RIJKSWATERSTAAT COMMUNICATIONS

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MUD DISTRIBUTION AND LAND RECLAMATION IN THE EASTERN WADDEN SHALLOWS

by

Dr. L. F. KAMPS †

Chief Engineer of the Land Reclamation Works in the Provinces of Friesland and Groningen at Baflo

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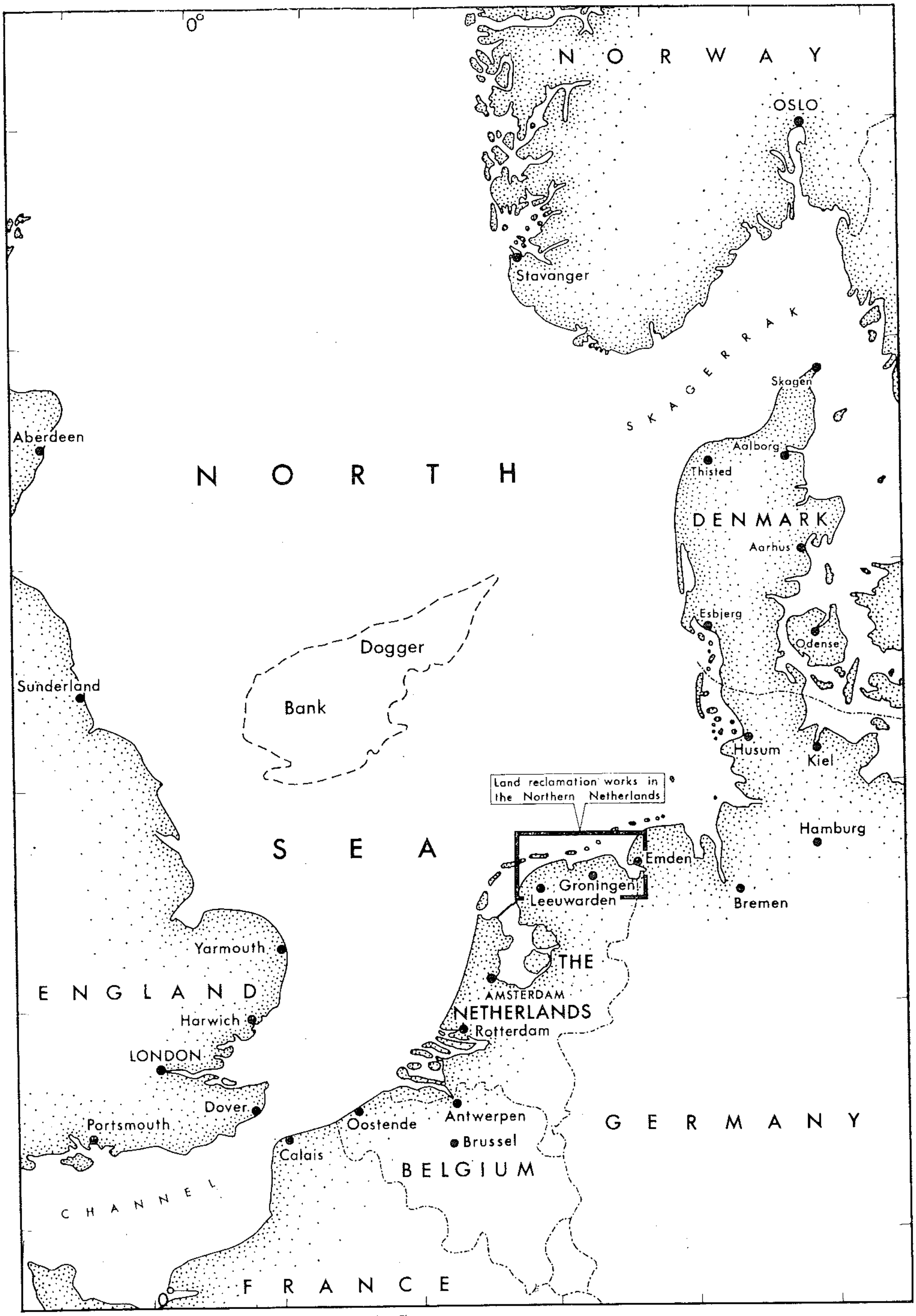

Figure 1. Outline map of the North Sea.

Foreword

In this publication Dr. L. F. Kamps describes the land reclamation work being done along the north coast of the Netherlands in the provinces of Friesland and Groningen. The research carried out in connection with the project is dealt with in detail. It was mainly undertaken with a view to solving practical problems, though it was treated as fundamental research whenever possible.

The publication appeared originally as an official report. Therefore it was presumed that the reader was acquainted with the background information, the geographical situation and local conditions. However, now that this account is to be more widely distributed so that it will become available to outsiders, it is desirable for the sake of clarity to outline the circumstances under which land reclamation is carried out in the north of the Netherlands and the research in question was undertaken.

It is regretted that Dr. Kamps died before he could write a preface.

Reclamation is taking place on the seaward side of the dyke protecting the land from flooding. There are extensive sandy shallows in that region (the Wadden Shallows) that are quite dry at low tide and are covered with water at high tide (figures 1 and 2). The level of the Wadden Shallows averages 0.5 m below A.O.D. *). These shallows are bounded on the north by a string of islands and high sandbanks lying five or six miles off the mainland. Deep, wide channels through which the tidal movements of the North Sea penetrate to the Wadden Shallows run between the islands and the sandbanks.

Mean High Tide in the Wadden Shallows is 1 m above A.O.D.; Mean Low Tide is 1.4 m below A.O.D. Under normal conditions 1.5 thousand million cub. m of water move in and out through six of these channels as a consequence of this difference in tidal levels. It is in these Wadden Shallows that the processes and operations described in the following discourse by Dr. Kamps take place.

Land is being reclaimed along the southern border of the Wadden Shallows beside the coast of the mainland. This coast shelters the work from the prevailing south-westerly winds. The area concerned stretches from 400 to 1200 m out from the coast and extends about 90 km along the coast. It adjoins the sea dyke in some places, in others it is separated from the dyke by a strip of salting. This is land outside the dykes that has been formed by deposits of silt rising a little above Mean High Tide (0.1 to 0.2 m). It is covered with salt resisting grasses and is used for grazing.

Land reclamation has been going on in the provinces of Groningen and Friesland for centuries. The geographical situation in the Wadden Shallows region of the Netherlands where land was formerly reclaimed differed little from the situation at the present day, except that the shallows between the coast and the screen of islands were wider than they are now. Consequently, the deep channels in the shallows are nearer to the dyke alongside which reclamation is taking place than they used to be.

The first dykes were built in about the year 1000, and were mainly the result of efforts on the part of various monasteries. The initial object was to *protect the existing land*. Later on *the protection with dykes of new accretions of land* washed up by the sea became more important. This gradually caused the coastline to be pushed outwards and a border of new polders of varying width came into existence outside the old land (figure 2).

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*) A.O.D. means Average Ordnance Datum (= N.A.P. = Normal Amsterdam Level), the usual datum line used for levelling. It indicates approximately the average level of the sea along the Dutch North Sea coast.

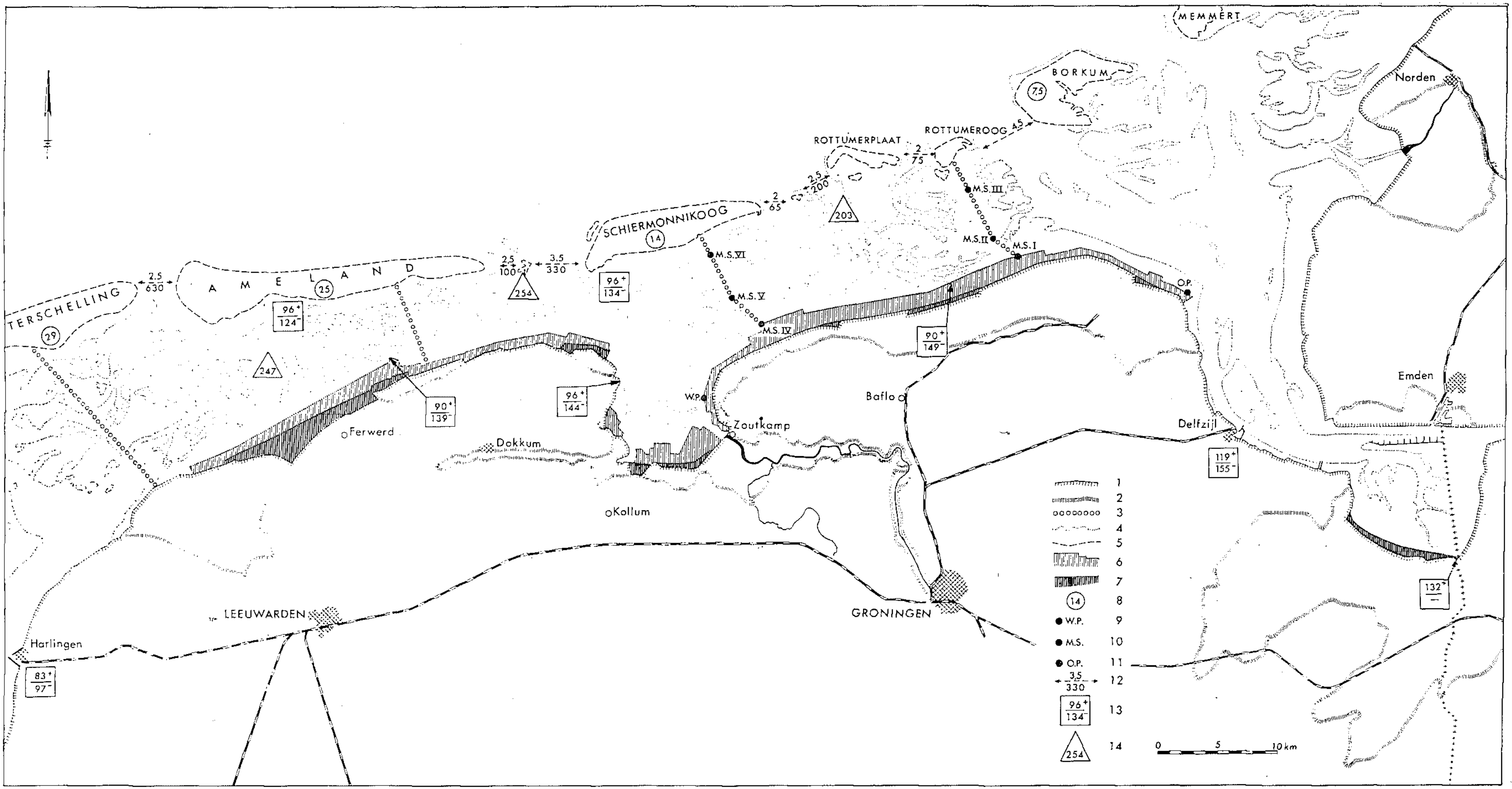

Figure 2. Outline map of the Eastern Wadden Shallows.

1. Seadyke.
2. Coastline in the year 1500.
3. Watershed.
4. Line of the Mean Low Tide.
5. Line of the Mean High Tide.
6. Land reclamation works.
7. Saltings and summer polders.
8. Length of the islands in km.
9. Measuring platform Westpolder.
10. Measuring platform I-VI.
11. Measuring platform Oostpolder.
12. Width of the sea-gaps in km, capacity of the sea-gaps in 10^6 m^3 (mean between low- and high-tide capacity).
13. Mean High Tide in cm above A.O.D. Mean Low Tide in cm below A.O.D.
14. Area of the tidal basin in km^2.

Originally the accretions were of natural origin. Later on silting up was accelerated by means of a system of ditches that speeded up the draining of the accretion and enabled vegetation to obtain a better hold. This form of land reclamation was carried out by the owners of the land bordering on the sea dyke, who could claim the newly drained land as their own. The labour needed for the ditch-digging was available in the months during which there was little other work for the farm labourers to do. This method of land reclamation, known as the farmers' method, was practised right up to the first quarter of this century.

However, the results landowners obtained by this method became worse and worse, for what reason it is difficult to say. It may have been particularly due to the fact that the succession of polders brought them nearer and nearer to the deep channels in the shallows which may have interfered with the process of silting up. Moreover, the increasing mechanization of farming reduced the number of permanent farm workers, so that less attention could be paid to the maintenance of the saltings. Altered social conditions and the economic depression of the thirties caused maintenance work to be so neglected that some of the land outside the dykes was lost again; the dykes were even affected in some places.

All these contingencies together with the serious unemployment of the early thirties led to the State taking over the task of land reclamation in 1935. Since the farmers who owned land adjoining the coast could claim the land outside the dyke as their property the State had to come to some agreement with them. The terms of settlement are laid down in the *delimitation contracts*. The land reclamation projects launched by the State provided work for a large number of unemployed.

In view of the deteriorating sedimentation conditions already described, however, a method was used that differed from that employed by the farmers. The aims of the projects, too, changed gradually. The farmers' method aimed at making the stretches of fairly high land already sparsely covered with vegetation (approximately 0.4 m below average high tide) silt up until they were just above Mean High Tide, forming saltings covered with salt-resisting grasses suitable for grazing. If the strip of salting was wide enough (from 800 to 1.000 m) it was dyked and turned into a polder. The land could then be used for purposes of cultivation. Its high level compared with average sea level enabled drainage to take place by gravitation. Experience had shown that saltings turned into polders produced excellent arable land.

The formation of salt marshes suitable for grazing is no longer the object of the modified Schleswick-Holstein method now used in the Netherlands, which is described in the report. The aim of the present system is to give the barren bottom of the shallows such a profile that fairly good arable land appears after it has been turned into a polder. This is mostly achieved at a considerably lower level than that of a salting. The artificially induced and therefore expensive process of silting up can then be stopped sooner, thus enabling the new polder to be completed more rapidly. Pumps are required to control the water level in such polders, which was not the case with the old salt marsh system. Owing to the development of pumping techniques and the more exacting demands present-day farming makes on water control, pumping is a more paying proposition than it used to be.

A comparison between the present method of land reclamation and the farmers' method used formerly shows that Man's influence on the silting-up process has greatly increased; this is apparent from the report. Consequently, the method has become increasingly vulnerable. If the work is inadequately maintained, Nature tries to restore the equilibrum upset by Man, which results in the loss of what has so far been gained.

It follows that land reclamation in its modern form may only be undertaken if it is certain that the necessary work can continue uninterruptedly for a number of years until the objective, the creation of a polder is achieved.

Baflo, November 1959.
Ir. R. J. de Glopper.

Summary

Foreword. The foreword gives a description of the general conditions under which land reclamation is taking place.

Introduction. The introduction gives a brief summary of the subjects discussed. They are the results of scientific research and a description of the technique applied.

The sediment before precipitation in the sedimentation fields. The sediment consists of sand, clay minerals, calcium carbonate and organic matter in varying proportions. The sand is almost certain to have come from the North Sea and most probably the clay minerals have, too. The calcium carbonate is partly of organic origin (shells, calcium skeletons) and partly the result of biochemical precipitation.

The clay minerals, combined into small, separate flakes which do not settle readily, enter the Wadden Shallows via the sea inlets. Molluscs eat these units together with organic food. In the intestinal tract the material, together with organic waste products, is formed into lumps of faeces. These lumps are more compact and larger than the original mud-flakes. After they have been excreted by the molluscs they rapidly sink to the bottom. At first these precipitated lumps of faeces are held down and covered by a layer of pituitous diatoms.

In rough weather the precipitated lumps are stirred up again and carried towards the shore. Some of them sink to the bottom close to the shore and remain there; others are carried back to the shallows by the outgoing tide. Some may actually be carried out into the North Sea in stormy weather.

The quantity of faecal matter in seawater can vary very considerably. It varies roughly from 25 milligrammes to 2.000 milligrammes per litre. It is greatest when the tide is coming in and in rough weather. On the watersheds, i.e. the separations between two tidal basins, the water contains more faecal matter than it does elsewhere, since the water is calmer there, resulting in a greater abundance of fauna. Consequently the sedimentation process takes place under more favourable conditions there than it does between the watersheds.

Land reclamation by means of silting up. The area of arable land can be increased in various ways. One way is by the natural or artificially induced silting up of the tidal foreshore.

Nearly everywhere where silting up occurs (silting up is a natural process almost everywhere), vegetation is playing a most important part. Plants consolidate the sediment and prevent the sea from washing it away. A feature of natural silting up is that the pattern both of the water-courses and of the nature of the soil is rather erratic.

In the north of the Netherlands the natural silting up process has been helped along for centuries by a system of grips (i e. small open ditches) laid out in a regular pattern (farmers' method). They were laid out on the tidal foreshore newly covered with vegetation (approx. 0.4 metre (= 16") below Mean High Tide). By clearing out these small trenches regularly and spreading the warp over the fields, the drying out process of the material and the growth of vegetation were promoted. Vegetation plays an important part in this system, too; it consolidates and protects the sediment. Under the influence of the regular drainage, the soil gradually becomes less heavy as one moves away from the shore and at right angles to it.

A similar method is used in north-west Germany (the Schleswick-Holstein method). In this method a new and important element is introduced, viz. groynes made of stakes and brushwood. They act as breakwaters, establishing another sedimentation field in front of the trenched area covered with vegetation. No trenches are dug there yet, but due to the protection provided by the groynes, soil accretion takes place more quickly than it does in the open shallows. This new sedimentation field is only trenched when vegetation begins to show. Vegetation is still an important factor in the consolidation of the sediment.

More or less the same system is used in the north of the Netherlands as is used in north-west Germany (modified Schleswick-Holstein method). There is, however, one big difference. With this method not only are the vegetated sedimentation fields trenched, but also the bare, low-lying areas. They are up to 1 metre below Mean High Tide. Vegetation is of far less importance in this system.

Finally, a few experiments with other systems are described. The results were not very satisfactory, so that these systems have never been actually used.

Silting up by the modified Schleswick-Holstein method. In the modified Schleswick-Holstein method sedimentation fields of 400 x 400 metres (440 x 440 yards) are laid out by enclosing areas within brushwood groynes with two openings in the groyne facing the sea for drainage purposes. There are often two or three such fields, one behind the other. The groynes consist of a double row of stakes with brushwood between them. The construction of the groynes and the modifications in design that have taken place down the years are discussed in detail. The brushwood groyne is replaced as soon as possible by an earth groyne which requires less upkeep. The sedimentation fields are subdivided by means of earth groynes.

The system of water-courses in the sedimentation fields, needed to let the flood-water in and out, consists of a network of main ditches, lateral ditches and grips. The main ditches are at right angles to the shore, 200 metres (220 yards) apart. The lateral ditches which are about 100 metres (110 yards) long and about 100 metres apart, run parallel with the shore. The grips run at right angles to the lateral ditches (figure 14).

The main ditches and lateral ditches are the main arteries of the system of water-courses. They are not greatly subject to silting up, except for the main ditches outside the enclosures which often fill up with sand rather quickly.

The grips are the last link in the system. In the higher, vegetated parts they merely serve to drain the intermediate plots. In the low-lying (and therefore bare) parts they act both as drains and as mud-catchers. When the water runs away it washes the fresh mud deposits into the grips. These two functions are essentially incompatible, so that the grips have to be dug anew every year. Experience has also shown that the grips in such areas should be of ample dimensions if they are to remain effective as drainage channels for any length of time.

The grips used to be dug by hand. Decreasing unemployment, however, caused a shortage of labour so that the possibility of mechanization was examined. Ploughs were used at first, drawn by tracked tractors. They could only be used in sandy areas. So a machine was designed consisting of a hydraulic grab mounted on a pontoon and propelled by means of an anchor-cable and winch (figure 34). Good results were obtained with this machine, so that most excavation work is now done with it.

Finally, a few words are said about soil survey of the sedimentation fields which helps to keep a check on the silting-up process and on the effect of modifications of working methods.

Vegetation in the region of the Wadden Shallows. The nature of the vegetation in a tidal area follows the height of the land very closely, so that on a regularly sloping foreshore various zones occur where the flora is determined among other things by the time per tide during which the bottom is flooded. The most important plants are:

1. Salicornia herbacea L., (glasswort or marsh samphire) which is regularly found above 0.3 - 0.4 metre (12" - 16") below Mean High Tide;
2. Spartina Townsendii, H. et J. Groves, (cordgrass) found at about the same height;
3. Puccinellia maritima Parl., (sea poa) which is only found regularly above 0.2 metre below Mean High Tide but really grows in abundance above Mean High Tide.
4. Festuca rubra L. (red fescue) which is regularly found above 0.3 metre above Mean High Tide.

The characteristics of these plants are described and also the methods of gathering the seed and sowing. Many other plants are found besides the species mentioned, but as a rule only as individual specimens. However, owing to the intensive grazing on the saltings the number of species is smaller than that in naturally developed areas.

Postscript. It is pointed out that land reclamation is a costly business. Before starting land reclamation by the modified Schleswick-Holstein method, one would be well advised to consider the financial consequences very carefully.

1. Introduction

The purpose of this report is to give a survey of the results of the research made by the Study Service of the Land Reclamation Department which was established in 1935 in order to obtain a better picture of the factors which are influencing sedimentation in general and within the sedimentation fields in particular.

By reason of certain circumstances the bulk of the information has been obtained on the Groningen Wadden Shallows, and it was only in the past few years that attention could also be given to the Frisian Wadden Shallows where some peculiar differences were observed. Because of this, it is essential to be very careful in drawing comprehensive conclusions; and for the same reason the areas in which the different information was collected are specifically mentioned here.

The method of land reclamation which is applied here, and which is described — in the writer's opinion incorrectly — as the Schleswick-Holstein method, aims at producing soil improvement which precedes diking. With this system of soil improvement the purpose in the first place is to create favourable circumstances for the deposition of material with sufficient clay*).

At first it seemed that enormous quantities of this material would be needed, as it was planned to form, according to the delimitation contracts, saltings lying well above Mean High Tide (M.H.T.). Later, however, it was found that this would demand a great amount of time and money, so it was decided to adapt it to the formation of a layer about 60 cms (24 inches) thick with an average clay content of 15%. It may be that in the future even this thickness of 60 cms will not be adhered to and that the 15% average will be required only for the upper 30 cms.

It will be clear, of course, that this change in the aim of the works has had its influence on the research, particularly on the botanical part of it. But as it is still necessary to retain a certain amount of clay for this form of land reclamation, this material has remained, and still remains, the centre of interest. It will, indeed, be extremely difficult to reclaim the land wholly, or almost wholly, without clay, because it is practically impossible under the present circumstances to supply fresh outside water to coastal polders with a sandy bottom during the vegetation period.

To ensure clarity, this research is not being discussed in chronological order. An effort has been made to provide a logical relationship between the various subjects by dividing them up according to the following scheme:

1. The sediment before deposition in the sedimentation fields, including a discussion on such things as the origin of the material, the ways by which it is supplied, and the changes to which it is subject. Considerable attention is also given in this respect to the influence of animal organisms and the lower plant life.
2. The various methods of land reclamation, dealing especially with their mutual connections and the differences there are between the various methods of working.
3. Other information about auxiliary means used, such as groynes, grips, main ditches, etc., as well as the influence of the number of sedimentation fields and the size of the working force.
4. A survey of the function of the vegetation. In this connection a few of the most important plants are given fairly detailed consideration, including such factors as the seed production, seed storages, and seed sowing.

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*) See also page 13.

One final remark may be made in this introduction. When reading the report it may be noticed that no figures are given about the annual heightening of the sedimentation fields. This omission is deliberate, because in recent times considerable changes have taken place in the local circumstances, such as the making of sub-divisions in the fields, the use of machines, etc., resulting in rather drastic changes in the general situation. However, with normal working a heightening of from 2 to 7 cms (¾ to 2¼ inches) a year can be counted on for the Dutch Wadden Shallows.

2. The sediment before deposition in the sedimentation fields

2.1. The most important components of the sediment

The material which is deposited in the sedimentation fields can be divided into *sand*, *clay minerals*, *calcium carbonate*, and *organic matter*. The great mass of sediment along the Groningen coast — as far as the dry matter is concerned — consists of *sand*. Just as the other material, this sand has usually been replaced many times by the water; and during such transport the grains are usually carried as separate units, as can be clearly seen not only during the sedimentation, but also in the sediment itself. It is only the very fine grains that are found regularly attached to other material during transportation.

A very important component of the sediment are the *clay minerals*, even though their quantity is somewhat small in proportion to the sand. If the clay particles would be transported through the water as separate units, then nowhere along the Groningen coast would clay be deposited in such quantities as to justify land reclamation in this area. That it has proved possible to fix successfully considerable quantities of this material along this coast is due to the fact that the clay particles always occur as complexes whose rates of sedimentation are considerably in excess of those of separate particles. These complexes contain, in addition to their clay particles, material of a completely different nature, while their shape and construction often show very great differences. These will be referred to later.

