Soil formation, microstructure and physical behaviour of Late Weichselian and Holocene Rhine deposits in the Netherlands

ONTVANGEN

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Rienk Miedema

Soil formation, microstructure and physical behaviour of Late Weichselian and Holocene Rhine deposits in the Netherlands.

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ter verkrijging van de graad van
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in het openbaar te verdedigen
op maandag 12 oktober 1987
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Cover photo: Coarse clods after ploughing of medium-textured imperfectly drained Late Weichselian soil near Aaldonk (North Limburg).

Opgedragen aan de voormalige doctoraalstudenten:

Gert du Bois, Jan Broekhuizen, Adri van Dis, Gijs Druijf, Eibert van Engelen, Gerrit Epema, Piet van der Gaauw, Simon de Groot, Tjisse Hiemstra, Jan Jacobs, Mustafa Kilig, Jan Klein-Hesselink, Walter Koppe, Cees de Kreij, Ben Lohues, Peter Martens, Fok van Oort, Henk van Reuler, Jan Robben, Nanno Vlaanderen, Jan Versluis en Jetty Wijntje-Bruggeman.

Zij zorgden voor de gegevens (ca. 5 jaar onderzoek) waarop dit proefschrift is gebaseerd.

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ERRATA

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A p223 = p227
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p IV : 4th line from the top: une = un
p IX : Fig. 37 E = F and F = E
p XI : Fig. 56 E = F and F = E
p XI : Fig. 58 p223 = p224
p XI : Fig. 59 p224 = p225
p XI : Fig. 60 p225 = p226

hroughout the English text scales of soil surveys have been wrongly indicated
.g. 1 : 10.000 should be 1 : 10,000 or 1 : 10 000.

1 : 2nd line from the bottom : consistency = consistence
4 : 5th line from the top : Lower = Low
5 : 4th line from the bottom : coarse, sandy = coarse sandy
8 : 5th line from the bottom : study of the = study the
0 : In Fig. 2 the NE corner should have been hatched as Pleistocene sand landscape.
2 : drawing 3B : black area = closest vertical hatching
2 : subscript B : corss section = cross section
3 : drawing 4D : black area Roode Wetering = closest vertical hatching
3 : drawing 4D : black border between peat and peaty clay = + c +
3 : drawing 4E : cross hatched part = closest vertical hatching
) : 5th line from the bottom : samples expressed = samples is expressed
/21 : Figs. 6 and 7: ordinates should read %>μm and %<μm
: 2nd line from the top : dted = dated
: 16th line from the bottom : absenc = absence
: 2nd line from the bottom : Lower = Low
5. 15 (p43), 17 (p46), 19 (p49), 21 (p51), 23 (p54), 25 (p56), 27 (p59):
Legend C : cm = dm

p58 : 9th line from the top : 0.5 to 1.5 below = 0.5 to 1.5 m below

p61 : 6th line from the bottom : a deeper, Late = a Late

p68 : 4th line from the bottom : (section 3.1.5) = (section 3.1.6)

p83 : Subscript C : mottle = mottled

p92 : last line:
Hiemstra (1979 and Van Oort, 1980) = Hiemstra (1979) and Van Oort (1980)

p99 : last line : from to = from

p110 : 2nd line from the bottom : wether = whether

p127 : 2nd line from the bottom : points = point

p138 : 6th line from the bottom : influences = influence

p139 : 5th line from the bottom : pF J 1.0 = pF $\gg$ 1.0

p146 : pF0 on the abscissa of Figs. 43 and 44 should be placed at the intersection with the ordinate. E, H and K on the abscissa of Fig. 43 indicate the correct pF value (around pF2) of the moisture content at field sampling.

p147 : Fig. 46 caption : μm = μm

p148 : 7th line from the bottom : reflect = reflects

p149 : 4th line from the top : as = are

p161 : 7th line from the bottom: favour = favours

p161 : 3rd line from the bottom : expierence = experience

p165 : 5th line above Table : carefully to = carefully remoistened to

p167 : 3rd line from the top : for at = for

p167 : 9th line from the top : of of = of

p167 : 13th line from the top : less is = less variation is

p181 : subscript E = F and F = E

p187 : 17th line from the top : origical = original

p187 : 9th line from the bottom : consistency = consistence

p199 : 7th line from the top : is = are

p203 : 16th line from the top : conductivity is = conductivity of Late Weichselian soils is

p203 : insert between line 16 and 17 from the top:
lower than that of Holocene soils; the levels of hydraulic conductivity

p203 : 17th line from the top : recorded are = recorded in Late Weichselian soils are

p207 : 8th line from the top : ui = uit

p207 : 10th line from the bottom : regelmatige = regelmatig

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STELLINGEN

1. De verschillen in korrelgrootteverdeling en in hoeveelheid, kwaliteit en verdeling van de organische stof veroorzaken een groot deel van de verschillen in fysische eigenschappen van Rijnafzettingen uit het Laat Weichselien en uit het Holoceen.

   Dit proefschrift.

2. Bodemvorming (met name in het Laat Weichselien) is verantwoordelijk voor de verschillen in chemische eigenschappen, in kleimineralogie en in bodemclassificatie van Rijnafzettingen uit het Laat Weichselien en uit het Holoceen. De zeer dichte, starre microstructuur van de rivierafzettingen uit het Laat Weichselien is eveneens het gevolg van periglaciale bodemvorming.

   Dit proefschrift.

3. Holocene Nederlandse rivierafzettingen zullen nooit zo dicht worden als rivierafzettingen uit het Laat Weichselien tenzij er een nieuwe ijstijd komt.

   Dit proefschrift.

4. De regeneratie van de porositeit van verdichte gronden of bodemlagen door biologische aktiviteit is kwalitatief verre te prefereren boven een regeneratie door mechanische ingrepen. Bij de bedrijfsvoering dient instandhouding of bevordering van de bodemmacro- en mesofauna te worden nagestreefd.

   M.J. Kooistra, J. Bouma, O.H. Boersma and A. Jager (1984): Physical and morphological characterization of undisturbed and disturbed ploughpans in a sandy loam soil.
   Soil and Tillage Research: 405-417.

5. Dat een proefschrift (ook dit) gewoonlijk slechts één auteur heeft, suggereert ten onrechte dat het een éénpersoons werkstuk is.

6. De opvatting, dat de bodemvorming in loess in Nederland alleen optreedt in het Holoceen, is onjuist.

   H.J. Mücher (1986): Aspects of loess and loess derived slope deposits: an experimental and micromorphological approach.
   Doctoral thesis University of Amsterdam; Nederlandse Geografische Studies, no. 23.

7. Grondmonsters dienen bewaard te worden bij een vochtgehalte binnen de grenzen van de natuurlijk ondervonden fluctuaties.

D. Tessier (1984): Etude expérimentale de l'organisation des materiaux argileux. Hydratation, gonflement et structuration au cours de la dessiccation et de la réhumectation.
Thèse Docteur ès Sciences, Université de Paris VII.

8. De (micro)morfologie is onontbeerlijk voor het ontwikkelen van meetmethoden en het begrijpen van de uitkomsten van bodemfysische metingen en het rheologisch gedrag van gronden.

D. Lafeber (1964): Soil fabric and soil mechanics.
In: A. Jongerius (Ed.): Soil Micromorphology: 351-360.

J. Bouma (1984): Using soil morphology to develop measurement methods and simulation techniques for water movement in heavy clay soils.
In: J. Bouma and P.A.C. Raats (Eds.): Water and solute movement in heavy clay soils. ILRI publication 37: 298-315.

9. Dat klei-inspoelingshuidjes macromorfologisch waarneembaar zouden zijn, zoals in veel profielbeschrijvingen staat vermeld, wordt bij nader micromorfologisch onderzoek in veel gevallen gelogenstraft.

10. Het niet inpolderen van overrijpe kwelders is strijdig met de eeuwenlange historische tradities die Nederland groot hebben gemaakt.

11. De psychiatrische behandelingsmethode met electroshocks dient te worden afgeschaft. Psychotherapie is op zich al schokkend genoeg.

12. Als in een rijksbegroting de defensie uitgaven structureel stijgen en er bezuinigd wordt op onderwijs, cultuur en volksgezondheid dan pleit dat niet voor de aan de mens toegeschreven verstandelijke vermogens.

13. Bij het uitschrijven van een Elfstedentocht gaat de Vereniging "De Friesche Elf Steden" niet over één nacht ijs, ondanks aandrang daartoe.

14. De sociale controle op alternatieve samenlevingsvormen kan er in de toekomst toe leiden dat huizen zonder voordeur worden gebouwd.

Stellingen behorend bij het proefschrift:

Soil formation, microstructure and physical behaviour of Late Weichselian and Holocene Rhine deposits in the Netherlands.
Rienk Miedema, 12 oktober 1987, Wageningen.

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ABSTRACT

Miedema, R. (1987). Soil formation, microstructure and physical behaviour of Late Weichselian and Holocene Rhine deposits in the Netherlands. Doctoral thesis, Department of Soil Science and Geology, Agricultural University, Wageningen, (XIV)+ 339 p. 60 figs. 78 tables, 224 refs, 5 appendices, Dutch summary.

Dutch Late Weichselian braided river deposits and Holocene meandering river deposits of the Rhine have been studied and compared. Cross sections demonstrate the lateral and vertical variations of the Late Weichselian sediments. Soil mapping of these deposits, even on a very detailed scale, proves very difficult. Best results have been obtained with a legend based on hydrology enabling the distinction of topo-hydrosequences of well drained brown soils, imperfectly drained mottled soils and poorly drained grey soils.

Advanced soil formation and notably the dramatic processes in the Late Weichselian period (decalcification, clay illuviation, pseudogleying, periglacial formation of a highly reoriented, very dense microstructure) have caused clay mineralogical, chemical and physical changes in the Late Weichselian soils.

The well drained and imperfectly drained Late Weichselian soils have an argillic horizon (Alfisols, Luvisols), occasionally with very low base saturation (Ultisols, Acrisols) and with strong subsequent pseudogleying in the imperfectly drained soils. The Holocene soils demonstrate decalcification and biogenic homogenization as well as some gleying according to their drainage position. These soils are classified as Inceptisols (Cambisols), occasionally as Mollisols (Phaeozems).

Less favourable physical characteristics and behaviour (soil strength, structure stability and tillage behaviour) of the Late Weichselian soils and soil material is quantitatively documented. Differences with the Holocene soils and soil material are statistically highly significant and are caused by differences in texture, content, quality and distribution of organic matter and the highly reoriented, very dense microstructure.

Use as permanent grassland or ley in the crop rotation is recommended to increase levels of biological activity. This seems the only remedy for the imperfectly and poorly drained Late Weichselian soils that are compacted by natural soil forming processes not counteracted by biological activity. Very recently improved drainage of large areas of Late Weichselian imperfectly drained soils has increased the saturated hydraulic conductivity to non-critical levels through increased earthworm activity to some metres depth.

Free descriptors: Late Weichselian braided river deposits, Holocene meandering river deposits, soil formation, Luvisols-Alfisols, Acrisols-Ultisols, Cambisols-Inceptisols, Phaeozems-Mollisols, micromorphology, clay mineralogy, physical characteristics, soil strength, structure stability, soil tillage.

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1. INTRODUCTION AND AIM OF THE INVESTIGATION

Koenigs (1949) was the first to recognize Late Weichselian Rhine deposits in the area of Azewijn in the eastern part of the Netherlands. In that area these deposits are extensively covered by Holocene fluvial deposits of varying thickness. Koenigs distinguished between these deposits on the basis of a number of differences in soil properties. Schelling (1951) and Pons (1957) mentioned essentially similar differences for their research areas where Late Weichselian Rhine deposits occur at the surface. These differences have also been described in the books accompanying the 1:400.000 and 1:200.000 soil surveys of the Netherlands (Edelman, 1950 and Soil Survey Institute, 1965 respectively). In recent soil survey reports accompanying map sheets of the systematic 1:50.000 soil survey these differences are again quoted in a somewhat extended form (Soil Survey Institute, 1970; 1972; 1975; 1976; 1979; 1983).

Late Weichselian deposits of loamy sand to clay differ from Holocene ones in the following aspects:

a. The particle size distribution of Late Weichselian and Holocene deposits is essentially similar, except for a coarser sand fraction in the Late Weichselian deposits.

b. Late Weichselian deposits have very low organic matter contents and are non-calcareous in otherwise comparable situations.

c. The colour of the well drained Late Weichselian deposits is more reddish (7.5 YR or redder) and has higher chromas. In imperfectly drained and poorly drained situations the colour of the deferrated zones is more light grey to whitish (higher values) with very pronounced colour contrasts and with more iron and manganese mottling and concretions of differing colours. Holocene soils generally have 10 YR colours in well- drained situations, tending to 2.5 Y and 5 Y colours in imperfectly and poorly drained situations.

d. Late Weichselian deposits have a more firm consistency, a drier habitus and a lower hydraulic conductivity than the Holocene deposits

in comparable situations.

e. Late Weichselian deposits have a lower structure stability.

f. Soil tillage of Late Weichselian deposits is more difficult. The moisture content range to obtain good tillage results is narrower in situations of comparable textures. When wet, these Late Weichselian soils become sticky and puddled and in dry conditions they get very hard, coarse clods. (Cover photo).

g. Late Weichselian deposits have a lower linear extensibility, specific surface area, base saturation and pH than Holocene deposits.

h. Late Weichselian deposits have a more advanced soil formation than Holocene deposits.

Farmers distinguish between the two materials and agree with the differences pertaining to soil management and tillage for arable cropping (Koenigs, 1949 and personal experience).

The above-mentioned differences are qualitative rather than quantitative. They have been attributed to weathering (Edelman, 1950), weathering and soil formation (Schelling, 1951) or to a difference in properties of the parent material rather than a difference in time of sedimentation or soil formation (Soil Survey Institute, 1975; 1979). Poelman (Soil Survey Institute, 1975; 1979) assumes that the clay fraction is different and contains more quartz. The reasons for the mentioned differences are still largely unknown and, quoting Schelling (1951): "It is difficult to explain the differences in behaviour without extensive chemical and clay mineralogical investigations". The aim of the investigation reported here was to determine the differences in a quantitative way and on the basis of detailed field investigations followed by micromorphological, chemical, clay mineralogical and physical analyses to put forward explanations for them.The consequences of these findings for land utilization types, and the possibilities for ameliorative measures will be discussed.

2. GEOLOGY, GEOMORPHOLOGY AND SOIL CONDITIONS

2.1. GEOLOGICAL SETTING

The Quaternary geology of the Meuse Valley and of the Lower Rhine Valley has been summarized by De Jong (1967, 1971), Braun *et al*, (1968), Quitzow (1974), Zonneveld (1977), Zagwijn (1975), Zagwijn and Van Staalduinen (1975), Van der Meene (1977) and Van der Meene and Zagwijn (1978). A general soil landscape map of the area is presented in Fig. 1. (Backflap).

In the east and south, the Lower Rhine Valley is surrounded by Paleozoic highlands. These highlands belong to the German Shale Plateau ('Schiefergebirge'). During Late Pliocene and Pleistocene times this plateau underwent severe tectonic activity and uplift. Incision of the Rhine, situated in a tectonically lowered block, kept pace with uplift; this resulted in the deep, narrow Middle Rhine Valley.

This uplift and incision caused considerable fluvial deposition in the Lower Rhine Valley which extends from Bonn (where the Rhine leaves the Shale Plateau and widens considerably) to the Dutch North Sea coast.

Tectonic history, and the Pleistocene sea-level changes shaped the Middle and Lower Rhine Valley. Changes in river regime and climate were responsible for changes in the kind of deposits, while incision of the Rhine in its own sediments resulted in a sequence of terraces, which are very clear along the Middle Rhine Valley and along the eastern border in the extreme southern part of the Lower Rhine Valley. The situation is more complicated along the western border of the Lower Rhine Valley, where, due to blockfaulting, younger deposits may be found as lower terraces or overlying older terraces. Younger deposits may also overly older ones in areas where the river gradient becomes less steep e.g. due to the sea-level rise in the Holocene and where subsidence plays a major role, as in the coastal areas of The Netherlands. As a result, there are several terrace crossings between Bonn and the North Sea coast. It is difficult to distinguish subsequent deposits

in the area close to a terrace crossing.

Three groups of terraces have been distinguished with respect to the Holocene flood plain of Meuse and Rhine: the High or Main Terrace, the Middle Terrace and the Low Terrace. Each of these groups has been further subdivided, but here only the subdivision of the Lower Terrace will be discussed in more detail.

Main Terrace

This comprises the Kiezeloolite Formation (Upper Tertiary to Pretiglian glacial), the Tegelen Formation (Tiglian glacial), the formations of Kedichem (Eburonian glacial and Waalian interglacial, Menapian glacial) and Sterksel (Menapian glacial and Cromerian complex of glacial and interglacial periods). The Main Terrace is found at the surface west of the Central Graben in the Netherlands, and at the surface or below a loess cover in South Limburg and adjoining Germany. Zagwijn and Van Staalduinen (1975) recorded its occurrence below younger strata. Relatively narrow strips are found along the Middle Rhine and along the eastern margin of the Lower Rhine Valley.

Middle Terrace

This comprises the Formations of Veghel (River Meuse) and Urk (River Rhine) and was formed during the Cromerian (glacial and interglacial), Elsterian (glacial), Holsteinian (interglacial) and Saalian (glacial). This terrace is normally covered by several metres of loess or coversand and occurs at a lower elevation adjacent to the Main Terrace. In the south and east the Middle Terrace consists of narrow strips, but it is more extensive in the western part of the Lower Rhine Valley. It is encountered at shallow depths on the Peel Horst, and in South and Middle Limburg in the Netherlands, and in adjacent Germany. Zagwijn and Van Staalduinen (1975) recorded its occurrence below younger strata.

Low Terrace

This comprises the Kreftenheye Formation, deposited by the rivers Rhine and Meuse during the Saalian glacial, the Eemian interglacial and the Weichselian glacial periods. Because the Saalian and Weichselian glacial periods had a major impact on the shaping of the study area, the changes in environment from the Saale glaciation onwards will be discussed in more detail.

Saalian period

During the maximum extent of the Saale glaciation, tongues from the mainland

ice body protruded southward into the Lower Rhine Valley. Such a tongue was found in the tongue basin of Valburg, bordered by the ice-pushed ridges of the Southern Veluwe and of Nijmegen-Kleve, which were then connected (Thomé, 1958, 1959; Verbraeck, 1975). Similar tonguebasins have been found near Kranenburg, Xanten, Moers and Düsseldorf and, further west, near Wageningen, Amsterdam and in Flevoland. The ice tongue from Düsseldorf forced the Rhine to abandon its northern branch and follow a more western course as an ice-marginal valley from Neusz through Viersen, Wachtendonk, Geldern, Goch, Ottersum, Gennep and Heumen. At Gennep, it joined with the Meuse. After the retreat of the land ice, the ice-pushed ridges of the Düsseldorf tongue basin were fully eroded and those of Moers strongly diminished and fragmented. Not until the end of the Saalian did the Rhine leave the ice-marginal valley to resume its northern course, which it kept during the Eemian interglacial and the beginning of the Weichselian glacial period. (Zagwijn, 1975; Zagwijn and Van Staalduinen, 1975; Van der Meene, 1977, 1979).

Weichselian period

In the Middle Weichselian, the Rhine curved north of the ice-pushed ridge of Montferland-Elten and flowed westwards into the former tongue basin of Valburg. In the Late Weichselian (Van der Meene, 1977), or possibly earlier (Verbraeck, 1985) the Rhine broke through the ice-pushed ridge of Nijmegen-Kleve-Elten-Montferland and created the gap known as 'Gelderse Poort' through which it flows at present. This change of course fossilized the former northern and southern branches, which functioned until the Late Weichselian as discharge outlets at extreme water levels.

The southern branch

Downcutting in the southern branch formed the distinct Middle Terrace of Krefeld (Thomé, 1958, 1959) and Late Weichselian Low Terrace deposits occur in the broad valleys. The coarse-grained Low Terrace ends with a finer-textured deposit, which is found at the surface. The Low Terrace can be traced to the Dutch North Sea coast, but from Nijmegen westward it is covered by Holocene deposits (Pons, 1954, 1957).

The northern branch

Middle Terrace deposits are not known from the northern Rhine branch, but Low Terrace deposits are extensive and similar to those in the southern branch.

The central branch

In the central branch, Low Terrace deposits are found from Millingen (Germany) upstream. The terrace crossing with the Holocene deposits is further east in the central branch than in the northern and southern branches. In Fig.1 the soils of the Low Terrace have been subdivided into three hydrological classes: well drained, imperfectly drained, and poorly drained, reflecting conditions experienced after deposition, as will be explained later (chapter 3).

Stratigraphy of the Low Terrace

Subdividion of the Low Terrace varies. In German literature, two main units are recognized (Paas, 1960, 1961, 1977; Steeger, 1952, 1954; Quitzow, 1956, 1974; Brunnacker, 1978; Thoste, 1974). This subdivision is based on the Allerød-time volcanic eruption of the Laacher See (Frechen, 1959) which brought pumice with the indicator mineral hauyn into the atmosphere. Pre-Allerød deposits (without pumice) belong to the Older Low Terrace, while Allerød and Post-Allerød deposits contain pumice and belong to the Younger Low Terrace. Within the Younger Low Terrace, Thoste (1974) recognized a younger 'degeneration' phase.

In the Netherlands, six deposits are recognized in the Kreftenheye Formation (Van der Meene and Verbraeck, 1975; Van der Meene, 1977; Van der Meene and Zagwijn, 1978; Verbraeck, 1985) i.e.

Kreftenheye 6: Late Weichselian and locally slightly younger pumice-containing deposits in erosion valleys of older Kreftenheye deposits,

Kreftenheye 5: Deposits in the northern and southern Rhine branches after abandonment of these branches

Kreftenheye 4: Early Weichselian deposits in the former northern Rhine branch

Kreftenheye 3: Eemian deposits

Kreftenheye 2: Deposits in glacial basins after melting of the ice

Kreftenheye 1: Deposits in the southern Rhine branch in front of the Saalian ice.

Wind erosion in the periodically dry Late Weichselian river floodplain resulted in coarse, sandy, river dunes. These dunes were initially formed during the Late Weichselian, but formation continued in the Holocene.

Surrounding Pleistocene deposits include coversands, melt-water and solifluction deposits, and basal till. These deposits are indicated in Fig. 1.

The Holocene floodplain

This floodplain has been subdivided into seven units by Brunnacker (1978). He distinguished 2 Old Holocene, 3 Middle Holocene, and 2 Young Holocene sedimentation periods. In the Netherlands, the Holocene Betuwe Formation has been subdivided into deposits Gorkum 1 through 4 and Tiel 0 through 3 (Soil Survey Institute, 1981). Havinga (1969) and Havinga and Op 't Hof (1975, 1984) identified four main phases of Holocene river sedimentation in the Betuwe area. In Fig. 1. Holocene deposits have been subdivided physiographically into levees and backswamps.

2.2. RIVER REGIMES DURING THE LATE WEICHSELIAN AND THE HOLOCENE

The two main types of river regimes are braided and meandering. Doeglas (1951, 1973) has summarized conditions and sediment characteristics of these regimes. The *braided river regime* is bound to conditions of intermittent discharge with very large differences between maximum and minimum discharge. Such conditions occurred during the stadials of the Weichselian glacial period. Vegetation was virtually absent, the soil permanently frozen and precipitation mainly in the form of snow. In the short summer period the snow melted but water could not penetrate into the frozen subsoil. Large masses of water, heavily loaded with weathering debris, accumulated in the river. After the short summer period, supply of water and sediment came to an end and the river bed went dry. In such conditions the river consists of a system of small and medium sized shallow water courses which branch and recombine, thus forming an anastomosing system. During the high summer discharges, transporting power is high, and gravel bars and sand bars form, separated by shallow gullies. During the winter, the whole floodplain is dry and wind erosion may lift sandy material from the floodplain and create river dunes.

The *meandering river regime* has a more permanent discharge, which, however, may vary considerably. The more regular discharge comes into existence when rainfall is intercepted by vegetation, infiltrates into the soil, and joins the groundwater before being discharged into the river. This situation is typical for interglacial periods, but may also occur during interstadials. The river is partly supplied with water by the groundwater, and part of the

sediment load is due to colluviation and to erosion of the floodplain. The river occupies a single bed, which meanders through the floodplain, which has a low gradient. The river may change its course by meander cut off and by breaking into backswamp areas (crevasse). The meandering river is characterized by point bar deposits, levees and backswamps.

The Low Terrace was deposited by a braided river system (Pons, 1954, 1957; Van der Meene, 1977). This is illustrated by former gully systems, as indicated by Pons (1957) and on recent soil maps 1:50.000 by the Dutch Soil Survey Institute and the Geological Survey of Germany.

The Holocene sediments were deposited by a meandering system: levees, backswamps and associated deposits are common features in these sediments.

The gradients of the Late Pleistocene and Holocene systems are very different. According to Pons (1954, 1957), the gradient of the Low Terrace is approximately 30 cm/km and that of the Holocene deposits approximately 10 cm/km. This difference in gradient is one of the explanations for the terrace crossing in the Nijmegen-Azewijn traject. West of this line, the Late Weichselian deposits are covered by Holocene deposits. A study done by the present author on detailed altitude maps of the Low Terrace deposits confirms the gradient given by Pons.

The transition of a braided system to a meandering one goes through intermediate forms. Generally, the major part of the shallow gullies of the braided system lose their function, fossilize and become silted up, while a few of the deeper gullies deepen and start meandering. Such gullies may show weakly expressed levees. In the present author's opinion, however, the main gullies of the former southern and northern branches of the Rhine are erosive rather than sedimentary in character, and levees are generally absent. This will be elaborated in section 2.7.

2.3 DATING OF DEPOSITS OF THE LOW TERRACE AND THE HOLOCENE FLOODPLAIN

The various deposits have to be dated to study of the impact of differing climatic conditions and time on soil formation in these deposits. Zonneveld (1973) describes various methods that can be successfully used. Palynology (pollen analysis) has given an insight in vegetation successions during the Pleistocene and Holocene. Results have been summarized by Zagwijn and Van

Staalduinen (1975), Van der Hammen *et al.* (1967) and Zagwijn and Doppert (1978). The biostratigraphy obtained through palynology has been linked to C^{14} determinations of absolute age for the period up to approximately 70.000 years before present. Vegetation studies offer an insight into climatic conditions, notably summer temperature. Features such as frost cracks, cryoturbation, gelifluction and desert pavements give an indication of winter temperatures. The combination of palynological, radiocarbon and morphological data allowed a detailed bio-chronostratigraphy to be constructed for the Weichselian and the Holocene. The methods described above have long been used to date Weichselian and Holocene fluvial deposits (Koenigs, 1949; Schelling, 1951; Pons, 1957; Von der Brelie and Rein, 1956; Teunissen and Van Oorschot, 1967; Paas and Teunissen, 1978; Urban, 1978, 1979; Teunissen and De Man, 1981). The use of palynology is not always feasible. To contain pollen, the sediment must have been preserved in anaerobic conditions. In many mineral soils this is not the case, and one will have to use peat or peaty deposits in former gullies or backswamps. Extrapolation of such data to nearby mineral sediments may be difficult because peat growth is not always synchronous with the termination of active sedimentation.

In other cases, lithostratigraphic data may be used to separate subsequent deposits. Such data include grain-size distribution, gravel composition, and heavy mineral composition. (Zonneveld, 1977; Zagwijn and Van Staalduinen, 1975). These methods have been successfully used to separate several Rhine terraces, as indicated before for the subdivision of the Low Terrace with the aid of pumice.

In tectonically stable areas, geomorphology, often combined with the previously mentioned methods, may provide determinations of relative age (Brunnacker, 1978). Other occasional stratigraphic markers include the Usselo paleosol of Allerød age, which is scarce in the fluvial area, and the occurrence of ancient dung beetle burrows. The latter are frequently encountered in Late Weichselian fluvial sand deposits and are mainly of early Preboreal age but fossil remains of these beetles are also known from the Late Weichselian interstadial periods (Brussaard, 1985).

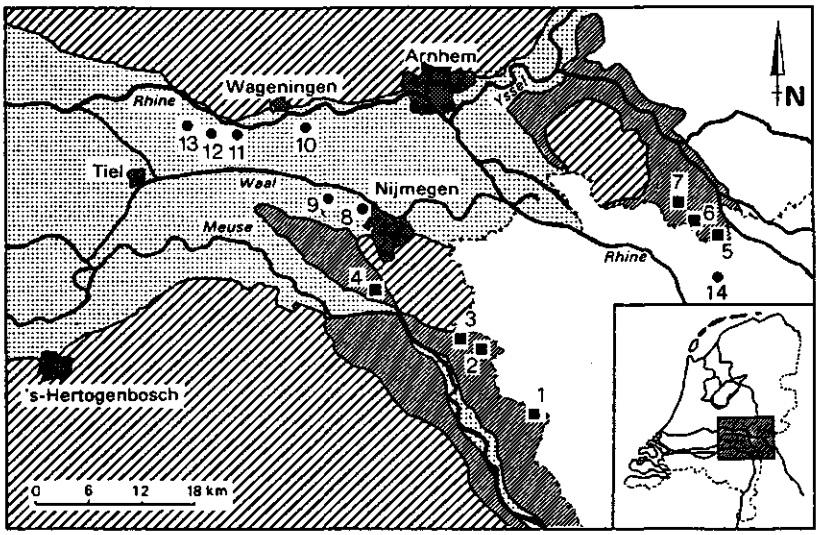
In Holocene sediments, archeological data may provide datable stratigraphic boundaries (Pons, 1957; Havinga, 1969; Brunnacker, 1978).

In the fluvial area, however, the scarcity of datable sites and sedimentological data makes exact dating of deposits very difficult,

especially in the vicinity of a terrace crossing, where landscape morphological criteria are of little help.

2.4 RESULTS OF FIELD INVESTIGATIONS

Fig. 2. Location of study areas and reference profiles.



Late Weichselian fluvial deposits and associated river dunes

Holocene fluvial deposits

Pleistocene sand landscape

■ location investigated areas

● and reference profiles

Area (Reference profile)

■ 1 = Siebengewald (A7)
2 = Ottersum (A6, A9)
3 = Milsbeek (A8)
4 = Heumen (A1, A2, A3, A12)
5 = Megchelen (A13, A16)
6 = Asbroek (A14, A5)
7 = Veldhunten (A4, A10, A11)

● 8 = Weurt (A18)
9 = Ewijk (A17)
10 = Randwijk (A19)
11 = Opheusden (A22)
12 = Kesteren (A20)
13 = Lienden (A21)
14 = Millingen (A16)

In the eastern part of the Dutch provinces of 'Gelderland' and 'Limburg' and in adjoining West Germany, Late Weichselian deposits occur at the surface (Fig. 1).

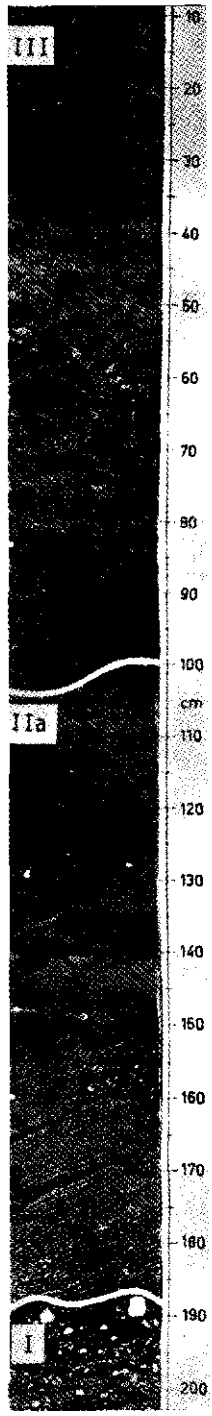
These areas have recently been mapped in the systematic 1:50.000 soil survey of the Netherlands (Soil Survey Institute, 1972, 1975, 1976, 1979, 1983). Detailed maps and cross sections of parts of this area were published by Koenigs (1949), Schelling (1951) and Pons (1957). In order to cover the variation in the Late Weichselian deposits, some areas were mapped in detail by the present author, and additional cross sections were prepared. Selection of reference profiles was based on these detailed studies. Locations of the studied areas and reference profiles are indicated in Fig. 2.

2.4.1. CROSS SECTIONS

The following cross sections were investigated (Van Engelen, 1975; Vlaanderen, 1976; Van Dis and Robben, 1978; Van der Gaauw, 1979; Broekhuizen and Epema, 1979). Their location is given on the soil maps (Figs. 15, 17, 19, 21, 23, 25, 27).

- *Siebengewald* cross section (Fig. 3A). This section starts at the German border close to the River Kendel, and runs SW. The total length is about 2800 m, and its average altitude is 16 m + NAP.
- *Ottersum* cross section (Fig. 3B). This section runs from the Reichswald, near the ice-pushed ridge of Nijmegen-Kleve, southwards. The total length is about 1500 m and its average altitude is 13 m + NAP.
- *Milsbeek* cross section (Fig. 3C). This section starts at the foot of the ice-pushed ridge of Nijmegen-Kleve and runs due south. Its total length is about 1100 m and its average altitude is 12 m + NAP.
- *Heumen* cross section (Fig. 3D). This section starts near a field road and runs NE to the Looistraat. Its total length is about 500 m and its average altitude is 9 m + NAP. This section was published by Miedema *et al.* (1978).
- *Megchelen* cross section (Fig. 4A). This section runs nearly NE-SW and connects two sections of the German border. Its total length is about 650 m, and its average altitude 16.5 m + NAP.
- *Asbroek* cross sections (Fig. 4B/4C). Section Asbroek I starts north of the

Fig. 5. The Late Weichselian sedimentation profile.



Munsterweg and runs south to the German border. This section is about 1000 m long. Section Asbroek II intersects the former perpendicularly, approximately half-way. This section is 700 m long. The surface in both sections is at an average altitude of 14.5 m + NAP.

- *Veldhunten* cross sections (Fig. 4D/4E). Veldhunten I runs SW from the village; Veldhunten II runs south from the village and proceeds SW after 450 m. Both sections are about 1100 m long and their surface is at an average altitude of 14 m + NAP.

Augering distances within the sections varied from 30-150 m, normally around 50 m. Average augering depth was 2.2 m.

The legend of all sections is based on texture and is given in Fig. 3. The Late Weichselian stratigraphy that can be concluded from the cross sections is described below and illustrated in Fig. 5.

Gravelly sand and sandy gravel

I The oldest deposits encountered in all sections are stratified very gravelly coarse sand and gravel. These very gravelly coarse sands have an undulating surface with many shallow and some deeper depressions; they are not always encountered within augering depth (e.g. Asbroek I). In the Siebengewald cross section this deposit locally passes with depth into sandy gravel. Composition and topography suggest a gravel bar system common to braided rivers.

Coarse sand

IIa The very gravelly coarse sands are

abruptly overlain by stratified coarse sands without gravel. The abrupt boundary suggests non- deposition or even an erosive contact. The stratified coarse sands are of variable thickness. In the Milsbeek, Megchelen and Asbroek I and II sections they are one to two metres thick and continuous, in the Siebengewald and Veldhunten I sections they are generally less than one metre thick and may be absent locally. The top of this deposit is undulating; the shallow depressions in its surface generally coincide with those in the underlying deposits, but the top of the sand may also be rather flat. The stratified sand deposit was exposed in the NE part of the Megchelen section. Its sedimentary structures point to a fluvial origin. In the Megchelen section, three filled channels are found within the sand body. Locally (Ottersum, Milsbeek and Veldhunten sections) wind action has built up high sand bodies.

Fine sand

IIb The stratified coarse sands are locally overlain by fine sand with clayey laminae. This deposit was not encountered in the Asbroek sections and occurs in isolated remains only in the Siebengewald, Megchelen and Veldhunten sections. It is transitional to the overlying finer deposits. If the deposit is present, the transition from sediment IIa to overlying finer textured deposits III is gradual. If the deposit is absent, the transition is abrupt and suggests wind and water erosion after deposition of the stratified coarse sands and the sands with clayey laminae. Locally, this erosion has removed most of deposit IIa, and sediments III directly overly deposit I. (Siebengewald section). In the latter case, overlying finer deposits may contain considerable amounts of gravel (10-30%, and locally more).
In the Milsbeek section, the top of deposit IIb is rather flat, without pronounced depressions.

