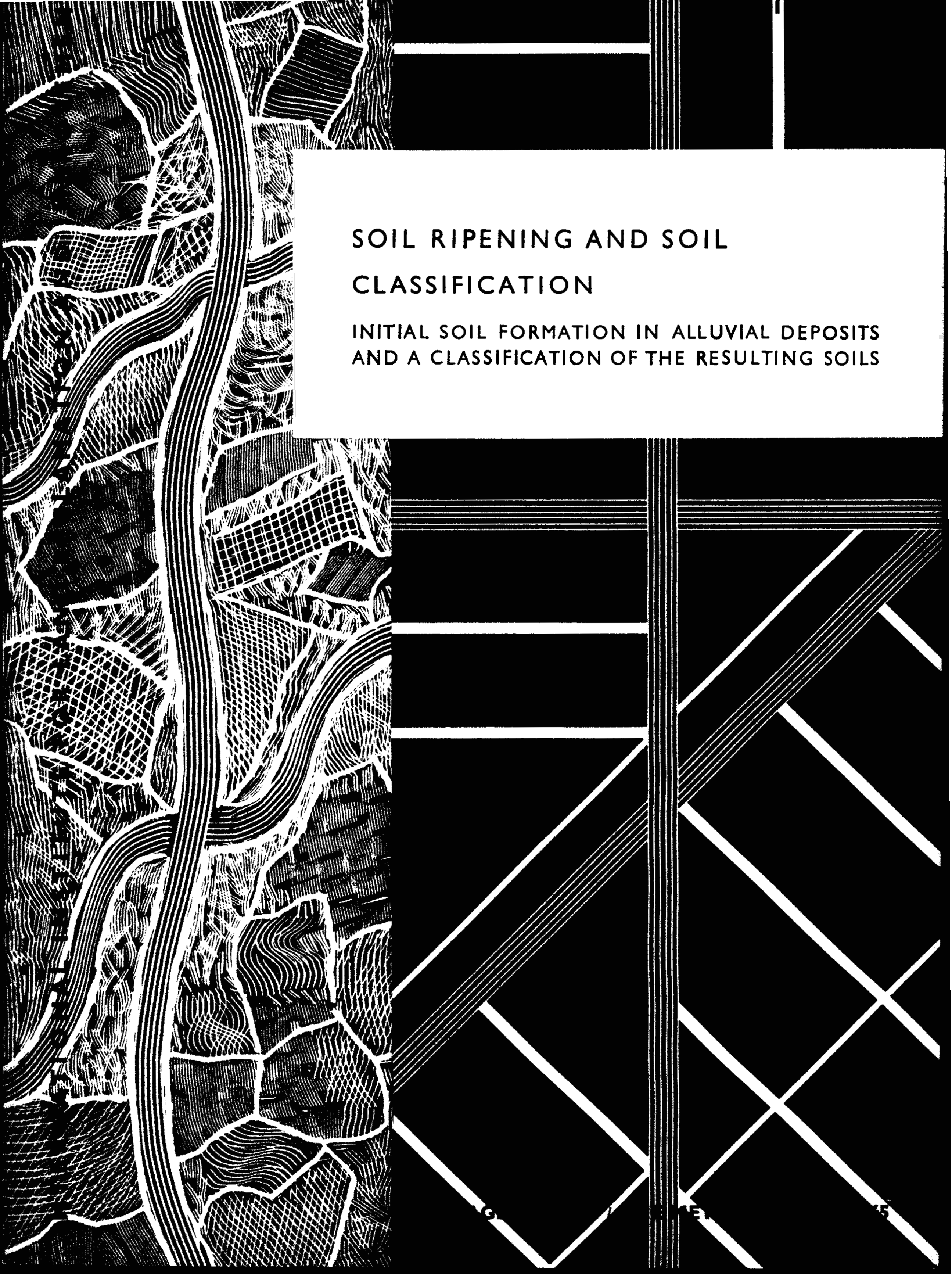

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INITIAL SOIL FORMATION OF ALLUVIAL DEPOSITS WITH A CLASSIFICATION OF THE RESULTING SOILS

PÉDOGENÈSE INITIALE ET CLASSIFICATION DES SOLS

INITIALE BODENBILDUNG UND BODENKLASSIFIKATION

PÉDOGENESIS INICIAL Y CLASIFICACIÓN DE LOS SUELOS

PROF. DR. L. J. PONS
DR. I. S. ZONNEVELD

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Instituto Internacional de Rescate y Mejoramiento técnico de Tierras

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About the authors:

Prof. Dr. L. J. PONS	Up to 1965 Senior Research Officer, Soil Survey Institute, Wageningen, The Netherlands. At present Professor of soil science in the State Agricultural University of Wageningen (Neth.). Studied the geogenesis and initial soil formation or ripening of river-clay and marine soils as well as the formation and pedogenesis of peat soils in the western part of The Netherlands. Co-operated with the second author in compiling the 1:200,000 scale soil map of the Netherlands and in drafting the map-legends for unripe and half-ripe soils. From 1962–1964, soil research in the young marine fluviatile coastal plain of Surinam (Dutch Guiana).
Dr. I. S. ZONNEVELD	Senior Research Officer, Soil Survey Institute, Wageningen, The Netherlands. At present Head of Soil Survey, Sokoto Valley Project UNSF/FAO, Sokoto, Northern Nigeria. From 1951–1955, studied initial soil formation and vegetation in the Biesbosch, a freshwater tidal area on the transition from marine to river deposits of the Rhine and Meuse in The Netherlands. In 1962-63, as a member of a team of Dutch and Japanese experts, participated in a study tour of the delta regions of the Far East, undertaken under the auspices of the U.N. Economic Mission for Asia and the Far East (ECAFE).

Prof. A. J. ZUUR (1902–1961): A WORD OF APPRECIATION

This study is dedicated to the memory of Professor A. J. ZUUR who did fundamental work in his studies on the soil development or ripening of young alluvial marine clay deposits and the improvement of polder soils.
As a soil scientist Professor ZUUR was concerned in the preliminary work of reclaiming and cultivating the Zuiderzee polders. Owing to his article entitled 'Over de bodemgesteldheid van de Wieringermeer' ('The character of the soils in the Wieringermeer', 1936) which dealt with the first Zuiderzee polder to be reclaimed, he became widely known. In this article, the author discussed the problem of the building up of alluvial layers and their soil development during and immediately after reclamation. The article employed a detailed soil map as the basis of universal agricultural planning. By introducing such a map as an indispensable means of research, professor ZUUR went on ahead of the pedological survey and land classification work hitherto done. This work was not to assume national proportions until the war, after which it rapidly attained international status.

During the subsequent reclamation of the other two Zuiderzee polders (the North-East Polder and Eastern Flevoland), ZUUR was Head of the Soil Research Department of the Zuiderzee Polders Development Authority. In this position, he was able to develop 'polder pedology' in further detail and to apply it to the implementation of the new polders. Also he was in charge of soil research work in the south-western part of The Netherlands, undertaken with a view to repairing the damage done by the wartime flooding in 1945 and the 1953 flood disaster. Both times, large areas including the islands of Walcheren and Schouwen-Duiveland were inundated with sea water. Moreover, ZUUR was engaged on new empoldering schemes in other parts of Holland (Frisian Islands, south-western marine clay area, peat polders).
In 1951, the State Agricultural University at Wageningen recognised his services by

appointing him as Professor Extraordinary at Wageningen, his subject being 'The science of cultivating reclaimed soils'.

His work was not confined to the Netherlands. His advice was frequently sought in connection with empoldering projects in alluvial areas outside the Netherlands, for which purpose he paid visits to Egypt, Great Britain, India, Iraq, Italy (Po Basin), Pakistan and other countries. This aspect of his work, of which he foresaw important developments, was unfortunately cut short owing to his death.

Much of the present Dutch reputation abroad in the field of research on reclamation of new land is due to the solution of the pedological problems involved, prof. ZUUR being the pioneer. In this way, a good foundation was laid for the design and construction of land reclamation projects throughout the world.

Unfortunately, Professor ZUUR was unable to publish the results of his later research work in a readily accessible form. Some of the ideas included in this hitherto unpublished work have served the authors as a guidance in the performance of their own research work, especially ZUUR's lectures dealing with 'The pedology of Dutch embankments and drainage works'. In these lectures, of particular importance are part B: The main composition and certain other chemical components of reclaimed soils (1954), and part C: 'The water content, dehydration and certain related processes' (1958).

We regard it as a privilege that Professor ZUUR before his premature death was still able to give valuable commentaries during the initial stage of preparation of our present study.

We dedicate this study to his memory in the consciousness that our contribution towards increasing knowledge on the initial pedological processes is one to which he would have given unstinted approval.

THE AUTHORS

TABLE OF CONTENTS

PREFACE AND ACKNOWLEDGMENTS

So far as is known, no attempt has ever been made at classifying young alluvial marine and fluviatile soils and peat soils on the basis of pedogenesis. The question of real pedogenesis in young sediments and peats received very little coverage in international literature.

However, pedogenetic processes occur in sediments, peats and very young alluvial soils to which we apply the term 'ripening' (a loan-translation of the Dutch term 'rijping'), otherwise known as 'initial soil formation'.

These processes result in very extensive changes in the soil. The new properties and qualities formed are not only very important from the point of view of ecology and agriculture but are also useful as soil classification characteristics.

The present paper tries to make up for the lack of literature on the subject of pedogenesis in relation to soil classification. Thus, this paper has a twofold purpose in that an attempt is made to give:

a. a summary description of the soil properties mentioned above and the processes on which they are based as regards their significance for the root zone and the soil use;
b. an explanation of the manner in which certain soil properties can be used as characteristics for a soil classification system.

As with all kinds of soil properties, there is a close relationship between the physiography of young alluvial and peat soils and the pedogenetically determined properties. This relationship is considered in detail in the present paper, since it should be regarded as a very important research element in all surveys.

Of the present study, a first draft was ready as early as 1961. Till then, the authors had

◀ **Photo 1. Mangrove vegetation (Rhizophora mangle) trying to overgrow an unripe mud flat along the estuary of the Surinam river near Paramaribo, thus initiating the ripening process.**

the opportunity to make researches into the subjects mentioned before under the auspices of the Soil Survey Institute at Wageningen, The Netherlands. Owing to various reasons, in particular a protracted stay abroad of both authors, publication of the results of their investigations was delayed for a considerable time. However, this delay proved to be an advantage inasmuch as it was possible to insert some of the results of the research work carried out afterwards by them in tropical regions. During their work there, the authors found that in principle the same pedogenetic processes occur in young soils under tropical climatic conditions, although in somewhat different relationships.

A study of this kind would not have been possible without the co-operation of many others. In the first place, the authors owe a special debt of gratitude to the late Professor ZUUR for many helpful comments and suggestions he made when perusing the manuscript.
Furthermore they wish to express their thanks to the Director of the Soil Survey Institute at Wageningen, for giving his consent to publish the results of their earlier researches, already mentioned above.
Also, they would like to thank dr. B. VERHOEVEN and mr. H. SMITS of Kampen (Neth.), as well as Professor G. H. BOLT of Wageningen, for reading and discussing the manuscript. For his kind primary corrections of the language, the authors are grateful for the help of dr. J. S. FRAZER, for their providing of analytical data for the appendix, to dr. P. J. ENTE at Kampen, and mr. H. DORST at Paramaribo (Surinam). Furthermore they wish to mention the kind co-operation of many colleagues of the Soil Survey Institute, in particular of mr. H. DE BAKKER. All gave very helpful comments on various parts of the manuscript.

Last but not least, the authors' grateful acknowledgments are due to the Director of the International Institute for Land Reclamation and Improvement at Wageningen for his interest in their studies and the willingness to include this paper in the series of publications of the Institute. The manuscript had to be submitted in a half-finished state as both authors departed in 1962 from the Netherlands for tasks overseas. The editorial staff of the International Institute dealt with a great volume of laborious work in making the manuscript ready for the press. For this co-operation, the authors are very thankful.

THE AUTHORS

1. INTRODUCTION

1.1. GEOGENESIS AND PEDOGENESIS

When studying very young alluvial soils and peat soils one is immediately confronted with the difficulty of determining the starting moment of real pedogenesis from the entire process of the genesis of marine, fluviatile and peaty materials. A distinction must therefore be made between *geogenesis* and *pedogenesis*, the former term relating to geological (sedimentological) processes, the latter to pedogenetical processes in the narrowest sense. We propose to define geogenesis as any kind of process relating to the origin and transport of sediments, to any form of sedimentation and to the growth and formation of peat.

On the other hand, we would define pedogenesis as the processes of soil formation which take place as soon as the sediments and sedentates have been deposited and the influence of soil-forming factors, especially climatological and biological ones, i.e. aeration and vegetation, begins to be felt.

However, it is sometimes difficult to define the borderline between geogenesis and pedogenesis for both one soil particle and an entire profile. For example, the sediment particles transported by rivers have properties that are determined by the pedogenetic processes taking place in the soils from which they were removed by erosion. In the profiles of periodically inundated sediments in tidal areas and river plains, the geogenetic process of sedimentation takes place during inundation. However, pedogenetic influence is also possible whilst these sediments are exposed to the air. In this particular case, therefore, pedogenesis and geogenesis alternate.

The irreversibility of some of the processes to be discussed below is due to the effectiveness of dry periods, even when they are of only short duration. Sometimes, during the geogenetic process of peat growth, a natural lowering of the water table takes place as a result of drier climatic conditions and pedogenesis begins. Subsequently, this process is checked by a rise of the water table and a renewal of peat growth. Where peat grows very slowly pedogenesis and geogenesis proceed absolutely simultaneously (Chapter 2).

Another borderline case is found in processes which occur under reducing conditions. The changes which take place in reduced back swamps will be classified under the heading of pedogenesis (decalcification, secondary formation of pyrites, etc). On the other hand, the chemical and physical reactions observed in unreclaimed underwater sediments should be classified under the heading of geogenesis, since a back swamp usually has a 'soil' which is capable of supporting plants, whereas a lake bottom generally has not. Another example is given in Photo 2.

However, although the above-mentioned examples show that the borderline is sometimes vague, in most cases the definition given proved to be of great value in discussions on the subject.

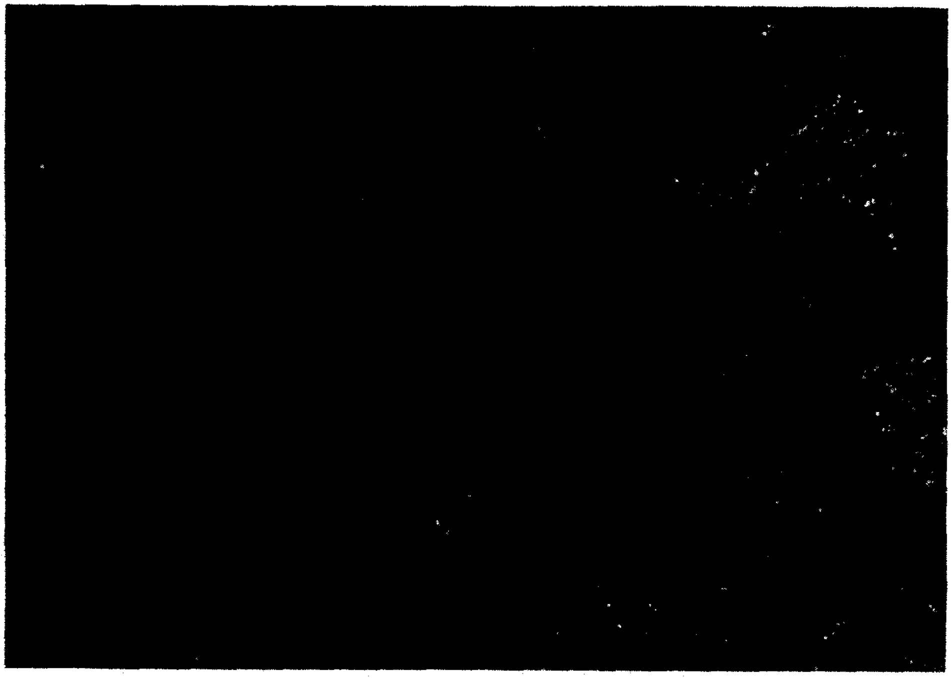


Photo 2. Totally unripe mud (n = ca. 2.0–3.0) deposited at about mean low water level in a fresh water tidal area of the Netherlands.
Gas formation by fermentation. A kind of chemical ripening somewhere between geogenesis (sedimentation) and pedogenesis (oxidation and related chemical processes), as can be observed by gas bubbles pointing to the relatively high content of organic matter.

1.2. FORMER INVESTIGATIONS

In a country like Holland, of which about 50% consists of marine, fluviatile and peat materials and whose whole history is very closely related to the struggle against flooding by the sea and rivers, it is not astonishing that the study of the genesis of the land began at an early date.

Originally, studies were mainly pursued from a *geogenetic* point of view. This has led to important results in recent times. Purely geogenetical studies of the marine parts of the Netherlands' coast or studies in which the geogenetical problem was the main point of interest have been published by BENNEMA 1954a, GROOT 1962, 1963, KAMPS 1963, DE KONING and WIGGERS 1955, PONS and WIGGERS 1959, 1960, PONS, JELGERSMA, DE JONG and WIGGERS 1963, POSTMA 1954, VAN STRAATEN 1954, WIGGERS 1955, ZONNEVELD 1960 and many others.

The geogenesis of fluviatile districts has also been the subject of many studies e.g. DE BOER and PONS 1960, EDELMAN 1950, PONS 1957 and SONNEVELD 1958. The geogenesis of peats has been studied by BENNEMA 1954b, DE BOER and PONS 1960, PONS 1961 and others. In other countries also much attention has been paid to the subject of geogenessis of marine and fluviatile areas and especially to the problem of peat formation.

The *pedogenesis* of young alluvial, marine and fluviatile soils and of peat soils, which occurs during and after the drainage and reclamation of land previously forming the bottom of lakes and such seas as the Zuiderzee, and of all kinds of land situated outside the dykes, e.g. tidal flats, marshes, forests and peat bogs, has been a special subject of study by Dutch soil scientists.

A great part of the soils of the Netherlands was reclaimed from the water during the last nine centuries, either by making polders outside the sea-dykes or by draining lakes. In addition to these activities, a considerable area was reclaimed by the drainage of vast peat bogs such as those situated in the central peat district of Holland. Finally, vast areas were drained and made suitable for agricultural use in the fluviatile district.

A rich experience has gradually been gained on the subject of drainage and reclamation, but there have been failures as well as successes. During the nineteenth century the increasing activities in the field of drainage and reclamation were placed on a more scientific basis. The increasingly specialized investigations into the properties and processes of this wet type of soil began during this period.

In 1886 VAN BEMMELEN began studying sulphuric acid production by the oxidation of pyrites-containing soils ('katteklei; cat clay'). His work was continued by VAN BEERS 1962, BENNEMA 1953, EDELMAN 1946, 1950, HARMSEN 1954, PONS 1956, VAN DER SPEK 1950, 1952, VERHOOP 1940 and ZUUR 1954. Desalinization and related problems are very important in the study of reclamation of marine forelands and sea and lake bottoms. These problems have been the subject of studies by HISSINK 1935, VAN DER MOLEN 1957, VERHOEVEN 1952, 1954, ZUUR 1932, 1936, 1939 and others. On the behaviour of lime and other elements in the soil, work has been done by BENNEMA 1953, BRUIN 1938, EDELMAN and DE SMET 1951, HISSINK 1935, 1954, MASCHAUPT 1947, 1950, PONS of chemical and biological ripening, in so far as required for a proper understanding of the entire study.

Where the word ripening is mentioned after sections 1.5 and 1.6 this refers exclusively to physical ripening.

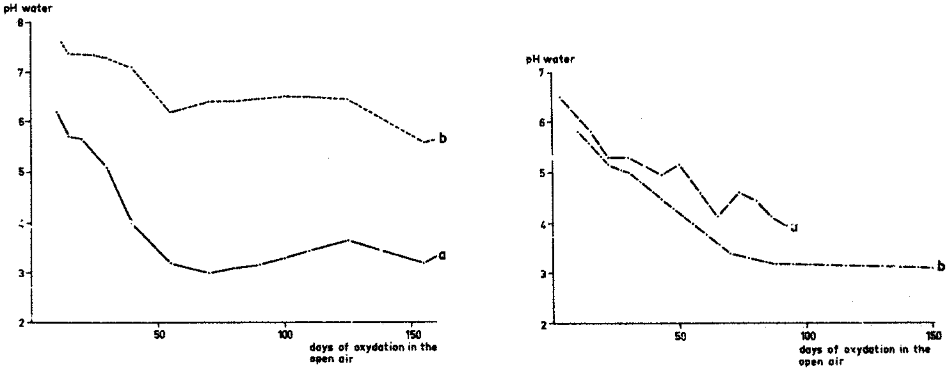
1.5. SOME ASPECTS OF CHEMICAL RIPENING

According to the definition of the difference between geogenesis and pedogenesis, the initial soil formation or ripening starts at the moment of drainage or oxidation of the soil. Oxygen enters the soil and causes all kinds of chemical reactions, depending on the chemical properties of the sediments and peats.

A part of the organic matter is oxidized and disappears. In organic compounds, originally bound in small quantities to this organic matter, are either liberated and react with others, sometimes giving inactive products or they are leached. In both cases these compounds are lost for plant growth (ZONNEVELD 1963).

Oxidation of the iron results in a wide variety of ferryhydroxides. Slight differences in water content, concentration of the iron and organic matter content produce a vast range of yellow, brown, red and even violet colours, mostly appearing as a mottling of the soil profile. Manganese acts in the same way as iron. These phenomena are very convenient as a means of determining the hydrological conditions in the soil, e.g. the groundwater table, its fluctuations and the permeability of the soil (ZONNEVELD 1960).

Fig. 1. The trend of the pH (water) of two reduced pyrite clays during oxidation.



Pyrite clay with organic material of Phragmites communis of a sub-recent marine deposit in a temperate climate (The Netherlands). Totally desalinized under reduced conditions:

- a. sample in natural state (fresh catclay)
- b. sample mixed with $CaCO_3$ (about 15,000 kg per tillage layer per ha).

Pyrite clay wih organic matter of Rhizophora spec. and Avicennia nitida of a recent marine deposit in humidtropical climate (Surinam). Totally reduced, only slightly desalinized:

- a. sample in natural state (salty pseudo catclay)
- b. sample artificially desalinized under reduced conditions (catclay).

A very important chemical ripening process is the oxidation of sulphur compounds (mostly pyrites) of the originally reduced sediments to sulphates and sulphuric acid. Depending from the neutralizing materials and the amounts of pyrites, the pyrite clays ripen to very poisonous cat clays (acid sulphate soils), weakly acid pseudo cat clays or neutral soils (VAN BEERS, 1962; PONS, 1963a). See Fig. 1.

The cations adsorbed to the clay- and humus-complex, are also affected by the changing cation concentrations of the soil-water solution caused by chemical ripening. Na-clays may be converted to Ca-clays or Mg-clays in combination with the various clay minerals, all of which have different physical properties (KOENIGS 1960). In the case of pyrite clays ripening to acid sulphate soils (cat clays), not only are the adsorbed cations affected but also a part of the clay complex itself is destroyed, producing Al-ions from which the very finely structured Al-clays originate.

The adsorption of K is also influenced by the conditions under which the chemical ripening develops. Together with the N- and the P-economy of the soil, both greatly depending on the starting amounts and the kind of chemical ripening, it is decisive for the future chemical value of the soils.

Events occurring during the process of chemical ripening determine both the physical and biological ripening. Thus, oxidation of the organic matter is very important for the course of physical ripening of the resulting soil. In peat soils, for instance, it means that part of the soil skeleton itself disappears, involving a total change of all soil properties, especially in the manner in which the process of physical ripening takes place.

Acid formation during the chemical ripening of pyrite clay can be so poisonous as to prohibit root growth in these soil layers. As a result physical ripening is stopped because moisture adsorption is mainly caused by root activity.

Numerous other processes occur in combination with biological ripening. In this connection the microbiochemical processes may be mentioned in particular. As this paper is mainly concerned with physical ripening, the foregoing brief remarks on chemical ripening may suffice.

1.6. SOME ASPECTS OF BIOLOGICAL RIPENING

Biological ripening is the result of the activity of all kinds of soil fauna and flora, including both the larger and the microscopic forms of life, but not including the direct activity of man.

One of the biological ripening processes is known as homogenization. This comprises all those digging, eating and excreting activities of soil organisms that may lead to the mixing of soil material and to a change in the structure of the soil.

Even before pedogenesis starts, animals can mix originally stratified sediments. This is of great importance for the subsequent ripening processes. VAN STRAATEN 1954 and ZONNEVELD and HEYLIGERS (in diss. ZONNEVELD, 1960) have described the activity of marine organisms in tidal flat areas which leads to partial homogenization even during geogenesis.

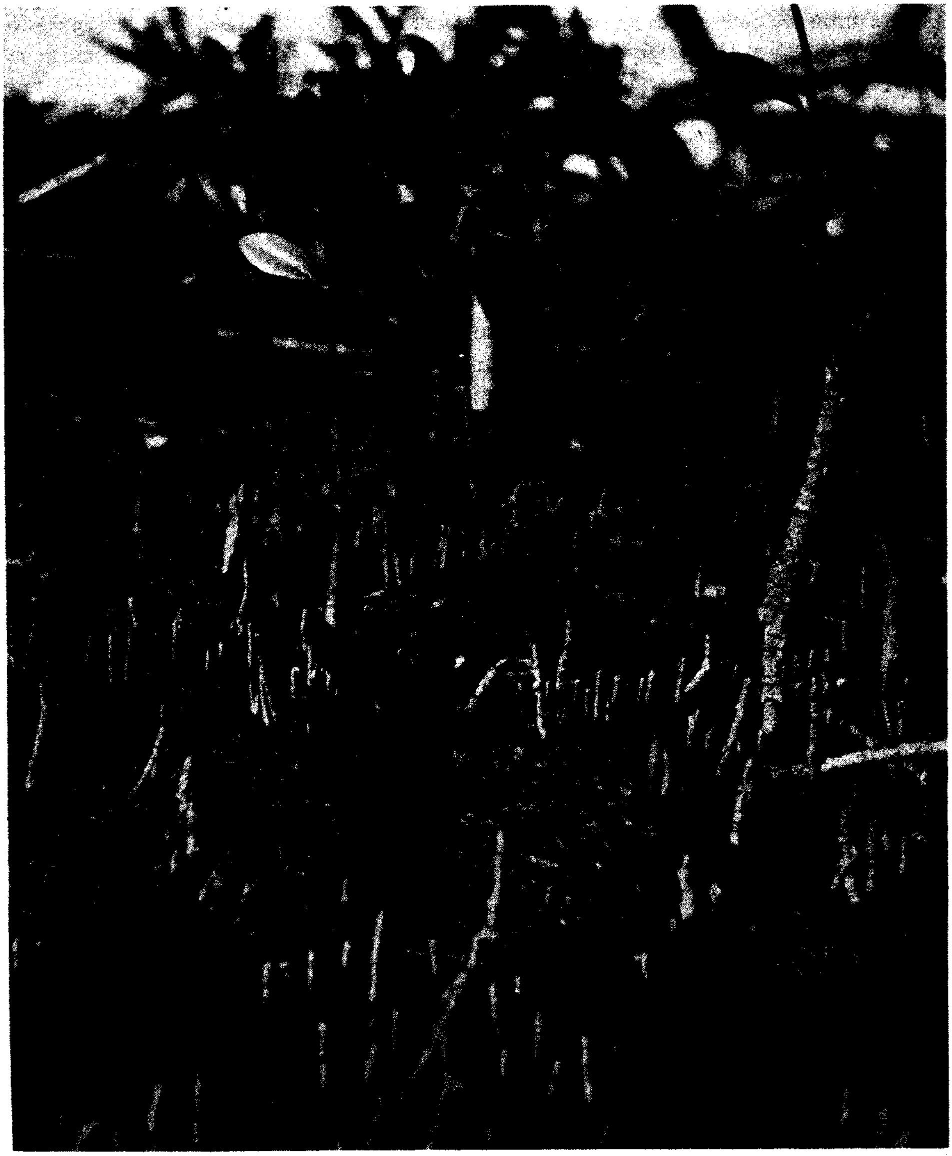
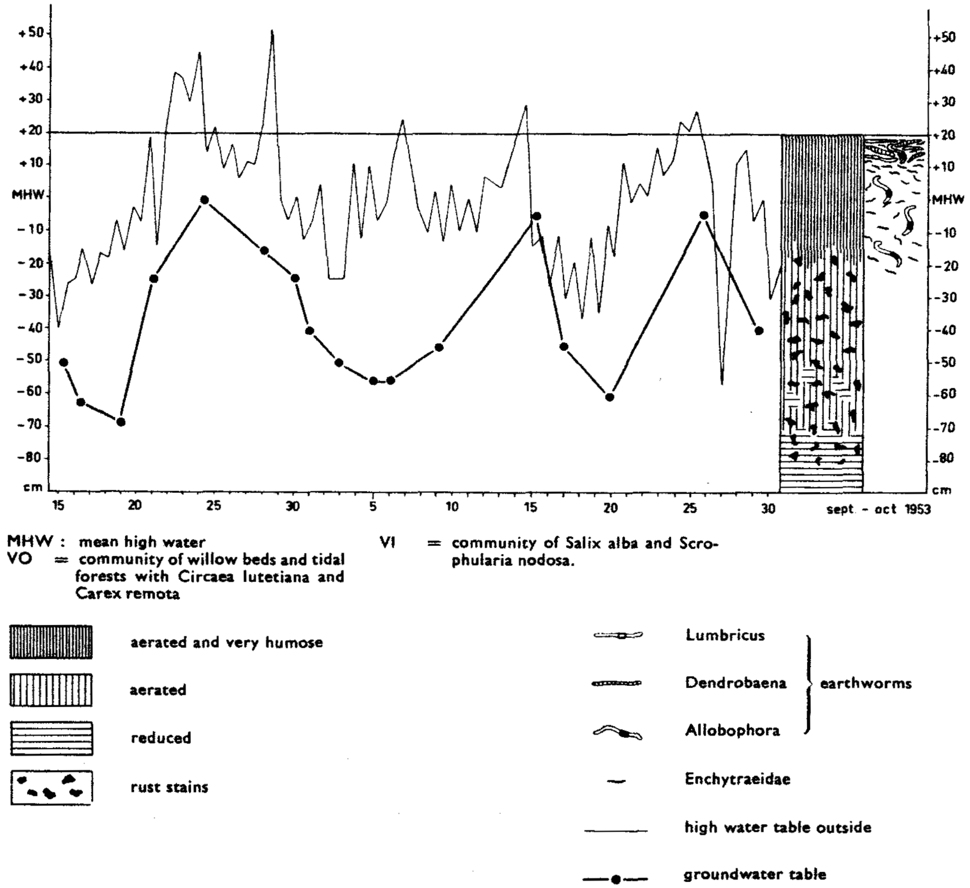


Photo 3. Mangrove marshes in the brackish to salty tidal part of the estuary of the Coppename river (Surinam).

There is intense crab activity between the air roots of the mangrove (Avicennia nitida). By digging holes, the crabs bring unripe soil from the subsoil to the surface, giving it a better chance to ripen and mixing the materials at the same time.

Fig. 2. Relationship between high tide levels, groundwater table, soil condition and vertical distribution of some soil organisms in the VO-VI vegetation type on the Driessen Hennip (recorded by P. C. Heyligers) in the freshwater tidal delta Biesbosch (Neth).



MHW : mean high water
VO = community of willow beds and tidal forests with Circaea lutetiana and Carex remota
VI = community of Salix alba and Scrophularia nodosa.

Doeksen and Minderman (oral communication) have done similar work on certain freshwater organisms (Tubificidae).

These are only some examples of the many studies now being carried out to learn the conditions under which fossil sediments were sedimented. For the subject dealt with in this paper, it is very important to take notice of these studies (cf. Fig. 2).
This biological activity continues on the border between geogenesis and pedogenesis. An excellent example is the activity of Crustaceae in tropical tidal forests (cf. Photos 1, 3 and 11). When oxidation conditions prevail, the activity of all kinds of other organisms starts.

Biological activity develops best in a humid climate in soils that are not extremely wet or dry and are of medium textures, at high temperatures with a fairly high production of organic matter. In the humid tropics, on well-drained, medium-textured soils, the biological activity of all kinds of worms, termites, ants etc., is very intensive. Drainage conditions and extreme soil conditions (e.g. very coarse, excessively drained sand) may greatly limit the biological activity.

In more arid zones of the tropics, termites are especially active and in temperate climates certain mammals.

In areas with a temperate humid climate, the activity of worms is important, but only during some parts of the year. In the Netherlands HOEKSEMA 1953 and HOEKSEMA and JONGERIUS 1959 have dealt with this type of homogenization.

Plant growth is also very important. Root activity mixes the soil particles and brings organic matter deep in the soil (EDELMAN, 1963). In the tropical rain forests and other zones with heavy forests considerable interest attaches to the homogenizing result of falling trees which with their root systems pull lumps of earth out of the soil, sometimes from a depth of over three feet.

The microbiological activity by which the organic compounds are broken down is to be noted during the ripening of organic soils. But they also play their invisible but important role through all kinds of other processes.

Biological ripening by eating animals in organic soils raises special problems, because during this process a considerable part of the soil skeleton of the organic soil profile, itself consisting of organic material, is consumed by all kinds of organisms. Sometimes the main part of the soil profile of these soils consists of primary and secondary excrements (VAN HEUVELN, JONGERIUS and PONS 1960).

There are many relationships between biological and physical ripening. One of the most important is the physical ripening caused by plants which consume the water attracted by the roots from the soil. Since soil drainage is also improved by this process, physical ripening can progress very rapidly. Some plant roots (for instance, Telmatophytes) are able to attract water from totally reduced soil layers, even when these are salty (e.g. Avicennia nitida and Rhizophora mangle). See Photos 1, 8 and 11.

The production, decomposition and preservation of organic materials is a very important subject and is partly connected with biological and partly with chemical and physical ripening. Thus owing to the great importance of the organic matter economy and the fact that these reactions take place on both sides of the border between pedogenesis and geogenesis, this subject is dealt with in a special chapter (Chapter 2).

There are also many interactions between biological and chemical ripening of which we would mention in particular the microbiochemical reactions.

1.7. THE ROLE OF RIPENING IN SOIL SCIENCE

In the foregoing paragraphs the ripening is defined as a pedogenetical process that converts soft, waterlogged and reduced materials into soils. We traced the borderline between pedogenesis and geogenesis as far as possible, and on the other hand fixed the transition between the initial soil formation and the more progressive part of this process.

We classify ripening as a physical, chemical and biological phenomenon, with the proviso that all these processes generally interact and can only be partially distinguished one from each other.

Chemical and biological ripening were dealt with in this chapter in more detail, as the next part of this paper will be primarily concerned with physical ripening.

Physical ripening is the part of the entire ripening process that is used as a basis for the soil classification and the determination of soil map units. Morphologically, this kind of ripening is relatively easy to determine. Its criteria are the same in soils derived from both salty and freshwater sediments, they are independent of the organic matter content and the texture of the sediments, and are also applicable to peats.

Moreover, it is only in the case of physical ripening that we practically have an irreversible process with a clearly defined end. The end of the chemical ripening process is very difficult to determine and the end of the biological ripening process cannot be distinguished from progressive biological pedogenesis.

Hence the main purpose of this report is to describe physical ripening under natural conditions and under conditions controlled and influenced by man.

In relation to the process of physical ripening organic matter is qualitatively, and in many cases also quantitatively a very important soil constituent. For this reason we shall proceed to discuss the role and behaviour of the organic material in the soil during and after ripening (Chapter 2). Chapter 3 deals with the whole process of physical ripening and the determination of the process in the laboratory and in the field.

In Chapter 4 we shall describe the physical ripening occurring in natural landscapes and under the influence of man. Correlations are discussed between ripening and all kinds of geomorphological and ecological conditions.

From an *ecological* point of view, a knowledge of the processes of ripening is very important. There is a close relationship between vegetation and the several stages of ripening. It is sometimes even possible to determine the stage of ripening by means of the vegetation (ZONNEVELD 1958, 1960).