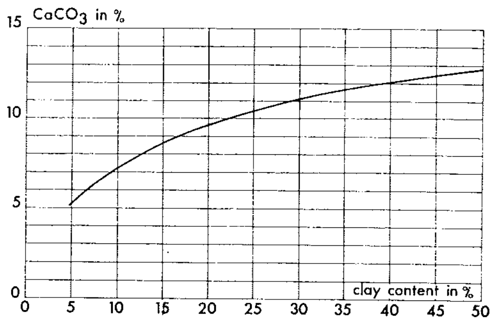


Figure 3. The rate between the clay content of the warp of the grips (free from shells) and its content of calcium carbonate.

When studying the size of the particles, *calcium carbonate* is certainly the most varied component. In addition to shells weighing several grammes, there is also very fine material with particles smaller than 0.5 micron. It has been definitely determined that part of the calcium carbonate is of organic origin, while that of the rest is not known. A few writers think it probable that a certain part has resulted from biochemical processes. However, along the Groningen coast calcium carbonate is never absent from the sediment, the amount usually varying from 5% to 15% of the total dry matter. In general, the clay-rich sediments contain more calcium carbonate than those that are poor in clay (figure 3). As with the sand, the coarser parts are moved separately, while the finer material, as before, is found in combination with other fine components of the sediment.

As far as qualities are concerned, the *organic matter* is perhaps the most varied. In addition to the remains of tissues of salicylic acid, with such difficult solubility, there

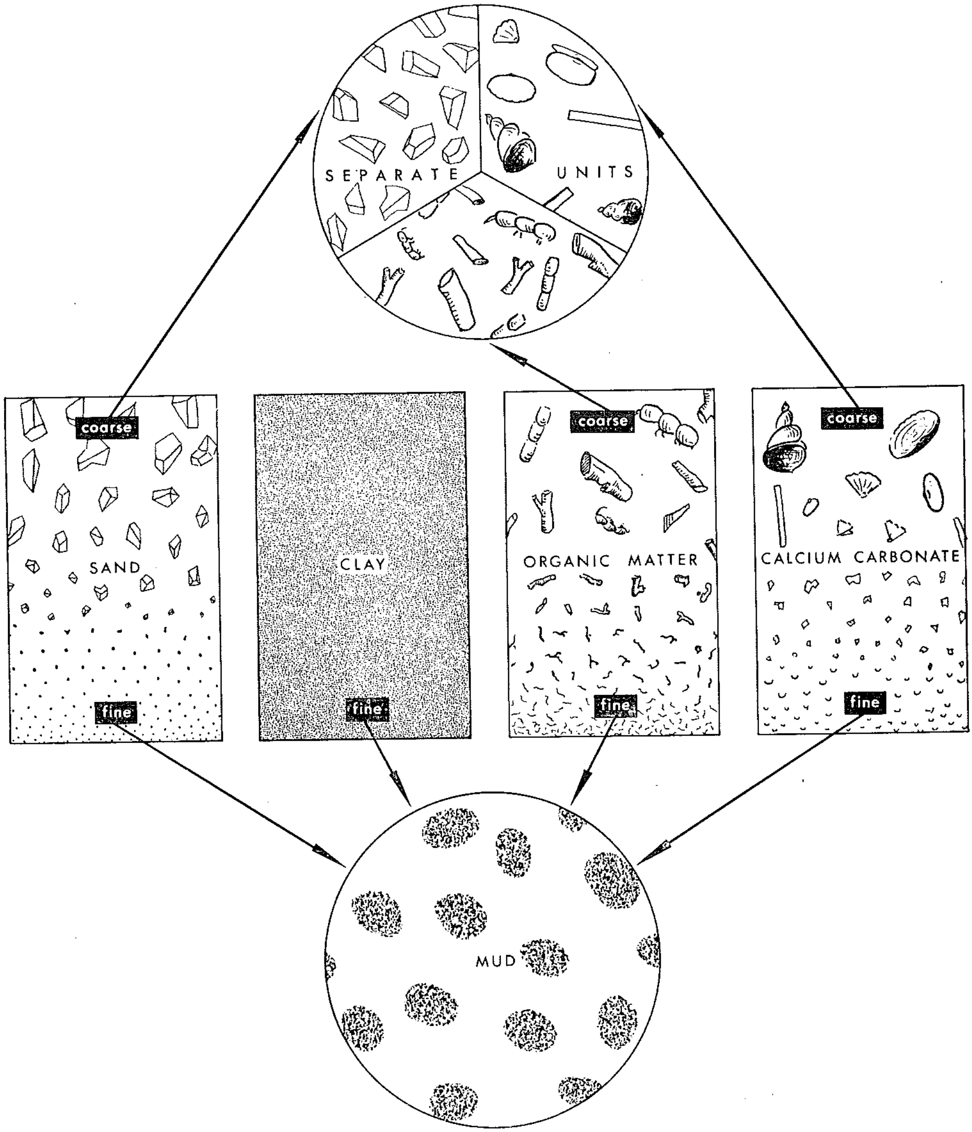


Figure 4. The components of the sediment and the way in which they are transported. The finer particles are transported as complexes (mud), the coarser parts as seperate units.

are easily broken up materials in the form of proteins and carbohydrates. There is also great variety as far as measurements are concerned, for in addition to the remains of micro-organisms there are complete plants of glasswort or marsh samphire or ears and leaves of cordgrass.

Another important organic material is the mucilage or mucus secreted by many and varied organisms, and which fulfils such a significant role as a means of binding in the sedimentation process, that it will be dealt with more fully later in this report. It can also be said that, like the other components, the coarser parts of the organic material are transported as separate units, while the finer ones are joined to other material to form compound units.

The factors mentioned above have been clarified by means of a diagram (figure 4). In general it can be said that the coarser components forming the sediment are moved through the water as separate particles, while the finer ones are joined to each other in groups or complexes. The great difficulty is, however, that no sharp or clearly- defined border can be indicated between the coarse and the fine. Particles of a size of 50 micron are still regularly found in the groups or complexes, while there are often also considerably smaller ones of about 20 micron being regularly transported as separate particles. Under 20 micron, however, there are comparatively few particles being transported separately. How this variation originates is, in the writer's opinion, nevertheless very clear when the origin of the mud-flakes is studied and when it is seen what a large variety of these there is. This point, however, will be dealt with more in detail in Sections 4 and 5.

In the preceding paragraph the term mud-flake has been used. Now in writing about land reclamation the words clay and mud cannot be avoided, but the difficulty is that these words are used in such a greatly varying significance and meaning that misunderstandings can easily occur. For the sake of clarity a brief description may be given here of the meaning of the words clay and mud. In general by the clay content is meant the content of particles smaller than 2 micron. In the Netherlands, however, for a long time it has been usual to call clay content the content of particles smaller than 16 micron. In marine sediments as considered here it is of no importance, but the clayey properties of the soil are characterised by the content of particles smaller than 2 micron or smaller than 16 micron, as there is a close connection between both contents. The content of particles smaller than 2 micron is about $^2/_3$ of the content of particles smaller than 16 micron or, put in another way, the rate between them is 2 : 3. *Where in this report the term clay content is used, it refers to the content of particles smaller than 16 micron.* When figures about the clay content are given the content of particles smaller than 2 micron is obtained by multiplying them by two-thirds.

The word mud also has various meanings. So a description is also given of what is meant by mud in this report. *Mud consists of small particles of the same or varying material joined into groups which behave as separate units when moving through and in the water.* In the diagram marked as figure 4 the material reproduced in the circle on the bottom agrees with this definition of mud.

Attention should be drawn at this stage to two points which are not shown on that diagram: the often very high *water contents* of the mud and the fact that this material under certain circumstances is very rich in living organisms. It is these organisms which appear to be able, when the mud has come to sedimentation, to stick it together to form a cohesive layer.

As for the remaining terms, there do not seem any more that needs explanation, except perhaps the word „*warp*", which can best be described as *young and water-rich sediment*.

2.2. The origin of the sediment

The extremely important question of the origin of the sediment has still even today only been partially answered, and as far as the clay minerals are concerned, even though they are so important for the land reclamation works in the north, surmises are all that can be expressed. This does not mean, of course, that no efforts have been made to find a solution, or to bring it nearer. In fact, in the early part of the investigation period research work was carried out by *Dr. R. D. Crommelin* and *Dr. J. Ch. L. Favejee* in behalf of the Land Reclamation Service with the object of determining the origin of the material deposited along the Groningen coast as sediment.

Apart from the fact that is was necessary to know the sources of the material for the land reclamation works as well as the quantities which could be expected per time-unit, there was also the conflict of ideas about the way the works should be executed. These things obviously demanded an investigation. The difference of views between the then Chief Engineer-Director of the Technical Office for the Crown Lands, *Ir. A. G. Verhoeven*, and the Chief Engineer-Director of the Provincial Waterways of Groningen, *Ir. J. Kooper,* was mainly on whether the sedimentation fields to be constructed should be allowed only to run along the coast and whether no dams were to be built across the watersheds to the islands off the coast. If the second system were used, the possibility of a mud-stream coming from the Rivers Ems, Weser and Elbe could, it was held by Ir. Verhoeven, have been prevented. Ir. Kooper, however, thought this would not be the case and so in his plan he proposed the construction of such dams.

To explain this difference of views in a little more detail, here are the main conclusions which have been published elsewhere of the investigations carried out by Dr. Crommelin and Dr. Favejee:

Dr. Crommelin's conclusion

> „Concerning the question of the origin of the shoal mud of a larger grain size than 10 micron, it must be concluded that it consists mainly of marine material. The possibility of a direct supply of mud from the Rivers Ems, Weser and Elbe on the shallows must be denied, although perhaps a part of the mud which is discharged into the North Sea is mixed with purely marine material and then brought into the shoals through the sea-gaps. But then they are thinned out so intensively that this is not shown mineralogically."

Dr. Favejee's conclusion

> „From textural and mineralogical research (photographic X-rays) of a number of samples of mud and water from the shoals and from the Ems, Weser and Elbe, it has appeared that there are differences between the samples from the shoals and those from the rivers on the basis of which the sedimentation of recent Ems, Weser and Elbe mud on the Groningen shoals must be considered unlikely."

From these conclusions it certainly appears that there is no direct transport of mud from the above-mentioned German rivers to the Groningen shallows. The sand is probably supplied by the North Sea.

As for the origin of the mud, much can be imagined about it, although nothing positive can be said. It may be accepted that the mud was originally transported to the sea by the rivers and that such transport is still going on every day. But whether the mud particles which have now been sedimented along the Groningen coast reached the sea recently or whether they are materials that have been freshly stirred up, remains an open question. It is probably the case that both old and recent material has been supplied.

There is one point, however, which should be dealt with a little more in detail, namely, the part the easterly shallows can supply themselves. In actuality this part may be regarded as very small, a conclusion based on the following facts:

1. The bottom of the shallows in the area of the large channels consists down to a considerable depth of sand with a very small clay content. By channel replacement material is stirred up, but when the clay content of the affected banks is compared with that of the newly-constructed banks, it appears that what comes into circulation on the one side is sedimented on the other side.
2. In the smaller channels the following symptoms are to be seen. When such a channel receives its water from an area where the faeces lumps (to be discussed later) are produced, then it is found that a clay-rich material is sedimented along the banks and that more clay is deposited than disappears by the crumbling of the banks. When in the current area of such a gully large quantities of mud-catching organisms do not appear and mud-rich banks are attacked, then the opposite symptoms are to be seen.
3. The various channels discharging the polder areas do not discharge significant quantities of mud into the shallows area, which means that these, too, are not important sources of the sedimented quantities of mud.
4. The recession of the saltings has been reduced considerably during the past few years and therefore supplies little mud for the construction of the young layers of sediment.

Based on these facts, it can be concluded that the clay along the Groningen coast is supplied from another source.

It is known that mud regularly comes through the sea-gaps, so that, as will appear from Section 3, this is one of the ways the mud is supplied to the eastern shallows, as much of this mud remains. Another source of supply is discussed in more detail in Section 8, namely, the supply across the watersheds in periods of rough weather. That is to say, even if these are not the actual sources of supply, they are two ways along which the mud is brought to the shallows.

2.3. The nature of the sediment entering through the sea-gaps

A number of attempts have been made at different times to obtain a picture of the nature of the mud which enters through the sea-gaps. The observations have shown that about 90% of the mud entering at flood-tide consists of small flakes which settle down extremely slowly. As a rule, they have a very irregular shape and actually give the impression of each being a separate flake. This smallness combined with their irregularity gives rise to the impression that the conditions for the formation of larger flakes in the sea are not favourable. In the water pumped up from the bottom of the sea-gaps there is only a little coarse matter.

Yet it cannot possibly be concluded from the information so far gathered that supply and discharge of coarse matter does not occur, for it was not possible to make observations in the sea-gaps during a storm. In the first place, there is no captain who dares to choose a mooringplace here in rough weather; while, secondly, it is not possible to make direct observations with a microscope during such bad weather conditions, which must be done immediately after taking the water sample when investigating the nature of the mud in their actual environment. Once the material to be studied has settled down, it can never be returned to its original state by stirring it up again. But as it has appeared from the measurements made on the platforms (see also Section 8) that the tides during hard winds or gales greatly influence the behaviour of the mud, and as there is no information available about the sea-gaps collected during similar tides, it cannot be said that the mud coming through the sea-gaps always consists of fine material.

However, during 80% of the tides the incoming material which joins the water is in a finely-distributed state. As already pointed out, the flakes are very irregular in shape, and organic matter is regularly found among them, coming from bottom organisms. A part of this mud, in fact, has very probably already been in contact with the bottom, as shown by the often present carcasses in it of diatoms living on the sea-bottom. Because of the low rate of sedimentation of the material that is entering the chance is small that it will be deposited somewhere on the shallows, especially as the water there is almost always moving. That, in spite of this, considerable quantities of mud are deposited along the Groningen and Frisian coasts must for the greater part be attributed, firstly, to animal organisms which link the fine flakes together into larger and denser units, thus enabling a more rapid sedimentation of these units, and, secondly, to the plant organisms which help keep the material in a state in which it can easily settle down. That such small organisms living in the shallows are able to wield such a great influence on the nature of the mud is due to the fact that they occur in such very large quantities.

2.4. The changes in the nature of the sediment under the influence of molluscs

Of the animal organisms those which have the greatest influence on the nature of the mud are a few Lamellibranchiae. The gills these creatures have for breathing also serve for the collection of food which they sieve out of the water. In this process, however, sand and mud components, which are of no value to the creature, also remain on the gills. By means of the vibration of small hairs the collected material is first transported to the mouth flaps from the edges of the gills where they are already covered with mucous or slime, then sorted out into fine and coarse material, and the coarser parts finally worked to the outside and ejected in the incoming water stream (pseudo faeces) (figure 5).

The fine material, including the mud, however, does not join the ejected pseudo faeces but disappears by means of the mouth opening into the intestinal tube. As the mud particles cannot be digested, after some time they are discharged with the other remnants of the digestion in the form of a tightly-glued mass (real faeces). The shape

Figure 5.
Mussel shells lying in a small pit. The faeces material in the form of small clods is clearly visible around the shells.

of the faeces lumps is often very characteristic, and in many cases it is possible to trace from the shape what type of creature used the material.

The most important characteristics of the faeces lumps are that:

1. the rate of sedimentation has greatly increased, and
2. the fine particles are mutually strongly joined together and remain so for a longer period.

Because of these factors the material can be transported over longer distances until it is deposited in a quiet place, either preliminarily or permanently. It also appeared from the analysis of various samples of faeces material, from both cockles and mussels, that in the ratio between the groups 0-2 micron, 0-8 micron and 0-16 micron no difference could be observed between material coming from the faeces lumps and material from the sedimentation fields.

Dr. Favejee, in his investigation already referred to, came to the same result. In addition to the texture, however, he also studied the mineralogical composition of a few samples of pure faeces material from mussels, coming to this conclusion:

> „Concerning the texture, these samples contain little material $>$ 20 micron, in comparison with the mud from the shallows, and even still less than the sea-water mud. The rates between the fractions $<$ 20 micron are similar to those found in mud from seawater and the shallows. Thus the proportionate differences in the quantities of the groups $<$ 20 micron are not caused because the coarser material is made finer by digestion but because this is taken up less by the mussels. The mineralogical composition of the fine group is absolutely in agreement with the texture (as already explained, there is a relationship between the texture and the mineralogical composition of sea-water mud and shallows mud), and is in no way different from the sea-water mud and the shallows mud. From this it can be concluded that there is absolutely no important change in the texture or the mineralogical composition of the mud during the digestion by the mussels".

The mollusc species which play a role of any importance in the binding of the mud on the Groningen and Frisian shallows are the mussel (Mytilus edulis L.), the cockle (Cardium edule L.), and the gaper-shell (Mya arenaria L.). With the two last-mentioned species the faeces material which is produced immediately enters the circulation again, while as to the mussel a portion of it remains. This type of creature, in contrast to the other two, lives on the bottom of the sea and not in it (figure 6).

Figure 6.
Detail of a mussel-bed.

As a result of this, some of the mud immediately settles down among these creatures. This compels them to work their way to the top of it, thus forming holes which are filled either with faeces material or, during gales, with sand. This, therefore, produces a very strange sediment which on being eroded is easily recognized as coming from mussels. The sandy parts are washed out and the portions containing clay form ribs, resulting in a typical picture which is clearly shown in figure 6. This way of life leads to the origin of clayey deposits in the middle of the shoals, a factor which is dealt with in more detail in Section 5 of this Chapter, while the transport of the joined mud is discussed in Section 7.

To give an idea of the quantities of material and the number of creatures involved, a few details will now be given gleaned partly from available literature and partly from the writer's own research.

The Belgian author *Damas* says that each adult cockle produces 420 clods of faeces, each of 0.3 mm^3 volume, an hour. With a population density of 400 cockles per square metre, this would mean the production of 0.18 m^3 of mud a year.

The English writer *White* says that mussels on a gravel bank off the English coast formed a mud layer about three feet thick during a period of three years, after which the bank was destroyed by gales and the process started again.

Tests have also been made with mussels in boxes in the Groningen shallows behind the Westpolder. These boxes (figures 7 and 8) were provided with holes so that the water could enter easily. They were used in rows of three: one box empty, one with mussel shells filled with concrete, and one with live mussels. This third box contained 80 mussels, and they sieved enormous quantities of material out of the water, as is clearly seen from the diagram (figure 9). The fact that 80 mussels were able to collect 4.2 kilogrammes (about 10 lbs) of dry matter in 14 days gives a striking idea of what can be achieved by these creatures. It should be noted here, however, that this quantity was obtained in surroundings which contained a great deal of floating material, so that it was really a peak achievement. But on an average more than 3 kilogrammes (over 6 lbs) was produced. Bearing in mind the huge quantities in which these creatures occur on the shoal, it can be readily understood how they can be an important factor in the land reclamation process. On the older mussel-banks, which are often many acres in size, the number of mussels can vary from 2,000 to 3,200 per

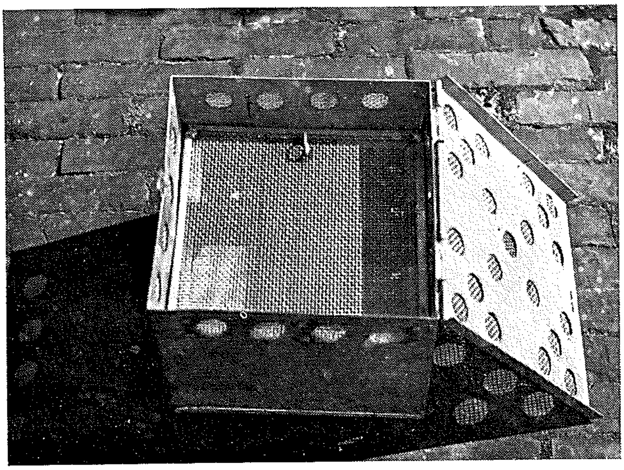


Figure 7. Mussel testing-box, with the mussels lying on the gauze. The openings in the sides and the cover are clearly seen.

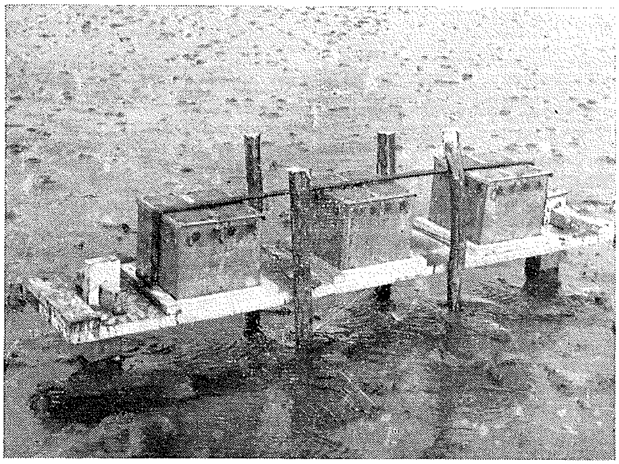


Figure 8. Row of mussel testing-boxes erected on the shoals.

square metre (10 square feet), while on the younger ones the number even goes as high as 7,500 per square metre.

As far as cockles are concerned, the greatest number of living creatures found amounted to 967 per square metre, although the normal number for cockle-banks in the northern part of the Dutch Wadden Shallows is about 400 per square metre, while in the southern part which is often much richer in clay the cockles are much fewer in number and considerably smaller at the same age. In the Groningen Wadden Shallows, indeed, the creatures remain far below the size of those living in the western shallows. Specimens larger than 2 cms, in fact, are fairly rare.

The most difficult information to obtain in this connection is an accurate picture of the number of gaper-shells. These creatures live together in large groups, although the real extent of the total size of the fields they populate cannot be stated, as they live

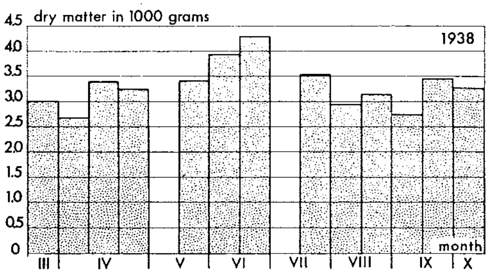


Figure 9. Quantities of mud (expressed as dry matter) in the form of faeces lumps by 80 mussels in periods of fourteen days collected in testing-boxes. The quantity of mud collected in the testing-boxes with shells filled with concrete, is deducted of the total quantity measured in the testing-boxes with living mussels. On 14 V a damage of the testing-boxes prevents observation, while on 9 VII the holes of the boxes were stopped by sea weed, so that the observation was unreliable.

at too great a depth to determine the number accurately. However, groups of from 100 to 250 per square metre are very normal.

In trying to estimate the quantity of mud which is transmuted into complexes by the mussels on the Groningen Wadden Shallows, a cautious calculation gives a total of about 1,312,500 tons of pure clay a year. The figures on which this calculation is based are:

area of mussel-banks	300 hectares (750 acres)
number of mussels per hectare	10,000 × 2,500
number of tides a year	500
number of hours per tide in which the creatures sieve	7
number of litres per hour per individual creature	2
average clay content per litre seawater	25 milligrammes.

If this material were deposited at the rate of 20 kgs per square metre in the sedimentation fields, then 65,625,000 square metres, or 6,562½ hectares, could be supplied.

An amount of 20 kgs per square metre with a clay content of about 20% means a heightening of about 10 cms (4 inches) a year, which is, however, more than actually takes place. Altogether in operation there is an area of about 4,000 hectares, so that on a very cautious calculation the mussels alone make more mud available for sedimentation than is really deposited in the sedimentation fields every year.

During the last survey of the mussel-banks, however, it was seen that the estimated area of 300 hectares was far too low. It now seems that the total mussel area is about 1,200 hectares, which means that more than four times as much mud should have been transmuted by the mussels than is actually being deposited on the sedimentation fields.

In this calculation, of course, the production of the cockles and the gaper-shells is not included, because it has not been found possible to obtain or estimate reliable figures about the quantities of material transmuted by these creatures. However, it is certain that the total production of the mussels, cockles and the gaper-shells must be considerably higher than the quantity which is actually and definitely deposited, especially as that material has to be transported over long distances and is on the way for a long time. It is during this transport that the faeces lumps partly break up again, with some of them presumably disappearing into the North Sea, a feature that will be referred to again later.