Loam

III The overlying fine deposits have loamy sand to loam textures and are still of Late Weichselian age. The texture shows strong lateral variations which are related to pre-existing topography and to channel systems in the deposit itself. Textures are coarsest in topographically high spots, and finest in channel fills. As was indicated under IIb, some or the channels, especially in the Siebengewald section, may contain considerable amounts of gravel, testifying to the erosion of

the gravelly coarse deposit I. Channels which have their base higher in the deposit are devoid of such erosion products, and indicate passive infilling. It is difficult to distinguish the various depositional stages which are suggested by the different levels of channels. It is hardly possible to relate specific channel systems to nearby deposits, although there are distinct phases in the activity of the various channels, and some terminated their activity prior to others.

'Dril'

In the Asbroek II and Veldhunten I sections, the Late Weichselian III deposits contain a layer of 'dril'. In the Veldhunten section, the 'dril' is found within the III deposits, in the Asbroek section it is encountered between the III deposits and the underlying deposits IIa. 'Dril' is a not fully ripened, sticky material which often contains numerous decomposing plant remains and is locally strongly calcareous. Koenigs (1949) indicated this material in his cross sections A, B, and D and stated that locally it showed signs of cryoturbation.

Channel infillings

One or more deep major channels partly infilled with peat and peaty deposits are encountered in almost every section. These channels are cut into the underlying I deposits and may be filled with more than four metres of Late Weichselian and Holocene material. Most complete channel fill sequences are found in the Heumen, Megchelen and Veldhunten sections. The channel in the SW of the Megchelen section is part of a meander-shaped outer bend. In the bottom part of the channel, calcareous sand and clay are found, overlain by lime gyttja. In turn, the lime gyttja is overlain by peat, peaty clay and by clayey deposits. Palynological investigation indicated that all sediments in the infilling are of Holocene age (section 2.5). Apparently, this meander was abandoned after the Late Weichselian. In the Roode Wetering channel of the Veldhunten I section, the bottom fill consists of lime gyttja and clayey peat. The lime gyttja is of Late Weichselian (Allerød) age, and the transition to the Holocene is found in the overlying clayey peat. This channel was abandoned before the Allerød (section 2.5). The lime gyttja was not encountered in the Roode Wetering infilling of Veldhunten II. Infilling of the major channel of Heumen was of Holocene age (section 2.5). The major channel in the

Ottersum, Siebengewald and Asbroek sections was presumably also infilled in the Holocene. The thick peat in the Ottersum section has been partly excavated and the present infilling of that channel has been strongly reworked. In some sections (Veldhunten I) similarly deep channels are found without peaty deposits but infilled by thick (Late Weichselian) clayey deposits.

River dunes

River dunes are found in the N and E part of the Veldhunten section, in the south of the Milsbeek section, and north of the Langhorsterstraat in the Ottersum section. The riverdunes overly the III deposit but may also be on top of deposit II. The riverdunes of the Veldhunten section have a plaggen epipedon. Such an epipedon was also encountered on the relatively high loamy deposits in the SW of the Heumen section (Druijff, 1979). Plaggen epipedons were also indicated by Koenigs (1949) on the riverdunes of his section E (Veldhunten).

Holocene deposits

IV Holocene clayey deposits. A thin veneer of Holocene clayey deposits is found in the Asbroek and Veldhunten sections. This cover of Holocene material subdues the underlying topography. It is generally less than 40 cm thick, but may be considerably thicker in infilled channels. Holocene clay in channels is also encountered in the Siebengewald, Megchelen and Heumen sections, where it is not found outside such channels.

In section Veldhunten I, the boundary between Holocene and Late Weichselian deposits is locally indicated by an old vegetation horizon. This horizon was already indicated by Koenigs (1949) in his section B and D. The absence of pollen in this horizon precluded palynological dating (Van den Berg van Saparoea, pers. comm.). The texture of the Holocene deposits appears to be somewhat related to that of the underlying material. It is loamy in the Veldhunten II section, and clayloam to clay in the Veldhunten I section. In the Asbroek sections, textures vary and appear to be related to distance from the main channel (e.g. Asbroek II).

2.4.2. TEXTURE OF REFERENCE PROFILES

Grain-size frequency distributions of Late Weichselian and Holocene reference profiles are presented as cumulative curves on probability paper (Appendix A). This allows specification of the stratigraphic units recognized in the cross sections. Reference profiles are indicated in the cross sections (Fig. 3 and 4) and are listed in Table 1 together with additional Late Weichselian reference profiles and the Holocene non-calcareous and calcareous reference profiles.

Table 1. Reference profiles

Cross section	References profile	Additional Late Weichselian reference profiles	Holocene reference profiles non calcareous	calcareous
Siebengewald	Siebengewald (A7)			
Ottersum	Ottersum(A6), Aaldonk(A9)	Ven-Zelderheide (A15)		
Milsbeek	Milsbeek(A8)			
Heumen	Heumen I(A1), II(A2), III(A3)	Woezik(A12)		
Megchelen	Megchelen(A14)	Millingen (West Germany)(A16)		
Asbroek	Asbroek(A13)	Gendringen II(A5)		
Veldhunten	Azewijn IV(A11)	Azewijn I(A10), Gendringen I(A4)		
no cross sections available			Ewijk(A17)	Kesteren(A1)
			Weurt(A18)	Lienden(A4)
			Randwijk(A19)	Opheusden(A22)

Fig. 5 presents the characteristic Late Weichselian sedimentation profile (reference profile A15 - Ven Zelderheide).

DEPOSIT I is only encountered in the Siebengewald profile. It is a very coarse deposit with major fractions 420-850 µm and 105-420 µm . Fractions smaller than 105 µm are nearly absent. It is characteristically fluvial.

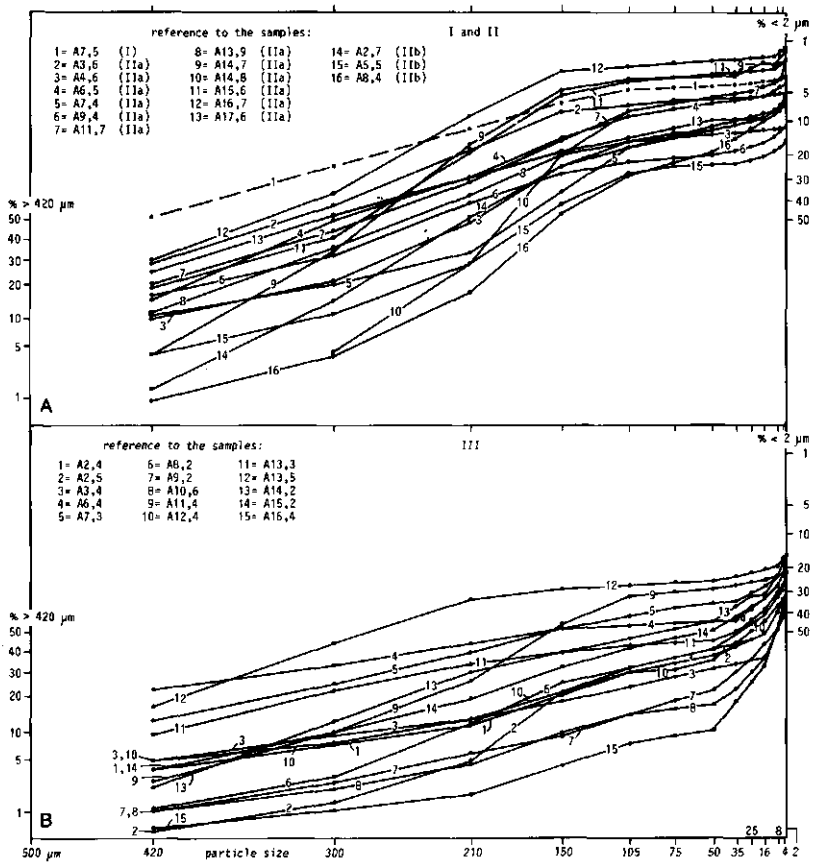
DEPOSIT IIa is found in all reference profiles. It has a fluvial characteristic with a main component between 105 and 420 µm , which locally may shift towards coarser fractions (Megchelen). A shift towards finer fractions (Siebengewald, 105-210 µm ; Milsbeek, 105-210 µm ; Megchelen 8, 105-300 µm) may indicate eolian reworking of the material or admixtures with fluvially reworked coversand.

DEPOSIT IIb is encountered in the Ottersum, Aaldonk, Milsbeek and Heumen profiles. The deposit is characterized by a mixture of fractions smaller than 50 µm and a deposit coarser than 105 µm . In most profiles, the deposit is clearly transitional to the overlying deposit III, in which sorting,

specially in the coarser fractions, is slightly worse.
DEPOSIT III is encountered in all Late Weichselian profiles and in the subsoil of the Ewijk profile. It is characterized by poor sorting (on the coarse side) and by a mixture of fractions coarser than 105 µm and finer than 50 µm. The bimodal character is most clearly expressed in Ottersum sample 4, where fractions between 50 and 150 µm are virtually absent. Sorting in the coarser fraction may be found, notably between 105 and 210 µm , and less frequently in the 150-300 µm fraction (Milsbeek).
DEPOSIT IV is the Holocene fluvial deposit which is encountered in the Holocene reference profiles (A17 through A22) and as topsoils (non-calcareous) in the reference profiles A3, A5, A10, A11 and A12. Its texture is transitional to the underlying Late Weichselian material especially in those profiles. In the Holocene reference profiles the absence of bimodality, a good sorting and the high silt content are characteristic attributes of the particle size frequency distributions. Sorting in the coarser fractions may be found notably between 105 and 210 µm and is clear in the few sandy subsoil samples. Of these samples Kesteren 6, Opheusden 7 and Weurt 6 have been designated IVa (Holocene sand deposit). All others belong to IVb (Holocene fine textured deposit).

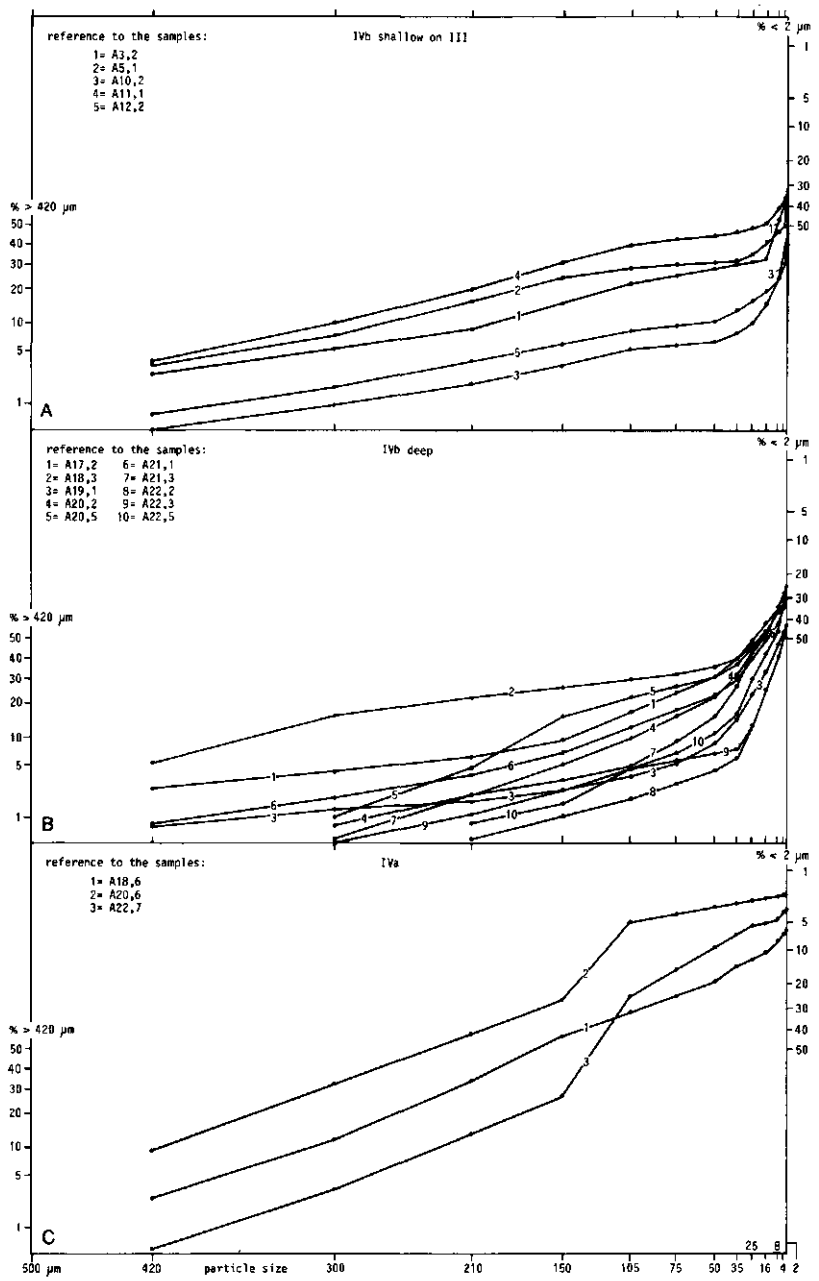
A selection of the particle size frequency distributions arranged according to deposit is presented in Figs. 6 and 7. The shapes of the curves of the Late Weichselian deposits I + II (Fig. 6A) and III (Fig. 6B) are more variable and distinctly different from these of the deep Holocene non calcareous and calcareous profiles (Fig. 7B). The intermediate position of the shallow Holocene deposits overlying Late Weichselian deposits is also evident (Fig. 7A). The sand subsoils of the Holocene deposits show a good sorting around 105-150 µm .The curves 5 and 10 in Fig. 7B are transitional to the underlying sand (Fig. 7C).
The sorting of the samples expressed by log $So=\frac{1}{2}\log Q3-\log Q1$ in which Q1 is the particle size with 25% smaller fractions and Q3 is the particle size with 75% smaller fractions. The median (Md50) separates equal weights of fractions (50%). Results are given in Table 2. (In cases where Q1 is <2 µm the value 2 µm has been taken for Q1).

Fig. 6. Selected particle size distribution curves of Late Weichselian deposits.



A. deposits I and II
B. deposit III

Fig. 7. Selected particle size distribution curves of Holocene deposits.



A. deposit IVb shallow on III
B. deposit IVb deep
C. deposit IVa

Table 2: Sorting and clay/fine silt ratio per deposit of samples of reference profiles.

Deposit	Name	Number of observations	Log So	σn	So	1/s [3] average	σ	1 [3] average	σ
II	Late Weichselian coarse	21	0.14	0.04	1.38	0.69	0.16	5.5	2.8
III	Late Weichselian fine	68	0.69	0.22	4.90	0.62	0.08	23.0	9.3
IV b	Holocene non calcareous fine	19[2])	0.64	0.21	4.37	0.58	0.05	31.4	10.8
IV b	Holocene calcareous fine	18	0.60	0.14	3.98	0.56	0.04	26.6	8.1
IV a	Holocene calcareous coarse	3[1])	0.13	0.05	1.35	0.69	0.12	4.2	1.9

[1]) Sample A18, 6 omitted in sorting calculation (log So 0.77;So=5.89)

[2]) Three samples with >50% clay (A12, 1 and 2 and A10,2) omitted from 1/s calculation (1/s average of these three samples 0.71 ± 0.06; 1 average of these three samples 56.6±3.8)

3) 1/s = clay(1)/fine silt(s) ratio

The values in Table 2 suggest that the Late Weichselian fine earth has a worse sorting and a higher clay/fine silt ratio because of a lack of fine silt. The variation between the data in each group is so large that this is not statistically reliable, however. Poelman (1966) also reported on the clay/fine silt ratio of fluvial clay soils.

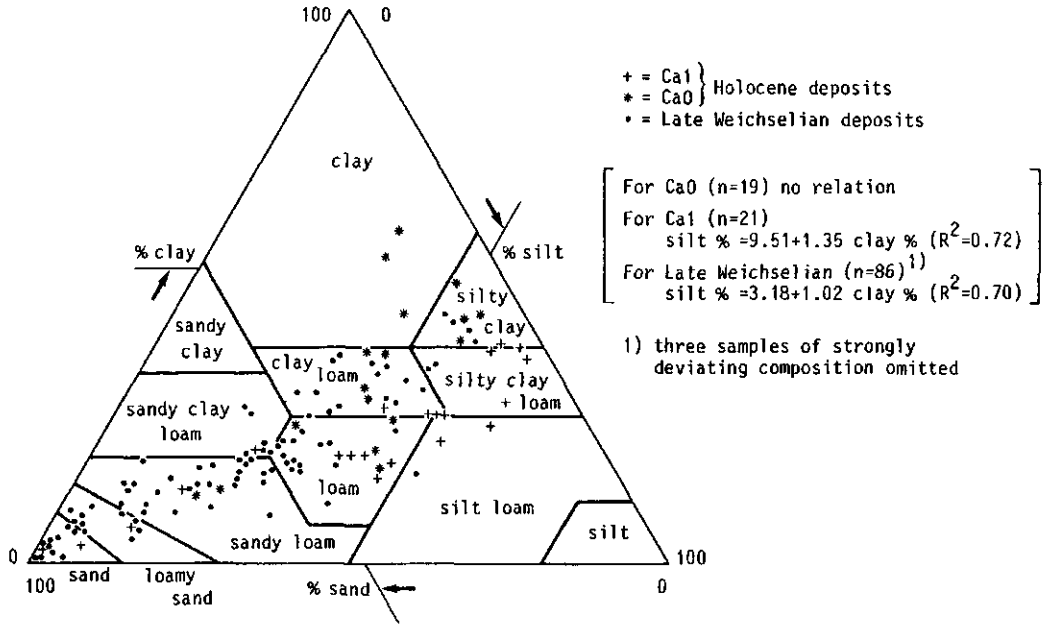


Fig. 8. Textural class of samples of reference profiles and the relation between clay content and silt content in Late Weichselian and calcareous Holocene deposits.

In Fig. 8 the texture class of the samples is given and it can be concluded that the Late Weichselian material has clearly less silt than the calcareous Holocene material, each group showing a good linear relationship. Holocene non-calcareous material does not show a good linear relation between clay and silt content. This is because of the intermediate position of the non-calcareous Holocene topsoils shallowly overlying Late Weichselian subsoils on one hand, and the transitional position to calcareous Holocene material on the other hand.

Fig. 9 shows the median of the relative sand fraction in relation to the clay content (Fig. 9A) and sand content (Fig. 9B). It can be concluded that the Late Weichselian material has a coarser sand fraction at similar clay contents than the calcareous Holocene material and the large variation in coarseness of the sand fraction at a given sand content in the Late Weichselian material is noteworthy. The non-calcareous Holocene material again demonstrates that many samples are transitional to the Late Weichselian material.

Summarizing the Late Weichselian fine textured material has in comparison with the calcareous Holocene fine textured material:

1) a bimodal particle size frequency distribution
2) less silt
3) coarser sand
4) a tendency of a higher clay/fine silt ratio and of a worse sorting.

2.5 PALYNOLOGY OF CHANNEL FILLS

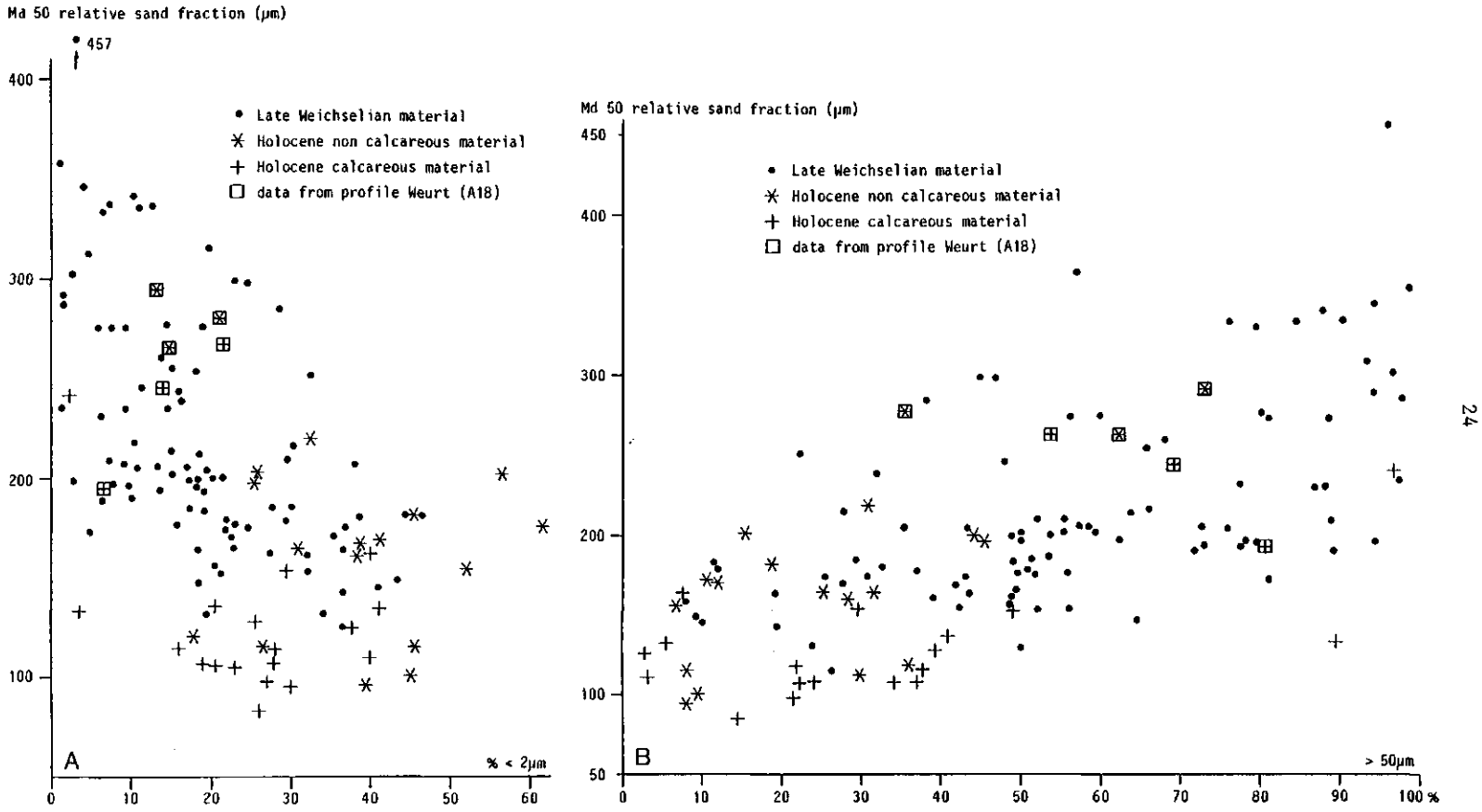
In order to determine the age of the channel fills in some of the main channels, peat deposits were been sampled at three sites. These sites were:

1) the main channel of the Heumen cross section (Fig. 3D);
2) the main channel of the Megchelen cross section (Fig. 4A);
3) the channel of the Roode Wetering in the Veldhunten I cross section (Fig. 4D).

Analyses of these deposits were compared with the palynological investigations of Koenigs (1949), Schelling (1951), Pons (1957), Teunissen and Van Oorschot (1967) and Teunissen and De Man (1981).

Pollen analysis was carried out by Mr. R.M. Van den Berg van Saparoea, under

Fig. 9. Median of relative sand fraction in samples of reference profiles.



A. in relation to clay content
B. in relation to sand content

guidance of Dr. A.J. Havinga, both of the Department of Soil Science and Geology of the Agricultural University of Wageningen. Results and interpretations are given in sections 2.5.1.1., 2.5.2.1. and 2.5.2.2.

2.5.1.NORTH LIMBURG AND 'LAND VAN MAAS EN WAAL' (LITERATURE CONCLUSIONS)

In North Limburg, pollen analysis indicated that most channels had been abandoned during the Late Weichselian, oldest fills dating back to the Allerød (Schelling, 1951). Schelling concluded that deposition of the loam cover had been completed before the Allerød, with exception of minor deposition in channels, which may have continued into the Preboreal.
In the 'Land van Maas en Waal', deposition of the loam cover had been completed in the Allerød (Pons, 1957). Pons reported that peat growth in channels did not start simultaneously: the oldest fills data from the Young Dryas, Allerød, or even Bølling, but Subboreal or Subatlantic deposits may also be found in the bottom part of channel fills. Apparently, not all channels were abandoned in the Late Weichselian. Teunissen and Van Oorschot (1967), who investigated palynologically many sections in this area, found that in channels the clay below the oldest peat tended to be of Young Dryas age. In some sites, however, peat growth started as early as the Allerød, or even the Bølling. The authors discussed the problems of extrapolating ages of channels fills to the adjacent mineral soils.
Teunissen and De Man (1981) compared pollen diagrams from three sites:

a) from a channel fill;
b) a profile west of the infilled channel with fine-textured sediments covered by drift sand and,
c) a profile in a channel-like depression, filled with sandy clay overlying gravelly sand.

In the channel fill (profile a), the oldest pollen spectra were of presumed Bølling age, followed by an almost continuous succession of Old Dryas and Allerød spectra. Young Dryas and Preboreal spectra were not encountered, and renewed sedimentation started during the Late Boreal. The peat was overlain by reworked Late Weichselian material. The presence of such reworked material had already been suggested by Poelman (1975).
In profile (b) the deepest fine-textured sediments represent the Late

Bølling. A continuous spectrum covers the Old Dryas, Allerød and early Young Dryas. The *Betula* phase of the Young Dryas is absent and younger spectra were not found. The analysis of the third profile (c) corroborates the foregoing. The fill of this depression yielded spectra representing the Bølling, Old Dryas and early Allerød. The uppermost spectrum represented the *Pinus* phase of the Allerød. The upper part of the section was disturbed.
The pollen spectra of these three profiles indicate that some channels lost their function as early as the Bølling, which is when the sedimentation of fine material started. Other channels gradually lost their function and sedimentation of fine-textured material continued into the Allerød. In many channels there is a marked gap between Late Weichselian and Holocene deposition.

2.5.1.1. OWN PALYNOLOGICAL OBSERVATIONS: THE HEUMEN CHANNEL

The location of the profile is indicated in section Heumen (Fig. 3D). The profile consists of 72 cm of silty clay loam overlying peat and passing to clay at a depth of 147 cm. The part between 70 and 155 cm has been sampled at 5 cm intervals. The pollen diagram is given in Fig. 10. Interpretation of the diagram is as follows:
BOREAL (155-150 cm). *Corylus* is dominant, *Pinus* is still important and *Quercetum* has already attained high percentages. This indicates a very young phase of the Boreal.
ATLANTIC (100-145 cm). The strong decline of *Pinus* marks the boundary with the Boreal. *Quercetum mixtum* reaches high percentages throughout. The marked increase of *Alnus* at the expense of *Pinus*, at a depth of 110 cm, may indicate a local shift to wetter circumstances. This is sustained by the sharp increase in *Cyperaceae*.
SUBBOREAL (70-95 cm). The start of the Subboreal is marked by the appearance of *Fagus* and the decline of *Ulmus* in the *Quercetum mixtum*. The appearance of *Plantago lanceolata* at 70 cm points to agricultural activities (Not indicated in the diagram). The pollen analysis indicates that the channel has remained active up to the Boreal. The channel has cut down in the surrounding sediments and started meandering. Clastic sediments in the deepest part of the channel may be of Boreal, Preboreal or Late Weichselian age.

2.5.2. AZEWIJN (LITERATURE CONCLUSIONS)

Palynological investigations by Koenigs (1949) showed that the earliest channel fills dted back to the Preboreal, and in some cases to the Late Weichselian. Peat growth, uninterrupted by clastic sedimentation, continued until the Mid-Atlantic, after which a period of clastic sedimentation set in. Van der Meene (1978), who analysed a Preboreal lime gyttja in the channel of the Roode Wetering, also found that channel activity had terminated in the Preboreal.

2.5.2.1. OWN PALYNOLOGICAL OBSERVATIONS: THE MEGCHELEN CHANNEL (LANDWEHR)

The profile of channel Megchelen (section Megchelen, Fig. 4A) is as follows:

0- 40 cm. man-made sand cover
40- 85 cm. clay; clay content increases with depth, ripening decreasing
85-125 cm. humic clay
125-165 cm. peaty clay
165-190 cm. clayey peat
190-295 cm. peat
295-305 cm. peaty gyttja
305-395 cm. lime gyttja with fresh water molluscs and peat detritus
395-445 cm. calcareous clay
445-475 cm. calcareous sand and gravel

The section between 155 and 475 cm was analysed. The sampling interval was 5 cm between 290 and 360 cm depth; and 10 cm in the remainder of the section. The pollen diagram is presented in Fig. 11 (backflap). In the lime gyttja and deeper deposits, the pollen spectrum reflects the vegetation in the neighbourhood of the channel (many aquatic elements) and the wider surroundings. This changes abruptly upon the onset of peat growth: aquatic plants decrease drastically and *Alnus*, the main element of arboreal vegetation on the peat at this stage, dominates. The ratio of arboreal to non-arboreal pollen (AP:NAP) is high throughout the diagram and indicates that the area has been densely forested. Some reworked older arboreal pollen are included in the NAP (*Fagus, Picea*). The diagram can be subdivided as follows:

BOREAL. (350-470 cm). This stage is characterized by relatively high percentages of *Pinus*, *Corylus*, *Quercus* and *Ulmus* pollen. Towards the end, *Corylus* dominates and the decline of *Pinus* indicates the transition to the Atlantic.

ATLANTIC. (160-350 cm). The transition from Boreal to Atlantic is taken at the intersection of the *Pinus* and the *Quercetum mixtum* curves. In the lower part, *Corylus* maintains high percentages, but above 325 cm, *Alnus* dominates at the expense of all other tree species, and *Corylus* gives way to *Quercus*. Occasional dominance of *Pinus*, e.g. at 220 cm, may reflect shifts in local vegetation. The decline of *Ulmus* near the top of the diagram indicates the end of the Atlantic. Subboreal spectra were not found in the analysed part of the section. The pollen diagram indicates that the channel continued functioning till Boreal times. Filling up started with about half a metre of clay, during the Boreal. Deposition of clay was resumed by the end of the Atlantic and may have continued to recent times.

2.5.2.2. OWN PALYNOLOGIVAL OBSERVATIONS: THE VELDHUNTEN CHANNEL (Roode Wetering)

The profile is indicated in section Veldhunten I (Fig. 4D). It consists of the following sediments:

0-120 cm. clay
120-137 cm. slightly humic clay
137-145 cm. peaty clay
145-170 cm. clayey peat
170-215 cm. peat
215-240 cm. slightly clayey peat
240-260 cm. lime gyttja with fresh water molluscs and peat detritus
260-270 cm. calcareous sand

The section between 130 and 270 cm was analysed. The sampling interval was 5 cm between 215 and 270 cm, 10-15 cm in the remainder of the section. The pollen diagram is presented in Fig. 12 (backflap). The diagram shows a number of very distinct transitions:

LATE WEICHSELIAN (230-270 cm): The first major transition is the strong decline of NAP from 230 to 225 cm depth. This indicates the transition from

an open to a closed (forest) vegetation. At the same depth *Pinus* succeeds *Betula* as the dominant arboreal species. Both the decline in NAP and the decline of *Betula* indicate the transition from Late Weichselian to Holocene. During the Late Weichselian, the vegetation consisted mainly of *Gramineae*, *Cyperaceae* and other herbaceous species, including *Equisetum*. The high fern (*Filices*) percentages at 230 cm probably represent undergrowth in the pine forest, and are not uncommon in *Pinus*-dominated vegetation of Preboreal and Boreal age. The spectra at 260 and 265 cm, with increasing AP and *Pinus* dominating over *Betula* may indicate the transition to the Allerød. Spectra at 250 and 255 cm contain some reworked *Fagus* and *Carpinus* pollen.

BOREAL (190-230 cm): From the Boreal onwards, the area was densely forested. The transition to the Atlantic is characterized by a rise in *Alnus*, which is more marked than that of the *Quercetum mixtum* and may indicate rather wet circumstances locally.

ATLANTIC (130-190 cm): *Corylus* and *Pinus* decrease further during the Atlantic. The upper part of the diagram ends in the Atlantic. The overlying sediments were not sampled. Although there is no clear interruption in sedimentation between 215 and 240 cm depth, the Preboreal is not clearly represented by pollen spectra, and Late Weichselian spectra are followed by Boreal spectra. Filling up of this channel appears to have started in the late Allerød to early Young Dryas.

2.5.3. CONCLUSIONS

The palynological investigation of channel fills indicates that some of the channel systems were already abandoned during the Late Weichselian (Bølling), while others may have been in operation until the Subboreal. Sedimentation was completed before the end of the Late Weichselian and dense forests occupied the area at least until Subboreal times. The marked gap between Late Weichselian and Holocene sedimentation (Heumen channel) may be because conditions for peat growth were not universal during the drier Preboreal and Boreal, but became more widespread during the much wetter Atlantic. Local Preboreal and Boreal peats indicate favourable conditions in more restricted areas. The Veldhunten (Roode Wetering) channel demonstrated the presence of Late Weichselian lime gyttja.

2.6. STRATIGRAPHIC RECONSTRUCTION

2.6.1. LATE WEICHSELIAN

All cross sections discussed in section 2.4. display a fining-upwards sequence, which is common in braided river systems (Reineck and Singh, 1973; Leeder, 1973).

Deposit I.

The deepest layers consist of very gravelly sand and sandy gravel (Deposit I). Some finer-textured material may be preserved in shallow channels. The frequent lateral changes in the deposit point to sedimentation by a braided river system, which indicates a cold (stadial) stage. This braided river deposit correlates with part of the Low Terrace of German and Dutch literature (Pons, 1954; Brunnacker, 1978; Braun, 1968; Thoste, 1974; and others).

The abrupt transition of Deposit I to overlying sediments indicates a period of erosion or non-deposition, which marks the onset of an interstadial phase. During the interstadial phase, the subsoil was no longer frozen and vegetation reappeared. This resulted in reduction of runoff and reduced transport of gravelly material towards rivers. Furthermore, river discharges were reduced and rivers did not transport gravelly material.

Deposit II.

Overlying Deposit I are stratified sandy deposits (Deposit II). These deposits are coarse sandy at the bottom and become finer higher up. The many shallow channels in this sandy deposit still point to a braided river system. Deposition must be attributed to a stadial phase. Again, some finer material is found in shallow channels. The thickness of Deposit II is variable, it is thin especially in topographically higher positions; this may be the result of wind action. Wind may have lifted part of the sand from the floodplain to create river dunes. In depressions, moisture may have prevented wind erosion, and the sand bodies tend to be thicker. Because of to transport over short distances, river dunes are often coarse-textured. Some admixture of finer-grained cover sand, which was transported over a larger distance, may have occurred.

Deposit II correlates with part of the Low Terrace of German literature

(Braun, 1968; Paas, 1960, 1961; Brunnacker, 1978; Schröder, 1979; and others).

Deposit III

Deposit II is overlain by even finer-textured sediments (Deposit III). Textures of this deposit are loamy sand to clayloam. The transition between Deposits II and III is either abrupt or gradual. In the latter case, the transition is marked by a deposit of sand with clayey laminae. This indicates a change in sedimentation environment; the sedimentation was occasionally (and locally) interrupted by wind or water erosion until the whole landscape became covered by fine-textured deposits. Still finer-textured deposits which were formed simultaneously, are found in channels and depressions. Deposit III probably formed during an interstadial phase. This characteristic succession can be seen quite clearly on Fig. 5 (reference profile Ven-Zelderheide, A15).

The river regime remains braided and Deposit III consists of several phases, which are very difficult to untangle. In the course of time, part of the channel system lost its function; the evidence for this is given in the palynological data of channel fills. Deeper channels may still have an appreciable bedload of gravel, probably because of erosion of gravelly layers in the subsoil, but shallow channels do not transport such coarse material (compare cross section Sieben-gewald, Fig. 3).

Deposit III correlates with the 'Hochflutlehm' and partly with the 'Hochflutsand' of German literature (Braun, 1968; Paas, 1968; Brunnacker, 1978; Schröder, 1979; and others).

Sedimentation and dating (Northern and Southern branch).

Deposits II and III cover the whole floodplain in a way similar to the present day foreland deposits, as was already suggested by Schelling (1951). In the course of time, the braided character of the river system became less pronounced and an increasing part of the channel system was abandoned. A change of the base level terminated sedimentation of clastic material over the whole floodplain. Some of the channels adapted to the changed situation by deep incision, sometimes down to the gravelly subsoil, and changing towards a meandering regime. This deep incision carved out some steep channels and increased the amplitude in level of the landscape. Some of the deep channels were soon abandoned and filled with clastic mineral and with peat. Peat growth in some channels started as early as the Bølling; other channels remained in operation until the Subboreal and Subatlantic and were

sources of Holocene sedimentation.