Soils originating from soft and waterlogged materials are generally used or considered as suitable for use for all kinds of *agricultural* purposes. Obviously therefore, a knowledge of the ripening processes is important for crop growth and for general land classification purposes. This aspect of practical application is dealt with in Chapter 5 together with such other aspects as the subsidence and permeability of the soils concerned, drainage improvements and construction works which may be required, etc.

In Chapter 6 a proposal is made to use the physical ripening stages as a basis for the classification of soils and also for the map units of soil maps. In this sense they are already used in the Netherlands by ZONNEVELD (1960), and for some map units of the new 1:200,000 and 1:1,000,000 soil maps of the Netherlands (Soil Survey Institute, 1961).

In this report we do not intend to cover the geogenetic processes (sedimentation and peat growth) although they are also very important in a soil classification system.

2. RIPENING AND THE ORGANIC MATTER EQUILIBRIUM A-HORIZON DEVELOPMENT AND PEAT FORMATION

2.1. ORIGIN AND QUANTITIES OF ORGANIC MATTER

Under marine conditions, the organic matter in floating silt in the sea and estuaries is present and transported as part of the 'clay-humus flake'. These complex sediment bodies are made up of varying quantities of organic matter, clay particles, some very fine silt, and small quantities of other constituents, for example small particles of lime, pyrite bodies, etc. The clay-humus flakes are derived from the excrement-producing activity of the fauna on the tidal flats (KAMPS 1950, 1956, 1962; POSTMA 1954; VAN STRAATEN 1954).

From the point of view of the genesis of the parent material of the alluvial soils, the organic matter and other constituents of the clay-humus flake can be considered as primary organic matter (PONS 1963a).

The organic matter content of subaquatic sediments within a single 'homogeneous marine sedimentation basin' is closely correlated to the clay content (ZUUR 1958). Figure 4 shows this correlation of the primary organic matter content and the clay content in particles <16 micron (100 particles <16 micron contain under normal conditions about 66 particles <2 micron), for bare marine forelands (curve 5). Figure 3 gives some more information on the primary organic matter content of floating marine silts and of sedimentated silt not overgrown by the vegetation from different areas. The differences are considerable. The contents in temperate climates are higher than in tropical areas.

In the Netherlands, the present marine silt in the northern and central part of the country has organic matter contents of about $4^1/_2$–5% for average clay contents of about 30%. Based on clay percentage this would be about 0.15% of organic matter. Tropical marine clays, for instance, along the Guiana coast (PONS 1963a) and in the

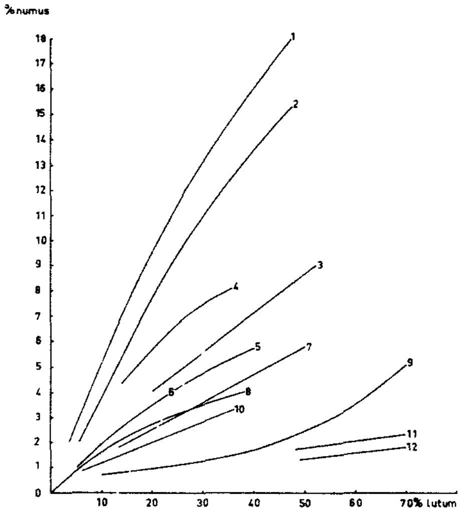
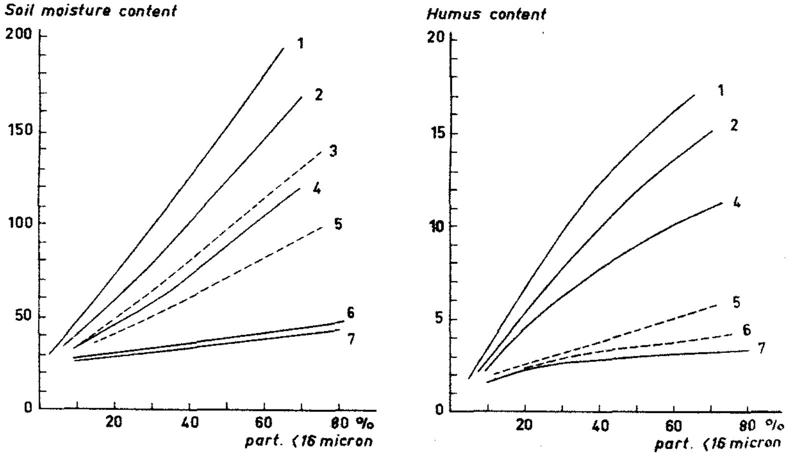


Fig. 3. The relationship between the primary humus content and the clay (lutum) content of sediments from the following locations:

1. Tidal rush marshes (freshwater). (Zonneveld, 1960)
2. Tidal reed marshes (freshwater). (Zonneveld, 1960)
3. Deposits along the German North Sea Coast (N. Friesland) (De Groot, 1962)
4. Zuiderzee, youngest deposit (Wiggers, 1955)
5. Dollard and IJsselmeer deposits (Wiggers, 1955)
6. Zuiderzee deposits with high silt contents (Wiggers, 1955)
7. Deposits along the German North Sea Coast (Ditmarschen). (De Groot, 1962)
8. Zuiderzee, deposits I and II (Wiggers, 1955)
9. Far East sea clay (Zonneveld, 1963)
10. Eastern Flevoland polder (Zuur, 1954)
11. Deposits of the coastal plain of Surinam
12. Sediments along the coast of Dutch Guiana (from the sea)

Fig. 4. The relationship between soil moisture content and humus content and the content of particles < 16 micron in the upper 80–120 cm of a number of soil layers from six typical kinds of geogenetically different alluvial soil profiles and one artificially drained profile with their own typical natural stages of initial soil formation from a temperate climate region (The Netherlands). Zonneveld, 1960.
Moisture content and humus content were both determined in g/100 g oven-dry soil.



1. Rough herbage and rush marsh
2. Tidal reed marsh
3. Zuiderzee silt
4. Salicetum willow coppice and tidal marsh
5. Marine foreland
6. Fraxinetum willow coppice
7. Polder

delta areas of south east Asia (ZONNEVELD 1963) have 0.02 % and 0.03 % of organic matter per % day, respectively, based on clay percentage, for clay content of about 30 %, or much smaller contents in up to one tenth of the comparable sediments in the temperate areas (Compare in Fig. 3 curves 3, 4, 5, with curves 9, 10, 11).

The differences around a basin like the North Sea are also remarkable. DE GROOT 1963 gives 0.25 % for the Elbe estuary and 0.18 % and 0.11 % for several parts of the German Wadden coast. WIGGERS 1955 mentions the same differences (from 0.25 % to 0.11 %) for sediment units of different age one on top of the other in the Zuiderzee area, each having a close correlation between the organic matter content and the silt content.

In fresh water sedimentation areas in the temperate climate, such as the fresh water tidal delta of the Biesbosch, there is a less close but significant correlation, the humus contents invariably being much higher than in marine areas, (ZONNEVELD 1956, 1960, see Fig. 3, curves 1, 2).

Important factors in freshwater sedimentation are recent biological activity (plankton and animals in the water and on the flats) and the combination of organic matter and clay particles produced by pedogenesis in the hinterland (mull particles produced by biological activity in all kinds of soils).

But much of the sedimentation areas that interest us here is covered by vegetation during sedimentation, especially under fresh and brackish water conditions in temperate climates and also under salt water conditions in the tropics. The growing vegetation adds different quantities of organic matter to the sediments which are preserved under reducing conditions and can be distinguished as secondary organic matter (PONS 1963a).

In sedimentation environments, e.g. fresh and brackish water tidal reedmarshes, fresh water tidal marshes of rough herbage and rushes (Fig. 4, curves 1 and 4), the increase of organic matter is mainly due to secondary organic matter (ZONNEVELD 1960). Under tropical conditions plant growth is very dense and may occur on brackish or even salty sediments (Avicennia, Rhizophora, Lingicularia, etc.) so that in most cases a large amount of secondary organic matter is produced in the unripe soil profile. Under brackish conditions in temperate climates this is only possible with Phragmites. Under fresh conditions it is well known from different climates. Formations of secondary organic matter produce every kind of transition from mineral sediments to pure peats.

Normally the primary organic matter in marine environments, being of animal origin, has high N contents. Under fresh water conditions more plant material is added, thus reducing the N contents (ZONNEVELD 1960). When there is a great deal of secondary organic material the N content, even that of marine deposits, is always reduced. The same result is obtained by mixing the primary organic material in marine environments with eroded peat material.

The characteristic properties of the materials subject to the process of ripening all originated during the geogenesis of the alluvial sediments and peats.

2.2. SOME ASPECTS OF THE DECOMPOSITION OF ORGANIC MATTER

An important part of the process of ripening which has a great effect on the total absorption of water is the change that occurs in the quantity and quality of the organic matter during ripening. This process covers both physical and chemical ripening. Figure 4 shows that the organic matter content is decreased by oxidation during ripening, viz. in freshwater and brackish tidal areas from bare silt flat via marsh and tidal forest to endikements, and in marine tidal areas from silt flat via salt marsh to polders. When the organic matter disappears, its absorbed moisture is removed with it. ZONNEVELD 1956, 1960 calculated that half the total moisture loss in freshwater tidal areas, and consequently half of the settling, was caused by oxidation of most of the organic matter.

Under the marine conditions obtaining in the Netherlands the loss of total moisture by oxidation of the organic matter is less than 20% of the original moisture content. In tropical areas with sediments very low in organic matter this loss is practically zero. The organic matter is also of a different type. In freshwater areas in temperate climates, where much organic matter originates from the vegetation during the ripening process, the C/N ratio decreases from about 25 to less than 10. At the same time the cation exchange capacity per g organic matter increases, while the water absorption capacity slightly decreases (see subsection 3.3.1.). This is presumably due to progressive humification of organic matter that was originally only slightly disintegrated (ZONNEVELD 1959, 1961).

In this case the decrease in organic matter must be attributed to the shifting of the equilibrium between the formation and the decomposition of organic matter. Within the same climate and under the same salinity, hydrological, and other conditions, the organic matter content has for each stage of ripening a characteristic value which is related to the clay content. An example of ripening of a sediment originally extremely poor in organic matter is the increase in organic matter content of sandy Zuiderzee soils that was observed by HISSINK (1954). The original organic matter content of these sediments was lower than the characteristic equilibrium normal in the polder stage (or the end stage of ripening).

In tropical areas, the organic matter content of most of the agriculturally interesting alluvial sediments is so low that the organic matter is scarcely involved in physical ripening. Moreover, the characteristic organic matter equilibrium at the end stage of ripening is very low, so that the entire organic matter content is quantitatively insignificant for physical ripening. Compared with chemical ripening, however, the organic matter is qualitatively very important.

2.3. A-HORIZON DEVELOPMENT

The developement of an A_1-horizon in alluvial soils is very closely related to the geogenesis and the entire process of ripening. Organic matter is produced by the vegetation present during ripening both in the upper layers and on the surface of the soil. Moreover, the original organic matter content of the sediments is also very important and may vary considerably. Animals and micro-organisms (biological ripening), decompose the organic matter originating from both sources, producing other kinds of organic compounds and mixing them with clay. The decrease of the organic matter content is compensated by new formations, in the top layers to a greater extent than in the lower horizons, and this explains the difference between A_1 and C_g or CG and G.

Fig. 2 (see p. 21) gave an example of a profile in a freshwater tidal area in relation to ground waters, inundation and some soil organisms. The type of A_1 horizon, thick or thin, prominent or weak, with a very low, a medium or a high organic matter content, depends on the quantities and type of available organic matter and the type of physical and biological ripening occurring in the profile.

In the top layers of sediments extremely deficient in organic matter, the A_1 formation usually leads to an increase in organic matter content, as was discussed in the previous paragraph. In tropical sediments this is often the normal situation. In temperate areas the content is normally decreased in most temperate marine sediments and to a greater extent in freshwater sediments, particularly peaty soils and peats.

Shallow A_1-horizons are particularly frequent in imperfectly drained soils. In the humid tropics under these conditions, but also in temperate areas under very bad drainage conditions, A_0-horizons are common. This is caused by the shallow rooting activity of grass vegetations and swamp forest vegetations and the absence of such deep homogenizing organisms as earthworms etc. In naturally well drained areas, wooded with deep-rooting trees, the soils are usually homogenized, i.e. intensively biologically ripened to a greater depth. This depth of homogenization depends to a greater or lesser extent on the drainage conditions which in this case determine the depth of biological homogenization. Consequently, if an indication can be obtained of the degree of homogenization of soil profiles, this may make it possible to determine the level of the ground water tables during the process of ripening of these soils. However, this intensity of homogenization greatly depends on soil conditions, climate and available organisms. For example, under eutrophic wet tropic conditions there is a very high level of biological activity in well-drained soils of medium textures. Hence regional studies are necessary for providing a good interpretation of the phenomena.

2.4. PEAT FORMATION

Under very poor drainage conditions, the only type of horizon which will generally develop is the A_0 horizon, or an A_1 horizon with a high organic matter content. Here we are once again on the borderline between pedogenesis and geogenesis. The decomposition of the organic matter produced may be arrested, and the type of production is not very much different from that occurring on aerated soils. The organic matter content of the A horizon is now able to increase, and in extreme cases, the 'peaty' A_0 horizons or A_1 horizons which only contain partly disintegrated organic matter, originate in this way.

The influence of climate on these processes is illustrated by the next example: In the southern 'étangs' of the Rhône delta, peat formation is not possible because these 'étangs', for reasons of climate, (low rainfall and relatively high temperature) contain salt and brackish water, thus preventing peat-forming plant growth with the result that there is no accumulation of organic matter. But, under less arid climatic conditions, these geomorphological units (back swamps or basins) are always filled with peat, as in the deltas of the rivers in north-western Europe and in the humid tropics.

Peat formation may also be hindered by an abundant supply of mineral sediment. Peat formation generally starts in humid climates, in both temperate and in tropical zones, under the very conditions that preclude physical ripening. It can be seen that in some respects peat formation is the reverse of ripening and consequently the reverse of 'pedogenesis'. Peat formation can thus be classified as geogenesis or the formation of new parent material for soil genesis. The climate factor (evaporation) is the chief factor eliminated during peat formation (see Photo 4). Both the geogenetic and the pedogenetic processes occur simultaneously, particularly at the very beginning of peat formation when the transition takes place between pedogenesis (A_1-formation) and geogenesis (peat-layer formation). The faster the peat layer grows, the less important is the part played by pedogenesis.

The decision as to whether a shallow peaty layer or the thicker top layer of a profile – both of which were very much disintegrated during peat formation – should be classified as a pedogenetic A_1 or A_0 horizon on the one hand, or as a geogenetic superficial peat layer on the other, is purely arbitrary. Thin peat layers are very common in the western peat and clay-on-peat district of the Netherlands, in the swampy marine clay areas of the South American Guianas and elsewhere on the tops of poorly drained mineral soils. Further micro-pedological research will probably produce more data for the characterization of these layers. Special difficulties arise because in dry periods in the tropics these superficial peat layers are often set on fire and disappear. In the Dutch system of soil classification we use the provisional term 'peaty A horizons', in which category we include all kinds of thin, superficial profile layers having a high organic matter content.

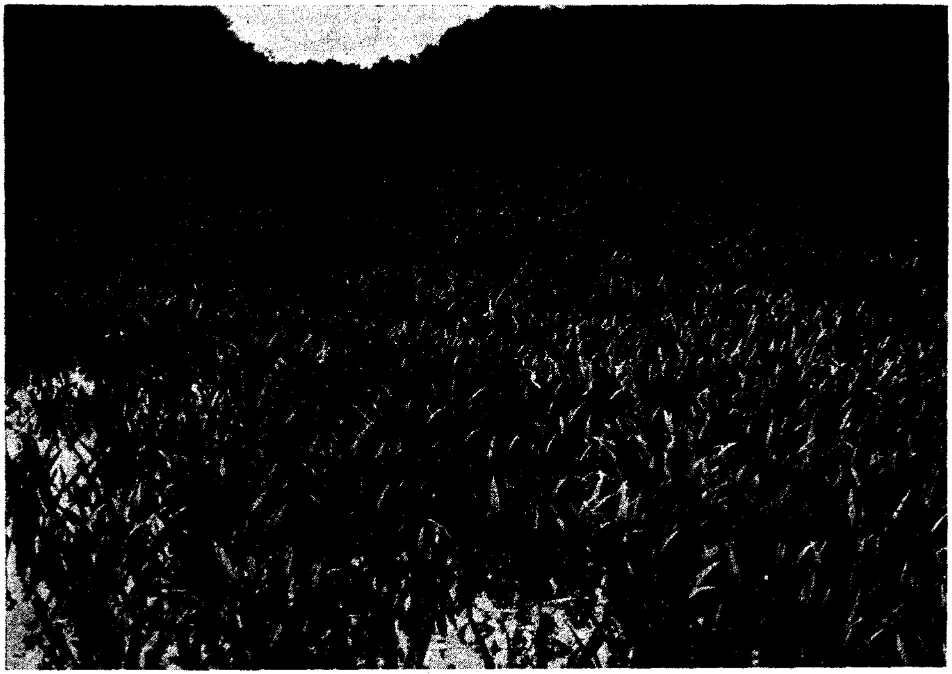


Photo 4. Formation of fen peat in mesotrophic to eutrophic water in the Netherlands (Overijssel Prov.).
The débris of the hydrophyte Stratoites aloides are accumulated to peat in a purely geogenetical way.

3. PROCESSES, CHARACTERIZATION AND DETERMINATION OF PHYSICAL RIPENING

3.1. DEHYDRATION

Physical ripening is the direct result of the withdrawal of water from the soft sediments and is affected by such well-known soil formation factors as parent material, climate (evaporation), topography (drainage), fauna and flora (homogenization and transpiration), time and man.

Dehydration during physical ripening is caused by:

A. the sagging due to gravity after drainage,
B. the direct evaporation of water from the soil, both superficially and through the cracks in the soil profile,
C. plant roots.

Factors A and B are obvious.

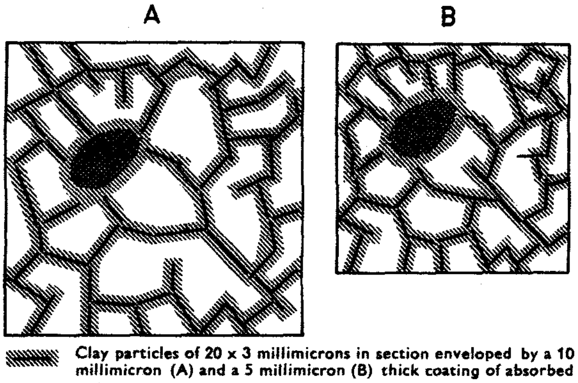
Factor C is particularly important, because without vegetation progressive physical ripening is hardly possible, especially in a temperate climate. A good drainage has no effect because unripened layers are very impermeable even with a relatively low clay content. ZUUR, in his lecture notes, quotes K-values of 10^{-4} cm/24 hours in non rooted layers containing more than 8 % clay, and K-values which are not much higher viz. 10^{-2} cm/24 hours in such layers containing 5–8 % clay. Values of the same order of magnitude were measured in low-lying, half-ripe freshwater tidal forest soils in the Biesbosch. The same K-values occur below the rooting zone of Avicennia nitida in the heavy marine clays of Surinam.

The stagnation of ripening can be determined experimentally and also from the following two observations:

Some sediments possess layers with large amounts of pyrites. During aeration (or at the very beginning of ripening) these pyrites oxidize as a result of chemical ripening processes, producing very acid soil layers. Under these conditions plant roots can neither develop in this layer nor in the underlying one and withdrawal of moisture is impossible in both layers. In such profiles despite a good drainage system of long standing, physical ripening is rendered stagnant because this special kind of chemical ripening has begun.

To promote physical ripening as much as possible in the new Zuiderzee polders, reed (phragmites communis) is sown as soon as the water cover has disappeared from the soils. By subsequently constructing ditches and drainage canals, man tries to provide the vegetation with the conditions necessary for a deep root system. Reed soon forms an extensive root system withdrawing considerable quantities of water from the soil and promoting physical ripening (Zuiderzee Works 1957).

The loss of water from the soil is not a simple evapotranspiration or sagging process. The water is more or less bound to the soil particles of a small grain-size. These particles are partly enveloped by a thin film of water (hygroscopic moisture) but also contain water in both their large and small cavities (free moisture).



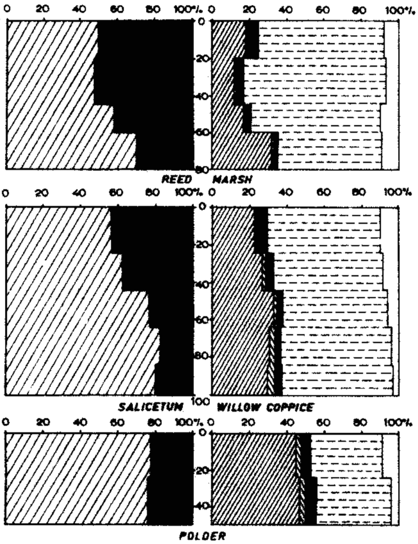
▨ Clay particles of 20 x 3 millimicrons in section enveloped by a 10 millimicron (A) and a 5 millimicron (B) thick coating of absorbed water

Fig. 5. Models of the microstructure of conglomerations of clay particles without sand and humus of a recently emerged unripe (A) and of a 100-year old ripe (B) Zuiderzee-bottom soil.
For convenience all particles, except one large one, have been drawn platy with the thin edge at right-angles to the intersecting plane (Zuur, 1958).

Clay minerals forming a real ‘harmonica structure’, e.g. montmorillonite, can store a great deal of water between their crystal lattices. The cavities between the particles may be of several kinds, depending on the origin of the parent material. When this material consists of laminar-shaped clay minerals, the fresh soft, loose sediments may be regarded as a honeycomb structure (ZUUR 1958, 1961, TAN TJONG KIE 1954). The particles are hinged together by electric forces at the points of contact (see Fig. 5). The crystalline lamellae are enveloped by a hygroscopic film of moisture which forms a stronger bond than the water in the cavities. The smaller the cavities, the more strongly bound is the water and the greater is the resemblance of this kind of moisture to

Fig. 6. Bulk density of the soil phases in different stages of initial soil formation (physical ripening).
Abscissa : volume of the unstirred soil constituents (in %).
Ordinate : depth in cm below surface (Zonneveld, 1960).

% particles < 16 micron	*colours of the Munsell Color Charts*
45.1	5Y 3-4/1
49.6	5Y 3-4/1
41.9	5Y 3-4 à 2-3/1
18.7	——
45.1	2.5 Y 3/2
33.7	10 Yr 2/2
42.5	5 Y 3/1–3/2
54.4	5 Y 4/1
49.2	5 Y 4/1
47,0	10 Yr 3/2
43,0	10 Yr 4/3



▨ mineral portion
■ organic matter
calculated as in wet conditions, air volume ignored

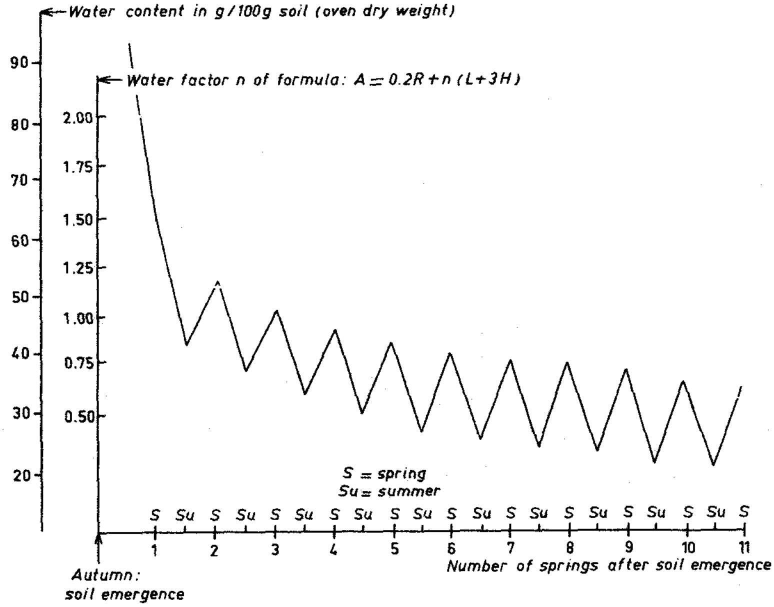
▨ mineral portion ($CaCo_3$ excluded)
▧ $CaCo_3$
■ organic matter
calculated as in dry conditions

▤ water
□ air

moisture of hygroscopic absorption. With the withdrawal of water, the quantity of moisture in the cavities decreases, resulting in a capillary contraction.
These processes reduce the volume of the sediments. (see Fig. 5).
The influence on the proportion by volume of the various soil compounds can be seen in the example given in Fig. 6.

The first contraction of the honeycomb cells is solely caused by the hinging of the points of contact, but when the forces increase as a result of the increasing capillary forces, the honeycomb cells are telescoped because the points of contact have been irreversible (TAN TJONG KIE 1954).
In the case of the organic matter the situation is more complicated. Here we find

Fig. 7. Water content and water factor n or n-value in spring (S) and summer (Su) of a Zuiderzee-bottom soil, with 25% clay (< 2 microns) and 2.7% humus, emerged in autumn. Thickness of layers 0–20 cm (Zuur, 1958).



amorphous and very finely-divided organic material, and even partly complete plant tissues that may have large cavities (some Cyperaceae, Gramineae and Spaghnum, for example). Organic particles, particularly those of a small size, will adsorb water on their inner surface. Very fine particles will produce a honeycomb-type structure in the same way as the clay minerals described above. These large cavities are a new phenomenon. Sediments and sedentates having this kind of cavity may contain a vast amount of water (for example, young Spaghnum peat). These materials will only release water in large quantities when pressure is exerted on them by overlaying layers, the process being similar to that of a sponge.

Lime sediment (lime gyttja) is another kind of sediment which may have a greater or smaller content of colloids with water-adsorbing properties. These sediments occur in a fairly pure state in warm seas and on the continents near geological formations rich in lime. Under moderate climatic conditions lime particles generally similar in size to silt particles (VAN DER MAREL 1950; VERHOEVEN 1962) also form an important constituent of the young mineral fluviatile and marine sediments. This material has not yet been studied from the ripening point of view, but the same ripening processes probably occur in the draining of pure, soft, fine textured lime sediments as have been found to occur in clayey sediments.

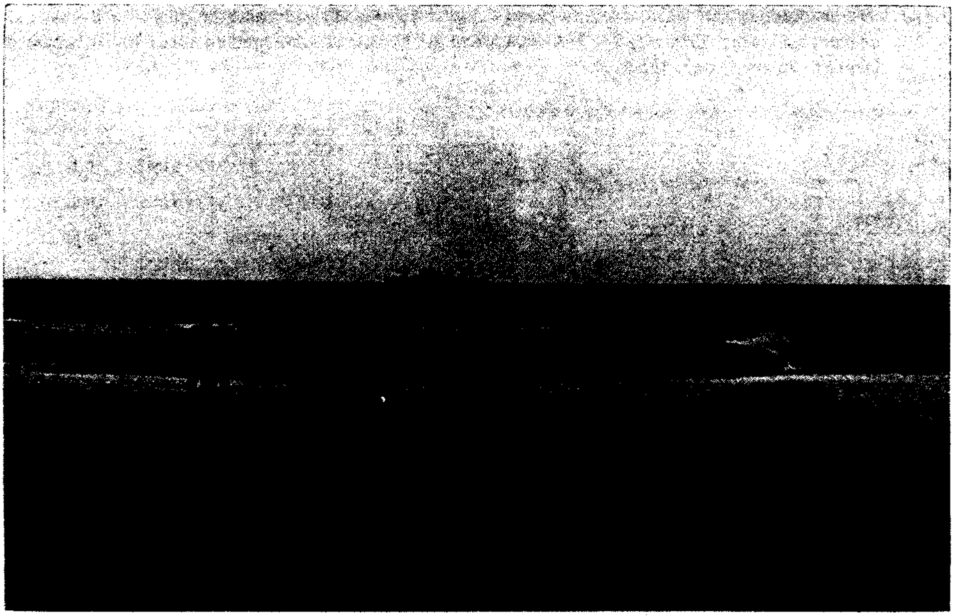


Photo 5. At low tide extensive sandbars appear in the salt water estuary of the Western Scheldt (Neth.).
The clay content of the sand is very low. This is an example of young alluvial deposits without criteria for physical ripening. This kind of soil is considered to be physically ripe.

It will be clear that sediments which have no fine particles and hence no colloidal material – in other words, silt, sand and gravel – will not have any significant water-absorbing capacity and not exhibit ripening phenomena. (Photo 5).
If for practical purposes we wish to draw a line of demarcation between soils rich and poor in colloidal materials, this would lie at a point where the clay content is about 8% in clay-containing soils with a very low organic material content. Of soils having only organic matter as colloidal material, colloidal rich soils should have an organic matter content higher than 3%.

3.2. IRREVERSIBILITY

One of the most important features of the process of physical ripening of predominantly mineral soils and of organic soils containing a large amount of amorphous organic matter is its irreversibility. Once such a soil has undergone the ripening process, and provided it does not change its position, it does not absorb the same quantities of water during new inundations as it contained immediately after sedimentation.
This irreversibility is due to the fact that the material of which the soil is composed

lacks elasticity, and this lack of elasticity can be attributed to the special character of the honeycomb structure described above. The forces resulting from the absorption of moisture are too weak to break up the telescoped clay particles, especially in the case of clay minerals.

Artificial mechanical disturbance of the soil structure in wet conditions causing reversible ripening is widespread in rice culture (puddling). Consequently the very top layers of paddy fields often have a relatively low stage of ripening, due to artificial conditions. Under the special conditions observed in Surinam one kind of reverse of ripening in the top layers of mineral soils is due to intensive root-growth under conditions of constant waterlogging.

In the case of organic matter, the honeycomb 'cell walls' are probably more flexible, so that the decrease in the cell volume of the honeycomb structure is rather the result of compression than telescoping. The new bonds created by this action are easily loosened by absorbed water (ZUUR 1958).

It is only as a result of very intensive dehydration that the humus particles are bound together so strongly that hydration is unable to loosen the bonds. This process is called 'the irreversible drying-out of peat' and mostly occurs in peat layers with a relatively high content of very small particles of organic matter, for instance slowly formed disintegrated peat subjected to strong pedogenetic influence during its growth (PONS 1961), or moulded peat (JONGERIUS and PONS 1962a and b). But very prolonged action of water on these soils leads to renewed absorption of water (BENNEMA and VAN DER WOERDT 1961). It is also probable that the water absorption on the surface of the soil particles is partly an irreversible process for the organic and mineral particles (exothermic process).

Irreversible dehydration of mineral soil material does not completely exclude the possibility of an increase in the water content of ripe soil material. The swelling of the soil with wetting is a familiar example. The water content of ripe soils fluctuates somewhat according to rainfall, drainage conditions, etc. A fluctuating moisture content has been recorded (see Fig. 4) during the ripening process of soil material which was originally very soft and wet. This phenomenon results from the force of repulsion existing everywhere between the particles except at the points of contact (sponge effect).

Certain types of peat which show only a slight degree of disintegration and contain large capillary cavities are so reversible that irreversible drying-out never occurs. This is the reason for the very favourable agricultural properties of granulated peat and tirr (young Spaghnum peats) which contain large water cells derived from the leaves of the original peat-forming plants.

3.3. PHYSICAL RIPENING AS A FUNCTION OF THE WATER ABSORPTION CAPACITY AND THE WATER CONTENT OF SOIL MATERIAL

In the preceding subsections ripening was described as a process involving a change in the micro-structure of the clay minerals and the fine colloidal organic matter, as well as a loss of water. While it is impossible to measure the changes directly, we can estimate the loss of water with a reasonable degree of accuracy. It may be assumed that the greater the telescoping of the clay (and organic matter) particles, the smaller will be the water-absorbing capacity of the colloidal material. The water binding capacity of colloidal material will therefore constitute a reasonable means of measuring the micro-structure, and hence of the stage of ripening.

It may be assumed that the total water content of a soil is roughly a function of the water- absorbing capacity inherent in each individual soil compound. Furthermore we assume that each component has its own characteristic water-absorption capacity, which is in equilibrium with that of the other components and only depends on the stage of ripening, that is the degree of change of the micro-structure.

However, soil is a mixture of colloidal and non-colloidal materials. Fine organic matter and clay form the colloidal soil components, their water absorption being totally dependent on the microstructure or telescoping of the colloids, and consequently on the physical ripening. Silt, sand and coarse organic matter structures are non-colloidal soil materials without or with only weak water-adsorbtion capacities but with varying water storage capacities which are not at all dependent on ripening, or only very slightly.

The storage capacity is particularly important in peat and peaty soils. In discussing the theory we will therefore distinguish between mineral soils and organic soils.

3.3.1. *Mineral soils*

In mineral soils the colloidal part of the soil is mainly the clay minerals of the clay fraction. Since the organic colloids in the soil are not constant during pedogenesis but can increase or decrease and change their qualities, we consider the water adsorbtion of the clay fraction as the most universal basis for the expression of the physical ripening. The clay fraction is practically constant both in a quantitative and a qualitative sense.

We now introduce a water factor **n** as a standard of physical ripening. This is the quantity of water in g which is adsorbed as purely as possible by 1 g of the clay fraction.

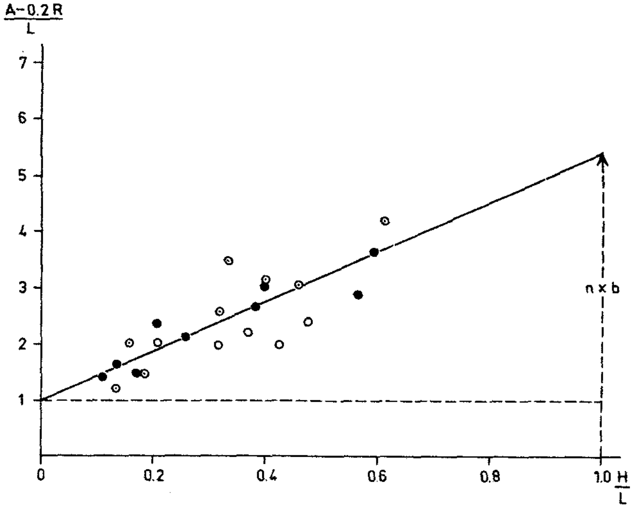
Taking the above approximate assumptions as our basis we can give a reasonable description of the phenomenon of the ripening in the form of an equation.

Let us represent the other factors as follows:

A = the total water content compared to 100 g of dry soil
L = the clay content (lutum)
H = the organic matter content
R = the non-colloidal mineral part of the soil (mainly silt, sand and lime, $R = 100 - H - L$)
b = the ratio of the water-adsorbtion capacity of organic matter to (illite-) clay
p = the water-storing capacity of non-colloidal parts

Fig. 8. Graphic determination of the ratio b between the water binding capacity of clay and organic matter in soils underlying Salicetum willow coppice. From this graphic representation also the waterfactor n can be determined.

- ● Type of vegetation V_3
- ○ Type of vegetation V_2
- ⊙ Type of vegetation V_4 and V_6



The water content of a soil can now be represented by the following simple addition of the water content of the three main components: clay, organic matter and non-colloidal material respectively:

$$A = nL + nbH + pR \qquad (1)$$

(ZONNEVELD 1959, 1960 and 1961).

In this equation A, L and H (and thus by inference R) can be measured in each soil sample.

It has been found from several measurements (DOMINGO 1951; ZONNEVELD 1960; ZUUR, 1958; and others; see also Fig. 8) that 100 g non-colloidal mineral material may contain about 20 g water; hence p is about 0.2. In pure sand this figure will be somewhat higher and in clayey sediment somewhat lower. In practical use this value always gives satisfactory results.

Theoretically, n and b can be found if we have two or more equations similar to equation (1), in which p, A, H and L (and thus by inference R) are known, but in which b and n are constant. We have assumed that b and n are constant within every stage of ripening. Hence the problem is to know beforehand whether samples are derived from the same ripening stage before we can subject the problem to a reliable mathematical treatment. The only means of comparison we dispose of, are landscape features types of vegetation and soil consistency.