2.5. The function of the lower plants in the sedimentation process

In addition to the animal organisms just described which withdraw the mud from the water in fine flakes and then return it to circulation again as material settling down more rapidly, there is a second group of living things which, although not turning fine floating material into faeces lumps nevertheless cooperate in a great measure in keeping transmuted mud in a condition ready for sedimentation.

The most important of these are the diatoms occurring in such enormous quantities that they sometimes colour the shoals brown over vast areas. These plants need light for their food supply, and in the shallows they would be doomed to die off very quickly

Figure 10. Diatomiaceous mud layer. The layer has been damaged by a caterpillar trail and the whole membrane has been rolled up and contracted. This picture was taken at a place where there were also many gaper-shells, and the openings through which they suck the water are clearly visible.

by the regular mud deposit were it not that they are able to escape from it by rising to the surface when covered by another body. The diatoms live in a kind of mantle of slime, which, incidentally, causes the slipperiness which is so characteristic of layers covered with this unicellular plants. They are able to go up, or to remain up, by the secretion of new quantities of slime. Perhaps another contributory factor is that the deposited mud gradually sinks through it. This, however, results in the settled-down particles being incorporated in their „companions in distress", thus originating mud deposits which are not touched by water in calm weather, although these layers cannot stand up to strongly-moving water. When this occurs, the membranes are completely or partially destroyed (figure 10). This means that the development of the diatomiaceous layers is to a very great extent dependent on peaceful waters.

The quietest parts of the shallows are usually found along the edges, particularly those where there is an offshore wind. The centre part of the shoal is the most restless, and so the diatoms are less developed in that region. The most favourable places of the Groningen Wadden Shallows lie along the north coast of this province. The coastal parts along the islands, on the contrary, show only a slight development of diatoms. When it is further seen that the sedimentation conditions for the mud along the north coast of Groningen, as a result of the greater calmness of the water, are more favourable than in the centre of the shallows or along the southern coast of the islands, then it is obvious that the strongest development of these diatomiaceous mud layers is found in the first-mentioned places.

To obtain an impression of the behaviour of these mud layers, a check was made in 1941 at 15 different places behind the Westpolder on how the mud deposits occur in the top half centimetre of the bottom of the shallows. It then appeared that not all places behaved in the same way, but that at the same time a loss occurred at one point while a gain was made at another, as can be seen from figure 11. These fluctuations

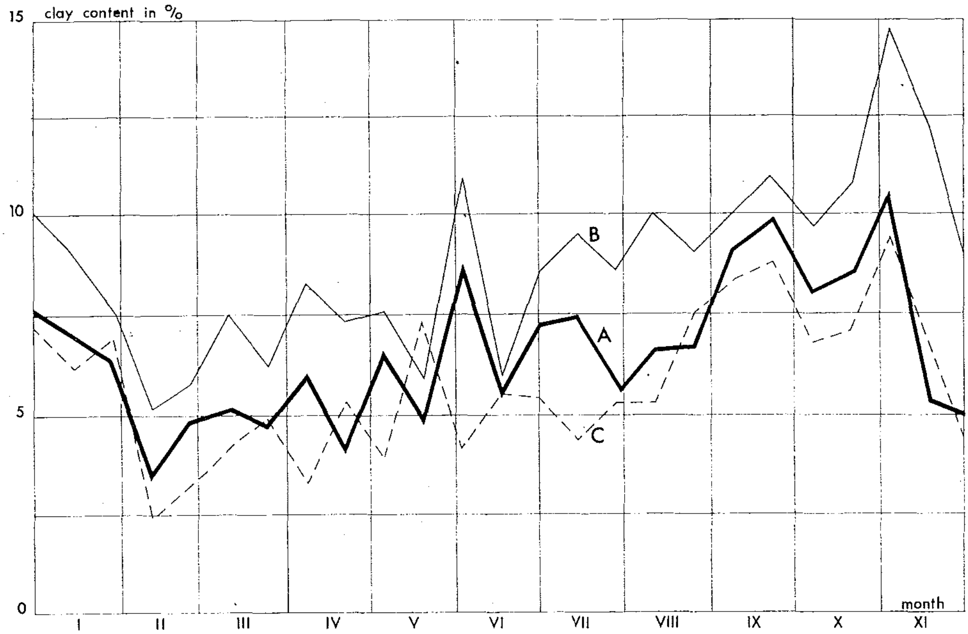


Figure 11. The variations in the clay content of the upperlayer (0.5 cm) of the shallow in the course of a year.
A = average of 15 measuring points; B = measuring point 7; C = measuring point 3.

were observed by determining the clay content. Taking the whole sampling period into consideration, it appeared that there was an increase in the clay content from the spring to the autumn. In the autumn and winter months it seemed that the amount of mud rapidly decreases, which means that during the spring and summer months large quantities of mud are deposited along the coast which disappear again during the autumn and winter months. In this connection it is interesting to recall that the former owners of the banks called the autumn months the warp-months.

In studying this autumn mud it appears that it is different in appearance from the faeces lumps. Its shape is much more irregular; in addition to a great deal of fine material it also contains much material which settles down rapidly, as shown by a number of measurements. As seen in the study of the mussels, little material larger than 20 micron is found in the faeces, although in the mud stirred up from the above-mentioned diatomiaceous layers sand grains upto 50 micron are found, which shows incidentally the way in which this sand really became part of the mud. The diatoms cover this material as well as the faeces with their slime. It is not possible to explain why the sand grains larger than 50 micron are also included but are seldom found in combination with mud-flakes, although this has been repeatedly proved by microscopic observations. Perhaps, however, the link up between the grains and the mud is inadequate, or it may be that they sink down through the slime layer.

Having discussed the most important plant and animal organisms which have a significant influence on the nature of mud in the shallows, there remains for examination a small and rather unimportant group of organisms which again use the material already settled down. These will be discussed in the following Section.

2.6. Organisms which make use of the deposited material a second time

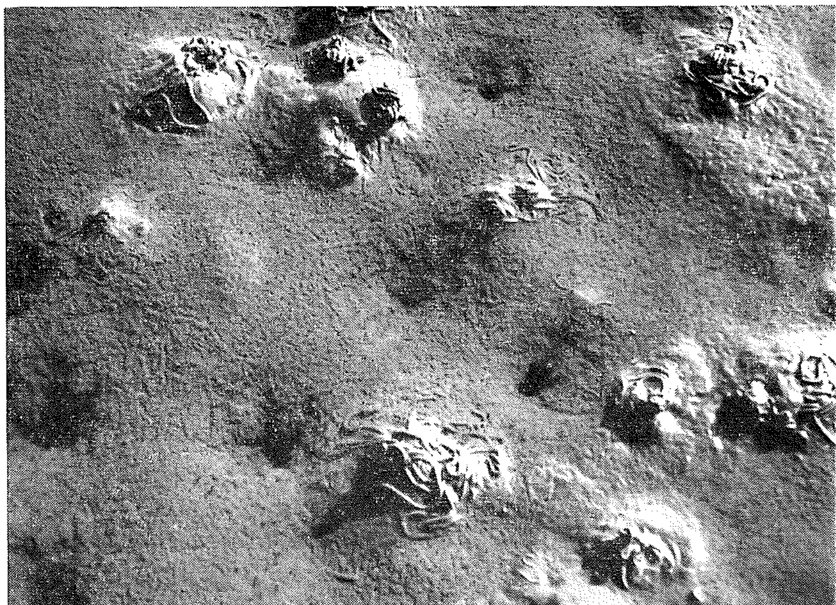
It occurs many times that certain organisms again use the material that has been deposited as sediment. These include some snails which feed on diatoms and seaweed fields, although their activity is not important for the sedimentation. Moreover, the faeces material of these creatures usually shows the same qualities as that of the mussels and cockles already mentioned. Important quantities, however, can only be used by animal species which operate in large numbers and which use a lot of such material.

In this connection a little attention must be given to the lug-worm (Arenicola marina L.) which we know can, under certain circumstances, influence the nature of the bottom. The most striking instance of repeated use of the sediment that has become known to the present writer is that of a mixed company of lug-worms and gaper-shells in the zone located behind the sedimentation fields west of the discharge channel of the Noordpolder. The lug-worm collects its food in funnels in which it settles down from the flowing water, and every tide this creature uses several cubic centimetres of it. In this case, where many gaper-shells were present along with the lug-worms, the mud was first collected from the water by the gaper-shells and then a considerable part of the sieved and transmuted material was again deposited in the funnels of the lug-worms (figure 12) which then used it again.

In this way the mud sieved and transmuted by the gaper-shells was at least partly deposited in the immediate surroundings of the organisms, whereas in other cases it was mainly discharged elsewhere.

Generally, however, it does not seem that the lug-worm has any significant influence on the clay content of the areas in which it lives. In contrast to much other faeces material, that of the lug-worm breaks up quickly, and the clay particles occurring in it are seen in a finely-divided and easily washed-out form.

Figure 12. Funnels of lug-worms and the heaps of faeces at the ends of the U-shaped corridors in which these creatures live.



2.7. Transport, uprooting and deposition of the transmuted mud

After the mud has been transmuted by the Lamellibranchiae, part of it comes into circulation with the mussels and almost all of it with the cockles and gaper-shells. Generally the material will first settle down in the neighbourhood of the organisms, at least when the wave movement is not very strong. In calm weather it is then to be seen heaped in the rills between the sand ridges. At about the time when the shallows become dry and the waves begin to affect the shoal surface, the faeces material that has been formed starts to move again. Indeed, it can be seen springing up again and again, meanwhile replacing itself in the direction of the current. This means that it is discharged from the banks where it originated into the gullies. When the bank becomes dry, the mud discharge can often be seen very clearly on the boundary between the land and the water (figure 13).

This discharge of mud can be seen from all banks which lie at a considerable distance from the coast and where there are regular water movements such as waves. In the gullies a quantity of mud is gathered in this way during low tide.

As already pointed out, it has not been possible to prove whether this material is discharged into the North Sea in significant quantities during calm weather through the sea-gaps. It is unfortunately impossible to obtain a correct idea of how it exactly behaves in the channels and whether it is drawn along easily by the current or stream. Nor is it known whether in these channels periods of transport alternate with periods of rest. But from the previous observations it seems most likely that the latter is usually the case, as otherwise much more faeces material would have been found in the water leaving the shoals.

When high tide finally comes through well, it is seen that considerable quantities of faeces material are transported back and spread again across the shallows. It is clear, too, that this process can be repeated many times before the transmuted mud can finally come to rest. As this concerns a rather soft substance, a decrease in the faeces lumps will most certainly occur, and a part of the particles linked together will return to their original finely-divided state. The fact that more mud is consolidated than finally comes to sedimentation is in complete harmony with this conclusion.

As already pointed out, the mud finds such a situation at certain places in the shoals so that it is at once deposited as sediment and remains there at least temporarily. The zones where this occurs easily, are characterised by low current velocities and little wave movement. In the Eastern Wadden Shallows it are the zones lying along the north coast of Groningen that are most favourably situated in this respect, while the situation in the environment of the watersheds, where the currents coming from the east and the west meet each other, are also more favourable than the areas lying in between. Along the coasts of the islands the circumstances are generally unfavourable, mainly because of their location relative to the dominating winds. It has also been shown that the mud layers originating in this way are often of a temporary character. During rough weather they are particularly strongly affected in the autumn, thus starting what might be called the second stage of the ramble of the mud. This question, however, must be considered a little more closely, because it also gives information about the removal from one shoal basin to another.

During rough weather, when the wind blows from between south-west and north, there is an increased water level in the shallows area with strong wave development. When, on the contrary, the wind comes from an easterly direction there are decreased water levels and the shoals often remain dry. It should also be mentioned that during the wind coming from the first-mentioned directions it was noticed that large quan-

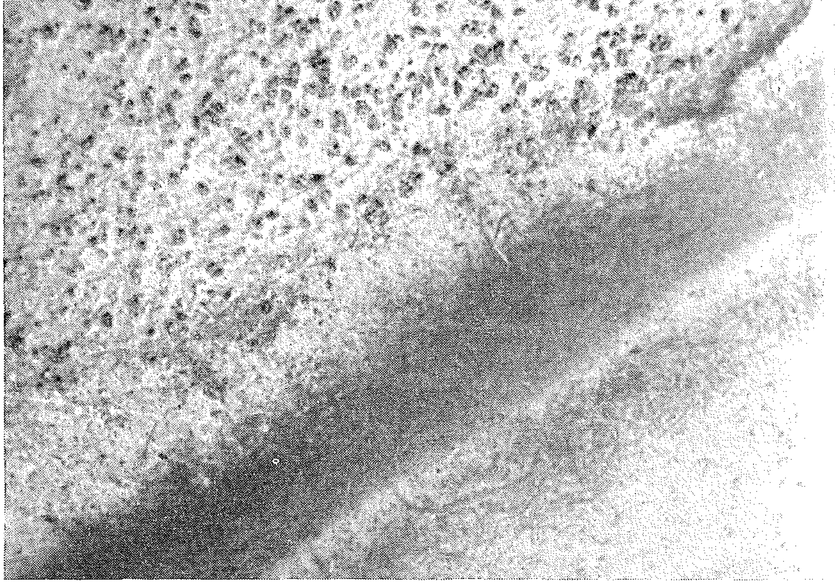


Figure 13. Mud discharge from a bank during falling water. The separation line between land and water runs about diagonally. The dark mass of the transported mud is in great contrast to its surroundings. On the top left the dry bottom part can be seen, while at the bottom right the area is still covered by water.

tities of water were moved across the watersheds. Thus a high water level is found with forceful winds from the west and with strong wave operation, causing much stirring up the mud and a removal of mud across the watersheds. This means therefore, a removal of mud from west to east during rough weather with winds from a westerly direction. The same might also be expected with easterly winds, but then the quantities of water are small and the water movement will also be small. Observations have shown that the transport from west to east is the dominating factor.

Another important point, but about which there is no definite information, is that during rough weather with westerly and north-westerly winds larger quantities of water are supplied to and discharged from the shallows, accompanied by very strong currents in the sea-gaps. It seems probable that under those circumstances a good deal of mud can be discharged into the North Sea. This supposition is supported by the fact that the production of consolidated material greatly exceeds the quantity deposited along the coast, and although it is clear that during transport a part of the faeces material disintegrates again, it is not likely that this is the case to a proportion of 80% or 90%. When measurements are made of the quantity of mud with a high rate of sedimentation during rough weather, the figure seems to be not more than 65% from the total mud present (it settles down within five minutes to a height of 30 cms). As the water is in violent movement and the currents are strong, it cannot be excluded that under those circumstances during ebbing tide considerable quantities of this type of mud are carried out to the North Sea. According to knowledgeable fishermen, there is a vast warp shoal at a depth of about 20 metres north of the Frisian Islands, and, as the warp is weak, it indicates recent deposition. The colour of the warp is black and the smell unpleasant. The fishes caught there look good but are bad to the taste. This shows, however, that there is sufficient food for the fish, probably because such sediments are generally rich in food shortly after their origin as a result of the numerous organisms that stay and live there.

Now this does not necessarily mean that the above-mentioned warp actually comes from the shallows, but its presence is certainly an indication of the direction to turn in the search for the disappearance of the consolidated mud from the shallows. Before 1935 there was a period when only very small quantities of mud were deposited along the coast and there is not one reason to suggest that in those years a piling up of mud originated in the shallows. Before 1935 this mud should practically have been disposed of each autumn and disappeared from the shallows. The place to which it could have gone was the North Sea, where it could perhaps have partly come to rest in areas where there was little water movement, such as places with sufficient depth and slight currents along the bottom. It is not to be excluded that the relatively quiet shallows area is the place where the material of the warp shoals outside the islands is prefabricated and transmuted into a state in which it could be deposited.

Summarising all that has been said on these points, the following picture can be delineated of the changes in the nature and the transport of the mud of the Dutch Wadden Shallows:

1. Small mud-flakes, settling down only very slowly, enter through the sea-gaps.
2. These flakes are partly transmuted by Lamellibranchiae into faeces lumps which settle down easily.
3. During periods of calm weather this material remains behind in the shallows and is there piled up along the edges in the form of small warp layers.
4. During rough weather these layers are affected by strongly moving water and the material starts to move again.
5. It then again settles down afterwards, and to a considerable degree rather rapidly.
6. The material which not settles down rapidly again next undergoes this movement:
   a. part of it goes to the sedimentation fields;
   b. part goes across the watersheds to an adjoining shallow basin (usually in an easterly direction);
   c. part of it is perhaps discharged into the North Sea;
   d. part remains behind in the shallows and again is deposited as sediment, and
   e. part is reduced to a finely-divided state.

2.8. The quantity of mud in the water

Little has been said so far about the quantity of mud in the water, although it must have appeared from the foregoing that this can vary greatly. The most important information on this point has been obtained from the measuring platforms erected at various points in the shallows. These are small sheds on a framework of piles from

Figure 14.
Measuring platform behind the Julianapolder.

which it was possible to make observations, even during gales, concerning the mud contents of the water. Figure 14 is a picture of such a platform.

As it is practically impossible to determine the amount of natural mud present in any water sample, another method was chosen, namely, the determination of the clay content in the same way as it is carried out in soil research work. This is the most important part of natural mud for land reclamation work, and moreover such a study gives an idea of the content of the mud in the water which generally lies on an average about 20% higher than the clay content. As all these measurements were made under many different conditions and circumstances, they have given an adequate insight into the factors which influence the mud contents of the water.

Before dealing with this in more detail, however, a short survey will be given of the places at which the measuring platforms were erected and the reason behind their selection. The various locations are shown in figure 2.

The first of these platforms to be put into operation were those behind the Westpolder and the Julianapolder (M.S. IV), and they were put there because of the great difference in silting up between the sedimentation fields located behind these polders. By erecting the platforms at those sites, and then taking samples from the points at which the water was supplied to and carried off from the fields, it was hoped to determine the causes of those differences. When those measurements were finished, platforms were built on the watersheds of Rottumeroog and Schiermonnikoog, aimed at observing a possible current passing across the watersheds and obtaining an idea of the mud contents of the water in the vicinity of the islands.

Attention will first be paid to the two first-mentioned platforms and to the results obtained there. On looking at the mud contents of the water during one tide in which the weather conditions do not change, it appears that the quantities of mud present per litre show considerable differences. When the tide is rising the first water is generally the most rich in mud, after which the contents decrease rather rapidly in the beginning and then more slowly upto the moment of high water (figure 15.A). Later the mud contents again increase, although the last low tide stream is usually less rich in mud than the first water of the incoming tide.

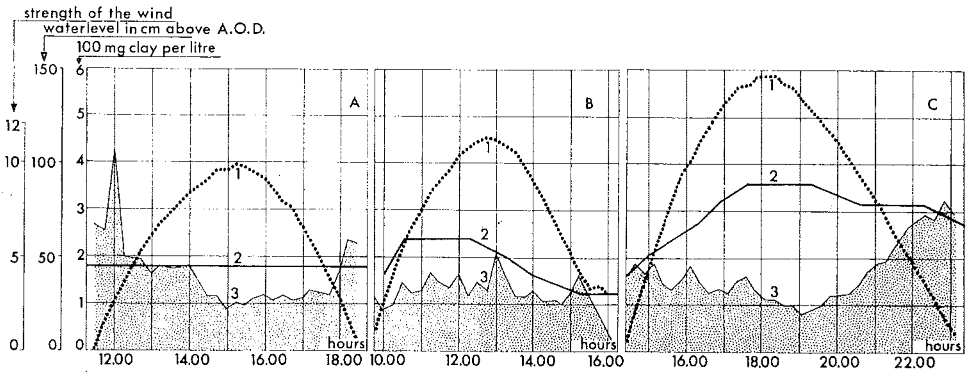


Figure 15. The course of the clay content of the seawater with the tide.
A. At normal weather conditions; B. When tide is making there is a strong wind, so the maximum of the clay content appears at high water; C. When tide is making there is a storm decreasing to strong wind during ebbing tide. The clay content increases considerably at ebbing tide. 1 = waterlevel in respect of A.O.D.; 2 = strength of the wind according to the scale of Beaufort; 3 = clay content of the seawater.

Then, too, the investigation made it absolutely clear that the wind is the most important factor influencing the mud contents. It can happen, indeed, that as a result of the wind the outgoing water is richer in mud than the incoming water (figure 15.C). Another symptom of importance is the sudden increase of the mud contents during

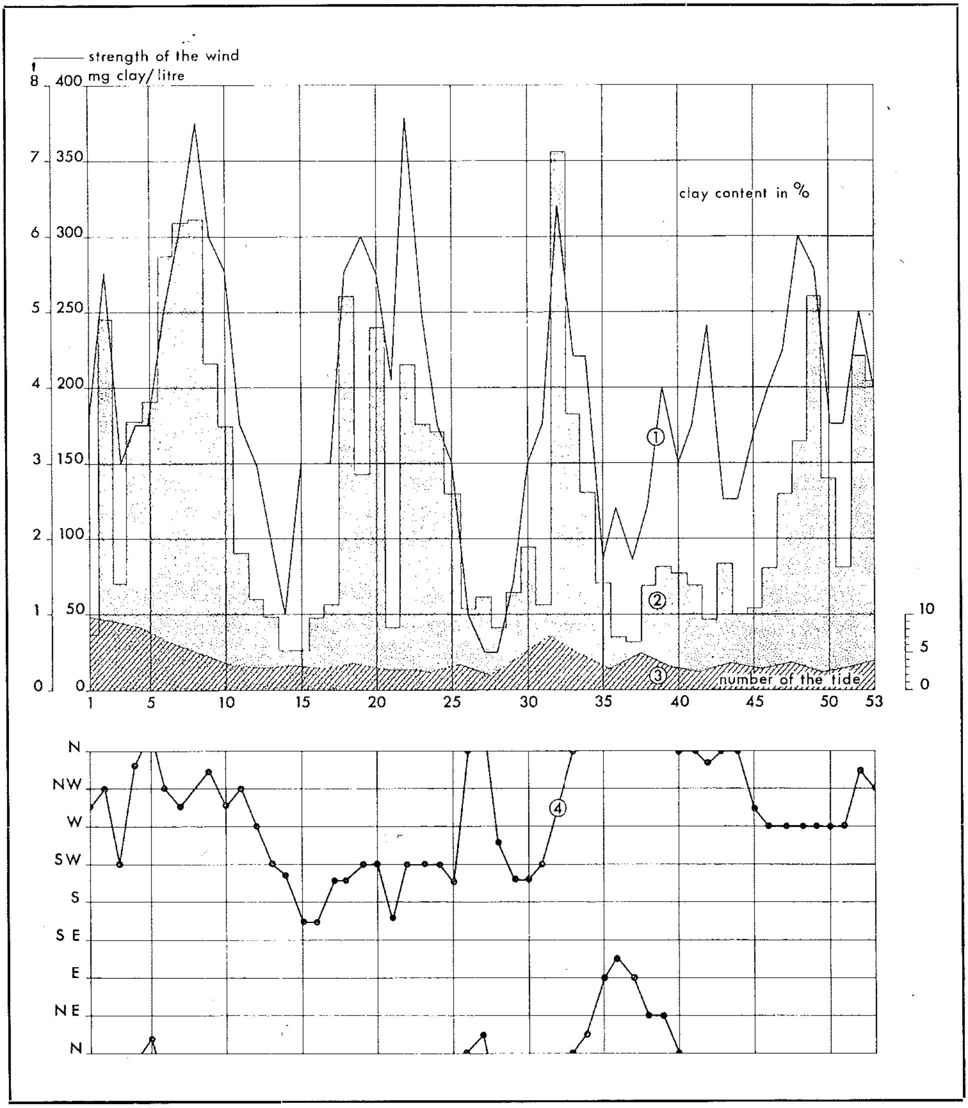


Figure 16. The relation between the strength of the wind, the clay content of the seawater, the clay content of the upper layer (0.5 cm) of the shallow and the direction of the wind during 53 tides.
1 = strength of the wind according to the scale of Beaufort; 2 = mg clay per litre seawater; 3 = clay content of the upper layer of the shallow; 4 = direction of the wind.

showers accompanied by a good deal of wind. This mud cannot possibly be supplied in such a short time from the sea, so it must therefore have been stirred up in the immediate vicinity of the measuring platforms, and resulting from the effects of the diatomiaceous layers already discussed. Hail showers falling during a period of incoming water also always supply a high mud content at the beginning of the tide, as the descending hailstones strongly affect the mud layer thickly covered with diatoms and thus start the material moving again.

The wind influence is emphasised in the diagrams on figure 16. This covers measurements over 53 successive tides determining:

a. the speed of the wind;
b. the direction of the wind;
c. the clay content of the surface layer of the shoal over a thickness of ½ cm, and
d. the clay content of the water.