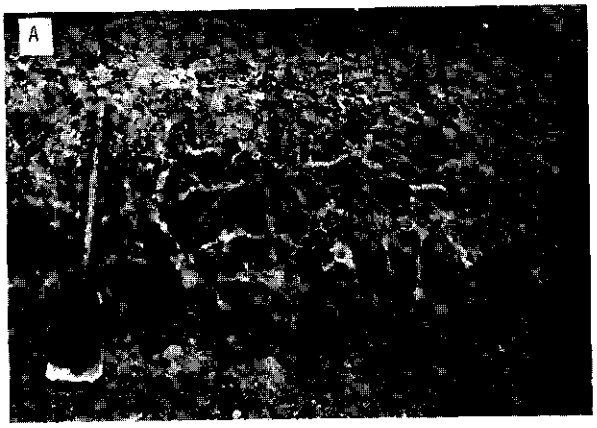
Pollen analysis indicated that Deposit III was formed during the Bølling, Old Dryas and Allerød, while similar fine deposits in channels were deposited during the Young Dryas (Teunissen and Van Oorschot, 1967; Teunissen and De Man, 1981). Only the upper parts of deposits III contain appreciable amounts of pumice fragments. This indicates that these parts are contemporaneous with the Laacher See eruption, which occurred during the Allerød (Frechen, 1976). Consequently the top of deposit III is of Allerød age. Teunissen and De Man (1981) have already questioned the model which presumes that fluvial influence decreased during the warmer interstadials of the Late Weichselian. They assumed an accelerated incision at the transition from interstadial to stadial, followed by sedimentation of fine-textured material in gullies during the stadial. This is in accordance with our data. Our field observations in the tract for the A73 highway near Heumen showed that over a considerable area, fine-textured deposits were overlain by sandy loam deposits with polygonal crack patterns (Fig. 13), both belonging to deposit III. This exception to the fining-upwards sequence can be interpreted as Old Dryas deposits overlying Bølling deposits, which were exposed to frost action during the Young Dryas. Allerød time pumice is absent in the deposit. These fossil polygons are sometimes demonstrated in reduced subsoils by undecomposed alder roots (Fig. 13).

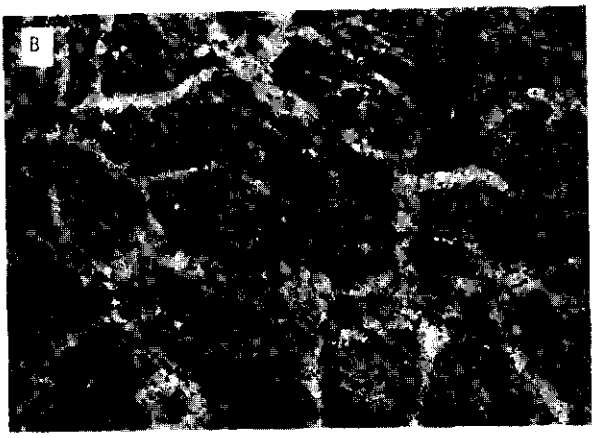
The absenc of pumice in gravelly deposits of the southern branche of the Rhine (Pons and Schelling, 1951; Pons, 1957) and part of the northern branch of the Rhine (Van der Meene, 1977, 1978) points to a pre-Allerød age of these deposits. The preceding discussion points to a pre-Bølling age, and hence these deposits should be attributed to the Pleniglacial-B.

Sedimentation and dating (central branch).

In contrast, the gravelly deposits of the present-day course of the Rhine do contain pumice layers. Such pumice admixtures have been reported from Xanten (Braun, 1968), the Betuwe (Verbraeck and Van der Meene, 1975; Van der Meene and Zagwijn, 1978; Van der Meene, 1977) and from the surroundings of Tiel (Verbraeck, 1970). Van der Staay (quoted in Van der Meene, 1977) found younger gravelly deposits with pumice in part of the former northern Rhine branch. These deposits occurred as infillings of depressions and were locally found on top of pre-Bølling deposits without pumice. The deposits with pumice correspond with the Younger Lower Terrace (Braun, 1968; Brunnacker, 1978) and its degradation phase (Thoste, 1974; Brunnacker,

Fig. 13. Late Weichselian polygonal crack pattern.





A. oblique view of polygonal crack pattern (note also the albic character of the overlying E horizon- spade length 120 cm)
B. detail of A (grip of the knife 10 cm)
C. polygonal crack pattern made visible by alder roots (sand subsoil Veldhunten area-measure 20 cm)

1978). This is synonymous with Terrace X of Pons (1957) and can be dated to the transition from Late Weichselian to Holocene. The degradation stage appears to indicate the change from a braided to a meandering river regime. In his subdivision of Late Weichselian deposits, Verbraeck (1985) assigned the investigated sediments to Kreftenheye 5, except for the pumice-containing topsoils in the southern and part of the northern Rhine branch, which he assigned to Kreftenheye 6.

2.6.2. HOLOCENE

As described in section 2.1., Brunnacker (1978) distinguished various deposition phases in the Holocene deposits between Bonn and the Dutch border. In the Netherlands, Havinga (1969) and Havinga and Op 't Hof (1975, 1984) described four phases of sedimentation from the Betuwe area, and Pons (1957) distinguished seven phases in the Land van Maas en Waal. The latter's evidence was based on archeological and palynological evidence.

Holocene sedimentation activity greatly increased from the Subboreal onwards, when the rise in sea level influenced the sedimentation characteristics of the Rhine. These younger sediments, which are separated from the Late Weichselian deposits by a wide time gap of non-deposition, now cover peaty deposits in the major channels of most of the cross sections. In the investigated part of the northern branch, they occur as a thin veneer on the Late Weichselian deposits, from which they may be separated by a locally occurring former vegetation horizon. The sedimentation characteristics of these Holocene and the Late Weichselian fine deposits are very similar. In both cases, sedimentation occurred when Rhine water was forced up small tributary streams and inundated the lower parts of the surrounding landscape: fine sediments were deposited in relatively low areas, whereas higher areas were not affected. One such inundation occurred as recently as 1926, when the highest Rhine level at Lobith reached 16.93 m + NAP (compare elevation of land in sections).

Further downstream, in the surroundings of Doetinchem and Doesburg, the Holocene deposits are found in channels of the Late Weichselian system. The texture of these deposits is similar to that of backswamp deposits, but levees are not found. This points to a passive infilling of the depressions.

The foregoing described the general aspects of the genesis of the landscape during Late Weichselian and Holocene. Local variations are the presence of river dunes, local accentuation of the relief by accumulation of plaggen epipedons, and - mainly in channels - local excavations.

2.7. SOIL CONDITIONS

In this section detailed soil maps of representative sample areas on Late Weichselian Rhine deposits are discussed. The detailed surveys preceded the selection of reference profiles in Late Weichselian sediments. The selection of reference profiles in Holocene sediments was based on available detailed soil maps.
The published soil maps of the Late Weichselian areas have a variety of legends: these are discussed in the next section.

2.7.1. LEGENDS OF PREVIOUSLY PUBLISHED SOIL MAPS OF LATE WEICHSELIAN DEPOSITS

The areas of soils on Late Weichselian Rhine and Meuse deposits are indicated in Fig. 1. The soils have been mapped on various scales and with different legends. A schematic comparison of legends in presented in Table 3.

Differentation in Koenigs (1949) map was based exclusively on thickness and texture of Holocene and Weichselian sediments.
Edelman (1950) introduced the concepts of soil landscapes, complexes and types. Soil landscapes have a common mode of formation but may comprise strongly varying soils.
The soils of characteristic elements in a soil landscape are grouped into soil complexes when map scale does not permit the various units (types) to be separated. A soil complex may contain considerable variation. At the lowest level, soil complexes are subdivided into soil types. Each type can be considered uniform in terms of its agricultural production capacity.

Table 3. Criteria for subdivision and their level of use in legends of soil maps of Late Weichselian deposits.

Author	Koenigs	Edelman	Schelling	Pons	Stiboka	Stiboka	GLA*
Year	1949	1950	1951	1957,1966	1965	1968-84	1968-84
Scale 1:	10.000	400.000	25.000	25.000	200.000	50.000	50.000
Criterion							
Parent Material	+++	+++[a]	+++[b]	+++[c]	+++	+++[d]	++
Hydrology	-	++	++	++	++	++	+++[e]
Texture	+	-	+	+	+	+	+
Soil formation	-	-	-	(+)[f]	+	+++	++

*) Geologisches Landesamt Nordrhein-Westfalen (GLA)

+++: highest level; ++: second level; +: third level; -: not used.

Footnotes:a) sandy soils excluded; b) Parent material is subdivided into river loam and river sand at this level; c) no Late Weichselian sands in this area; d) Late Weichselian sands are included in the non-calcareous sandy soils; e) hydrology is reflected in attribution to 'Terrestrische Böden, Semiterrestrische Böden, Moore/Organogene Böden' (well drained soils including surface water gleying, gley soils and soils of flooded areas, and peat and peaty soils, respectively); f) soil formation as described by Pons (1957) and in chapter 3 of this thesis can be used for differentiation in legends of soil maps at 1:25.000 or 1:50.000.

These concepts form the basis for the later legends by Schelling (1951) and Pons (1957, 1966), who used hydrology for differentation at the second level and distinguished soil complexes of Well Drained Brown Soils, Imperfectly Drained Mottled Soils, and Poorly Drained Grey Soils. The hydrological subdivision was retained in the 1:200.000 soil map of the Netherlands (Soil Survey Institute, 1965) and soil formation according to the model of Pons (1957) was used at the second level.

The legend of the systematic soil survey of The Netherlands at scale 1:50.000 (Steur, 1966; Steur and Heijink, 1983) distinguishes simple and compound mapping units. At the highest level, the simple mapping units are arranged according to parent material and sometimes to soil formation. The Late Weichselian clay soils (more than 8 per cent clay in more than half of the upper 80 cm) are subdivided into soils with a *'briklaag'* (Dutch equivalent to argillic horizon, De Bakker & Schelling, 1966): BZ and BK, and soils with no such layer: KR. Hydromorphic characteristics are used for subdivision at the second level, and topsoil textures for subdivision at the third level. Texture trends with depth are not used because of the large variation. At the fourth level, the groundwater class is added. For example: KRn2V is a soil on Late Weichselian clayey deposits with no *'briklaag'* (KR), with hydromorphic properties within 50 cm (KRn; n, 'nat'=wet), a topsoil texture class 2 or 'zware zavel' (KRn2) and a groundwater class V (roman

numeral V; mean highest groundwater level within 40 cm, mean lowest level deeper than 120 cm). The 1:50.000 mapping of soils on Late Weichselian deposits was completed recently.*) Table 4 shows the area per drainage class of each mapping unit. Of the total area of approximately 36.000 hectares,

Table 4. Surface areas (in ha) of mapping units of soils on Late Weichselian deposits in the Netherlands, subdivided according to groundwater class.

	Groundwater class							
	I	II	III	IV	V	VI	VII	Total
Mapping Unit								
BZd 23	-	-	-	-	-	-	250	250
BZd 24	-	-	-	-	-	-	200	200
BKd 25	-	-	-	-	-	250	3000	3250
BKd 26	-	-	-	-	-	350	650	1000
BKh 25	-	-	-	-	-	50	200	250
BKh 26	-	-	-	-	-	200	350	550
BKn 25	-	-	-	-	-	150	50	200
BKn 26	-	-	-	-	-	100	-	100
KRd 1	-	-	-	-	-	400	6000	6400
KRd 7	-	-	-	-	-	350	850	1200
KRn 1	-	150	3000	450	3200	3350	50	10200
KRn 2	-	100	2650	900	1150	3350	50	8200
KRn 8	-	-	2200	50	800	1000	50	4100
Total	-	250	7850	1400	5150	9550	11700	35900

some 13.100 ha. are well drained (part of groundwater classes VI and VII). In 7600 ha. of the well-drained soils, an argillic horizon is not indicated (KRd). Of the remaining 5.500 ha., pseudogleying in the E-horizon (BKn) or in the Bt-horizon (BKh) is encountered in 1100 ha. Imperfectly and poorly drained soils with hydromorphic properties within 50 cm from the surface occupy 22.500 ha (KRn). These soils have dominant groundwater classes III, V and VI. The extent of soils in the lower groundwater classes may be underestimated because peaty variants are grouped with peat and peaty soils.

*) Late Weichselian soils occur on the map sheets 33E (Apeldoorn, 1979), 39E (Rhenen, 1973), 40WE (Arnhem, 1975), 41W (Aalten, 1983), 45E ('s Hertogenbosch, 1976), 46WE (Vierlingsbeek, 1976), 52W (Venlo, 1968), 52E (Venlo, 1973), 58W (Roermond, 1972), 58E (Roermond, 1968), 59 (Peer, 1970), 60WE (Sittard, 1970).

In West Germany, the 'Geologisches Landesamt für Nordrhein-Westfalen' (GLA) mapped soils on Late Weichselian deposits of the Rhine and its former courses and tributaries in the Lower Rhine Basin. Soil maps at a scale of 1:50.000 are available for most of the area **

The legend of these maps is based on soil formation which depends on hydrological position (see footnote e of Table 3). Soil formation and parent material, using Mückenhausen's (1969) classification, are used at the second level. Textural characteristics ('Bodenarten') and their variations with depth ('Bodenartenschichtung') are used at the third level. Groundwater class and the presence of surface water gleying ('Pseudogley') are indicated by symbols on the map. As nearly all mapping units are associations (Steur *et al.*, 1984), the co-dominance of soils within an association is indicated by 'und' (and), subdominance with 'zum Teil' (partly) and impurities or inclusions with 'stellenweise' (locally).

In all legends discussed above, soils on Late Weichselian deposits are separated from those on Holocene sediments. Hydrology, soil formation and textural characteristics are the main criteria for subdivision of the former. Variation occurs as to the level of use of the differentiating critera.

2.7.2. LEGEND FOR THE 1:10.000 SOIL MAPS OF THIS STUDY

Student field parties who surveyed the various areas made about 2 augerings per hectare (unpublished reports by Van Engelen (1975), Van Reuler (1978), Van Dis and Robben (1978), Broekhuizen and Epema, 1979). In each augering, clay content, hydromorphic features (mottling), colour, gravel content, lime content and evidence of soil formation (e.g. banded Bt horizons) were recorded every 10 cm. The horizon designation was also recorded but had to

**) Late Weichselian soils occur on 1:50.000 map sheets L4104 (Bocholt, 1983), L4302 (Kleve, 1985), L4304 (Wesel, 1983), L4502 (Geldern, 1975), L4504 (Moers, 1974), L4506 (Duisburg, 1979), L4704 (Krefeld, 1969), L4706 (Düsseldorf, 1978) L4904 (Mönchengladbach, 1971), L4906 (Neusz, 1972), L4908 (Solingen, 1976), L5106 (Köln, 1973), L5108 (Köln-Mülheim, 1980) and L5308 (Bonn, 1983). The soil map 1:100.000, sheet C4302 (Bocholt,1968) covers the adjoining German area between Siebengewald/Goch and Aalten/Barlo. The soils of Nordrhein-Westfalen (1:500.000) are presented in the 'Deutscher Planungs-atlas' (Maas and Mückenhausen, 1971).

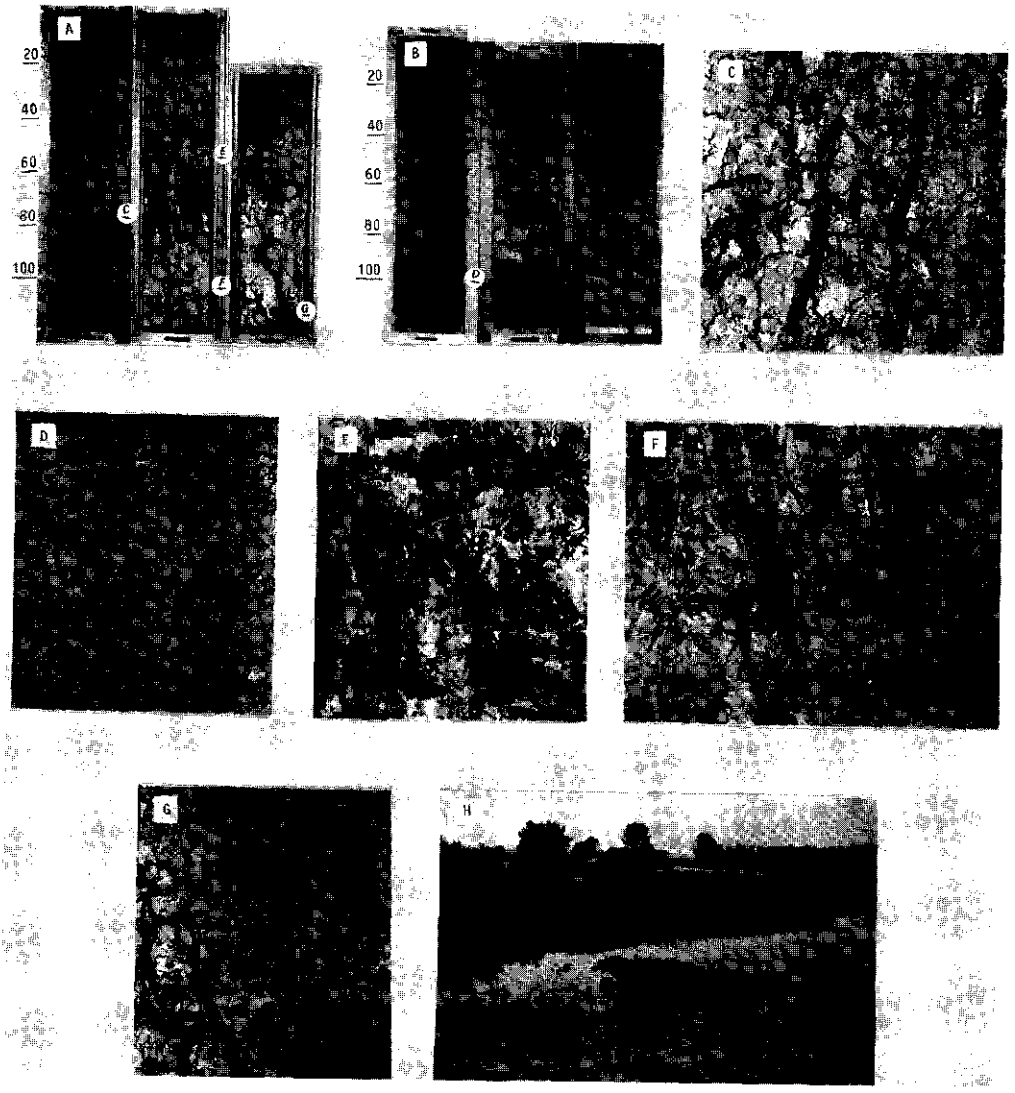
be amended after further research (Chapter 3). The distinction between Holocene and Late Weichselian material was made using criteria described by Koenigs (1949), Schelling (1951) and Pons (1957). In poorly drained soils or very wet soil material, the distinction was somewhat difficult. The surveyed areas predominantly consist of Late Weichselian material. Holocene deposits occupy the lowest positions and are generally found in former river channels or as a thin veneer on top of Late Weichselian deposits. Holocene redeposition of Late Weichselian material in some river channels (Poelman, 1975) may cause an overestimation of real age in some cases.

During the field survey, attemps were made to relate soil conditions to visible microtopography. Cross sections were used to relate microtopography to soil texture. In the first survey (Van Engelen, 1975) a density of 10 augerings per hectare was used; information from this survey was used in the subsequent surveys of other areas. Discussion of the legend of the 1:10.000 maps will be focussed on the subdivision of soils on Late Weichselian deposits.

Best related to microtopography were depth of occurrence and expression of hydromorphic characteristics. This allows the soils to be grouped in topo-hydrosequences. Fig. 14 shows examples of such topo-hydrosequence with textures of sandy loam and clay loam respectively and details of relevant horizons. As can be read from the cross sections, topsoil texture, textural profile and thickness of clayey deposits were also related to topography. In each of the surveyed areas, the range of textures within any given hydrological class was narrower than the overall variation of texture mentioned in Table 5.

Relation between texture and topography was less pronounced than that between topography and hydrology. Therefore, hydrology was used as differentiating criterion at the highest level, and textural variation was described at a lower level. Table 5. shows the final legend, which was used for all areas. In the table, mottling characteristics are given for three depth intervals in each mapping unit, together with the overall texture variation per depth interval. Reference profiles (section 2.4.1.) provide detailed information on textural characteristics of each mapping unit. Reference profiles from outside the surveyed areas have been assigned to a mapping unit and included. Textural classes of samples of the reference profiles, are given in Fig. 8.

Fig. 14. Characteristic topo-hydro sequences of Late Weichselian soils.



A. Clay loam texture: well drained brown soil (HB-reference profile A16); imperfectly drained mottled soil (MB-reference profile A2); poorly drained grey soil (LG-reference profile A3)
B. Sandy loam texture: well drained brown soil (HB-reference profile A6); imperfectly drained mottled soil (MB-reference profile A7); poorly drained grey soil (LG-reference profile A8)
C. Detail of HB (clay loam)-note worm activity
D. Detail of HB (sandy loam)-note biogenic structure
E. Detail of MB (clay loam)-pseudogley with bleached ped faces
F. Detail of MB (clay loam)-gley with iron coatings around former root channels
G. Detail of LG (clay loam)-grey groundmass colour and undecomposed dead roots
H. Excavation wall (Heumen area) demonstrating part of topo-hydro sequence: imperfectly drained mottled soils (left hand side) changing to poorly drained grey soils changing to very poorly drained peaty soils (infilled channel - right hand side)

Table 5. Legend: Hydromorphic features and range of textures of mapping units in the soil maps 1:10.000.

	Mottling and range in clay content											
	0-40 cm				40-80 cm				80-120 cm			
	Fe	Mn	Red	clay %	Fe	Mn	Red	clay %	Fe	Mn	Red	clay %
LATE WEICHSELIAN DEPOSITS												
Clayey Soils												
Well and moderately well drained soils												
HL 1	-	-	-	<8-25	-	-	-	<8-35	(+)	(+)	-	<8[1]
HL 2	-	-	-	10-25	(+)	(+)	-	<8-40	+	+	(+)	<8
HL 3	(+)	(+)	-	15-25	+(+)	+(+)	-	15-30	++	++	+	<8
Imperfectly and somewhat poorly drained mottled soils												
ML 1	+(+)	+(+)	(+)	10-25	++	++	+	10-35	++	++	+	<8
ML 2	++	++	+	10-35	++(+)	++(+)	++	10-35	+(+)	+(+)	+++	<8
ML 3	++	++	++	15-35	++	++	+++	10-45	+(+)	+(+)	+++	<8
Poorly and very poorly drained grey soils												
LL 1	++	-(+)	+++	15-25	++	-(+)	+++	25-45	(+)	-(+)	+++	<8
LL 2	++	-(+)	+++	10-25	+(+)	-(+)	++++	10-45	(+)	-	+++	<8
LL 3	+(+)	-(+)	++++	10-30	(+)	-(+)	++++	25-45	-	-	++++	<8
Sandy Soils												
S River dunes												
HOLOCENE DEPOSITS												
More than 80 cm Holocene sediments												
K Clay												
KV Clay on Peat												
V Peat												
HOLOCENE DEPOSITS OVERLYING LATE WEICHSELIAN DEPOSITS												
K-- Holocene cover 40-80 cm thick: Letter K preceding HL, ML or LL												
k-- Holocene cover less than 40 cm thick: Letter k preceding HL, ML or LL												

Explanation: Fe = iron mottles, Mn= Manganese mottles; Red= reduction colours; [1]=banded

Abundance:
- \- no mottles
- -(+) few mottles in less than 50% of observations
- (+) few mottles in more than 50% of observations
- \+ few mottles in all observations
- +(+) few to common mottles in all observations
- \+ + common mottles in all observations
- ++(+) common to many mottles in all observations
- \+ + + many mottles in all observations
- \+ + + + more than 70% reduction colours (area)

Three maps are presented for each survey: soils (based on hydrology), texture of topsoil, and elevation. The textural classes are those used in the 1:50.000 surveys. Elevation was taken from 1:10.000 altitude maps published by the Netherlands Topographical Service. For the Heumen area (Figure 15), depth to sand is given as well.

2.7.3. DESCRIPTION OF THE 1:10.000 DETAILED SOIL MAPS

2.7.3.1. HEUMEN AREA (Fig. 15)

The survey covers about 12 ha and includes 140 augerings; the map and cross section (Van Engelen, 1975) were published in Miedema *et al.* (1978). Elevation ranges between 8.5 and 10 m above NAP.

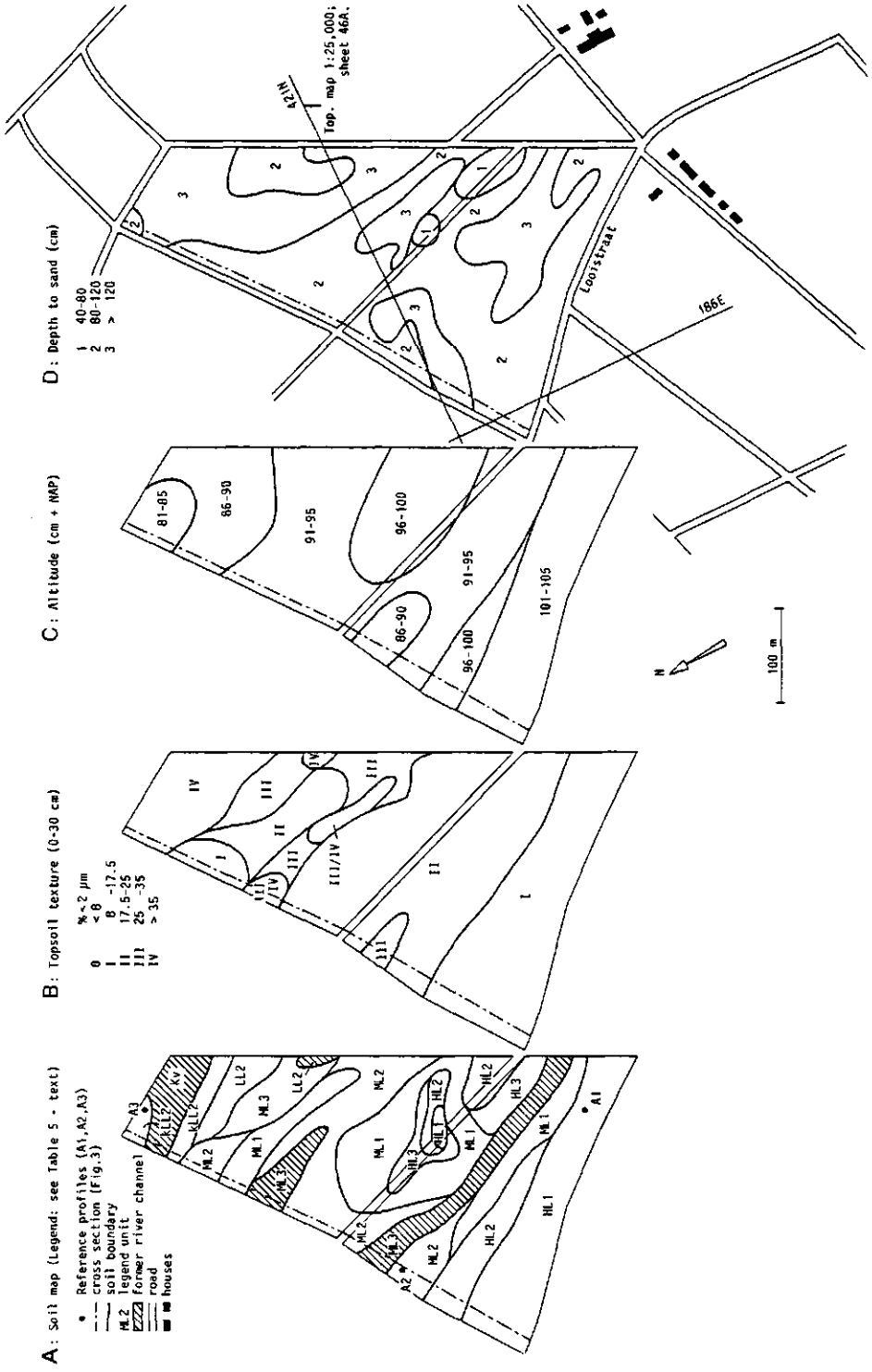
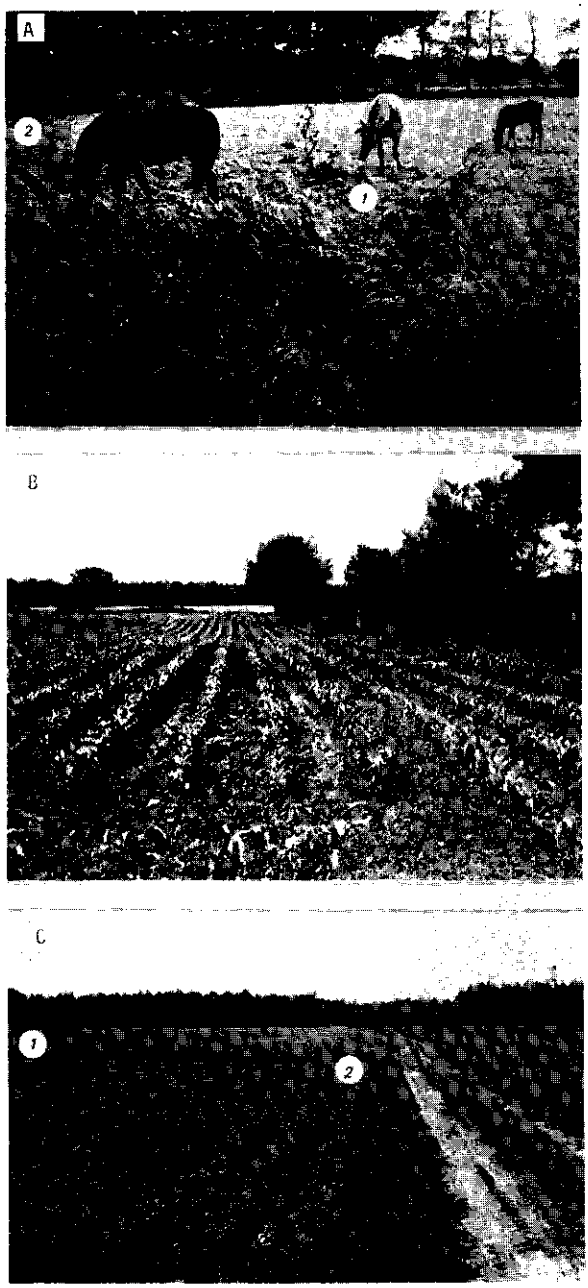


Fig. 15. Soil map (A), topsoil texture (B), altitude (C) and depth to sand (D) of the Heumen area.

Fig. 16. Landscape Heumen area and location of the reference profiles.



A. The Heumen channel (mapping unit KV-grassland) where palynological samples were taken (1). Location of reference profile A3 (mapping unit kLL2) on left hand side of the photo (2)
B. Characteristic microtopography with ML3 channel and ML2 and ML1 flankings (arable land)
C. Broad ridge (arable land-background) with HL1 and HL2 soils (reference profile A1-1) with ML3 channel (foreground) and ML2 flankings (reference profile A2-2)

In the northeast of the soil map a major river channel filled with Holocene clay and peat (palynology section 2.5.1.1) is indicated by unit KV. The channel is bordered by fine-textured Late Weichselian soils (LL2, ML3) with locally a thin veneer of Holocene clay (kLL2, reference profile A3; Fig. 16A). Southwest of this channel, a slightly elevated narrow ridge (ML1) with fine-textured flanks (ML2) is found. From a second depression (ML3; Fig. 16B) the landscape ascends through coarse-textured ML2 to ML1 and scattered islands of shallow, coarse-textured HL1, HL2 and HL3 on sand. The ML2 and ML1 flanks of these islands are imperfectly drained. In the next channel (ML3) which traverses the map approximately N-S, sediments become finer with increasing depth. The flanks of the channel widen northward and become finer with depth (ML2, reference profile A2; Fig. 16C). The southwestern border of the mapped area is marked by a broad, high ridge with well-drained, coarse-textured soils (HL1, reference profile A1; HL2) and an imperfectly drained, coarse-textured northern flank (ML1).

Topsoil textures (Fig. 15B) clearly show the ridge in the southwest and the major channel in the northeast. The coarse-textured ML1 island and the channel bordering this island to the west are also clearly visible. In the remainder of the area, correlation between soils, topography and texture is less pronounced. Thickness of the clayey sediments, as indicated in Fig. 15D, is not clearly related to either drainage or texture. Some very shallow soils are found in the southwest. There is a distinct relation between elevation (Fig. 15C) and hydrology.

2.7.3.2. SIEBENGEWALD AREA (Fig. 17)

Two sample areas of 75 ha each were mapped. The northern area was surveyed in detail (120 augerings) and has elevations between 15 and 17 m above NAP. The southern area lies between 15 and 16.5 m above NAP; 60 augerings were made here. Soil units and cross section were described by Van Dis and Robben (1978).

In the northeast of the northern area a slightly elevated plateau occurs with rather fine-textured, deep to shallow HL1, HL2 and HL3 (Fig. 18). Directly north of this plateau, on German territory, is the deeply incised Kendel Stream (not shown on the map). Southwest of the Augustinusweg is a

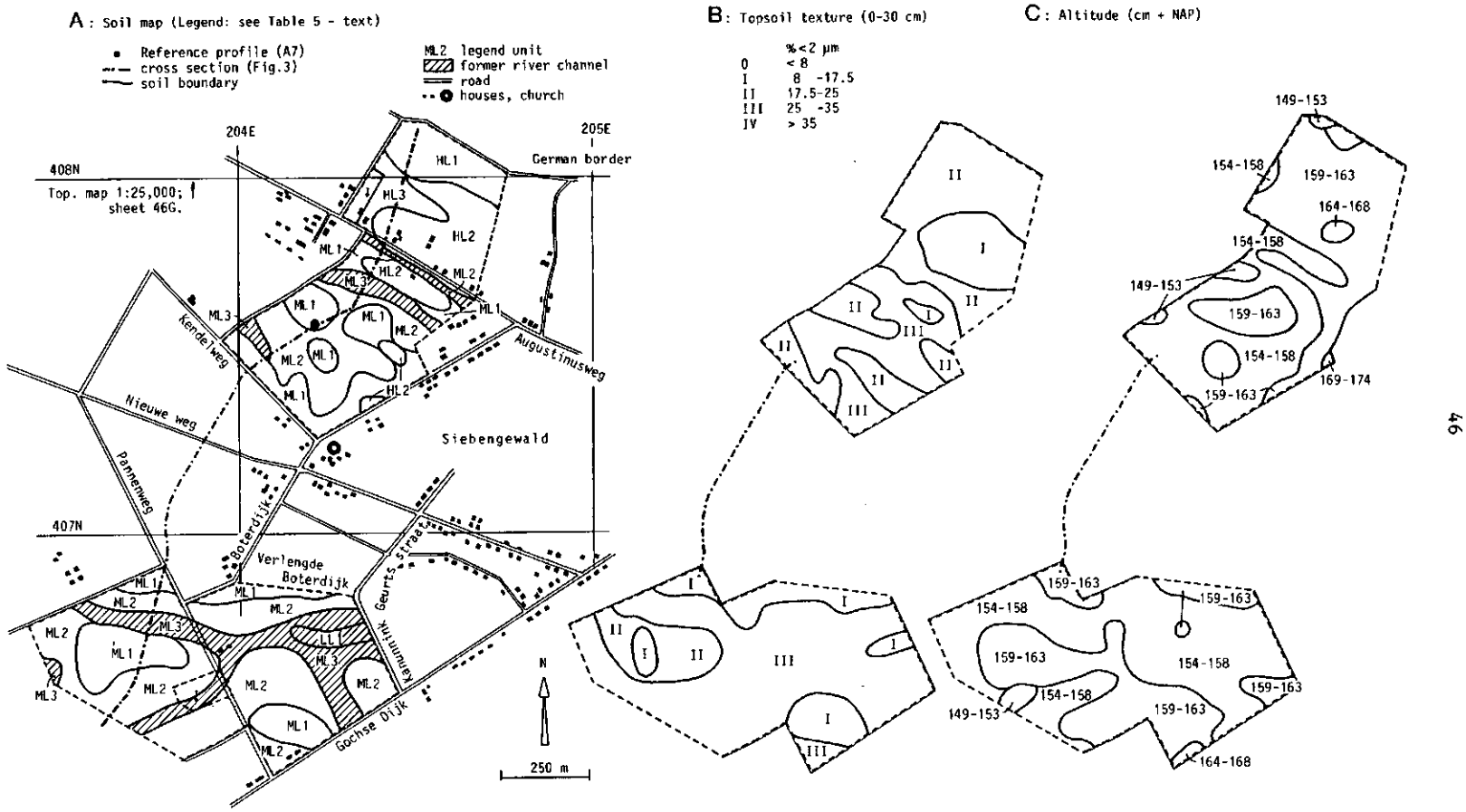


Fig. 17. Soil map (A), topsoil texture (B) and altitude (C) of the Siebengewald area.