Only the most homogeneous soils (subsoil of a tidal forest; Zuiderzee mud) appeared to give reliable results when submitted to algebraic and diagrammatic investigation. Figure 9 gives a graphic calculation of the factor b in a number of samples with the same n-factor because originating from the same ripening stage occurring under comparable vegetation types in the freshwater tidal area of the Biesbosch (ZONNEVELD 1960).

Equation (1) can also be written:-

$$nb \times H/L + n = (A - 0.2\ R)/L \qquad (2)$$

The several factors from this equation $H/L, (A - 0.2\ R)/L$, n and nb are all presented in the graph in Figure 8. The b-factor found by these methods was 3 to 4. This is in reasonable agreement with the general experience that the ratio between the cation- and the water-adsorbtion capacity of illite and humus should be about 3. Similar experiences in other sediments are discussed in section 3. Of these mostly marine sediments a b-factor of 3 is most common. Other ratios are obtained for more or less undecomposed organic matter. This will be discussed in subsection 3.3.2. If the b-factor can be estimated, the only other unknown factor is the n-value, viz. the water-binding capacity of 1 gram of illite clay.

Absolute or nearly absolute data about n-factors and ripening stages are easily obtained from certain tropical marine deposits, poor in organic matter, for example the heavy clays along the Guiana coast. These deposits have a very low organic matter content i.e. H is nearly zero and b is of no practical significance (cf. the examples given in the Appendix). With this aid the n-factor is determined for each stage of ripening and from this the b-factor can be calculated.

From all these measurements and estimations we know that the b-factor for highly decomposed organic matter is about 3 and about 4 for somewhat lesser decomposed organic matter.

The n-values were calculated for several hundred soil samples of mineral soils with the following formula derived from (1):

$$n = (A - 0.2\ R) / (L + bH) \qquad (3)$$

Here a b-factor of 3 is used for soils with an organic matter content which has been well humified (this can be confirmed microscopically) and a b-factor of 4 for soil samples with clearly visible plant remnants containing cell structures, etc. (cf the Appendix). In this way a reasonable measure of agreement has been achieved with the physiography described in the preceding subsections 3.3.1 and 3.3.2 (viz. ZONNEVELD 1960, 1964).

Most Western European clays mainly consist of illite with a cation exchange capacity of about 60 m.e.p. 100 g clay.

In accordance with the procedure suggested by Prof. ZUUR (personal-communication), we propose to use the n-factor for illite as the general ripening standard. If other clay minerals occur, we propose to convert their n-values into that for illite, in which case formula (1) must be written:-

$$A = n\ (\text{illite})\ L_I + n\ b_1\ L_1 + n\ b_2\ L_2 \ldots \text{etc.} + n\ b_h\ H + 0.2\ R \qquad (4)$$

In this formula, b_1, b_2 etc. represent the ratio between the water-adsorbing capacity of illite and that of the other clay minerals, the weights of which are represented by L_1, L_2 etc. The factor b_h represents the ratio between the water-adsorbing capacity of illite and that of organic matter. L_i represents the weight of the illite content, Hence:

$$n = \frac{A - 0.2\,R}{L_i + b_1 L_1 + b_2 L_2 .... + b_h H} \tag{5}$$

In this way it is possible to arrive at a universal classification of the ripening stage by means of a single figure [1]).

ZUUR (1958) and SMITS (1953) developed the following slightly different formula, which at our suggestion was also used in the 7th Approximation (cf. Soil Survey Staff, 1960):

$$n = (A - 20) / (L + bH) \tag{6}$$

If the same b-value is used the n-values obtained with this formula are 0.1 to 0.2 lower, depending on the organic matter content. Here n does not represent the water content in grams per gram illite, as in our previous formulae 1–4, but the tangent of a line drawn in a graph with A on the ordinate and L + bH on the absciss a.

Prof. ZUUR agreed that the use of our formulae (3) and (5) was 'theoretically somewhat more correct and in practice gave somewhat more logical results.' Although it does not make much difference which formula is used, we prefer our own, particularly (3) and (5), as they provide a less abstract mathematical, and more concrete description of the phenomenon (the simple addition of components) [2]).

3.3.2 *Organic soils*

As we saw in subsection 3.3.1, the b-factor for well decomposed and humified organic matter in mineral soils is about 3.

If organic matter is present which is not totally decomposed the large cavities characteristic of this material (plant tissues) can be filled up with water, thereby increasing the ratio (ZONNEVELD 1959, 1960, 1961; PONS 1958, 1961; ZUUR 1958). On the other hand, it has already been mentioned (section 2.2) that the cation binding capacity is lower in less decomposed material than in real humus because in the former case it is only the internal surface that is important and not the large cavities.

If the formulae for ripening developed for mineral soils are applied to organic soils without clay, or with only very little clay, the equation can be written as follows:

$$A = n.b.H. \tag{8}$$

---

[1]) If no exact determination of clay minerals exists, but only the cation exchange capacity of 100 gr clay is known (CEC), the said b-value can be estimated by the following calculation: $b = CEC/60$. This is permissible because the cation exchange capacity of these very young mineral soils is closely related to the water-adsorbing capacity. It is not permitted to do so for organic soils.

[2]) Before devising formulae (1–5), ZONNEVELD 1956 used the following equation:

$$n = A/(L + bH) \tag{7}$$

Our new formulae (1–5) lie between (7) and (6) and may be considered the best formulae at present possible.

For purely amorphous organic matter it should be possible to write for b the relative adsorption capacity of organic matter in relation to that of illite ($b = 3$). In this case the factor n would be comparable with that for mineral soils. A peat and a mineral soil with the same ripening factor would have reached the same stage of ripening.

Organic soils of purely humified organic matter are very rare. Normal organic soils always have large quantities of undecomposed plant remains. During ripening the influence of the tissue cavities is an important factor in most peat soils. If we confine our considerations to less compressed peat soils in conditions of absolute saturation, it may be possible to subdivide the 'water factor' nb into a ripening factor n and a 'material' factor b. These have, however, a more arithmetical (and less concrete) value than that already given for mineral soils. Thus, b-values can be computed by comparing organic soils with mineral soils at the same stage of ripening and thus having by definition the same n-value. The identity of this stage of ripening can only be discerned from the physiographical conditions but is not so easy to determine as for mineral soils.

The b-values estimated in this way for partly disintegrated organic matter of different origins in clayey to pure peats usually seem to fluctuate between 3 and 6 according to data supplied by PONS. For non-disintegrated young Spaghnum peat this value is probably about 9. There is some connection between these values and the botanical composition and, within each botanical class, between the b-values and the degrees of humification described by VON POST (1926).

It may also be possible to deal with the problem by introducing a water factor for organic material, n_h (n_h: amount of water absorbed at 1 g organic matter) being determined in the same way as the water factor for clay n_i (n of illite). Further experience and research on initial soil formation of organic soils is required before a result can be achieved which is equally good for mineral soils.

3.4. DETERMINATION OF THE PHYSICAL RIPENING STAGE IN THE FIELD

The determination of the above mentioned value **n** always entails laboratory analyses. For mapping and other purpose, however, it is useful to have an estimation method for use in the field. For young sea bottom polders, ZUUR and SIEBEN have made a field estimation of ripening in mineral soils by assessing the extent of cracking. The most important field method is the determination of the consistency, which, by its very nature, is closely related to n. The consistency, however, also depends on the clay and organic matter contents. After long field experiences it has become possible to estimate clay and organic matter content in a sufficient correct way. Consequently, it is now possible also to estimate ripening by means of the consistency of soils especially for the low ripening stages. Moreover, for certain practical purposes it is particularly important to know the consistency for the purpose of forecasts on structure, shrinkage, drainage requirements, etc.

In 1960 ZONNEVELD estimated the ripening of topsoils with the consistency method by assessing the depth to which a man sinks into the mud or, to use a more precise method, the extent to which a special rod, falling from a fixed height, sinks into the soil surface. This method does not appear to be new because about 1000 years ago the early inhabitants of Peru were ordered by the Inca Gods to measure the friability of the soil by dropping a golden rod before they founded a new settlement, the town of Cuzco.

PONS afterwards tried to determine the consistency of soil layers with a penetrometer, measuring the pressure exerted at the point of a cone as it slowly penetrates the soil. This cone has a special surface and a top angle of 90°. Both authors found a fairly good correlation between the pressure reading in kg/cm^2 and the n-value for soil layers having at least 20% clay.

Figure 9 shows the relationship for totally reduced clays and clay loams.

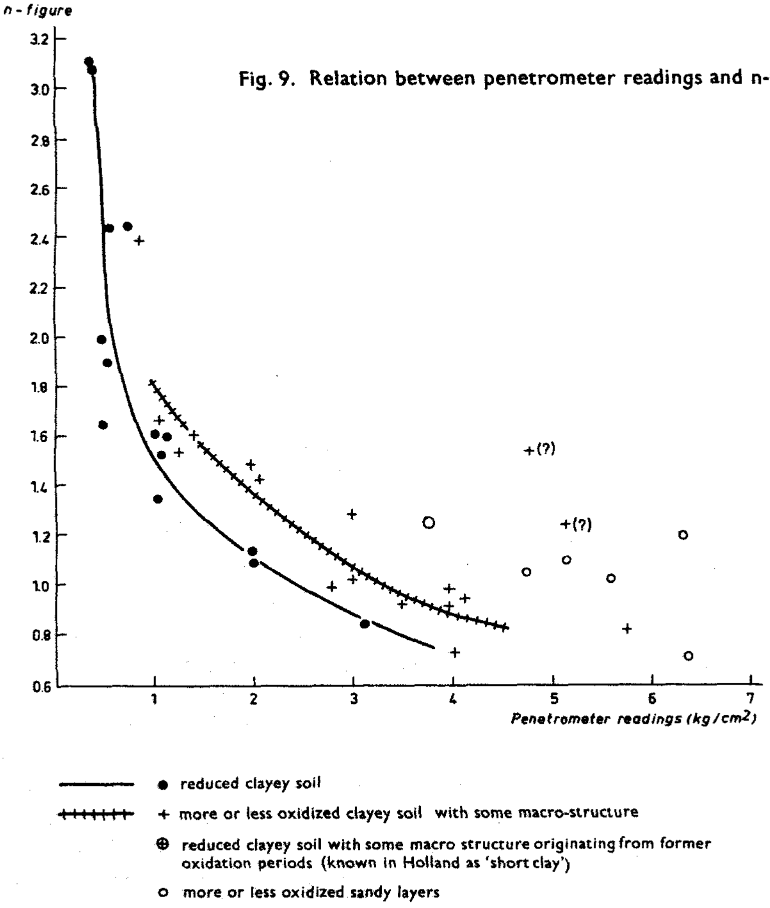


Fig. 9. Relation between penetrometer readings and n-value

In reduced soil layers without structure development the correlation is very good, but somewhat different results are obtained when the soil macrostructure has been developed by aeration. Nevertheless, the method is easy to follow in the field. This method, when used in mineral soils containing a large amount of organic matter, or in peat soils with much fine textured humified organic matter, also gives good results provided use is made of the specific b-values for each botanical type of peat. In this case also the presence of aerated soil layers, possessing a macrostructure gives rise to various problems, as also does the presence of coarse and fibrous plant remains in less humified peats.

The same experiments applied by JANSSEN and KAMERLING (1964) in Surinam to tropical marine clays with the same CEC as the clays of figure 9 give totally comparable results and are also possible when these very heavy clay soils have developed some structure.

The quantity and quality of the cations bound to the clay complex will probably also cause minor differences in consistency at the same n-value, as was shown by the work of KOENIGS (1961). But the cations primarily determine the stability of the structure. In section 6.2 we shall discuss a routine method of measuring the consistency by pressing with the hands and which has been found to give good results.

4. PHYSICAL RIPENING UNDER NATURAL CONDITIONS AND AS INFLUENCED BY MAN

The vertical or horizontal sedimentary pattern, or in other words the geomorphological structure of the natural alluvial (fluviatile and marine) landscape is determined both by the frequency and duration of the inundations and the velocity of the running water. Moreover, the differences in the actual ripening are very important and influence the vegetation, the sedimentation, and consequently the entire geomorphology. Owing to hydrological conditions the frequency and duration of the inundations the particular phase of ripening depends in turn on the geomorphology and the vegetation.

In fact, the conditions determining physical ripening under artificial drainage are the same as under natural equilibria. The only difference is usually the more rigorous way in which the ripening proceeds, accompanied by specific characteristics of the resulting soils. We shall deal with this in the following sections.

4.1. PHYSICAL RIPENING UNDER NATURAL CONDITIONS OF VEGETATION-BEARING SOILS IN AREAS OF FLUCTUATING WATER LEVELS

Gradual ripening, producing horizontally homogeneous, partly ripened profiles up to some depth

Fluctuating inundations can be found under various conditions, e.g. in tidal areas, either under marine conditions along the coast or in the lower courses of rivers, or in areas where the water level fluctuates, either as a result of the various discharges from rivers or a temporary rise or fall in the water tables of shallow lakes and seas caused by strong winds. The ripening of tidal areas has been the subject of numerous studies by HISSINK (Laboratory of Soils, Kampen 1935) and several reports by ZUUR (1958) and ZONNEVELD (1956, 1958, 1960, 1963).

As already stated, physical ripening starts immediately after aeration and/or drainage.

Photo 6. Back swamp tidal forest in the freshwater tidal area of the Biesbosch (Neth.).
Clay deposits with a fairly high organic matter content under a vegetation of Salix spec. A physically practically unripe soil with an n-value from 1.7–2.0, impassable to man, or only passable with great difficulty. The ripening stage is comparable to that under a rush marsh vegetation (Photo 10) and under young mangrove vegetation (Photo 11).

Every sedimentation area which originated from the transport and deposition of particles by running water and where sand, silt and clay are present, is characterized by relatively high and low-lying parts. Geomorphologically the high lying parts are characterized as natural levees, coastal barriers or similar kinds of narrow strips, situated at a relatively considerable height above sea level. The latter have a light texture, are well drained and border on the water channels. Behind these natural levees are the low-lying parts, e.g. back swamps, basins, lagoons and similar types of relatively low-lying, natural terrain, which is poorly drained and in most cases has a heavy texture (see resp. Photos 7 and 6).

During the sedimentation, and also after sedimentation has stopped, the process of initial physical soil formation proceeds very slowly or stops wholly in these swampy areas, though the latter is not always the case. In the high-lying parts, which are usually relatively well drained and sometimes even intensively drained, this process develops very intensively both during sedimentation and afterwards. The sediments in back swamps or basins (see Photo 6) which are never aerated, even during periods with the

Photo 7. Reed marsh soil in the freshwater tidal area of the Biesbosch (Neth.).
Nearly unripe, with n-value from 1.5 to 1.7. Only the upper 15 cm of the profile is slightly aerated. Reed roots (of Phragmites communis) grow in completely reduced layers and are able to extract water from their environment (Telmatophytes). The stratification is due to differences in texture, the more sandy layers being more easily eroded in the profile wall. Total height of the artificial wall approx. 1.5 m.

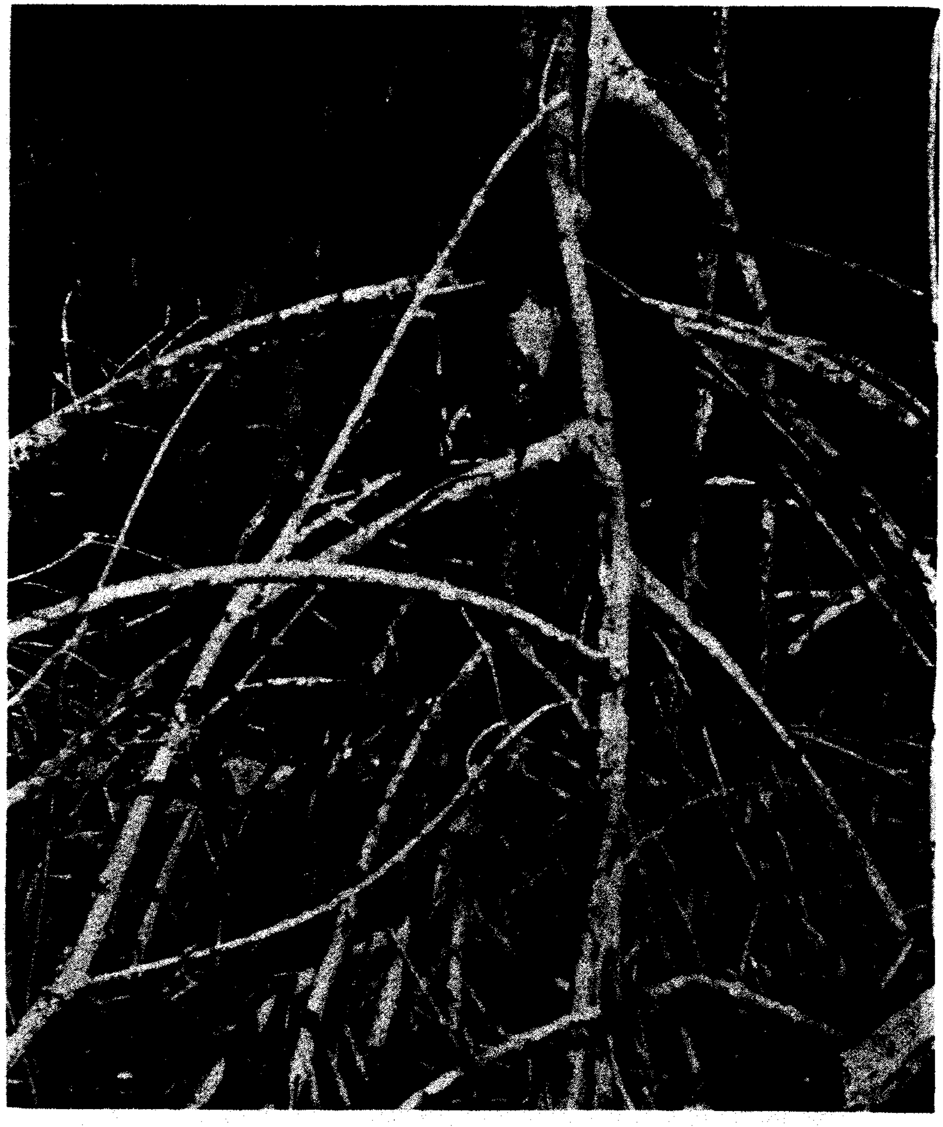


Photo 8. The root system of an old Rhizophora tree mangle in Surinam.

The tree grows especially on brackish, nearly half-ripe to unripe, mostly totally reduced muds. Owing to its numerous aereal branches and relatively extended surface above the soil the root system is adapted to very soft and unstable soil conditions, flooding and reducing conditions.

lowest water table, may have a high moisture content and a high n-value even when they are of a considerable age. There is hardly any physical ripening in these sediments. Nevertheless, in some places, especially where clay or sandy clay layers cover soft peat or clayey peat layers, the pressure of the covering layers may lead to a slight decrease of the water content and consequently in the n-value of the lower layers (see section 4.3). Superficial ripening, giving heterogeneous soil profiles (ripe with an unripe subsoil), is common in these poorly drained areas.

Physical ripening by evaporation-transpiration usually starts above the permanent reduction level in the soil. When the plant roots of certain special species (Telmatophytes) are able to penetrate and withdraw a certain amount of water (Photos 7 and 8), it is possible for ripening to begin even within the permanent reduction zone where no air is admitted. However, even in these cases some movement of water in the permanently reduced soil is necessary to remove more or less poisonous reduction products. This movement is promoted by tidal movements (see also Photo 18).

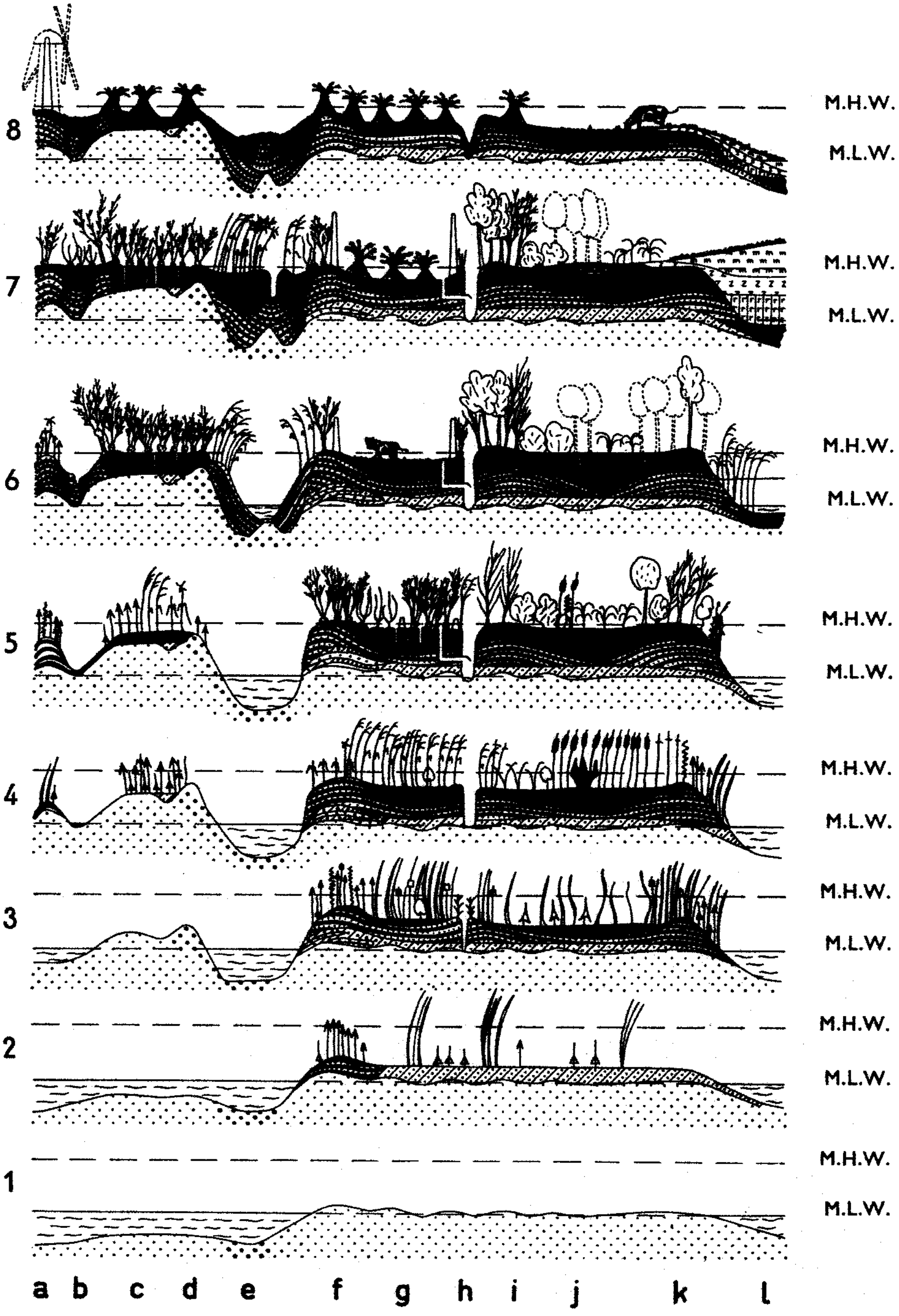
Consequently, ripening and silting-up are to some extent simultaneous processes. Furthermore, because a decrease in volume, as we have seen in chapter 3, is inevitably associated with the ripening process, it follows that the settling and silting-up processes are also simultaneous. As an example, a diagram is given in Figure 10 of the several stages of land formation, vegetation and shrinkage occurring in the freshwater tidal areas of the Netherlands (see also Figure 4).

In the freshwater tidal areas in the Netherlands, sediments with an n-value of slightly more than 1.0 and a clay content of 25% settle to the extent of 50% before an n-value of 0.6 is reached. In these areas of freshwater tidal marshes (in Dutch: 'gorzen') overgrown with rushes, rough herbage or reed and situated between mean high tide and mean low tide, an equilibrium has been reached between settling and silting-up, which has also been influenced by the digging of the ditches. The marshes silt up and grow without a comparable rise of the surface, but in view of the possible increase in the weight by volume, this growth is a potential one. After diking in, the settling in these physically riper tidal marshes will be less than on tidal marshes which have the same level but are less physically ripe (cf. ZONNEVELD 1960).

In fairly well aerated willow coppices (a cultivated form of tidal forest) on the natural levees in freshwater tidal areas (ZONNEVELD 1956, 1958, 1960) and on corresponding sites (salt marsh with grassy and herbaceous halophytic vegetation, called in Dutch 'kwelders' and 'schorren') in the marine areas of N.W. Europe, profiles occur which, for a depth of about 80 cm, show an identical phase of ripening (cf. the Appendix and Figure 4).

This phenomenon, which is characteristic of land subjected to fluctuating inundations beyond the dikes, is the result of the mechanism of the silting-up process, in the course of which every layer in the profile has at some time been the upper layer, and while in this position has been aerated and partly ripened. The higher the layer in the profile, the more intensive will be the aeration. But the upper layers are more recent than the lower ones, in which ripening is less intensive. Consequently, to a depth of about

Fig. 10. The accumulation of land (shown diagrammatically) Zonneveld, 1960 (Biesbosch, Neth.).
MHW = mean high water – MLW = mean low water



Legend to figure 10

⋯	medium fine sand
⁘	coarse sand
▨	clay containing sand
■	clay
≋	alternating clayey and sandy layers
v v v	peaty clay
r r r	reed peat
m m m	Sphagnum peat
z z z	Sedge peat
∩	dike
	mill drainage
∟	culvert
∧	small dike

Sea Club-rush *Scirpus maritimus*

Triangular stemmed Mud-rush *Scirpus triqueter*

True Bulrush *Scirpus lacustris s.l.*

Green Reed-grass *Phalaris arundinacea*

Great Fen Ragwort *Senecio paludosus*

Purple Loosestrife *Lythrum salicaria*

Great Hairy Willow-herb *Epilobium hirsutum*

Reed *Phragmites communis*

Sedge *Carex div.sp.*

Gipsy-wort *Lycopus europaeus*

Great Reed-mace *Typha latifolia*

Lesser Reed-mace *Typha angustifolia*

Marsh marigold *Caltha palustris*

Reed Sweet-grass *Glyceria maxima*

Common bur reed *Sparganium erectum*

Common Arrowhead *Sagittaria Sagittifolia f. Sagittifolia*

V_1–V_3	original vegetation V_1: community of Salix alba and Scrophularia nodosa V_3: comm. of Salix alba, Cardamine amara and Anthriscus Silvestris
V_1–V_3	willow bed
V_4, V_5	original vegetation V_4: comm. of Salix div.spec., Sium erectum and Rumex obtusifolius ssp. Silvester V_5: comm. of Salix purpurea, Alisma plantagoaquatica and Sium erectum
V_4, V_5	willow bed
	Alnetum glutinosae
V_0	original vegetation comm. of willow coppice and tidal forest with Circaea lutetiana and Carex remota
	pasture
	arable land
	Sphagnetum
Rdq	comm. of Scirpus triqueter and Scirpus maritimus
Rdh	comm. of Scirpus maritimus and Phalaris arundinacea
Rc	comm. of Senecio paludosus, Lythrum salicaria and Scirpus maritimus
Rdf	comm. of Scirpus lacustris and Lythrum salicaria
Rf	comm. of Scirpus lacustris and Sagittaria sagittifolia f. Sagittifolia
Re	comm. of Typha latifolia and Sparganium erectum ssp. polyedrum
R	rough herbage and marsh of rushes
Rb	comm. of Epilobium hirsutum and Phalaris arundinacea
Rp	comm. of Veronica anagallis-aquatica and Polygonum hydropiper

1 metre in the profile, the phase of ripening of the upper layers will not differ extensively from that of the lower layers.

In the tropical brackish and salt water tidal areas of Surinam, where the geomorphological conditons are the same as those described above, the same type of ripening, settling and silting up occurs. Mud banks with n-values of 1.8 to 3 are overgrown with mangrove vegetations (Avicennia nitida under salt conditions; Laguncularia racemosa and Rhizophora mangle under brackish conditions) at or somewhat above mean water level. Under Rhizophora mangle shallow soil layers ripen to n-values of between 1.0 and 1.4. At the same time the soil shrinks and silts up with clay layers which have also ripened to the same n-value. In this way, under Rhizophora, layers of about 2 metres in depth and n-values of mostly about 1.4 can develop under tidal conditions. Under the deeper rooting Avicennia nitida, which grow on better drained places the soils produced are more or less ripened, and from the point of view of physical ripening are half-ripe to a considerable depth.

4.2. PHYSICAL RIPENING AS A RESULT OF ARTIFICIAL DRAINAGE

Sudden ripening, producing vertically heterogeneous profiles in which the ripening decreases with depth

The course of ripening in subaquatic sediments which are suddenly drained is different from that in sediments subject to fluctuating inundations. The sudden drainage of a subaquatic sediment is a rare occurrence under natural conditions, so that this type of sediment is usually only subject to ripening as a result of drainage by human agency. The process of ripening of this type of sediment in the polders of the Zuiderzee has been described by DOMINGO (1951), ZUUR (1954, 1958, 1961) and SMITS (1953) in various reports of the Board of the Zuiderzee Works. The ripening of these soils is characterized by the formation of broad cracks caused by the horizontal component of the decrease in volume because of the high original water content (high n-figure) and the relatively high content of organic matter of these sediments from temperate areas (Photo 9). In tropical areas these sediments are much rarer, as is also this type of ripening.

During a very gradual drainage the ripening symptoms are more comparable with those occurring in sediments from areas subject to fluctuating inundations. The progressive cracking accompanying the course of ripening causes the sediments to break

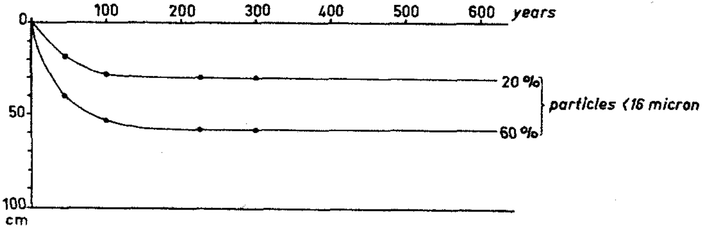


Fig. 11. Decrease in thickness of the upper 100 cm, caused by settling (Salicetum willow coppice). Zonneveld, 1960.

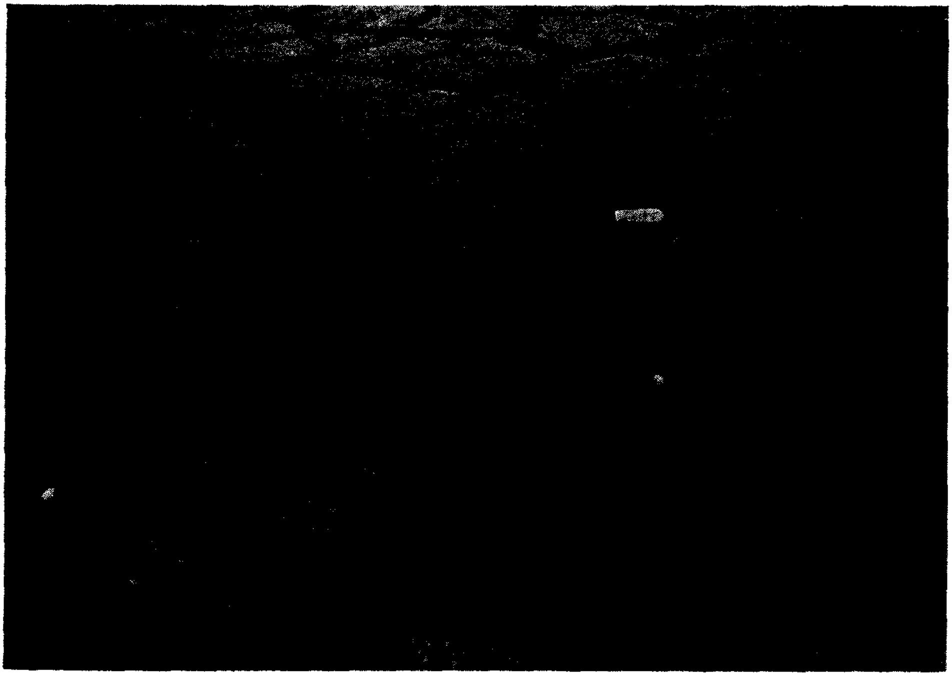


Photo 9. Sudden ripening in soft clayey sediments deposited without vegetation on low water level, after endyking and drainage of the North Sloe, prov. of Zeeland (Neth.). August 1961.
Irreversible cracks of several kinds can be seen.
Some Salicornia herbacea plants and Mia shells are visible, indicating a salt environment.

down into units known as 'passive' structures (HOEKSEMA and JONGERIUS 1959). These irreversible cracks are very important from the point of drainage.

In these artificially drained soils ripening always gradually decreases with depth. Another typical aspect of these soils is the fact that the topsoil or top layer is always totally ripened, unlike ripening under natural conditions, in which the top layers are always partly ripened.

The process of physical ripening takes time. According to data given in reports of the Zuiderzee Polders Development and Colonization Authority and by ZONNEVELD (1960), the upper three feet of an unripe sediment which is suddenly subjected to optimum drainage will take 50 to 100 years to become ripe (cf. Fig. 11).

Even 10 years after reclamation, deep drainage and crop growing in the North-East Polder (Netherlands), the n-values of the top layers did not exceed or only just exceeded the limit for ripe soils, viz. 0.7. It is evident, for example, that structural properties change considerably throughout this period of ripening.

4.3. SETTLING BY PRESSURE UNDER THE WEIGHT OF THE TOP LAYERS

In the subsoil of the natural landscape a considerable degree of settling may be caused by upper layers. Peat layers situated on an undulating mineral subsoil show this phenomenon particularly clearly. Layers of a special composition, such as thin mineral layers which are easy to recognize in the peat profiles and were originally deposited in a horizontal layer, are now situated at widely varying depths in the peat profile as a result of varied degrees of settling during peat growth. BENNEMA (1954b) gave some very good examples of this phenomenon (Fig. 12; cf. also ZONNEVELD 1960).

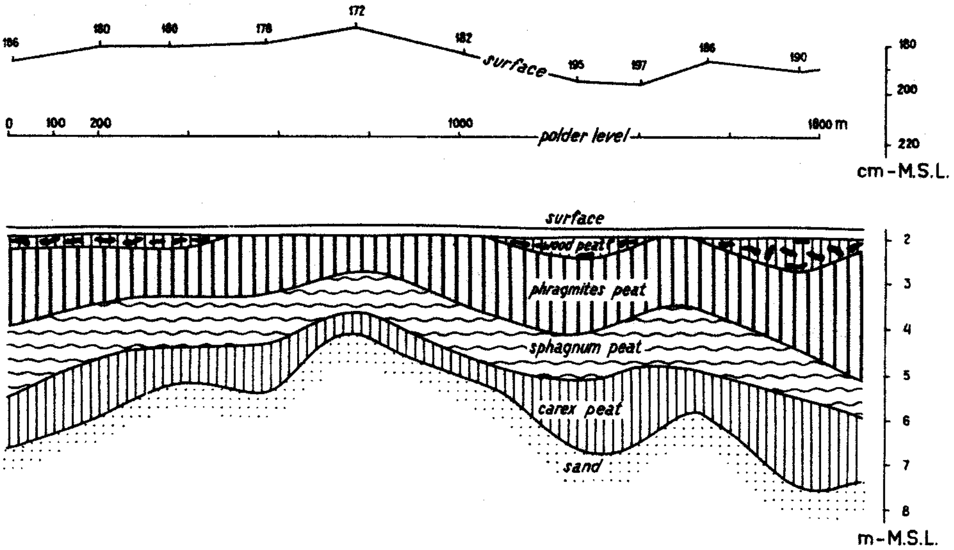


Fig. 12. A cross-section in Gaasp and Gein (prov. of North-Holland, Neth.)
The peat layers undulate in accordance with the topography of the sandy subsoil. This is particularly noticeable in the case of the Sphagnum peat layer. To a lesser extent, the soil surface has the same feature (Bennema, 1954).