The dominating influence of the speed of the wind is emphasised here very clearly.

Finally figure 17 gives a survey of the clay content during certain wind directions observed on the platforms behind the Westpolder and the Julianapolder. From this it can once again be seen how strong is the influence of the winds from a westerly direction and how rather small it is when coming from the east. It is further seen how large quantities of material have been supplied during a somewhat small number of tides and how these exert such a dominating influence. All the tides carrying a large supply are always accompanied by strong winds from a westerly direction.

It also appears from the diagrams that the clay content varies very considerably, ranging between 25 mg and 800 to 900 mg per litre. These figures are calculated as averages over the whole of the tide, although at the beginning of a tide and towards the end quantities are found which can be four or five times greater. On these measuring points more will be said later.

Then finally there is another fact which must not remain unmentioned here, namely, that sometimes there is little or no difference in the mud content of the water around the measuring platforms and that in the sea-gaps. This is only the case when weather is very calm. From this fact it can be concluded that the current is, therefore, of little importance as far as it concerns the mud contents of the water but is important only for the transport of the material. Here, however, an exception must be made for the larger and smaller channels, for in them material is always being stirred up and then transported by the strong currents running through them. But apparently this material comes to sedimentation very rapidly outside the channels, so that it is noticed only a very little on the measuring platforms located a good distance from the channels.

As far as the platforms on the watersheds are concerned, little can be said here, as not all the data have been worked out, so that the results so far as obtained are still liable to change. But it has appeared that on the watershed of Rottumeroog the mud content is lowest at the platform nearest to the island (figure 2, M.S. III) and that there is about one-quarter (clay content 36 mg per litre) of the average at the platform on the coast (figure 2, M.S. I). The quantities found there are generally somewhat higher than in the Julianapolder (M.S. IV), the average contents of all measurements worked out being 135 mg clay per litre compared with 128 mg in the Julianapolder. The platform lying in between (figure 2, M.S. II) has an even lower average of 101 mg.

From the platforms situated on the watershed of Schiermonnikoog, very little material has yet been studied, but here too a somewhat similar impression has so far been obtained.

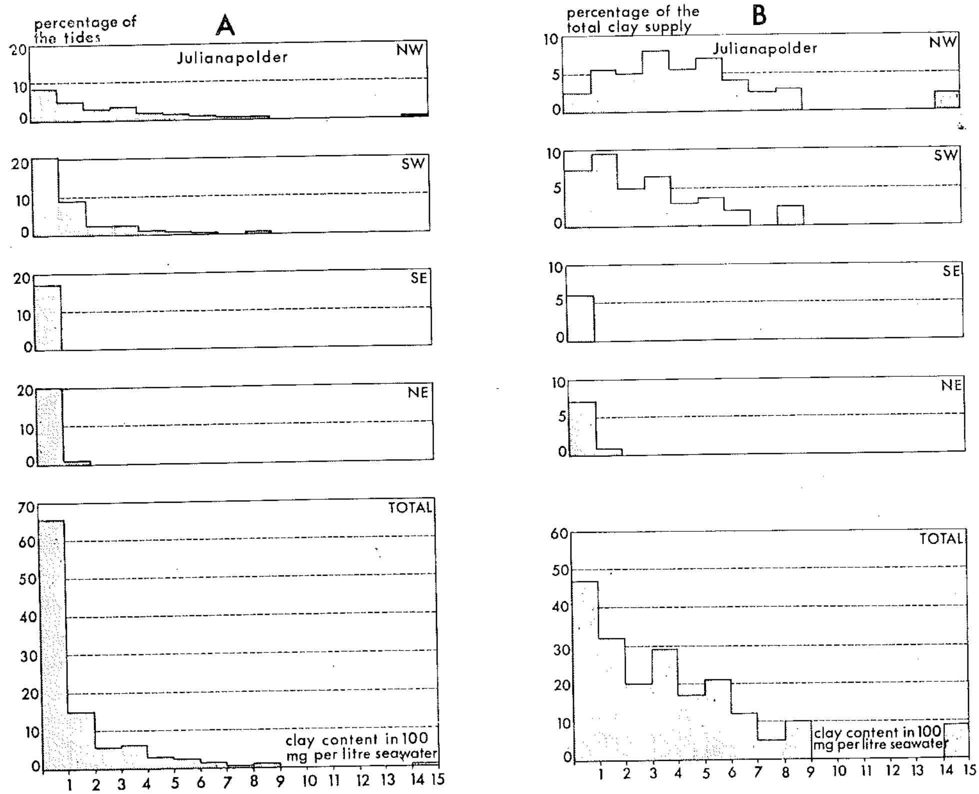
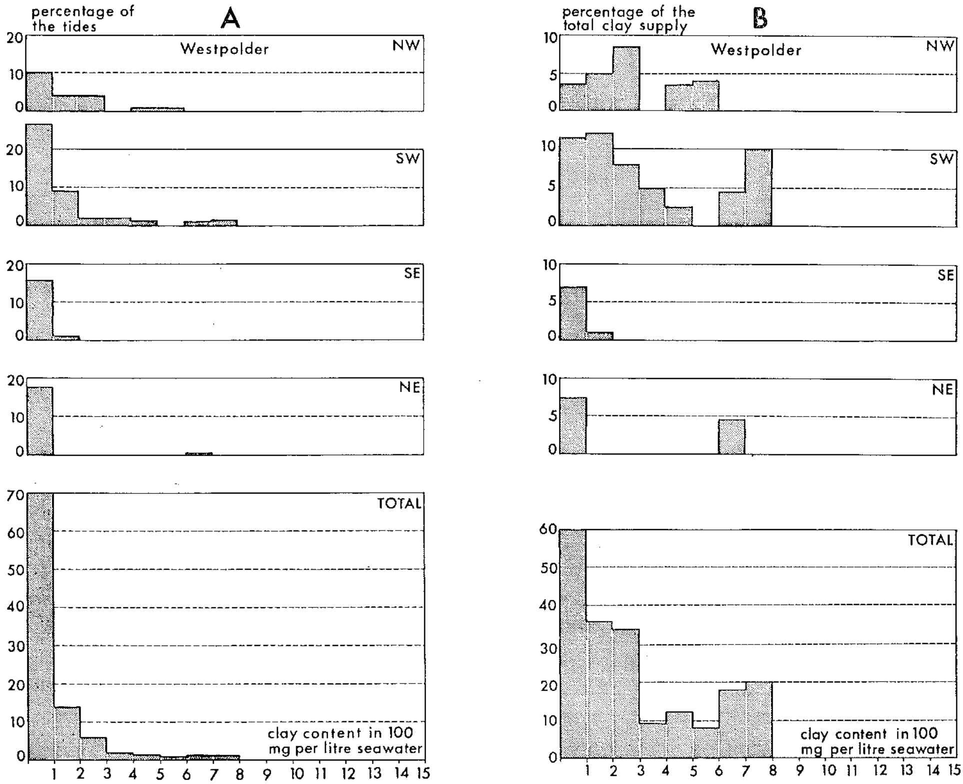


Figure 17. The frequency of the tides with a given clay content of the seawater (A) and the to the direction of the wind. (Data obtained from the

It has also appeared that during strong winds there is replacement of material across the watersheds and that the transport of this has a surplus in an easterly direction. But a complete survey can only be given after all the remaining data have been studied and evaluated, as at the present time too few samples have been examined to produce reliable results.

2.9. **Differences in the sedimentation conditions along the coast**

Experience had already shown that great differences exist in respect of land reclamation between various points along the coast, a fact which is underlined by the survey just given. As far as the whole of the Eastern Wadden Shallows are concerned, it is clear that the Groningen coast offers more favourable possibilities for the deposition of mud than the south coast of the islands; the more so, too, because its location gives that coast greater protection against the dominating south-western winds and because in front of this coast the provisional mud layers which finally must supply the material for the warp deposit are more easily formed. It is also clear that, given equal measures and the same average mud content of the water, sedimentation is more favoured at places less exposed to the effects of the waves, just as places where the current strongly diminishes, such as in the vicinity of watersheds and near a dyke also offering favourable conditions.



relation between the clay supply and the clay content of the seawater (B); both total and subdivided measuring platforms Julianapolder and Westpolder).

Viewing the general situation of the north coast of Groningen (figure 2), the following picture can be presented:

1. *Panserpolder and Kerkvoogdijpolder*

Because of the high shallow on the other side of the sailing channel to Zoutkamp, which is completely overgrown, the situation is rather quiet. Moreover, as this area lies at the end of a mud-carrying channel, favourable results can be expected in this area.

2. *Westpolder Bend*

A considerable pre-sedimentation area lies in front here, although its advantages are partly destroyed again by its less favourable location as far as the winds are concerned. As a result, in the past this has been one of the most unfavourable zones for land reclamation.

However, the platform measurements have shown that it is not a question here of lack of mud. The average clay content of the water supplied to the Westpolder was 99 mg, compared with 132 mg in the Julianapolder. The difference in silting up already mentioned must be chiefly explained by the fact that on an average much less mud remains in the Westpolder than in the Julianapolder. In the latter, this average was 17% of the mud supplied, whereas it was only 10% in the sectors behind the measuring platform of the Westpolder.

3. *Area between the Westpolder Bend and the Schiermonnikoog watershed*

As the zone here where pre-sedimentation can take place is becoming more and more favourable, much better results can be expected in the direction of the east.

4. *Area between the Schiermonnikoog and Rottumeroog watersheds*

Going farther east, broad pre-sedimentation areas are seen, although they become considerably narrower behind the Noordpolder, a factor which certainly influences the practical results to be obtained there. Behind the Lauwerpolder are other large pre-sedimentation areas, while there are also a great number of mussel-beds in front of this polder. On this part of the coast a rather favourable mud deposit may be expected, with the minimum behind the Noordpolder and the maximum at each end.

5. *Area east of the Rottumeroog watershed*

Here is certainly a wide sub-terrain, but as it appears to have a low clay content in the upper layer the course of sedimentation will not be very satisfactory. By means of a small auxiliary measuring platform behind the Oostpolder a number of mud measurements were made which showed that, in contrast to the Westpolder, the less favourable circumstances were due to the lack of mud.

This may be explained as follows:

a. The area north of these polders is poor in Lamellibranchiae.
b. When the tide is ebbing the rather low quantity of transmuted mud is discharged into the River Ems.
c. When the tide is rising and is flooding the shallows, a great quantity of water has already entered through the River Ems, while measurements showed that this rising water mainly contains fine mud that settles down only slowly.
d. When mud-rich water runs over the watershed of Rottumeroog during strong westerly winds, the area can only profit by it during that time in which the water

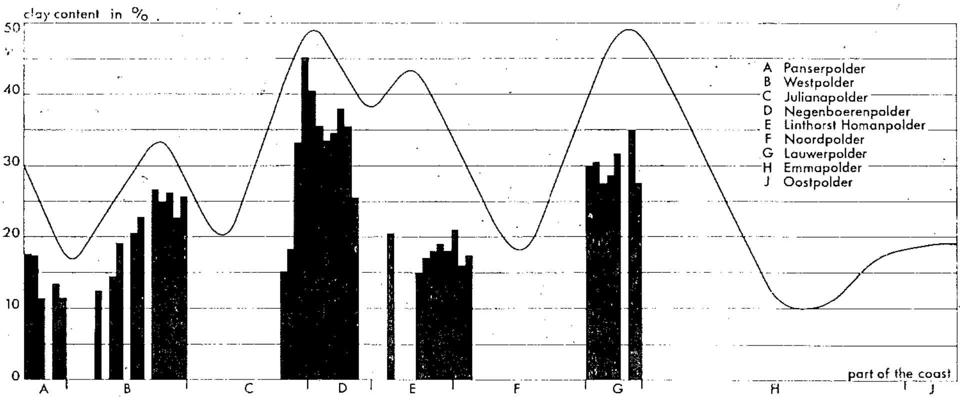


Figure 18. The average clay content of the surface layer per sedimentation field and of the warp in the grips per sedimentation field, both in the row of sedimentation field nearest to the coast.

is actually passing, because the material that does not come to rest during that tide is mostly lost, being swallowed up by the great mass of Ems water and only a small part of it returning.

So the conditions for the deposition of mud are certainly not favourable in this area.

Comparing now the facts deduced above for these areas with the results of other investigations, this is the result. A check-up of the average clay content of the deposited layers of the first row of sedimentation fields in 1941 (figure 18) shows that the two watersheds clearly take a prominent place, while the bend of the Westpolder and the Noordpolder compares unfavourably. For this comparison the sedimentation fields constructed before 1940 were taken, because, as far as „gripping" was concerned, a uniform system was applied while generally only two fields appeared in succesion. The same picture is obtained from the study of the clay content of the warp in the grips (figure 18) which was investigated during a period of three successive years, and which also makes it very clear that there are mutual differences between the various points along the coast.

In practice this means that the land reclamation work will run more favourably at one place than at another. In some cases, for example, where there is mud present, it will be possible to make the land reclamation much better by improving the sedimentation conditions and by nullifying the effects of the deposited material. But at those places at which sufficient mud is not available, it will not be possible — except by means of very drastic and costly measures — to obtain it, and at the most all that will be obtained is a heightening of the land with material with a low clay content.

To end this chapter it must be admitted that there is still a great deal missing from our knowledge of the behaviour of the mud in this region, although this investigation has certainly produced a number of facts which are of considerable importance for the execution of the land reclamation works and which will be further discussed in the following chapters.

3. Land reclamation by means of silting up

3.1. General remarks

Land reclamation is generally understood as winning of land from the water for the benefit of agriculture. Many forms of this reclamation are recognized, one of which is reclaiming land by means of the silting up of soil outside the dykes. This method, in turn, has various forms, of which four will be discussed here:

1. natural silting up;
2. silting up by means of gripping according to the farmers' method;
3. silting up according to the Schleswick-Holstein method, and
4. silting up by the modified Schleswick-Holstein method.

After dealing with each of these separately, a few other possibilities of soil improvement, which is the aim of all these methods, will be discussed very briefly.

3.2. Natural silting up

There was a period in which all the land in the north of the Netherlands suitable for inpoldering outside the dykes accreted in a natural way. Human labour was restricted to the building of dykes around those areas which were being sufficiently raised. But at the present time this kind of land accretion is no longer found along the northern

Figure 19. Layers of mud deposited on a low level in the Dollard.

coasts of Groningen and Friesland; in its place, land reclamation works are to be seen everywhere. Where no such works are in progress, then there is no silting up. For this reason, nothing can be said here about natural silting up in that area, but only on this form of land accretion in other places.

In studying this subject, the present writer has been greatly struck by the role which vegetation plays in the final period of the silting up process and in the formation of the clay-containing upper layers. In many cases it is a plant cover by which a deposition of clayey layers finally takes place. It seems certain that the fineness of the sediment almost always increases after the development of such a cover of plants, the only exceptions being the growth zones located nearest to the sea where the process sometimes leads to the heaping up of coarse materials during periods in which no further expansion of plant-growth takes place. In most places the deposition of clayey layers only starts when the growth is developing, but this is certainly not always the case. The Dollard is an example of an area in which clay was already deposited long before reclamation work was started, and thus also before the time when vegetation began to develop (figure 19).

The question arises, therefore, as to why vegetation promotes so strongly the deposition of fine material. In answer, two causes may be indicated. In the first place, vegetation creates tranquillity in the water and the sediment is protected by the plant cover; and in the second place, the drying and draining is strongly promoted, because on the one side the vegetation causes heightening and on the other side it helps to form and to keep the gullies intact. By this, indeed, the influence of the vegetation can go even outside the areas of the overgrown zone itself.

In an area heigthened by sedimentation it is generally seen that the highest parts mostly occur along the coast. It is here that the first growth usually develops. In such development, however, it is seen that the coverage is not of the same density along the whole zone, but that there are local differences and that places even occur at which there is absolutely no growth whatever. When such a vegetation expands it appears that gullies develop, because the plants compel the water to take certain directions. On reaching the area in which there is no growth, the gullies often end in a pool (fgure 20, 1st stage). Then when the zone with vegetation gets broader, a few of these channels unite and are finally able to form a larger channel and to keep it open even in the barren region with no growth. Such a channel originates because the water that has penetrated into the vegetation during the high water period can run back less rapidly at ebb tide than the water which is over the foreground (figure 20, 2nd stage). As some of the small gullies join together, the quantities of the water still waiting to be discharged become so large that they can scour out a big channel in the bottom of the shallows, resulting in a better drainage of the plant-grown area and, in turn, producing a more rapid drying out of the deposited material in the overgrown area while also it is affected much less by the water movement (figure 20, 3rd stage).

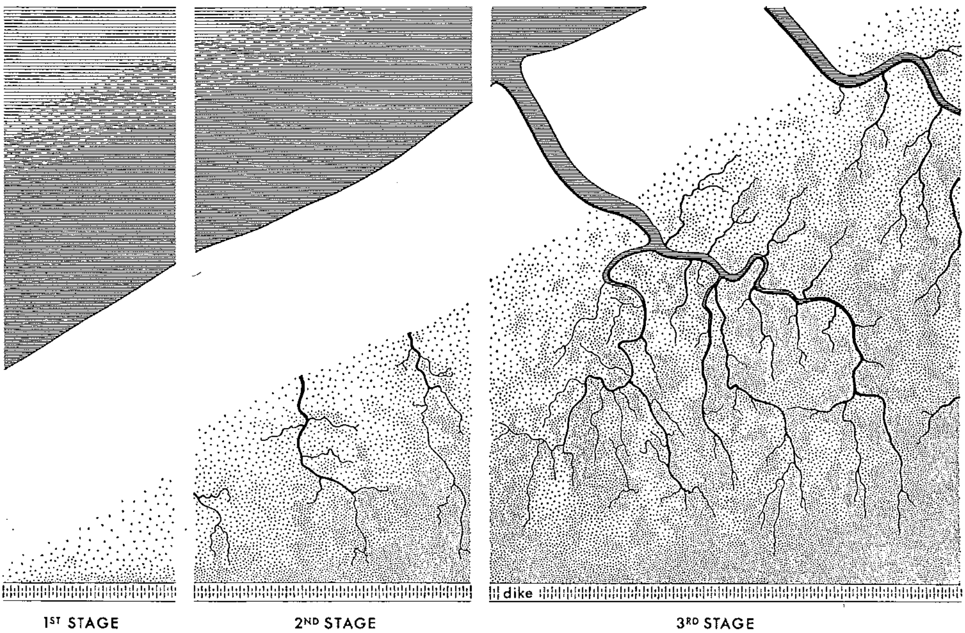


Figure 20. Schematic picture of the natural accretion.
1st stage. Vegetation starts; 2nd stage. Gullies develop in the vegetation; 3rd stage. The system of gullies is developed wholly, a big gully to the deep water is formed.

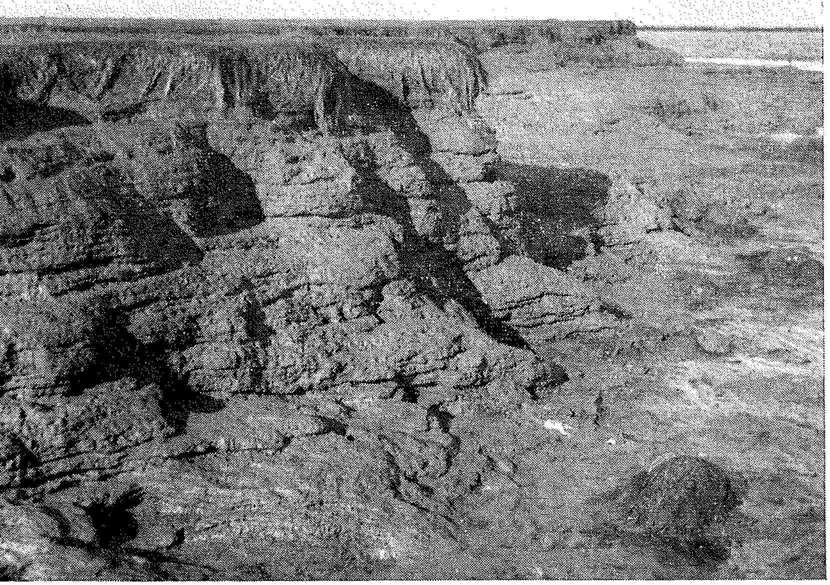


Figure 21. Receding rim of a salting showing clearly the lamination of the profile.

As has been stated earlier, the first incoming water is the most rich in mud. This is driven nearest to the coast. This is one of the causes by which, in natural silting up, the parts most rich in clay lie immediately along the coast. A second cause is that, as the vegetation expands, deposits of sand and shells which are moved in great quantities during a storm are mostly caught up in the area of the vegetation belt nearest to the sea, and in which the shell material can often be clearly seen as definite strips or bands. When such a deposit is followed in the direction of the dyke, it can be observed that the material gets finer and finer and richer in clay. It should be pointed out here that under certain circumstances there can be a danger for the already deposited bottom layers in this sieving of the coarse material in the form of the creation of receding edges.

As the overgrown area becomes wider and lies further from the dyke, the deposited sediment becomes coarser and poorer in clay, thus reducing the possibilities of any expansion of the plantcovered zone. It is known that the growing of pioneer plants glasswort or marsh samphire (Salicornia Herbacea L.) and cordgrass (Spartina Townsendii H. et J. Groves) are greatly dependent on the nature of the soil and the roughness of the water (see Chapter 5, Sections 2 and 3). As a result, it is always possible that the expansion of the vegetation zone stands still for a few years, possibly producing some local and often very large heaping up of coarse material (sand, shells and shell grit) in the extreme outside areas. This, indeed, is the cause of the origin of the salting rims to be found all along the north coast of Groningen (figure 21). When such a rim is once formed, it maintains its existence.

During periods of rough weather, however, the rim is again attacked and is pushed back nearer to the coast, so that not only does its height increase as the affected layer is getting thicker, but also because the affected material is transported by the currents in the direction of the coast. The only possibility of stopping this recession of the salting is by smoothing the rim by giving it a gradual transition into the foreland area. During the war years, when land reclamation works were either stopped for a long time or were only very badly maintained, such broken or receding rims originated at a number of places along the coast.

Summarising the most important characteristics of natural silting up, two factors predominate:

1. In the first instance, there must be a regular supply and deposit of more or less coarse material.
2. After the start of vegetation the nature of the sediment begins to alter, because the vegetation promotes the silting up by reducing the water movement (by which more and finer material is deposited), by protecting the sediment, and finally by improving the draining.

3.3. Silting up by gripping according to the farmers' method

This method, which around 1935 was not being practised in many places except, for example, in the area of the present Linthorst Homanpolder, was formerly used at many places along the coast by the farmers to increase the area of saltings. But uncertainty about the future ownership of the accreted land, the great increase in wages, and the change in social conditions, combined to put a stop to such works. However, inquiries made among a number of the farmers about this subject have enabled to obtain a rather precise picture of the method that was then used.

When a new dyke was built in those days it was not located at the most extreme edge of the vegetation zone but at some distance from it. This had the advantage that it was not necessary to protect the foot of the dyke with a stone slope, as this could then be done with clay and turf. The shoal in the front of the new dyke, which gradually gets higher in the direction of the dyke, and the already existing foreland jointly acted as breakwaters. A start was then made on trenching or ditching the foreland for the purpose not only of retaining the existing land but also of expanding it where possible, thus killing two birds with one stone, as it were, namely, providing better protection for the dyke and increasing the area of land.

The system used was to make grips or trenches of little width and depth and about 100 metres (320 feet) long. The actual measurement of the width varied locally according to the circumstances, but was usually about 40 to 60 cms (16 to 24 inches). The first grips were dug about one spade deep, or about 25 cms (10 inches), while the wider grips upto about 60 cms were later made narrower but also deepened to about 40 cms (16 inches). The soil excavated from the trenches was thrown onto the fields, with care taken to see that there was more in the middle than around the edges. Thus the fields showed a certain roundness so that the water could be discharged fairly rapidly into the grips at low tide. The distance between the grips was usually 5 to 6 metres (16 to 19 feet) wide, and each new field taken into use lay about 100 metres (320 feet) further on in the direction of the sea.

Particularly important was the time at which work was started on a new field (figure 22). It appears that this was done when the preceding field was entirely or nearly overgrown with glasswort. Incidentally, in those days the cordgrass was not yet known in this area. It is clear that the method is closely connected with natural accretion. The first stage of the silting up was left to Nature, with Man stepping in when the soil had reached a certain height. Experience had shown that when the field last taken into operation became fully grown with glasswort, the foreland had generally reached a height at which succesfully trenching work could be carried out. If too large an area was taken into operation at once, then there was little success with these small grips, an experience which was also obtained in the land reclamation works after 1935 (see Section 5, and also Chapter 4, Section 4).

