lying "kog"s, and this has no doubt contributed essentially to the annihilation of the big salt marsh areas, caused by the floods.

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