Fig. 18. Plateau (arable land) with fine-textured HL1, HL3 and HL3 soils.

narrow former channel (ML2) bordered to the south by a low ridge with HL2 and ML1 shallow on sand. The finer textured and deeper ML2, which is widespread between the Augustinusweg and the Kendelweg also lies in a depression, the lowest part of which is occupied by a channel (ML3). The remainder of this area consists of ridges and islands of shallow ML1 on sand with HL1 and HL2 in well-drained positions. The Siebengewald reference profile (A7) is situated in the unit ML1.

Topsoil textures (Fig. 17B) are sandy along the Augustinusweg, in part of the HL2 unit. The remainder of the plateau, and part of units HL2, ML2 and ML1 have texture class II, while class III is found in ML2, ML3 and ML1 positions. The pattern of topsoil textures suggests a channel system which is not identical to the pattern indicated by hydrology. The latter is reflected in the elevation map (Fig. 17C). Both the plateau in the north and its extension along the eastern boundary of the surveyed area stand out, and the ridge along the Augustinusweg is also distinguishable. A high elevation does not always correspond with a sandy topsoil texture.

The pattern in the southern area is very clear. A major channel with fine-textured, deep ML3 and LL1, bordered by fine-textured, deep ML2 flanks runs through the area from east to west and bifurcates near the Pannenweg and towards the Gochse Dijk. The higher islands all have coarse-textured, shallow ML1. ML2 flanks mark the transition to channel positions. Part of

the deposits have been excavated for the manufacture of roof tiles ('Pannenweg').

The above pattern is clearly reflected in the topsoil textures (Fig. 17B): units ML2, ML3 and LL1 have class III (fine) textures, while the ML units have class I and II textures. The elevation map (Fig. 17C) shows a pattern which only partly coincides with patterns of topsoil texture and hydrological units.

For both areas of the Siebengewald survey, the relation between elevation and hydrology is better than that between elevation and topsoil texture. In general, topsoils become sandier with increasing elevation, but the plateau in the northern part is a clear exception. Similar topsoil textures are found over a range of hydrological (mapping) units.

2.7.3.3. OTTERSUM AREA (Fig. 19)

The Ottersum area is about 75 ha and its elevation ranges between 11 and 14 m above NAP. It was surveyed in detail (130 augerings). The soil units and cross sections were described by Van Dis and Robben (1978). The area can be subdivided into three:

- The southern part, south of the LL1 channel near the Aaldonkse Straat is a well-drained plateau with coarse-textured, deep to shallow HL1, HL2 and HL3. Just beyond the southern boundary of the map runs the deeply incised Niers stream. Reference profiles Ottersum (A6) and Ven-Zelderheide (A15; Fig. 5) are located on the HL1 plateau. The HL3 unit occupies depressions in the plateau.
- A former river channel with strongly reworked LL1 and LL3+V (Fig. 20) separates the southern plateau from a second relatively high area between Panoven and the Hoevense Straat. This area contains high islands of coarse-textured, shallow HL2 dissected by former channels with finer-textured ML1, ML2 and, locally, ML3.
- North of the Hoevense Straat is a relatively low area, dominated by fine-textured deep to shallow ML2 with channels of ML3 and LL2+V. The Aaldonk reference profile (A9) is situated in unit ML2, slightly east of the surveyed area. A river dune (S) is encountered at the junction of Hoevense Straat and Biezendijkse Baan. In the northern area, the sediment is

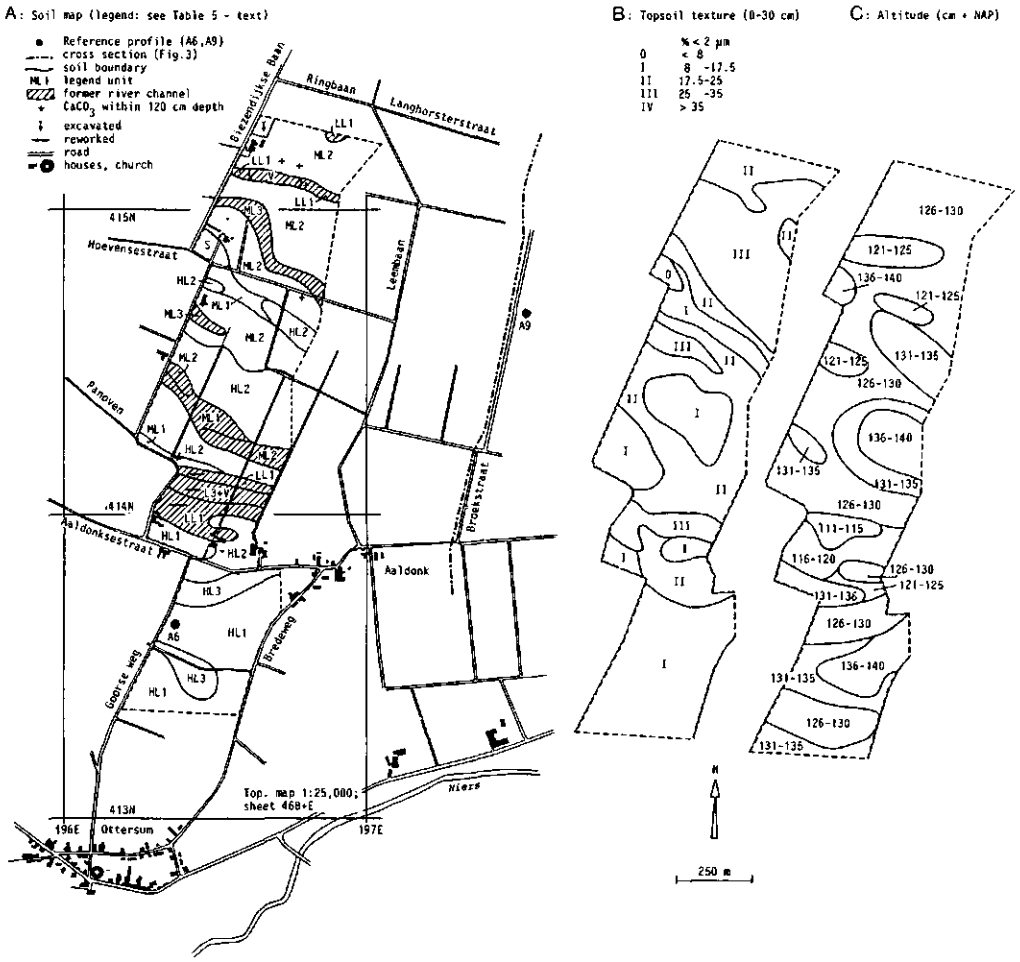


Fig. 19. Soil map (A), topsoil texture (B) and altitude (C) of the Ottersum area.

Fig. 20. Former major river channel (grassland) with strongly reworked LL1/LL3 + V soils. Background demonstrates HL2 soils (arable land).

locally calcareous, which is indicated in the map. Calcareous material is restricted to the vicinity of former channels, but its occurrence is erratic. The presence and significance of $CaCO_3$ will be discussed in section 3.3.

The three areas delineated above are reflected in the topsoil textures (Fig. 19B). The topsoil textures of the southern plateau are class I, with a few class II; those of the channel just north of the plateau are class III. North of the channel, elevated parts have topsoil textures of class I, surrounded by class II with locally class III in channels. The northern part is dominated by topsoil textures of class III with class II in slightly more elevated areas. Class II near the northern boundary marks the transition to a ridge just outside the mapped area.

In the elevation map (Fig. 19C), the higher parts of the southern and middle area, and the channel in between are clearly indicated. The 50 cm interval is too coarse to reflect the microtopography of the northern part.

In the Ottersum area, the relation between hydrology and topsoil texture stands out, and relations between elevation and hydrology and between elevation and topsoil texture are both fairly well expressed. The three maps are similar but far from identical.

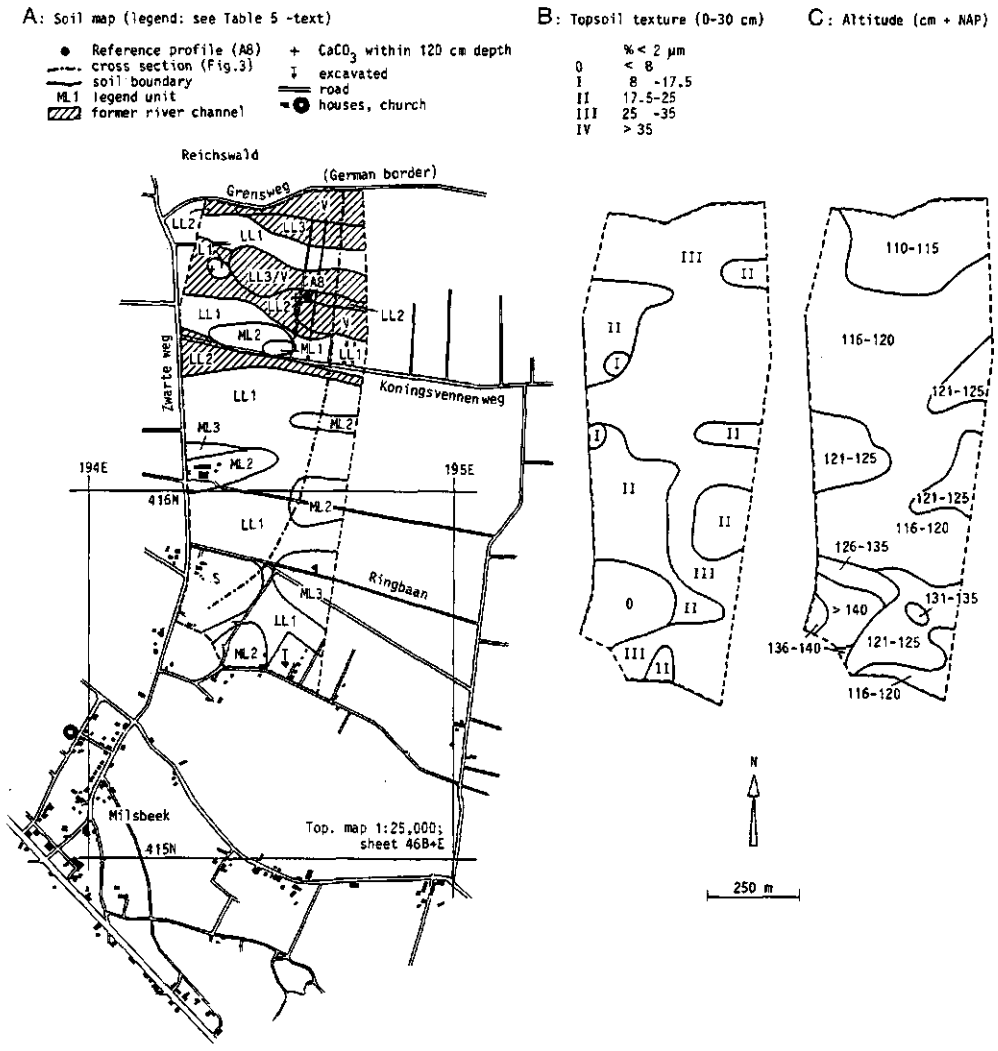


Fig. 21. Soil map (A), topsoil texture (B) and altitude (C) of the Milsbeek area.

2.7.3.4. MILSBEEK AREA (Fig. 21)

The Milsbeek area is about 60 ha; its elevation, the river dune area in the southwest excepted, ranges between 11 and 12.5 m above NAP. The maps are based on 105 augerings. Soil units and cross section are described by Van Dis and Robben (1978). The river dune is recognizable by its topography. The influence of wind-blown sand on the immediate surroundings is reflected in sandier topsoils (class II, Fig. 21B). Also, the ice-pushed ridge immediately north of the mapped area, in Germany (Fig. 22) is a distinct morphological unit. The remainder of the area is dominated by fine-textured, deep LL1 soils, with higher islands of ML2 and ML3 soils, mainly south of the Koningsvennenweg. In these ML2 and ML3 soils, contrast of mottling is less pronounced than in the Siebengewald and Ottersum areas. North of the Koningsvennenweg, drainage conditions are even less favourable and slightly elevated parts have fine-textured deep to shallow LL1 and LL2 soils, while LL3 and V soils occur in channels. In this area, topsoils have been sanded locally, to improve bearing capacity. Reference profile Milsbeek (A8) is situated in unit LL2. A single area of coarse-textured, shallow ML1 is found at a slightly elevated site just north of the Koningsvennenweg.

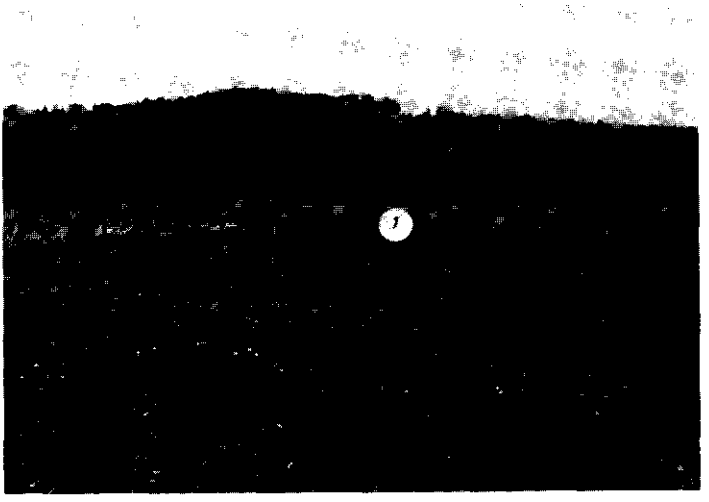


Fig. 22. Ice-pushed ridge (forest) and characteristic micro-topography (foreground) with LL1, LL2, LL3 and V soils. Reference profile A8 (mapping unit LL2) is located at (1).

$CaCO_3$ was locally found to occur within 120 cm depth in the area north of the Koningsvennenweg; its occurrence will be discussed in section 4.3.
Topsoil textures in the area are class II or III (Fig. 21B), with exception of the river dune, which consists of pure sand (S). The elevation map (Fig. 21C) shows that the area near the Grensweg is lowest (11-11.5 m + NAP). The remainder of the area ranges between 11.5 and 12 m, with higher islands between 12 and 12.5 m + NAP. The river dune rises above 14 m + NAP. Elevation correlates with hydrology to some extent. Poor drainage in the northern part, however, is not exclusively due to its low position, but is enhanced by seepage from the ice-pushed ridge in the north. This poorer drainage is reflected in the weaker contrasts of mottling in ML2 and ML3.
Relation between topsoil texture and elevation is less pronounced than that between topsoil texture and hydrology, but the patterns on the various maps do not correspond exactly.

2.7.3.5 MEGCHELEN AREA (Fig. 23)

The Megchelen area is about 45 ha and was surveyed with some 150 augerings; its elevation ranges between 14 and 17 m + NAP. The area has a very pronounced topography. The soil units and cross section were described by Broekhuizen and Epema (1979).
A major river channel runs along the German border, in the southeast. Pollen analysis (section 2.5.2.1.) confirmed that infilling of the channel occurred during the Holocene, and hence the mapping units were designated K and KV. The clay is very fine-textured, but topsoils may locally be sandy, because local farmers have added sand. The channel is an outer bend that eroded the Late Weichselian terrace plateau to the north. The terrace plateau consists of well-drained, coarse-textured, shallow HL1. The Megchelen reference profile (A14) is situated here, and the Millingen reference profile (A16) is from a similar position, in neighbouring West Germany. Three channels are encountered in the terrace surface. Running along the eastern border of the survey area is a channel with poorly-drained and strongly mottled or reduced, variably textured ML3 and LL2 with locally very strong Mn accumulation. A second channel runs parallel to the Grensweg, represented by ML3+LL1 and gravelly ML1. In the northern part, this channel is joined by a branch from the southwest. Note that the depressions on the terrace do not

Fig. 23. Soil map (A), topsoil texture (B) and altitude (C) of the Megchelen area.

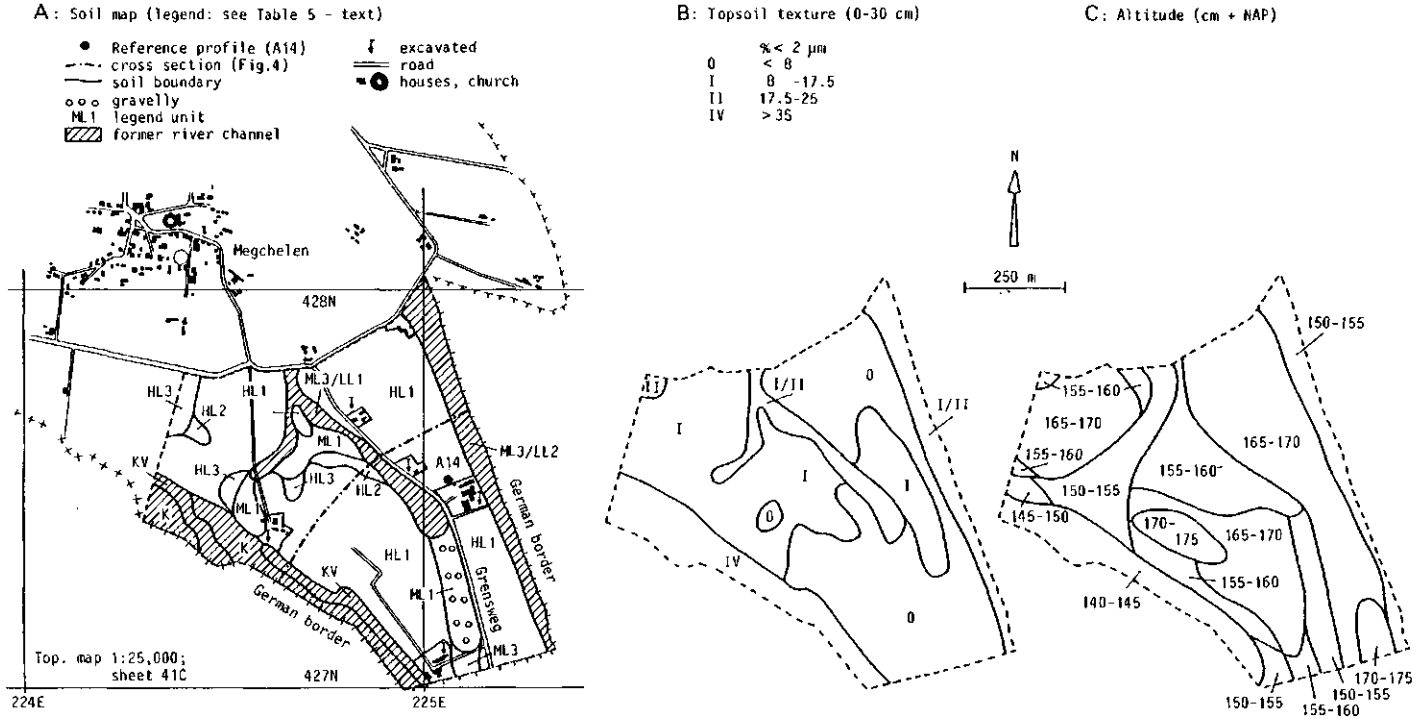
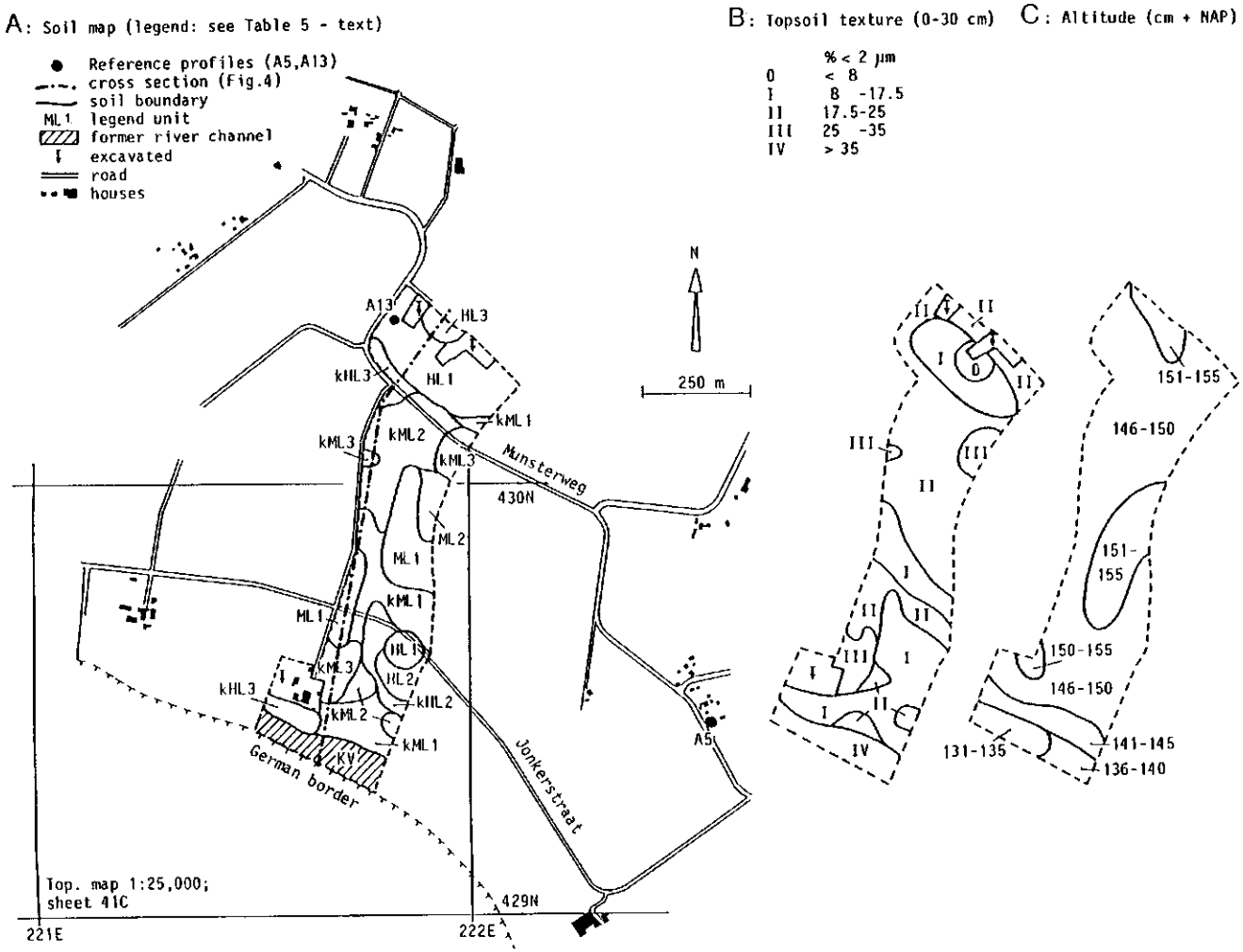


Fig. 24. The Megchelen channel (Landwehr) where palygonological samples were taken. Terrace plateau with HL1 soils in background (arable land).

drain towards the Holocene channel. A similar situation is found in the Asbroek area (section 2.7.3.6.). Topsoil textures (Fig. 23B) of the Late Weichselian surface are sand (0) to slightly clayey (I), whereas channels in the terrace are filled with slightly finer textured material (I/II). The Holocene infilling of the southwestern channel is much finer (IV).

The elevation map (Fig. 23C) shows the incision of the southwestern channel very clearly. Also, the channels in the Late Weichselian surface are one to two metres lower than the surrounding terrace, but transition to the plateau is gradual, while the eastern channel again shows an abrupt descent. The bifurcated channel was the first to be abandoned, followed by the eastern channel, which shows some depth erosion. The southwestern channel alone remained active through the early Holocene. Holocene sediments have not been encountered in the other channels, unless part of the Weichselian material was redeposited. Within the Late Weichselian material, hydrology is clearly related to elevation (Fig. 23C). Topsoil texture allows a sand member and a slightly clayey member to be distinguished in HL1. The occurrence of sand in the highest positions is not consistent throughout the area.

Fig. 25. Soil map (A), topsoil texture (B) and altitude (C) of the Asbroek area.



2.7.3.6. ASBROEK AREA (Fig. 25)

This area covers about 25 ha and ranges in elevation between 13 and 15.5 m above NAP. It was surveyed with some 100 augerings. The soil units and cross section were described by Broekhuizen and Epema (1979).
On the southern margin an erosive outer bend of a Holocene channel is indicated by KV. Its position and genesis is comparable with the Holocene channel of the Megchelen area. In the north is an elevated area with well-drained, sometimes fine-textured sandy soils (HL1, Asbroek reference profile A13).

Fig. 26. Barely perceptible microtopography with ML1 and ML2 soils on the higher elevations (farmhouse) and kML2 soils in the foreground (grassland).

In the eastern part of the tract between Munsterweg and Jonkerstraat (Fig. 26) is a relatively elevated part with ML1 and ML2 soils, and immediately south of the Jonkerstraat are coarse-textured, well-drained soils (HL1, HL2) at slightly lower elevation. In the south and centre, the Late Weichselian deposits have a thin veneer of Holocene clay (Gendringen II, A5, is a reference profile in kML2 from the near surroundings). Areas without Holocene cover are only decimetres higher than those with this cover. Despite the apparent flatness of the surface, soils vary considerably in hydrology and texture.
Topsoil textures (Fig. 25B) show areas of class I, surrounded by class II.

Class III is encountered sporadically. In the north and the south, texture class I corresponds with part of the HL units, but evidently, variations in hydrology are more pronounced than variations in topsoil texture. Thickness of the Holocene cover, and mixing of thin Holocene covers with underlying Late Weichselian material obscures the correlation between texture and hydrology of the Late Weichselian soils. The elevation map (Fig. 25C) indicates three relatively higher areas. Except for the area along the Jonkerstraat, these correspond with the occurrence of better-drained soils. Incision of the Holocene channel is clear; its surface is 0.5 to 1.5 below the adjacent Late Weichselian terrace.
Vaiations in hydrology and thickness of Holocene cover are not clearly related to microtopography.

2.7.3.7. VELDHUNTEN AREA (Fig. 27)

This area covers about 30 ha and ranges in elevation between 13.5 and 15 m above NAP. It was surveyed with some 120 augerings. Soil units and cross section were described by Broekhuizen and Epema (1979).
In the north, at the elevation of the hamlet of Veldhunten, the soils are shallow, coarse-textured HL1. With the exception of this area, and a small enclave of ML1 and HL2 in the southeast, all soils have a Holocene cover. The Gendringen I reference profile (A4) is representative of unit ML1, but was taken outside the surveyed area. In most of the Veldhunten survey, the Late Weichselian deposits are covered by less than 40 cm of Holocene clay (k--); the deposit is thicker in former channels, where units K--, K and KV may be encountered. The palynology of the infilling of the Roode Wetering (section 2.5.2.2.) indicates that this channel was abandoned during the Late Weichselian. The general aspect of the area is that of an alternation of former ridges and channels covered with Holocene sediments. Differences are mainly in hydrology. Reference profiles are Azewijn I (A10, kML2) and Azewijn IV (A11, kHL3), both from just outside the surveyed area.
The northern part has a predominantly east-west drainage pattern, while the southern part shows a southeast-northwest course. At the transition is a distinct channel (K, with flanks of kLL1). This channel joins the Roode Wetering just north of the surveyed area.

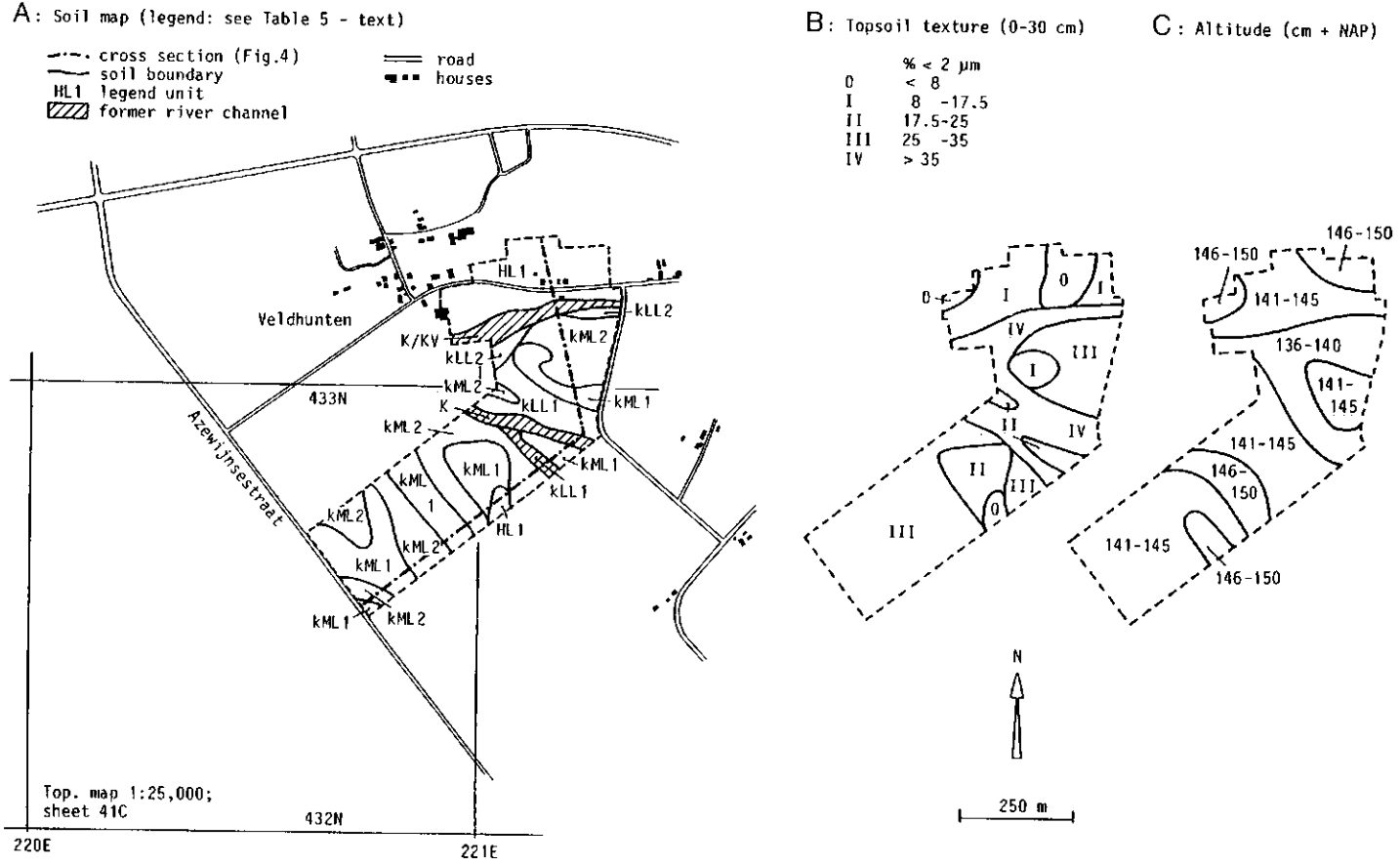


Fig. 27. Soil map (A), topsoil texture (B) and altitude (C) of the Veldhunten area.

Topsoil textures (Fig. 27B) indicate fine-textured (IV) sediments in the main channels; Class III textures occur widespread south of the Roode Wetering, and coarse-textured topsoils are mainly confined to the northern part, near Veldhunten hamlet. Topsoil textures reflect the influence of the uniform Holocene cover, which is partly mixed with the more variable Late Weichselian subsoil. The degree of mixing partly depends on hydrology.
Ridges and channels are recognizable on the elevation map (Fig. 27C). The pattern does not coincide with that of the hydrological units, because the 50 cm interval of the altitude map is too coarse.

2.7.4 COMPARISON WITH EXISTING SOIL MAPS

The soil map 1:25.000 of Pons (1966) includes the Heumen area. The similarity between that map and our 1:10.000 soil map (Fig. 15) is striking. The larger scale of our soil map permitted a mappable subdivision of the three main units of well drained brown, imperfectly drained mottled and poorly drained grey Late Weichselian soils. Less detail is shown on the 1:50.000 soil map covering that area (sheet 46 West, Vierlingsbeek) published by the Soil Survey Institute (1976), but the map pattern agrees with our soil map.
The soil map 1:25.000 of Schelling (1951) includes the Siebengewald, Ottersum and Milsbeek areas. In comparison with our 1:10.000 soil maps (Figs. 17, 19, 21) there is one consistent difference: the extent of poorly drained grey soils on Schelling's map is much larger than on our soil maps. Our mapping proved to separate the soils with an argillic horizon which subsequently experienced (pseudo)gley to a varying extent from those soils that do not have an argillic horizon due to their poor drainage position throughout time (correlation with soil formation, chapter 3). On the 1:50.000 soil map (sheet 46 West, Vierlingsbeek) covering those areas the limitations of mapping on a smaller scale necessitated generalizations, but the general map pattern agrees with our soil maps. It is surprising is that in similar soils on the same well-drained ridge near Ottersum an argillic horizon may or may not be present. This will be discussed further in chapter 3.
The 1:10.000 soil map of Koenigs (1949) covers the Asbroek and Veldhunten

areas (Figs. 25, 27). As his soil map is based on separation of Late Weichselian and Holocene deposits in combination with their texture, it is difficult to compare it with our soil maps, which are primarily based on hydrology. The textures correspond reasonably and the map pattern also shows similarities, because of the correlations between texture and landscape position evident from the cross sections. One general difference is that Koenigs assigned the well-drained brown soils to the Holocene sediments whereas they belong to the well-drained Late Weichselian deposits; this can be proved by the soil formation (chapter 3).
The 1:50.000 map sheet 41 West, Aalten published by Soil Survey Institute (1983) covers the Megchelen, Asbroek and Veldhunten area (Figs. 23, 25, 27). The map pattern shows similarities, but in a more generalized way, because of the scale of the map. On this map sheet it is striking that the well drained Late Weichselian soils with an argillic horizon are limited to the German territory. On the German soil map of the same area (Sheet L4104, Bocholt) published by GLA (1983) soils with an argillic B-horizon are indicated on Dutch territory, too.

2.7.5. THE HOLOCENE REFERENCE PROFILES

The many reference profiles representative of the variation in Late Weichselian soils were compared with Holocene non-calcareous and calcareous reference profiles. The site for these reference profiles was selected from existing detailed soil maps. The choice of profiles was guided by the wish to sample a texture range comparable with the texture range in the sampled Late Weichselian soils. It is difficult to find non-calcareous coarse-textured Holocene soils. The sampled Weurt profile (A18) is coarse-textured, and has a very coarse sand fraction because of the neighbouring ice-pushed ridge of Nijmegen. The sampled Ewijk profile (A17) is situated in a complex part of the fluvial area and has a deeper, Late Weichselian deeper subsoil. The choice of the site of these sample profiles was based on the soil maps 1:25.000 by Pons (1966). The sampled Randwijk profile (A19) is situated in a transitional position to a backswamp and is fine-textured. The age of these non-calcareous reference profiles is estimated to be around 2000 years based on the sedimentation history described by Pons (1957,1966) for the Weurt and

Ewijk sites and Havinga and Op 't Hof (1969, 1975, 1984) for related areas in the Betuwe. The intermediate position of the sampled non-calcareous reference profiles is frequently mentioned in the discussions about their properties. Their drainage position ranges from moderately well-drained (A18) to imperfectly drained (A17, A19).

The calcareous Holocene reference profiles were sampled in the recently diked Maas, Lede and Oudewaard polder between Kesteren and Lienden. Diking of this polder was completed in 1805, sedimentation continued untill then. In this polder the profiles Kesteren (A20) and Lienden (A21) were sampled. The sites were based on the detailed 1:10.000 soil map of this polder. In order to achieve the goal of sampling a representative and comparable texture range in the Late Weichselian and non-calcareous Holocene soils, a fine-textured calcareous profile had to be found. This profile was found in the foreland near Opheusden (A22). These three calcareous Holocene profiles are representative for very young Rhine soils. Their drainage position is moderately well drained. Profile photographs are given in Appendix A.

2.7.6. LAND USE

The land use of the reference profiles is indicated in Table 6. On the selected sites the land use was similar to that of the surrounding area. In each investigated area the land use was partly arable, partly grassland. In cases where the present land use differs from the land use of previous years this is indicated.