Comparing this farmers' trenching or gripping system with the natural accretion described in Section 2, it appears that there is only little difference. The drying which originated with the natural silting up after the vegetation appeared merely took place earlier. Because of the more favourable circumstances for drying and by the artificially obtained field ridges, the vegetation came to development earlier than under natural conditions. In spite of the fact that along the Groningen coast there has been no natural land accretion without this help, these non-interfering measures have apparently already been sufficient to produce the formation of new saltings.

It surely is unfortunate that as a result of the above-mentioned factors and the fact that the work done was irregular, haphazard and uncoordinated, this early land accretion has not only stagnated but much of what had been accreted has been lost again. The many so-called salting rims along the Groningen coast, which in some cases are more than three feet high, show this very clearly. The recession of the salting often went so far that at several points the dykes which were originally protected by the salting later had to be protected aganst the attacks of the sea by a stone slope.

By this method of land reclamation, as with that of natural accretion, the deposits most rich in clay are found in the vicinity of the dykes. This clay content decreases in a seaward direction, with coarse elements becoming more and more numerous. The explanation for this is the same as that for the system of natural accretion.

Summarising, it can be said that the system discussed here agrees completely with the natural silting up described in Section 2. The moment of drying, however, comes earlier and stimulates the growth of plants. The draining is artificially maintained by trenching with grips that are small in dimensions, while experience has taught that the fields to be constructed should not go too far seaward outside the zone of vegetation. It is also clear that the omissions in the maintenance of the works led in many cases to the loss of land already accreted.

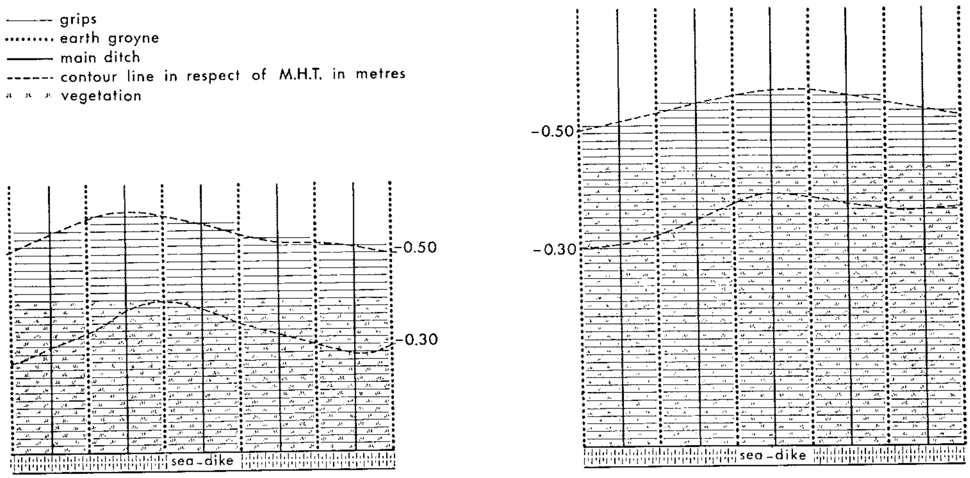


Figure 22. Schematic picture of the farmers' method. Grip-digging in the overgrown area and in a small area before it.

3.4. Silting up by the Schleswick-Holstein method

When in 1935 the Netherlands Government made a start in the execution of land reclamation works here, a change was made from the farmers' method to the so-called Schleswick-Holstein method, which originated in Northern Germany. As will appear later, however, the application of this system in the Netherlands was accompanied by changes which made it somewhat different from the original method. In this system one new but important element appeared, namely, the groyne which is used with this system (figure 23), which can be either an earth groyne or a groyne of stakes and brushwood *).

With the aid of these groynes sedimentation fields are formed measuring about 400 metres (about 1,300 feet) square. The purpose of the groynes is clear: to produce tranquillity in the water and thus allow the sand and mud to settle down. In the beginning the construction of one or two sedimentation fields is started, depending on the level

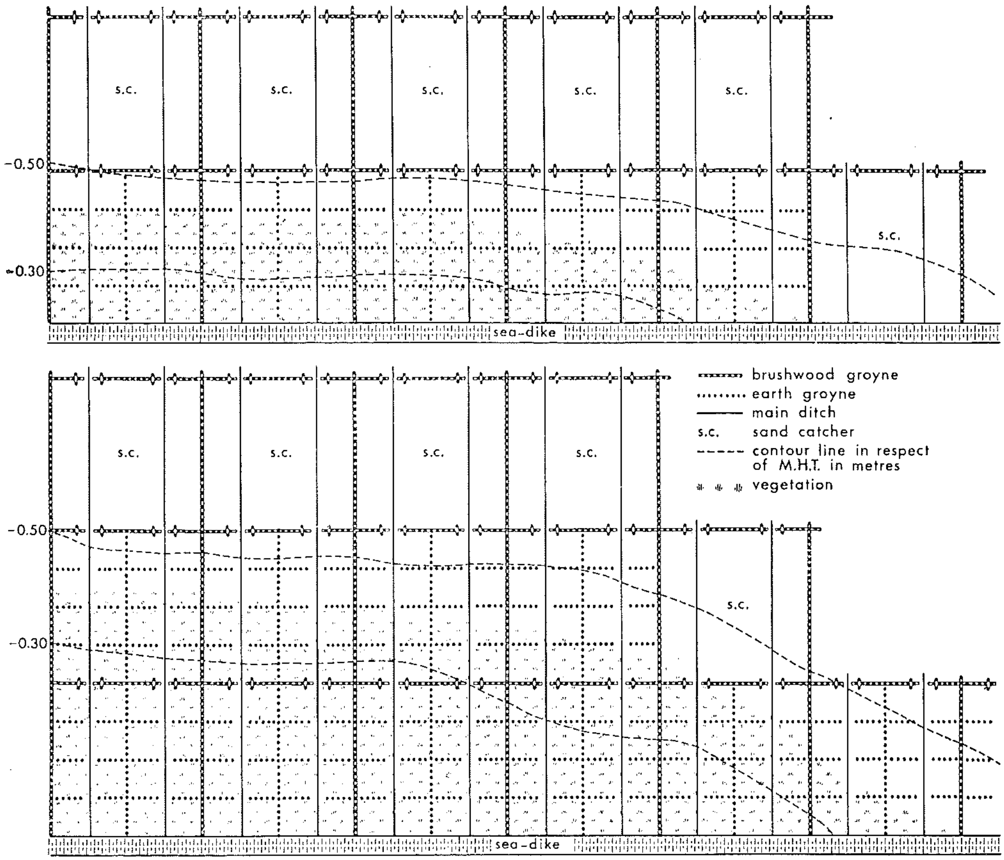


Figure 23. Schematic picture of the Schleswick-Holstein method. No grips are dug in the sedimentation fields, marked with s.c.; the grips are not indicated.

*) In this review this type of groyne is called brushwood groyne for brevity's sake.

of the shoal. When the terrain is lying low, only one field is constructed in which no grips are dug before it has reached a height at which plant-growth can soon be expected. When that stage is reached, a start is made on trenching the sedimentation field and a second sedimentation field is constructed in front of the first. In this second field, grips are not dug immediately but it serves as a sand-catcher. It is assumed that in the field nearest to the sea the period of heightening with sand is shortened by the greater calmness of the water and that the mud moves onto the first sedimentation field where a sediment richer in clay settles down.

With this method every effort is made to obtain saltings amply located above Mean High Tide. It should be noticed, however, that the works done in Schleswick-Holstein by this method are mainly for better dyke protection, whereas in the land reclamation projects in Groningen and Friesland the emphasis is placed more on the obtaining of new land. It is also very clear that this system strives to let Nature do as much as possible, and gripping is only started when rapid plant-growth occurs which will greatly promote and help the fixing of the material supplied. This system also aims at influencing and shortening the period before the occurrence of plant-growth by the construction of groynes, thereby gradually extending the sedimentation fields according to the rate at which the material is deposited.

The Schleswick-Holstein method can, moreover, be seen as a further development of the farmers' method. An important new element, however, is the groyne, especially the brushwood groyne.

The method, therefore, can be summarised thus:

1. It influences the last stage of the heightening of the terrain immediately before the height at which plant-growth will occur, first by the construction of groynes and later by the digging of grips or trenches to promote the drying of the land.
2. It promotes the sedimentation and the fixing of the mud by groynes and grips which in turn stimulates the plant-growth by which the clay content increases.

3.5. Silting up by the modified Schleswick-Holstein method

The system applied in Groningen and Friesland is usually described as the Schleswick-Holstein method, and at a rough glance it certainly looks like it (figure 24). But in actual fact, a method of working is used here which differs in a few respects from the original Schleswick-Holstein method, although, as with the Schleswick-Holstein method, groynes are made to get tranquil water in the sedimentation fields. The main difference, however, is that in these Dutch provinces a start is made on the construction of at least two sedimentation fields one after the other, and that these two fields are immediately trenched without taking the level of the terrain into account. Just how this change came about does not seem clear. Perhaps it was thought that by the immediate carrying out of gripping the heightening would be considerably speeded up. However, the narrow trenches used at the beginning were of little value in this respect when they were dug on too low-lying land, for they silted up again very quickly. At a later date views on this point changed considerably, and although at present all fields are gripped, there is the difference that in general the measurements of the trenches have greatly increased, especially after it was understood that the grips fulfilled a double purpose, namely, draining as well as catching and retaining the warp. It is true, of course, that with other systems the trenches also become filled with warp, as can be appreciated in the first stages; but once the vegetation has started to grow, the warp deposit decreases. What is still deposited is often seen as a necessary evil from which there is no escape.

The development of the gripping system, however, is discussed more extensively in Chapter 4, Section 4.

The original idea to obtain saltings located amply above Mean High Tide has also been abandoned and a new aim has been introduced. The land reclamation works in the northern part of the Netherlands are directed at obtaining soil which after diking is suitable for arable land and not for the also important side purpose of providing still better dyke protection. All that is now sought for is the deposit of a layer of sediment which will supply a soil able to produce a good crop without a fresh water supply from outside the polder. And because the work is started on a much lower level, in many cases the layer of soil of the required quality must be formed without the aid of vegetation, whereas in the methods that have just been discussed it is this vegetation which plays an important role in the formation of the layers necessary to form a soil suitable for arable land.

The centre of gravity with the method now being applied has been completely moved from Nature to Man. There are admittedly, however, a number of disadvantages connected with this method. One of the greatest is that there is now no such protection which the plants give in the other methods. Another by no means small disadvantage is that the work must be carried out at a lower level, with all the attendant objections such as the slower drying out of the warp dug out and the greater chance of deterioration, as well as considerably shorter working periods. A third defect, which is also very important, is that there must always be sufficient workers and machines available to carry out the work. In practice it has certainly appeared that if the trenching is not

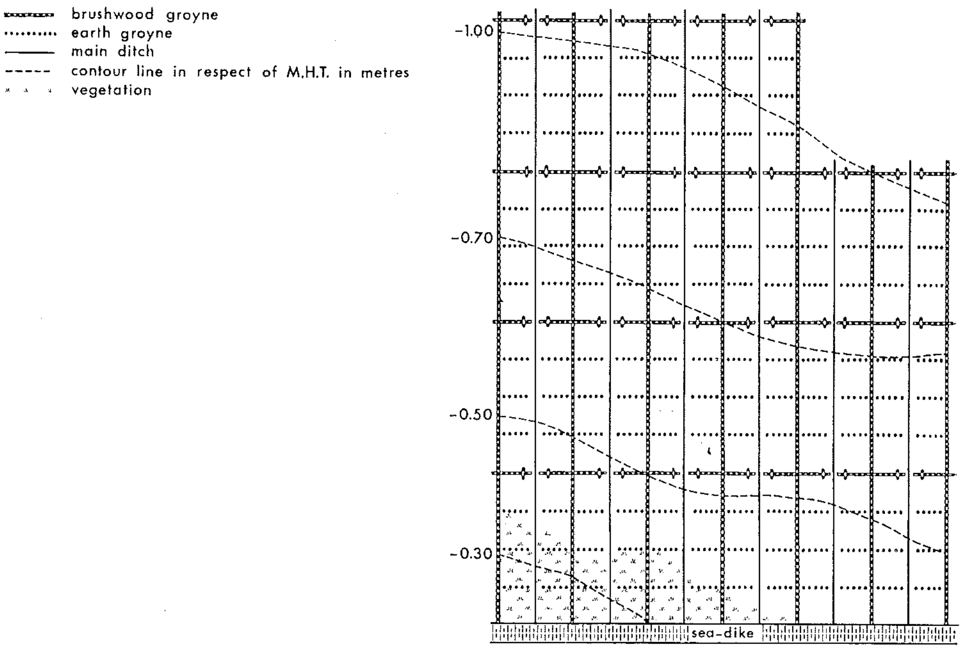


Figure 24. Schematic picture of the modified Schleswick-Holstein method. Grips are dug in all the sedimentation fields. The grips are not indicated.

executed in time, great damage can be caused (see Chapter 4, Section 4). However, the great advantage of the method is that much less material needs to be fixed, so that the ultimate purpose is attained much more quickly.

The applied groynes and the sedimentation fields they have formed, have also brought about a great change in the pattern of the clay content of the deposit. It can be generally said that the clay content of the deposit is strongly ruled by the groynes. The clay content is highest on that side of the groynes where the shelter is the greater, so that along the Groningen and Frisian coasts this is usually on the eastern side (leeside) of the groynes. The differences in the clay content of the deposits perpendicular to the coast now appear very much more marked than the former very striking differences parallel to the coast. This subject, however, will be returned to in the discussion of the sedimentation field system dealt with in Chapter 4, Section 1.

Summarising, therefore, it can be said that the Schleswick-Holstein method applied here differs in some respects from the original one. The name modified Schleswick-Holstein method is accordingly more correct.

The most important characteristics of this changed system are:

1. In the methods discussed in Sections 3 and 4, and in natural land accretion, the vegetation plays a very significant part in the formation of the upper layers, whereas in this modified method the importance of the vegetation has greatly diminished, only playing a role in the deposit of warp in the parts located at high levels.
2. The grips system constructed chiefly for draining in the other methods has here got a second function of importance, namely, that of warp-catcher. As previously pointed out, Nature has been replaced by Man.
3. The pattern of the clay content of the deposit has been considerably altered.
4. It is usually not necessary to continue the works to the height of a salting to obtain a soil suitable for arable land after being diked.

3.6. **Other methods of soil improvement**

It may well be asked whether there are no other methods which would produce a rapid formation of soil layers with a sufficiently high clay content. There are some such methods, and a few of them will now be briefly discussed.

a. *Mussels*

In the first place attention is drawn to mussels. As already pointed out, these creatures can sieve large quantities of mud from the water. Because of this an experiment was tried behind the Julianapolder to produce a layer of warp inside a low-lying sedimentation field by means of mussels. They were bedded out in strips 4 metres (13 feet) wide, with the strips being 10 metres (32 feet) apart (figure 25). At first the experiment went very favourable and a considerable layer of warp was deposited. The greatest difficulty, however, was the draining, as it appeared it was not possible to keep it in a good state. As a result, the deposited warp remained very weak and waterlogged, which meant the destruction of the mussels. They were alright during the summer when they lay quietly on the bottom, but during the autumn storms they were swept off the field along with the warp and then dashed against the groynes.

However, as after a short time a good deal of material had been deposited (figure 25), the experiment was repeated with protection given to the mussels by placing them between two low groynes. It was hoped this would give them sufficient hold, but neither have these measures given the desired result. Here, again, the mussels were washed away, and so the experiment was stopped. Had it been possible to obtain in one or two years, with the aid of these creatures, a warp layer of sufficient thickness, conditions might have been created under which land could have been reclaimed at a good speed on a low-lying shallow (1.00 m — M.H.T. or lower). As it turned out, the warp deposit was more than adequate, but the change of the loss of the mussels and warp is so great that there are too many risks attached to such a system.

b. *Wet sedimentation field*

A second method which was tried out was the so-called wet sedimentation. In this experiment a field was surrounded by dams in which a valve culvert was installed. This valve door was opened by the rising water and then closed as the water level fell. But as the water could only trickle away slowly through a number of small openings, this meant that the mud had ample time to settle down quietly. Over this field, measuring about 2½ acres, a warp layer about 7 cms (just over 2 inches) thick was deposited on the bottom in two years, but even in this small basin the material was stirred up and discharged in rough weather, so that it could not by any means be regarded as a successful experiment. It must also be considered that this system is very expensive because of the construction of high watertight dams, so that it obviously can only be used for fields with a large area in which the cost of the dam construction per surface unit does not rise very high. As, however, even in fields covering 2½ acres there is a breaking up and discharge of the warp layer, the system can hardly be recommended.

Nevertheless, great silting up can often be seen under conditions which apparently are the same as in this last experiment, namely, with the so-called dyke-pits. Behind the Westpolder such a pit silted up completely in 15 years, the deposited layer of heavy soil being at least 1½ metres (nearly five feet) thick with a high clay content (35% - 40%). It must be recognized here, however, that such pits lie in the middle of a salting and that the water in them is very quiet. Particularly during the first period after it is dug the wave movement will never reach the bottom, so that the circumstances are certainly considerably more favourable than in the wet sedimentation field in the low-lying shallows in the experiment here mentioned.

c. *Harbour warp*

Finally, there is a third method of obtaining a warp layer, although this has very little to do with land reclamation by means of silting up. This method is that of providing warp from elsewhere and then using it for land improvement. In the Netherlands there are many places which can serve as warp sources, namely, the harbours, in which enormous quantities of warp are deposited which have later to be regularly removed at great cost of money and labour. The solid matter of this deposit usually consists largely of fine material; the clay content varies from 40 to 60%.

In Rotterdam this material is stored in large quantities in the form in which it is obtained, and an extensive report has been published by *Professor Dr. Ir. A. J. Zuur* about its quality and its behaviour as arable soil. Here it is material in its original form, and the soil which is formed in this way is too heavy for arable land according to present-day ideas. The question is whether it is not possible to spread this material in less thick layers and to mix it with the subsoil. If this could be done, the material would be used in the most economical way and more would not be put per surface unit than was absolutely necessary. In any case, it is clear that the harbour warp and its possibilities should be thoroughly investigated, because in other areas of Holland there is urgent need of clay-containing soil, particularly where dykes are under construction.

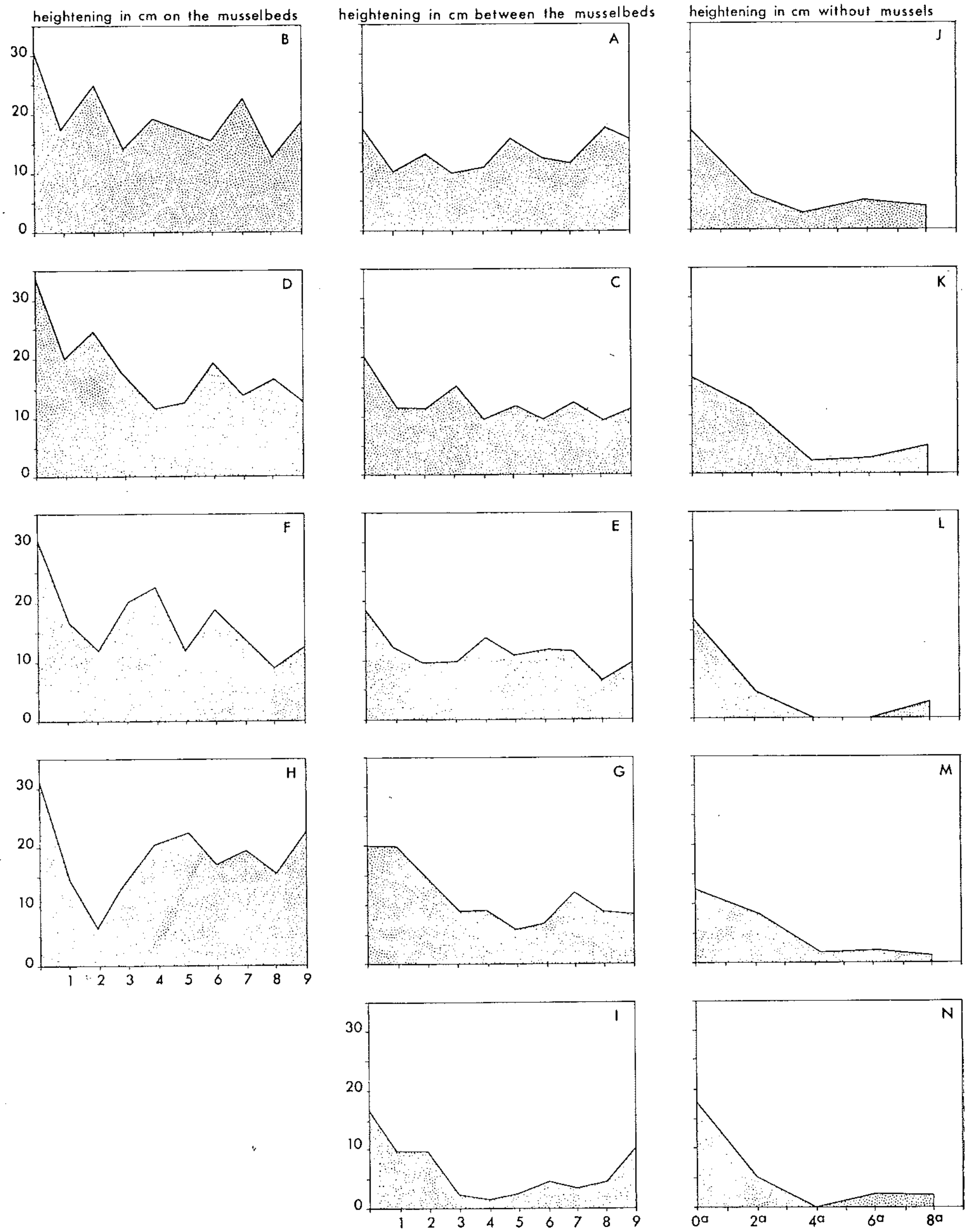
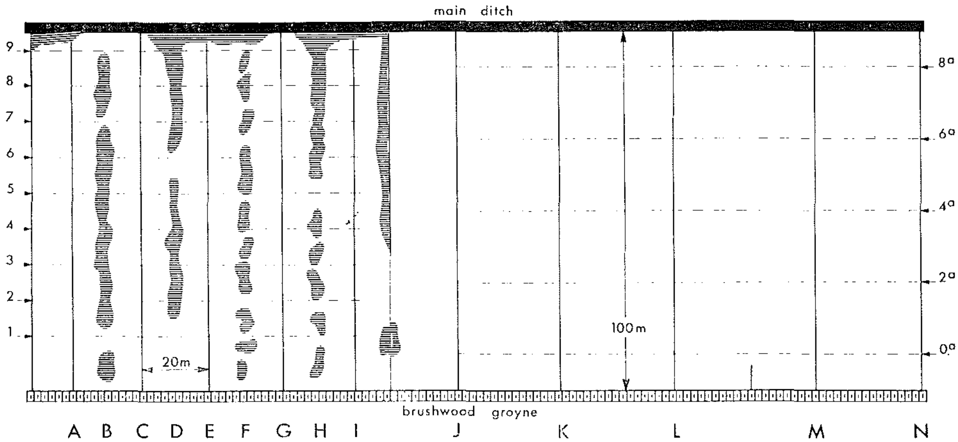


Figure 25. The trial with mussels. To the right (next page) the situation of the mussel-beds, on this page the thickness of the deposited warp layer on and between the mussel-beds and for comparison the thickness of the deposited warp layer on fields without mussels. The numbers in the diagrams agree with those on the situation picture; the zero of the distances in the diagrams lies left on the vertical line in the situation picture.



The main objection to the use of harbour warp is its costly transport, especially in the circumstances under which it is obtained by dredging. Nevertheless, thought must be given to the fact that these dredging works and the removal of the warp already cost large sums for which there is no return.

4. The modified Schleswick-Holstein method

4.1. The sedimentation fields

In the preceding chapter a survey has been given of the various methods of land reclamation by silting up. In this chapter the modified Schleswick-Holstein method as used in the northern part of the Netherlands will be examined more closely.

The size of the fields is usually 400 x 400 metres (1,312 x 1,312 feet), and today this area is never exceeded. At the beginning, however, it often occurred that they were larger, because for administrative reasons the location of the groynes was attuned to the boundaries of the plots behind the dykes. But for works of this type, which are so strongly dependent on natural influences, this was not the right method. The measurements of the fields should be suited to the natural circumstances which differ from place to place. This also means, however, that neither is it correct to adhere slavishly to the size of 400 x 400 metres.