On the other hand, we are also familiar with the phenomenon of thin peat layers in soft mineral sediments, which sometimes also follow a very undulating course. Originally, these thin peat layers were horizontal, but subsequent sedimentation and a varying degree of settlement of the underlying layers has in some places caused the peat layers to be pressed down to a great depth; this is well illustrated by ZUUR (1936), PONS and WIGGERS (1960) and ZONNEVELD (1960).

There are well-known cases in the Netherlands where originally soft clay and peat layers resting on permeable sands are heavily pressed by overlying sandy sediments and converted by loss of water into impermeable, very sticky layers.

4.4. VERTICAL-HETEROGENEOUSLY RIPENED SOILS AND THE NATURAL AND ARTIFICIAL CONDITIONS OF THEIR GENESIS

When sedimentation stops, homogeneous vertical ripening changes into heterogeneous ripening. In back swamps the ripening process is often similar to the artificial processes occurring in drained lake bottoms where heterogeneously ripe soil profiles are produced. The ripening stage of the soil material becomes gradually and distinctly more advanced the nearer the soil is to the top where sedimentation is complete.

The converse of this is caused by incomplete sedimentation and cutting of the sedimentation sources, while only superficial ripening has started. Extended back swamps, having no possibilities of drainage owing to the presence of natural levees or coastal barriers, exist in some areas of the young coastal plain of Surinam. The soils here are only superficially ripe and cannot develop further owing to lack of drainage.

In the greater part of the artificially embanked Netherlands marine landscape heterogeneously ripe soils are very common under poor or fairly poor drainage conditions, originating from incomplete sedimentation. Heterogeneously ripened soil profiles are found in the western peat district of the Netherlands in particular and also in the relatively large areas consisting of shallow clay layers on peat, which are used almost exclusively as grassland with high groundwater tables. The topsoil is ripe to a depth of about 30 cm ($n < 0.7$); the subsoil, on the other hand, is only partly ripe to a depth of from 30 to 60 cm ($n > 0.7$) and is more soft. If the groundwater table is lowered by lowering the ditch levels, this should promote a progressive ripening of the subsoil in this kind of soil. This will, however, be accompanied by a considerable shrinkage of the peat layers in the subsoil, this being partly due to the resultant increase in the pressure from the drained, and therefore heavier, top layers. The ultimate result is a considerable lowering of the surface (see also chapter 5). For several reasons it is preferable to maintain a high water level in the ditches so that the present situation is continued, the hydrologic conditions are not changed, and the ripening equilibrium stagnates.

Soils subject to seepage (e.g. in polders) also usually show a very limited and superficial form of ripening, despite an intensified drainage system. Thus the process of ripening in Zuiderzee soils in the Netherlands is greatly hampered by a very slight upward seepage (VAN DER MOLEN and SIEBEN 1955). Crops suffer under these conditions, especially in wet summers, and they cannot be grown at all under conditions of heavy seepage. There is no remedy for heavy seepage, but fortunately this type of seepage is not very common.

In Surinam, soil survey of the unreclaimed marine clay swamps is mainly based on the ripening stage the soils reached before being overgrown with shallow peat layers ('pegasse') as a result of the decreasing drainage conditions. The heavy clays which were ripe to a depth of 1 m before reclamation show no cracking after reclamation. Soils which are not fully ripe, for example ripe with an unripe subsoil to depths of 1 m, develop subsoil cracks under better drainage conditions and are afterwards more permeable than the former: lands reclaimed from soils as unripe as possible are the best because permeability is the most important soil factor in such heavy clay soils.

It may also happen under natural conditions that the topsoil is more thoroughly ripened during short periods of better drainage. Later on, during periods of more rapid sedimentation and less effective drainage, less ripe layers may be superimposed. Such periods of better drainage will lead to the presence in the subsoil of low n-value layers within a soft profile with a predominantly high n-value. These phenomena occur not only in such mineral deposits as fluviatile basin clays (lacquer-layer) and marine clays, but also in peat profiles.

In addition to physical ripening, there are some processes of (physico-) chemical ripening which have a very important effect on the kind of sediments and sedentates occurring in the back swamps and basins of sedimentation areas. Other important influencing factors include the loss of lime by decalcification during sedimentation or during ripening and the phenomena of 'cat' clay and 'knip' clay (initial solonetz clay) but these subjects are outside the scope of the present study (cf. PONS 1960a and b; ZONNEVELD 1960, 1961, 1963).

4.5. RELATION BETWEEN GEOMORPHOLOGICAL UNITS AND THE STAGE OF PHYSICAL RIPENING

Geomorphologically equivalent units in marine and fresh, tropical and temperate areas, even with great differences in vegetation and organic matter contents, seem to have the same consistency and the same phase of ripening and, consequently, the same n-value.

The n-value of very soft freshly sedimentated subaquatic mud for instance with either a low or high organic matter content, lies between 3.0 and 5.0 under both brackish and freshwater conditions (SMITS 1957, PONS 1958). Unsettled mud from the Surinam coast have the same values of 3.0–5.0.

Values of between 2 and 3 have been found for recently settled sediments originally subaquatically deposited in the Zuiderzee area and in mud banks before the Surinam coast (Photos 1, 2, 4, 6, 10). The single Avicennia tree shown in Photo 11, growing just below mean high tide, is on the transition to the following stage.

The levee accretions at about mean high tide in the temperate marine area salt marsh (in Dutch 'schorren' and 'kwelders') bearing a vegetation of grasses and low herbs (Puccinellia), as well as the accretion in the fresh water areas bearing a wooded vegetation (willow tidal forest and willow coppices) have comparable n-values of about 1.0–1.4 (cf. Photos 12, 14 respectively). The same n-value of 1.0–1.4 is found in Surinam in well-developed old Avicennia nitida mangrove forests without undergrowth (Photos 15, 18).

Under these conditions of relatively fast sedimentation and relatively good aeration combined with a fluctuating water level, n-values all over the profile are of the same magnitude; in other words, the soil is at approximately the same phase of ripening throughout the profile (see the Appendix).

On recent accretions situated at a very high level compared with the mean water level, and only rarely inundated, the ripening of the upper layers may be greater than that of the subsoil. Under these conditions the top layer will soon reach an n-value of <0.7 which is the n-value of a totally ripe soil (Photos 16, 17). In a natural landscape in the highest locations, under favourable drainage conditions the whole profile down to a depth of 90 cm (3 feet) will have this n-value. Good examples of this type of soil are the elevated parts of the outer marshes of the present-day Dutch rivers, or the levees of such rivers as most of those in Surinam, which under natural conditions are inundated for only a very short time and have homogeneous physically ripe soils to a depth of more than 120 cm (4 feet).

In basins or back swamps all phases of ripening are possible both in the top layers and in the subsoil. If water tables are periodically very low, the soils in back swamps will be totally and homogeneously ripe. On the other hand, under conditions where drainage is consistently bad ripening will be non actual (Photo 19).

The deposits in tidal areas in present-day north-west Europe are influenced artificially, unlike those in tropical deltas in South America, Africa and south-east Asia. Large back swamp areas are very rarely found in the natural state. In most cases, these areas were embanked a long time ago and the present land beyond the dikes has the characteristics associated with natural levees (cf. the remarks in section 4.4 on unripe subsoil in peaty areas).

In freshwater areas, most of the small unembanked back swamps which still occur, have been enclosed by ditches in order to put the soil to more intensive use (e.g. reed marsh osiers). In saline areas the same has been done to increase sedimentation.

The ripening process is exactly the same in these soils as that referred to above in connection with the well-aerated parts of natural landscapes. If the embanked area is an advanced phase of sedimentation and ripening, scarcely any further ripening takes place after embanking. In this case, embankments are only constructed to control floods which may be dangerous for men and cattle. Embankments at a 'young' phase of sedimentation lead to a considerable increase in physical ripening and related phenomena.

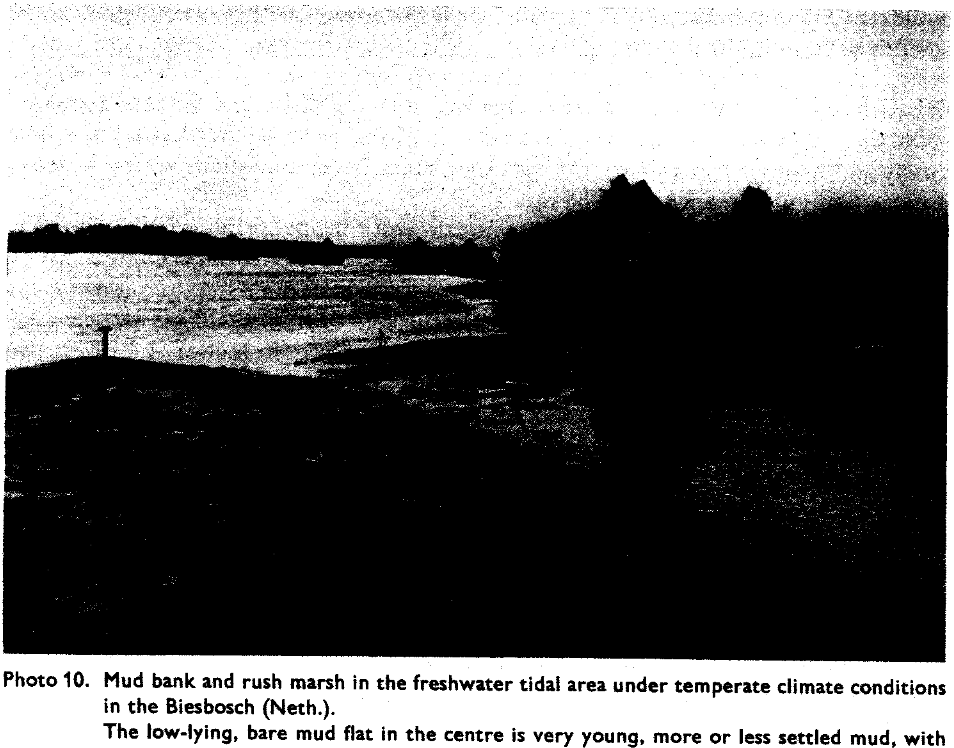


Photo 10. Mud bank and rush marsh in the freshwater tidal area under temperate climate conditions in the Biesbosch (Neth.).
The low-lying, bare mud flat in the centre is very young, more or less settled mud, with n-values of 2.0 and over. On the left is a vegetation of Vaucheria compacta and other Vaucheria Spec. (Chlorophycaea) with n-values of 2.0. On the right is Scirpus maritimus with n-value of the mud of about 1.7. The rush-cutters are carrying Scirpus lacustris cut in the back swamps.

Photo 11. Mud bank with pioneering Avicennia nitida in a salt tidal area under a tropical climate before the seacoast, north of Paramaribo (Surinam).

In the foreground a shallow creek filled with water and mud. All bare mud flats are unripe saline heavy clays, silted up to about mean tide with n-values of about 2.0, decreasing in tho subsoil to 1.75. Mangrove (Avicennia nitida) becomes established on the mud bank at about mean tide.

In the very foreground very young plants. On the other side of the creek older trees with clearly visible air roots (n-value 1.6). Behind the rear tree the mud bank shows a grey surface due to crab excrement. The ripening stages of the corresponding geomorphological units of both Photos 10 and 11, expressed in n-values, are wholly comparable.

Photo 12. Marsh landscape in the salt water tidal area of Zealand (Neth.).
On the levee, along the creek, vegetation of Puccinellia maritima and Halimione portulaccoides, etc.; in the back swamps behind the creek Spartina, Aster tripolium, etc. The levees are half-ripened and have n-values of 1.0–1.4. Their elevation is comparable to that of the levees shown in Photo 14. The tidal amplitude is about 2 metres. The only difference between the area represented here and that shown in Photo 14, which is revealed by a difference in vegetation and therefore in landscape, is in the salt content of the water, which is very high in the former area and low in the latter.

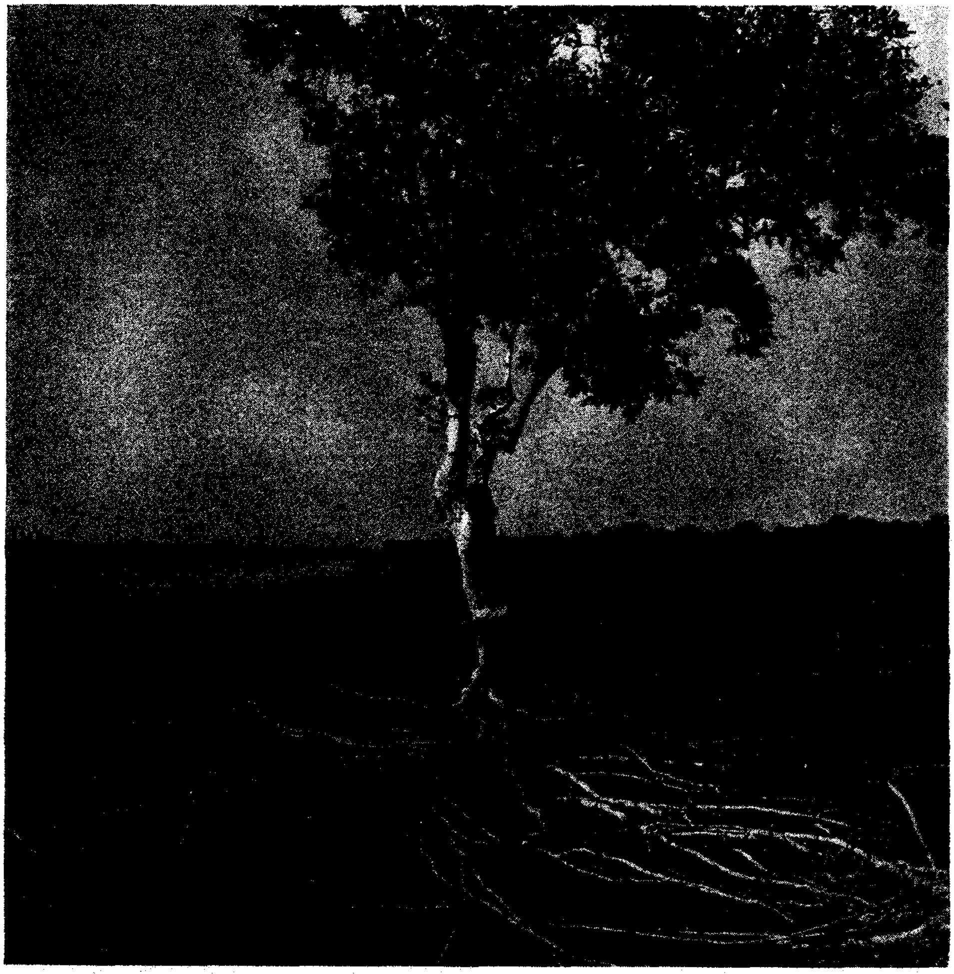


Photo 13. Young mangrove tree (Avicennia spec.) and forest (background) on mud accretion in salt water tidal part of the Ganges estuary (Sherpal Khal river), Sundarbans, India.
Silted up to about mean high water level. Soil physically half-ripe with n-values of 1.0–1.2.

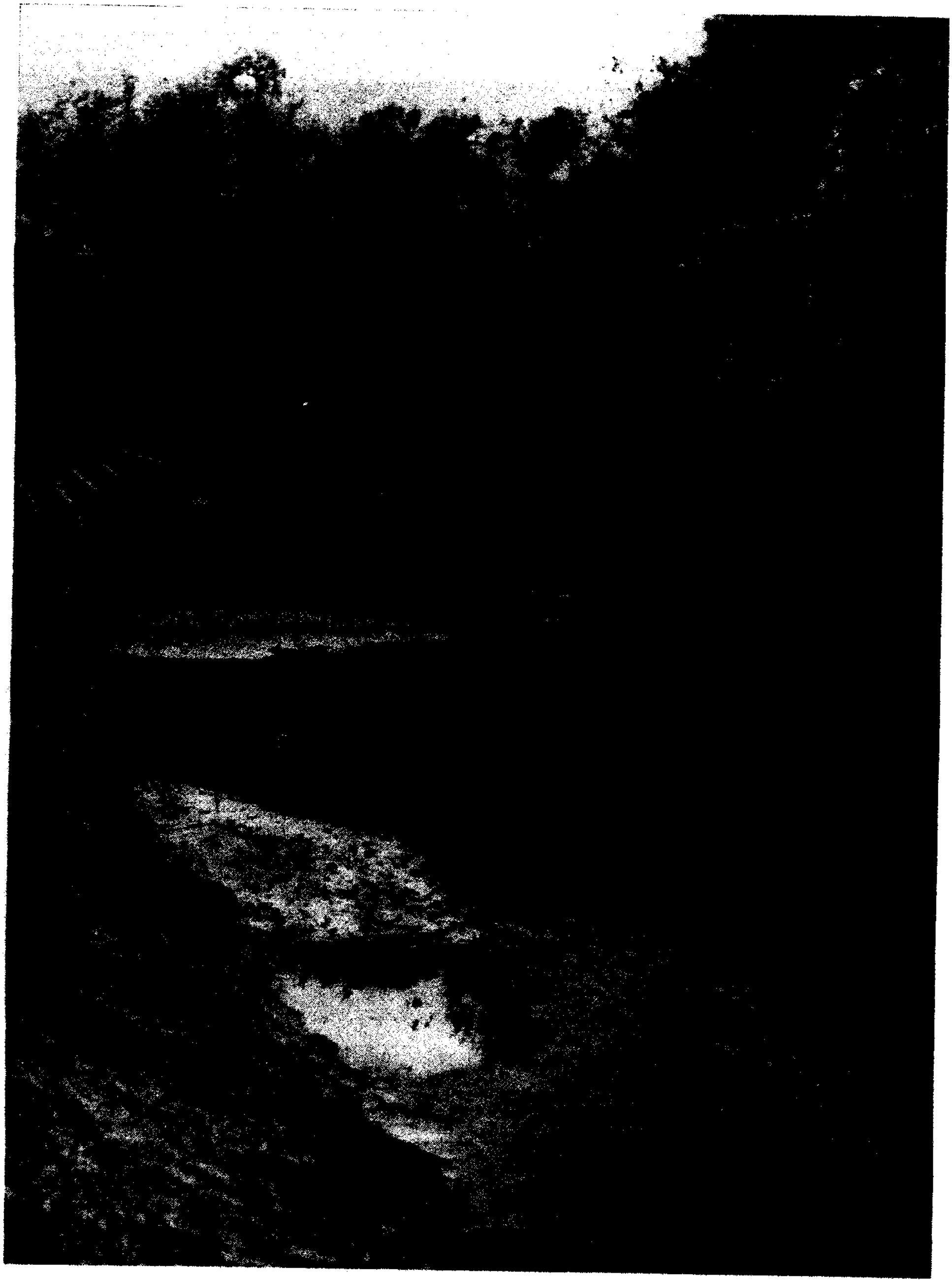


Photo 15. Mangroves in the salt water tidal area of the Sundarbans, Ganges estuary, India.
The soils are in different stages of ripening, each stage being comparable to that shown in Photos 12 and 14. On the levees the soils are half-ripe to nearly ripe and are homogeneous to a depth of about 60 cm.

◀ Photo 14. Tidal forest landscape in the freshwater tidal area of the Biesbosch (Neth.) during low tide (tidal amplitude 2 metres).
The levees along the creek bear a vegetation of Salix spec. The levee soils are half-ripened with n-values of 1.0–1.4.

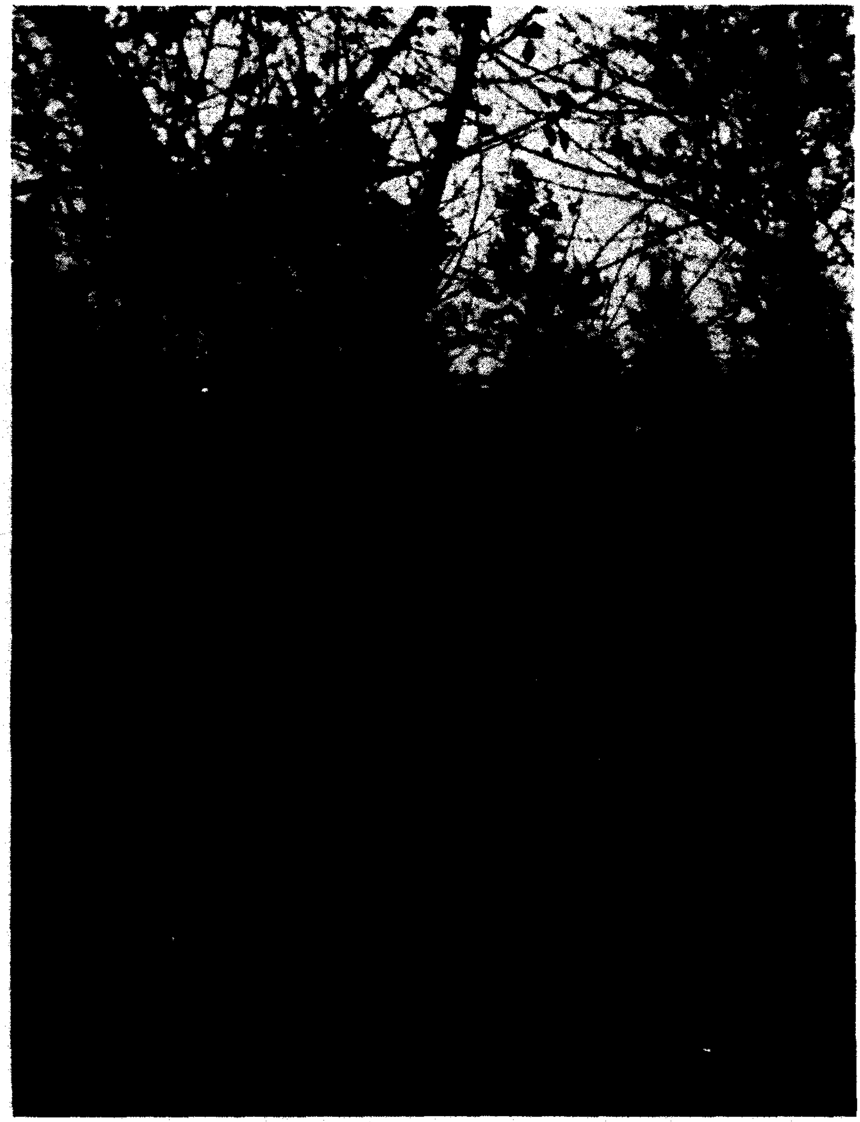


Photo 16. Tidal forest in the freshwater tidal area of the Biesbosch (Neth.).

On a young, relatively high natural levee (surface level approx. 10–20 cm above medium high tide) the soils are ripened to nearly ripe (n-value approx. 0.9) with a half-ripe subsoil. The Populus (hybr.) trees are shallow rooting because of the half-ripe subsoil, and the consistency of the top layers is too low to support the shallow root system.

Photo 17. Creek at low tide in saline part of the Ganges estuary near Tiger island along the Matla river, Sundarbans, India.
The bare clay sediments are practically unripe with n-values of about 1.5. On the natural levees, silted up to above mean high tide level, the soils are ripe with an unripe subsoil (n-value resp. 0.5 and 0.8). The vegetation on the levees consists of mangrove including palms (Phoenix spec.).

Photo 18. Marshes with old mangrove forest (Avicennia nitida) in the salt tidal area under a tropical climate along the coast near Coronie (Surinam) about 2 km inland.
In the foreground a small natural levee, silted up to about mean high tide level, with a vegetation of mangrove trees. The soil is half-ripe (n-values in top layers 1.0–1.2; subsoil 1.2–1.4) and covered with a dense system of air roots. Much crab activity. Since the creeks are silting up, natural drainage is decreasing and behind the natural levee a kind of back swamp is visible in which the original mangrove vegetation has been killed. On the levee the results of the decrease in natural drainage can also be seen from the inundation and dying of some of the trees and the toppling over of others.

Photo 19. Coastal swamp with swamp-forest vegetation in Coronie (Surinam). ▶
Originally a salty, tidal clay ripened to a half ripe soil under tropical mangrove (Avicennia) vegetation (see also Photo 18). Owing to coastal accretion the area has turned into a swamp with little or no drainage. The soils are now developing a peaty top layer (pegasse) on the half-ripe profile under a vegetation in which clumps of pina palms (Euterpe olosacea) are numerous.

5. APPLICATION OF THE KNOWLEDGE OF PHYSICAL RIPENING TO RECLAMATION, AGRICULTURAL PRACTICE AND LAND CLASSIFICATION

In this chapter we shall deal with some phenomena which are closely related to physical ripening and important from the technological and agricultural point of view. In agricultural practice it makes a great deal of difference whether or not the sediments from which the soils develop, are horizontally homogeneous.

5.1. SUBSIDENCE IN HORIZONTALLY HOMOGENEOUS SEDIMENTS

Homogeneous sediments are common. Most subaquatic deposits, for example, are homogeneous up to distances of one minor drainage unit. These include most lagoonal deposits and shallow sea-bottom deposits. Other examples are many back swamps, heavily textured coastal sediments, and some riverain deposits.

One important result of the process of physical ripening is the subsidence of the surface during the drainage and reclamation of weak, soft sediments which contain a large quantity of water and are rich in clay and/or organic matter. In homogeneous sediments the subsidence never results in unequal land surfaces over short distances.

Technicians are interested in knowing the extent of the subsidence in advance so that they can make the necessary allowances for its consequences. The phase and depth of physical ripening and settling depend on the depth of drainage. In thick sediments rich in low and/or organic matter the subsidence may often be considerable. In the North-East Polder (ZUUR 1958) and the Eastern Flevoland polder (DE KONING and WIGGERS 1955) the total subsidence is about 1 metre.

On the basis of comparisons of the weights by volume of ripe and unripe soil samples and the knowledge of the profiles and the phase of ripening in the profiles, calculations can be made of the anticipated surface subsidence.

Comparative investigations by SMITS and WIGGERS showed that even in lake bottom reclamations such as the Beemster (a Dutch lake drained in the 17th century; see Location map no. 1) the surface has subsided more than 1 m since that date. About 0.6 m of this subsidence can be accounted for in terms of the physical ripening through shrinking of the upper 2 metres of the clay profile. The reason why the total subsidence is in excess of this figure is that the lower parts of the very deep clay profile are also compacted by the heavier weight of the drained top layers.

The IJ polders (Location map no. 1), reclaimed about a century ago, which in addition to a very heavy texture, had very soft deposits rich in organic matter and water, bear marks of a considerable degree of subsidence. In some places which originally had these soft deposits to a great depth, subsidence has been as much as about 2.5 m.

In the young coastal plain of Surinam and the other Guianas, where extremely homogeneous heavy clays often occur, we never saw any important differences in subsidence over long distances (see Photo 20). The reason must be the very low content of organic matter of the original marine muds and the relatively progressive stage of ripening of the swamp clays before empoldering. ZONNEVELD (1963) obtained the same impression in other tropical areas. Nevertheless we know that Surinam (PONS, 1963), and especially British Guiana (PONS, YVEL and PARSAN 1963) also have large areas in older parts of the young coastal plain with sediments high in organic matter and a very soft consistence. Reclaimed parts of these soils in British Guiana show specimens of heavy cat clays together with high degrees of settling. Obviously, the post-reclamation subsidence must also be a problem in the tropics, at any rate in several cases.

Forecasts of the degree of settling in post-drainage peat reclamations are also important. The surface of the peat soils in the western parts of Holland was somewhat higher than sea level during the reclamation period (about A.D. 1000 to 1200). At present the surface of these peat profiles, which were originally about 4 to 6 m thick, is about 2 m below mean sea level. Most of this subsidence is caused by the physical ripening process which affects only the top metre of the profiles, but the oxidation and disintegration of organic matter in the upper layers and the compression of the lower parts of the peat profile are also contributory factors, an absolute rise in sea level only accounting for a few decimetres.

5.2. SUBSIDENCE IN HORIZONTALLY HETEROGENEOUS SEDIMENTS

Many 'old' (atlantic and subboreal) and younger marine clays and other deposits bear evidence of sedimentation mechanisms resulting in very different types of sediments or within short distances. Most sediments were deposited in natural landscapes with salt marshes and brackish to fresh reed marshes intersected by many water channels. The resulting sediments are very heterogeneous, and in brackish and fresh back swamps they have very soft parts rich in clay and organic matter. They are crisscrossed by narrow sandy strips (the old levees of creeks) containing sediments which are rich in

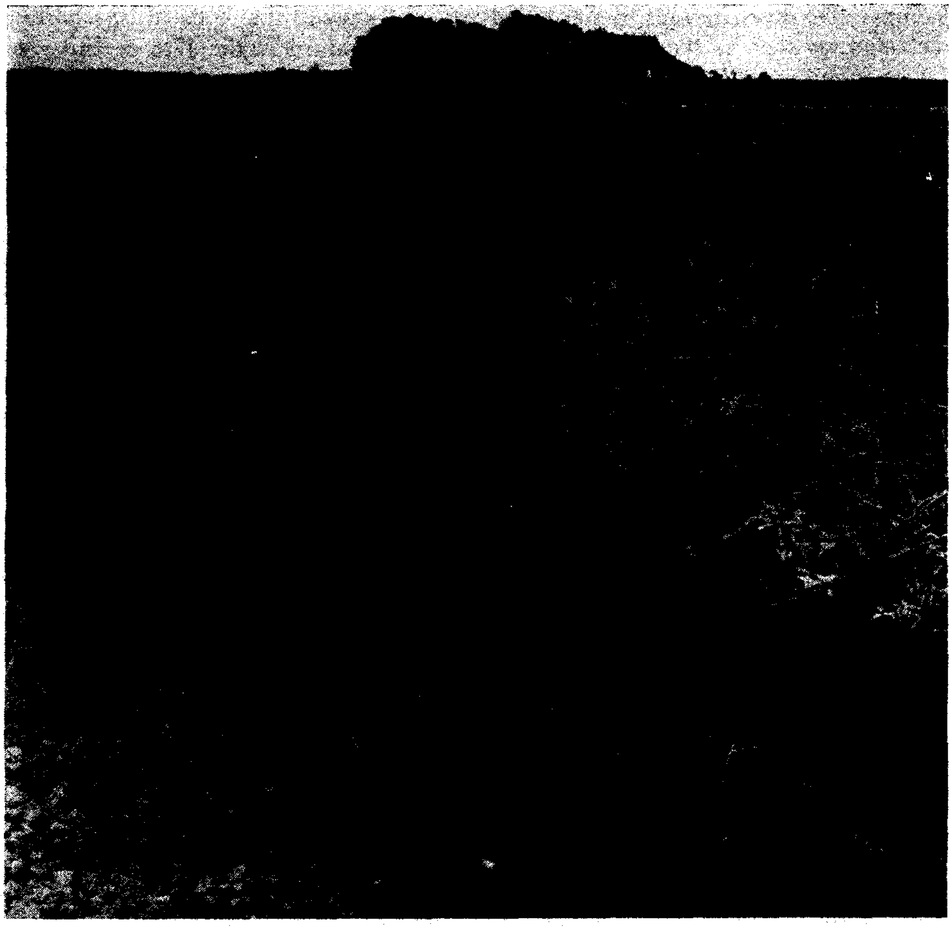


Photo 20. Recent reclamation of clay soils from brackish grass swamps in the Wageningen polder, Nickerie distr., Surinam.

Originally the clays were deposited under salt water conditions (see Photo 15) and ripened wholly or practically wholly under mangrove (Avic. nitida) (see Photo 18). With further coastal accretion the mangrove forest was changed to a very poorly drained brackish grass swamp with nearly ripe soils with peaty top layers. Along the ditch in the background can be seen the normal marine soil which is nearly ripe with an unripe subsoil. In the middle can be seen a so-called 'indian field' subsequently formed by depositing soil from a circular ditch on the original peaty clay surface to a thickness of about 50–70 cm. Measurements at this place showed that the difference in subsidence of the old peaty clay surface was only about 15 cm and caused by improved ripening of the soil below the field due to the much deeper root activity up to 3 m of parwa trees (Avicennia) and to the ripening at this place (n-values from 1.2–1.8), compared with the adjoining field where both are much shallower (up to 1.20 m below the surface).

sand and incapable of subsiding. These heterogeneous sediments are well known from temperate areas, but they no doubt also occur under tropical conditions.

After reclamation the soft parts settle to a very marked degree and change into the low-lying basins found between the more elevated sandy strips which have not yet settled (ZUUR 1936, BENNEMA 1953, ZONNEVELD 1960). Variations in surface levels may amount to 1 or 2 metres over short distances. From the point of view of land reclamation the heterogeneous form of subsidence presents a difficult problem.

Another aspect of the problems of heterogeneous subsidence is represented by the peaty soils in reclaimed low peat areas which have been excavated for the production of fuel. In this kind of polder, original peat soils occur in narrow strips. These soils are partly ripened and have subsided alternately with very soft peat and gyttja layers on a solid sandy subsoil. During the reclamation and levelling of these soils, the soft parts should be raised to compensate for any future subsidence. Special difficulties may arise in connection with tile drainage, as the tiles also subside after some time and the drainage system ceases to function.

Varying subsidence is also common in other landscapes, e.g. polder soils containing peat with or without a shallow clay layer lying on an undulating sandy subsoil, such as occur in fluviatile landscapes containing relatively thick and extended peat basins and narrow old channels filled up with sand (DE BOER and PONS 1960). These phenomena are very common in landscapes where the subsoils contain a large quantity of peat, and are known as 'inversion landscapes'.

In the freshwater tidal areas the subsidence after endiking and reclamation varies considerably, depending on the geogenetic and pedogenetic stage of land growth indicated by the vegetation. Physical ripening of rush and reed marshes results in twice as much subsidence as that of willow tidal forest (osiers). The latter, in turn, although being the same geomorphological unit in the same phase of ripening as the Puccinellia salt marshes in the marine areas, still undergoes twice as much subsidence during physical ripening as that of the latter salt marshes, because the organic matter content is higher in the fresh tidal forests.

5.3. INFLUENCE OF PHYSICAL RIPENING ON PERMEABILITY AND DEVELOPMENT OF MACRO-STRUCTURES

An important phenomenon is the irreversible cracking of the sediments during physical ripening, especially in soils rich in organic matter and/or clay. Since these irreversible cracks are very resistant, they greatly increase the water storage capacity of the soils and promote good permeability.

During the reclamation of the North-East Polder the clay content of the profile was used as the sole criterion for the spacing of tile drains. In soils rich in clay the tile drain spacing is wider than in silty soils (SIEBEN 1951).

In the North-East Polder and in parts of the freshwater tidal delta (SONNEVELD 1958) 'sloef' layers are very common (these almost entirely consist of very fine silt and scarcely any clay). In these soils no cracks develop during physical ripening. Consequently the permeability, which is already very low in this type of soil, does not increase during ripening, and tile drains have to be laid at very short intervals.

Cracking is also known to occur in the IJ polders (Neth.) and is one reason for the very good physical condition of these very heavily textured clay soils.

Most peat soils situated at mean sea level are very impermeable when not ripe, but the permeability increases considerably during physical ripening. In the immediate vicinity of the ditches, however, water always penetrates sufficiently to prevent physical ripening of the subsoil (VAN DER MOLEN 1954; SONNEVELD 1954). In the centre of such plots physical ripening may penetrate very deeply owing to the impermeability of the ditch borders, and may cause cracking and subsidence. The level of the surface is therefore lower at the centre of the plots than alongside the ditches. This basin-like formation has a harmful effect on grassland productivity.

Another phenomenon on peat soils which we have already discussed, and which also impairs grass production, is the irreversible drying-out process. This may be regarded as an excessive form of physical ripening occurring in certain peats (HOOGHOUDT, VAN DER WOERDT, BENNEMA and VAN DIJK 1960). In such cases, the possibility of moisture absorption has been drastically reduced and the absorption period lengthened. This phenomenon is due to the extensive withdrawal of moisture under conditions in which the moisture loss cannot be made good owing to long rainless periods or breaks in the capillary system. It can be prevented by maintaining fairly high water tables or by sprinkler irrigation during dry periods. However, this phenomenon is often associated with heterogeneous physical ripening and heterogeneous surface levels, for which reason the situation is difficult to improve.