Table 6: Land use of the reference profiles

	arable land	grassland
Late Weichselian soils	A1, A2, A7, A9	A3, A4*, A5*, A8, A6*, A10, A11, A12, A13*, A14, A15*, A16*
Holocene non calcareous soils	A17, A19	A18*
Holocene calcareous soils	A20, A21	A22

* former arable land

3. SOIL FORMATION

3.1. MORPHOLOGICAL ASPECTS

The reference soils have been subdivided into Late Weichselian and Holocene Rhine soils. Further subdivision of the Late Weichselian soils into 'well drained brown' soils (HB), 'imperfectly drained mottled' soils (MB) and 'poorly drained grey' soils (LG) (Fig. 14) follows the mapping units of our soil survey (section 2.7). The subdivision of the Holocene soils into non-calcareous (Ca0) and calcareous (Ca1) soils reflects age differences: non-calcareous soils are roughly 2000 years old and calcareous soils are developed in sediments of some 500 years of age. This subdivision will be used throughout the following chapters.

The following soil-forming processes can be inferred from profile descriptions and thin section studies:

- weathering of silicate minerals
- physical reorientations resulting from stress and friction
- decalcification
- clay and groundmass illuviation
- pseudogleying and gleying
- biological activity
- human activity.

Table 7 summarizes the macromorphological features pertinent to these processes and Tables 8 through 11 summarize micromorphological aspects. Full details are given in Appendix A, and in unpublished reports of Van Engelen, (1975), Vlaanderen (1976), De Kreij (1976), Van Dis and Robben (1978), Druijff (1979) and Broekhuizen and Epema (1979).

3.1.1. PARENT MATERIAL AND WEATHERING

Macroscopic aspects related to parent material include geogenic stratification and texture. In all the reference soils, macroscopically visible geogenic stratification is found in the sandy subsoil; in the

overlying finer strata it is not evident. Microscopically, evidence of geogenic stratification is found in clustered and banded distribution patterns of skeleton grains and plasma. The depth at which these microscopic phenomena are encountered is related to the relative drainage position of the soils: in poorly drained soils they are found at shallow depth, in well drained soils such structures have been obliterated to greater depth. Also in young soils (Cal) microscopic evidence of geogenic stratification is encountered at shallow depth.

All reference soils have a similar range in clay content (Table 8); this was the original aim of the sampling and enables us to compare other characteristics (Detailed grain-size frequency analyses of the reference profiles were discussed in section 2.4.2).

The main evidence for weathering is the brown colour of soils in well drained positions. Microscopically, weathering is indicated by dissolution and alteration of skeleton grains and rock fragments, accompanied by the formation or iron hydroxide segregations in and on grains. The original mineralogical composition of the sand fractions of the investigated soils shows only minor differences, but their weathering status is clearly different.

In both Holocene and Late Weichselian soils, some 20-30% of the skeleton grains are non-quartz. These include micas (muscovite, biotite), feldspars, glauconite, some volcanic fragments and other, unidentified, minerals.

The Holocene soils show fresh mineral grains without alteration phenomena and no changes in contents of easily weatherable minerals with depth were observed in these soils. Late Weichselian soils show stronger weathering, illustrated by smaller amounts of micas and feldspars in the topsoils and by alteration phenomena such as exfoliation of biotite and liberation of Fe along microcracks (Fig. 28). Such weathering phenomena are particularly evident in the well drained brown (HB) and imperfectly drained mottled (MB) soils and are also detected in the composition of the clay fraction (section 3.2.1). Weathering phenomena in the topsoils were reported earlier by Miedema *et al.* (1978).

Primary calcite skeleton grains are encountered throughout the profile of all Holocene calcareous soils (Cal) and become more numerous with depth. Primary calcite was also observed in the subsoil of the non-calcareous Weurt soil (A18), which is transitional to the Cal soils. The occurrence of primary calcite in the imperfectly drained Late Weichselian Azewijn I soil

Table 7. Summary of some macromorphological observations from the profile descriptions of the reference soils.

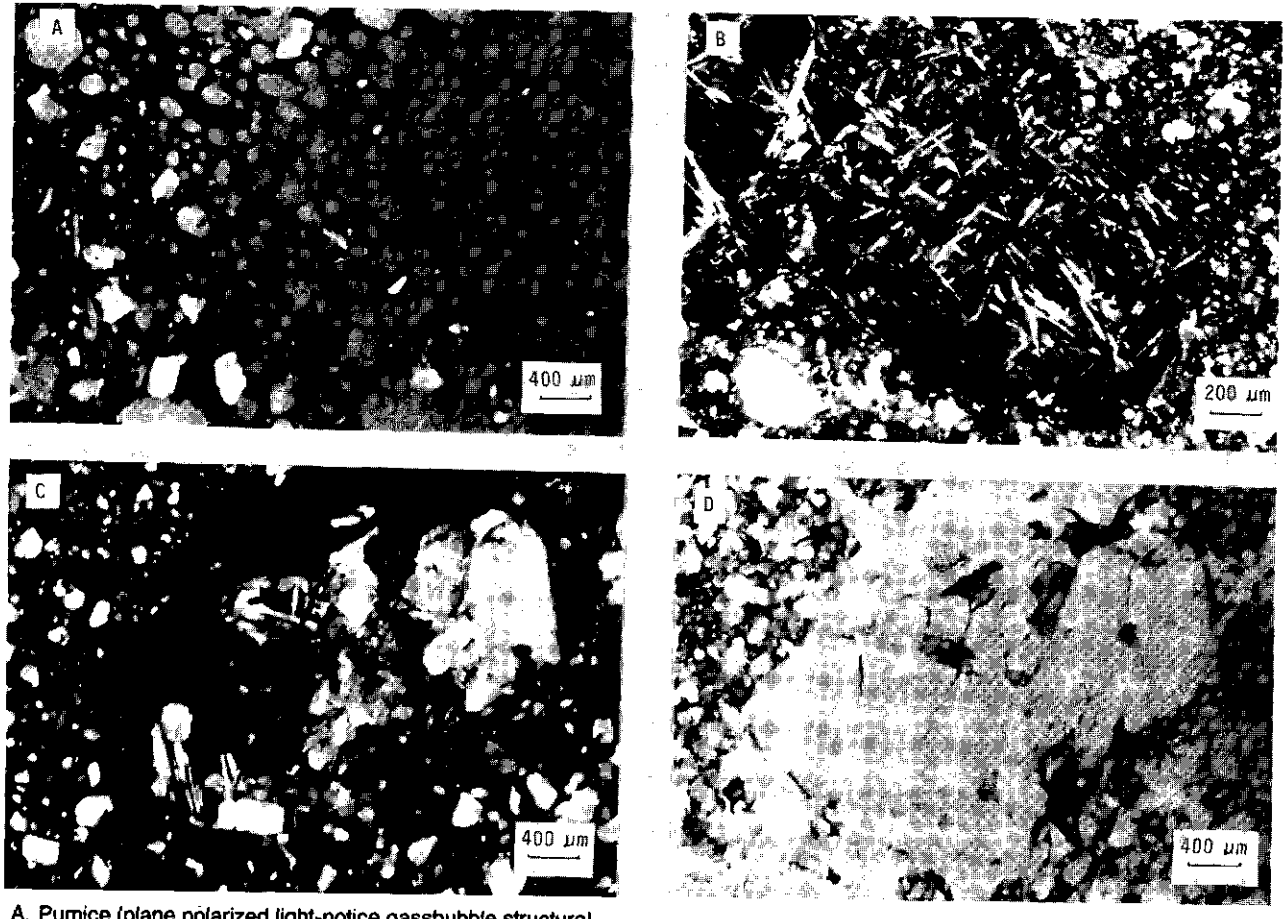
			Consistence	Structure	Biopores		Pseudogley(ps)	Bt	Human
			moist	macro	large	fine	Gley(g)	lamellae	activity
Group	Code	Name							
HB	A1	Heumen I	friable	sab-sponge	++	+++	(+)ps	+	plaggen epipedon
	A6	Ottersum	friable	sab-sponge	++(+)	+++	-	+	Ap
	A11	Azewijn IV	friable(firm)	sab-sponge	++	+++	(+)ps	+	excavation
	A13	Asbroek	(very)firm	cp(sab/ab)	++	++	(+)ps	(+)	Ap
	A14	Megchelen	friable(firm)	sab-sponge	+++	+++	(+)ps	(+)	Ap/excavation
	A15	Ven-Zelderheide	friable	sponge	++(+)	+++	-	+	Ap
	A16	Millingen	firm(friable)	cp(ab)	+++	+++	(+)ps	+	Ap
MB	A2	Heumen II	firm	cp(ab/sab)	+++	++	++ps+g	-	Ap
	A4	Gendringen I	(very)firm(friable)	sab	++	+++	+(+)ps	+	Ap
	A5	Gendringen II	firm	cp(sab)	+(+)	++	++ps+g	-	Ap
	A7	Siebengewald	firm	sab	+	++	++ps	+	Ap
	A9	Aaldonk	firm(friable)	cp(sab)	+	+(+)	++ps+g	-	Ap
	A10	Azewijn I	(very)firm	cp(ab/sab)	+	++	++ps+g	-	excavation
	A12	Woezik	firm(friable)	ab	+	++	++ps+g	-	Ap
LG	A3	Heumen III	firm	cp(ab)	+++	+++	+g	-	topsoil
	A8	Milsbeek	firm	cp(sab)	+	+++	+g	-	-
CaO	A17	Ewijk	firm(friable)	cp(ab)	+	++(+)	+(+)g+ps	-	Ap
	A18	Weurt	friable(firm)	cp(sab/sponge)	+++	+++	(+)g	-	Ap
	A19	Randwijk	firm	sp-ab	+	+	++g	-	Ap
Cal	A20	Kesteren	friable(firm)	sab-sponge	+++	+++	(+)g	-	Ap/plowpan
	A21	Lienden	friable	cp(ab/sab-sponge)	+++	+++	(+)g	-	Ap/plowpan
	A22	Opheusden	friable(firm)	cp(ab/sab-sponge)	+++	+++	(+)g	-	excavation

Key:	Biopores	+	few	Bt lamellae	-	absent
		++	common		(+)	thin
		+++	many		+	clear
	Pseudogley/Gley	-	absent	Structure	sab	subangular blocky structure
		(+)	weak		ab	angular blocky structure
		+	clear		cp	compound prismatic structure
		++	very clear		sp	simple prismatic structure

(A10) and in the poorly drained Late Weichselian Milsbeek soil (A8) will be discussed in section 3.1.3.

Fragments of pumice (Fig. 28), originating from the Allerød-time eruption of the Laacher See, have been observed in small quantities in the topsoils of some Late Weichselian soils (A1, A2, A3, A4, A5, A6, A8, A13). All these soils are situated in abandoned floodplains of the river Rhine. Apparently, these soils have received little or no sediment in and since the Allerød. The well drained Late Weichselian Millingen soil (A16) lies within, but slightly above the present floodplain and has pumice throughout the sampled depth. This indicates an active sedimentation during the Allerød stage, because its position precludes Holocene sedimentation.

Fig. 28. Parent material and weathering.



A. Pumice (plane polarized light-notice gassbubble structure)
B. Pumice (cross polarized light-notice lath shaped plagioclase feldspars)
C. Iron liberation in microcracks of rockfragment (cross polarized light)
D. Iron liberation in microcracks of rockfragment (plane polarized light)

Laacher See pumice was also sedimented in the Holocene floodplain, as is evident from its presence throughout the sampled depth in the non-calcareous Weurt soil (A18) and in the topsoils of the non-calcareous Randwijk soil (A19) and the calcareous Kesteren (A20) and Lienden (A21) soils.

3.1.2. PHYSICAL PROCESSES AND PLASMA REORIENTATIONS

Physical processes in the soil are macroscopically reflected by partly or fully physicogenic structures, such as angular blocky and simple smooth prismatic structures. These are normally linked with a high clay content and reflect the occurrence of swelling and shrinking. The physicogenic structures have generally been modified by biological activity (section 3.1.5). Micromorphologically, physical processes are reflected in the plasmic fabric. Stress and friction cause the clay plasma to be reoriented with respect to the skeleton grains ('plasma separations', Brewer, 1964, b-fabrics, Bullock *et al*, 1985).

Table 8 summarizes the major groundmass characteristics and reorientations encountered in the reference profiles (Fig. 29). The relation of the clay plasma with the silt and sand fractions, in microscopic dimensions, is expressed in the 'related distribution pattern' (Table 8), which includes microporosity. This groundmass microstructure determines the 'consistence', which was determined in the field and included in the profile descriptions. The estimates of fine (meso) and large (macro) pores in the profile description complete the structural aspects from micro to macro dimensions. Table 7 (macrostructure, consistence and biopores) and Table 8 (micromorphological groundmass characteristics) thus provide the information for the following discussion.

The *well drained, medium-textured brown Late Weichselian (HB) soils* have subangular blocky structures tending to sponge structures. In the fine and very coarse sandy variants these are bound up in compound rough prismatic structures. The plasmic fabric is asepic, or asepic with locally sepic parts (A11, A13, A15); the finer-textured variant (A16) has a distinctly sepic plasmic fabric (Fig. 29). In all the soils investigated, skelsepic and insepic reorientations are very common; in the finer-textured variant, omnisepic plasmic fabrics also occur.

Table 8. Groundmass and reorientation characteristics of the groups of reference soils,

	Late Weichselian			Holocene	
	HB	MB	LG	CaO	Cal
Features/characteristic					
Biogenic voids (vughs, channels)	++	+	+	+/++	+++
Homogenisation depth(cm)	50-100	20-50	0-40	50-70	30-50
Physicogenic voids (planes)	-/+	++	+/++	++	++
Sepic plasmic fabrics	-/+/++(+)	++(+)	+/+++	+(+)	-
skelsepic	1.6	2.1	1.5	0.5	0.3
glaesepic	0.7	1.3	-	0.5	-
vosepic	0.1	1.8	1.5	1.0	0.3
insepic	1.7	1.9	1.5	0.5	0.7
omnisepic	1.0	1.8	1.5	1.0	-
masepic	-	0.9	0.5	0.5	0.7
average intensity of sepic fabrics	0.9	1.6	1.1	0.7	0.3
range in clay (%)	10-40	15-45	20-40	15-45	20-40
crystic plasmic fabric	-	_1)	_1)	_1)	++(+)
related distribution pattern	pp/dp	vdp	(v)dp	dp/vpp	vpp

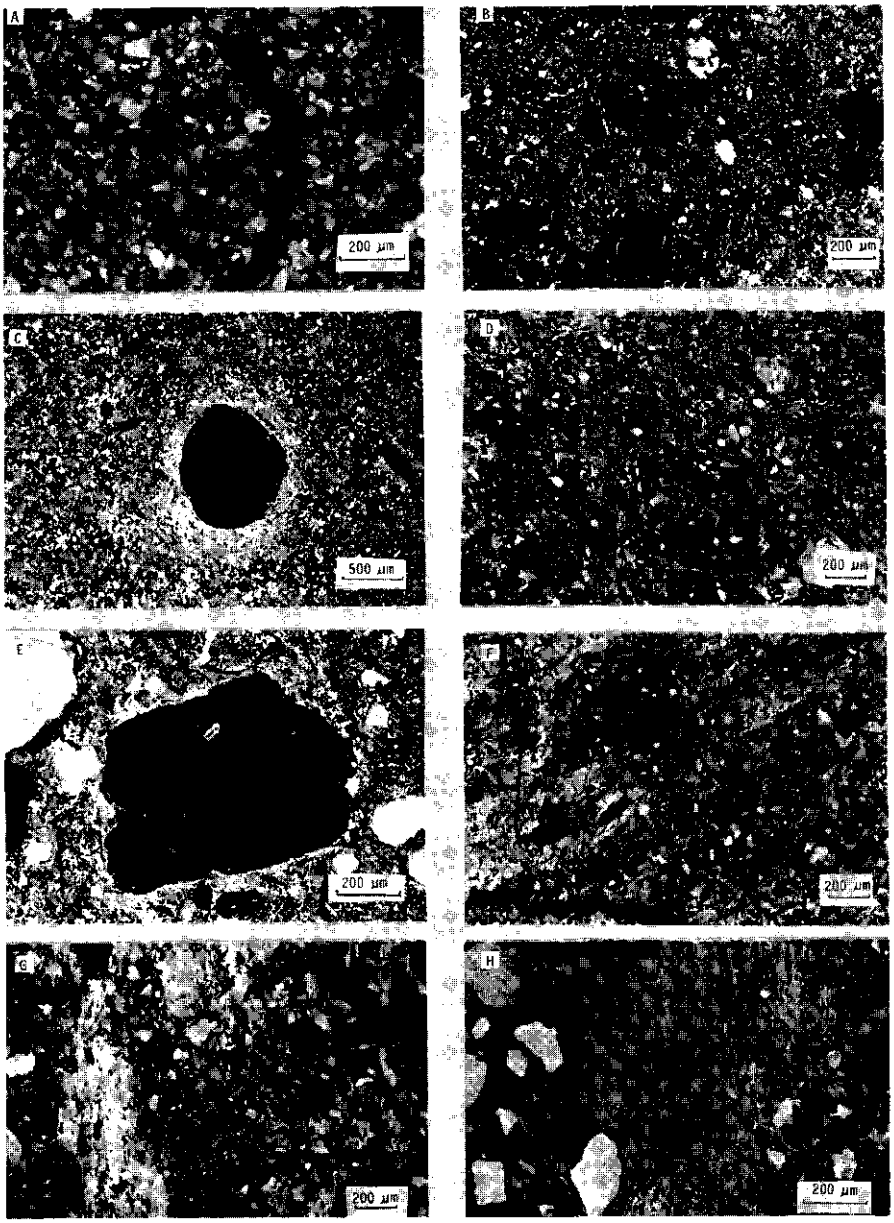
Key: Biogenic voids - absent; Plasmic fabric - absent; Calculation: Averages
Physicogenic voids + few; + faint; using faint= 1, clear=2 and
++ common; ++ clear; prominent= 3
+++ many; +++ prominent

Related distribution pattern: vpp = very porous porphyroskelic
pp = porous porphyroskelic
dp = dense porphyroskelic
vdp = very dense porphyroskelic

1) Azewijn I (A10), Milsbeek (A8) and Weurt (A18) have layers in the subsoil with crystic plasmic fabrics.

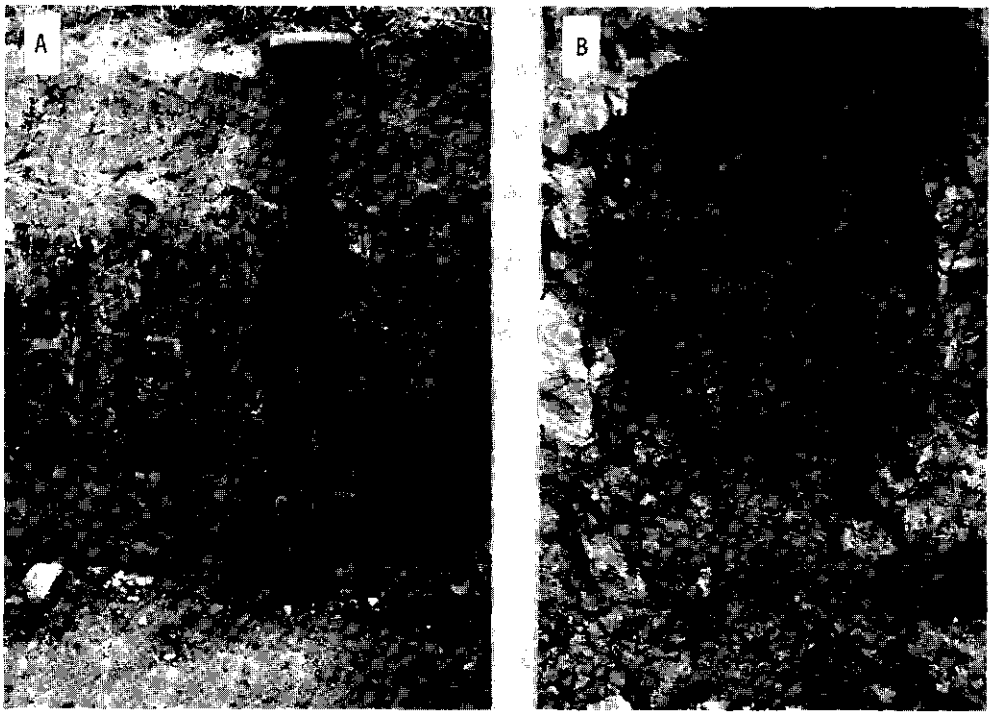
The high biogenic microporosity (Table 8) and the many meso and macro biopores indicate that these soils have a friable consistence. Despite this biological activity, skelsepic, locally, even insepic fabrics are found embedded in the groundmass, especially in the sandier variants. Such embedded insepic fabrics may cause a firm consistence. They are responsible for the firm to friable consistence encountered in the fine-textured variant (A16) where sepic fabrics (omnisepic and insepic) are common, although biological activity is very high also in this profile. Continuous and intense biological activity (section 3.1.5.) in the well drained soils has obliterated most of the fabrics that are the result of physical processes (stress, friction), and caused a porous porphyroskelic related distribution pattern.

Fig. 29. Plasmic fabrics in Late Weichselian and Holocene reference profiles.



A. Crystic plasmic fabric (cross polarized light)-Holocene Cal soils
B. Asepic plasmic fabric (cross polarized light)-Holocene Ca0 soils
C. Vosepic plasmic fabric (cross polarized light)-Holocene Ca0 soils
D. Insepic plasmic fabric (cross polarized light)-Late Weichselian soils
E. Skelsepic plasmic fabric (cross polarized light)-Late Weichselian soils
F. Omnisepic plasmic fabric (cross polarized light)-Late Weichselian soils
G. Omnisepic and unistrial plasmic fabrics (cross polarized light)-Late Weichselian soils
   Note also ferri-argillic papules (clay illuviation - right hand corner of the photo)
H. Unistrial plasmic fabric (cross polarized light)-Late Weichselian soils

Fig. 30. Large worm channels in imperfectly drained MB soils resulting from recently improved drainage.



A. Imperfectly drained MB profile (Heumen II - spade is 120 cm)
B. Large worm channels penetrating to sand subsoil (knife grip is 10 cm)

The *imperfectly drained, medium-textured Late Weichselian (MB) soils* have subangular blocky structures, frequently organized into compound rough prismatic structures. Although the meso/macro porosity is occasionally high, microporosity is always low and as a result these soils have a characteristic firm to very firm consistence. The plasmic fabric is moderately to strongly sepic, with dominating skelsepic, insepic, omnisepic and vosepic reorientations (Fig. 29). These reorientation fabrics are the result of physical processes and have not been obliterated by biological activity (see section 3.1.6). The many large biopores found in some of these soils (Fig. 30) have been formed in the last 30 years, since the drainage has been improved. Thin sections show coarse skeleton grains embedded in a very dense groundmass and the related distribution pattern is therefore

described as very dense porphyroskelic. (Table 8).

The *poorly drained, medium to fine-textured Late Weichselian (LG) soils* show a compound rough prismatic structure, subdivided into angular and subangular blocky structures. The plasmic fabrics in the two reference soils are very different. The Heumen III soil (A3) has clear sepic fabrics (skelsepic, omnisepic and vosepic plasma reorientations). The Milsbeek soil (A8) does not have clear sepic fabrics apart from some skelsepic fabrics around embedded sand grains, but it has a crystic plasmic fabric between 45 and 70 cm depth. Both soils have low microporosity; their mesoporosity is high because of to their grassy vegetation. Macroporosity is high in A3, where earthworms benefit from recently improved drainage, but is low in A8, which is situated in a still swampy position. Because the biological activity in both soils is relatively low, the reorganizations, which are mainly the results of physical processes, have been left practically intact. As a result, both soils have a firm consistence, because of a dense porphyroskelic related distribution pattern.

The *moderately well to imperfectly drained, non-calcareous, medium to fine-textured Holocene (Ca0) soils* show prismatic structures that are normally subdivided into angular blocky structures. The Weurt soil (A18) is transitional to the calcareous Ca1 soils and has a subangular blocky structure, tending to spongy. The Ca0 group is diverse because as well as the transitional soil A18 it contains a soil with a Late Weichselian subsoil (Ewijk, A17), transitional to the MB group, and a fine-textured, imperfectly drained soil (Randwijk, A19). Accordingly, the plasmic fabrics of these soils vary: the Weurt soil (A18) has an asepic fabric; the Holocene part of A17 has a faintly sepic fabric and the Randwijk soil (A19) is sepic throughout. Micropores and macropores are few in A17 and A19 but many in A18. Mesopores are few in A19 but many in A17 and A18. This results in a friable (locally firm) consistence in A18, which has a very porous porphyroskelic related distribution. A17 and A19 have a firm (locally friable) consistence and a dense porphyroskelic related distribution. Physical reorientations are strongly related to clay content and comprise vosepic and masepic fabrics; insepic and omnisepic reorientations are exclusively encountered in the Late Weichselian subsoil of A17.

The *moderately well drained, medium to fine-textured, calcareous Holocene (Ca1) soils* show angular and subangular blocky structures tending to sponge structures, which are organized in compound rough prismatic structures in

the finer-textured variants (A21, A22). The plasmic fabric (Fig. 29) is crystic in the subsoils and asepic in the topsoils; some faint sepic fabrics occur locally in the fine-textured profiles A21 and A22. Micro, meso and macro porosity are very high in all three soils. This leads, characteristically, to friable soils with very porous porphyroskelic related distributions. Plough layers (Ap), traffic pans and finer layers may still have a firm consistence. Because they are extremely young, these levee and foreland soils with very high biological activity still contain micro evidence of geogenic stratification at shallow depth.

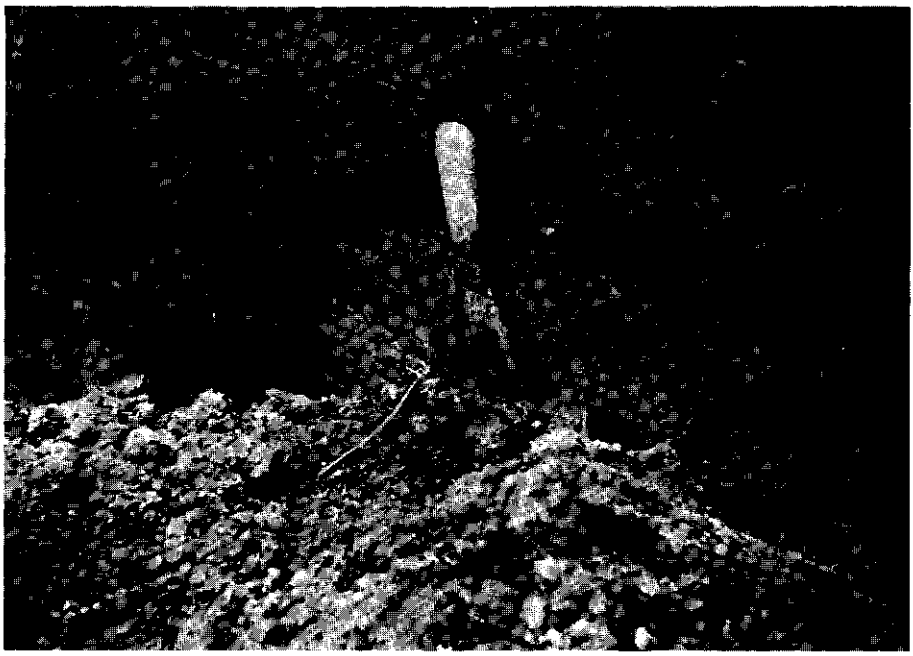
An outstanding difference between the Late Weichselian and the Holocene soils is the strong expression of sepic fabrics, even in coarse and medium-textured material, in the former, and an absence, except in fine-textured variants, in the latter. In the Late Weichselian soils, the very dense porphyroskelic fabric leads to a very firm to very firm consistence. Only in the well drained HB soils are the sepic fabrics largely obliterated by biological activity.
The types of sepic fabrics (insepic, omnisepic, locally unistrial-Fig. 29), point to conditions of repeated melting and freezing and were formed in the periglacial conditions of the Late Weichselian period. The effect of this microstructure is enhanced by the absence of silt/fine sand (i.e. coarse sand skeleton grains embedded in reoriented clay plasma) and the virtual absence of organic matter below the A horizons in these Late Weichselian soils. In the Holocene soils, the crystic plasmic fabric changes into an asepic plasmic fabric by decalcification. Vosepic and masepic reorientations resulting from to swelling and shrinking only occur in the finer-textured non-calcareous soils.
The influence of microstructure on the physical behaviour of the soils will be discussed in Chapter 4 and 5.

3.1.3. DECALCIFICATION.

Calcium carbonate occurs erratically in the *Late Weichselian soils*, but it is always found in the vicinity of former river channels (Jongmans and Miedema, 1986b). Of the reference soils, only the poorly drained Milsbeek

soil (A8) and the imperfectly drained Azewijn I soil (A10) contained primary calcite. In certain other soils (A1, A4, A5, A7, A14) topsoils contained calcite because of additions of sugarsludge lime. In the Heumen area, an imperfectly drained profile (Heumen V) not described in detail here lies close to reference profile Heumen II (A2) and was found to contain primary calcite in the subsoil. All the other Late Weichselian soils are non-calcareous. The occurrence of calcite between 45 and 70 cm depth in Milsbeek (A8) was not detected when the profile was first described, but subsequent inspection of the site indicated that the calcite-rich material was restricted to several cubic metres only (Fig. 31). The primary calcite skeleton grains have sizes similar to those of the other skeleton grains in the same layer. They show dissolution holes (Fig. 32) and corroded edges. Primary calcite is also present in the form of fragments of snail shells. Secondary calcite occurs as calcite nodules, neocalcitans and calcitans and crystal tubes, which all point to reprecipitation of dissolved calcite. Below 70 cm depth, corroded primary calcite grains are encountered only sporadically. Calcite grains are also detected in the topsoil, presumably because of biological translocation.

Fig. 31. Calcareous bodies in Late Weichselian soils (measure is 20 cm).

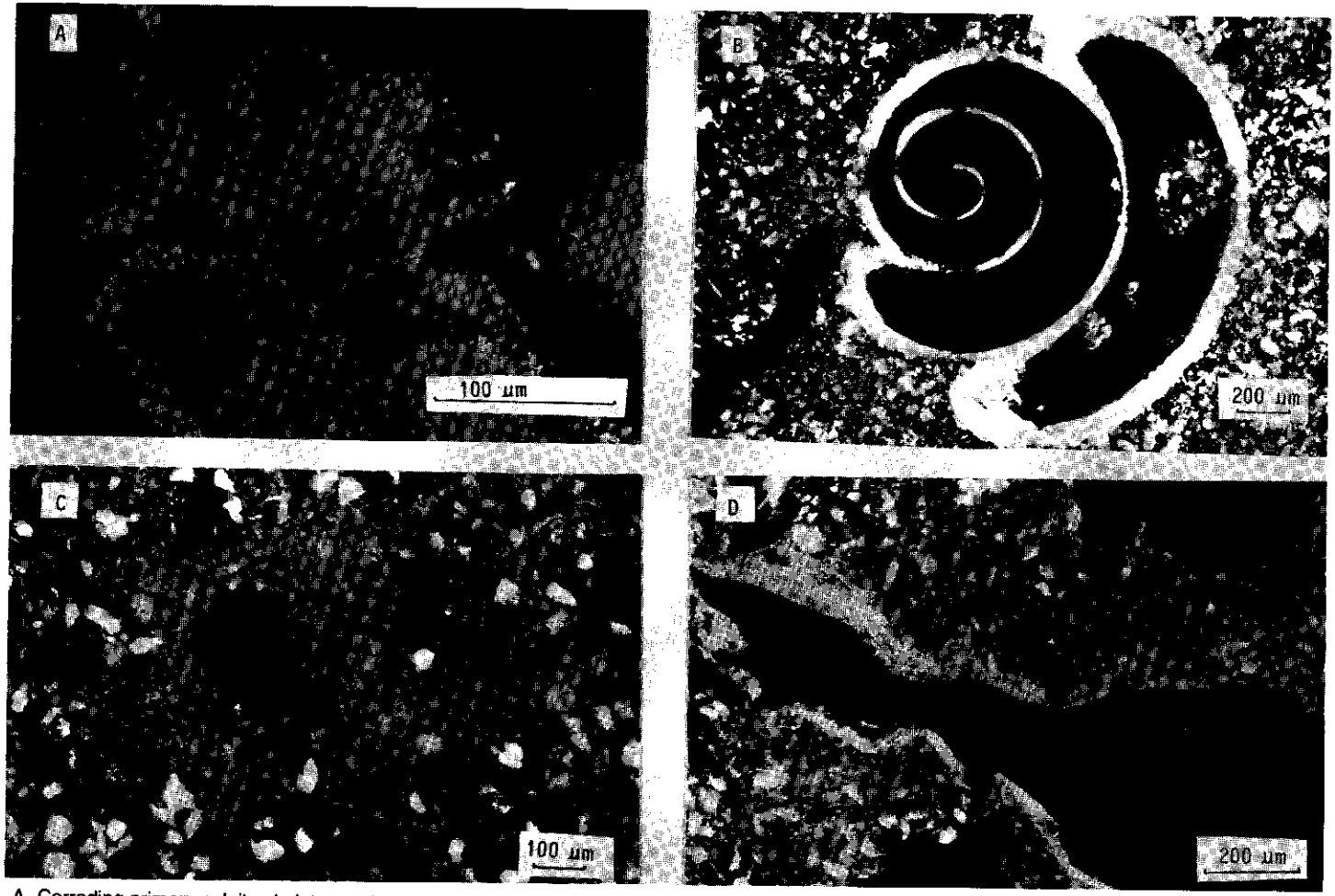


In the Azewijn soil (A10), calcite is dominantly present in secondary forms such as calcitic nodules, neocalcitans and calcitans and calcitic tubes, between 110 and 120 cm depth. Some of these secondary forms occur in banded distribution patterns related to geogenic stratification. Below 120 cm corroded primary calcite skeleton grains, of sizes similar to those of the other skeleton grains, predominate. Between 110 and 120 cm depth shell fragments are common. The locally cryoturbated 'calcareous dril' (Koenigs, 1949) appears to be a local accumulation of part of the calcite that was dissolved from the Late Weichselian deposits. Similar accumulations were encountered at the bottom of deep former river channels as lime gyttja or hard calcite concretions (section 2.4.1.; cross sections). Our own palynological investigation of the Veldhunten channel (Roode Wetering, section 2.5.2.2) indicates that this lime gyttja is of Late Weichselian age. The cryoturbation of this material, mentioned by Koenigs (1949) corroborates this dating.

Calcite, related to the sedimentary stratification, was observed between 75 and 130 cm depth in profile Heumen V. Contents of corroded primary calcite skeleton grains vary from absent to abundant. Secondary calcite occurs in an banded distribution (geogenic stratification), as calcitic nodules, neo calcitans and calcitans and calcitic crystal chambers and tubes. The strong variation in primary calcium carbonate in layers with undisturbed stratification makes speculations on the original calcite content hazardous. Yet it is clear that the calcite grains were deposited with the sediment. In some cases, resedimentation of decalcified material should not be ruled out. The seemingly erratic distribution of calcite along former river channels can be explained by mechanisms operative under periglacial conditions in the Late Weichselian (Jongmans and Miedema, 1986b).