As previously pointed out, the sedimentation fields here have not been expanded gradually as in the case of the original Schleswick-Holstein method, but two fields have been constructed immediately in succession, and then gripped. At some places even, more than two fields were constructed at the same time. At the places where this was done (the watersheds) it was known that the silting up occurred more favourably than in other places. But no research had yet been done into the nature of the supplied mud. It had been thought that it was only present in the water in a finely-distributed form, so the mud only came to sedimentation at the turn of the tide. Furthermore, it was not known that the first rising flood water contained more mud than that supplied later. If these facts had been known, as well as the distribution of the rising flood water over the sedimentation fields, it does not seem probable that there would have been made a third, or even at some places a fourth, sedimentation field at the same time.

What happens when three or four sedimentation fields are constructed at the same time? The first water entering the area distributes itself over the sedimentation field lying nearest to the sea. The water coming afterwards, which is already poorer in mud, covers not only the most outside field but also the adjoining one inland, and the sedimentation fields located nearest to the coast will be flooded with the water poorest in mud. In most cases the first sedimentation field will contain more clay than those located more seawards, so that from this point of view there does not seem any great objection to this form of mud distribution. This would certainly be the case if the same amount of mud had to be obtained on all fields. But the great danger of this method of working is that the mud now comes on the low-lying fields from which losses will originate when it is not possible to maintain them adequately because of the shortage of workers. Only when this work is kept well in hand and when grips can be made at the right times, is it possible to make more than two sedimentation fields one after the other.

During the past few years a system has been started of the construction of open and narrower sedimentation fields along a few stretches of the coast, in which the field is not closed off on the seaside by a brushwood groyne. A more favourable distribution of the mud is expected over these 200-metre (650-feet) wide sedimentation fields as the water is distributed in a totally different way, namely, the mud-containing water is pushed farthest to the coast. But too little information is yet available, however, to reach any definite conclusion on the success of this system. Probably a system will be developed, to prevent wastage of material, into the construction of dams provided with culverts running parallel to the dykes after sufficient clay containing material has been settled on a certain area. Such a system is really a variation of the old gripping method of the shore-owners to which dams have now been added.

4.2. **The groynes**

The sedimentation fields here referred to are bordered by groynes, the purpose of which is to promote tranquillity in the water by preventing strong currents and wave movements. There are two types of groynes, namely, brushwood groynes and earth groynes. The first type is made because it is not possible to construct earth groynes immediately on ungrown terrain. The original shallow bottom is sandy and the earth groynes made of that material would quickly disintegrate. But as the brushwood groyne has a limited life, it is replaced as soon as possible by an earth groyne, constructed of material which is not immediately affected by the water as sand is. To achieve this, so-called groyne-ditches are made running parallel to the groynes at a distance of about 5 metres (16 feet). In these ditches there is a deposition of warp; that material is then thrown against the brushwood groynes when the ditches are full, and then on both sides of this groyne an earth groyne is built which can stand up against the water. The warp which is dug out of the groyne-ditches, has a much higher clay content than the original shallow, so it has a higher cohesion and is less affected by the waves than sand. In fact, the brushwood groynes are really auxiliary constructions which act as a preparatory foundation for the earth groynes.

Although in the past few years other types of groynes have been tried out, the original type has always been returned to, namely, a double row of stakes in between which the brushwood is placed (figure 26). The width of each row is 30 cms (12 inches), and the poles themselves are 60 cms (24 inches) apart, with those in each row being in cross-connection. The groynes have a height of 1.30 metre (about 3½ feet) + N.A.P.

which agrees with 0.30 m (1 foot) + M.H.T., and the stakes stand with $^{3}/_{5}$ths in the ground and $^{2}/_{5}$ths above. The brushwood is stamped down between the stakes, after which galvanised wire is stretched over the top from stake to stake to prevent the brushwood from being forced upwards. Before he brushwood is put in, however, a small trench is dug between the stakes in which straw is laid to prevent under-flooding.

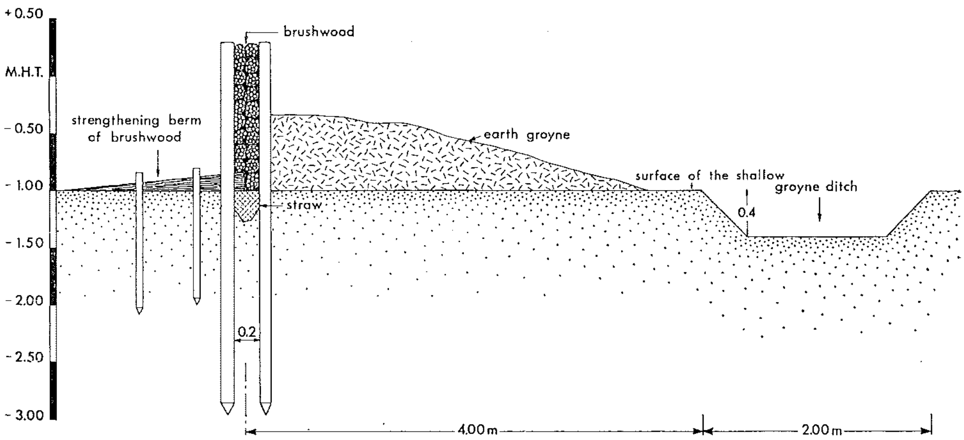


Figure 26. Cross section of a brushwood groyne and the belonging earth groyne and groyne ditch. The earth groyne is built up from warp dug out of the groyne ditch annual. Left the strengthening berm of brushwood is marked.

At first a strengthening berm or ledge was constructed on each side of the groyne, consisting of clumps of brushwood placed flat on the shallow with their woody ends turned towards the groyne and made into a floor with pickets and wire (figure 26). This, however, not only made the work much more expensive but turned out to be more harmful than useful in at least 95% of the cases in which the system was used. It was at first thought that these would be useful to prevent earth being washed away from the feet of the groynes by the water streaming over them in a sandy area. But it was seen that it would really have been better to omit them, as the damage they caused was greater than any advantages they may have had.

In the first place it appeared that the warp dug out of the groyne-ditches and thrown on these berms did not stay. Tremors in the groynes caused by strong winds and wave movements were immediately transmitted to the berm. Then, too, the protruding uncovered ends of the brushwood were moved about by the passing currents, thereby breaking up the cohesion of the earth so that after some time it was washed away (figure 27).

Figure 27.
Strengthening berm. The earth deposited against the groyne does not stay there.

This, however, was not the only disadvantage of the berms. By the washing away of the earth, holes often originated in the vicinity of the groynes which remained as pools during low water. The result was that the dreaded ship-worm (Teredo navalis) established itself in the woodwork at these spots. After the Second World War, when the groynes had not had any maintenance for a long time, it was found that this mollusc had become very common and that at least one-third of the stakes had become affected. When there are no pools because the earth is retained, as it is nowadays, the ship-worm has no chance. During the past few years, for instance, no ship-worm has been seen in the stakes of the groynes with the exception of those stakes standing at the ends of the wings in the main ditches which are usually constantly surrounded by water.

This factor of the earth being washed away also has very harmful results when there is ice on the water. Because the foot of the groyne is not heightened, practically every tide (and also at easterly winds) forces water against the groyne. When ice is formed in very cold weather, it becomes very easily attached to the groyne, and if it is formed in thick layers there is the great chance that with a very high tide the groyne itself will be lifted up (figure 28). When, however, there is an earth groyne lying against a brushwood groyne, the chance of lifting practically disappears. Another difficulty arising during the formation of ice is the danger of the groyne being almost completely covered by the ice that is drifting against the groyne (figure 29). With a high groyne this ice-covering brings a great risk of part of the groyne being sheared off. But when there is a fair-sized earth groyne on each side of the brushwood groyne, this risk is greatly reduced. In fact, during the past few years when land reclamation has been regularly carried out, no ice damage worth mentioning has been caused.

Finally a little more should be said about the so-called groyne-ditches constructed along the groynes. As they supply the material for the formation of the earth groynes along the brushwood groynes and being really part of the groynes, they are discussed here along with the groynes. Originally these ditches were made about 100 metres (325 feet) long, at the end of which there was left a narrow earth groyne. It turned out, however, that these last groynes, without being made stronger and heavier, could not withstand the water running over, so that in practice the ditches became about 400 metres (1300 feet) long. But with such a length it soon became clear that the deposit of warp was less than was wanted, at the place farthest from the dyke, so that it was later

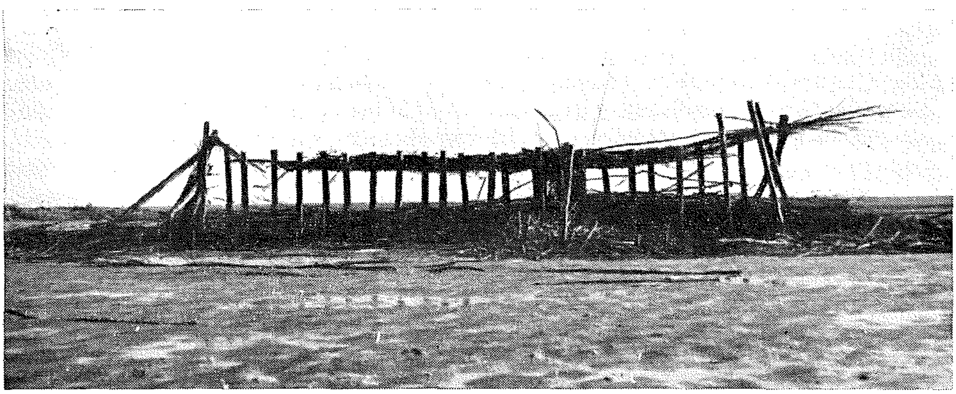


Figure 28. Part of a brushwood groyne lifted up by ice.

found necessary to divide the ditches into four sections by means of big earth groynes and then to fill and empty them by a supply from the main ditches.

As already pointed out, it is finally intended to have an earth groyne built on the place of the original brushwood groyne. But, in addition, earth groynes have also been constructed directly on the sedimentation fields over a period of a few years. This was

Figure 29.
Groyne being covered with ice.

found necessary because, before the war, a number of places inside the sedimentation fields remained far behind in the process of being heightened. To remedy this it was decided to sub-divide the sedimentation fields by means of earth groynes to produce fields of about 1 hectare (2½ acres) in area. At the beginning, these groynes have to withstand a great deal, and their maintenance is difficult. Large quantities of material have to be moved, not only because it is necessary for it to dry out and stiffen quickly but also to give it a considerable height within a short time. It is also important that during construction the tops of the groynes are made as level as possible, as an uneven finishing-off will inevitably result in the passing water making stream channels.

The influence of the groynes on the sedimentation will be discussed later in Section 6, dealing with the soil survey of the sedimentation fields.

4.3. The main ditches

The main ditches are the chief channels for the supply and discharge of the water. In every sedimentation field there are two of these main ditches which, in principle, are dug at right angles to the coast. The distance between them is, therefore, about 200 metres (650 feet).

The great usefulness of good drainage has already been pointed out repeatedly, and so it is obvious that these main ditches must be kept in very good condition to ensure that water can be drained quickly away during low tide. It would be foolish to trench a field excellently and then to neglect the discharge of the water from it, as that would mean that the all-important drying-out would not be adequately provided for. However, main ditches can often be kept open only with the greatest attention, especially in the initial period, because of the repeated deposition of sand. Such material must be removed by the current in the main ditch, which means that the force must be considerable. This is only the case when the water has withdrawn from the shallows and when an adequate stream of water pours out from the sedimentation fields.

When a sedimentation field has been recently constructed, sand deposits usually originate about 10 or 15 metres behind the point at which the water is discharged from the field. These are caused by sedimentation of material washed away during the initial period from the vicinity of the spot where the main ditch passes the groyne, and which is deposited in a bow-shaped ridge in front of the mouth. This mainly occurs shortly after the fields are constructed, but during that period often causes difficulties. One frequent result is that the remaining part of the main ditch both inside and outside the sedimentation field is also filled with mud and sand because the remaining water cannot remove the sand that has been deposited. Within the older sedimentation fields, however, the main ditches almost never close up, and so as a general rule little has to be done about maintenance.

It can be clearly seen, therefore, that in the interests of good drainage and discharge the maintaining of the main ditches in a good condition is just as important as the regular trenching of the sedimentation fields themselves.

4.4. **The grips**

The grips form the last link in the system of water channels in the sedimentation fields. From the main ditches the flood water is led to the grips by means of cross-ditches dug at intervals of about 100 metres (325 feet), with the distance between the grips themselves varying from 5 to 10 metres (16 to 32 feet).

As has already been shown in the discussions of the various systems of land reclamation, the grips can have two functions. On the one hand, they can serve only for the discharge of water, and on the other, they can both discharge water and collect warp. In fact, however, the last two functions cannot really be combined, because when the grips has to serve as water discharge, as little warp must be gathered as possible, while when the warp deposit occurs favourably and rapidly, the water discharge and the drying of the fields inevitably clash with each other. At first the grips were dug almost exclusively for making the land dry, leaving the warp to be fixed mainly by vegetation.

The early grips, therefore, had rather limited measurements. In an overgrown area there is certainly no need for large and wide trenches, in the contrary, narrow and deep ones are preferable. The disadvantage of large grips is that when they are re-dug a great deal of warp becomes free which has to be used in the field between them. But a large quantity of warp suddenly introduced is harmful to the vegetation, as it suffocates the plants. Grazing also is difficult with large and wide grips.

As already stated, in the land reclamation works in this northern part of the Netherlands all fields were gripped immediately, even those in which at first no vegetation could be expected because they were low-lying. These grips were small and triangular in shape, the upper width being 60 cms (24 inches) and the depth from 25 to 30 cms (10 to 12 inches). The distance between each grip was 5 metres (about (16 feet). The soil excavated from the grips was thrown to form ridges on the field between them, but it turned out that in low-lying fields this method was useless, as the small ridges did not dry quickly enough and so usually fell apart within a short time.

It was also found that the small grips quickly filled up, so that the water discharge again fell into a bad state very shortly after the grips had been made. Moreover, the warp deposited on the fields in quiet times formed a soft weak layer as it could not lose its superfluous water, so that when the water became turbulent during storms the warp was carried away elsewhere. This might suggest that perhaps grips should be made at shorter intervals, but this is not possible because the warp in the grips must be sufficiently solid to be used. At least three months should elapse before this is done, unless the deposited warp contains very little clay.

By digging larger grips the following advantages present themselves:

1. Large quantities of warp are obtained, enabling good-sized and rapidly drying ridges to be formed which quickly become solid.
2. The mud deposited on the fields (as with the faeces material in the shallows) is discharged with the falling water into the grips, but because they are larger, these trenches do not quickly fill up and therefore serve for a longer period in the process of drying out the land.
3. The strong field ridges break the force of the waves and thus promote calmness in the water, which in turn promotes sedimentation.

Only in this way, too, is it possible to gain and hold warp in the low-lying sedimentation fields without vegetation. Nowadays, therefore, wide and possible deep grips are constructed in the outside sedimentation fields up to the time that vegetation can be expected. Thereafter the sizes of the trenches are gradually reduced so that the vegetation can develop and take over the mud-catching task from the grips.

A point about which there has been some difference of opinion for a long time was whether the grips should be parallel to or at right angles to the dyke. During a trial in the Westpolder, however, it appeared that the grips parallel to the dyke certainly silted up more rapidly, but the final outcome was that the fields with the grips dug at right angles to the dyke gave better results, although admittedly the difference was small. In this experiment, moreover, there could clearly be observed a difference in the process of drying, which was more favourable with the grips vertical to the dyke than with these dug parallel to it. It is in this factor that the real difference between the two systems must be sought, for the grips at right angles to the dyke contained less warp than those parallel to it. Here again it is seen how important the question of drying the land is.

Finally, another very important point is the period of the year in which the grips are dug. From the reports about the mud it is clear that in the autumn months the largest quantity of mud is supplied. The land reclaimer, therefore, must try to catch that material during that period, which means that before the autumn storms start the grips must have been re-dug to enable the newly-supplied material to be deposited. This work must be commenced immediately at the end of the summer to ensure it being ready in time, for the warp taken out of the grips must have sufficient time to dry so that it can give maximum resistance to the water movement during the stormy season. Especially must the low-lying fields, where this process takes much longer because of the extended flooding period, be ready in ample time.

Measurements made on the platform behind the Julianapolder have shown that during the digging of grips under favourable weather conditions, and for a week after, more material is discharged from the sedimentation fields than has been brought there. From this it is evident that the digging of every grip is accompanied by a certain loss of material and that when the weather conditions are unfavourable large losses must be taken into account. During the first period after the grips have been dug the excavated warp is very sensitive to the effects of wave movement and currents.

When the warp yield is large, grips can be made twice a year, and the work must be done for the first time in the spring, preferably too, in a period when not many storms are to be expected. With large deep grips there is always the chance that they are not entirely filled during the summer, as sedimentation is small than. The summer warp, however, has a higher clay content. When carrying out spring grip-digging, a start must be made on the fields with the highest location, because there the warp dug out dries more quickly and is usually already more solid during digging so that there is less chance of losses from possible late storms. The fields with the lowest locations have their turn last. One disadvantage of this time-table, however, is that the spring and late summer grip-digging fall very close to each other, with the chance of only half-filled grips in the last section. To offset this, however, there is the benefit that these fields receive the most mud-rich water and that actually these low-lying fields profit most from a good water discharge and draining. So, all in all, this double seasonal grip-digging is recommended.

It has already been pointed out that land reclamation works are projects which cannot be finished at one time and that they need regular workers for a number of years after they have been started, because not only does the sedimentation stop but also erosion results from bad maintenance of the grips system. So although it would be preferable to make the grips, as recommended above, in two periods, namely, spring and late summer, this is practically impossible, partly because of the labour situation and partly because the provision of an adequate number of machines would mean too great an investment. In practice, therefore, the work will be extended as much as possible over a longer period, while at the same time taking into consideration the fact that for a number of sedimentation fields the work is decisively tied to a certain period of time. Grip-digging works, as well as all digging operations, should definitely not be undertaken in the winter if that can be avoided. Digging operations are only justified in this period when carried out to prevent damage or worsening of the work already done, such as to close holes in the groynes or to repair main ditches which have been blocked by earth deposits.

Summarising, therefore, it can be said:

1. The grips which are to serve as mud-catchers must be ready in the autumn.
2. The excavated warp must have the opportunity to dry sufficiently before the start of the storm season.
3. The spring grip-digging must be started with the most high-lying area so as to limit the possible losses to the minimum.
4. Grip-digging in periods with a good chance of rough weather can lead to heavy losses.
5. Regular grip-digging is essential.

Figure 30.
The digging part of the first-designed grip-making machine.

4.5. Methods of executing the gripping

During the first years the only method of grip-digging to be used was by spades, which meant that a large number of workers had to be mustered. Such a method has both advantages and disadvantages. One of the greatest advantages is that the warp can be put practically anywhere it is wanted. Possible pits and holes can be filled up; the warp can be thrown into ridges or be spread over the field, as is necessary, for example,

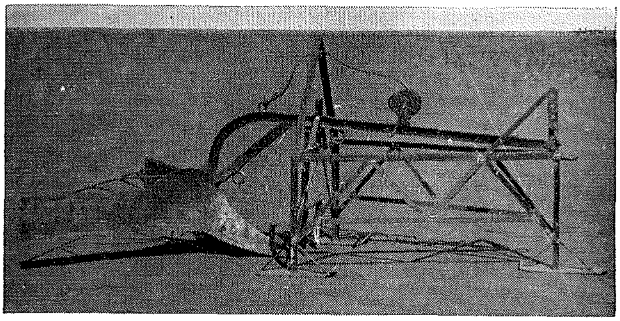


Figure 31.
The predecessor of the large ploughs subsequently used.

in areas with vegetation. A great disadvantage, however, is that per man hour only comparatively little warp is moved, so that a large number of workers are required for a proportionately small job of work. An even greater objection is that these workers are wanted just at times when there is a great need of workers for other activities. It were considerations such as these which led to doing as much work as possible by machines in the sedimentation fields.

The first trial of machine digging of grips ended in failure. The special digging implement designed for that purpose (partly seen in figure 30) was not continued with when it was seen that this wheel did not come up to expectations. After the war further trials in this direction were made by private firms as well as by the Study Service, encouraged by the need for overcoming the shortage of workers. But tests with a digging machine with conveyor belts also failed.

On the other hand, success was obtained with a plough, after various small models had been tried out in a sand-bed. The trials led to a model shown in figure 31 with which the first grips in the shallows were made. After the defects of this prototype plough had been removed, a start was made on the construction of large ones (figure 32) which were able to dig grips with a top width of from 80 to 100 cms (32 to 40 inches) and a depth of 25 cms (10 inches). The bottom width was from 60 to 75 cms (23½ to 29½ inches). A plough was also constructed which was able to widen the grips upto 2 metres (6 ft 6 inches) but which was mainly intended for the digging of main ditches. Both implements were drawn by a caterpillar tractor with a towing capacity of 65 hp at the drawing hook (figure 33).

The advantage of the ploughs is that they work very rapidly, although as the terrain must have a certain degree of firmness, their usefulness is rather limited. Where this characteristic is absent, the difficulty is not only with the plough but even more with the machine which has to carry out the actual moving and cannot find sufficient hold on a soft and loose bottom. Then, too, for safety's sake it is necessary for two caterpillar tractors to be at work in the same neighbourhood, so that one can help the other if it gets stuck in the mud. Furthermore, the disadvantages of these ploughs is that they must always make a rather large turn when they reach the ends of the grip,

Figure 32. Ploughed grip.

resulting in the last stretches at each end not being dug until they are finished off by hand labour. Thus when ploughing the sedimentation fields, they must be subdivided as little as possible so that the plough does not need to turn many times, although of course long grips have the disadvantage of catching less warp. The sub-dividing which is decided on for a more equal composition of the soil must disappear, so that a less regular distribution of the sediment across the field is promoted. And finally, the vegetation often suffers great damage because the sliding boards which have to carry the warp to the middle of the fields destroy a good deal of the plant-growth.

The great advantage of the ploughs is, as can be seen, that a big amount of work can be done within a very short time, provided the soil is suitable. The ploughs are almost ideal to keep the main ditches open, as these channels are often very long and thus very well fitted for work with the plough. On comparing ploughing with manual labour, it appears that one plough achieves about 60 times as much as one man.

Yet another implement was introduced in 1954, namely, a gripper mounted on a small flat-bottomed boat (figure 34). The engine of this vessel provided power both for the gripper and the boat's own propulsion. It is located in the pontoon and can be covered by a hood to protect it against rain or other water. It is operated by only one man who runs the digging part working hydraulically, as well as the engine for moving the vessel along. A disadvantage is that these two functions cannot be carried out

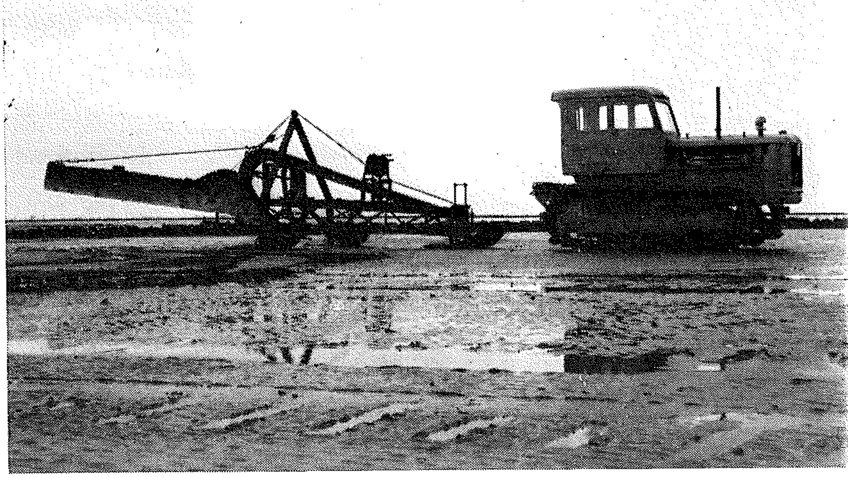


Figure 33.
Tractor with large plough.

simultaneously, as they alternate with each other and thus do not promote operational speed.

This system comprises a cable from the boat stretching about 100 metres (325 feet) behind the apparatus attached to a ploughshare anchor; by winding up this cable the machine draws itself backwards. Grips of varied sizes can be dug by means of it, but for the best results it is necessary to have, in addition to the driver, another man removing clods of warp remaining in the grip and levelling off any heaps of warp that may be formed on the field.