As we have already mentioned in chapter 3, a lowering of the water table of soils with a soft subsoil (of peat and/or mud clay), for example to improve physical ripening of the subsoil, and as a consequence of permeability, leads to subsidence and therefore has little effect in the long run. We also explained there why such measures are unnecessary. Hence, intensive drainage can, and in many cases must be avoided in peaty areas.

Another effect of physical ripening on permeability, occurring more or less at the same time as chemical and biological ripening, is found in tropical marine Avicennia clays. During sedimentation these clays are vertically perforated with root channels to a fairly great depth. Ripening results in affixation of these channels making them resemble to iron pipes. These become interconnected by minor cracks caused by irreversible physical ripening. This is the origin of very permeable subsoils.

5.4. SUITABILITY OF THE SOIL FOR CROPS. LAND CLASSIFICATION AS DETERMINED BY THE PROCESS OF PHYSICAL RIPENING

The suitability of the soil for agricultural purposes is greatly determined by physical ripening. The ripening stage of the layers of the soil profile to a depth of about 1 m (for fruit trees it can be even more) has a decisive effect on the physical conditions in the soil profile and hence on the suitability of the soil for crops.

Thus reeds and rushes prefer the waterlogged conditions of unripe soils (ZONNEVELD 1960), whereas the soft consistency of the half-ripe soils beyond the dikes, which will not support heavy loads, may render these soils unsuitable for the growth of timber, even if the aeration and chemical conditions are suitable (for example, Populus, which grows on certain types of soil in freshwater tidal areas of the Netherlands) (Photo 16). There may also be a similar species of tree in tropical tidal forests. Examples of important timber species that are able to grow on a halfripe soil is Salix alba in the Netherlands freshwater tidal area and Virola surinamensis ('Baboen') in back swamps in Surinam, the latter with stilt roots supporting it on the weak substratum.

Grassland having a vegetation of shallow roots can readily adapt itself to conditions where the profile is only ripe down to a depth of 0.3 m. The same is true of some horticultural crops such as greens. Deep-rooted horticultural and agricultural crops which grow in dry soils cannot tolerate these conditions and need profiles which are ripe to a greater depth. It is for this reason that the soils in the western peat district of the Netherlands are only suitable for grassland and certain horticultural crops.

In most cases the damage and limitations caused by a bad drainage are actually due to the incomplete ripening of the subsoil. The idea of increasing drainage with a view to improving agriculture is in many cases tantamount to promoting ripening of the subsoil and thus development of the structure and better growing conditions for roots. In many cases improving rooting depths by better drainage conditions means improving the ripening of the subsoil. This is also true of temperate and tropical areas, and a better result is obtained if the improvement is started from more unripe soils. Improvement of drainage in soils which were considerably ripened in former times and were afterwards subject to poor drainage conditions, is a far more difficult matter and never gives good results. Numerous examples are known from temperate areas, for example in the Netherlands (in certain swamp soils) and also from the tropics, for example Surinam (Coropina soils). Ripening must be taken seriously into consideration when drafting a land classification within the framework of a drainage improvement scheme.

6. PHYSICAL RIPENING AND SOIL CLASSIFICATION

6.1. CRITERIA AND GUIDES FOR CLASSIFICATION

The characteristic features for each soil classification unit should be derived from the properties and qualities of the soil itself. We do not favour classification based on the features of processes or milieu, which was, for example, the method used by OBREANU and LANCOVICI (1956) for alluvial soils. We regard milieu and genesis solely as a guiding principle, and prefer to take pedogenesis as the main guide.

The ripening or initial soil formation is an important pedogenetic process in alluvial (fluviatile and marine) and peat soils. Soil properties change considerably during physical ripening and, as mentioned earlier, they are relatively easy to determine. Hence physical ripening is a very suitable 'differential characteristic' (CLINE 1949) for soil classification.

In the new Dutch soil classification scheme physical ripening is used to classify alluvial (= fluviatile and marine) soils as well as peat soils. As we have already stated on our suggestion, ripening has been included in the U.S. system (Soil Classification, 7th Approximation Soil Survey Staff, Soil Conservation Service, United Department of Agriculture, August 1960).

6.2. CLASSIFICATION OF SOIL MATERIAL

Before classifying soil profiles, it is necessary to classify the ripening of soil material. In Table 1 we mention five classes of ripening which have proved useful under Dutch conditions, using the n-value referred to in chapter 2 as a characteristic. Investigations in Surinam showed that these classes are also the most suitable classification for clays under humid tropical conditions.

Table 1 gives a description of the consistency of several soil materials in each of the five ripening classes. The consistency is here defined by the form taken by the soil when squeezed by hand or by the bearing value for man or cattle, together with related characteristics.

TABLE 1

Classification of soil material according to physical ripening

n-value	designation	suffix to horizon symbol	description of consistency (valid for average clay content)
< 0.7	ripe	r	firm, does not stick to the hands or only slightly and cannot be squeezed through the fingers
0.7–1.0	nearly ripe	wα	fairly firm, tends to stick to the hands and cannot be easily squeezed through the fingers
1.0–1.4	half ripe	wβ	fairly soft, sticks to the hands and can be easily squeezed through the fingers
1.4–2.0	practically unripe	wγ	soft, sticks fast to the hands and can be easily squeezed through the fingers
> 2.0	unripe	wδ	liquid mud, cannot be kneaded

Under practical conditions it is possible after some experience to estimate the class of physical ripening of any soil profile layer.

Sandy material poor in colloidal particles cannot be included in this classification because, as already stated in chapter 3, no n-value can be calculated for this material.

Peats and materials very high in organic matter are in principle also included in this classification, although the great quantities of fibrous plant remains however make it difficult to determine the ripening stage with the given properties. More study is needed for this kind of material and of resulting soils.

6.3. HORIZON SYMBOLS IN CONNECTION WITH RIPENING

Before dealing with the ripening of soil profiles, we will describe the soil horizons of the very young alluvial soils in relation to physical ripening.

Soil horizons which are totally physically unripe are totally reduced. They are grey to bluish grey and bluish black and are usually referred to as G-horizons.

Sometimes, totally reduced, bluish grey or grey layers have firm consistencies and may therefore have low n-values. These are the horizons of a soil which was once ripe and subsequently inundated again. This kind of horizon is also known as a G-horizon.

It might be logical to call a totally unripe, soft, grey or bluish horizon, a C-horizon, but this would cause confusion. Moreover, some reduction processes actually start directly after sedimentation (chemical ripening). We therefore propose to designate such a horizon respectively 'G', 'CG' or 'Cg' in the usual way, depending on the stage of oxidation reduction with the addition of the subcript 'w' ('w' = weak, water, wet, the 'u' of unripe is used for other purposes, viz. Soil Survey Manual). Also unripe A-horizons exist and may have a subscript 'w'. In the same way, physically ripe A, G, CG or Cg etc. horizons may be designated by the subscript 'r'. The various stages of ripening may be designated by the suffix wα, wβ, wγ and wδ mentioned in table 1 (cf. Fig. 13.)

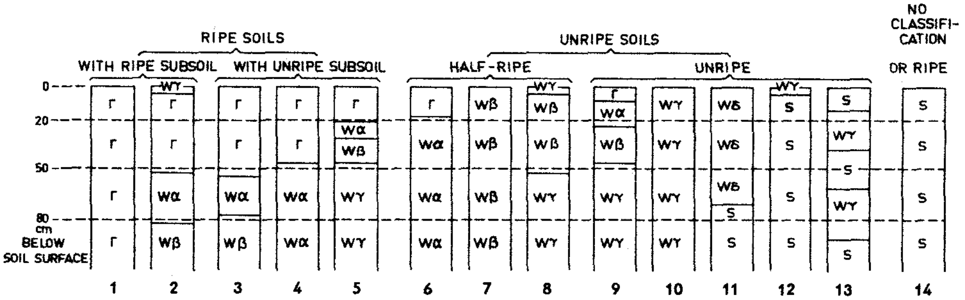


Fig. 13. Some examples of classification of soil profiles according to physical ripening, partly situated at the border-line between classes.

r : n-value < 0.7
wα : n-value 0.7–1.0
wβ : n-value 1.0–1.4
1, 2, etc. refer to the Appendix

wδ : n-value 1.4–2.0
wγ : n-value < 2.0
S : sand < 8% clay and/or < 3% organic matter

It is not always essential to use the subscript 'r' because no 'w' means not unripe and hence ripe. It is not possible to give sandy horizons any special designation referring to physical ripening.

All intensively aerated horizons in all stages of physical ripening, except those which can be classified as A-horizons, will always have recent or fossil 'g' phenomena. It would thus seem that there are no really pure C-horizons in alluvial soils.

In physically totally ripe soil layers under well-drained conditions and subject to a high degree of biological activity, soil layers can be produced which bear no traces of reduction and are totally homogenized. But such layers low in organic matter content, may be referred to as 'A' because of this marked biological activity. Such horizons are called A_3 in Surinam soil surveys. Characteristics originating from the preceding initial soil formation, especially biological ripening, such as (B)- and B-horizons etc., can be designated in the conventional way.

A more accurate description of the stage of ripening can be given by supplying the n-value[1]).

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[1]) The letter 'n' should always be written as a small letter and never as a capital, the form in which it appears in the American 7th Approximation of Soil Classification.

6.4. CLASSIFICATION OF SOIL PROFILES

In classifying soil profiles in relation to ripening we will use physical ripening as the key and check the development of physical ripening throughout the profile down to depths of about $1^1/_2$ feet (50 cm) and about $2^1/_2$ feet (80 cm), which has been found to be the best depth in the Netherlands. For the tropics, however, as a result of more intensive soil development, these limits can probably better be chosen at greater depths, for example 2 feet (60 cm) and $3^1/_2$ feet (100 cm).

In the Appendix the stage of physical ripening expressed in terms of the n-value throughout the profile is given for a number of representative soil profiles to be found in temperate areas as the Netherlands and some tropical areas, especially in Surinam and the Far East.

Table 2 gives the criteria for the classification based on properties of the stage of physical ripening of the several soil layers.

In the Dutch soil classification system we define at sub-order level the distinction between (a) physically ripe soils and (b) physically unripe soils, as is shown in Table 2 and in Fig. 13.

Soil profiles classed as physically ripe have an n-value not exceeding 0.7 to a depth of at least 20 cm and can therefore be identified as profiles having a physically ripe topsoil or plough layer. On the other hand, in soil profiles classed as physically unripe within a depth of 20 cm, an n-value of at least 0.7 must be found.

Soil samples should be taken from layers of about 10 cm thickness. Thin superficial layers with a variable n-value should be disregarded if the profile consists of several dm of sediment containing colloids.

For geomorphological reasons we propose to include sandy soils with a thin but readily distinguishable unripe clayey layer under the heading of unripe soils, e.g. silt flats. On the other hand, sand banks etc. cannot be included in the class of unripe soils because of the lack of colloids, although it would be desirable from a geomorphological point of view (Photo 5).

This pedogenetical distinction runs parallel with the geomorphological one, with on the one hand:

a. embankments and reclamations, both in alluvial areas and clay on peat districts and some very well-drained peat soils, together with the high old forelands in marine and the bulk of the natural levees and higher parts of back swamps in natural fluviatile areas, all with physically ripe soils;
   and on the other hand:
b. the bulk of the young forelands (tidal marshes, tidal forest, etc)., unreclaimed or only partially reclaimed, low fluviatile back swamps, peat areas, etc.; all with physically unripe soils.

As far as can be seen from the literature, this distinction is applicable to peat bogs in general, for instance in the peat bogs and gyttja sediments in Scandinavian countries and the peat bogs of Germany, although there are still major problems to be solved

TABLE 2

Classification of mineral and organic soil profiles according to physical initial alluvial soil formation or physical ripening[1])

classes	sub-classes and transition grades	depth 0–20 cm	depth 20–50 cm	depth 50–80 cm	examples in the appendix
		n-value	*n-value*	*n-value*	
physically not ripe	unripe	> 0.7	> 1.4		A
	half-ripe	> 0.7	> 0.7– < 1.4		B
physically ripe mineral soils	with unripe subsoil	< 0.7	> 0.7	and-or > 1.0	C
	with ripe subsoil	< 0.7	< 0.7	< 1.0	D
physically ripe organic soils[2])	with unripe subsoil	< 0.7	> 0.7	> 1.0	C
	with ripe subsoil	< 0.7	< 0.7	< 1.0	D

[1]) This scheme applies to regular profiles with homogeneous or downwardly increasing n-values. If an n-value is required above a certain value the definition must be read in such a way that the n-value mentioned occurs within the depth limits. It is unnecessary for the whole horizon to have the same n-value: lower n figures, as for instance 0.7 may also occur in the 0–20 horizon of an unripe soil, when in this horizon the lowest part has at least an $n > 0.7$. If n must be less than a certain figure (indicated by the symbol $<$) then no higher value must occur within the limits. Thin superficial layers of a few cm which occur on profiles rich in colloidal parts to the extent of several dm are not included. The n-values must be made of samples of about 10 cm in height. It is only in the case of thin unripe clayey layers on sand (silt flats) that the ripening condition of very thin layers will make the profile unripe. Lower levels of classification are to be subdivided according to the n-values of top soil and sub-soil.

[2]) For the organic soils this proposal in still tentative.

with regard to the separation of b- and n-values in organic deposits. For marine forelands in the USA, cf. 7th Appr. of American Soil Classification, 1960, p. 119.

The class of physically unripe soils can be subdivided into sub-classes (Fig. 13). One of the sub-classes forms an intergrade to the class of physically ripe soils and includes soils which have half or nearly ripe layers ($w\beta$ or $w\gamma$) throughout the depth of the profile but lack a topsoil which is physically totally ripe. The n-values of the profile layers are not higher than 1.4 to a depth of 50 cm, but higher than 0.7 to a depth of 20 cm. However, since the stage of ripening reached by these profiles is usually homogeneous within the depth concerned, the whole profile may be said to have an n-value of 0.7 to 1.4.

This sub-class includes the soils of salt marshes, medium high, not too old tidal forests (including tidal willow coppices), and relatively well-drained rush and reed marsh levees, in other words soils that have already undergone some physical ripening during the silting-up process. It also includes insufficiently drained and poorly rereclaimed peat soils and peat soils with a top layer of clay. Generally speaking, the bearing power of these soils is high enough to permit the passage of man.

The central concept of the class of physically unripe soils includes soils which are very wet and soft and have a low bearing power and are not passable for man, or only become passable because of the presence of vegetation roots (e.g. Phragmites communis, Typha div.spec., Avicennia nitida, Rhizophora div.spec., etc.).

This sub-class of physically unripe soils includes those with n-values of > 1.4 within a depth of 50 cm or in most cases even throughout the profile. It includes the soils of lower reed (Phragmites communis) or rush or rice grass marshes, silt flats and also lower temperate and tropical tidal forests, e.g. in back swamps and on young accretions. Sand flats with a thin top layer of unripe silt also belong to this sub-class.

However, pure sand banks which have profiles consisting of sand containing less than 8% of clay (particles <2 mu), and have no thin clay layers showing evidence of ripening are regarded as physically ripe soils. The physical properties of these soils do not differ much from those of ripe soils and they do not change very much after drainage.

The class of physically ripe soils is also subdivided into sub-classes (Fig. 13). A sub-class which overlaps that of the physically unripe soils includes all alluvial and peat soils having a physically ripe top soil and a physically unripe subsoil. The n-value of the profiles should be smaller than 0.7 down to 20 cm, larger than 0.7 within 20–50 cm, and larger than 1.0 down to 80 cm[1]).

This sub-class includes all young reclaimed soils, for instance the Zuiderzee soils that are still less than half a century old and consequently have hitherto only matured superficially in the ripening sense, and the soils on many seepage sites in older reclamations. Many reclaimed peat soils and peat soils with a top layer of clay are important members of this sub-class. All the grassland, referred to in chapter 4, which cannot be drained more deeply, is also a good example of this type of soil.

Under conditions existing in the Netherlands most organic soils under reclamation are physically ripe but have physically unripe subsoils. Consequently our 'normal' peat soils come under this sub-class. For this reason in the Dutch soil classification system the sub-class of physical ripe soils with a physically unripe subsoil is to be considered as the central concept for the sub-order of organic soils. On the other hand, the

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[1]) In a similar way we can make a distinction in the unripe soils between those with a ripe subsoil and those with an unripe subsoil, the latter being the normal situation. In most cases, the first type of soil consists of puddled or very wet tilled paddy fields and other irrigated arable land and of inundated old land surfaces silted up with thin layers of new young sediments. Irrigation without extensive mechanical reworking of the soil has no effect on the ripening stage of the top soil. The criteria have still to be studied. It is certain, however, that sandy subsoils will have to be excluded.

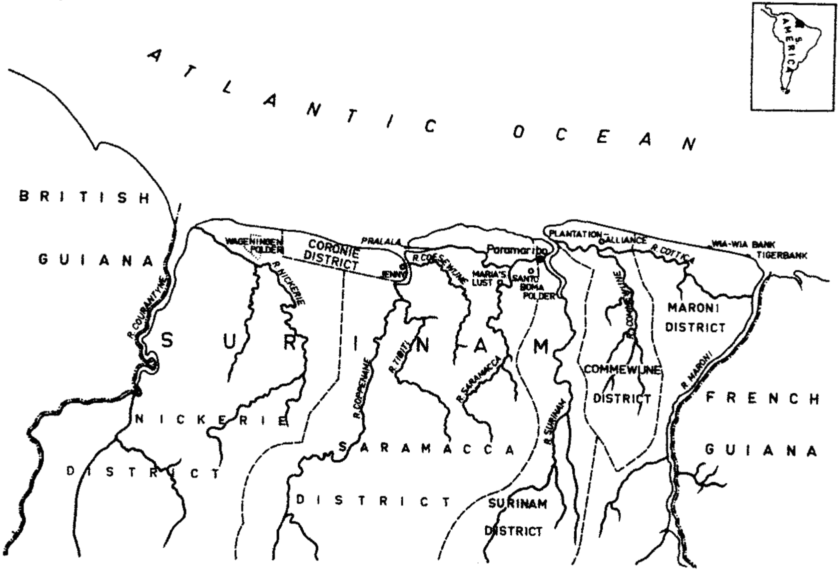
sub-class of the physically ripe organic soils with a totally physically ripe profile should be regarded as a sub-class forming a transition to a situation in which the whole profile consists of irreversibly dried-up peat.

The central concept of the physically ripe mineral soils includes a physically ripe subsoil. The sub-class covers all physically ripe soils with n-values not higher than 0.7 between a depth of 0–50 cm and not higher than 1.0 between a depth of 50–80 cm. The sub-class includes all main alluvial soils in older reclamation and embankments with adequate drainage over a long period, together with most fluviatile alluvial soils which are now naturally drained or were formerly naturally drained. The proposed classes and n-value criteria are summarized in Table 2.

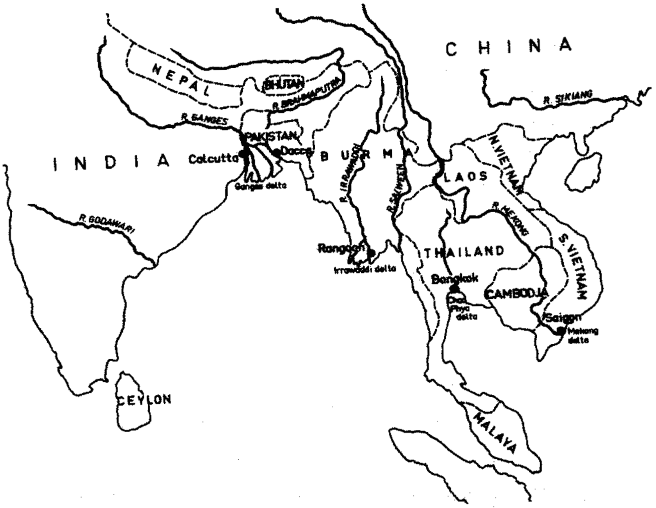
The level to which ripening should be classified in the soil classification system is arbitrary, but in the Dutch system we use the classes at sub-order level and the subclasses at sub-group level. In the American system (7th Approximation, 1960), physical ripening is classified at group level, at which level a group of 'hydraquents' is distinguished.

Location map 1. The Netherlands (referring to geographic names as they are used in the text).

Location map 2. Surinam



Location map 3. S.E.Asia



APPENDIX

EXAMPLES OF FACTORS OF RIPENING IN SEVERAL RIPENING STAGES IN DUTCH AND TROPICAL SOILS[1]

Examples	Classification of the profile in relation to physical ripening according to fig. 13	Depth in cm	% Na of adsorbtion in complex	(H) organic matter	(L) clay	CaCO$_3$ lime	n	(b)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A. *Unripe soils, lowest stage*								
1. Totally reduced subaquatic marine deposit, near sample no. 5. Eastern Flevoland (the Netherlands)	11	0–40	–	3.3	35.5	10.7	2.4	(3)
2. Unsettled mud from the surface of the coastal mud flat Tijgerbank, Maroni district (Surinam)	11	0–10	high	2.1	55	0	4.7	(3)
3. Unsettled mud from the surface of the coastal mud flat Wia Wia bank, Maroni district (Surinam)	11	0–10	high	2.4	56	0	3.8	(3)
4. Item as no. 1	11	115–150	–	8.5	13.8	1.9	2.8	(3)
5. Subaquatic marine deposit in the most recent Zuiderzee polder.	11	0–20	–	2.9	44.4	13.5	2.0	(3)
		20–40	–	3.0	53.6	11.3	2.05	(3)
		40–60	–	3.6	64.7	9.0	1.9	(3)

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[1] See page 86

Examples	Classification of the profile in relation to physical ripening according to fig. 13	Depth in cm	% Na of adsorbtion in complex	(H) organic matter	(L) clay	$CaCO_3$ lime	n	(b)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Short subsequent exposure to air. Totally unripe soil with permanent reduction at a depth of 22 cm. Eastern Flevoland (the Netherlands)		60–80	–	4.3	54.2	10.4	2.55	(3)
		80–100	–	7.1	52.0	10.6	2.55	(3)
		100–125	–	6.9	32.6	7.5	2.55	(3)
6. Settled coastal mud flat, silted up to about medium tide level. No vegetation; crab activity to a depth of about 30 cm. Totally reduced clay (G-profile). Wia Wia bank, Maroni district (Surinam)	10	20–40	high	1.5	60	0	1.9	(3)
		50–90	,,	1.0	56	0	2.0	(3)
		120–170	,,	1.3	55	0	1.8	(3)
		350–400	,,	1.1	55	0	1.65	(3)
7. Salt marsh with a vegetation of Spartina Townsendii, silted up to between mean high tide and mean low tide. Totally unripe soil with permanent reduction (G) beginning at a depth of 10 cm. Braakman, Zeeuws-Vlaanderen, (the Netherlands)	10	0–5	32.8	4.7	24.8	21.5	2.2	(4)
		5–20	34.2	3.9	23.7	20.2	1.9	(4)
		20–50	37.5	3.8	20.0	21.2	1.9	(3)
		50–80	36.4	3.1	19.9	22.0	1.7	(3)
8. Fresh water reed marsh (Phragmites communis and Caltha palustris). Silted up to 50 cm below mean high tide. Totally unripe soil with permanent reduction (G) beginning at a depth of 15 cm. Hout Ganzewei, Biesbosch (the Netherlands)	9–10	10–18	2.1	14.8	23.6	4.2	1.25	(4)
		30–38	–	16.0	26.7	5.6	1.9	(4)
		45–53	–	9.9	23.7	2.7	2.0	(4)
		63–71	–	3.8	11.1	4.8	2.0	(3)
9. Coastal salt marsh with very young mangrove vegetation (Avi cennia nitida).Silted up to between mean tide and mean high tide.	10	0–15	high	2.2	55	0	1.8	(3)
		30–50	,,	2.2	–	0	–	(3)
		70–90	,,	2.0	56	0	1.7	(3)
		120–140	,,	1.8	55	0	1.7	(3)
		170–190	,,	1.9	53	0	1.8	(3)

Examples	Classification of the profile in relation to physical ripening according to fig. 13	Depth in cm	% Na of adsorbtion in complex	(H) organic matter	(L) clay	$CaCO_3$ lime	n	(b)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
The crab activity in the totally reduced mud (G-profile) reaches to a depth of about 45 cm and the roots of the mangrove to about 75 cm. Estuary of Coppename river (Surinam)								
10. Estuary brackish marsh with mangrove vegetation (Rizophora mangle). Silted up to mean tide. Totally reduced mud (G.profile) with roots of mangrove to a depth of 50 cm. Near Alliance, along Commewijne river (Surinam)	10	0–20	medium	5	52	0		
		20–40	,,	4.5	55	0	1.5	(4)
		40–60	,,	4	50	0	2.0	(4)
11. Estuary salt water-marsh with mangrove vegetation (Avicennia) without forest floor vegetation. Totally reduced soil, nearly unripe; very difficult to walk upon. Ganges estuary, Sundarbans West Bengal (India)	10	0–20	30.1	1.0	42.3	2.5	1.6	(3)
		20–40	34.8	1.0	39.2	2.3	1.6	(3)
12. Back swamp sedimentation in the marine forelands outside seadike with a vegetation of Nipa palms and strong activity of Crustaceae. Half ripe to nearly unripe soil with some aeration to a depth of 40 cm and some fossil ripening cracks in the totally reduced subsoil. Near Songh Khlong, southeast of Bangkok (Thailand)	10	0–35	–	4.5	64.3	0.10	1.4	(3)
		50–100		5.1	64.8	0.15	1.5	(3)
		100–150		3.3	67.4	0.50	1.6	(3)

Examples	Classification of the profile in relation to physical ripening according to fig. 13	Depth in cm	% Na of adsorbtion in complex	(H) organic matter	(L) clay	$CaCO_3$ lime	n	(b)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
B. *Half ripe soils*								
1. Salt marsh with a vegetation of Puccinellia maritima (L) Aellen. Half ripe soil (fairly low stage) with permanent reduction beginning at a depth of 55 to 80 cm. Braakman, Zeeuws-Vlaanderen (the Netherlands)	7	0–55	33.3	8.9	30.1	12.9	1.6	(4)
		5–20	31.2	4.9	27.6	14.4	1.2	(4)
		20–50	30.1	2.3	17.7	13.3	1.3	(3)
		50–80	25.9	1.7	13.2	12.9	1.2	(3)
2. Salt marsh with a vegetation of Puccinellia maritima (L) Aellen and Halimione portulacoides (L) Aellen, silted up to some dm above mean high tide. Half ripe soil (normal stage) with permanent reduction (G) at a depth of about 80 cm. Braakman, Zeeuws-Vlaanderen (the Netherlands)	7	0–5	34.3	9.2	28.8	8.4	1.0	(4)
		5–20	32.1	4.4	28.7	10.9	1.0	(4)
		20–50	32.6	2.9	30.9	11.6	1.2	(3)
		50–80	33.2	2.1	19.3	12.2	1.4	(3)
3. Fresh water tidal forest with a vegetation of willows and herbs (Salix alba), Cardamine amara and Antriscus	7	10–20	1.9	13.5	23.3	2.2	1.0	(4)
		30–40	–	7.4	18.8	5.0	1.2	(4)
		50–60	–	4.4	24.7	5.3	1.2	(3)
		70–80	–	3.1	30.0	8.0	1.3	(3)

Note of pag. 83

[1] In the Netherlands the clay fraction ($<2\mu$) almost completely consists of the clay mineral illite. In Surinam the clay fraction of the clay of the young coastal plain contains the following clay minerals (figures are averages of some samples of coastal clays, röntgenologically analysed by R. Brinkman, 1960):

quartz 20%	kaolinite 40%	illite 20%	montmorillonite 20%

The cation exchange capacity of this mixture is about the same as for 100% illite, consequently the absorbtion activities of the Netherlands' soils and of the Surinam coastal clays can be compared one with the other without correction.
The Asiatic samples are corrected with the help of the cation exchange capacity. Here too there is no great difference with the adsorbtion capacity of soils predominantly composed of illite.

Examples	Classification of the profile in relation to physical ripening according to fig. 13	Depth in cm	% Na of adsorbtion in complex	(H) organic matter	(L) clay	$CaCO_3$ lime	n	(b)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
silvestris) Zonneveld, 1960. Silted up to about mean high tide. Half ripe soil with permanent reduction (G) at a depth of 50 cm. Biesbosch (the Netherlands)		90–100	–	3.4	25.2	13.8	1.4	(3)
4. Fresh water tidal forest with a vegetation of willows and herbs (Salix alba and Heracleum sphondylium. Zonneveld 1960), on a natural levee silted up to about 20 cm above mean high tide. Half ripe soil with permanent reduction (G) at a depth of 85 cm. Biesbosch (the Netherlands)	7	5–15	1.7	6.8	4.1	7.0	0.8	(4)
		25–35	–	4.2	8.8	8.0	1.0	(4)
		45–55	–	3.2	8.6	7.8	1.2	(3)
		65–75	–	3.0	9.7	7.5	1.2	(3)
		85–95	–	1.6	7.7	8.2	1.4	(3)
5. Peaty river clay about 25 cm thick on atrophic wood peat. Reclaimed in the 14th century but never manured well and only extensively used as hayland (blue grassland). Half ripe soil with permanent reduction at a depth of about 50 cm. Berkenwoude (the Netherlands)	6–7	8–18	–	33.3	32	–	0.9	(5)
		20–40	–	50.1	22	–	1.0	(5)
		40–60	–	80.1	6	–	1.4	(5)
6. Salt marsh with an old and well developed mangrove forest (Avicennia nitida) on a natural levee, silted up to slightly above mean high tide. Half ripe soil oxidized (with brown and pale-brown mottles) (Cg-CG-G-profile) to a depth of about 60 cm, with activity of Crustaceae	7	0–20	very high	2.5	56	0	1.25	(3)
		40–60	,,	2.1	57	0	1.25	(3)
		70–100	,,	2.3	55	0	1.4	(3)
		120–140	,,	2.1	55	0	1.5	(3)
		170–200	,,	2.1	55	0	1.4	(3)

Examples	Classification of the profile in relation to physical ripening according to fig. 13	Depth in cm	% Na of adsorbtion in complex	(H) organic matter	(L) clay	$CaCO_3$ lime	n	(b)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
to the same depth. Avicennia or remnants of roots are penetrating at least to a depth of 200 cm. Estuary of Coppename river (Surinam)								
7. Fresh to brackish estuary marsh, silted up to slightly above mean high tide level; in non-embanked state now used for rice production. Near Kan-Ywa, along Panmawadi-river Irrawady estuary (Burma)	6–7	0–20 40–60 80–100	– – –	3.2 4.0 3.5	41.4 44.4 45.2	0.05 0.10 0.05	1.0 1.0 1.1	(3) (3) (3)
C. *Ripe soils with an unripe subsoil*								
1. A reclaimed subaquatic marine deposit in the Zuiderzee some 13 years ago. Ripe with an unripe subsoil, aerated with permanent reduction (G) at a depth of 97 cm. North East Polder (the Netherlands)	4	0–5 5–20 20–50	– – –	2.1 2.1 2.2	19.0 18.8 19.2	10.9 10.9 8.8	0.2 0.4 0.75	(3) (3) (3)
2. Old salt marsh, reclaimed from a lake at the beginning of the 17th century by pumping with windmills. Today grassland of high quality. Ripe soils with an unripe subsoil, with permanently reduced subsoil (G) beginning at a depth of 80 cm. Beemster (the Netherlands)	4	0–10 10–20 20–40 40–60 60–80	0.6 0.55 0.9 1.95 3.4	15.2 7.3 4.2 1.7 2.3	36 39 46 42 42	0.1 0.3 1.0 16.3 18.1	0.7 0.55 0.55 0.9 0.9	(4) (4) (4) (4) (4)
3. Old brackish reed marsh later covered with peat. After	4–5	15–20 35–40	0.6 0.8	19.7 3.4	30 41	0.1 0.1	0.25 0.75	(3) (4)

Examples	Classification of the profile in relation to physical ripening according to fig. 13	Depth in cm	% Na of adsorbtion in complex	(H) organic matter	(L) clay	$CaCO_3$ lime	n	(b)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
the peat had been dug out for fuel and the site had been transformed into a lake which was pumped out in the 19th century, the soils were reclaimed to grassland of medium quality. The soils are ripe with an unripe subsoil with permanent reduction (G) beginning at a depth of about 80 cm. The progressive ripening of the subsoil is prevented by acidity resulting from the oxidation of pyrites. Nieuwkoop (the Netherlands)		65–75	0.85	2.5	41	0.1	1.1	(4)
		75–100	1.1	3.5	40	7.8	1.4	(5)
4. Carex peat, reclaimed in the 13th century by simple tidal drainage. Under grassland the soil developed a ripe top soil with a moulded A_1 horizon. The subsoil is unripe with a permanent reduction beginning at a depth of about 90 cm. This profile is typical of the greater part of the low lying peat soils in the western peat district of Holland. Loosdrecht (the Netherlands)	4	15–30	–	15.3	14.4	–	0.6	(4)
		30–40	–	23.5	13	–	0.7	(5)
		50–60	–	39.8	7.4	–	0.8	(6)
		70–80	–	39.8	7.2	–	1.0	(6)
5. Marine clay layer of about 15 cm thick on oligotrophic peat. Reclaimed from a very soft peat in the 12th century. The profile is ripe with an unripe subsoil with permanent reduction (G) beginning at a depth of 70–80 cm be-	5	0–10	–	48.4	26	–	0.7	(5)
		10–20	–	11.2	52	–	0.6	(4)
		20–40	–	8.9	52	–	1.4	(5)
		40–60	–	50.1	28	–	1.8	(5)

Examples	Classification of the profile in relation to physical ripening according to fig. 13 (1)	Depth in cm (2)	% Na of adsorbtion in complex (3)	(H) organic matter (4)	(L) clay (5)	$CaCO_3$ lime (6)	n (7)	(b) (8)
cause of bad drainage conditions. Broek in Waterland (the Netherlands)								
6. Marine mangrove marsh soil, about 12 years ago reclaimed from a brackish grass swamp with superficial pegasse (peat) layer. Soil ripe to nearly ripe with an unripe subsoil with permanent reduction at a depth of about 90 cm (Ap-Cg-CG-G profile with brown mottles). Intensive rice cultivation (3 crops in 2 years). Polder Wageningen (Surinam)	3–5	0–30	fairly	15.3	58	0	0.65	(4)
		30–60	high	2.5	59	0	0.85	(3)
		60–90	,,	1.7	54	0	1.1	(3)
7. Salt estuary mangrove marsh silted up on a natural levee to above mean high tide with a vegetation of palms (Phoenix sp.) and some mangrove species. Tiger footprints. The soil is ripe with an unripe subsoil iron oxide mottled (5 $y^{5/2}$), with permanent reduction beginning at a depth of about 100 cm. Westside 'Tiger-island' Sundarbans, West Bengal (India)	4	0–20	35.4	1.2	34.2	0.5	0.5	(3)
		30–50	37.4	1.1	39.6	0.1	0.7	(3)
		60–100	39.2	1.1	41.7	0.05	0.8	(3)
D. *Ripe soils with a ripe subsoil*								
1. Old (Atlantic) salty tidal flat deposits later covered with peat. After removing the peat and pumping the lake in the 18th century the soils have now	2	0–18	–	11.7	20	1.5	0.5	(4)
		18–40	0.9	2.6	13	2.3	0.3	(4)
		40–55	1.8	0.7	14	12.5	0.65	(3)
		55–70		0.7	14	12.5	0.75	(3)
		70–100	–	0.6	10	13	1.0	(4)
		100–130	–	0.6	12	12.9	1.15	(5)