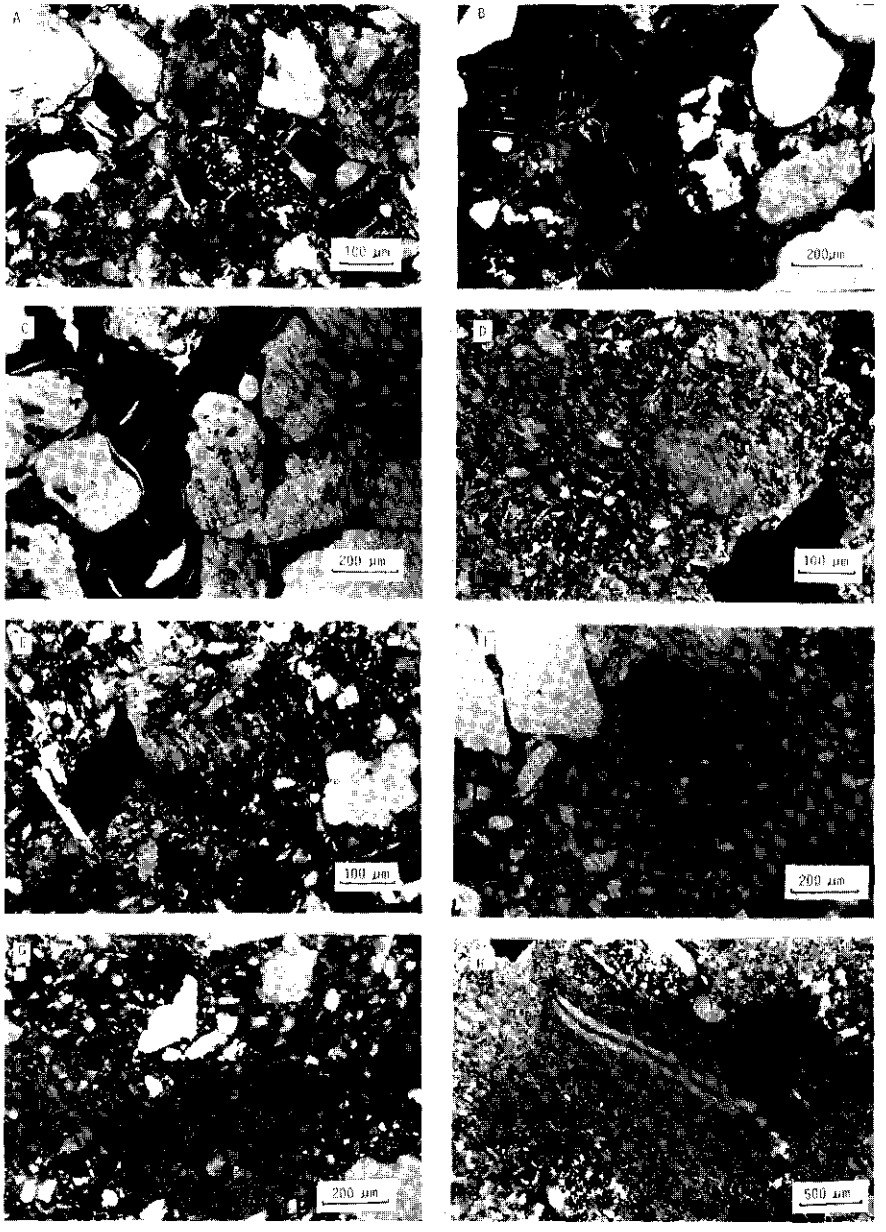
In the *non-calcareous Holocene soils* calcite is only found in the Weurt profile (A18) apart from anthropogenic additions of calcite (A19). In this soil, corroded primary calcite grains are found below 90 cm, in amounts that further increase with depth. Between 83 and 120 cm secondary calcite accumulations are abundant (calcitic nodules, neo calcitans and calcitans, calcitic chambers and tubes). The occurrence of some strongly corroded primary calcite crystals between 0 and 35 cm depth in this profile corroborates the hypothesis that it is composed of two sediment layers. The upper 56 cm is coarse sandy. In contrast, the silt content is higher between 56 and 83 cm (section 2.4.2.) and calcite grains occur only sporadically.

Fig. 32. Calcium carbonate features.



A. Corroding primary calcite skeleton grains in Holocene Cat soils (cross polarized light)
B. Fresh water snail fragment (biorelict) in Holocene Ca1 soils (cross polarized light)
C. Channel neocalcitan in Holocene Cat soils (cross polarized light)
D. Lublinitan in Holocene Cat soils (cross polarized light)

Fig. 33. Clay illuviation and groundmass illuviation features.

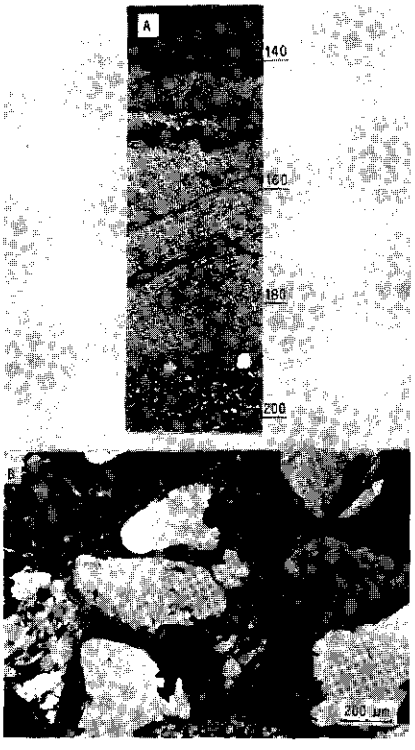


A. Channel ferri-argillans in Late Weichselian HB and MB soils (cross polarized light)
B. Brunified free grain ferri-argillans in Late Weichselian HB soils (cross polarized light)
C. as B (plane polarized light)
D. Ferri-argillic papules in Late Weichselian HB soil (cross polarized light)
E. Matri-ferri-argillan (groundmass illuviation) in Late
F. Weichselian and Holocene soils (cross polarized light)
G. Slaking crust fragments (included in groundmass illuviation
H. (cross polarized light)

The Weurt profile is one of the few Holocene profiles in which a significant part of the dissolved calcite has been re-precipitated within profile depth (horizon designation k). In most profiles, all the calcium bicarbonate has been removed by the groundwater (Miedema, 1980).

All *calcareous Holocene soils* contain primary calcite grains and shell fragments (Fig. 32) throughout. In the topsoils, calcite skeleton grains are less abundant and more strongly corroded, which is reflected by a less violent reaction with 2M HCl. Between 35 and 50 cm depth, the plasmic fabric changes from asepic to crystic. Calcitic nodules and neocalcitans (Fig. 32) are common to few. In the Kesteren soil (A20), an accumulation of calcite (Cgk) is found at the transition to the stratified sandy subsoil. In the Opheusden (A22) and Kesteren (A20) profiles, lublinite was found in large biopores (Fig. 32). Differences between the profiles are small; all profiles have some decalcification of the topsoil, and secondary calcite is not abundant.

Fig. 34. Textural Bt lamellae.



A. Macroscopic (reference profile A15-HB)
B. Microscopic (free grain ferri-argillans - cross polarized light)

3.1.4. CLAY ILLUVIATION AND GROUNDMASS ILLUVIATION

Clay illuviation

Clay illuviation is inferred from the presence in thin sections of void or free grain ferri-argillans and ferri-argillic papules (Fig. 33) which are composed of fine clay. Macromorphologically, clay illuviation can be deduced from the presence of the characteristic Bt lamellae (Dijkerman, 1965; Dijkerman *et al.*, 1967; Van Reeuwijk and De Villiers, 1985) in sandy material (Fig. 34), notably in the Late Weichselian HB soils but also in some MB soils.

Groundmass illuviation is indicated by the presence of matri-ferri-argillans and clusters and cutans of groundmass components that are the result of slaking (Fig. 33). Such concentrations may have considerably more clay than the surrounding groundmass (matri-ferri-argillans), or be almost similar to the surrounding groundmass (matrans). These illuviation features have been quantified by point-counting and are summarized in Table 9.

Table 9 shows that clay illuviation is not found in the Holocene soils. In the Late Weichselian HB and MB soils, clay illuviation features qualify for an argillic horizon (USDA, 1975; FAO, 1974). An illuviation Profile Index (Pi) was calculated for each of the reference soils. This index is obtained by multiplying the thickness of each horizon in cm by the amount of illuviation in %, and adding up the values for all horizons (Miedema and Slager, 1972). In some HB and MB soils, the Pi is strongly influenced by illuviation in lamellae (banded Bt horizon), which have a relatively high content of free-grain ferri-argillans. This is especially the case in the HB soils A11 and A13 and explains the high average Pi in the HB soils. If free-grain argillans are excluded from the profile index, the profile index for HB and MB soils is not significantly different and ranges from 100 to 500 %cm. Such values are commonly found in Dutch Late Weichselian loess soils (Miedema and Slager, 1972) and in Late Weichselian Meuse Soils (Miedema *et al.*, 1983). If the banded Bt horizon is excluded, both thickness of the Bt horizon and amount of illuviation are similar in HB and MB soils. The fraction of in-situ illuviation features (void ferri-argillans) has a mean value of only 40%, which indicates considerable translocation and is also similar in both groups of soils. In the HB soils, translocated fragments are round to square and have a high sphericity; translocation is mainly the

Table 9. Micromorphological quantification of clay and groundmass illuviation in the reference soils.

	Group	Mapping unit	Profile	Code	PI (%cm)	fPIfgfa (%cm)	fPIfap (%cm)	fPIfa (%cm)	fPIp (%cm)	cm Bt	fa/fap x100% Average % fap/cm Bt	In situ (rel %)	Fraction wd	PI mfa (% cm)	cm mfa	Average % mfa	Landuse
Late Weichselian Soils	HB	HL1	Heumen I	A1	231	39	192	69	123	30	6.6	36	0.85	158	125	1.3	a
		HL1	Ottersum	A6	560	351	209	57	152	43	4.9	27	0.98	54	105	0.5	a
		kHL3	Azewijn IV	A11	921	804	117	61	56	50	2.3	52	0.67	80	116	0.7	g
		HL1	Asbroek	A13	1269	977	292	71	221	33	8.8	24	0.87	127	142	0.9	g
		HL2	Megchelen	A14	318	172	146	59	87	45	3.2	40	0.68	80	111	0.7	g
		HL1	Ven-Zelderheide	A15	685	406	279	112	167	57	4.9	40	0.97	36	109	0.3	g
		HL1	Millingen (WD)	A16	960	460	500	268	232	50	10.0	54	0.94	554	120	4.6	g(a)
	AVERAGE AND STANDARD DEVIATION				706±343	458±307	248±119	100±71	148±60	44±9	5.8±2.6	39±11	0.85±0.12	156±167	118±12	1.3±1.4	
	MB	ML2	Heumen II	A2	431	85	346	106	240	75	4.6	31	0.52	377	130	2.9	a
		ML1	Gendringen I	A4	804	472	332	201	131	60	5+5	61	0.52	212	115	1.8	g(a)
		kML2	Gendringen II	A5	438	233	205	105	100	50	4.1	51	0.51	157	115	1.4	g(a)
		ML1	Stiebengewald	A7	792	666	126	57	69	30	4.2	45	0.53	38	60	0.6	a
		ML2	Aaldonk	A9	876	431	445	175	270	49	9.1	39	0.31	137	129	1.1	a
		KML2	Azewijn I	A10	164	-	164	14	150	60	2.7	9	0.60	194	130	1.5	g
		kML2	Woezik	A12	288	20	268	15	253	75	3.6	6	0.37	89	105	0.8	g
		KML2	Ewijk[2]	A17	200	139	61	28	33	33	1.7	46	0.73	322	105	3.1	a
		kML2	Azewijn II	-	710	560	150	57	93	65	2.3	38	0.58	126	120	1.1	g
		ML2	Heumen IV	-	252	53	199	43	156	70	2.8	22	0.50	159	95	1.7	a
		ML2	Heumen V	-	122	21	101	43	58	50	2.0	43	0.51	197	130	1.5	a
	AVERAGE AND STANDARD DEVIATION				462±271	244±233	218±112	77±60	141±78	36±14	3.9±2.0	36±16	0.52±0.10	183±93	112±20	1.6±0.8	
	LG	kLL2	Heumen III	A3	11	-	11	2	9[1]	-	-	-	-	143	90	1.6	g
		LL2	Milebeek	A8	-	-	-	-	-	-	-	-	-	12	45	0.3	g
		KLL1	Daas II	-	101	-	101	11	90	50	2.0	11	0.50	148	110	1.3	g
														101±63	82±27	1.1±0.6	
Holocene Soils	Ca0	-	Weurt	A18	-	-	-	-	-	-	-	-	-	267	131	2.0	g
		-	Randwijk	A19	-	-	-	-	-	-	-	-	-	277	68	4.1	a
														272±5	100±32	3.1±1.1	
	Ca1	-	Kesteren	A20	-	-	-	-	-	-	-	-	-	285	116	2.5	a
		-	Lienden	A21	-	-	-	-	-	-	-	-	-	90	130	0.7	a
		-	Opheusden	A22	-	-	-	-	-	-	-	-	-	41	105	0.4	g
														139±105	117±10	1.2±0.9	

Key: PI = Profile index (%cm over profile depth - Miedema and Slager, 1972)
fPI = Fraction of profile index
fgfa = free grain ferri-argillans and argillans
fa = ferri-argillans and argillans
p = ferri-argillic papules and argillic papules
cm Bt = thickness Bt horizon till sand subsoil (profile description)
fraction wd = (yellow + brown)/(yellow + brown + iron covered + pale + grainy)
mfa = macri-ferri-argillans (groundmass illuviation)

} clay illuviation

Groundmass illuviation: a+g(a) 2.0±1.2 (n=14); g 1.0±0.5 (n=12)

Remarks: 1) erratic occurrence, no Bt horizon designation used.
2) Ewijk has been transferred to the HB because of its Late Weichselian subsoil.

Landuse: a = arable
g(a) = grassland (former arable)
g = grassland

result of biological activity. In the MB soils, translocated fragments are more elongated and fragmentation and embedding in the groundmass are probably the result of repeated freezing and melting; biological translocation is restricted in these soils. Of the Late Weichselian LG soils, A8 did not have any clay illuviation, and A3 only very small amounts. Another profile not included in the reference profiles (Daas II) had weak illuviation. As in the fine-textured MB soils (A10 and A12), only a minor proportion of the illuviation is found in situ. This may be the result of Holocene resedimentation of Late Weichselian material, as was postulated by Poelman (1975). The landscape position of the LG and the two MB soils would allow this. The field distinction of the groups within the Late Weichselian soils is thus corroborated by differences in soil formation.

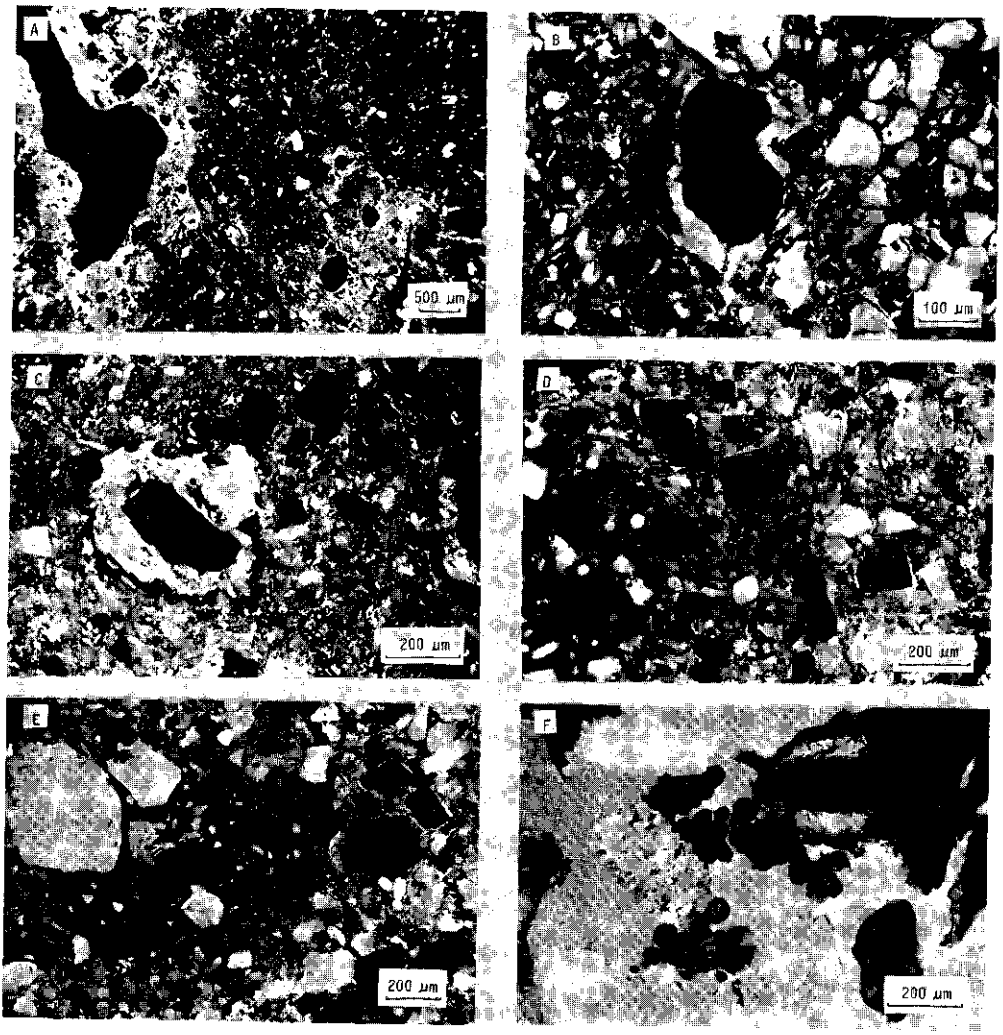
Groundmass illuviation

Groundmass illuviation occurs in all the soils investigated. According to the relevant profile index (Pi-mfa), groundmass illuviation is relatively strong in the MB and CaO groups. This may be explained by absence of homogenization or by a greater structure instability in these groups. In the LG group, infrequent dessication could be the cause of relatively weak groundmass illuviation. Comparison of groundmass illuviation intensity and land use, however, indicates that such illuviation is much stronger under arable land (2.0±1.2%) than under permanent grassland (1.0±0.5%). This suggests that recent land use, irrespective of the original age of the soils, determines groundmass illuviation.

3.1.5. PSEUDOGLEYING AND GLEYING

The distribution of iron and manganese mottles and of iron/manganese depleted zones in gley situations is different from that in pseudogley situations. In gleying, the groundmass is reduced (grey colours) and iron and manganese mottles commonly occur along voids. In pseudogleying, the zones of iron and manganese depletion penetrate into an oxidized groundmass (Fig. 13; Fig. 35) and Mn (as Mn^{++}) and Fe (as Fe^{++}) move towards the oxidized zones. Because iron needs a lower oxygen pressure than manganese to oxidize and re-precipitate, a characteristic distribution is frequently encountered. Iron forms a rim around the oxidized parts and manganese re-

Fig. 35. Pseudogley and gley features.



A. Iron depletion zones along voids (pseudogley-cross polarized light) in Late Weichselian MB soils
B. Channel ferri-argillan partly covered by iron (left hand side) and partly depleted in iron (right hand side) as a result of subsequent pseudogleying in Late Weichselian MB soils (cross polarized light)
C. Quasi-ferran resulting from iron depletion around channel in Late Weichselian MB soils (cross polarized light)
D. Large ferric nodules (mottles) resulting from iron accumulation in Late Weichselian MB soils (cross polarized light)
E. Channel neo-ferran (gley) in Late Weichselian MB and LG and Holocene soils (cross polarized light)
F. Pyrite framboids in poorly drained Late Weichselian LG soils (plane polarized light)

precipitates within the oxidized parts. The absence of gleying and pseudogleying is indicated by uniform brownish or reddish colours and a lack of grey parts.

Macromorphology

Macromorphological differences in this respect between the Late Weichselian HB, MB and LG soils are clearly indicated in the profile descriptions:

In the *well drained HB soils*, pseudogley features are only faintly discernible in the subsoils and reduction phenomena are subdued. B-horizon colours range from 10 YR 5/6 through 7.5 YR 4/4-5/6 to 5 YR 4/4-4/8. The colours are influenced by weathering (liberation of iron) and clay illuviation (accumulation of iron-coated clay). The sandy subsoils have more yellowish colours, between 10 YR 6/3 and 10 YR 6/7, but occasionally 7.5 YR colours also occur. The colours of the Bt lamellae are characteristically 7.5 YR 5/6, occasionally redder (5 YR 4/4).

In the *imperfectly drained MB soils*, pseudogley features are prominent (Fig. 14). The reduced ped exteriors may have colours of 10 YR 7/1 (soils A2, A7, A9 - Fig. 14E) and sometimes bleached E horizons are pronounced (A2, A5; Fig. 13; Fig 36). B-horizon colours in the oxidized parts are similar to those in the HB soils but may have higher chromas (8) because of higher iron contents. The subsoils of MB profiles have gley phenomena, and iron segregations are found along former root channels (Fig. 14F) in a reduced groundmass (A2, A5, A12). Soil A7 has a water-saturated subsoil without reduction phenomena and with a 5 YR 3/5 colour. (Fig. 14B).

In the *poorly drained LG soils*, the groundmass is reduced and has colours with hues of 10 YR to 5 Y, values between 4 and 6 and chromas of 1 or 2. Clear iron segregations are found along former root channels. At shallow depth, root channels commonly contain dead root fragments. (Fig. 14G).

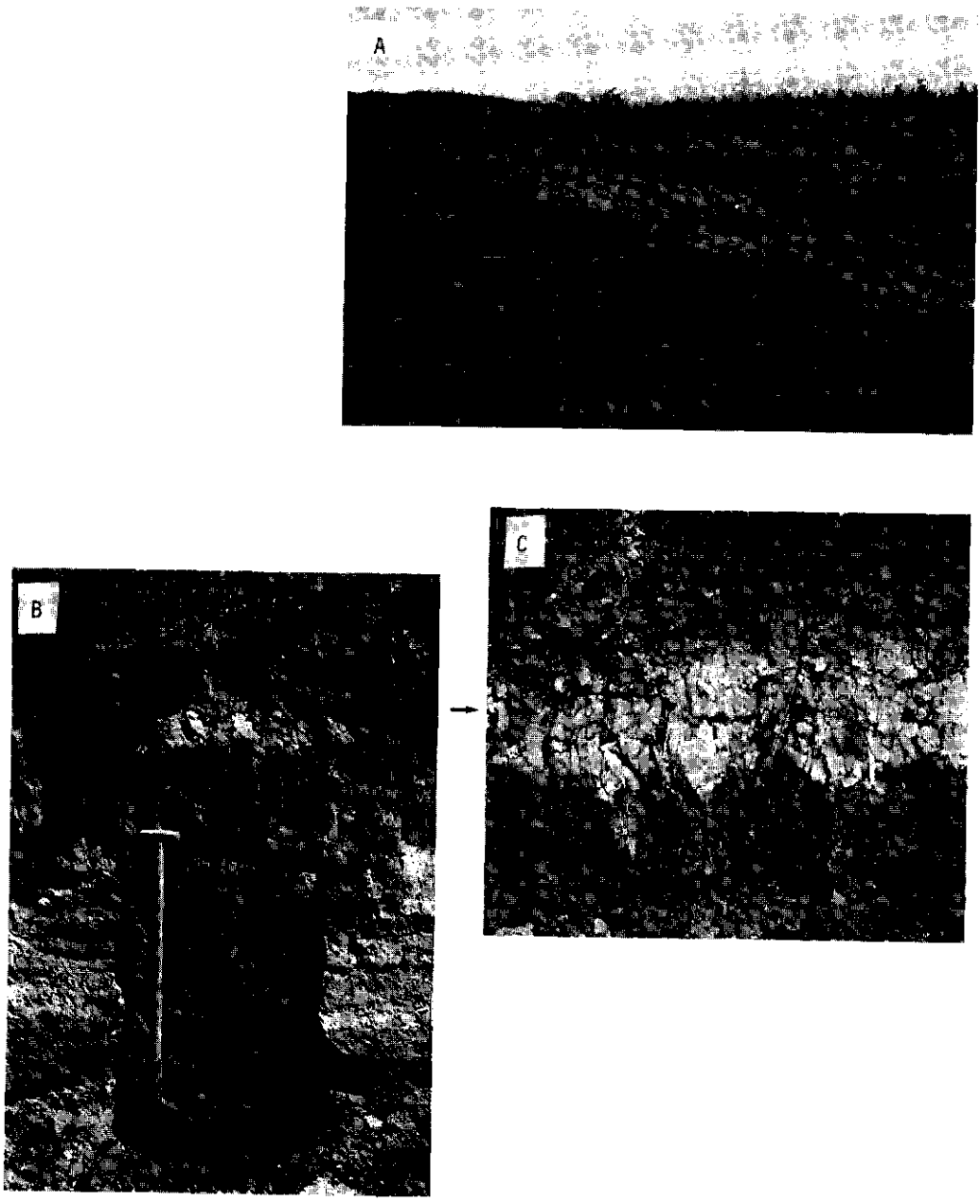
In the *calcareous Holocene soils (Ca1)*, gley phenomena are weakly expressed below depths of 50 to 80 cm. B-horizon colours are from 10 YR 4/4 to 6/4.

The *non-calcareous Holocene (Ca0) soils* vary strongly. The Weurt soil (A18) is similar to the Ca1 soils; the Ewijk soil (A17) has a pseudogleyed Late Weichselian subsoil. Both A17 and A19 (Randwijk) are imperfectly drained and have B horizon colours of 10 YR 4/2, 4/3 or 5/2 with clear gley mottling.

Micromorphology

Micromorphologically, gleying and pseudogleying are indicated by the same features of iron and/or manganese concentrations and depletions, and their relative distribution. (Fig. 35).

Fig. 36. Pronounced albic E horizon in Late Weichselian MB soils.



A. Excavation wall in highway A73 tract (spade is 120 cm)
B. Profile with albic E horizon and sand subsoil (spade is 120 cm)
C. Detail of albic E horizon overlying mottle fine-textured deposit (knife is 20 cm)

In the *Late Weichselian soils*, gley and pseudogley features postdate clay illuviation (Miedema *et al.*, 1978, 1983) as is demonstrated by partly iron-covered ferri-argillans, partly iron-depleted ferri-argillans (Fig. 35) or fully iron-depleted argillans. The grainy character of the groundmass and of clay illuviation features indicates breakdown of clay minerals by ferrolysis (Brinkman, 1970, 1979; Brinkman *et al.*, 1973) a process operative in pseudogley soils. The impact of hydromorphism is indicated by the index of unaffected clay illuviation phenomena (yellow and brown ferri-argillans; fraction *Wd*). This *Wd* fraction is 0.85 in the HB and 0.52 in the MB soils (Table 9). The remainder of the illuviation features is affected by hydromorphism and iron-covered, iron-depleted or grainy (fraction *Pd*). This difference in hydromorphism justifies the subdivision into HB and MB. The LG virtually lack clay illuviation and are therefore not subject to this criterion. The intensity and occurrence of gley and pseudogley features in the reference soils is summarized in Table 10.

In the *HB soils*, pseudogley features are restricted to the subsoils and have a weak contrast.

Table 10. Micromorphological gley/pseudogley and ferrolysis features in the reference soils.

	Late Weichselian soils			Holocene soils	
	HB	MB	LG	CaO	Cal
Features					
Ferric/manganic nodules	-/++	+++	+/++	+++	++
Fe/Mn depleted groundmass	-/+	++	+++	+/+++	+
neo/quasi ferrans/mangans	-/+	++/+++	++/+++	+/+++	++
iron covered/					
depleted clay illuviation	-/+	++	-	-	-
grainy cutans	-/+	+/++	-	-	-

Key: - = absent
+ = few
++ = common
+++ = many

In the *MB soils*, pseudogley features occur in the topsoils and the upper Btg horizons, while the lower Btg horizon is gleyed (profiles A2, A5, A10, A12) as is demonstrated by neo- and quasiferrans (Fig. 35). Pseudogley is found throughout the sampled depth in profiles A4 and A9; in A7 a brown oxidized subsoil is found below the pseudogleyed zone. In all cases, contrasts between oxidized and reduced parts are strongly expressed. The bleached, pseudogleyed parts are preferential water ducts. Depletion of iron causes a

preferential mobilization and deposition of groundmass in these ducts. In some cases, the distinction between depletion of material along ducts and illuviation of depleted material is hard to make, as already discussed by Murphy *et al.* (1985). Present-day poor drainage conditions in the subsoils of MB profiles A10 and A12, and below 30 cm in the LG profile A8, are emphasized by the presence of unoxidized pyrite (Fig. 35). Pyrite in such non-marine environments is described by Poelman, 1973 and Miedema, 1980).

The two *non-calcareous Holocene soils* have a rather different hydrology. A18 is relatively well drained and has few neo- and quasiferrans of weak contrast in the subsoil. The soil contains many ferric nodules, which seem to be unrelated to the present hydrology. A19 is a poorly drained soil with a clear grey reduced colour and prominent iron concentrations in the groundmass and along voids.

The *calcareous Holocene soils* are moderately well drained but contain appreciable amounts of ferric nodules in a brown groundmass. In the subsoils, moderately contrasting iron concentrations are found in a moderately iron-depleted groundmass.

If sediment age, age of clay illuviation processes and decalcification are used as a reference, pseudogley and gley can be dated as well. In the soils on Late Weichselian sediments, decalcification, clay illuviation and plasma reorientations resulting from physical processes have all taken place during the Late Weichselian. Pseudogley postdates both clay illuviation and plasma reorientations. In the HB soils, biological activity has obliterated most of the plasma reorientations, but this is not the case in the MB and LG soils. This smaller impact of biological activity in the MB and LG soils is presumably the result of drainage problems (pseudogley), which probably started during the Late Weichselian or Early Preboreal. A periodically frozen subsoil and/or the very dense porphyroskelic structure may have caused stagnation of water. The gleying that is encountered in some MB subsoils also postdates the clay illuviation but may have started later than the pseudogley. It may be linked with the general increase in groundwater level that accompanied renewed sedimentation during the Atlantic/Subboreal. In Holocene soils, gleying is directly linked to sedimentation position.

3.1.6. BIOLOGICAL ACTIVITY

The general level of biological activity in the various soil groups was described in section 3.1.2. Special features resulting from biological activity are summarized in Table 11. These features comprise (Fig. 37):

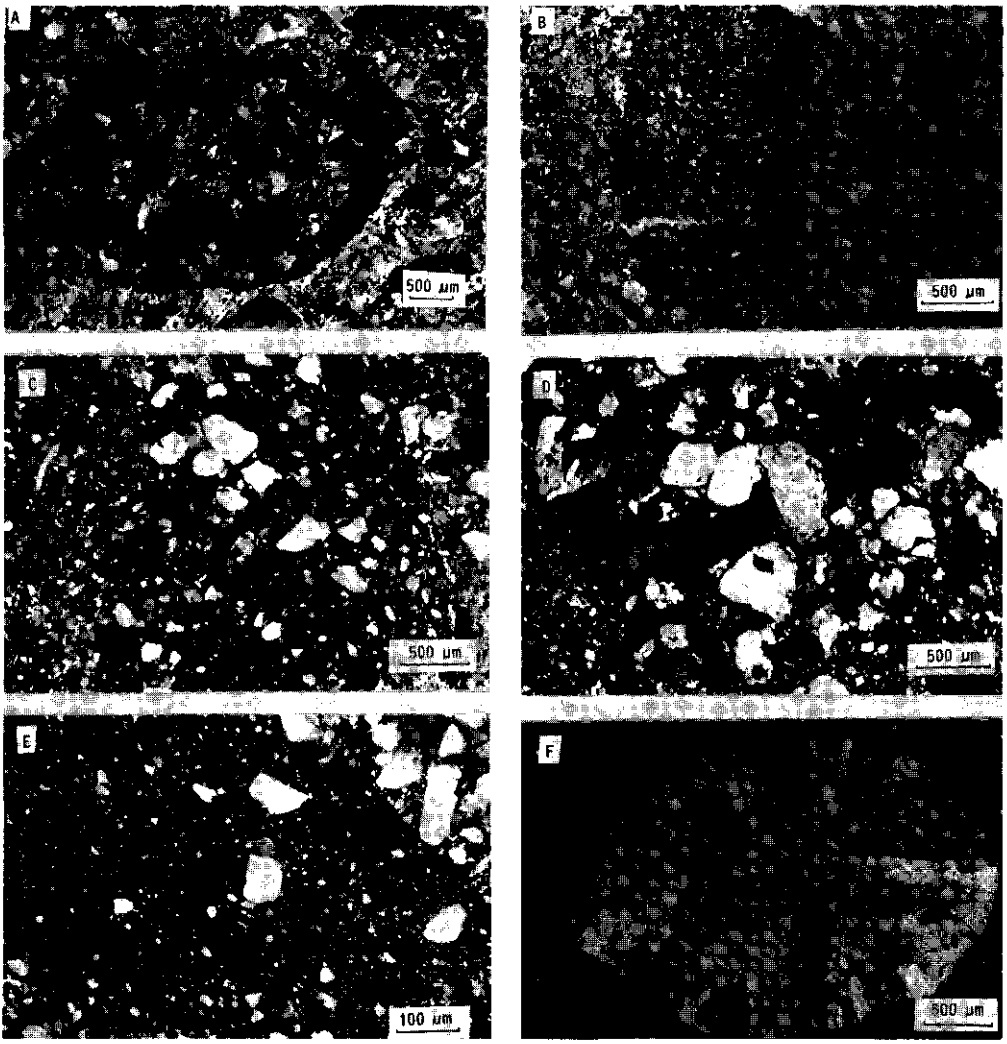
- pedotubules, notably aggrotubules and granotubules, but also isotubules and striotubules,
- organic and matric fecal pellets, predominantly in and near decomposing plant remains (organic fecal pellets) and in aggrotubules (matric fecal pellets),
- ferri-argillic papules; these are only partly attributable to biogenic translocation,
- biorelicts such as snail shell fragments (sedimentary relicts) and plant remains,
- biogenic calcite.

Details are given in Appendix A.

In the *well drained Late Weichselian (HB) soils*, aggrotubules predominate to depths of 50 to 80 cm, and isotubules are common. Granotubules are found near the boundary with the sandy subsoil (in A14, A15, A16) and occasionally in the Ap horizon (A11). Matric fecal pellets (Fig. 37A) predominate in the aggrotubules. Organic fecal pellets were only found in A15. Because the groundmass has been strongly biogenically reworked, the pedotubules are not very discrete. The ferri-argillic papules are round to square fragments of illuviation cutans and are predominantly the result of biogenic translocation. Plant remains are present in amounts decreasing with depth (many above 30/50 cm; common to 60/80 cm; few to 90/110 cm depth).

In the *imperfectly drained Late Weichselian (MB) soils*, aggrotubules with matric fecal pellets predominate to depths of 20-60 cm and are accompanied by common isotubules. Granotubules (Fig. 37D) are encountered near the sandy subsoil (A2, A9) but also in topsoils (A2, A5, A12, A17). No organic fecal pellets were found. The pedotubules are distinct entities in the dense surrounding groundmass. The round to square ferri-argillic papules are common in profiles A2, A4 and A5 but are accompanied by elongated fragments, which are predominant in A10, A12 and A17. Fragmentation of the illuviation cutans and incorporation into the groundmass of the papules thus formed are

Fig. 37. Biogenic special features.



A. Matric aggrotubule in Holocene Ca0 soils (cross polarized light)
B. Organic isotubule in Holocene Ca1 soils (plane polarized light)
C. Organic isotubule in Holocene Caī soils (cross polarized light)
D. Granotubule in Late Weichselian HB soils (cross polarized light)
E. Pottery sherd in plaggen epipedon of Late Weichselian soil A1 (plane polarized light)
F. Biogenic calcite in Holocene Caī soils (cross polarized light)

Table 11. Biogenic special micromorphological features in the reference soils.

	Late Weichselian soils			Holocene soils	
	HB	MB	LG	CaO	Cal
Feature					
Pedotubules	+++	++/+++	++/+++	++/+++	+++
Fecal pellets	++/+++	+/+++	++	++/+++	+++
(Ferri)-argillic papules	+++/++	++/+++	-/+[3]	-	-
Biogenic calcite	-	-/+[1]	+	-/+[5]	++
Snail shells	-	-/+[2]	-/+[4]	-	++/+
Plant remains	+++/++	+++	+++	++/+++	+++

Key: - = absent
+ = few
++ = common
+++ = many

1) A4, Gendringen I; Ap
2) A10, Azewijn I; 2Cgk
3) A3, Heumen III; 2Bwg
4) A8, Milsbeek; Cg, 2Cr
5) A18, Weurt; Ap, Bw, Bwg, Bwgk1

thought to be mainly caused by repeated freezing and melting. Some stress deformation may have played a role in finer-textured soils. Some snail shell-fragments are encountered in the 2Cgk horizon of A10. Plant remains are frequent to depths of 20-30 cm and decrease to few at 50 cm depth. As a result of poor drainage conditions, partly decomposed plant fragments are common in the subsoil of profiles A10 and A12.

In the *poorly drained Late Weichselian (LG) soil* A8, many aggrotubules with organic fecal pellets occur to a depth of 30 cm. Aggrotubules with matric fecal pellets are common in the Ahg horizon of profile A3. The organic fecal pellets in A8 are derived from the peaty topsoil, which must have been thicker previously. As in the MB soils, the pedotubules are discrete entities in a dense groundmass. Occasional granotubules occur throughout profile A3. The 2Bwg horizon of profile A3 contains very few elongated ferri-argillic papules. Some snail fragments occur in the Cg and 2Cr horizons of profile A8. Some biogenic calcite occurs in the Ahg horizons A3 and A8. As a result of the poor drainage, plant remains are common in both LG soils. Their amount changes with depth: abundant in topsoils, common in the middle subsoil and again abundant (and coarse) in the lower subsoil.