These machines work considerably slower than the ploughs, but to offset this they can operate on practically any kind of terrain without risk. Moreover, all the digging work can be done by them, including the digging of groyne-ditches, which cannot be done by ploughing. When it is necessary to move from one sedimentation field to another, the whole installation is towed by a tug during high water. During high tide it stays behind anchored in the sedimentation fields. The capacity of this machine is equal to that of 8 or 10 men, and although this is much below that of the ploughs it must be remembered that not only can it work almost anywhere but also that it can do all the necessary digging work.

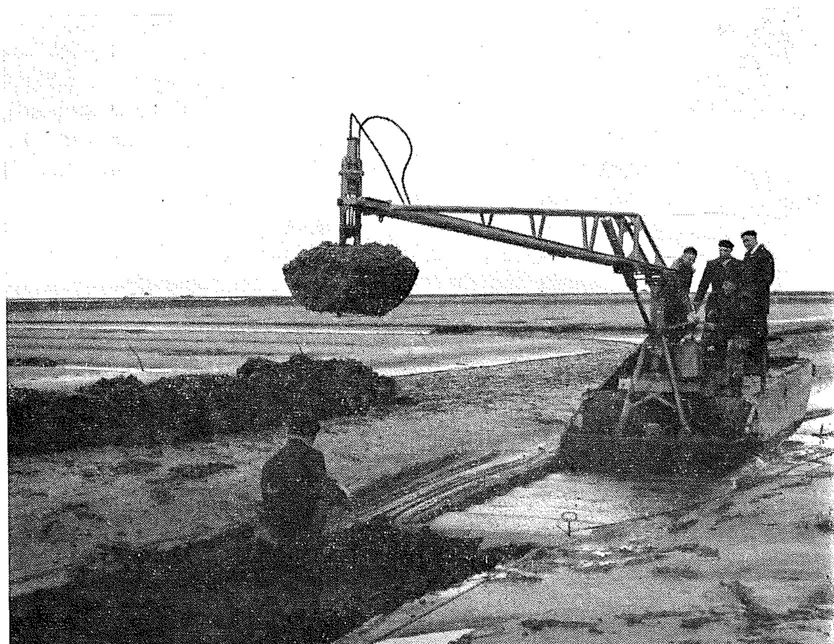


Figure 34.
Digging machine as now used
on the sedimentation fields.

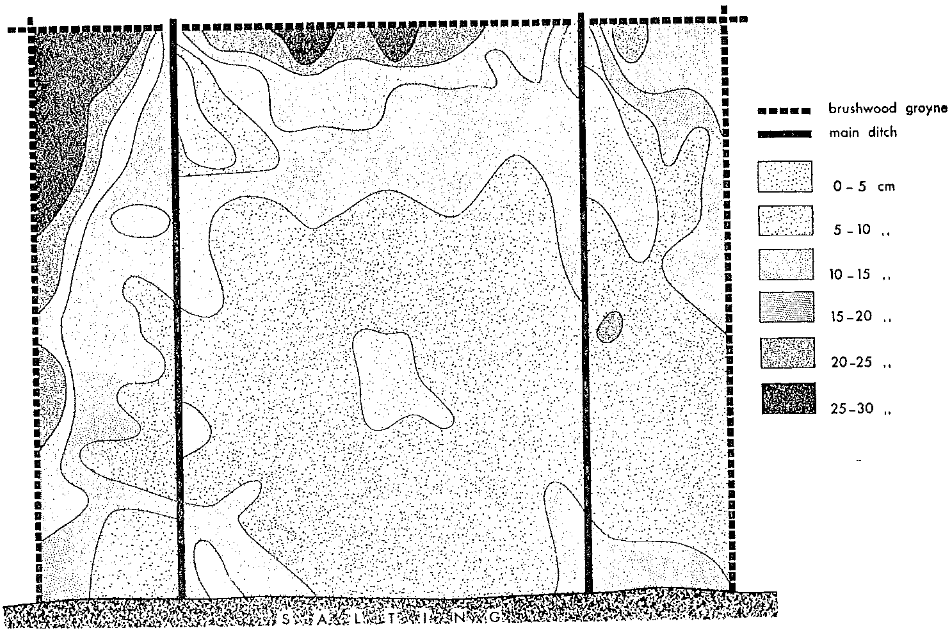


Figure 35.1. The differences in the thickness of the deposited warp layer in a sedimentation field without subdivision.

4.6. **Soil survey of the sedimentation fields**

It may seem a little strange to find the soil survey mentioned as part of the auxiliary means of land reclamation, although actually it is quite correct. It is true that not a grain more of mud is supplied by this activity, but nevertheless the soil survey contributes to an important degree in the work being done as efficiently as possible. In the first stage it was the soil survey that gave an idea of the pattern of the mud settled down within the sedimentation fields, and thus gave an insight into the weak spots of the methods applied. Furthermore, it revealed the differences in the sedimentation circumstances which existed at various points along the coast, as well as giving an impression of the influence being produced by the different improvements in the methods. And finally, it gave indications as to how the work was proceeding and the ways in which the whole project could be most economically completed.

Looking back at the first soil survey made after the construction of the sedimentation fields and comparing the results of it along the whole coast, it appears that they vary considerably at different points (figure 18). The favourable position of the watersheds is immediately noticed. Corresponding results were supplied by platform measurements and by samples of the grip warp (figure 18). Moreover, the measurements and the situation of the pre-sedimentation areas also give the same indication (see Chapter 2, Section 9), so that the favourable circumstances on and near the watersheds are well established.

On the other hand, the unfavourable results in the sedimentation fields behind the Westpolder were made clear by the soil survey, and led to the construction of a

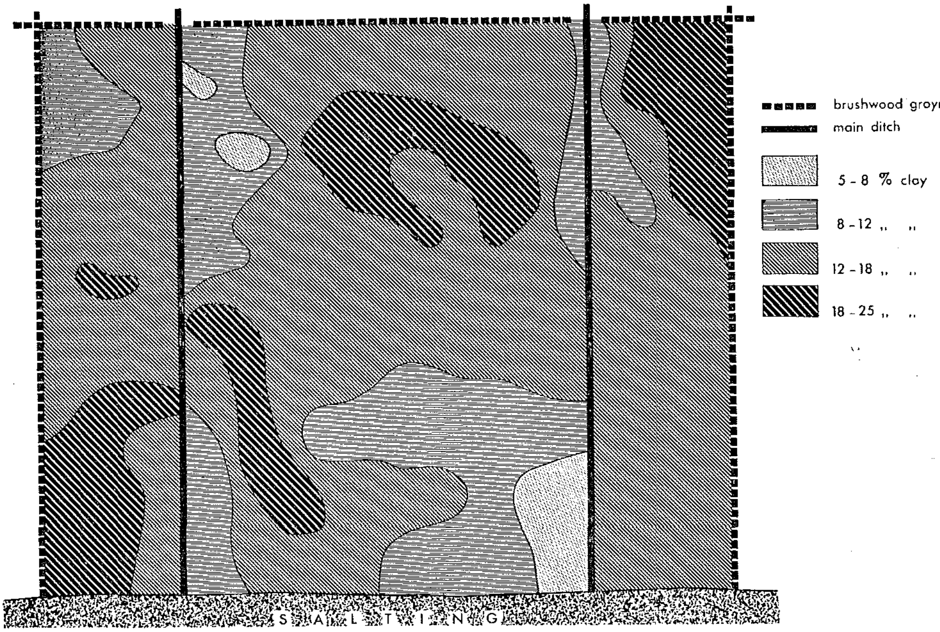


Figure 35.2. The differences in clay content of the deposited warp layer of the same sedimentation field as in figure 35.1.

measuring platform on this point. From the information collected it became evident that it was not a question here of lack of mud in the water but rather of unfavourable circumstances for sedimentation which was being hampered by the wave movement. The same was the case behind the Oostpolder where the soil survey also showed that the results were bad. Here, however, the supplementary investigation on a measuring platform demonstrated that it was a case of lack of mud.

As far as the silting up within the sedimentation fields is concerned, the soil survey also supplied some interesting information. It showed that the deposit of the material started first east of the brushwood groynes running in the direction of the sea and south of the cross groynes. On the west side of the brushwood groynes the sedimentation took place less smoothly, and in the south-eastern corners of the sedimentation fields it was almost completely absent. Figure 35 gives a good picture of the pattern of the silting up within the sedimentation fields. There can be no doubt that here the wind has a great influence, and that if it were not present the distribution of the sediment would be much more favourable. It is on these observations that the sub-division of the sedimentation fields by earth groynes is based. It is unfortunate, however, that the formation of these earth groynes takes so long, as it is only after a few years that their usefulness can be seen. From the adjoining example (figure 36) it is clear that the presence of these earth groynes has greatly improved the situation.

Then, again, the soil survey is a means of preventing extra or unnecessary work. In this respect it is of very great significance, because as the land reclamation already demands a great deal of labour it is essential to deal as economically as possible with the workers available. As soon as a sufficient quantity of warp has accumulated, or when the support of vegetation can be depended on, the actual work can be limited to giving the area a good drainage. The soil surveyors make maps based on the information they collect and on the extent of the vegetation, and which are therefore very useful for the supervisors charged with carrying out the work. Experience has shown, too, that these maps are of special value for the transition areas.

Finally, the soil surveys supply the necessary information about the subsoil and its composition, so that even before the diking actually starts all necessary details are known about the future shallow bottom.

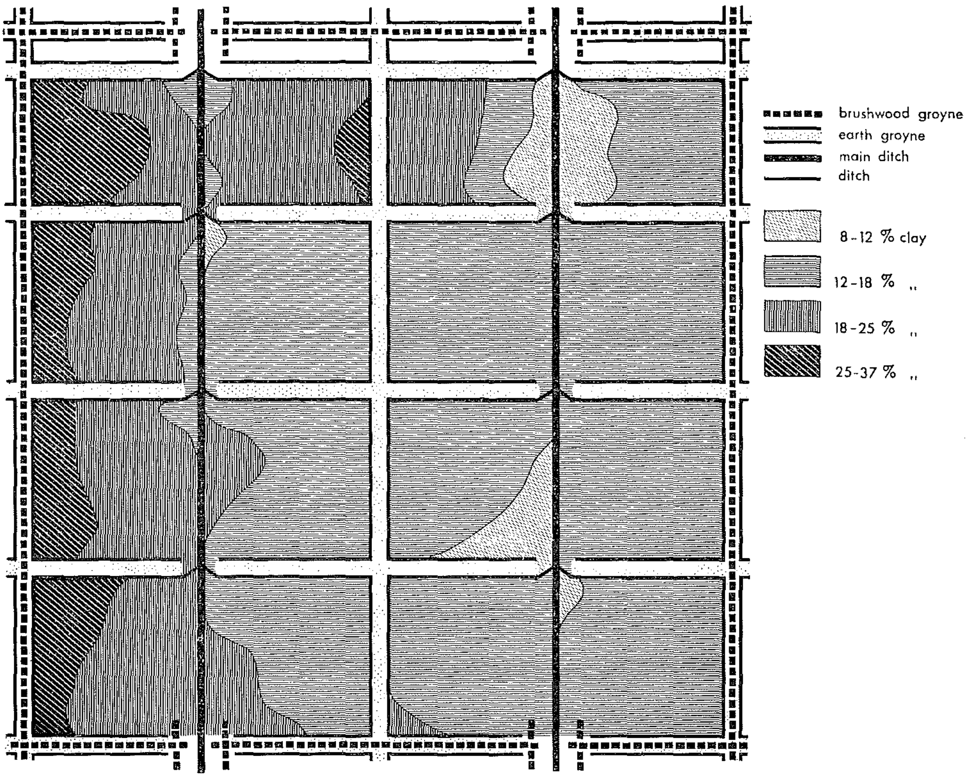


Figure 36. The differences in clay content in the upper layer (30 cm) of a sedimentation field, subdivided by earth groynes. The pattern has become more regularly, especially the influence of the brushwood groyne must be mentioned.

4.7. **The labour force**

From what has been said in the foregoing pages it is obvious that there must be sufficient workers available if success in land reclamation is to be assured. The re-digging of the grips and smaller ditches, the maintenance of the groynes, and similar work must be continuous; it cannot be stopped for any length of time without causing damage. Moreover, as work cannot be done during the winter months, it all has to be compressed into a certain period of the year. For this reason it is necessary to work out in advance the number of workers who will be available during a certain period, and then fix the size of the work accordingly. Obviously this will not be possible as there is a lot of uncertainty about the size of the labour force that will be available. Moreover, it is not even possible to predict when in a certain year workers will actually become available. In these northern provinces particularly, this is almost wholly dependent on work in the agricultural sphere. Indeed, this question of labour is one of the most difficult and uncertain factors with which the carrying out of this form of land reclamation has to struggle.

However, as nowadays the mechanical digging of grips is possible, these works are less dependent on the offer of human labour than before. By careful calculation the complete execution of the work on time can be assured — which was not formerly the case — so that there is no longer the great danger as hitherto of losing through shortage of labour what had been gained with the expenditure of much money and effort. The reclamation work being done here, the success of which has been greatly determined by the activity of men — in contrast to the former farmers' method and the Schleswick-Holstein method where the influences of Nature are much stronger — can therefore profit by the machine labour now available, so that the size of the project and the amount of work have become less important factors than they were some years ago.

5. The vegetation in the Dutch Wadden Shallows

5.1. General remarks

The influence of the vegetation on sedimentation has already been discussed in earlier chapters of this review. Reference has also been made to the fact that the role of vegetation in the present form of land reclamation has become rather a small one, although there is still taken advantage of, whenever and wherever possible. At the outset of the work it was the formation of saltings that was the aim, and if this had been continued the vegetation would have fulfilled an important function in the fixing of the mud. Because of the original aim, a good deal of attention was given to the most important plants that played a significant part in the sedimentation process. These have, indeed, been given a great deal of study, particularly in connection with their multiplication and expansion possibilities.

The number of species of plants which play an important part in the fixing of the sediment just as the number of marine creatures, which sieve mud out of the water, is very few. There are, of course, very many species which occur occasionally in the area silting up, but these never serve anything like a useful purpose compared with that of the following three species:

a. glasswort or marsh samphire (Salicornia herbacea L.);

b. cordgrass (Spartina Townsendii H. et J. Groves), and

c. sea poa (Puccinellia maritima Parl.).

Each of these species will now be discussed more or less extensively, after which a few remarks will be made about some of the less important species and the grazing of the saltings.

5.2. Glasswort (Salicornia herbacea L.)

This plant is an annual and occurs in a great number of varieties. Its height is never more than 25 cms (10 inches). It is of a succulent type and grows very slowly in the initial period. In October the plants die off, after which the seeds embedded in the parenchymatic tissue, are set free by the rotting of the tissue. The woody part of the stem often remains as a bare bush at the place of growth.

Before 1928 glasswort was the first higher plant to appear as the bottom of the shallows became higher. In many respects, it is an interesting plant, but its direct value for land reclamation has often been over-estimated. For a plant to be important for silting up, the crop must be close and preferably covering the bottom. This certainly cannot be said of the glasswort, especially not in the most outside zone of the area in which it is found. Its value cannot possibly be seen in the function of fixing the mud. Moreover, this annual crop develops very slowly and dies off in the autumn, so that during the period of rough weather (autumn and winter) it is of little use. On the contrary, it seems that the occurrence of glasswort often means more damage than advantage, because by its presence the material already deposited can again be stirred up as a result of the remaining dead bushes making a rotating movement, caused by watercurrents.

There is, however, one reason why glasswort can certainly be appreciated, namely, the important role it fulfils in the spreading and expanding of the sea poa which is so valuable for silting up. Indeed, it has been shown that as far as the spreading of the sea poa is concerned, it is largely dependent on the presence of glasswort. The sea poa is spread either not at all or only in a very small measure by seed, but mainly by vegetative parts torn off from the parent plant. These torn-off parts are moved by the rising and falling water, as a result of which the greater part of them ends up at the foot of the dyke. The smaller part, however, remains behind hooked on to the living or dead glasswort bushes on the shallows. Now these torn-off vegetative parts have a very tenacious life. Although they often look completely wilted or dried up, it can be seen on closer examination that only a portion of them is really dead and that most of them are able to form roots rapidly with which they fasten themselves to the bottom.

How strong the influence of the glasswort is on the establishment of the sea poa can be seen from the following test that was carried out. On four fields one-half of the area was cleared in the spring of the old glasswort bushes and the sea poa plants already settled there. On the other half the bushes were left alone, but the sea poa plants were removed in the spring before the start of the experiment. At the end of June the half of the fields from which the dead bushes had been removed in the spring was also carefully cleared of the young glasswort plants. When the results of the test were examined in October, it appeared very clearly that considerably more sea poa plants had settled in the fields covered with glasswort bushes than in those fields that had been cleared of glasswort, showing that the spreading of sea poa is to a great degree dependent on the occurrence of glasswort. The number of settled sea poa plants varied considerably, being from 6 to 13 times more on the glasswort fields than on the bare fields.

It also appeared that for the settlement of sea poa it is important that it occurs in the surroundings, because on the fields located in the coastal areas where sea poa occurred, the quantity of torn-off pieces caught and settled was considerably larger than elsewhere.

To prevent any misunderstanding, it must be pointed out here that the appearance and development of sea poa plants in the summer does not mean that this plant also continues to live during the winter. For its definite establishment the terrain must be of a certain height (about 20 cms — M.H.T.), or, namely, about 20 cms (8 inches) higher than the zone in which the most outside glasswort plants are found (about 40 cms — M.H.T.).

The height of 40 cms — M.H.T. mentioned above does not mean that on all areas which have reached that height glasswort is also to be found, even when there has been a good provision of seed. *) It is always dangerous to draw conclusions about the course of the sedimentation from the occurrence of this plant. Experience has shown that by so doing conclusions are reached which are not in accordance with reality. This is a result of the fact that the plant is an annual and that both the seed distribution and the germination often occur very unfavourably, so that, although there has been heightening of the soil, the vegetation border can have receded a lot in respect to the preceding year. In this connection perennial crops such as sea poa give a better hold, provided the survey of the vegetation is always carried out in the same season.

When a beginning was made with land reclamation according to the modified Schleswick-Holstein method, glasswort occurred only here and there. The reputation this plant had gained as a great promotor of silting up therefore necessitated an investigation into how a means could be devised to make it possible to stimulate the distribution of this crop. For such a distribution, however, it is not necessary for the whole area to be directly covered with plants, but rather that there are small centres from which the distribution of seed can take place in the following autumn by natural means. In this connection a number of problems admittedly arose, but all were ultimately solved, so that in the end, after complicated methods of seed production and sowing had been applied, a simple way of seed distribution was developed which is proving very satisfactory.

At first efforts were made to free the seed which, as already pointed out, lay embedded in the parenchymatic tissue of the stem, by means of drying and then

*) The level on which a certain species can settle or is able to maintain itself is determined largely by the time the soil is covered by the water at each tide.

Figure 37. The glasswort seed being forced out by a jet of water. In the background on the right is one of the mice-free racks on which the crop of bushes is stored.

threshing. But it later appeared that two big mistakes had been made. In the first place, the tissue had been allowed to become so tough that the seed could hardly be removed with the aid of steel brushes. In the second place, it appeared that by the drying of the seed its germinative power had been lost. In 1938 *Wohlenberg* published an important article about the gaining of seed and the sowing of glasswort in which he indicated the best ways to carry this out. The train of thought in Germany had been that in Nature the seed becomes free by the rotting of the parenchymatic tissue, and that if this process

Figure 38. Machine for the sowing of glasswort. The lightly constructed wheel which moves the seed distributor can be clearly seen.

is left to be carried out in its own way while preventing the seed from being washed away, it may well be successful in separating the seed from the rest of the plant. That, indeed, appeared to be the case, especially when there was the assistance of a strong jet of water which forced the parenchyme to remain and the seeds to be pushed away from the woody parts of the plant so that they could be caught in a barrel filled with water. The very light floating parenchyme particles floated with the water over the brim of the barrel, while the seed remained on the bottom with other heavy material such as sand. This experiment gave excellent results (figure 37).

After being made free in this way the seed must be rapidly made air-dry although care must be taken that drying is not too strong, as in that case the seed loses its germinative power. The keeping of the seed also requires continuous care. It must not be stored in thick layers because that would cause fermentation, while precautions must also be taken to ensure that it does not get mouldy. So it must be kept in a cool place and regularly turned. Even before the seed is obtained there is the risk that if the plants are stored in too thick layers or if the temperature rises too high, the seeds will start to burst. Water also promotes the bursting of the seeds to a considerable degree. Then, if the weather is suitable, the seeds can be sown in the beginning of March.

In Germany, however, the sowing created difficulties because it was impossible to use the seed-sowing mechanism of the existing machines. So all the seed, which is very fine, had to be sown by hand. This difficulty, fortunately, has been solved in Holland as can be seen in figure 38, showing the Dutch-designed sowing machine.

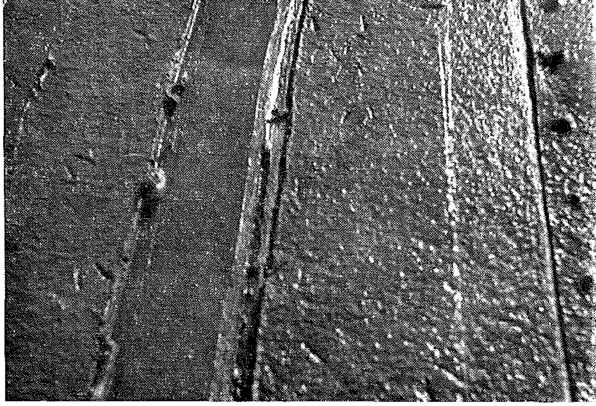


Figure 39.
The tracks of the seed-sowing machine. On the left is the imprint of the sowing foot, while on the right the trail of the gliding-iron and the points of the wheel which moves the distributing mechanism can also be seen.

The machine itself is pulled on two gliding irons, while a light wheel with long pins moves the mechanism that distributes the seeds. These are led through a tube to the sowing foot to which, in sandy soil, a pin is attached to form a very shallow channel which is closed again by a small sliding-board after the seed has been put in. When used on clayey warp, the seed needs only to be pressed in a little by the machine's sliding-board. If, however, the seed is put in too deep (say more than 2 mms.), then there is a great chance that it will not germinate (figure 39). If, however, such a machine would have to be made nowadays, it would be fitted with the so-called aeroplane wheels to facilitate movement. The same machine, it can be added, can also be used for the sowing of cordgrass seed by making a small change in the sowing foot.

After success had been achieved, through a great deal of effort, in gaining and sowing the seed, efforts were made to simplify the whole process. The method developed was certainly simple, but it was still rather laborious. Finally, however, the solution turned out to be a very simple one, namely, by direct sowing immediately after the crop. To do this the harvested plants were cut into pieces of about one inch by means of a chaff-cutter, and these were at once disseminated by throwing them down with some force on the surface of the shallows. It was found, however, that such a method is not successful on sandy soil. Figure 40 shows the result of such sowing on clayey warp. This simple method not only saves a great deal of work and care with the seeds, but is also easier to handle.

Nowadays glasswort appears along the whole of the Groningen coast and it is no longer necessary to promote the distribution of the crop artificially. Although the density and size of the area covered with this crop varies from year to year, the natural seed distribution is practically always more than sufficient to produce a good crop, even in unfavourable years. In the very few cases where this does not happen, the cause is usually to be sought in bad weather conditions during the initial stages of growth, when the small plants are often washed away. Another reason why this crop does not always make reasonably quick coverage is to be found in too intensive grip-digging which results in the plants not being given a chance to develop themselves.

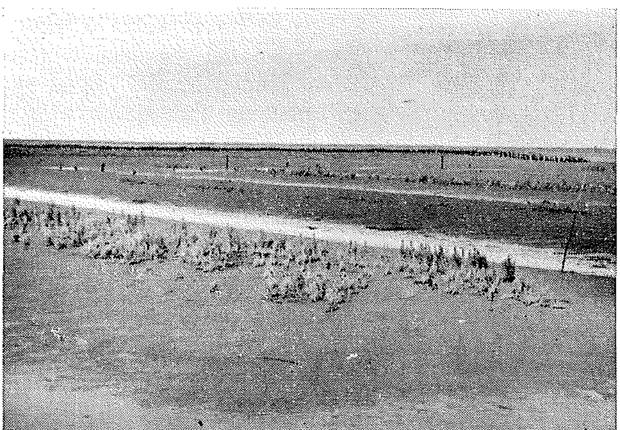


Figure 40.
Result of sowing glasswort on a sedimentation field behind the Westpolder. In this area only every alternate field was sown.