Examples	Classification of the profile in relation to physical ripening according to fig. 13	Depth in cm	% Na of adsorbtion in complex	(H) organic matter	(L) clay	$CaCO_3$ lime	n	(b)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ripened under well drained conditions into ripe soils with a ripe subsoil and a prominent A_1 horizon. The beginning of the permanent reduction is at a depth of 220 cm. Hazerswoude (the Netherlands)								
2. Old (Atlantic) salty tidal marsh deposits. About the same reclamation history as profile D_1. The soils have now ripened under permanent grassland to a ripe soil with the permanent reduction (G) beginning at a depth of about 125 to 130 cm. Benningbroek (the Netherlands)	2	0–10	1.2	13.1	32	0.2	0.7	(4)
		10–20	1.1	7.5	33	0.1	0.55	(4)
		20–40	1.6	4.3	38	0.1	0.45	(3)
		40–60	1.5	2.4	48	0.1	0.45	(3)
		60–80	1.3	1.8	44	3.1	0.75	(4)
		80–100	–	1.0	23	11.0	1.07	(5)
3. Brackish subaquatic sediment, deposited in the Y basin. Drained and reclaimed by pumping out in the 19th century. The soils are ripe with a subsoil under highly productive arable land. The permanent reduction (G) begins at a depth of 140 cm. Spaarnwoude (the Netherlands)	2	0–20	–	7.8	30	4.3	0.6	(4)
		20–45	0.75	7.0	36	4.5	0.6	(3)
		45–70	0.7	7.5	39	4.7	0.65	(3)
		70–85	1.2	9.6	42	4.1	0.95	(4)
		85–110	–	16.0	42	1.1	1.1	(4)
4. Fluviatile back swamp of the river Waal, silted up in the 4th or 5th century, reclaimed from marshy forests in the 13th century.	1	0–8	–	15.9	48.0	–	0.45	(4)
		8–20	–	8.8	50.5	–	0.45	(3)
		20–37	–	7.7	51.6	–	0.45	(3)
		37–43	–	8.6	63.9	–	0.45	(3)
		43–47	–	8.0	60.6	–	0.6	(4)

Examples	Classification of the profile in relation to physical ripening according to fig. 13	Depth in cm	% Na of adsorbtion in complex	(H) organic matter	(L) clay	CaCO$_3$ lime	n	(b)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
The soils are ripe to considerable depths. Bergharen (the Netherlands)		47–51	–	6.1	45.0	–	0.5	(4)
		51–60	–	6.3	45.9	–	0.5	(4)
5. Fresh water tidal deposit on a natural levee of the river 'Oude Rijn' sedimented in the 4th or 5th century. Orginally under forest, after the Middle Ages the soil developed to a ripe soil with a prominent A_1 profile and the permanent reduction (G) beginning at a depth of 130 cm. Alphen a.d. Rijn (the Netherlands)	1	4–12	–	15.5	28	0	0.65	(4)
		12–25	–	10.3	34	0	0.55	(4)
		25–40	–	5.1	38	0.1	0.35	(3)
		40–60	–	3.1	51	0	0.45	(3)
		60–80	–	1.7	33	0.1	0.4	(4)
		80–100	–	1.7	33	0.1	0.5	(4)
		100–120	–	1.9	28	7.6	0.55	(5)
6. Fresh water tidal atrophic forest peat, reclaimed in the 12th century and today used for horticulture. Under the intensive culture the soil developed into a ripe soil with ripe subsoil and the permanent reduction beginning at a depth of 83 cm. Roelofarendsveen (the Netherlands)	2	0–20	–	24.1	12	–	0.5	(4)
		20–35	–	19.0	12	–	0.7	(5)
		35–50	4.3	18.4	10	0.1	0.65	(5)
		70–85	–	84.5	3	0.1	0.95	(5)
7. Brackish tidal mangrove marsh, as a natural levee silted up to above mean high tide. The 'Kanazo mangrove forest' (Heritiera littoralis) has dense forest floor vegetation. The soil is ripe with a ripe subsoil, iron-mottled and with a permanent reduction beginning at depths of about 100 cm. Near Ngayokkaung, in the Irrawaddy estuary (Burma)	1	0–20	–	3.5	32.4	0.05	0.55	(3)
		30–50	–	2.0	36.0	0.05	0.6	(3)
		70–90	–	1.6	35.7	0.05	0.7	(3)
		110–125	–	1.5	41.1	0.05	0.9	(3)
		250–350	–	2.4	38.6	0.05	1.0	(3)

Examples	Classification of the profile in relation to physical ripening according to fig. 13	Depth in cm	% Na of adsorbtion in complex	(H) organic matter	(L) clay	$CaCO_3$ lime	n	(b)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
8. Salty tidal marsh, about 500 years old embankment now used as a paddy field. Soil ripe with a ripe subsoil, iron oxide mottled with a permanent reduction (G) beginning at depths below 100 cm. Frasergang, Ganges estuary, Sundarbans, West Bengal (India)	1	0–20	9.6	1.4	29.7	0.0	0.7	(3)
		30–50	22.4	0.7	35.8	0.05	0.4	(3)
		60–80	29.8	0.5	35.7	0.0	0.4	(3)
9. Salty tidal mangrove marsh, reclaimed some 200 years ago from a brackish grass swamp as a plantation with gravity drainage, now used for fruit cultivation. Soil ripe, with a ripe subsoil, oxidized, and brown iron oxide mottled with permanent reduction (G) beginning at depths of more than 150 cm (A_1-Cg-CG-G-profile). Plantation Alliance, Commewijne district (Surinam)	1	0–20	low	3.1	53	0	0.35	(3)
		30–40	„	1.7	58	0	0.6	(3)
		50–70	„	2.0	58	0	0.7	(3)
10. Old salty tidal mangrove marsh, desalinized under fresh water swamp forest with thick pegasse (peat) layer reclaimed 4 years ago and now used for cultivation of bananas. Soil ripe, with half ripe deeper subsoil oxidized and yellowish brown, iron mottled. Permanent reduction beginning at depths of 180 cm (A_0-A_1-Bg-BG-CG-G-profile).	2	30–0	low	78	–	0	–	–
		0–10	„	13.2	58	0	0.75	(5)
		10–25	„	2.1	68	0	0.7	(3)
		25–35	„	1.1	65	0	0.7	(3)
		40–65	„	1.5	64	0	0.6	(3)
		70–90	„	0.9	36	0	0.9	(3)
		100–120	„	1.5	55	0	0.8	(3)
		130–160	„	1.8	52	0	1.2	(3)
		180–200	„	2.5	33	0	1.0	(3)
		200–220	„	2.1	28	0	1.0	(3)

Examples	Classification of the profile in relation to physical ripening according to fig. 13	Depth in cm	% Na of adsorbtion in complex	(H) organic matter	(L) clay	$CaCO_3$ lime	n	(b)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Santo Boma polder, Surinam district (Surinam)								
11. Old salty tidal mangrove marsh, item as D9, silted up as a natural creek levee or kind of coastal barrier with fairly good drainage under natural conditions. Soil ripe and oxidized, and red and red-brown mottled to depths of more than 200 cm, with a firm texture. B-horizon (A_1-B2g-CG-G-profile). Plantation Alliance, Commewijne district (Surinam)	1	0–15	low	3.5	58	0	0.5	(3)
		40–45	,,	1.5	60	0	0.55	(3)
		50–70	,,	1.8	60	0	0.5	(3)
12. Fluviatile natural levee deposit now reclaimed for shifting cultivation ('kostgrondje') from natural levee forest. Soil ripe to considerable depths, oxidized and red to red, yellowish brown and brown mottled to a depth of at least 400 cm, with development of a very firm texture B-horizon (A_1-B2g-CG-G-profile). Maria's Lust, Saramacca river (Surinam)	1	50– 70	very low	1.2	45	0	0.5	(3)
		100–120		1.5	42	0	0.4	(3)
		190–210	,,	1.7	48	0	0.45	(3)
		230–250	,,	2.0	35	0	0.4	(3)
		350–370	,,	1.1	40	0	0.4	(3)

SUMMARY

This study describes the pedogenesis of very young marine and fluviatile sediments and peat soils.

From the tenth century onward much experience has been gained in the Netherlands in reclaiming these soils and bringing them under cultivation. Although great successes were achieved in reclaiming fertile marine clay polders and marshland as well as in development of river clay and peat areas, there were also many setbacks. In the 19th century and the beginning of the 20th scientific investigations became of great importance, and the large-scale reclamations of the Zuiderzee polders stimulated this research work. A leading person in the research work was the late Professor Zuur (1961), who developed the pedogenesis of polder soils.

The processes occurring during genesis of alluvial areas and peat areas (e.g. sedimentation, sedentation, overgrowing of the sediments and of the peat, natural drainage and the changes in the soil under influence of artificial drainage and agricultural use) gradually shade off into each other; the processes often occur simultaneously as well. We distinguish in these processes the geogenesis and the pedogenesis. Geogenesis includes all processes of sedimentation, peat development, etc. Pedogenesis, named in this study initial pedogenesis or ripening, begins when the air penetrates into the soil, as for example through drainage or plant growth. Sometimes it is difficult to draw a strict dividing line between geo- and pedogenesis (Photos 1, 2 and 3).

Soil ripening includes physical ripening, chemical ripening and biological ripening, processes which are usually more or less simultaneous. The physical ripening includes loss of water, development of the structure, soil subsidence, changes in the consistency and permeability of the soil, and the desalinization of the soil.

The chemical ripening has a bearing on such processes as oxidation of all sorts of components in originally reduced sediments, e.g. iron compounds, sulphur compounds, organic matter etc. It also includes the changes occurring during the ripening in the cations of the absorbtion complex, and the behaviour of the phosphates and Na-compounds, the decalcification, etc.

Ferrihydroxide mottling is an important characteristic for the determination of the ripening stage and the hydrological condition of the ripening soil. Oxidation of sulphur can give very acid 'catclays' or acid 'pseudo-catclays' (Fig. 1).

Biological ripening includes both the microbiological processes taking place during aeration and the mechanical shifting and homogenization of the soil caused by macro-organisms and the production of organic matter by the plants. Biological homogenizations start during geogenesis but are especially important during pedogenesis under good drainage conditions (Fig. 2).

As soon as the more progressive processes of soil formation commence, e.g. development of structural B- or textural B-horizons, the stage of ripening or initial soil formation is over. The physical ripening has been selected as characteristic of the whole ripening process of the young soils for the soil classification, as this phase of ripening is most readily determined in the field and physical ripening is independent of salt content, clay content, content of organic matter etc. of the soil. Moreover, the process of physical ripening is irreversible and its end is easy to determine.

The organic matter plays an extremely important part in ripening.

Chapter 2 discusses the equilibrium between the production and the destruction of the organic matter in connection with geogenesis and pedogenesis. Peat formation takes place on the geogenetical side of the boundary zone between geogenesis and pedogenesis when the destruction of organic matter is slowed down by poor drainage (Photos 4, 18 and 19). On the other side of the boundary zone, in peats and in many clays, organic matter is decomposed.

Marine sediments (geogenesis) have typical organic matter-clay relationships (Figures 3 and 4), very low organic matter contents in the tropics, fairly high ones in marine areas in temperate climates, and very high ones under fresh water tidal conditions.

During geogenesis, addition of secondary organic matter originating from vegetation during sedimentation gives rise to all kinds of transitions between peat and mineral soils. During each stage of the ripening there is a typical equilibrium-level in the relation between organic matter and clay content, and the organic matter content decreases or increases until this equilibrium is reached (see Fig. 4).

The development of the A_1-horizon is also dependent on the ripening stage and the original organic matter. Under very wet conditions an A_0-horizon (peaty A_1) is formed, and under good drainage conditions a very weak A_1-horizon.

In chapter 3 the process of physical ripening is dealt with in more detail. Physical ripening includes all processes connected with the dehydration of the colloidal part of the soil.

This takes place as a result of: (1) the sagging of water or by (2) the direct evaporation. The most important process, however, is (3) the evapotranspiration by the roots of plants.

Plant growth in combination with a perfect drainage greatly assists ripening. In view of experience gained in this respect it was decided to plant reed in the Zuiderzee polders. For many reasons, stagnation of root development therefore decreases ripening.

When the soil colloids lose water their respective attraction forces increase, the consistency increases, the volume of the mineral parts is reduced (Fig. 5) and the relative proportions by volume of several soil compound changes (Fig. 6). When much organic matter is present the water content is very high.

Physical ripening is mostly an irreversible process. The smaller uptake of water in a wet period compared with the original unripe soil and the consequent swelling of the particles prevent the soil from acquiring the original unripe status (Fig. 7).

Physical ripening can be measured by the water content of the colloidal part of the soil, and in mineral soils by the clay content. We introduce a water factor **n** as a standard value of physical ripening, i.e. the quantity of water in g which is absorbed by 1 g of the clay fraction. The following formula gives the relation with other soil characteristics:

$$n = (A - 0.2\,R) / (L + bH),$$
in which

A = total water content compared to 100 g dry soil
L = clay content (lutum <2 micron)
H = organic matter content
R = non colloidal mineral part of the soil ($R = 100 - H - L$)
b = the ratio of the water-absorbtion capacity of organic matter to that of illite clay.

With the help of parallel series of the same n-value and various other factors, the factor b can be determined for given situations and in the same way the n-value of series with a constant b-factor can be determined as in the graphic calculation of Figure 8. We propose to define the n-factor in relation with illite clay.

In the case of other kinds of clay minerals the following formula should be used:

$$n=(A - 0.2R) / (L_i+b_1L_1+b_2L_2 \ldots +b_hH),$$
in which:

L_i = content of illite clay
b_1, b_2 ,etc.: the ratio between the water absorbtion-capacity of illite clay and that of other clay minerals
L_1, L_2 = contents of other clay minerals.

The factor b_h represents the ratio between the water-adsorbing capacity of illite and that of organic matter.

For soils with high contents of organic matter the n-value is more complicated and cannot be so correctly determined. It may be necessary to introduce an n_h-value (the amount of water in g absorbed by 1 g of organic matter).

With some reservations the n-value can be measured in the field by the determination of the consistency when a good correlation exists between consistency and penetrometer readings (Figure 9).

In chapter 4 the connection is discussed between physical ripening and the genesis of the landscape (inundations, sedimentation, drainage, vegetation etc.) (Fig. 10). Profiles occurring under natural drainage conditions show vertically a homogeneous ripening up to a certain depth. Ripening caused by artificial drainage (e.g. when reclaiming a polder) is always vertically heterogeneous. This ripening caused by human action is often accompanied by broad shrink crusts in the subsoil that are very conducive to internal drainage (Photo 9).

Vertically heterogeneous ripened soils are not only formed under artificial drainage conditions but also as a result of a decrease or cessation of sedimentation in natural landscapes, for example in backswamps, clay on peat areas, etc.

Ripening under artificial drainage conditions is a terminative process, and under good drainage conditions an unripe soil can develop into a completely ripe soil in 50 to 100 years (Figure 11).

Under the influence of the weight of later sedimented layers a sediment or sedentate may be pressed together and thus ripen also. Originally horizontal, thin peat layers, dividing an older marine sediment in the subsoil from a younger marine sediment on top may show a very undulating pattern as a result of partial ripening of the older sediment. Figure 12 gives an example of an originally horizontal peat layer, pressed to varying depths in the subsoil under the weight of younger peat layers.

Geomorphologically corresponding landscape elements appear to have the same ripening stage in salt, brackish and salt sedimentation areas, in both the tropics and temperate climates. Section 4.5 deals with some examples as given on page 98.

Basins and backswamps, etc. vary considerably in ripening stage as a result of very different drainage possibilities of basins (Photo 6).

In chapter 4.1 closer attention is given to

Type of sediment or soil	n-value	Photos
Unsettled mud	3–5	–
Recently settled mud	2–3	2, 10, 11
Marshes with top levels between Mean High Water (MHW) and Mean Low Water (MLW)	1.5–2.2	6, 7, 8, 10, 12, 13, 14
Marshes with tops on or slightly above MHW	1.0–1.4	12, 13, 14, 15, 16, 17
Marshes high above MHW	0.7–1.0	16, 17
Marshes under very good drainage and only inundated for short periods annually	<0.7 (totally ripe)	

ripening, subsidence and sedimentation and the part played by organic matter. Figure 10 gives a schematic survey of the genesis of the various landscape elements from the fresh water tidal area up to the formation of polders with well ripened soils (Photos 2, 6, 7, 10, 14, 16).

In chapter 5 some ripening problems are treated as they occur in practice in polder construction, e.g. subsidence, etc. When constructing polders and designing drainage systems technicians are interested in knowing the extent of subsidence in advance. Clays rich in organic matter and peats often show considerable subsidence during ripening, in some cases up to 2½ m. The surface of peat soils in the western part of the Netherlands has subsided about 2 m since A.D. 1000. Horizontally heterogeneous sediments or undulating solid bottoms under peats sometimes result in different subsidence with variations in surface levels of 1 to 2 metres over short distances.

With help of the ripening data it is easy to calculate the anticipated surface subsidence as shown in figure 12 (Photo 20).

Physical ripening promotes the permeability of the soils, especially when it starts from the more unripe sediments or takes place in soils containing a high colloidal part (Photo 9).

The suitability for crops of peats and soft sediments is greatly determined by the ripening stage. Unripe soils can only support some special plants. Some timber species can grow on half ripe soils, especially in the tropics. Grasses and some legumes can grow on more or less ripe soils with an unripe subsoil. In order to give maximum yields, crops and fruit trees need a soil ripe to sufficient depth to develop an extended root system. In many cases, the damage caused by bad drainage conditions is caused by the presence of unripe subsoils.

Chapter 6 discusses the manner in which the process of ripening can be made use of for the classification of soils. Soil properties change considerably during physical ripening and classes of physical ripening can therefore be used as differential characteristics for a soil classification.

Chapter 6.2 deals with the classification of the ripening of soil material. Table 1 lists five ripening classes for varying soil material which are valid for temperate and tropical conditions, for heavy textured clays and sandy clays with a high or low organic matter content. The determination of the ripening classes is based on the n-value and can be determined in the field by squeezing by hand and by the degree of stickiness of the soil.

Soil horizons of very young alluvial soils and peat soils can also be described in relation to physical ripening. Totally reduced G-horizons normally are physically unripe and enti-

Table 1. Classification of soil material according to physical ripening

n-value	designation	suffix to horizon symbol	description of consistency (valid for average clay content)
<0.7	ripe	r	firm, does not stick to the hands, or only slightly, and cannot be squeezed through the fingers
0.7–1.0	nearly ripe	wα	fairly firm, tends to stick to the hands and cannot be easily squeezed through the fingers
1.0–1.4	half-ripe	wβ	fairly soft, sticks to the hands and can be easily squeezed through the fingers
1.4–2.0	practically unripe	wγ	soft, sticks fast to the hands and can be easily squeezed through the fingers
>2.0	unripe	wδ	liquid mud, non kneadable

Table 2. Classification of mineral and organic soil profiles according to physical initial alluvial soil formation or physical ripening[1])

classes	sub-classes and transition grades	depth 0–20 cm	depth 20–50 cm	depth 50–80 cm
physically not ripe		*n-value*	*n-value*	*n-value*
	unripe	>0.7	>1.4	
	half ripe	>0.7	>0.7–<1.4	
physically ripe mineral soils	with unripe subsoil	<0.7	>0.7	and/or >0.1
	with ripe subsoil	<0.7	<0.7	<1.0
physically ripe organic soils[2])	with unripe subsoil	<0.7	>0.7	>1.0
	with ripe subsoil	<0.7	<0.7	<1.0

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[1]) This scheme applies to regular profiles with homogeneous or downwardly increasing n-values. With an n-value, marked in the table by > the whole horizon need not necessarily have the same n-value.
Lower n-figures, as for instance 0.7 may also occur in the 0–20 horizon of an unripe soil, when in this horizon the lowest part has at least an $n > 0.7$.
With an n-value marked by < (e.g. < 0.7 or < 1.0) no higher n-value must occur within the given limits.
Thin superficial layers of a few cm which occur on profiles rich in colloidal parts to the extent of several dm are not included.
The n-values must be made of samples of about 10 cm in height. It is only in the case of thin unripe clayey layers on sand (silt flats) that the ripening conditions of very thin layers will make the profile unripe.
Lower levels of classification are to be subdivided according to the n-values of top soil and subsoil.

[2]) In the case of organic soils the proposals are still tentative.

rely blue or gray. With increasing oxidation (process of chemical ripening) such horizons are normally designated as 'G', 'CG', 'Cg' or 'A_1'. The physical ripening can be designated in these horizons with the subscript 'w' (means: unripe) or 'r' (means: ripe).

The various stages of the ripening may be designated by the suffixes $w\alpha$, $w\beta$, $w\gamma$ and $w\delta$ (see Figure 13).

Table 2 shows the classes of physical ripening of alluvial and peat profiles based on the development of the ripening down to depths of about 1½ feet (50 cm) and about 2½ feet (80 cm).

Soils with a content of colloids below the minimum, e.g. 8 % of illite clay or 3 % organic matter, as is for instance the case with sandy soils, are considered to be physically ripe (Photo 5).

The class of physically unripe soils (in U.S.A. soil classification system on group level, in Dutch soil classification system on sub-order level) is divided in the sub-classes of unripe soils (in U.S.A. soil classification system on class level, in Dutch soil classification system on sub-group level) and in half ripe soils.

The class of unripe soils includes tidal marshes, tidal forests, low fluviatile backswamps, peat areas, etc. The sub-class of half ripe soils (Appendix-B) includes that part of the unripe soils which shows some physical ripening during the silting up process, for example high salt marshes, medium high fresh water tidal forests, insufficiently drained peat soils and peat soils with a top layer of clay.

Lower reed marshes, silt flats, low brackish mangrove forests are included in the sub-class of totally unripe soils (Appendix-A). They are impassable by man.

The class of physically ripe soils is subdivided into a sub-class with physically ripe soils to great depths and a sub-class with physically ripe topsoil and an unripe subsoil. The latter (Appendix-C) includes all young reclaimed soils, or older ones with impeded drainage. In the Netherlands all organic soils under reclamation can be included in this category.

The sub-class of physically ripe soils to great depths (Appendix-D) includes a physically ripe subsoil. This sub-class covers all alluvial soils in older reclamation areas where the soil has been adequately drained over a long period, as well as most of fluviatile alluvial soils.

RÉSUMÉ

PÉDOGENÈSE INITIALE ET CLASSIFICATION DES SOLS

Cette étude porte sur la pédogenèse de très jeunes sols marins et fluviatiles et de sols tourbeux.

Aux Pays-Bas, depuis le 10e siècle on a, acquis une précieuse expérience dans l'aménagement de ces sols et leur mise en valeur par la culture. Mais, en dehors des succès obtenus dans la mise en valeur des fertiles argiles marines des polders aussi bien que dans celle des argiles fluviatiles ou des zones tourbeuses, beaucoup de déboires ont été enrégistrés. Au 19^{e} siècle et au début du 20^{e} les recherches scientifiques dans ce domaine, tout particulièrement stimulées par les grands travaux d'aménagement des polders du Zuiderzee, ont pris une grande importance. Le professeur Zuur, décédé en 1961, a été un des chefs de file de cette recherche par ses études sur la pédogenèse des sols des polders.

Les processus qui interviennent au cours de la genèse des régions alluviales et tourbeuses: sédimentation, sédentation, accroissement des sédiments et de la tourbe, drainage naturel et transformation du sol sous l'influence du drainage artificiel et de l'utilisation agricole s'intriquent étroitement; ils peuvent aussi agir de façon simultanée. On distingue dans ces processus la géogenèse et la pédogenèse. La géogenèse comprend tous les phénomènes de sédimentation, développement de la tourbe, etc. La pédogenèse, appelée dans cette étude pédogenèse initiale ou développement, débute lorsque l'air pénètre dans le sol, par exemple sous l'effet du drainage ou de la croissance des végétaux. La limite exacte entre géo- et pédogenèse est souvent difficile à préciser (Photos 1, 2 et 3).

Le développement pédologique est le résultat des évolutions d'ordre physique, chimique et biologique, phénomènes qui se produisent de façon plus ou moins simultanée. Dans le développement physique interviennent la perte en eau, le développement des structures, la subsidence, les modifications dans la consistance et la perméabilité du sol, la désalinisation. Le développement implique l'intervention de nombreux processus comme l'oxydation de tous les composants du sol réduits à l'origine, composés ferreux, sulfureux, matière organique. En outre les changements survenus pendant la pédogenèse dans les cations du complexe adsorbant, dans le comportement des phosphates et des composés du sodium, dans la décalcification, etc. y prennent place.

Les traces d'hydroxyde ferreux constituent une caractéristique importante dans la détermination du degré d'évolution d'un sol et de ses conditions hydrologiques. L'oxydation des sulfures peut donner des 'catclays' très acides ou des 'pseudo catclays' acides (Fig. 1). Le développement biologique comprend à la fois les processus micro-biologiques qui agissent lors de la pénétration de l'air dans le sol ainsi que la mobilisation et l'homogénéisation du sol par les micro-organismes et la production de matière organique par les végétaux. L'homogénéisation biologique débute dès la géogenèse, mais se développe de façon importante pendant la pédogenèse lorsqu'il existe de bonnes conditions de drainage (Fig. 2).

Aussitôt qu'apparaissent des phénomènes plus complexes de la formation d'un sol, comme le développement d'horizons structuraux B ou texturaux B, le stade de développement ou de formation initiale du sol est dépassé. L'état d'évolution physique a été choisi pour caractériser le degré de développement générale d'un sol jeune dans la classification des sols, parce qu'il peut être aisément déterminé sur le terrain, et parce que l'évolution physique est indépendante des teneurs en sels, en argile, en matière organique, etc. Par contre, le processus est irréversible, et la fin de son action peut être parfaitement déterminée.

La matière organique joue un rôle très important dans l'évolution.

Le chapitre 2 examine l'équilibre entre la production et la destruction de la matière organique en relation avec la géogenèse et la pédogenèse. La formation de tourbe se place du côté 'géogenèse' de la zone limite entre géo- et pédogenèse quand la destruction de la matière organique est ralentie par un mauvais drainage (Photos 4, 18 et 19). De l'autre côté de la limite, dans les tourbières et dans de nombreuses argiles, la matière organique est décomposée.

Les sédiments marins (géogenése) présentent des relations très caractéristiques entre la matière organique et l'argile (Fig. 3 et 4): une très faible teneur en matière organique sous les climats tropicaux, une teneur sensiblement plus élevée dans les régions marines des climats tempérés, une très forte teneur dans les zones littorales.

Pendant la géogenèse, l'addition de matière organique secondaire provenant de la végétation au cours de la sédimentation donne toutes les sortes de transitions entre les sols tourbeux et les sols minéraux. A chaque stade du développement, il existe un équilibre caractéristique entre la matière organique et la teneur en argile, et la teneur en matière organique croît ou décroît jusqu'à ce que cet équilibre soit atteint (voir Fig. 4).

Le développement de l'horizon A_1 dépend aussi du degré de développement et du matériau organique d'origine. Sous conditions très humides, un horizon A_0 (A_1 tourbeux) est formé, sous de bonnes conditions de drainage un horizon A_1 mal défini apparaît.

Dans le chapitre 3, le processus de développement physique est traité de façon plus détaillée. Le développement physique englobe tous les phénomènes en relation avec la déshydratation de la partie colloidale du sol.

Celle-ci se produit: (1) par expulsion de l'eau ou (2) par évaporation directe. Le phénomène le plus important est cependant (3) l'évapotranspiration par l'intermédiaire des racines des végétaux.

La croissance des végétaux, combinée à un excellent drainage, amène le sol à un degré avancé de développement.

D'après les résultats des expériences entreprises dans ce sens, il a été décidé de planter des roseaux dans les polders du Zuiderzee. Pour maintes raisons, l'arrêt du développement des racines entrave l'évolution du sol.

Quand les colloides du sol perdent leur eau, leurs forces respectives d'attraction augmentent, la cohésion s'accroît, le volume de la fraction minérale est réduit (Fig. 5) et les proportions relatives des volumes de plusieurs des composants du sol changent (Fig. 6). Lorsque la teneur en matière organique est importante, la proportion d'eau est très élevée.

L'évolution physique est le plus souvent un processus irréversible. La plus petite adsorption d'eau durant une période humide comparée avec le sol non évolué originel et le gonflement des particules qui l'accompagne empèche celui-ci de revenir à l'état original non développé (Fig. 7).

Le degré de développement physique peut être mesuré par la teneur en eau de la fraction colloidale du sol, et dans les sols minéraux par la teneur en argile. On introduit un facteur **n** de teneur en eau comme valeur standard de développement physique, qui est la quantité d'eau en grammes adsorbée par 1 g de la fraction argileuse. La formule suivante donne la relation de n avec les autres caractéristiques du sol

$n = (A - 0{,}2\ R) / (L + bH)$ dans laquelle

A est la teneur totale en eau comparée à 100 g de sol sec
L est la teneur en argile (lutum <2 micron)
H est la teneur en matière organique
R est la fraction minérale non colloidale du sol ($R = 100 - H - L$).
b est le rapport de la capacité d'adsorption d'eau de la matière organique à celle de l'illite.

A l'aide de séries parallèles de la même valeur n et en faisant varier les autres facteurs, le facteur b peut être déterminé pour des cas donnés, et, de la même façon, avec des séries où le facteur b est constant, la valeur de n peut être obtenue comme il est indiqué par le calcul graphique de Fig. 8. Nous proposons de définir n en relation avec l'illite.

Dans le cas d'autres espèces de minéraux argileux, la formule suivante peut être employée.

$n = (A - 0.2\ R) / (L_1 + b_1L_1 + b_2L_2 \ldots + b_hH)$, dans laquelle

L est la teneur en illite
b_1, b_2, etc. le rapport entre la capacité d'adsorption d'illite et celle des autres minéraux argileux
L_1, L_2, la teneur en minéraux argileux autres que l'illite.

Le facteur b_h représente le rapport entre la capacité d'adsorption d'eau d'illite et celle de la matière organique.

Pour les sols ayant une teneur élevée en matière organique, la valeur de n est plus difficile à établir correctement. Peut-être l'introduction d'une valeur n_h (quantité d'eau en grammes adsorbée par 1 g de matière organique) sera-t-elle nécessaire.

Avec quelques réserves, la valeur n peut être définie sur le terrain par la détermination de la consistance, lorsqu'il existe une bonne correlation entre celle-ci et les lectures au pénétromètre (Fig. 9).

Dans le chapitre 4, les relations entre le développement physique et la genèse du site sont examinées (inondations, sédimentation, drainage, végétation, etc.) (Fig. 10). Les profils formés dans des conditions de drainage naturel montrent jusqu'à une certaine profondeur un développement vertical uniforme. Le développement provoqué par un drainage artificiel (par exemple lors de l'aménagement d'un polder) est toujours verticalement hétérogène. Ce développement provoqué par l'intervention humaine est souvent accompagné de fentes très larges de réfricissement dans le sous-sol, lesquelles sont très favorables au drainage interne (Photo 9).

Les sols développés verticalement hétérogènes ne se forment pas seulement lors du drainage artificiel, mais peuvent aussi résulter d'un ralentissement ou d'un arrêt de la sédimentation dans des sites naturels, comme dans les marécages, les zones argileuses ou tourbeuses, etc.

La pédogenèse initiale dans des conditions de drainage naturel est un processus terminal, grâce auquel, si le drainage est bon, un sol non développé peut se transformer en un sol complètement développé en 50 ou 100 ans (Fig. 11).

Sous le poids des couches déposées ultérieurement, un sédiment ou sédentat peut être comprimé, ce qui provoque aussi un développement. De fines couches de tourbe, horizontales à l'origine, séparant un sédiment marin ancien sous-jacent d'un sédiment marin plus jeune sous-jacent peuvent prendre une forme très ondulée, résultant du développement partiel du sédiment le plus ancien. La Figure 12 montre l'exemple d'une couche de tourbe horizontale à l'origine, comprimée à des profondeurs variables dans le sous-sol sous le poids des couches de tourbe plus jeunes.

Les éléments du site géomorphologiques correspondants paraissent être au même stade de développement dans les zones à sédimentation saline ou saumâtre, aussi bien sous climat tropical que sous climat tempéré.

Dans le paragraphe 4.5, les exemples suivants sont donnés:

Le type du sédiment ou du sol	valeur de n	Photos
Vase non sédimentée	3–5	–
Vase récemment sédimentée	2–3	2, 10, 11
Marais dont les niveaux supérieurs sont entre Haute Mer Moyenne (H.M.M.) et Basse Mer Moyenne (B.M.M.)	1,5–2,2	6, 7, 8, 10, 12, 13, 14
Marais dont les cotes supérieures sont au niveau ou légèrement au dessus de H.M.M.	1,0–1,4	12, 13, 14, 15, 16, 17
Marais considérablement au-dessus de H.M.M.	0,7–1,0	16, 17
Marais sous de bonnes conditions de drainage et inondés seulement pendant de courtes périodes chaque année	<0,7 (complètement développée)	

Le degré de pédogenèse initiale des bassins, marécages, etc. varie beaucoup suivant les différentes possibilités de drainage (Photo 6).

Dans le chapitre 4.1, une attention plus soutenue est donnée à la subsidence et à la sédimentation au cours du développement et au rôle joué par la matière organique. La Figure 10 donne un schéma de la genèse des différents éléments du site depuis la zone littorale soumise aux marées, jusqu'à la formation de polders aux sols bien développés. (Photos 2, 6, 7, 10, 14, 16).

Dans le chapitre 5, quelques problèmes d'évolution sont traités tels qu'ils se posent dans la pratique lors de l'aménagement des polders, tels que la subsidence, etc. Pour l'aménagement des polders et l'établissement des projets de systèmes de drainage, les techniciens désirent connaître à l'avance quelle pourra être l'ampleur de la subsidence. Tout particulièrement les argiles riches en matière organique et en tourbe subissent souvent une subsidence importante au cours de l'évolution, supérieure dans certains cas à 2,50 m. La surface des sols argileux de la partie occidentale des Pays-Bas s'est enfoncée d'environ 2 m depuis l'an 1000. Des sédiments horizontalement hétérogènes, ou des couches solides ondulées au-dessous de tourbes donnent souvent lieu à des variations de la subsidence, avec des différences de niveaux de la surface de 1 à 2 m sur de courtes distances.

L'observation du degré d'évolution facilite la prévision de la future subsidence de la surface, ainsi que le montre la Figure 12.

La pédogenèse physique favorise la perméabilité des sols, particulièrement lorsqu'elle agit au départ sur les sédiments les moins évolués, ou lorsqu'elle se produit dans des sols à haute teneur en colloïdes (Photo 9).

L'aptitude à la culture des sédiments tourbeux et meubles est bien déterminée par le degré de développement. Des sols peu développés ne peuvent porter que quelques espèces d'arbres cultures très spéciales. Quelques espèces particulières peuvent pousser sur des sols mi-développés spécialement en zone tropicale. Les végétaux herbacés et quelques légumes peuvent croître sur des sols plus ou moins développés, à sous-sol non développé. Enfin, pour donner des rendements maximaux, les céréales et les arbres fruitiers nécessitent un sol évolué jusqu'à une certaine profondeur, afin que le système radiculaire puisse se développer. Dans bien de cas, les dommages causés par un mauvais drainage sont dus à la présence d'un sous-sol non développé.

Le chapitre 6 examine la façon dont le processus de développement peut être employé dans la classification des sols. Les propriétés des sols se modifient considérablement au cours du développement physique, et les degrés de ce développement peuvent servir de caractéristiques différentielles pour une classification.

Dans le chapitre 6.2, la classification du développement du sol est traitée. Dans le tableau 1, cinq classes de développement pour differents sols sont définies. Elles sont valables aussi bien sous climat tempéré que sous climat tropical, pour des argiles à texture lourde et pour des argiles sableuses, pour des sols à faible teneur ou à teneur élevée en matière organique. La détermination des classes de pédogenèse initiale est basée sur la valeur de n et peut être faite sur le terrain en pressant entre les doigts un fragment de sol et en appréciant son degré d'adhésivité.