In the *non-calcareous Holocene (CaO) soil* A18, aggrotubules with matric fecal pellets are abundant and are accompanied by common isotubules. As in the HB soils, the tubules are indiscrete in a biologically reworked groundmass. Granotubules occur near the boundary with the sandy subsoil. In

the much finer-textured soil A19, the common aggrotubules with matric fecal pellets occur in a dense groundmass and are readily recognized. No papules of argillic or ferri-argillic nature were encountered in the CaO soils. Biogenic calcite, related to the primary and secondary carbonates in the lower subsoil, was encountered throughout profile A18. In this profile, plant remains are numerous in the upper 40 cm and decrease gradually downwards. The amount of plant remains was much lower in A19.

In the *calcareous Holocene (Cal) soils*, the numerous pedotubules with matric and occasionally organic fecal pellets (A20, A22) are indiscrete entities in a groundmass that has been biogenically reworked till depths of 60-80 cm. Noteworthy are the traffic pan in A20 and the dense Ap and traffic pan in A21, where the tubules are less abundant but more discrete. Organic isotubules (Fig. 37B/C) accompany the aggrotubules. Granotubules occur between 50 and 100 cm depth in all three profiles and are clearly associated with the sandy subsoil. Because clay illuviation is absent in these soils, ferri-argillic papules are absent. Snail fragments and biogenic calcite (Fig. 37E) are common in these soils and occur to depths of more than 1 metre. Plant remains show a regular decrease in abundance with depth.

3.1.7. HUMAN ACTIVITY

In general, macromorphological observations were substantiated by micromorphological investigations. Examples of these observations are: the sharpness of the lower boundary of the Ap horizon, the occurrence of sugarsludge lime, the presence of a traffic pan and, in profile A1, the presence of pottery sherds to a depth of 70 cm (Fig. 37F; Druijff, 1979; Miedema *et al.*, 1978). Charcoal is generally found to great depth and is probably of synsedimentary origin. In the topsoil of A3, material excavated from a nearby ditch is encountered as pedorelicts. The compacted nature of the topsoils of some profiles (A10, A11, A14) is the result of to their location. These profiles were taken from the wall of an excavation now used as garbage dump.

3.2. CLAY MINERALOGICAL ASPECTS

3.2.1. X-RAY DIFFRACTION ANALYSIS

Clay fractions were separated by sedimentation in 0.005 NaOH, after organic matter had been removed with a 10% H_2O_2 solution buffered at pH 5. This procedure ensured that interlayer aluminium remained intact. Clay minerals were identified by X-ray diffractometry. Subsamples were saturated with Mg and analysed air-dry and after saturation with glycerol. Other subsamples were saturated with potassium, and analysed air-dry (50% RH) and after various heat treatments. The following minerals were identified:

Kaolinite: Basal spacing of 0.71 nm does not change upon saturation with different cations or glycerolation. Reflection disappears upon heating to 550 °C.

Mica: Basal spacing of 1.0 nm does not change upon saturation with different cations, glycerolation or heat treatment.

Smectite: 1.4 nm reflection of air-dry, magnesium-saturated samples shifts to 1.7-1.8 nm upon glycerolation. Potassium does not cause collapse of 1.4 nm spacing, but collapse to 1.0 nm is obtained upon heating to 550 °C.

Mica-Smectite interstratification: diffuse basal spacing around 1.2 nm shifts to higher values upon glycerolation. Potassium saturation does cause slight collapse. Collapse to 1.0 nm is obtained upon heating to 550 °C.

Al-interlayered Smectite: Large part of the 1.4 nm reflection of the air-dry sample disappears upon glycerolation without appearance of a 1.7-1.8 nm reflection.

Vermiculite: 1.4 nm reflection of air-dry, magnesium saturated samples does not shift to higher spacings upon glycerolation. Potassium saturation causes a collapse to 1.0 nm, which is enhanced by heating.

Al-interlayered Vermiculite: 1.4 nm reflection of air-dry, magnesium saturated samples does not change upon glycerolation. Potassium saturation causes only partial collapse, and further slow collapse follows progressive stages of heating.

Chlorite: 1.4 nm reflection of air-dry, magnesium saturated samples does not change upon saturation with potassium or glycerolation. Intensity of reflection may increase upon heating to 550 °C.

Mica-Vermiculite interstratifications: diffuse basal spacing around 1.2 nm (Mg, air-dry) does not shift upon glycerolation but may collapse partially upon saturation with potassium. Heating causes further collapse to 1.0 nm.

Table 12. Clay mineralogical characteristics of the soils groups.

	K	M	S	M-S	S-int	V	V-int	C
SOIL GROUP								
HB	2	2	-	0-½	0-1½	-	1-2	0-½
MB	2	2	1-2*	0-½	1-2*	½-2*	1½-2½*	0-½
LG	2	2	see text					
CaO	2	2	1-2	-	1-2	1½-2	-	½
Cal	2	2	½-1	-	1-2	1-1½	-	½-1

K= kaolinite, M= mica, S= smectite, M-S= mica-smectite interstratifications, S-int= aluminium interlayered smectite, C= chlorite, V= vermiculite, V-int= aluminium interlayered vermiculite.

- : absent
½ : minor amounts
1 : moderate amounts
2 : fair amounts
2½: large amounts (predominant)
*= depth trend

In the clay mineralogical analysis of profiles and deposits (Table 12, Appendix B) kaolinite and mica contents are very similar.
Both minerals are present in fair and approximately equal amounts. The five groups of soils profiles (HB, MB, LG, CaO and Cal) are characterized as follows.

HB.

This group of soils lacks significant smectite contents. If present, the smectite is Al-interlayered and has an abundance of 0-1½. All samples have some interstratified mica-smectite (abundance 0-½) and low chlorite contents (0-½, occasionally 1). Mica-vermiculite interstratifications are scarce. All profiles have moderate to fair amounts (1-2) of Al-interlayered vermiculite; the vermiculite is always Al-interlayered.

MB.

The MB groups has significantly higher smectite contents than the HB. In most profiles this smectite is Al-interlayered (abundance 1-2), but normal smectite generally increases with depth and may reach an abundance of 2 in some C-horizons. Chlorite occurs in amounts similar to those in HB.
Al-interlayered vermiculite is abundant (1½-2½) in topsoils, but decreases with depth. In the lower horizons, vermiculite (½-1½) is normally not Al-interlayered. Mica-smectite interstratifications are found in minor amounts in most samples (0-½).

LG.

Only two LG profiles were analysed, and the results do not agree in all aspects. Profile Heumen III (A3) has low (½) amounts of smectite in the upper three horizons and moderate to fair (1-2) amounts in the lower three. Al-interlayered smectite is virtually absent. The upper three horizons are characterized by fair (2) amounts of vermiculite with slight Al-interlayering. In the lower three horizons, this mineral is less abundant (0-1) and is not Al-interlayered. Chlorite occurs throughout (1) and some mica-smectite interstratification is found. In profile Milsbeek (A8), both smectite and Al-interlayered smectite occur in fair amounts (1½-2) throughout the profile, while kaolinite and mica contents are distinctly lower in the upper two horizons. Chlorite occurs in minor amounts only (½) and so does Al-interlayered vermiculite (½).

CaO.

Profiles A17 (Ewijk) and A18 (Weurt) have moderate to fair amounts (1-2) of both smectite and Al-interlayered smectite. Chlorite is found in minor amounts (½) and vermiculite (not Al-interlayered) in fair amounts (1½-2).
Profile A19 (Randwijk) is slightly different: it has low (0-½) amounts of Al-interlayered smectite.

Ca1.

The mineralogy of the three calcareous profiles is very homogeneous. All samples have low to moderate contents of smectite (½-1), moderate to fair amounts of Al-interlayered smectite (1-2), low to moderate contents of chlorite (½-1) and moderate to fair amounts of vermiculite (1-1½). 1.2 nm reflections are not encountered and vermiculites are not Al-interlayered.

Obviously, the occurrence of smectite versus Al-interlayered smectite and of vermiculite versus Al-interlayered vermiculite is related to soil formation. In well drained profiles (HB) and in the upper layers of MB, Al-interlayered minerals tend to dominate over non-Al-interlayered minerals. This is most clearly reflected in the vermiculites, where gradual transitions between interlayered and non-interlayered minerals are easily recognized. Normal smectite is scarce in HB. In the poorly drained gleyed and pseudo-gleyed subsoils of MB and LG, Al-interlayering in vermiculites is virtually absent and interlayering in smectites is strongly reduced. The presence of Al-interlayers in smectite and vermiculites in well drained Late Weichselian topsoils was demonstrated by Hiemstra (1979 and Van Oort, 1980), who

obtained better (001) reflections after extracting of the clay with sodium citrate.

The Holocene soils do not have Al-interlayered vermiculites. Their composition is similar to that of several MB subsoils. Clay mineral composition does not show trends with depth.

Unlike with soil formation, there is no relation between clay mineral assemblage and deposit. This indicates that the primary mineralogy of the deposits was very similar. The mineralogy of thin Holocene covers over Late Weichselian material demonstrates transitional properties to the underlying soils with their soil formation (HB, MB, LG).

If the soil profiles are examined individually the following properties stand out:

- Holocene deposits will generally be recognized by their different mineralogy
- Ploughed layers and anthropic epipedons are recognized by their different mineralogy
- Some transitions between mineral assemblages within one profile suggest that the subdivision in sedimentary units could sometimes be amended.
- Interstratifications in vermiculite and smectite tend to disappear in imperfectly and poorly drained subsoils.

In none of the profiles is there a distinct relation between clay mineralogy and horizon denomination. Within one profile it is sometimes possible to trace transitions from one deposit to the next by changes in clay mineralogy, although in general deposits are not characterized by a specific mineralogy. Separate analysis of brown and bleached parts in MB (Hiemstra, 1979) indicated more Al-interstratification, less smectite and lepidocrocite in the grey parts. Smectite increased and chlorite and quartz disappeared in the fine clay fractions (<0.2 μm) in all the samples investigated.

3.2.2. TOTAL CHEMICAL ANALYSIS OF THE CLAY FRACTION

Ba-saturated clay fractions of samples of all reference profiles were chemically analysed; the results are given in Appendix A. The whole population contains 121 samples, all belonging to fluvial soils. The Late Weichselian population contains 81 samples (HB:37, MB:36, LG:8) and the

Table 13. Correlation coefficient (R) of SiO_2 and Al_2O_3 with selected chemical properties in different subdivisions (with $p \leq 0.05$).

		N	SiO_2	Al_2O_3	Si/Al*	Fe_2O_3	MgO	K_2O	BaO	TiO_2	P_2O_5	CaO	Na_2O
	Subdivision												
SiO_2	Holocene, Cal	(21)		-	-	*0.53*	-	-	-	-	-0.49	-	-
	Holocene, CaO	(19)		-	-	-	+0.47	-	-	-	-0.46	-0.46	-
	Holocene, clayey	(37)		-	+0.35	-0.33	-	*-0.40*	-	-	-0.32	-0.31	+0.34
	Holocene, all	(40)		+0.34	-	*-0.42*	-	*-0.40*	-	-	*-0.38*	*-0.42*	+0.30
	Late Weichselian HB	(37)		-0.29	*+0.84*	*-0.74*	-	*+0.41*	*-0.46*	*+0.57*	-	-	-
	" " MB	(36)		*+0.48*	*+0.47*	*-0.93*	-	-	*-0.51*	+0.36	-0.35	-	-
	" " LG	(8)		-	*+0.87*	-	+0.65	-	-0.73	+0.72	-0.74	-	-
	" " clayey	(64)		-	*+0.70*	*-0.73*	-	-	*-0.41*	*+0.43*	*-0.32*	-	-
	" " sandy	(17)		-	*+0.65*	*-0.87*	-	*+0.58*	-	-	*-0.80*	-	-
	" " W	(31)		-	*+0.63*	*-0.76*	*+0.59*	+0.35	-0.35	+0.36	*-0.60*	-	-
	" " Wint+Hint	(60)		-	*+0.76*	*-0.75*	-	-	-0.31	*+0.46*	*-0.40*	-	-
	Late Weichselian, all	(81)		-	*+0.69*	*-0.76*	-	+0.21	*-0.27*	*+0.38*	*-0.36*	-	-
	Fluvial, all,	(121)		-	*+0.53*	*-0.71*	-	-	-0.21	*+0.34*	*-0.36*	-	-
Al_2O_3													
	Holocene, Cal	(21)	-		*-0.80*	*-0.71*	*+0.58*	*+0.55*	*-0.66*	-	*-0.69*	*-0.62*	*-0.65*
	Holocene, CaO	(19)	-		*-0.86*	*-0.75*	-	*-0.87*	*-0.65*	-	*-0.73*	-	*-0.62*
	Holocene, clayey	(37)	-		*-0.84*	*-0.76*	-	*-0.75*	*-0.42*	-	*-0.58*	-0.32	-0.36
	Holocene, all	(40)	+0.34		*-0.82*	*-0.75*	-	*-0.72*	*-0.41*	-	*-0.61*	*-0.42*	-0.34
	Late Weichselian, HB	(37)	-0.29		*-0.76*	-	*+0.59*	-	-	-0.52	*-0.40*	*-0.41*	-0.29
	" " MB	(36)	*+0.48*		*-0.55*	*-0.66*	-	+0.30	*-0.53*	-	-	*-0.39*	*-0.44*
	" " LG	(8)	-		*-0.92*	-	-0.71	-	-	-	-	-	-
	" " clayey	(64)	-		*-0.58*	*-0.48*	-	-	-0.25	-	-0.21	-	-0.27
	" " sandy	(17)	-		*-0.74*	-	-	-	-	-0.42	-	*-0.67*	*-0.59*
	" " W	(31)	-		*-0.56*	*-0.63*	-	-	-	-	-	-	-0.40
	" " Wint+Hint	(60)	-		*-0.70*	-	*+0.30*	-	-0.24	*-0.49*	*-0.36*	*-0.38*	*-0.33*
	Late Weichselian, all	(81)	-		*-0.65*	*-0.38*	-	-	*-0.27*	-	-0.20	-0.19	*-0.38*
	Fluvial, all	(121)	-		*-0.79*	*-0.34*	-0.18	*-0.42*	*-0.39*	-	*-0.28*	*-0.55*	*-0.33*

- if $p > 0.05$

0.38 if $0.01 < p \leq 0.05$

0.38 if $p \leq 0.01$

* molar ratio

Holocene population contains 40 (CaO:19, Cal:21). If texture and age are used as criteria, the total population can be subdivided into Holocene clayey samples (37), Late Weichselian clayey samples (64) and Late Weichselian sandy samples (17). A final subdivision into samples with strong aluminium interlayering in the clay minerals (H_{int}+W_{int}, n=60) and those without such interlayering (W; n=31) was based on X-ray diffraction analysis of the clay fraction (see section 3.2.1). Because of its erratic BaO contents, reference soil Al has not been included.

A correlation matrix of selected chemical properties with SiO_2 and Al_2O_3 contents is presented in Table 13. The study of the correlation matrix preceding this analysis, indicated that the distinction in five groups (HB, MB, LG, CaO, Cal) gave better correlations than if two groups (Late Weichselian, Holocene) were distinguished, or when sediment layers were used as populations. In Table 15 average element contents for each of the five groups are given, and the oneway analysis of variance is given in Table 16.

Table 14. Correlation coefficient (R) of Si/Al ratio with BaO, K_2O, MgO and TiO_2 contents in different subdivisions (with $p \leq 0.05$).

		N	BaO	K_2O	MgO	TiO_2
	Subdivision					
Si/Al	Holocene, Cal	(21)	*+0.54*	*-0.71*	*-0.57*	-
	Holocene, CaO	(19)	+0.52	*+0.70*	-	-
	Holocene, clayey	(37)	*+0.43*	*+0.48*	-	-
	Holocene, all	(40)	*+0.43*	*+0.48*	-	-
	Late Weichselian, HB	(37)	-0.30	+0.38	*-0.48*	*+0.68*
	Late Weichselian, MB	(36)	-	-	-	-
	Late Weichselian, LG	(8)	-	-	+0.76	+0.75
	Late Weichselian, clayey	(64)	-	-	-	*+0.37*
	Late Weichselian, sandy	(17)	-	-	-	-
	Late Weichselian, W	(31)	-	-	*+0.61*	-
	Late Weichselian, Wint+Hint	(60)	-	-	*-0.34*	*+0.65*
	Late Weichselian, all	(81)	-	-	-	*+0.39*
	Fluvial, all	(121)	+0.21	*+0.39*	+0.18	*+0.32*

Key: - if $p > 0.05$
0.54 if $0.01 < p \leq 0.05$
0.54 if $p \leq 0.01$

Table 13 demonstrates the changes of the correlations upon various subdivisions. The strong positive SiO_2 with Si/Al correlation parallel with the positive SiO_2 with TiO_2 correlation, and the negative correlation between SiO_2 and BaO (CEC) in the Late Weichselian samples suggests that part of the SiO_2 is not bound in clay minerals (free quartz or amorphous silica - Poelman, 1975). In the Holocene samples, no correlation was found between SiO_2 and Si/Al, TiO_2 or BaO. In the Holocene samples, there is a clear positive correlation between Si/Al ratio and BaO content, which reflects the higher CEC of 2:1 clay minerals compared with 1:1 minerals (Table 14).

The negative correlation between Al_2O_3 and K_2O in the CaO soils (Table 13) demonstrates the initial weathering in these samples. This is also reflected by the positive correlation between Si/Al and K_2O in Table 14. In the Cal soils, however, there is a positive correlation between Al_2O_3 and both MgO and K_2O (Table 13). The high contents of MgO and K_2O in the Cal soils (Table 15) illustrate the low weathering status, and the positive correlation of Al_2O_3 with MgO and K_2O is probably the result of absence of Al-interlayering in the clay minerals. Fe_2O_3 correlates negatively with both SiO_2 and Al_2O_3 for both Late Weichselian and Holocene soils. This would suggest that Fe_2O_3 accumulates in the soil upon weathering, or that Fe_2O_3 is added from other sources, such as groundwater (gleying).

Mean values of oxide contents (Table 15) of the various groups and the oneway analysis of variance (Table 16) show that the calcareous Holocene soils have highest MgO, CaO and K_2O contents. The Al_2O_3 content of the Cal soils is lower than that of the Late Weichselian soils. The Si/Al ratio in the Holocene CaO and Cal soils is higher than that in the HB and MB soils. The BaO content (CEC) is lowest in the Late Weichselian HB soils; this reflects their higher degree of weathering in agreement with X-ray diffraction analysis (section 3.2.1). Because of the permanent reduction in the subsoil, Fe_2O_3 and MnO contents are lowest in the LG soils. Also P_2O_5 is lowest in the LG soils. Higher contents of phosphate are encountered in the HB soils and may reflect the long use of these soils as arable land. MB soils are used for both arable and grassland, while the LG soils are exclusively under grassland. The relatively high CaO contents in the LG soils are probably the result of waterlogging hindering eluviation.

Weathering in the soils can be illustrated by grouping of samples according to the presence of aluminium interlayering in the clay minerals

Table 15. Means and standard deviations of selected chemical properties of the clay fraction of the reference soils (in 5 subgroups).

	Fluvial (n=121)	Late Weichselian (n=81)			Holocene (n=40)	
		HB(n=37)	MB(n=36)	LG(n=8) (%)	CaO(n=19)	Cal(n=21)
Element						
SiO_2	47.22±1.87	46.53±1.81	47.38±2.11	48.86±2.08	47.99±1.55	46.82±0.93
Al_2O_3	23.72±1.27	24.36±0.78	23.96±1.15	24.70±1.15	23.18±1.31	22.23±0.70
Fe_2O_3	8.71±1.67	9.14±1.33	8.97±2.15	5.62±0.39	8.43±0.73	8.97±0.69
FeO	0.67±0.22	0.74±0.20	0.54±0.21	0.78±0.38	0.58±0.12	0.80±0.13
MnO	0.13±0.10	0.15±0.07	0.12±0.12	0.02±0.01	0.17±0.10	0.13±0.07
MgO	2.05±0.43	2.06±0.21	1.80±0.30	2.01±0.56	1.89±0.39	2.61±0.42
CaO	0.12±0.12	0.05±0.04	0.07±0.05	0.18±0.09	0.17±0.09	0.29±0.13
Na_2O	0.28±0.18	0.27±0.07	0.29±0.23	0.24±0.06	0.37±0.26	0.22±0.09
K_2O	3.17±0.43	3.12±0.28	2.99±0.30	3.11±0.63	3.05±0.57	3.70±0.18
TiO_2	0.83±0.12	0.83±0.13	0.84±0.16	0.76±0.09	0.85±0.08	0.84±0.03
P_2O_5	0.41±0.27	0.52±0.36	0.32±0.17	0.19±0.10	0.44±0.30	0.39±0.14
BaO	4.33±0.89	3.72±0.84	4.41±0.95	5.03±0.64	4.88±0.67	4.52±0.29
H_2O	8.63±0.75	8.73±0.57	8.62±0.85	8.51±1.10	8.73±0.99	8.40±0.29
Si/Al	1.69±0.11	1.62±0.09	1.68±0.08	1.68±0.13	1.76±0.11	1.79±0.06

Table 16. One way analysis of variance of reference soils (in 5 subgroups).

	HB	MB	LG	CaO	Cal	Fratio	Fprob.
Element							
CaO	A*	A	BC	B	C	42.15	0.0000
MgO	B	A	ABC	AB	C	21.14	0.0000
Al_2O_3	C	BC	BC	AB	A	18.25	0.0000
Si/Al	A	A	AB	B	B	14.09	0.0000
K_2O	A	A	AB	A	B	13.30	0.0000
Fe_2O_3	B	B	A	B	B	10.45	0.0000
BaO	A	B	B	B	B	10.06	0.0000
FeO	B	A	AB	A	B	9.01	0.0000
MnO	B	B	A	B	B	4.72	0.0015
P_2O_5	C	AB	A	BC	BC	4.37	0.0025
SiO_2	A	AB	AB	B	AB	4.31	0.0027

* Groups having the same letter are not different at the 5 % level of significance.

(section 3.2.1). Such weathering is clear in the topsoils of all Late Weichselian soils and shallow Holocene topsoils overlying Late Weichselian soils (Population 'Wint + Hint'). The subsoils of Late Weichselian soils have no or little aluminium interlayering (population W). The remaining CaO and Cal are from deep Holocene profiles. The mean oxide content of these four populations are given in Table 17, and the oneway analysis of variance

Table 17. Mean oxide contents (%) and standard deviations of Wint+Hint, W, CaO (profiles) and Cal samples.

	Wint+Hint (n=60)	W (n=31)	CaO (n=9)	Cal (n=21)
			%	
Element				
SiO_2	47.23±1.82	47.21±2.48	48.09±1.11	46.82±0.93
Al_2O_3	24.32±0.84	24.00±1.20	22.10±0.86	22.23±0.70
Fe_2O_3	8.64±1.30	8.59±2.71	9.01±0.31	8.97±0.69
FeO	0.70±0.20	0.55±0.27	0.55±0.09	0.80±0.13
MnO	0.15±0.08	0.07±0.10	0.22±0.10	0.13±0.07
MgO	1.99±0.31	1.87±0.40	1.75±0.05	2.61±0.42
CaO	0.08±0.07	0.11±0.08	0.14±0.11	0.29±0.13
Na_2O	0.25±0.07	0.31±0.24	0.53±0.31	0.22±0.09
K_2O	3.00±0.35	3.06±0.41	3.49±0.33	3.70±0.18
TiO_2	0.88±0.14	0.75±0.08	0.85±0.05	0.84±0.03
P_2O_5	0.45±0.31	0.28±0.15	0.57±0.38	0.39±0.14
BaO	3.83±0.82	4.87±0.71	5.42±0.39	4.52±0.29
H_2O	8.72±0.56	8.70±1.20	8.31±0.28	8.40±0.29
Si/Al	1.65±0.09	1.67±0.10	1.85±0.06	1.79±0.06

Table 18. Oneway analysis of variance of Wint+Hint, W, CaO (profiles) and Cal samples.

	Wint+Hint	W	CaO	Cal	Fratio	Fprob.
Element						
Al_2O_3	B*	B	A	A	35.48	0.0000
CaO	A	A	A	B	31.30	0.0000
MgO	B	AB	A	C	25.05	0.0000
K_2O	A	A	B	B	24.28	0.0000
BaO	A	BC	C	B	24.02	0.0000
Si/Al	A	A	B	B	23.33	0.0000
TiO_2	B	A	B	B	9.67	0.0000
Na_2O	A	AB	B	A	9.45	0.0000
MnO	B	A	B	AB	8.60	0.0000
FeO	BC	AB	A	C	7.48	0.0001
P_2O_5	B	A	AB	AB	4.18	0.0075

* Groups having the same letter are not different at the 5 % level of significance.

is given in Table 18.

Table 17 shows that the alteration trends observed in clay mineral analysis are substantiated by chemical analysis. The most striking differences are higher Al_2O_3 contents, lower K_2O content and lower Si/Al ratio in both the (Wint + Hint) and the W populations, compared with the CaO and Cal populations. The very low BaO contents of the (Wint + Hint) population are in accordance with the most strongly Al-interlayered character of the

samples. High values for MgO and CaO in the calcareous Holocene soils underline the rather unweathered character of this group. The higher TiO_2 contents in the (Wint + Hint) group as compared with the W group again indicate the more weathered nature of the former. The other significant differences cannot be explained without speculation.

3.3. CHEMICAL ASPECTS

3.3.1. $CaCO_3$ CONTENT AND pH-KCl

Data on $CaCO_3$ content and pH-KCl of the reference soils are summarized in Table 19. Full details can be found in Appendix A. Holocene non-calcareous topsoils overlying Late Weichselian soils (A3, A5, A10, A11, A12) have not been included, as have the two samples with calcareous 'dril' from profile A10.

From Table 19 it is evident that the pH-KCl of the Late Weichselian soils is considerably lower than that of the Holocene soils. No differences are found between the subgroups of the Late Weichselian soils. The Holocene non-calcareous soils have a pH-KCl that is significantly higher than that of the Late Weichselian soils but significantly lower than that of the Holocene calcareous soils.

Table 19. pH-KCl and $CaCO_3$ content of reference soils (means and standard deviations).

		pH-KCl						$CaCO_3$(%)			
		n	total soil	n	topsoil	n	subsoil	n	topsoil	n	subsoil
Late Weichselian	all	(87)	4.7±0.7	(14)	5.4±0.8	(73)	4.5±0.6		-		-
	HB	(45)	4.6±0.6	(7)	5.5±0.6	(38)	4.4±0.4		-		-
	MB	(34)	4.9±0.8	(5)	5.7±0.8	(29)	4.8±0.7		-		-
	LG	(8)	4.3±0.3	(2)	4.2±0.3	(6)	4.3±0.3		-		-
Holocene	CaO	(9)	6.0±0.8	(3)	6.2±0.6	(6)	5.9±0.9	(3)	0.2±0.1	(6)	0.1±0.1
	Cal	(21)	7.3±0.2	(4)	7.0±0.2	(17)	7.4±0.2	(4)	3.7±1.8	(17)	10.9±5.1

Because of fertilization, the pH-KCl of HB and MB topsoils is higher than that of subsoils. This was not found in the LG soils, probably because these soils only support grassland. Slightly elevated pH values resulting from to

fertilization are also encountered in the Holocene non-calcareous soils. The calcareous Holocene soils show an increase in pH-KCl with depth, because of increasing $CaCO_3$ contents (decalcification of topsoils). Very low pH-KCl values ($\leq$ 4.0) occur in all Late Weichselian soil groups: HB (A6, A14, A15, A16), MB (A2, A9) and LG (A3).

The Late Weichselian soils are devoid of calcium carbonate, with the exception of the two samples of calcareous 'dril' in the subsoil of A10. The Holocene non-calcareous soils have only traces of calcite left. The decalcification in the calcareous Holocene soils is clearly demonstrated by the different content of $CaCO_3$ in topsoils (3.7%) and subsoils (10.9%).

3.3.2. CONTENT AND COMPOSITION OF ORGANIC MATTER

The mean organic matter contents of the reference soils are summarized in Table 20. Details can be found in Appendix A. When calculating the means, the topsoil of A22, which had an exceptionally high organic matter content (9.8%) was left out. Means were calculated for topsoils and subsoils separately.

Table 20. Organic matter content of reference soils (means and standard deviations).

		organic matter (%)			
		n	topsoil	n	subsoil
Late Weichselian	All	(14)	2.9±1.0	(74)	0.4±0.4
	HB	(7)	2.8±0.8	(37)	0.5±0.3
	MB	(5)	3.0±1.2	(31)	0.2±0.3
	LG	(2)	2.7±1.0	(6)	0.7±0.5
Holocene	*CaO*	(3)	2.2±0.9	(6)	0.6±0.4
	Cal	(3)	2.8±0.3	(17)	1.0±0.6

Topsoil organic matter contents vary little, mainly because of the land utilization system, under which organic manure is routinely added to all soils. The organic matter contents of subsoils, however, show clear differences, with the MB group having particularly low contents. Higher contents are found in the Holocene and in the LG soils. In the latter, this may be the result of partly decomposed or undecomposed root remains.

Late Weichselian HB and MB soils have an abrupt decrease in organic matter

content below the A horizon. This transition is much more gradual in the Holocene soils. This implies that the Late Weichselian soils had a very low sedimentary organic matter content. However, because of high standard deviations the groups cannot be separated statistically.

Apart from the content of organic matter, its composition is also important. In an attempt to characterize the Late Weichselian and Holocene soil materials, the organic matter of topsoils was analysed by Pyrolysis-Mass Spectrometry (Halma *et al.*, 1978). These samples failed to show differences, because the organic matter in Late Weichselian topsoils is recent. Fortunately, it was also possible to analyse subsoil samples, notwithstanding their low organic matter contents. Samples from 40-60 cm depth showed clear differences in organic matter composition between Late Weichselian and calcarous Holocene soils. An example of a pyrolysis spectrum is given in Fig. 38A. In the non-linear map of Fig. 38B the two groups are very distinct. The non-calcareous Holocene soils were transitional between the two populations. Further analysis (Fig. 38C) showed that aromatic hydrocarbons (mass 78-benzene, 105 and 106) are high in Late Weichselian soils, whereas carbohydrates dominate in Holocene soils (mass 96, together with 68 and 110). This indicates a clear difference between the active young humus of the Holocene soils and the old humus of the Late Weichselian subsoils. More differences were found in the spectra, but cannot be interpreted unambiguously.

3.3.3. CEC OF THE CLAY FRACTION, BASE SATURATION AND COMPLEX COMPOSITION

CEC-clay

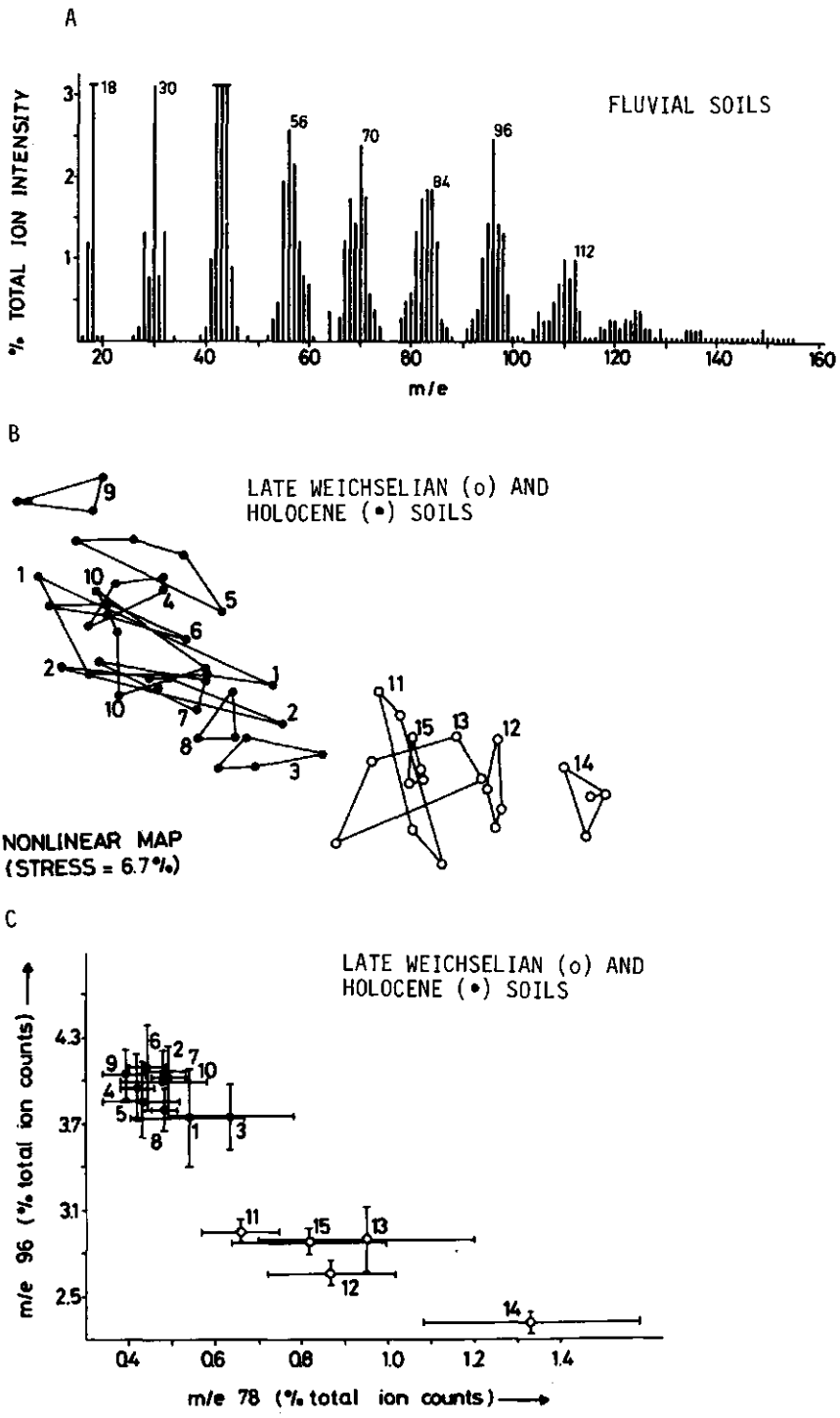
Cation adsorption capacity of the clay fraction was calculated in two ways:

1. by calculation from the BaO content of Ba-saturated clay fractions analysed by X-ray fluorescence (saturation-pH approximately 5)
2. by dividing the CEC of the soil (Li-EDTA, pH7) by the clay content.

These data, together with the base saturation that was obtained by the Li-EDTA method, are reported in Table 21.

Reference soil A1 was left out because of strongly fluctuating high BaO contents, which may have been the result of incomplete washing. The mean values of Table 21 have large standard deviations, and the conclusions

Fig. 38. Results of Pyrolysis-Mass Spectrometry on organic matter from Late Weichselian and Holocene fluvial Rhine soils.



A. Pyrolysis mass spectrum representative of Dutch fluvial Rhine soils.
B. Nonlinear map of Dutch fluvial Rhine soils. Stress value indicates the distortion resulting from projecting the spatial configuration from a 40-dimen-sional space onto a plane
C. Scatter diagram of ion intensities at m/e 78 and m/e 96 for Late Weichselian (open dots) and Holocene (solid dots) fluvial Rhine soils. 'Error' bars indicate maximum and minimum values (range) of the individual samples of that particular site

Table 21. CEC-clay and base saturation (BS) of reference soil (means and standard deviations).

	n	CEC-BaO (mmol/kg)	CEC-Li-EDTA (mmol/kg)	BS (%)
Late Weichselian soils	(81)	542±126	443±149	78±26
Holocene soils	(29)	627±67	499±142	not calculated
Late Weichselian soils				
HB	(37)	486±109	396±163	77±27
MB	(36)	575±122	491±117	79±27
LG	(8)	656± 80	517±136	80±17
deposit III	(50)	534±123		
deposit IIb	(11)	556±117		
deposit IIa	(7)	513±127		
Holocene soils				
CaO	(9)	707± 46	610± 58	87±10
Cal	(20)	591± 37	446±139	100± 0

should therefore be viewed critically. The standard deviations are larger in the Late Weichselian soils than in the Holocene soils. The HB group has CEC-clay (BaO) values that are distinctly lower than those of the Holocene soils. In general, the CEC-clay (BaO) values corroborate the data on clay mineral composition (section 3.2.1.). The deposits IIa, IIb and III show a wide range in CEC-clay, and deposits cannot be separated by means of this property. Calcareous and non-calcareous Holocene deposits have a significantly different, higher CEC-clay, which probably reflects a slightly higher vermiculite content in CaO profiles. In the Late Weichselian soils, a slight increase in CEC-clay with decreasing drainage is apparent. This is explained by a stronger Al-interlayering in smectites and vermiculites of the well drained profiles. This Al-interlayering depresses the CEC. The large standard deviation in MB and HB soils is caused by a number of very low CEC values which are encountered in deposit III (values below 400 mmol/kg). The CEC-clay calculated from the Li-EDTA data is always lower than the value obtained fom the BaO content (75-86% of the CEC-clay (BaO)). This is unexpected, because the Li-EDTA values include the adsorption due to organic matter content. Two possible explanations are that 1) the Li-EDTA method is an underestimate because Ba is adsorbed in preference to Li and 2) the separation of the clay fraction caused de-blocking of negative charge because sesquioxides were removed.