5.3. Cordgrass (Spartina Townsendii H. et J. Groves)

Cordgrass is a graminaceous plant imported into the Netherlands from the English south coast. It is a coarse crop looking slightly like reed (Phragmites communis L.) which can reach a height of just over three feet under favourable conditions. Several varieties are known which, however, differ considerably in their qualities. The crop comes to development at about the same level as glasswort, but its growing period starts later and also ends much later. Cordgrass also offers protection to the soil in the winter and the spring as its died-off leaves and stems remain for a long time. When land reclamation work was started in this area, a good deal of experience had already been gained with cordgrass in the south-western part of the Netherlands (Zeeland). This was so favourable that it was thought it would be of considerable use in promoting sedimentation in the north if it were planted on a large scale.

But although the expectations were high, the crop proved disappointing in practice, for which there were several reasons. In the first place, the plants supplied from Zeeland did not seem able to cope with the climate in the Wadden area; from the thousands of cuttings planted, less than 1% remained, the rest having been frozen out. This situation, moreover, occurred many times, so it seemed very obvious that the material supplied was not sufficiently winter resistant. It had also been hoped that cordgrass would develop here in such a way that it could take over part of the task of the groynes. But this expectation also proved unfounded. Because of the sandy soil the ground around the plants was easily washed away, so that finally they were torn out of the soil by the water currents and disappeared. Moreover, the crop would not grow on the open shallows without groynes, and therefore replacement of the groynes by cordgrass was not possible. Furthermore, the speed with which the transplanted cuttings expanded was also very disappointing. It is now known that cordgrass needs a food-rich soil for a rank growth and also that every year it requires a new small layer of fresh warp, so the poor sandy bottom of the shallows is not suitable to produce a luxurious crop of cordgrass.

In Zeeland the plants were set out at intervals of about 5 metres (16 feet), and after about five years they covered the whole area. But in the north the plants grew much more slowly, as shown in the following table. From this it is very obvious that the growth in the northern part of the Netherlands is slower than in Zeeland.

Expansion speed of cordgrass cuttings after planting

	after 1 year	after 2 years	after 3 years
Average diameter per tussock	32 cms (12 inches)	52 cms (21 inches)	82 cms (33 inches)
Extreme values	23-45 cms (10-20 inches)	37-83 cms (15-33 inches)	58-143 cms (24-58 inches)

To overcome the difficulties, the first thing done was to try to select a winter-resistant variety. At various points along the coast groups of the remained cuttings together with the remnants of what had previously been planted by the „Bond van Kustwaterschappen", were planted out in the hope of obtaining clumps which were winter-resistent. It was also hoped in this way to get plants producing seed with a higher germinative power, as from tussocks standing alone this capacity is often very

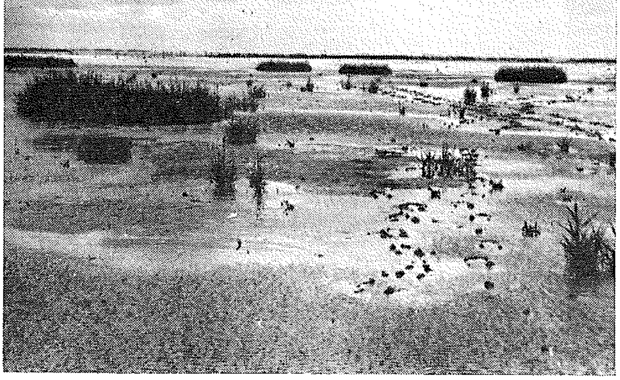


Figure 41. A few of the oldest cordgrass tussocks. This area is now completely overgrown with cordgrass, a number of new tussocks having been planted between the old ones.

low. This effort succeeded, and has had the result that there are now large cordgrass fields along the Groningen coast (figure 41). Moreover, success was also achieved in obtaining seed from these plants so that the crop could be further multiplied by sowing.

As with glasswort, a great deal depends on this gaining of seed. Because the crop develops late, both the flowering and the ripening of the seed are also rather late, so that the further the harvest is delayed into the autumn, the better chance there is of obtaining mature seed. One danger, however, connected with a late crop is that of night frosts, which can do a good deal of damage. It had appeared, for example, that after one or two considerable night frosts, with temperatures lower than —4°C., the seed easily falls away from the stems, so that the risk is too great to leave the harvesting later than mid-November.

Another point to notice is that when there is a cool summer, seed production is rather bad, as the plants then develop too slowly. One more thing: the cordgrass seed must not be allowed to dry out completely as with glasswort; it must, indeed, be kept in almost the same way. After mid-April the germinative power declines very rapidly, so the best time to sow is from mid-March to mid-April. The sowing can be done in the same way as glasswort, except that the seeds must be put a little deeper in the soil. This can be done by fitting a larger pin to the sowing machine. Figure 42 shows a row of cordgrass plants sprouting up from the seed.

In addition to seed-sowing, however, multiplication can be done by means of cuttings, transplanting of tussocks, and planting of seedlings. With the planting of

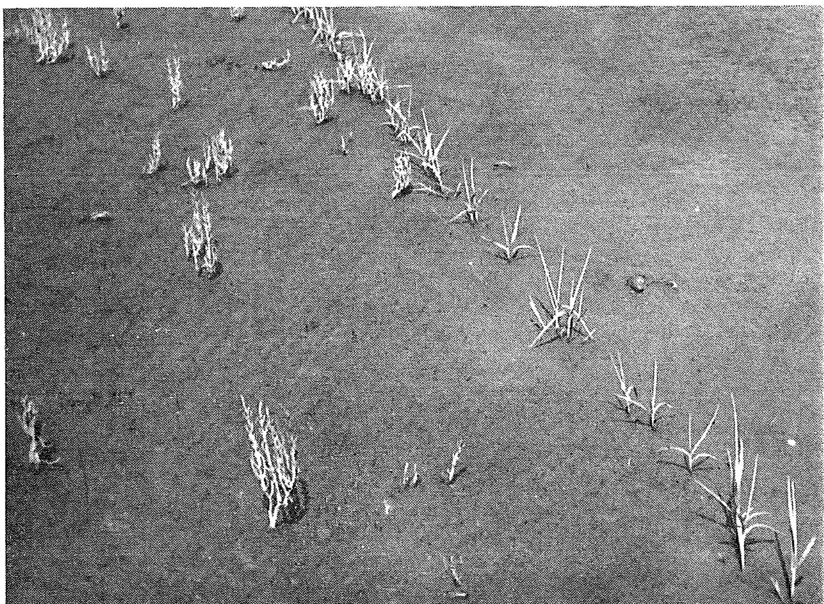


Figure 42.
Cordgrass plants sprouting from the sown seeds.

Figure 43. Cordgrass cuttings as planted in shallows.

cuttings, a start should not be made before May 15 and be finished not later than August 15, but preferably earlier, as otherwise the plants are not sufficiently well rooted before the autumn. After the transplantation, a yellowing of the leaves usually occurs (figure 43).

As already stated, there are different varieties of cordgrass which differ in growth, in the shape of the ear, the colour of the stalks and leaves, the length of the stems, and in flowering time, as well as in the rate of extension (figure 45). One of the medium heavy varieties is early flowering and supplies considerable quantities of seed, and so it forms for the greater part the present cordgrass growth. Unfortunately the varieties which extend the most rapidly can be multiplied only by planting cuttings or tussocks, as the seed ripens much too late and does not come to maturity.

As stated, in addition to cuttings, rooted tussocks can also be planted. This way of multiplication gives the best results but is very expensive, as it also means the replacement of a good deal of soil. In certain years there are sufficient seedlings of adequate development suitable for planting out, and this method then becomes the most economical of all the planting methods (figure 44).

Although cordgrass undoubtedly promotes still water, it is not yet certain whether it has really any utility for the northern Holland areas. In the first place, it extends slowly, so that it takes a few years for a field to be covered. In that period, however, the level of the soil has already been heightened so much that often the sea poa can

Figure 44.
Cordgrass seedlings ready for planting out. Remains of the seed can be seen on some of them.

also grow there. This is a great disadvantage, because the sea poa is of much greater use than cordgrass which has practically no value as a cattle fodder. The cattle do not like it fresh and it is also useless for fodder both when dried or as silage.

Another great disadvantage of cordgrass is that both the plants and the seedlings have a marked preference for a place in the grips. This creates many difficulties during the digging, for not only must the crop first be mowed at considerable cost but also the soil replacement costs more in time and money than with other plants as a consequence of the many and strong roots of these plants. Furthermore, it is not possible to determine with such a tall crop whether the excavated material is put in the right spots in the field.

All these disadvantages mean that a method is now being sought to remove it, at least in certain areas. The use of toxic sprays along the dyke is not permissible because of the danger to cattle and children. Moreover, it is not certain whether this crop would react to any spraying, because the sprayed liquid does not attach to the stalks and the leaves but merely runs off them. The crop cannot be removed by mowing because the uneven surface in many places prevents the short cutting which is so essential. As it is known from experience that cordgrass is very sensitive to damage to the roots, the best results can perhaps be obtained by developing a method for dealing with the roots.

So altogether it can be concluded that cordgrass has not come up to expectations. Its development and extension are too slow; while when it finally does cover a field completely it prevents the establishment of another, and much more useful crop, the sea poa, because cordgrass, unlike the glasswort previously, does not disappear when the sea poa arrives.

Figure 45. Various varieties of cordgrass; the difference between them can be readily seen. The tussocks originate from cuttings planted at the same time.

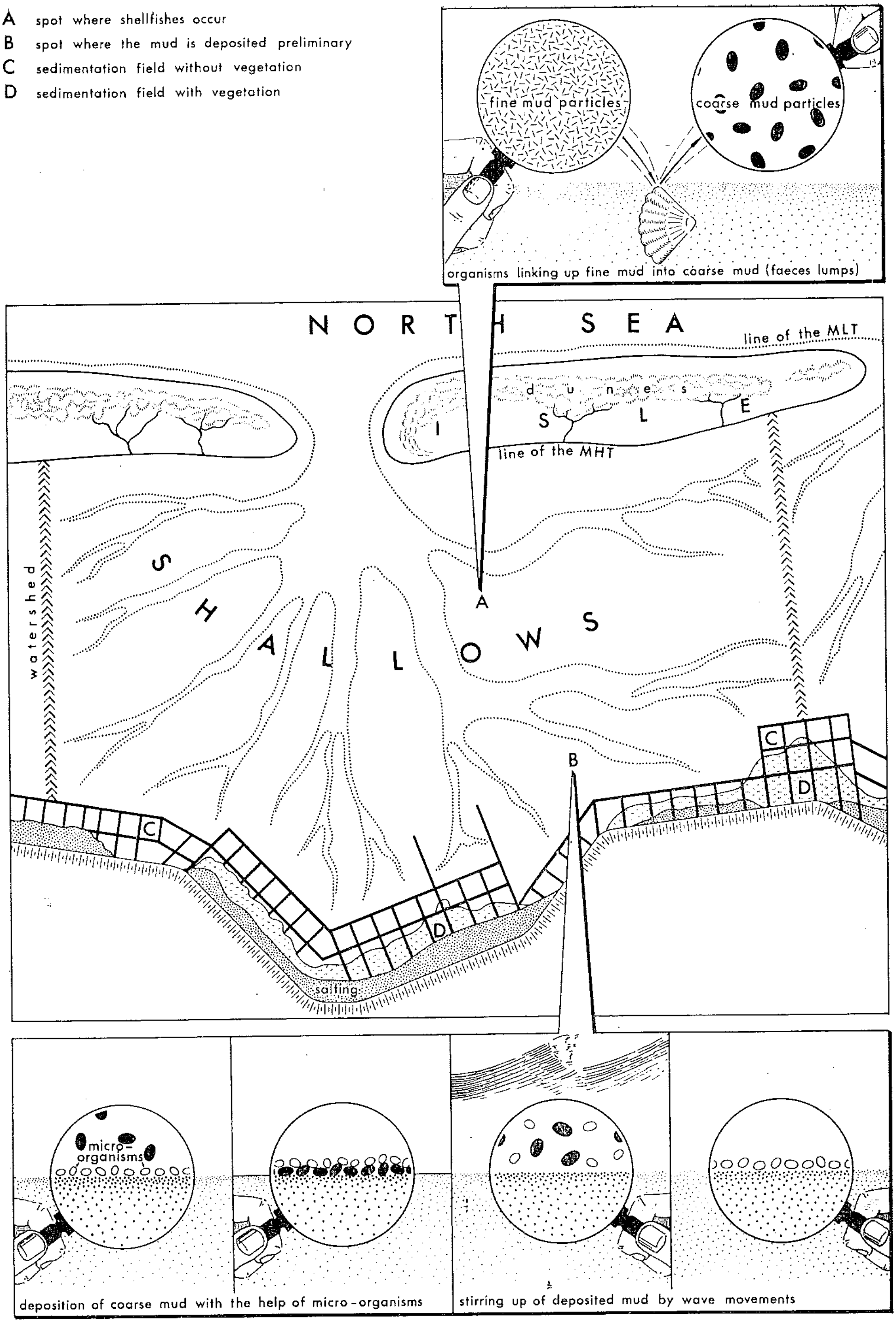
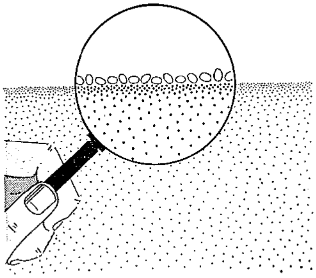
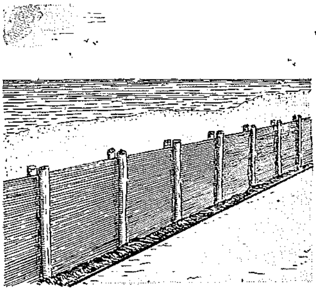


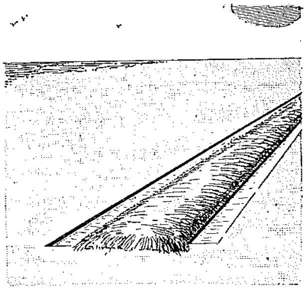
Figure 46. Sketch of the movements and changes in the nature of the mud on



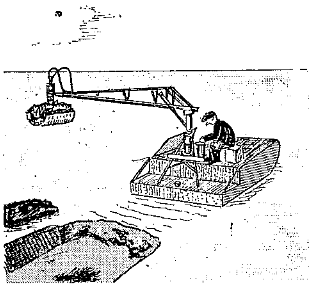
original shallow



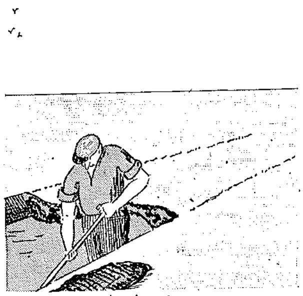
brushwood groyne



earth groyne

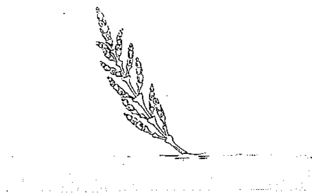


mechanical grip-digging

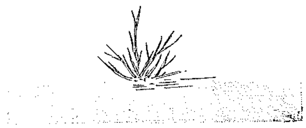


grip-digging by hand

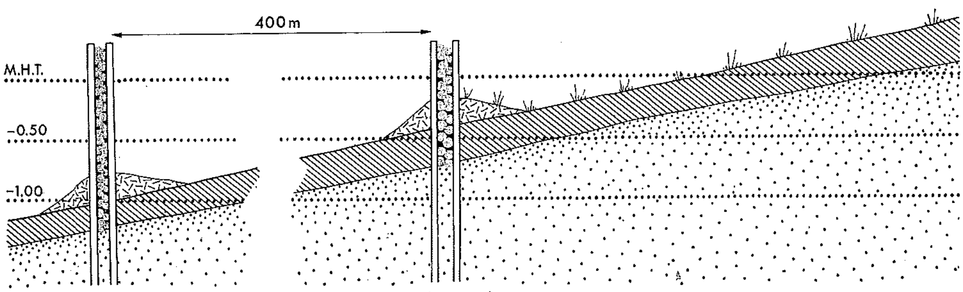
spartina townsendii (1:25)



salicornia herbacea (1:10)



puccinellia maritima (1:5)



schematic profile of the sedimentationfields perpendicular to the coast

the shallows (left) and the components of the land reclamation works (right).

5.4. Sea Poa (Puccinellia maritima Parl.)

The sea poa is a rather low crop. It is a grass which forms many shoots which root easily at various points, so that the plants occupy large areas within a comparatively short time. The cattle on the saltings like to eat it, and at the same time by natural means contribute to the distribution of this plant. As flowering plants seldom occur, the distribution is done mainly by vegetative parts which are in one way or another broken off and carried away from the parent plants. In this connection glasswort plays a significant role, as already explained.

The sea poa, like glasswort, occurs only above a stated height (about 20 cms — M.H.T.). When that height is reached and the plants are well settled, the chances are small that it will disappear again. Observation has shown that the rate at which the tussocks get higher varies from 3 to 9 cms (1 to 2½ inches) in the summer season. The heightening consisted in this case almost entirely of sand which probably came from the immediate vicinity. It was this ability to fix material that was also responsible for so much sand being collected on the seaward side of the former saltings and why they were so greatly sandy on the outside edges. The strange ability of this grass is that, having worked itself completely into the sand and been entirely covered by it, the plants work themselves out of it again.

The fixing capacity of this grass is attributable to its denseness and fine leaves which retain a great deal of material from the flooding water, as appeared from the following experiment. Measurements were made in a sedimentation field on grips which were 35 metres (115 feet) apart. One grip was entirely bordered by fields covered with sea poa, and the other by fields covered with glasswort. The grips were dug at the same time. In the glasswort-bordered grips five times as much warp was deposited as in the grips surrounded by the field covered with sea poa, showing that during ebbing tide this grass greatly hampers the washing of mud, settled down on the field during high tide.

With the land reclamation works under consideration, it was seen that the expansion of this useful crop has sometimes been less advantageous and satisfactory at the outset because the digging of deep ditches often was continued too long. Because of that delay, the growth of glasswort was hampered and the distribution and settlement of the sea poa was largely prevented. So in more recent years attempts have been made to extend sea poa artificially by scattering and treading in large numbers of offshoots. The results of these tests, however, have been very varied, although it has not been possible to find out why. Especially for earth groynes which suffer considerably from water movement because of their greater height, the growing of grass is very important, as it can contribute to a very great extent in limiting the effects of the flooding water.

5.5. Less important plants; the grazing on the saltings

The grass that follows the sea poa when the level of the salting rises is red fescue (Festuca rubra L.). So it occurs only on the higher saltings. It is not as resistant against regular flooding with salt water as the sea poa, and therefore has little significance as far as the fixing of material is concerned. It is discussed here because it has been seen that it is of special importance for the turfing of the dykes and for the supply of seed which can be used for sowing on the foot of the dyke.

From the foot of the dykes to the top, various zones are found which are individually characterised by the particular species of grasses occurring in them. This in itself creates problems. For example, when a damaged spot is to be repaired, it will be very infrequently that a sod taken from the saltings will contain just that mixture of grasses belonging in that particular zone. So if the grass of such a sod consists of sea poa, then it must be replaced by other grasses, as the sea poa cannot maintain itself in the new and drier milieu. But as the seed supply on the dykes is usually bad as a result of the very intensive grazing, the sea poa is often replaced by weeds instead of by other grasses, which again produces a bare and weak spot in the dyke because they give less coverage to the soil, especially in the winter. This means that in the following year, or at least a year later, the spot must once more be re-turfed. To solve this problem, nowadays seed is strewn onto the spots which have to be re-sodded, taking care to use seed of the grasses which normally grow in that zone. For the low zone of the dyke this is seed of red fescue collected from the saltings and originating from a salt-resistant variety.

Finally a plant should be mentioned which rarely appears on the sedimentation fields and saltings along the North Groningen coast, namely, the sea aster (Aster trifolium L.). At first it seems surprising that this crop, which occurs so often in the Lauwers Sea and covers large areas of the Dollard with plants upto 2 metres (6½ feet) high, is almost entirely absent here. The explanation seems to be that it is so liked by sheep that these animals immediately graze every germinating plant to the root. So while there are plenty of germinating plants, or seedlings, practically none of them ever grows to maturity.

One last word must be said about the grazing of the saltings. Generally these are grazed by sheep, although today there are also polders in which heifers are admitted to the dykes and saltings. A few years ago many complaints were heard about a lung sickness which attacked sheep grazing on the saltings, but nowadays little is heard about it, so that at the present prices (1955) for sheep and wool the possession of saltings is greatly appreciated, even though there have been times when the opposite was the case.

Grazing with geese, such as is frequent in Schleswick-Holstein, is not known here. It is true that these creatures need regular supervision, but as the financial results there are favourable, it would seem that when a considerable formation of saltings could be obtained in this area (which is not yet the case), it would be worth investigating whether geese-breeding might not offer good prospects, especially as the results of sheep-rearing are very uncertain.

Postscript

Dr. Kamps' publication only touches upon the scientific and technical aspects of land reclamation and the factors influencing the results. He wished to abstain from expressing an opinion on the economic side of the matter. Nevertheless it might be useful to say a few words about the subject. For this publication might easily tempt one to undertake land reclamation along a certain stretch of coast without first giving due consideration to the financial implications.

Land reclamation by the modified Schleswick-Holstein method as was first undertaken along part of the coast of the northern part of the Netherlands requires a very large labour force indeed. Although mechanization has radically altered this, the cost per annum is still high because of the unfavourable working conditions and the special machinery required, which latter can hardly be used anywhere but in the shallows. The brushwood groynes are still made and kept in good repair by hand. So that part of the work is relatively expensive until the brushwood groynes are replaced by earth groynes.

The thickness the layer of soil to be reclaimed should have before it is fit to turn into a polder depends on the nature of the bottom of the original shallows. This thickness varies from between 0.25 m and 0.9 m. Since the rate of silting up along the coast varies considerably, the time required for silting up to take place may vary from between three and forty years or more. When the reclamation of a layer of good soil takes several decades the cost per hectare is of course exorbitant. However, in another area sedimentation conditions may be so favourable that the digging of ditches is practically unnecessary. Then, of course, the cost is relatively low. Such areas, however, are few and far between. The cost price of a hectare of land on the coast of the Netherlands that is ripe for turning into a polder ranges from 1,000 to 40,000 guilders. In return for the sum paid one gets a piece of undyked land with a soil profile that may make very good arable land on being turned into a polder.

The cost of encircling land with dykes and turning it into polders is also high, because relatively narrow polders (approx. 1,000 m) only can be designed for this type of reclamation. The length of the dyke will then be great in proportion to the area turned into a polder (the dyke factor). As a consequence of the demands made nowadays upon a sea dyke the cost of building dykes under the conditions prevalent in the Netherlands is from 15,000 to 20,000 guilders per hectare. Preparation of the polder for cultivation involves an additional expenditure of about 2,500 guilders per hectare.

Therefore the total cost of one hectare of land encircled by a dyke and reclaimed by the modified Schleswick-Holstein method ranges from 20,000 to 60,000 guilders. However, if the existing sea dykes have to be raised, as is the case along the coast in the north of the Netherlands, the cost of doing so can be deducted from the total cost of the new polder, since the very construction of the new polder makes the strengthening of the existing sea defences unnecessary. The resulting saving is in the range of 10,000 to 12,500 guilders per hectare of newly reclaimed land. So such land may cost anything from 10,000 to 50,000 guilders per hectare, the average figure being in the range of 25,000 or 30,000 guilders.

In view of the present cost of agricultural land reclamation does not pay if it is undertaken by private enterprise. Opinions differ considerably as regards the value judged from the point of view of national economics. Calculations based on data obtained from the Agricultural Investment Committee *) show that the national value of land reclaimed

*) „Proeve van een nationaal-economische beoordeling van investeringen, toegepast op de inpoldering van oostelijk Flevoland."

and enclosed in dykes in the north of the Netherlands may now be set at about 10,000 guilders per hectare. Although approximately 15% of the total expenditure can be deducted as covering the reduction in unemployment (the percentage varies with the economic situation) land reclamation by the modified Schleswick-Holstein method followed by the building of enclosing dykes hardly pays at all nowadays when looked at from the point of view of the national economy.

So local conditions must be studied closely before undertaking land reclamation by this method. An idea of those conditions can be obtained and the cost and returns estimated by laying out some trial sedimentation fields. They will show whether land reclamation by this method is economically justified.

Baflo, November 1959.
Ir. R. J. de Glopper.

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