Les différents horizons de sols alluviaux très jeunes ou de sols tourbeux peuvent également être décrits en fonction du développe-

TABLE 1. La classification d'un échantillon en relation avec le développement pédologique physique initial

Chiffre n	Nom	L'addition aux symboles des horizons	La description de consistance
<0,7	totalement développé	r	Solide, ne colle pas ou presque pas à la main; il n'est pas possible de presser ou de faire passer entre les doigts
0,7–1,0	développé à peu près totalement	wα	Un peu plastique, colle à la main et il faut forcer pour faire passer netre les doigts
1,0–1,4	Semi développé	wβ	Plastique, colle fortement à la main, en pressant il est aisément possible de faire passer entre les doigts
1,4–2,0	peu développé	wγ	Très plastique, colle très fortement à la main, tout le sol passe entre les doigts avec peu de pression
>2,0	non développé	wδ	Mou, pas possible de tenir en main; pseudo fluide

ment physique. En général des horizons complètement réduits sont non évolués physiquement et sont tout à fait colorés en bleu ou gris. Lorsque l'oxydation progresse (processus de développement chimique), ces horizons sont définis comme ‘G’, CG‘‘, ‘Cg’, ou ‘A_1’. Le développement physique peut y être précisé par l'indice ‘w’ (non développé) ou ‘r’ (développé).

Les phases différentes de la pédogénèse initiale peuvent être désignées par $w\alpha$, $w\beta$, $w\gamma$ and $w\delta$ (voir Fig. 13).

Dans le tableau 2, les classes de développement physique de profils alluviaux et tourbeux sont déterminées d'après le développement de la pédogenèse jusqu'aux profondeurs de 50 et 80 cm.

Les sols dont la teneur en colloides est en-dessous du minimum, e.à.d. 8% d'illite ou 3% de matière organique, comme c'est le cas par exemple pour les sols sableux, sont considérés comme physiquement évolués (photo 5).

La classe des sols physiquement non développés (dans la classification des sols des U.S.A.: le groupe, dans celle du Pays-Bas: le sous-ordre) est divisée en deux sous-classes (classes dans le système des U.S.A., sous-groupe dans celui des Pays-Bas: les sols non développés) et les sols semi-développés.

La classe des sols non développés comprend les marais littoraux, les forêts littorales, les marécages fluviatiles bas, les zones de tourbes etc. La sous-classe des sols semi-développés (annexe-B) inclut ceux des sols non

TABLE 2. La classification des profils minéraux et organiques en relation avec la pédogenèse initiale physique des sols des alluvions et des tourbes1).

Classes principaler	Sous-classes	Valeur du chiffre n du développement physique dans les couches à la profondeur de:		
		0–20	20–50	50–80
Sols non développés	non développés	>0.7	>1,4	–
	Semi développés	>0,7	>0,7–<1,4	–
Sols minéraux développés	Avec sous sol non développés	<0,7	>0,7	et/ou >1,0
	Avec sous-sol développé	<0,7	<0,7	<1,0
Sols organiques développés2)	Avec sous-sol non développé	<0,7	>0.7	>1,0
	Avec sous-sol développé	<0,7	<0,7	<1,0

1) Ce schéma s'applique à des profils réguliers, où les valeurs de n sont homogènes ou croissent avec la profondeur. La valuer n étant marquée avec >, il n'est pas nécessaire que l'horizon entier ait la même valeur.
De faibles valeurs comme 0,7 peuvent se trouver dans l'horizon 0–20 d'un sol non développé quand dans cet horizon la partie inférieure présente au moins une valeur de n > 0,7.
Avec une valeur n marquée avec < (p.e. < 0,7 ou < 1,0) une valeur n plus élevée ne doit pas figurer entre les limites données.
Les couches fixes superficielles de quelques cm qui apparaissent dans les profils riches en particules colloidales jusqu'à une profondeur de plusieurs dm ne sont pas prises en considération. Les valeurs de n doivent être établies sur des échantillons d'environ 10 cm de hauteur. C'est seulement lorsque de fines couches argileuses non développées sont rencontrées dans des sables (niveaux de silt) que les conditions de développement de très fines couches détermineront le non-développement du profil.
Mes degrés inférieurs de la classification sont subdivisés d'après les valeurs de n du sol supérieur et du sous-sol.

2) Pour les sols organiques, il ne s'agit encore que d'un essai.

développés qui montrent un début de développement physique pendant la sédimentation, comme par exemple les marécages salins hauts, les forêts littorales en partie soumises aux marées, les sols tourbeux insuffisamment drainés et les sols tourbeux recouverts d'une couche d'argile.

Les marais à roseaux très bas, les bas-fonds silteux, les forêts à mangrove basses et saumâtres sont comprises dans la sous classe des sols non développés – Ils sont inaccessible à l'homme. La classe des sols physiquement développés est subdivisée en une sous-classe de sols physiquement développés jusqu'à une grande profondeur et une sous-classe à couche supérieure physiquement développée avec un sous sol non développé. Dans cette dernière (annexe-C) se trouvent tous les sols récemment aménagés, ou les plus anciens dont le drainage est insuffisant. Aux Pays-Bas en fait, tous les sols organiques mis en valeur peuvent être classés dans cette catégorie. La sous-classe des sols physiquement développés jusqu'à une grande profondeur (annexe-D), implique l'existence d'un sous-sol physiquement développé. A cette sous-classe appartiennent tous les sols alluviaux des régions anciennement aménagées, lorsque le sol a été bien drainé pendant une longue période, ainsi que la plus grande partie des sols alluviaux fluviatiles.

ZUSAMMENFASSUNG

INITIALE BODENBILDUNG UND BODENKLASSIFIKATION

In dieser Abhandlung wird die Bodenbildung in sehr jungen marinen und fluviatilen Sedimenten und in Mooren beschrieben. Seit dem 10. Jahrhundert hat man in den Niederlanden viele Erfahrungen gewonnen bei der Trockenlegung und Urbarmachung dieser Böden. Obwohl die Landgewinnung und die Urbarmachung von Flusston- und Niedermoorgebieten grossen Erfolg hatte (fruchtbare Marschtonpolder und trockengelegte Seen) gab es auch viele Enttäuschungen. Im 19. Jahrhundert und Anfang des 20. Jahrhunderts gewannen die wisserschaftlichen Untersuchungen an Bedeutung besonders bei der Trockenlegung der Zuiderzeepolder.

Eine führende Persönlichkeit bei dieser Forschungsarbeit war der 1961 verstorbene Professor Zuur, der die Theorie über die Bodenbildung der Polderböden entwickelte.

Die Prozesse welche bei der Bildung alluvialer und Moorböden auftreten gehen allmählich ineinander über und treten häufig auch gleichzeitig auf. Es handelt sich u.a. um Sedimentation, Sedentation, Überwachsung der Sedimente und des Moores, natürliche Entwässerung, Änderungen im Boden infolge der künstlichen Entwässerung und der landwirtschaftlichen Nutzung.

Wir unterscheiden bei diesen Prozessen die Geogenese und die Pedogenese. Geogenesis umfasst Sedimentation, Moorbildung usw. Die Pedogenese, die in diesen Studien 'initiale Bodenbildung' oder 'Reifung' genannt wird, fängt an wenn die Luft im Boden eindringt (z.B. infolge Entwässerung, oder Pflanzenwuchs). Die Grenze zwischen Geogenese und Pedogenese ist manchmal schwer zu erkennen (Bilder nr. 1, 2 und 3).

Die Bodenreifung wird unterteilt in physikalische, chemische und biologische Reifung; Prozesse die meistens mehr oder weniger gleichzeitig ablaufen.

Die physikalische Reifung umfasst u.a. den Wasserverlust, die Entwicklung der Bodenstruktur, die Bodensetzung, die Änderung der Konsistenz und Durchlässigkeit des Bodens, sowie die Entsalzung.

Die chemische Reifung bezieht sich auf Prozesse wie die Oxydation von Bestandteilen des ursprünglich reduzierten Sediments, wie Eisen- und Schwefelverbindungen, organische Substanz usw. Ferner treten während der Reifung im Kationenbelag Veränderrungen am Sorptionskomplex auf, die das Verhalten der Phosphor- und Stickstoffverbindungen sowie die Entkalkung usw. beeinflussen. Die durch Ferrihydroxyd bedingte Fleckigkeit ist ein wichtiges Merkmal zur Bestimmung der Reifungsstufe und des hydrologischen Zustandes eines reifenden Bodens. Durch Oxydation von Schwefel können besonders saure 'Maibolt' oder saure 'Pseudo-Maibolt' entstehen (Fig. 1).

Die biologische Reifung bezieht sich sowohl auf die mikrobiologischen Prozesse während der Durchlüftung, wie auch auf das Umwühlen und Homogenisieren des Bodens durch Makro-organismen und auf die Bildung organischer Substanzen durch Pflanzen. Die biologische Homogenisation beginnt bereits während der Geogenese, erreicht jedoch bei günstigen Entwässerungsverhältnissen während der Pedogenese ihre grösste Bedeutung (Fig. 2).

Wenn weiter fortgeschrittene Bodenbildungsprozesse einsetzen, wie z.B. die Entwicklung struktureller oder textureller B-Horizonte ist das Stadium der Reifung bzw. initialer Bodenbildung als beendet zu betrachten.

Zur Kennzeichnung der Stufen des Reifungsprozesses junger Böden zum Zwecke der Bodenklassifizierung wurde die physikalische Reifung gewählt, weil diese Merkmale der Reifung sich am leichtesten im Felde bestimmen lassen und die Bestimmung der Reifungsstufe unabhängig ist vom Gehalt des Bodens an Salz, Ton, organischer Substanz usw. Ausserdem ist dieser Prozess nicht umkehrbar und sein Endpunkt kann gut bestimmt werden.

Die organische Substanz spielt bei der Reifung eine äusserst wichtige Rolle. Im zweiten Abschnitt wird das Gleichgewicht zwischen Produktion und Abbau organischer Substanz im Zusammenhang mit der Geo- und Pedogenese behandelt. Wenn der Abbau organischer Substanz durch schlechte Entwässerung behindert wird bildet sich Torf als geogenetischer Vorgang (Bilder 4, 18 und 19). Der Abbau organischer Substanz in Mooren und vielen Tonen gehört zur Pedogenese. Meeresablagungen (Geogenese) besitzen charakteristische Verhältnisse zwischen organischer Substanz und Ton (Humus-Tonverhältnisse) (Fig. 3, 4): sehr niedrige organische Substanz-Gehalte in den Tropen, ziemlich hohe in gemässigten Klimaten und sehr hohe in Süsswasserzeitengebieten.

Während der Geogenese verursacht die Beimischung organischer Substanz aus der bei der Ablagerung Anwächsenden Vegetation allerlei Übergänge zwischen Moor- und Mineralböden. Während jeder Reifungsstufe besteht ein charakteristischer Gleichgewichtszustand im Verhältnis der organischen Substanz zum Ton. Der Gehalt an organischer Substanz erhöht oder erniedrigt sich bis dieses Gleichgewicht erreicht ist (Fig. 4). Auch die Entwicklung des A_1-Horizonts hängt von der Reifungsstufe und vom organischem Ausgangsmaterial ab. Unter sehr nassen Verhältnissen wird ein A_0-Horizont (mooriger A_1) geformt, bei guter Entwässerung dagegen ein sehr schwach entwickelter A_1-Horizont.

Im dritten Abschnitt wird der Prozess der physikalischen Reifung mehr in Einzelheiten behandelt. Die physikalische Reifung umfasst alle Prozesse die mit der Wasserentnahme (Dehydratation) des kolloidalen Bodenanteils zusammenhängen. Diese findet statt: 1) durch das Absickern von Wasser oder 2) durch direkte Verdunstung. Der wichtigste Prozess ist aber 3) die Evapotranspiration durch die Pflanzenwurzeln.

Pflanzenwuchs, kombiniert mit einer perfekten Dränung, fördert die Reifung im hohen Masse. Die hierbei gemachten Erfahrungen veranlassen die Anpflanzung von Schilf auf den trockenfallenden Boden der Zuiderzeepolder. Aus mehreren Gründen wird die Reifung verzögert wenn die Wurzelentwicklung gehemmt ist.

Wenn die Bodenkolloiden Wasser verlieren, wächst ihre gegenseitige Anziehungskraft an, die Konsistenz wird grösser, das Volumen der Mineralteile wird kleiner (Fig. 5) und das Volumenverhältnis der Bodenbestandteile (Strukturelemente) ändert sich (Fig. 6). Bei

Anwesenheit von vieler organischen Substanz ist der Wassergehalt sehr hoch.

Die physikalische Reifung is grösstenteils ein nicht umkehrbarer Prozess. Auch bei geringere Wasseraufnahme in Nassperioden im Vergleich zu dem ursprünglichen Boden und bei damit zusammenhängenden Quellung der Bodenteilchen tritt der ursprüngliche Zustand der Unreife nicht wieder ein (Fig. 8).

Die physikalische Reife kann an dem Wassergehalt des kolloidalen mineralischen Boden am Tongehalt abgemessen werden. Wir führen einen Wasserfaktor **n** als Standardwert für die physikalische Reife ein, nämlich die Wassermenge in Gramm die von 1 gr. Tonfraktion absorbiert ist. Folgende Formel zeigt den Zusammenhang mit anderen Bodengrössen an:

$$n = (A - 0{,}2\ R) \,/\, (L + bH) \text{ wobei}$$

A = Gesamtwassergehalt bezogen auf 100 gr. Trockenboden
L = Tongehalt (lutum <2 mikron)
H = Gehält an organischer Substanz
R = nicht kolloidaler mineraler Bodenanteil ($R = 100 - H - L$)
b = Verhältnis des wasserabsorbierenden Vermögens der organischen Substanz zu dem von Illit-Ton

Mit Hilfe paralleler Serien bei gleichem n-Wert und wechselnder Grösse der anderen Faktoren ist es möglich für eine gegebene Situation den Faktor b zu bestimmen. Gleichfalls kann bei Serien mit konstantem b-Faktor der n-Wert bestimmt werden, wie es z.B. in der graphischen Bestimmung in Fig. 8 getan wurde. Wir schlagen vor den n-Faktor bezogen auf Illit zu definieren.

Bei Anwesenheit anderer Tonminerale wäre die folgende Formel zu benutzen:

$$n = \frac{A - 0{,}2\ R}{L_i + b_1 L_1 + b_2 L_2 \ldots + b_h H}, \text{ wobei}$$

L_i = Illitgehalt
b_1, b_2 = Verhältnis des Wasseradsorbierenden Vermögens anderer Tonminerale zu dem von Illit
L_1, L_2 = Gehalt an anderen Tonmineralen

Der Faktor b_h repräsentiert das Verhältnis zwischen den Wasseradsorbtionsvermögen von Illit zu dem von organischem Material.

Bei Böden mit hohem Gehalt an organischer Substanz ist die Bestimmung des n-Wertes komplizierter und weniger genau. Wahrscheinlich ist die Einführung eines n_h-Wertes (die Wassermenge in Gramm die von 1 gr. organischer Substanz adsorbiert wird) nötig. Mit einigem Vorbehalt kann der n-Wert im Feld gemessen werden durch Bestimmung der Konsistenz, falls eine gute Korrelation zwischen der Konsistenz und Penetrometerablesungen vorliegt (Fig. 9).

Im vierten Abschnitt wird die Beziehung zwischen der physikalischen Reifung und der Entstehung der Landschaft (Überflutung, Sedimentation, Entwässerung, Vegetation usw.) (Fig. 10) besprochen. Profile die unter natürlichen Entwässerungsverhältnissen vorkommen, zeigen in senkrechter Richtung eine homogene Reifung bis zu einer gewissen Tiefe auf. Reifung infolge künstlicher Entwässerung (z.B. bei Anlage eines Polders) ist immer vertikal heterogen. Bei dieser, durch menschliches Eingreifen verursachten Reifung entstehen oft breite Schwundrisse bis in den Untergrund, die fur die innere Entwässerung von grosser Bedeutung sind (Bild 9).

Vertikal heterogen gereifte Böden bilden sich nicht nur unter künstlichen Entwässerungsbedingungen sondern auch infolge eines Abnehmens oder Aufhörens der Sedimentation in natürlichen Landschaften, z.B. in Hinterwässern, Moormarschgebieten usw.

Die Reifung bei künstlicher Entwässerung ist ein abläufender Prozess bei welchem unter guten Bedingungen ein unreifer Boden sich innerhalb von 50 bis 100 Jahren zu einem volständig reifen Boden entwickeln kann (Fig. 11).

Durch das Gewicht später sedimentierter Schichten kann ein Sediment oder Sedentat zusammengedrückt werden und auf diese Weise ebenfalls reifen. Ursprünglich waagerechte, dünne Torfschichten, die eine ältere Meeresablagerung im Untergrund von einer jüngere obenaufliegenden Meeresablagerung trennen, können einen sehr welligen Verlauf annehmen infolge stellenweiser Reifung der älteren Ablagerung. Figur 12 zeigt eine ursprünglich horizontale Torfschicht, die unter dem Gewicht jüngerer Torfschichten bis zu verschiedenen Tiefen in den Untergrund gedrückt wurde.

Geomorphologisch übereinstimmende Landschaftselemente zeigen in Süss-, Brack- und Salzwassergebieten, sowohl in den Tropen wie auch in gemässigten Zonen, dieselbe Reifungsstufe auf.

Im Abschnitt 4.5 werden folgende Beispiele gezeigt:

Sediment- und Bodentypen	n-Wert	Bilder
schwebender Schlamm	3 bis 5	–
frisch abgesetzter Schlamm	2 bis 3	2, 10, 11
Marsche wovon die höchsten Stellen zwischen Mittleres Hochwasser (MHW) und Mittleres Niedrigwasser (MNW) liegen	1,5 bis 2,2	6, 7, 8, 10, 12, 13, 14
Marsche wovon die höchsten Stellen auf oder ein wenig über MHW liegen	1,0 bis 1,4	12, 13, 14, 15, 16, 17
Marsche hoch über MHW	0,7 bis 1,0	16, 17
Marsche mit ausgezeichneter Entwässerung welche jedes Jahr nur kurze Perioden überflutet werden	$<0,7$ (völlig reif)	

Becken, Hinterwässer u.a. haben sehr verschiedene Reifungsstufen infolge der grossen Unterschiede in den Entwässerungsmöglichkeiten der Becken (Bild 6).

Im Abschnitt 4.1 wird näher auf die Reifung, die Setzung und die Ablagerung eingegangen, sowie auf die Rolle, welche die organische Substanz dabei spielt. Figur 10 gibt eine schematische Übersicht der Genese der verschiedenen Landschaftselemente vom Süsswassergezeitengebiet bis zu der Entstehung von Poldern mit gut gereiften Böden (Bilder 2, 6, 7, 10, 14, 16).

Im fünften Abschnitt werden einige Reifungsfragen, die in der Praxis bei der Anlage von Poldern auftreten, wie u.a. die Setzung, näher behandelt. Bei der Anlage von Poldern und dem Entwurf von Dränungssystemen möchten die Techniker gerne im voraus die Grösse der Setzung kennen. Besonders an organischer Substanz reiche Tone sowie Torfe zeigen oft eine beträchtliche Setzung während der Reifung, in einigen Fällen bis zu 2,5 m. Die Oberfläche der Moorböden im westlichen Teil der Niederlande ist seit 1000 n.C., etwa 2 m. abgesackt. In horizontaler Richtung heterogene Ablagerungen oder welliger fester Untergrund unter Mooren bewirken manchmal Unterschiede in der Setzung wodurch über kurze Abstände Höhenunterschiede von 1 bis 2 m. an der Oberfläche auftreten.

Mit Hilfe der Daten, die bei der Feststellung der Reifungsstufe anfallen, kann wie in Figur 12 und im Bild 20 gezeigt wird, die voraussichtliche Absenkung der Oberfläche leicht errechnet werden.

Die physikalische Reifung fördert die

Durchlässigkeit der Böden, besonders wenn man von unreiferen Ablagerungen ausgeht oder wenn es sich um Böden mit einem hohen Kolloidanteil handelt (Bild 9).

Die Eignung von Moorböden und mit tonigen Ablagerungen überdeckten Mooren für bestimmte Kulturen wird im hohem Masse von der Reifungsstufe bestimmt. Unreife Böden können nur einige besondere Gewächse tragen. Einige Holzarten können auf halbreifen Böden wachsen, besonders in den Tropen. Gräser und einige Gemüsearten können auf mehr oder weniger gereiften Böden mit unreifem Untergrund wachsen. Um Höchsterträge geben zu können, brauchen die Gewächse und Obstbäume einen Boden der bis zu genügender Tiefe gereift ist, um die Entwicklung eines ausgedehten Wurzelsystems zu ermöglichen. In veilen Fällen ist der Schaden der durch schlechte Entwässerungsverhältnisse verursacht wird auf die Anwesenheit unreifen Untergrundes zurückzuführen.

Abschnitt 6. behandelt die Weise wie der Reifungsprozess für Zwecke der Bodenklassifikation benutzt werden kann. Die Bodeneigenschaften ändern sich während der Physikalischen Reifung erheblich und können deshalb als Unterscheidungsmerkmale für eine Bodenklassifikation benutzt werden.

Im Abschnitt 6.2 wird die Klassifizierung der Reifung von Böden behandelt. In der Tabelle 1 werden fünf Reifungsklassen für verschiedene Böden aufgeführt, und zwar für gemässigte wie auch für tropische Umstände, fur leichte und sandige Tone, und für Böden mit hohem bzw. niedrigem Gehalt an organischer Substanz. Die Feststellung der Reifungsklassen stützt sich auf den n-Wert und kann im Feld bestimmt werden durch die Fingerprobe.

Bodenhorizonte von sehr jungen alluvialen Böden und von Moorböden können ebenfalls in Bezug auf die physikalische Reifung beschrieben werden. Blau oder grau gefärbte, völlig reduzierte G-Horizonte sind durchwegs physikalisch unreif. Bei zunehmender Oxydation (ein Prozess der chemischen Reifung) werden diese Horizonte gewöhnlich mit ‘G’, C‘G’, ‘Cg’ oder ‘A_1’ bezeichnet. Die

TABELLE 1. Klassifikation des Bodenmaterials nach physikalischem Reifegrad

n-Wert	Bezeichnung	Indizes1)	Konsistenzbefund bei mittlerem Tongehalt
<0,7	reif	r	fest, haftet nicht oder nur wenig an den Fingern und geht beim Quetschen nicht zwischen den Fingern durch
0,7–1,0	beinahe reif	wα	ziemlich fest, hat Neigung an den Fingern zu haften und kann nicht mühelos zwischen den Fingern durchgequetscht werden
1,0–1,4	halb reif	wβ	ziemlich weich, haftet an den Fingern und kann ohne Mühe zwischen den Fingern durchgequetscht werden
1,4–2,0	beinahe unreif	wγ	weich, haftet stark an den Fingern und kann ohne Mühe zwischen den Fingern durchgequetscht werden
>2,0	unreif	wδ	flüssiger Schlamm, unknetbar

1) zusätzlich zu den üblichen Kennzeichen der Horizonte.

TABELLE 2. Klassifikation mineralischer und organischer Bodenprofile nach der alluvialen physikalischen Initialbodenbildung oder physikalischen Reife[1]).

Klassen	Subklassen und Übergänge	n-Wert in den Tiefen		
		0–20 cm	20–50 cm	50–80 cm
physikalisch unreif	unreif	>0,7	>1,4	–
	halb reif	>0,7	>0,7–<1,4	–
physikalisch reife	mit unreifem Untergrund	<0,7	>0,7	und oder >1,0
	mit reifem Untergrund	<0,7	<0,7	<1,0
physikalisch reife organische Böden[2])	mit unreifem Untergrund	<0,7	>0,7	>1,0
	mit reifem Untergrund	<0,7	<0,7	<1,0

[1]) Diese Tabelle gilt für normale Profile mit homogenen oder nach unten zunehmenden n-Werten. Bei einem n-Wert, der sich in der Tabelle durch > kennzeichnet, ist es nicht nötig, dass der gesamte Horizont denselben n-Wert besitzt.
Niedrigere n-Zahlen, wie z.B 0,7 im 0–20 Horizont eines unreifen Bodens dürfen vorkommen, wenn nur der untere Teil einen n-Wert von über 0,7 aufzeigt.
Bei einem n-Wert, die durch < gekennzeichnet ist (z.B < 0,7 oder < 1,0), darf innerhalb des angegebenen Tiefenbereichs kein höherer n-Wert vorkommen.
Dünne (nur einige cm mächtige) oberflächliche Schichten bei Profilen, die über einige dm reich an Kolloidteilchen sind, werden nicht mitgerechnet. Die n-Werte müssen an Mustern von ca 10 cm Höhe bestimmt werden. Die Reifungstiefe dünner Schichten wird nur bestimmt im Falle dünner unreifer toniger Schichten über Sand (schlickiges Watt).
Niedrigere Niveaus in der Klassifikation können nach den n-Werten von Oberboden und Untergrund unterteilt werden.

[2]) Für organische Böden wird dieser Vorschlag mit Vorbehalt gemacht.

physikalische Reifung kann in diesen Horizonten mit zusätzlichen Indizes w (für unreif) bzw. r (für reif) angegeben werden. Die Reifungsstufen könnten mit $w\alpha$, $w\beta$, $w\gamma$ und $w\delta$ angegeben werden (siehe Fig. 13).

In der Tabelle 2 werden die Reifungsklassen von Profielen alluvialer Böden und Moorböden gezeigt, wobei als Grundlage das Fortschreiten der Reifung bis 50 bzw. 80 cm. Tiefe benutzt wurde.

Böden mit einem under dem Mindestmass liegenden Kolloidgehalt (d.h. 8% Illit oder 3% organische Substanz) wie z.B. Sandböden, werden als physikalisch reif betrachtet (Bild 5).

Die Klasse der physikalisch unreifen Böden (im Bodenklassifikationssystems der U.S.A. auf Gruppenniveau, in dem der Niederlande auf Subordnungsniveau) ist in die Subklassen unreife Böden und halbreife Böden unterteilt worden (Bodenklassifikation U.S.A. = Klassenniveau; Niederlande = Subgruppenniveau).

Der Klasse der unreifen Böden gehören Gezeitenmarschen, Gezeitenwälder, Hinterwässer der Flussauen, Moorgebiete u.s.w. an.

Die Subklasse der halbreifen Böden (Anlage-B) umfasst den Teil der unreifen Böden, der während der Aufschlammung eine gewisse Reifung aufzeigt, z.B. hohe Salzwassermarschen, mittelhohe Süsswassergezeitenwälder, ungenügend entwässerte Moorböden und Moormarsche.

Niedrigere Schilfmarsche, schluffige Watten, tiefliegende brackige Mangrovenwälder gehören in der Subklasse der völlig unreifen Böden (Anlage-A). Sie sind für den Mensch unbegehbar.

Die Klasse der physikalisch reifen Böden ist unterteilt in einer Subklasse mit bis auf grosse Tiefe physikalisch gereiftem Boden und einer solchen mit physikalisch gereiftem Oberboden und unreifem Untergrund. Letztere (Anlage-C) umfasst alle jungen urbar gemachten Böden und die älteren mit behinderter Entwässerung. In den Niederlanden können tatsächliche alle urbar gemachten organischen Böden dieser Klasse zugeteilt werden. Die Subklasse der tief gereiften Böden (Anlage-D) fordert einen gereiften Untergrund. Sie umfasst sowohl alle alluvialen Böden in älteren Poldergebieten, wo der Boden nach der Urbarmachung längere Zeit dräniert wurde als auch den grössten Teil der alluvialen Flussböden.

RESUMEN

PEDOGÉNESIS INICIAL Y CLASIFICACIÓN DE LOS SUELOS

Este estudio describe la pedogénesis de sedimentos marinos muy jóvenes, de sedimentos de origen fluvial y de las turberas. Desde el siglo décimo mucha experiencia se ha adquirido en Holanda en la recuperación de estos suelos y en su puesta en cultivo. Si bien se han obtenido grandes éxitos en la recuperación de suelos de origen marino, arcillosos y fértiles y de las tierras pantanosas, ha habido también muchos fracasos. En el siglo XIX y en el comienzo del XX, la investigación científica llegó a adquirir gran importancia. La necesidad de recuperar grandes extensiones de tierra tales como los llamados pólderes del Zuiderzee estimuló mucho este tipo de investigación. Un personaje destacado eneste trabajo de investigación fué el fallecido profesor Zuur (1961) quien estableció las bases y describió la pedogénesis de los suelos de pólder.

Los procesos que ocurren durante la génesis de áreas aluviales y de turberas tales como la sedimentación, la sedentación, el creumiento de los sedimentos y de la turba, el drenaje natural y los cambios experimentados por el suelo durante el proceso de drenaje artificial y los ocasionados por su utilización en la agricultura, se oscurecen gradualmente unos a otros; además a menudo ocurren simultáneamente. Nosotros distinguimos en esfos procesos la geogénesis y la pedogénesis. La geogénesis comprende todos los procesos de sedimentación, desarrollo de la turba, etc. La pedogénesis, llamada en este estudio pedogénesis inicial o 'ripening', comienza cuando el aire penetra en el suelo después del drenaje o debido al crecimiento de las plantas por ejemplo. A veces es difícil separar estrictamente la geogénesis de la pedogénesis (Fotos 1, 2 y 3).

La pedogénesis inicial comprende tres procesos a saber: el físico, el químico y el biológico, los cuales ocurren mas o menos simultáneamente.

El proceso físico comprende la pérdida de agua, el asentamiento, los cambios en la consistencia y permeabilidad del suelo y la desalinización del mismo.

El proceso químico incluye la oxidación de toda clase de compuestos que se encontraban en el sedimento originalmente reducidos, por ejemplo compuestos de hierro, de azufre, materia orgánica, etc. Además comprende los cambios que ocurren en los cationes del complejo de adsorción durante la formación inicial del suelo, el comportamiento de los

fosfatos y de los compuestos de sodio, la decalcificación, etc.

El moteado ocasionado por el hidróxido férrico es una caracteristica importante para la determinación del grado de avance del proceso de formación inicial del suelo y de sus condiciones hidrológicas. La oxidación del azufre puede dar origen a '*catclays*' * fuertemente á cidas y a '*pseudo-catclays*' ácidas (Fig. 1).

El proceso biológico comprende los cambios ocasionados por los microorganismos durante la aereación del suelo, el acarreo y la homogeneización del mismo por los macroorganismos y la producción de materia orgánica por las plantas. La homogeneización debida a factores biológicos comienza desde la geogénesis; pero adquiere importancia especialmente durante la pedogénesis en buenas condiciones de drenaje (Fig. 2).

Tan pronto como comienzan los procesos más avanzados de la formación del suelo tales como el desarrollo de horizonte B estructural o textural, la primera etapa de la formación del suelo termina.

El proceso físico de la pedogénesis inicial ha sido escogido para caracterizar en conjunto la pedogénesis inicial de los suelos jóvenes con el fin de clasificarlos, debido a que sus efectos pueden determinarse fácilmente enel campo y porque es independiente del contenido del suelo en sales, arcilla, materia orgánica, etc. Además este proceso es irreversible y su fin puede fácilmente determinarse.

La materia orgánica juega un papel extremadamente importante en el proceso inicial de la formación del suelo.

El capítulo 2 trata sobre el equilibrio entre la produccíon y la destrucción de la materia orgánica en relación con la geogénesis y la pedogénesis. Aunque como queda dicho la separación estricta entre la geogénesis y la pedogénesis es difícil existe sin embargo una zona limítrofe; cuando la destrucción de la materia orgánica es retardada por un drenaje deficiente, la formación de la turba tiene lugar, en esta zona limítrofe pero dentro aún de la geogénesis. En esta zona también pero ya dentro de la pedogénesis, la materia orgánica de las turbas y de algunos suelos arcillosos entra en descomposición.

Los sedimentos marinos (geogénesis) presentan relaciones materia orgánica-arcilla típicas (Figs. 3, 4), el contenido de materia orgánica es muy bajo en las zonas tropicales, alto en las áreas marinas de las zonas templadas y muy alto en zonas litorales de agua dulce.

La adición de materia orgánica secundaria que proviene de la vegetación y que ocurre durante la sedimentación dentro del proceso de la geogénesis, dá lugar a toda clase de suelos transicionales entre las turbas y los suelos minerales. Durante cada una de las etapas de la pedogénesis inicial existe un estado de equilibrio característico entre el contenido de materia orgánica y de arcilla; la materia orgánica aumenta o disminuye hasta que se alcanza este estado de equilibrio (Fig. 4).

El desarrollo del horizonte A_1 depende también del grado de avance de la pedogénesis inicial y del tipo de materia de orgánica origen. En condiciones muy húmedas se forma un horizonte A_0 (A_1 turboso), en condiciones de buen drenaje se forma un horizonte A_1 muy delgado.

El capítulo 3 trata del proceso físico de la pedogénesis inicial con mayor detalle. Este proceso comprende todos los cambios relacionados con la deshidratación de la fracción coloidal del suelo.

Esta tiene lugar debido a: (1) el descenso del nivel del agua o (2) la evaporación directamente. El proceso mas importante es sin embargo (3) la evapotranspiración por los raíces de las plantas.

El crecimiento de las plantas en combinación con un drenaje perfecto favorece en alto grado el proceso pedogenético. Teniendo en

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* Nombre asociado con el excremento de los gatos y que por abuso se aplica a toda clase de suelos pobres.

cuenta esta experiencia se ha decidido plantar carrizales en los pólderes del Zuiderzee. Un estancamiento del desarrollo radicular retarda obviamente la evolución del suelo.

Tan pronto como la deshidratación de los coloides comienza, las fuerzas de atracción entre sus partículas y la consistencia aumentan, el volumen de la fracción mineral se reduce (Fig. 5) y por lo tanto las relaciones de volumen entre los diversos componentes del suelo cambian (Fig. 6). Cuando el material es muy rico en materia orgánica, el contenido de agua es muy alto.

El proceso físico de la pedogénesis es en gran porte un proceso irreversible. La absorción menor de agua durante un període húmedo y el aumento en volumen así ocasionado impiden que el suelo pueda volver posterior mente a su estado original (fig. 7).

Este proceso puede medirse mediante el contenido de agua de la fracción coloidal del suelo que en el caso de los suelos minerales corresponde fundamentalmente al contenido de arcilla. Los autores introducen un 'factor agua' n, como un valor estándard del proceso físico de la pedogénesis, este valor es la cantidad de agua en gm que es adsorbida por 1 gm de la fracción arcillosa. La siguiente fórmula expresa la relación con otras características del suelo:

$$n = (A - 0.2\ R) / (L + bH)$$

en la que

A = contenido total de agua comparado a 100 gm de suelo seco.
L = contenido de arcilla (lutum) (<2 micras).
H = contenido de materia orgánica.
R = fracción mineral no coloidal del suelo ($R = 100 - H - L$).
b = relación de la capacidad de adsorción de agua por la materia orgánica comparada con la capacidad de adsorción de la ilita.

Con la ayuda de series paralelas del mismo valor n y variando otros factores, el factor b puede ser determinado para una dada situación y, del mismo modo conservando b constante, el valor n puede determinarse como se hizo en el cálculo gráfico de la figura 8. Se propone definir el factor n en relación con la ilita.

En el caso de otras clases de arcillas la siguiente fórmula debe utilizarse:

$$n = (A - 0.2\ R) / (L_i + b_1L_1 + b_2L_2 \ldots + b_hH)$$

en la que:

L_i = contenido de ilita.
b_1, b_2, etc.: la relación entre la capacidad de adsorción de agua de la ilita y la capacidad de cada una de las otras arcillas.
L_1, L_2 = contenido de otras arcillas.

El factor b_h representa la relación entre la capacidad de adsorción de agua de la ilita y la capacidad de adsorción del material orgánico.

Para suelos con alto contenido de materia orgánica el valor n no es muy exacto y su determinación es complicada. Quizás la introducción de un valor n_h (la cantidad de agua en gm adsorbida por 1 gm de materia orgánica) fuese necesario.

Con ciertas restricciones el valor n puede medirse en el campo mediante la determinación de la consistencia siempre y cuando exista una buena correlación entre la consistencia y las lecturas de un penetrómetro (Fig. 9).

En el capítulo H se discute la conexión entre el proceso físico de la pedogénesis inicial y la génesis del paisaje (inundaciones, sedimentación, drenaje, vegetación, etc.) (Fig. 10). La evolución causada por drenaje artificial, por ejemplo en la recupera ción de un pólder, es siempre verticalmente heterogénea mientras que los perfiles, que tienen buen drenaje natural son verticalmente homogéneos hasta cierta profundidad. La evolución ocasionada por la acción del hombre a menudo es acompañada por contracciones y agrietomientos en el subsuelo los cuales son muy favorables para el drenaje interno (Foto 9).

Los suelos evolucionados que presentan una heterogeneidad vertical no sólo se forman bajo condiciones de drenaje artificial sino también como resultado de una disminución o detención del proceso de la sedimentación en condiciones naturales por ejemplo en pantanos, capas de arcilla sobre turba, etc.

La evolución provocada por drenaje artificial es un proceso que termina mediante el cual si el drenaje es bueno, un suelo no evolucionado puede transformarse en uno completamente evolucionado en un periodo de 50 a 100 años (Fig. 11).

Bajo la influencia del peso de capas de sedimento depositadas posteriormente, un sedimento puede ser comprimido y evolucionar conjuntamente.

Las capas delgadas de turba que originalmente se encontraban horizontales dividiendo un sedimento marino antiguo (subsuelo) de uno joven (capas superficiales), presentan a veces ondulaciones como resultado de una pedogénesis parcial del sedimento antiguo. La Figura 12 muestra un ejemplo de una capa de turba originalmente horizontal comprimida irregularmente bajo el peso de nuevas capas de turba.

Los elementos del paisaje de las áreas salinas, salobres o de sedimentación de sales, presentan la misma etapa de evolución tanto en climas templados como tropicales.

La sección 4.5 trata de algumos ejemplos como los mencionados mas abajo.

Debido a diferentes posibilidades de drenaje de las cuencas, éstas y los pantanos etc. varian mucho en lo que respecta al avance de su evolución pedogenética (Foto 6).

En el capitulo 4.1, se trata más detalladamente del proceso pedogenético inicial, del descenso de nivel, de la sedimentación y del papel que juega la materia orgánica. La Figura 10 presenta esquemáticamente la génesis de varios elementos del paisaje comenzando con las zonas litorales de agua dulce para terminar con la formación de pólderes con suelos bien evolucionados (Fotos 2, 6, 7, 10, 14, 16).

En el capítulo 5 algunos problemas de la pedogénesis son tratados conforme se presentan en la práctica al construir los pólderes como por ejemplo, el descenso de nivel o asentamiento; los técnicos necesitan cono-

Clase de sedimentos o suelo	Valor n	Fotos
Lodo no depositado	3–5	-
Lodo recientemente depositado	2–3	2, 10, 11
Pantanos cuyo punto mas alto se encuentra comprendido entre los niveles regularmente alcanzados por la alta y baja mareas, designadas respectivamente MHW y MLW	1.5–2.2	6, 7, 8, 10, 12, 13, 14
Pantanos cuyo punto mas alto se encuentra en un nivel ligeramente superior al alcanzado por MLW	1.0–1.4	12, 13, 14, 15, 16, 17
Pantanos mucho mas altos que el nivel alcanzado regularmente por MLW	0.7–1.0	16, 17
Pantanos con muy buenas condiciones de drenaje que se inundan sólo por cortos periodos en el año	<0.7 (totalmente evolucionados)	

cer por adelantado el grado de asentamiento cuando se trata de construir pólderes o diseñar sistemas de drenaje. Los suelos arcillosos ricos en materia orgánica y las turbas presentan a menudo un marcado descenso de nivel, en algunos casos hasta de 2.5 metros, durante el proceso de la pedogénesis inicial. La superfície de los suelos turbosos del oeste de Holanda ha descendido cerca de 2 metros desde el año 1000 DC. El abatimiento del nivel superficial es desigual en los sedimentos horizontalmente heterogéneos o en las turbas que tienen subsuelos ondulados, lo cualse traduce en un nivel del suelo irregular variando en distancias tan cortas como de 1 a 2 metros.

Con la ayuda de los datos obtenidos del proceso evolutivo del suelo, es fácil calcular por adelantado el abatimiento superficial como lo muestra la Figura 12 (Foto 20).

La evolución de carácter físico favorece la permeabilidad, especialmente cuando se inicia en los sedimentos menos evolucionados o cuando tiene lugar en suelos ricos en coloides (Foto 9).

La aptitud de las turbas y de los sedimentos blandos para la producción de cosechas es determinada en gran parte por su grado de evolución. En los suelos no evolucionados sólo pueden crecer algunas plantas especiales. Algunas especies leñosas pueden crecer en suelos parcialmente evolucionados, especialmente en los trópicos.

Los zacates y algunas leguminosas pueden prosperar en suelos mas o menos evolucionados aún cuando estos tengan un subsuelo no evolucionado. Los árboles frutales y la mayor parte de las plantas anuales de cultivo necesitan un suelo evolucionado hasta una profundidad suficiente para poder desarrollar un amplio sistema radicular y producir así rendimientos máximos. En muchos casos, el daño causado por un drenaje deficiente es debido a la prescencia de un subsuelo no evolucionado.

El capítulo 6 trata de la forma en que se puede utilizar el proceso evolutivo para la clasificación de suelos. Las propiedades del suelo cambian considerablemente durante el proceso puramente físico de la evolución y

CUADRO 1. Clasificación del material del suelo de acuerdo con el proceso físico de la pedogénesis inicial

Valor n	Designación	Sufijo para el símbolo del horizonte	Descripción de la consistencia (válido para un contenido promedio de arcilla).
<0.7	evolucionado	r	firme, no se adhiere a las manos o sólo ligeramente y no puede ser pasado entre los dedos oprimiéndolo
0.7–1.0	casi evolucionado	wα	bastante firme, tiende a adherirse a las manos y no puede pasarse fácilmente con presión entre los dedos
1.0–1.4	semi-evolucionado	wβ	bastante blando, se adhiere a las manos y puede fácilmente ser pasado con presión entre los dedos
1.4–2.0	prácticamente no evolucionado	wγ	suave, se adhiere fuertemente a las manos y puede fácilmente ser pasado con presión entre los dedos
>2.0	no evolucionado	wδ	lodo liquido, no amasable

las clases de este proceso pueden utilizarse como características distintivas para la clasificación de los suelos.

El capítulo 6.2 trata de la clasificación de los suelos en proceso de evolución. En el cuadro 1 se mencionan 5 clases de evolución en diferentes tipos de suelo es decir, para suelos de climas templadas o tropicales, para suelos arcillosos o arcillo-arenosos, y para suelos con contenidos de materia orgánica altos o bajos. La determinación de las clases de evolución se basa en el valor n y puede efectuarse en el campo, haciendo pasar con presión el suelo entre los dedos

Los horizontes de suelos aluviales muy jóvenes y de las turbas pueden ser descritos también en relación con el proceso físico de su pedogénesis. Los horizontes G totalmente reducidos no están físicamente evolucionados y se encuentran coloreados de azul o gris. Si la oxidación aumenta (proceso químico de la pedogénesis) estos horizontes son normalmente designados, 'G', 'CG', 'Cg' o 'A_1'. El proceso físico de la pedogénesis puede ser designado en estos horizontes con el subíndice 'w' (no evolucionado) o 'r' (evolucionado). Las diferentes etapas de la evolución pueden designarse con los sufijos wα, wβ, wγ, y wδ (Fig. 13).

En el cuadro 2, se muestran las clases de evolución de carácter físico de perfiles aluviales y de turbas, tomando en cuenta el avance de la evolución hasta una profundidad de cerca de 1.5 pies (50 cm) y de cerca de 2.5 pies (80 cm).

Los suelos con un contenido de coloides inferior al mínimo o sea 8% de ilita ó 3% de materia orgánica son considerados evolucionados físicamente (Foto 5). Este es el caso de los suelos arenosos.

La clase de suelos físicamente no evolucionados (en el sistema americano de clasifica-

CUADRO 2. Clasificación de perfiles de suelos minerales y orgánicos de acuerdo con el proceso físico de su pedogénesis inicial[1]).

Clases	Subclases y grados transicionales	Profundidad 0–20 cm	Profundidad 20–50 cm	Profundidad 50–80 cm
		valor n	valor n	valor n
físicamente no evoluciondo	no evolucionado	>0.7	>1.4	–
	semi evolucionado	>0.7	>0.7–<1.4	–
suelos minerales físicamente evolucionados	con subsuelo no evolucionado	<0.7	>0.7	y ó >1.0
	con subsuelo evolucionado	<0.7	<0.7	<1.0
suelos orgánicos físicamente evolucionados[2])	con subsuelo no evolucionado	<0.7	<0.7	>1.0
	con subsuelo evolucionado	<0.7	<0.7	<1.0

[1]) Este esquema se aplica a perfiles regulares con valores n homogéneos o que aumentan regularmente en profundidad. En el caso de los valores n marcados en el cuadro con el símbolo >, no es necesario que todo el horizonte tenga el mismo valor n. Valores de n bajos, por ejemplo 0.7 pueden presentarse en el horizonte de 0–20 cm de un suelo no evolucionado cuando la parte inferior de este horizonte tiene un valor n por lo menos > 0.7. En el caso de los valores n marcados en el cuadro con el símbolo < (por ejemplo <0.7 ó <1.0), un valor n superior no debe presentarse dentro de los límites de la referida profundidad. Las capas superficiales que tienen sólo unos cuantos cm de espesor que se encuentran en perfiles ricos en materiales coloidales hasta de varios dm, no están incluídas. La determinación de los valores n debe hacerse en muestras de mas omenos 10 cm de espesor. Es sólo en el caso de capas delgadas de arcilla no evolucionada, que reposan sobre arena ("*silt flats*") que *las condiciones de evolucion* de algunas capas, sumamente delgadas le imprimen al perfil un carácter inmaduro. Los nive les inferiores de la clasificación deben subdividirse de acuer do con los valores n de la parte superior del suelo y del subsuelo.

[2]) Nuestra proposición es aún tentativa para los suelos orgánicos.

ción de suelos considerada en el nivel de grupo, en el sistema holandés considerada en el nivel de suborden) es dividida en subclases de suelos no evolucionados (En la clasificación americana en el nivel de clase, en la clasificación holandesa en el nivel de subgrupo) y en suelos semi-evolucionados.

La clase de suelos no evolucionados incluye pantanos y bosques de regiones litorales de agua dulce, áreas de turba, etc. La subclase de suelos semi-evolucionados (Apéndice B) incluye los suelos no evolucionados que presentan cierta evolución de caracter físico durante el proceso de deposición de materiales en suspensión por ejemplo pantanos salinos evelados, bosques medianamente elevados que de regiones litorales de agua dulce, turberas insuficientemente drenadas y turberas con una capa superficial de arcilla.

Los pantanos bajos de carrizales y las planicies de limo fino dépositado por las mareas, se incluyen en la subclase de suelos totalmente no evolucionados (Apéndice A). Son impasables por el hombre.

La clase de suelos físicamente evolucionados es subdividida en una subclase de suelos físicamente evolucionados a grandes profundidades y una subclase en que sólo la capa superficial esta físicamente evolucionada. La última clase (Apéndice C) incluye todos los suelos jóvenes recuperadoso los suelos viejos con drenaje deficiente. En los Países Bajos, de hecho todos los suelos orgánicos en proceso de recuperación pueden considerarse en esta categoría. La subclase de suelos físicamente evolucionados a grandes profundidades (Apéndice D), incluye los suelos con un subsuelo físicamente evolucionado. Esta subclase incluye todos los suelos aluviales en antiguas áreas de recupe ración, en donde el suelo ha sido adecuadamente drenado por un largo periodo de tiempo, así como también la mayor parte de los suelos aluviales de origen fluvial.

REFERENCES

BEERS, W. F. J. VAN, 1962: Acid sulphate soils. Bull. no. 3, International Institute for Land Reclamation and Improvement. Wageningen.

BEMMELEN, J. M. VAN, 1886: Bijdrage tot kennis van den alluvialen bodem in Nederland, III: De samenstelling en vorming van de zure gronden in het Nederlandse alluvium *(Contributions to the study of alluvial soils in the Netherlands, III: The composition and formation of acid soils in the Netherlands alluvium)*.
Verhandelingen Koninklijke Akademie van Wetenschappen, afd. Natuurkunde, 25, p. 33. Amsterdam.

BENNEMA, J., 1953: De ontkalking tijdens de opslibbing bij Nederlandse alluviale gronden *(Decalcification during silting-up in Netherlands alluvial soils)*. Boor en Spade, 6, pp. 40–51.

BENNEMA, J., 1954a: Bodem- en zeespiegelbewegingen in het Nederlandse kustgebied *(Soil and sea-level movements in the Dutch coastal area)*. Boor en Spade, 7, pp. 1–93.

BENNEMA, J., 1954b: Humusvormen in Nederland *(Types of humus in the Netherlands)*. Landbouwk. Tijdschr., 66, pp. 375–384.

BENNEMA, J. & D. VAN DER WOERDT, 1960: De veldbodemkundige oorzaken van de verdroging; verbreiding en eigenschappen van de verdroogde gronden *(The pedological causes of the drying; occurrence and properties of dried peat soils)*. Part II of: Hooghoudt, S. B., D. van der Woerdt, J. Bennema & H. van Dijk, 1960: Verdrogende veengronden in West-Nederland *(Irreversibly drying peat soils in the West of the Netherlands)*. Versl. Landbouwk. Onderz., no. 66.23.

BOER, TH. A. DE & L. J. PONS, 1960: Bodem en grasland in de Vijfheerenlanden *(Soil and grassland in the Vijfheerenlanden)*. Versl. Landbouwk. Onderz., no. 66.6.

BRINKMAN, R., 1960: Rapport onderzoek kleimineralen Suriname en Venezuela, delta Amacuro *(Report on an analysis of clay minerals in Surinam and Venezuela, delta of the Amacuro)*. Rapport Ingenieursonderzoek. Wageningen.

BRUIN, P., 1938: De aanwezigheid van calcium-magnesium-carbonaat naast calcium-carbonaat in kleigronden en de ontleding dezer carbonaten onder invloed van zoutzuur, azijnzuur en bodemzuren *(The presence of calcium magnesium carbonate in clay soils and the analysis of these carbonates with the aid of hydrochloric acid, acetic acid and the soil acids)*. Versl. Landbouwk. Onderz., no. 44 (15) A.

CLINE, M. G., 1949: Basic principles of soil classification, Soil Science, 67, no. 2, pp. 81–91.

DOMINGO, W. R., 1951: De fysische rijping van de jongere Zuiderzeeafzettingen in de Noordoostpolder *(The physical ripening of the younger Zuiderzee deposits in the North East Polder)*. Van Zee tot Land, no. 2. Zwolle.

EDELMAN, C. H., 1946: Katteklei (Cat clay). Groenten en Fruit, no. 32 en 33. Reprinted in: Boor en Spade, 1 (1948), pp. 172–176.

EDELMAN, C. H., 1950: Inleiding tot de bodemkunde van Nederland *(Introduction to soil science in the Netherlands)*. Amsterdam.

EDELMAN, C. H., 1963: Bospodzolen en heidepodzolen *(Forest podzols and heath podzols)*. Boor en Spade, 13, pp. 51–60.

EDELMAN, C. H. & L. A. H. DE SMET, 1951: Over de ontkalking van de Dollardklei *(Decalcification of Dollard clay)*. Boor en Spade, 4, pp. 104–144.

EDELMAN C. H. & J. M. VAN STAVEREN, 1958: Marsh Soils in the United States and in the Netherlands. Journ. of Soil and Water Cons., 13, no. 1, pp. 5–17.

GROOT, A. J. DE, 1956: Influence of age and organic matter on the availability of manganese in marine and estuary soils. Rapports VIe Congr. Int. de la Science du Sol, Vol. B, pp. 531–539. Paris.

GROOT, A. J. DE, 1962: Mangaantoestand van Nederlandse en Duitse Holocene sedimenten in verband met slibtransport en bodemgenese *(Behaviour of manganese in Netherlands and German Holocene sediments in relation to transportation of silt and soil genesis)*. Thesis. Utrecht.

HARMSEN, G. W., 1954: Observations on the formation and oxidation of pyrites in the soil. Plant and Soil, 5, no. 4, pp. 324–348.

HART, M. G. R., 1959: Sulphur oxidation in tidal mangrove soils of Sierra Leone. Plant and Soil, 11, no. 3, pp. 215–236.

HART, M. G. R., 1962 & 1963: Observations on the source of acid in empoldered mangrove soils. I (Formation of elemental sulphur); II (Oxidation of soil polysulphides). Plant and Soil, 17, pp. 87–98; 19, pp. 106–114.

HESSE, P. R., 1961: The decomposition of organic matter in a mangrove swamp soil. Plant and Soil, 14, no. 3, pp. 249–263.

HESSE, P. R., 1961: Phosphorus fixation in mangrove swamp muds. Nature, 193, pp. 295–296.

HESSE, P. R., 1961: Some differences between the soils of Rhizophora and Avicennia mangrove swamps in Sierra Leone. Plant and Soil, 14, no. 4, pp. 335–346.

HEUVELN, B. VAN, A. JONGERIUS & L. J. PONS, 1960: Soil formation in hydromorphic organic soils. Transact. VIIth Int. Congr. of Soil Science Madison (Wisc.), Vol. 4, pp. 195–204.

HISSINK, D. J., 1935: De bodemkundige gesteldheid van de achtereenvolgens ingedijkte Dollardpolders *(The character of the soil in the successively reclaimed Dollard polders)*. Bijdrage tot de kennis van het verouderingsproces van de zware zeekleigronden *(Contribution to the study of the aging process of heavy marine clay soils)*. Versl. Landbouwk. Onderz., no. 41B, pp. 47–172.

HISSINK, D. J., 1954: De humus en stikstofgehalten van de ingepolderde gronden in de voormalige Zuiderzee *(The humus and nitrogen contents of the impoldered soils of the former Zuiderzee)*. Van Zee tot Land, no. 10. Zwolle.

HOEKSEMA, K. J., 1953: De natuurlijke homogenisatie van het bodemprofiel in Nederland *(Natural homogenisation of the soil profile in the Netherlands)*. Boor en Spade, 6, pp. 24–30.

HOEKSEMA, K. J. & A. JONGERIUS, 1958 & 1959: Deterioration of soil structure due to exhausting methods of land use and its influence on recent crop rotations. Proc. Int. Symp. Soil Struct., pp. 16–23. Gent. Also: 1959: Med. van de Landbouwhogeschool en de Opzoekingsstations van de Staat te Gent, 24, 1, pp. 16–23.

HOOGHOUDT, S. B., D. VAN DER WOERDT, J. BENNEMA & H. VAN DIJK, 1960: Verdrogende veengronden in West-Nederland *(Irreversibly drying peat soils in the West of the Netherlands)*. Parts I, II and III. Versl. Landbouwk. Onderz., no. 66. 23.

JAKOBSEN, B. & K. L. M. JENSEN, 1956: Undersøgelser verdrørende landvindingsmetoder i det danske Vadehav *(Research in land reclamation methods in the Danish tidal flats)*. Geografisk Tidsskrift, 55, pp. 21–61.

JANSSEN, B. H. & G. E. KAMERLING, 1964: Een onderzoek naar de consistentie, de stabiliteit en de rijping van enkele kleigronden in de kustvlakte van Suriname *(Consistency, stability end ripening of some claysoils in the coastal plain of Surinam)*. Landbouw Proefstation, Paramaribo. Intern rapport no. 18.

JONG, J. D. DE, I. S. ZONNEVELD & J. I. S. ZONNEVELD, 1962: Air trip to the Delta Area. A pocket guide to the excursions of the jubilee convention of the Royal Mining Society of the Netherlands. Excursion I, The Hague.

JONGERIUS, A. & L. J. PONS, 1962a: Soil genesis in organic soils. Boor en Spade, 12, pp. 156–158.

JONGERIUS, A. & L. J. PONS, 1962b: Einige micromorphologische Bemerkungen über der Vererdungsvorgang im Niederländischen Moor *(Some micromorphological observations on the process of moulding in peats of the Netherlands)*. Zeitschr. für Pflanzewern. Düng. Bodenkunde, 97, pp. 243–255.

KAMPS, L. F., 1950: Enige gegevens over de sedimentatie in het waddengebied ten noorden van de provincie Groningen *(Some data on sedimentation in the Shallows north of the Province of Groningen)*. Tijdschr. Kon. Ned. Aardr. Gen., 67, pp. 369–373.

KAMPS, L. F., 1962: Mud distribution and land reclamation in the eastern wadden shallows. Communications no. 4, Rijkswaterstaat. 's-Gravenhage. Also: 1963: Publication no. 9, International Institute for Land Reclamation and Improvement. Wageningen.

KIVINEN, E., 1958: Om möjligheter att inverka pa myrjordens temperatur *(Possibilities of influencing the temperature of peat soil)*. Grundförbättring, 11, no. 2, pp. 73–81.

KIVINEN, E., 1960: Über die Moore Finnlands und ihre Nützung *(The Finnish marshes and their utilization)*. Wasser und Boden, 1, pp. 2–6.

KOENIGS, F. F. R., 1961: The mechanical stability of clay soils as influenced by the moisture conditions and some other factors. Thesis Wageningen.

KONING, J. C. DE & A. J. WIGGERS, 1955: Over de bodemgesteldheid van Oostelijk Flevoland *(The nature of the soil in Oost Flevoland)*. Van Zee tot Land, no. 15. Zwolle.

MAREL, H. W. VAN DER, 1950: Het voorkomen van calciet en dolomiet in de kleifractie van de Nederlandse gronden *(Occurrence of calcite and dolomite in the clay fraction of the Netherlands soils)*. Landbouwk. Tijdschr., 62, pp. 300–306.

MASCHHAUPT, J. G., 1947: Opmerkingen over de ontkalkingssnelheid van Nederlandse zeekleigronden *(Observations on the decalcification velocity of Netherlands marine clay soils)*. Landbouwk. Tijdschr., 64, pp. 372–377.

MASCHHAUPT, J. G., 1950: Het koolzure-kalkgehalte der Dollardgronden *(The calcium carbonate content of the Dollard soils)*. Tijdschr. Kon. Ned. Aardr. Gen., 67, pp. 374–381.

MOLEN, W. H. VAN DER, 1954: Over de landbouwkundige betekenis en de kartering van de kavel in de Noordoostpolder *(The agricultural importance and the surveying of the plots in the North East polder)*. Int. rap. Directie van de Wieringermeer, juni 1954. Zwolle.

MOLEN, W. H. VAN DER, 1957: The exchangeable cations in soils flooded with sea water. De inundaties gedurende 1944–1945 en hun gevolgen voor de landbouw, deel 9 *(The 1944–1945 inundations and their effect on agriculture, part 9)*. Versl. Landbouwk. Onderz., no. 63. 17.

MOLEN, W. H. VAN DER & W. H. SIEBEN, 1955: Over de landbouwkundige betekenis en de kartering van de kwel in de Noordoostpolder *(The occurrence of seepage in the reclaimed polders in the former Zuiderzee and its consequence for agriculture)*. Van Zee tot Land, no. 12. Zwolle.

MOORMANN, F. R., 1960: Acid sulphate soils (cat clays) of the tropics. State Secr. for Agr. Div. Research and Study in Agronomy, For. and Zootechn. Soil Service Publ., A pp. 12–28, III, Bhea-28. Saigon.

MOORMANN, F. R. & THÁI-CÔNG-TUNG, ca. 1960: Rapport sur la mission de reconnaissance au centre d'implantation de la région An-Xuyên-Ba-Xuyên (Caman) *(Report of the survey made of the central plot in the An-Xuyên – Ba-Xuyên region)*. Notes et rapports sur les conditions pédologiques du delta du Mekong *(Notes and reports on the pedological conditions of the Mekong Delta)*, pp. 3 –10 Secrétariat d'état à l'agriculture du Viêt-Nam, Saigon.

OBREJANU, GR. & B. LANCOVICI, 1956: Observations sur les sols de la région inondable du Danube *(Observations on the soils in the Danube area which are prone to flooding)*. Rapports VIe Congr. de la Science du Sol, Vol. E, pp. 647–653. Paris.

PHAM-HUU-ANH, F. R. MOORMANN & J. D. GOLDEN, 1961: Liming experiments on acid sulphate soils. Depart. of Rural Affairs, National Div. of Agr. Soils Service, Soil fertility section, Publ. no. III. Bheb, 58. Saigon.

PONS, L. J., 1956: Some aspects of the improvement of pyrites-containing old marine soils in the Netherlands. Rapports VIe Congr. Int. de la Science du Sol, Vol. B, pp. 727-734. Paris.

PONS, L. J., 1957: De geologie, de bodemvorming en waterstaatkundige ontwikkeling van het land van Maas en Waal en een gedeelte van het rijk van Nijmegen *(The geology, the soil formation and the development of drainage in the Maas and Waal conservancy areas and in a part of the Nijmegen area)*. Versl. Landbouwk. Onderz., no. 53. 11.

PONS, L. J., 1958: De fysische rijping van profielen met veen en venige lagen *(The physical ripening of profiles containing peat and peaty layers)*. Voorlopige wetenschappelijke mededeling no. 1, Stichting voor Bodemkartering.

PONS, L. J., 1960: Soil genesis and classification of reclaimed peat soils in connection with initial soil formation. Transact. 7th. Int. Congr. of Soil Science, Vol. 4, pp. 205–211. Madison (Wisc.).

PONS, L. J., 1960: Het voorkomen en de vorming van pyriet in diverse mariene afzettingen in Nederland en een verklaring van het ontstaan van het knipverschijnsel. *(The occurrence and formati on of pyrites in various marine deposits in the Netherlands and an explanation of the origin of the "knip" phenomenon)*. Voorlopige wetenschappelijke mededeling, no. 13, Stichting voor Bodemkartering.

PONS, L. J., 1961: De veengronden *(Peat soils)*. In: Bodemkunde; voordrachten gehouden op de B-cursus Bodemkunde sept. 1959, pp. 173–194. Ministerie van Landbouw & Visserij. The Hague.

PONS, L. J., 1963a: Pyrites as a factor controlling chemical "ripening" and formation of "cat clay", with special reference to the coastal plain of Surinam. Proc. Congr. Agr. Res. Guianas, Paramaribo, 1963. Bull. no. 82, Agr. Exp. Stat. Paramaribo.

PONS, L. J., H. M. YVEL & B. PARSAN, 1963b: Verslag van een bodemkundige excursie naar Brits Guyana, Oktober/November 1963 *(Report on a pedological excursion to British Guiana, October/November 1963)*. Rapport Dienst Bodemkartering. Paramaribo.

PONS, L. J. & A. J. WIGGERS, 1960: De Holocene wordingsgeschiedenis van Noordholland en het Zuiderzeegebied *(The Holocene genesis of Noordholland and the Zuiderzee area)*. De Stichting voor Bodemkartering Wageningen en de Direktie van de Wieringermeer, afd. Noordoostpolderwerken, Kampen. Reprint from: Tijdschr. Kon. Ned. Aardr. Gen., 76, pp. 104–152; 77, pp. 3–57.

POST, L. VON, 1926: Einige Aufgaben der regionalen Moorforschung *(Some examples of the investigation of marshy areas)*. Sver. geol. Unders. Arsbok C.

POSTMA, H., 1954: Hydrography of the Dutch Wadden sea. A study of the relations between water movement, the transport of suspended materials and the production of organic matter. Arch. Néerl. de Zoölogie, 10, pp. 405–512.

PUROKOSKI, P., 1958: Die Schwefelhaltigen Tonsedimente in dem Flachlandgebiet von Liminka im Lichte chemischer Forschung *(The sulphur-containing clay deposits in the Liminka flats from the viewpoint of chemical research)*. Agrogeologisia Julkaisuja, no. 70; Agrogeologische Publikationen, no. 70.

PUROKOSKI, P., 1959: Über die schwefelhaltigen Böden von der Küste Finnlands *(The sulphur-containing soils of the Finnish coast)*. Agrogeologisia Julkaisuja, no. 74; Agrogeol. Publ., no. 74.

SIEBEN, W. H., 1951: De ontwatering van de zavelgronden in de Noordoostpolder *(The drainage of the sandy clay soils in the North East Polder)*. Van Zee tot Land, no. 3. Zwolle.

SMITS, H., 1953: Over de inklinking van Oostelijk Flevoland *(The embankment and drainage of Eastern Flevoland)*. Directie Wieringermeer (Noordoostpolderwerken), Kampen.

SMITS, H., 1956: De inklinking van de Zuidplaspolder *(The embankment and drainage of the Zuidplaspolder)*. Flevo-Berichten, A, no. 2. Zwolle.

SMITS, H. & A. J. WIGGERS, 1959: Soil survey and land classification as applied to reclamation of sea bottom land in the Netherlands. Publ. no. 4, International Institute for Land Reclamation and Improvement. Wageningen.

SOIL SURVEY STAFF, SOIL CONSERVATION SERVICE, UNITED STATES DEPARTMENT OF AGRICULTURE, Aug. 1960: Soil classification, a comprehensive system. 7th Approximation. Washington.

SONNEVELD, F., 1954: Het slootkanteffect in het klei-op-veengebied in Zuidholland, with a summary *(The ditch bank effect in the province of South Holland, where the soil consists of clay underlain by peat)*. Boor en Spade, 7, pp. 187–195.

SONNEVELD, F., 1958: Bodemkartering en daarop afgestemde Landbouwkundige onderzoekingen in het land van Heusden en Altena *(Soil survey and attuned agricultural investigations in the land of Heusden and Altena)*. Versl. Landbouwk. Onderz., no. 64. 4.

SPEK, J. VAN DER, 1934: Bijdrage tot de kennis van zure gronden in het Nederlandse alluvium *(Contributions to the study of acid soils in the Netherlands alluvium)*. Versl. Landbouwk. Onderz., no. 40B, pp. 409–503.

SPEK, J. VAN DER, 1950: Katteklei *(Cat clay)*. Versl. Landbouwk. Onderz., no. 56. 2.

SPEK, J. VAN DER, 1952: Over het verdwijnen van koolzure kalk uit zeekleiafzettingen ten gevolge van de oxydatie van hierin aanwezige sulfaten *(The removal of calcium carbonate from marine clay deposits as a result of the oxidation of the presence of sulphates)*. Landbouwk. Tijdschr., 64, pp. 473–478.

STICHTING VOOR BODEMKARTERING, 1961: Bodemkaart van Nederland *(Soil map of the Netherlands)*, 1:200.000.

STRAATEN, L. M. J. U. VAN, 1954: Composition and structure of recent marine sediments in the Netherlands. Leidse Geol. Meded., 19, pp. 1–110.

TAN TJONG KIE, 1954: De rheologische eigenschappen van klei *(The rheological properties of clay)*.

TOMLINSEN, T. E., 1957a: Relationships between mangrove vegetation, soil texture and reaction of surface soil after empoldering saline swamps in Sierra Leone. Trop. Agr. Trinidad, 34, pp. 41–50.

TOMLINSEN, T. E., 1957b: Changes in a sulphide-containing mangrove soil on drying and their effect on the suitability of the soil for the growth of rice. Empire J. Exp. Agr., 25, pp. 108–118.

VERHOEVEN, B., 1952: Embankment and cultivation of marine foreland. Soil Science, 74, pp. 91–96.

VERHOEVEN, B., 1953: Over de zout- en vochthuishouding van geïnundeerde gronden *(The salt and moisture control of inundated soils)*. Versl. Landbouwk. Onderz., no. 59. 5. Also: Thesis Wageningen.

VERHOEVEN, B., 1954: Enkele opmerkingen over de groei van de schorren in de Brakman *(Some observations on the growth of the salt marshes in the recently reclaimed Brakman area)*. In: Langs gewonnen velden; facetten van Smeding's werk. Wageningen.

VERHOEVEN, B., 1963: On the calcium carbonate content of young marine sediments. Neth. Journ. Agr. Science, 10, 1, pp. 58–71. Also: Bull. no. 4, International Institute for Land Reclamation and Improvement. Wageningen.

VERHOOP, J. A. D., 1940: Chemische en microbiologische omzettingen van ijzersulfiden in de bodem *(Chemical and microbiological conversion of iron sulphides in the soil)*. Thesis Leiden.

WIGGERS, A. J., 1955: De wording van het Noordoostpoldergebied *(The genesis of the North East Polder area)*. Van Zee tot Land, no. 14. Zwolle.

WIJK, C. L. VAN, 1951: Soil survey of the tidal swamps of South Borneo in connection with the agricultural possibilities. Contr. Gen. Agr. Res. Sta., no. 123 (June 1951), pp. 1–49. Bogor Indonesia.

WIKLANDER, L., G. HALGREN & E. JONSSON, 1950: Studies on gyttja soils. III Rate of Sulphur oxidation. kgl. Lantbr. Högsk. Ann., 17, pp. 425–440.

ZONNEVELD, I. S., 1956: Physical ripening of fresh water tidal sediments (in the Biesbosch). Rapport VIe Congr. de la Science du Sol, Vol. B, pp. 281–290. Paris.

ZONNEVELD, I. S., 1958: Bodenbildung und Vegetation im alluvialen Gebiet (with a summary). Symposium für Pflanzensoziologie und Bodenkunde *(Soil formation and vegetation in alluvial areas. Symposium for plant sociology and soil science)*. Angewandte Pflanzensoziologie, 15. Stolzenau: Weser.

ZONNEVELD, I. S., 1959: Bodemvorming in alluviale gronden (in het bijzonder in verband met bodemclassificatie) *(Soil formation in alluvial soils (with particular reference to soil classification))*. Voorlopige wetenschappelijke mededelingen, no. 7, Stichting voor Bodemkartering.

ZONNEVELD, I. S., 1960: De Brabantse Biesbosch. Een studie van bodem en vegetatie van een zoetwatergetijdendelta. A. Engelse samenvatting met tekstfiguren en tabellen. B. Nederlandse tekst. C. Bijlagen *(The Brabant Biesbosch. A study of soil and vegetation of a fresh water tidal delta. A. English summary with text figures and tables. B. Dutch text. C. Appendices)*. Bodemkundige Studies, no. 4. Stichting Bodemkartering. Wageningen.

ZONNEVELD, I. S., 1961: De minerale alluviale gronden *(Mineral alluvial soil)*. In: Bodemkunde; voordrachten gehouden op de B-cursus Bodemkunde september 1959, pp. 194–218. Ministerie van Landbouw en Visserij. The Hague.

ZONNEVELD, I. S., 1963: Soil formation in deltaic areas. Appendix to the Proceedings of the Regional Symposium on Flood Control Reclamation, Utilization and Development of Deltaic areas, 2–9 July 1963, held at Bangkok. New York, 1963. 224 pp. United Nations Economic Commission for Asia and the Far East (ECAFE), Water Resources Series no. 25.

ZUIDERZEEWERKEN, 1957: Bodemkundig onderzoek *(Soil Survey)*. Driemaandelijks bericht betreffende de Zuiderzeewerken, 38, 4e kw., pp. 216–222.

ZUUR, A. J., 1932: Over de ontzilting van den bodem in den Andijker proefpolder *(The desalinization of the soil in the Andijk test polder)*. Meded. 2, Comm. v. Advies omtrent Landbouw-techn. Aangelegenheden betr. Proefpolder nabij Andijk, pp. 185–275.

ZUUR, A. J., 1936: Over de bodemgesteldheid van de Wieringermeer *(The nature of the soil in the Wieringermeer)*, The Hague.

ZUUR, A. J., 1938: Over de ontzilting van den bodem in de Wieringermeer. Een studie over de zout- en waterbeweging in jonge poldergronden *(The desalinization of the soil of the Wieringermeer*. The Hague.

ZUUR, A. J., 1939: Bodemvorming in Nederland uit jonge zeeafzettingen *(Soil formation from young marine deposits in the Netherlands)*. Tijdschr. Kon. Ned. Aard. Gen., 56, pp. 62–80.

ZUUR, A. J., 1951: Onstaan en aard van de bodem van de Noordoostpolder *(Origin and nature of the soil in the North East Polder)*. Van Zee tot Land, no. 1. Zwolle.

ZUUR, A. J., 1960: Inpoldering in de delta's van Po en Nijl. (1) en (2) *(Impolderings in the deltas of Po and Nile)*. Land en Water, 4, pp. 208–216; 268–274.

ZUUR, A. J., 1961: Initiële bodemvorming bij mariene gronden *(Initial soil formation in marine soils)* Meded. van de Landbouw hogeschool en de Opzoekingsstations van de Staat te Gent, 26. No. 1