Base saturation and complex composition

The calcareous Holocene soils have a 100% base saturation (BS) and a mean complex composition of 74±9% Ca^{++}, 21±7% Mg^{++}, 3±2% Na^{+} and 2±1% K^{+}. The non-calcareous Holocene soils are already slightly undersaturated but have a mean complex composition that is similar to that of the Cal group. The Late Weichselian soils are even more desaturated and BS values may be below 50% (HB: A1, A6, A14, A15; MB: A7, A9) or even below 35%. The base saturation tends to be highest in the LG and lowest in the HB, but, in view of the high standard deviations, this is not statistically significant. The mean complex composition of the Late Weichselian soils is 78±15% Ca^{++}, 21±12% Mg^{++}, 2±4% K^{+} and negligible amounts of Na^{+}. The HB and MB groups have a very similar composition with 80% Ca^{++} and 19% Mg^{++} and 1% K^{+}, but the LG group shows a surprising shift in Ca and Mg contents: 57±16% Ca^{++} and 37±12% Mg^{++}. Exchangeable Al^{+++} and H^{+} were determined in selected Late Weichselian soils. The highest values were 56 mmol/kg 1/3 Al^{+++} and 9 mmol/kg H^{+} in A9 (MB) and 36 mmol/kg 1/3 Al^{+++} and 5 mmol/kg H^{+} in A6 (HB). Appreciable amounts were also found in A2 (MB) and A3 (LG).

3.3.4. EXTRACTABLE Fe_2O_3 AND Al_2O_3

Dithionite-EDTA extractable ('free') iron and aluminium, and oxalate-extractable ('amorphous') iron are reported in Table 22.

Table 22. Extractable iron and aluminium in the reference soils (means and standard deviations).

	Fe_2O_3(d) %	Al_2O_3(d) %	Fe_2O_3(o) %	Fe_2O_3(t) %	Fe_o/Fe_d	Fe_d/Fe_t	n
Late Weichselian							
Soils							
HB	1.6±0.8	1.1±0.6	0.4±0.2	1.8±0.6	0.25	0.89	(44)
MB	2.5±1.4	1.0±0.4	0.5±0.3	3.3±1.8	0.20	0.76	(36)
LG	0.9±0.3	0.9±0.4	0.3±0.2	1.4±0.7	0.33	0.64	(8)
Holocene Soils							
CaO	2.9±0.9	1.4±0.8	0.7±0.2	3.9±1.6	0.26	0.69	(9)
Cal	2.2±0.8	1.1±0.5	0.7±0.3	2.6±1.2	0.32	0.85	(21)

o=oxalate-extractable; d=dithionite-extractable; t=total, by XRF.

Differences between the various groups are not significant, except for the low dithionite-extractable iron contents in the LG groups. The individual

figures suggest an increase in dithionite-extractable iron with increasing clay content, which may partially reflect a stronger weathering. Oxalate-extractable iron is higher in the Holocene soils than in the Late Weichselian soils, which may reflect more active soil formation. The degree of activity ('Aktivitätsgrad', Schröder, 1979), expressed as Fe_o/Fe_d is strongly obscured by gleying processes. This also holds true for the weathering status, as reflected by the Fe_d/Fe_t ratio. The ratio is high in the strongly weathered HB soils, and also in the very young Cal soils.

3.4. SOIL CLASSIFICATION

The classification of the reference soils according to the FAO-Unesco (1974) Legend of the World Soil Map, the USDA Soil Taxonomy Soil Survey Staff, (1975) system and the Dutch Soil Classification system of De Bakker and Schelling (1966) is given in Table 23.

In the preceding sections the information necessary for the recognition of diagnostic horizons (such as colour, clay illuviation, hydromorphic properties, base saturation and homogenization) was discussed.

Table 23. Soil classification of reference soils.

Subgroup	Code	Name	Mapping unit	Soil Taxonomy (1975)	FAO-Unesco (1974)	De Bakker and Schelling (1966)
HB	A1	Heumen I	HL1	Plaggeptic Hollic Hapludalf	Orthic Luvisol	Tuinoerdgrond
HB	A6	Ottersum	HL1	Humic Hapludult	Luvic Phaeozem	Radebrikgrond
CaO/HB	A11	Azewijn IV	kHL3	Hollic Hapludalf	Orthic Luvisol	Daalbrikgrond
HB	A13	Aabroek	HL1	Typic Hapludalf	Chromic Luvisol	Radebrikgrond
HB	A14	Hegchelen	HL2	Typic Hapludalf	Orthic Acrisol	Radebrikgrond
HB	A15	Ven-Zelderheide	HL1	Typic Hapludult	Orthic Acrisol	Radebrikgrond
HB	A16	Millingen	HL1	Typic Hapludalf	Chromic Luvisol	Radebrikgrond
HB	A2	Heumen II	HL2	Aeric Ochraqualf	Eutric Podzoluvisol	Kuilbrikgrond
HB	A4	Gendringen I	HL1	Typic Hapludalf	Orthic Luvisol	Daalbrikgrond
CaO/HB	A5	Gendringen II	kHL2	Aquic Hapludalf	Orthic Luvisol	Daalbrikgrond
HB	A7	Siebengewald	HL1	Aeric Ochraqualf	Gleyic Luvisol	Daalbrikgrond
HB	A9	Aaldonk	HL2	Aeric Ochraquult	Gleyic Podzoluvisol	Kuilbrikgrond
CaO/HB	A10	Azewijn I	KHL2	Thapto Ochraqualfic Fluventic Eutrochrept	Gleyic Cambisol	Poldervaaggrond (Kuilbrikgrond)
CaO/HB	A12	Woezik	kHL2	Aquollic Hapludalf	Gleyic Luvisol	Kuilbrikgrond
CaO/HB	A17	Ewijk	KHL2	Thapto Hapludalfic Aeric Haplaquept	Eutric Gleysol	Poldervaaggrond (Kuilbrikgrond)
CaO/LG	A3	Heumen III	kLL2	Typic Haplaquept	Eutric Gleysol	Poldervaaggrond
LG	A8	Hilsbeek	LL2	Fluvaquentic Haplaquoll	Mollic Gleysol	Leekeerdgrond
CaO/Cal	A18	Weurt	-	Fluventic Eutrochrept	Eutric Cambisol	Hofeerdgrond
CaO	A19	Randwijk	-	Typic Haplaquept	Eutric Gleysol	Poldervaaggrond
Cal	A20	Kesteren	-	Fluventic Hapludoll	Calcaric Phaeozem	Hofeerdgrond
Cal	A21	Lienden	-	Fluventic Eutrochrept	Calcic Cambisol	Ooivaaggrond
Cal	A22	Opheusden	-	Fluventic Eutrochrept	Calcic Cambisol	Hofeerdgrond

The classifications in Table 23 are based on this information and can be summarized as follows:

- All Late Weichselian HB and MB soils have an argillic horizon or 'briklaag'.
- The Late Weichselian LG soils and the Holocene soils do not have an argillic horizon, but do have a cambic horizon.
- Some Late Weichselian HB and MB soils have a base saturation below 50% (FAO-Unesco: Acrisols) or even below 35% in the Bt horizon (FAO-Unesco: Acrisols; Soil Taxonomy: Ultisols). Such low base saturation reflects old age and strong weathering and is especially common in the former southern branch of the Rhine system (Ottersum, HB-A6; Ven-Zelderheide, HB-A15; Aaldonk, MB-A9), but also occurs occasionally in the northern branch (Megchelen, HB-A14).
- Most epipedons are ochric, but some are mollic, leading to classifications of Phaeozems or Mollisols.

The subdivision of the Late Weichselian soils is reflected in their classification; the HB soils are all Udalfs or Udults, the MB soils are Aqualfs or aquic subgroups, and the LG soils are Aquepts/Aquolls. The intermediate position of some reference profiles is recognizable from their classification.

The distinction made between hydromorphic properties in the E *and* in the Bt horizons (Kuilbrikgronden) and those in the Bt horizon alone (Daalbrikgronden), used in the Dutch classification system, is useful to indicate the transitional character of the MB group. The E and Bt horizons can only be identified after micromorphological studies. In some cases, the pseudogley in the MB soils is sufficiently expressed for the soils to be classified as a Podzoluvisols in the FAO-Unesco system.

The strongly varying landscape position of the CaO soils is clearly reflected in their classification: A17 is clearly transitional to the MB soils, A18 is transitional to the Cal soils and A19 is poorly drained.

The relatively young age and weak development of the Cal soils is expressed by the subgroup adjective 'fluventic' (= stratified; Soil Taxonomy) or by the 'calcic' or calcaric' subtype name in the FAO-Unesco classification.

The Dutch classification and Soil Taxonomy both recognize the effect of long-term addition of stable manure in the 'Eerdgrond' or 'Plaggen' soil (A1), and the presence of a dark topsoil in the Holocene soils A18, A20 and A22. In the Dutch classification, the profiles A10 and A17 would be

classified as 'Poldervaaggrond' owing to the thickness of the Holocene cover, but both have an argillic horizon in the subjacent sediment within 80 cm depth which justifies the classification as 'Kuilbrikgrond' as well.

3.5. CONCLUSIONS

The conclusions of this chapter concern the differences and similarities between Holocene and Late Weichselian soils and between the subdivisions into five groups of soils.

Although the Late Weichselian soils are somewhat more weathered than the Holocene soils, *parent material* is similar. This corroborates the data of Schröder (1979), Verbraeck (1970, 1985) and Berendsen (1982).

Micromorphologically, the most important differences between Holocene and Late Weichselian soils are found in the *microstructure*: Holocene soils have an asepic or crystic plasmic fabric, which results in a friable consistence, whereas the Late Weichselian soils have abundant plasma reorientations in those parts that have not been biologically homogenized, leading to a firm or very firm consistence.

Except for local occurrences of calcareous material, the Late Weichselian soils have been *decalcified* and have low to very low *pH-KCl* values. The non-calcareous Holocene soils are all decalcified, but may occasionally contain some calcite in the subsoil (A18); their pH-KCl is moderately acid with values between 5.5 and 6.0 The calcareous Holocene soils demonstrate some decalcification but contain primary calcite throughout the profile; pH-KCl values range between 7.0 and 7.5.

Clay illuviation occurs to a similar extent in both the well drained brown and the imperfectly drained mottled Late Weichselian soils. The poorly drained grey Late Weichselian soils do not normally have clay illuviation. Miedema *et al.* (1983), however, demonstrated that clay illuviation in such soils did occur in terraces of the Meuse river, and one of the Rhine soils also contained minor illuviation. Clay illuviation was not found in Holocene soils.

Groundmass illuviation was of similar magnitude in the Late Weichselian and Holocene soils and is primarily the result of differences in land use rather than to differences in age. It is a recent phenomenon.

In the Late Weichselian soils, reduction and oxidation phenomena are the result of *pseudogleying and gleying*. All imperfectly drained soils have pseudogley features above gley features. The poorly drained grey soils have always been waterlogged and hence have not been subjected to clay illuviation. Some of these grey soils may have had better drainage drainage formerly, and been subjected to clay illuviation, but were subsequently turned completely grey by strong gleying. All reduction and oxidation phenomena in Holocene soils are the result of groundwater fluctations.

Biological activity is very strong in the calcareous Holocene soils and in the well drained Late Weichselian (HB) soils. In the latter, it is responsible for a large part of the ferri-argillans to be translocated into papules. In the MB and LG soils, biological activity has generally been restricted because of poor drainage conditions since the Late Weichselian. The non-calcareous Holocene soils are transitional between the Cal and the Late Weichselian soils, but their biological activity is variable because of a large variation in hydrological position.

Human activity is evident from the presence of a plaggen epipedon in reference soil A1, and Ap horizons in most soils, testifying their past or present use as arable land. Profiles in the walls of sand pits had compacted topsoils, and some soils had a traffic pan.

Late Weichselian and Holocene soils have a similar *organic matter content and composition* in their A horizons. Below the A horizons, organic matter contents fall abruptly in Late Weichselian soils and decrease more gradually in Holocene soils: this agrees with Schröder's results (1979). The organic matter composition of the subsoils indicated more inert aromatic groups in the Late Weichselian soils and more active polysaccharides in the calcareous Holocene soils, with intermediate contents in the non-calcareous Holocene soils. Presumably, sedimentary organic matter contents were very low in Late Weichselian sediments, and organic matter quality was poor, as Schröder (1979) also assumed. The topsoils are similar because of the addition of organic manure and relatively short turn-over time.

The Late Weichselian HB and MB soils have strongly aluminium-interlayered smectites and vermiculites, especially in their topsoils. Such interlayering is virtually absent in the LG and in the Holocene soils. Differences in *clay mineralogy* are reflected by the BaO contents of Ba-saturated clay separates, which are a measure of the cation exchange capacity of the clay fraction. The strongly Al-interlayered clays of the HB and MB soils have significantly

lower BaO contents than the LG and Holocene soils. Variation in the MB group is very large, but low values are common in this group.

The *base saturation* of the Late Weichselian soils is strongly variable but averages below 80%. Very low base saturations (below 50 or 35%) were found in the HB and MB soils. In agreement with the low pH-KCl values in these soils, exchangeable Al^{+++} and H^{+} may attain high values. The Holocene soils are nearly saturated, with values around 90% for the non-calcareous soils and 100% for the calcareous soils.

Chemical analyses of the clay fraction offer quantitative substantiation of differences in mineralogy, CEC and base saturation. Calcareous Holocene Cal soils are characterized by high K_2O, MgO and CaO contents, low Al_2O_3 contents and a high Si/Al atomic ratio. The Si/Al ratio is also high in the non-calcareous Holocene CaO soils, but low in the Late Weichselian soils. The HB soils have high Al_2O_3 contents and low BaO contents.

The Holocene soils could not be differentiated from the Late Weichselian Soils on the basis of *extractable Fe_2O_3 and Al_2O_3* contents. Schröder (1979) also found this. All Late Weichselian HB and MB soils have an *argillic horizon* (Alfisols, Luvisols) with occasionally low to very low base saturation (Ultisols, Acrisols). Strong expression of pseudogley features leads to classification as Podzoluvisols/Aqualfs. Most Holocene soils have ochric epipedons and are Inceptisols; those with a mollic epipedon are Mollisols.

Advanced soil formation in the Late Weichselian soils is responsible for differences in clay mineralogy, chemical properties, CEC, pH-KCl and base saturation. Differences in physical behaviour between the Holocene and the Pleistocene soils are caused by differences in texture, plasmic fabric, microstructure and the quantity, quality and distribution of organic matter (Chapter 4 and 5).

4. PHYSICAL CHARACTERISTICS AND BEHAVIOUR

4.1. INTRODUCTION

This chapter deals with the physical characteristics and behaviour (structure stability and tillage behaviour) of ground fine earth, natural aggregates, core samples and soil columns. The data are used to define differences and similarities between the Late Weichselian and Holocene soil groups and their subdivisions. They are derived from unpublished reports of De Kreij (1976 b), Du Bois and Wijntje-Bruggeman (1977), Klein-Hesselink (1978), Jacobs (1978, 1981), Broekhuizen and Epema (1979), Kiliç (1979), Van Oort (1979, 1980), Broekhuizen (1980), Koppe (1980), Martens (1980), De Groot (1981), Lohues (1981) and Versluis (1984).

The 5 basic data sets comprise the results of: linear extensibility of condensates (SWELL.DAT); Atterberg limits of ground fine earth (ATT.DAT); physical characteristics of natural aggregates (AGGR.DAT); physical characteristics of core samples (CORE.DAT) and data on structure stability (STAB.DAT). These data sets are presented in Appendix C. Besides these data, in this chapter also results from measurements concerning shear strength, unconfined compression, micro-tillage test and hydraulic conductivity will be discussed. A comparative study of the pore system of the B-horizons of a Late Weichselian MB soil, a Holocene CaO soil and a Holocene Cal soil has also been included. In that study a series of methods has been employed that cover the range in pore diameters from nanometres to millimetres with sufficient overlap. The methods consisted of morphological (micromorphology, scanning electron microscopy), micromorphometrical quantification on thin sections and physical methods (bulk densities, moisture characteristic and mercury intrusion).

The central question to be answered is wether there are any differences besides those induced by differences in the 5 independent basic explanatory

variables clay, silt and sand (texture), organic carbon and $CaCO_3$. A sequence of statistical analyses, which will be outlined in section 4.2, was carried out to test the presence of differences.

The methods used to measure the physical characteristics are mentioned only briefly in the text. Literature references are given for details on the methods used. All samples have been subjected to identical tests to ensure legitimate comparison of the results. Many of the methods used are described in Black *et al.* (1965) and Burke *et al.* (1986).

4.2. STATISTICAL TECHNIQUES USED

This section is mainly based on Draper and Smith (1981). For more details reference to that publication is suggested. The 5 available data sets were subjected to the same sequence of statistical techniques that aimed at summarizing the data and distinguishing differences (or lack of differences) between the various soil groups.

Descriptive statistics

1. Descriptive statistics (means, standard deviations) and other measures of scale and dispersion were calculated for each of the 5 data sets to characterize the data. Let Z_j^i denote the jth variable in the ith data group ($i= 1,..,\ 5;\ j= 1,..,\ n_i$). Some variables appear in all the data sets (clay, silt, sand, organic carbon and $CaCO_3$). These 5 variables will be referred to as the 'basic explanatory variables'.
   In all instances a correlation matrix was calculated. The significancy of the coefficients has been determined by means of a standard t-test (Draper and Smith, 1981, p.46).

Analysis of variance

2. An analysis of variance (ANOVA) was done to reveal significant differences between the soil groups. Differences between the Late Weichselian (W) and Holocene (H) soil groups were analysed, as well as differences between the 5 subgroups (HB, MB, LG, CaO, Cal). The analysis was done on the 5 basic explanatory variables and on the dependent

variables. The F test indicates the variance between the groups compared to the variance within the groups.

So, let z^i_1 ,.., $z^i_{n_i}$ stand for the n_i analysed variables in the i-th data set. Each data set is then split up into 2 groups (W,H) or into 5 groups (HB, MB, LG, CaO, Cal). The ANOVA can be formulated when we add two more indices to variable Z^i_j, say k and l, where k= 1,2 or k= 1,.., 5, representing the number of groups and l= 1, .., n_{ik}, where n_{ik} is the number of observations in the i-th data set and the k-th group. The models are written out as follows:

$$Z^i_{jkl} = \mu^i_j + t^i_{jk} + e^i_{jkl}$$

i= 1,.., 5
j= 1,.., n_i
k= 1,2 or k= 1, .., 5
l= 1, .., n_{ik}

Thus, μ^i_j stands for the mean of variable Z^i_{jkl} in the i-th data set
t^i_{jk} stands for the k-th group effect
e^i_{jkl} stands for the random effect

Stepwise multiple regression

3. To elucidate the importance of the contribution of the basic explanatory variables to the other dependent variables, a stepwise multiple regression was carried out, with the basic explanatory variables as independent variables. The model is written out as follows:

$$Y^i_j = X^i_j \beta^i_j + e^i_j$$

i= 1, .., 5
j= 1, .., n_i (n_i is the number of dependent variables)

where X^i_j is composed of observations on the 5 basic explanatory variables. Via stepwise regression techniques (Draper and Smith, 1981) the number of significantly contributing basic explanatory variables was reduced.

Dummy variables

4. A direct answer to the central question can now be made by adding some dummy variables to the model, $Z^i_{n_i+1}$,.., $Z^i_{n_i+4}$, where $Z^i_{n_i+1}$ stands for

differences between Late Weichselian and Holocene, $Z^i_{n_i+2}$, $Z^i_{n_i+3}$, $Z^i_{n_i+4}$ for differences within Late Weichselian and Holocene groups and between subgroups in the i-th data set.

For example to test differences between Holocene and Weichselian groups a dummy variable was added which was assigned -1 if an observation originated from the Holocene group and +1 if an observation originated from the Weichselian group. The model can be formulated in terms of technique 3 described above:

$$Y^j_i = X^i_j \beta^i_j + e^i_j$$

where X^i_j is now composed of observations on the n_1+4 variables $Z^i_1, \ldots, Z^i_{n_i+4}$. Again, a stepwise regression was done to detect the most important effects, with special emphasis on the contribution of the dummy variables in relation to the difference between the Late Weichselian and Holocene groups and subgroups.

Classification based on discriminant analysis

5. Finally, to view the central question from another angle, discriminant analysis was performed. Classification into 2 and 5 groups was carried out by determining the discriminating functions on the basis of the physical characteristics and to reclassify the investigated samples by means of these functions. Although this technique is known to give slightly optimistic results (Dillon and Goldstein, 1984) because the same samples are used to discriminate and to classify, it was used to reveal more about where typical differences might be expected. The set of variables now consists only of the dependent variables, which can be symbolized by $Z^i_j, \ldots, Z^i_{n_i}$, where n_i is the number of dependent variables in the i-th data set. The k= 1,2 or k= 1,.., 5 groups were classified. In both cases, the aim was to achieve clearly distinctive groups. In the case of the 5 groups, discriminant analysis was also carried out with 2 discriminating functions (instead of a maximum of 4), because with 2 discriminating functions fairly clear groupings of variables evolved.

Analyses were carried out with SPSS-X (Nie *et al.* 1975) as well as with some own statistical modules.

Because of the diverse character of the data sets, no effort was made to use a statistical technique to combine the 5 data sets. The results of

the statistical sequence described above on each of the 5 data sets have to be interpreted from a soil science point of view. The conclusions from the separate data sets will be synthesized in section 4.9.

4.3. PHYSICAL CHARACTERISTICS OF GROUND FINE EARTH

4.3.1. PARTICLE DENSITY

Particle density was calculated from the volume of a known weight of oven-dry ground fine earth. The volume was determined through water displacement in a calibrated pycnometer. The data (191 samples) are means of duplicate or triplicate measurements and have a very high reproducibility.
Table 24 presents means and standard deviations for the various groups.

Table 24. Means and standard deviations (SD) of the particle density data (PD - kg/m^3) and the 5 basic explanatory variables (clay, silt, sand, organic carbon and $CaCO_3$ - %).

GROUPING		FLUVIAL		WEICHSELIAN		HOLOCENE		HB		MB		LG		CaO		Cal	
number of samples		n=191		n=130		n=61		n=44		n=68		n=18		n=38		n=23	
VARIABLE		mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Clay	(CL)	25.4	13.1	22.1	11.7	32.5	13.2	15.2	5.8	25.1	11.5	27.7	15.4	37.5	13.5	24.3	7.4
Silt	(SI)	31.9	13.2	27.5	11.7	41.3	11.2	23.7	10.6	28.0	12.5	34.8	7.1	38.2	8.3	46.4	13.4
Sand	(SA)	42.7	23.4	50.4	21.6	26.2	18.0	61.1	14.9	46.9	22.7	37.5	20.7	24.3	17.0	29.3	19.4
Org. carbon	(OC)	0.8	0.9	0.6	0.7	1.2	1.0	0.7	0.7	0.5	0.6	1.0	1.0	1.6	1.1	0.6	0.5
$CaCO_3$	(CA)	1.1	3.5	0.0	0.1	3.5	5.5	0.0	0.1	0.0	0.1	0.1	0.2	0.0	0.1	9.2	5.3
Part. density	(PD)	2690	50	2690	50	2690	50	2670	30	2705	45	2685	70	2690	60	2700	20

The measured mean particle densities vary between 2690 and 2705 kg/m^3. Because quartz and organic matter have a particle density lower than these values, whereas both clay minerals and calcite have higher particle densities, it is to be expected that sand (predominantly quartz) and organic carbon will have a negative correlation with particle density and that clay and $CaCO_3$ will correlate positively with particle density. This is indeed the case: see the correlation matrix of the 5 basic explanatory variables with the particle density (Appendix D). The positive correlation with the silt fraction in all groups suggests that the silt fraction contains clay minerals and $CaCO_3$ (only in the Cal subgroup).

Differences between groups were tested with ANOVA at 95% and 99% confidence limits (Table 25): significant differences have been indicated by A, B or C (A indicating the *lowest* values of the mean). Table 25 indicates that the particle densities of Late Weichselian and Holocene soil materials are not significantly different. There are significant differences between the subgroups, however. The high particle density in the MB subgroup is not the result of any of the 5 basic explanatory variables but rather results from the abundance of iron and manganese hydroxide mottles. In the Cal subgroup the high particle density is the result of the $CaCO_3$ content of that subgroup.

Table 25. Results of ANOVA of the particle density data and the 5 basic explanatory variables.

GROUPING	W	H	Ftest	probability	HB	MB	LG	CaO	Cal	Ftest	probability
Variable											
CL	A[1)]	B	30.6	**[2)]	A	B	BC	C	B	21.5	**
SI	A	B	58.7	**	A	A	B	C	BC	21.3	**
SA	B	A	57.7	**	C	B	AB	A	A	22.2	**
OC	A	B	19.0	**	A	A	AB	B	A	12.7	**
CA	A	B	51.3	**	A	A	A	A	B	126.5	**
PD	A	A	0.1		A	B	AB	AB	B	4.2	**

1) A, B, C etc. indicate significant differences at 95% confidence limits; A indicates the lowest mean values.
2) Probability: ** $p<0.01$
* $p<0.05$

Table 25 also demonstrates the characteristic and highly significant differences in the 5 basic explanatory variables between the Late Weichselian and Holocene groups and subgroups.
Stepwise multiple regression (Table 26) indicated that about 60-75% of the variation in particle density can be explained by the variables clay and organic carbon. The 4 dummy variables did not significantly differ from zero: therefore no differences, apart from those induced by the 5 basic explanatory variables, are to be expected.
The regression equation found for all 191 samples is as follows:

$$PD = 2660 + 2.40\ CL - 38.2\ OC$$

PD= particle density (kg/m^3)
CL= clay content (%)
OC= organic carbon content (%)

Table 26. Variance explained (%) of the particle density (PD) data by stepwise multiple regression with 9 and 5 basic explanatory variables.

	9 variables	5 variables							
GROUPING	FLUVIAL	FLUVIAL	WEICHSELIAN	HOLOCENE	HB	MB	LG	CaO	Cal
number of samples	n=191	n=191	n=130	n=61	n=44	n=68	n=18	n=38	n=23
variance explained[1]	R^2	R^2	R^2	R^2	R^2	R^2	R^2	R^2	R^2
VARIABLE									
PD	72	72	74	68	74	77	63	70	57

[1]) variance explained at 95% confidence limits

The constant (2660) is very close to the particle density of quartz (2650 kg/m^3), which is the main constituent of the sand and silt fractions. When extrapolated to zero organic carbon content, the particle density of the clay fraction is 2900 kg/m^3, which closely corresponds to the value of 2880 kg/m^3 quoted by Poelman (1975) for samples of fluvial soils from the Netherlands.

Conclusion

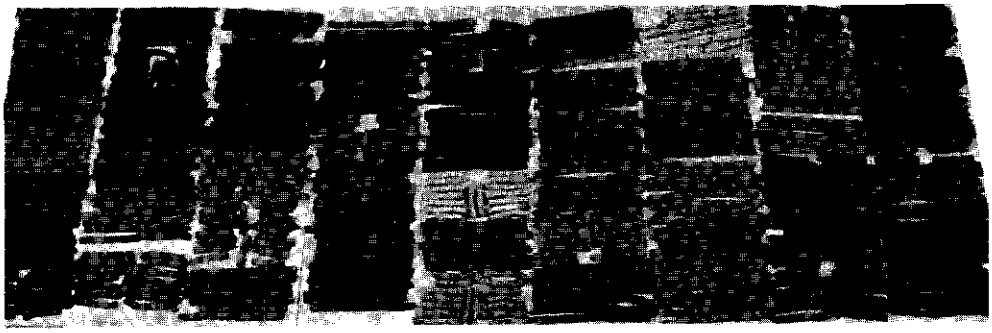
In conclusion, it can be stated that the particle densities of Late Weichselian and Holocene fluvial soil materials are not significantly different, and that particle density is mainly a function of clay and organic carbon.

4.4. PHYSICAL CHARACTERISTICS OF CONDENSATES

4.4.1. LINEAR EXTENSIBILITY

For extensibility studies, condensates were used instead of natural aggregates, in order to eliminate differences in pore volume, pore size distribution and microstructure (Martens, 1980). The properties of the clay fraction are revealed best when condensates are used. Condensates were made by kneading a ground fine earth sample to a homogeneous paste at a moisture content just below the sticky point (SP: see section 4.4.2). Cylindrical condensates with a diameter of about one centimetre were prepared from this paste (Fig. 39). These condensates were slowly dried over a saturated NaCl solution which had an osmotic pressure of 32 MPa (equal to pF 5.5) and were subsequently air-dried.

Fig. 39. Condensates used in extensibility studies.



The air-dried condensates were slowly and in steps brought to pF2, pF1.5, pF1 and pF0.5 and weighed. After presaturation with kerosene to fill remaining air-filled pores, the total volume was determined according to the method of Koenigs (1981, 1984). The condensates were suspended in kerosene and the downward thrust on the vessel was recorded. Subsequently the condensates were oven-dried and weighed. The total volume of the aggregate follows from the recorded downward thrust on the vessel divided by the density of the kerosene. The moisture content follows from the weights of the moistened condensates and their oven-dry weight. On the other hand with the aid of the known particle densities and the dry bulk density of the condensates the pore volume of the air-dry condensates can be calculated. With the measured moisture contents at pF2 and pF1, the pore volume of the air-dry condensates and the particle density the linear extensibility of the condensates is *calculated* according to Kuipers (1961) from air-dry to pF2 (LE2 calc.) and from air-dry to pF1 (LE1 calc.). This calculation is based on the assumption that at moisture contents equal to the dry pore volume and above no gas fase is present. From the changes in *measured* total volume from air-dry to pF2 and from air-dry to pF1 (volume extensibility) linear extensibilities were calculated (LE2 meas. and LE1 meas. respectively). The 55 samples investigated were selected from the 191 samples mentioned in Table 24. They were chosen to represent the characteristics of all 191 samples. This can be seen in Table 27 where means and standard deviations are given. ANOVA results are given for the basic explanatory variables of the 55 samples in Table 28. Tables 29 and 30 present the corresponding data for extensibility results and bulk densities.

Table 27. Means and standard deviations (SD) of the 5 basic explanatory variables (X) of condensates.

GROUPING		FLUVIAL		WEICHSELIAN		HOLOCENE		HB		MB		LG		CaO		Cal	
number of samples		n=55		n=30		n=25		n=9		n=17		n=4		n=11		n=14	
VARIABLE		mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Clay	(CL)	28.0	10.1	24.1	7.2	32.6	11.2	18.1	4.6	27.3	6.6	24.3	6.7	37.6	12.3	28.6	8.8
Silt	(SI)	39.5	12.6	32.8	9.6	47.4	11.2	24.3	7.7	36.5	8.7	36.0	3.7	42.3	9.3	51.5	11.2
Sand	(SA)	32.6	19.0	43.1	14.8	20.0	15.6	57.6	9.2	36.2	12.8	39.8	10.3	20.1	13.8	19.9	17.3
Org. carbon	(OC)	0.89	0.72	0.88	0.80	0.90	0.64	0.72	0.60	0.82	0.74	1.53	1.28	1.21	0.60	0.66	0.59
$CaCO_3$	(CA)	2.2	4.4	0.0	0.0	4.8	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	8.6	4.5

Table 28. Results of ANOVA of the 5 basic explanatory variables of condensates.

GROUPING	W	H	Ftest	probability	HB	MB	LG	CaO	Cal	Ftest	probability
VARIABLE											
CL	A[1)]	B	11.6	**[2)]	A	B	AB	B	B	7.1	**
SI	A	B	27.4	**	A	B	B	BC	C	13.0	**
SA	B	A	31.7	**	C	B	ABC	A	A	13.3	**
OC	A	A	0.0		A	A	A	A	A	1.9	
CA	A	B	23.3	**	A	A	A	A	B	35.8	**

1) A, B, C etc. indicate significant differences at 95% confidence limits; A indicates the lowest mean values.

2) Probability: ** p< 0.01
* p< 0.05

The dry bulk density of the condensates of Late Weichselian (W) soil material is not significantly different (Table 30) from that of the Holocene soil material (H), but in 5 subgroups the difference between the condensates of the various groups are more obvious and significant. Although the differences are considerably smaller than the differences between natural aggregates (section 4.6) small differences remain between the 5 subgroups. The significant difference in bulk density at pF2 and pF1 (BD2 and BD1) between W and H is caused by the lower bulk densities of the HB subgroup. Linear extensibility is significantly lower for the Late Weichselian soil material than for the Holocene soil material: this holds true for both calculated and measured values at pF2 and pF1. The lowest linear extensibility is in the HB subgroup. The differences between the other subgroups are the result of differences between the MB and LG subgroups on the one hand, and the Holocene subgroups on the other: this is especially the case for extensibility values at pF1 (LE1 calc. and LE1 meas.).

The calculated extensibilities are systematically lower than the measured extensibilities and are even negative for the HB subgroup at pF2 (LE2 calc.). The extensibilities calculated from particle density, pore volume and water retention values underestimate the real extensibilities, especially in the case of pF2, where complete saturation does not always occur.

The degree of swelling and shrinkage in the samples is primarily the result of clay content. Thus, the positive correlation of extensibility with clay content (Appendix D) is to be expected. Organic carbon also correlates positively with extensibility, although only significantly and strongly in the case of the Cal subgroup; this suggests a combined effect of clay and organic matter. Quartz and calcite (sand and $CaCO_3$) are inert. High sand contents imply low clay contents, and hence the negative correlation is to be expected. The significant negative correlation of extensibilities with $CaCO_3$ in the Cal subgroup might be the result of extensibility being suppressed by the influence of released Ca-ions on the electric double layer. Correlation with the silt fraction is erratic and in most cases not significant and depends on the composition of the silt fraction.

Table 29. Means and standard deviations (SD) of linear extensibility data (LE-%) and bulk densities (BD-kg/m^3) of condensates.

GROUPING	FLUVIAL		WEICHSELIAN		HOLOCENE		HB		MB		LG		CaO		Cal	
number of samples	n=55		n=30		n=25		n=9		n=17		n=4		n=11		n=14	
VARIABLE	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
LE 2 calc.	2.1	2.4	0.9	1.8	3.6	2.1	-0.4	1.1	1.5	2.0	1.3	0.9	4.1	2.3	3.2	1.9
LE 2 meas.	3.2	1.9	2.4	1.1	4.2	2.1	1.5	0.7	2.8	1.0	2.9	0.6	4.7	2.4	3.8	1.9
LE 1 calc.	3.3	2.3	2.2	1.6	4.6	2.3	1.1	1.3	2.9	1.5	2.0	1.0	5.7	2.2	3.8	2.1
LE 1 meas.	4.1	2.1	3.2	1.4	5.1	2.4	2.0	1.1	3.8	1.3	3.5	0.4	6.1	2.4	4.3	2.2
BD 2	1630	110	1670	100	1585	105	1760	55	1640	80	1580	105	1615	130	1560	80
BD 1	1590	115	1630	110	1540	100	1735	60	1595	95	1555	90	1550	115	1535	95
BD dry	1790	85	1790	85	1790	85	1830	65	1790	90	1725	100	1845	85	1750	50

The fact that the correlation between the clay content and extensibilities is much higher for the Holocene soil material (R about 0.9) than for the Late Weichselian soil material (R about 0.6-0.7) is probably the result of strong aluminium interlayering of swelling clay minerals in the Late Weichselian soil material, as was indicated in the clay mineralogical analysis (section 3.2).

Table 30. Results of ANOVA of linear extensibility data and bulk densities of condensates.

GROUPING	W	H	Ftest probability		HB	MB	LG	CaO	Cal	Ftest probability	
VARIABLE											
LE 2 calc.	A[1)]	B	26.4	**[2)]	A	B	AB	C	BC	9.2	**
LE 2 meas.	A	B	16.0	**	A	B	B	B	B	5.9	**
LE 1 calc.	A	B	19.6	**	A	B	AB	C	BC	9.0	**
LE 1 meas.	A	B	13.6	**	A	B	B	C	BC	7.0	**
BD2	B	A	9.5	**	B	A	A	A	A	7.2	**
BD1	B	A	9.9	**	B	A	A	A	A	6.9	**
BD dry	A	A	0.0		B	AB	AB	B	A	3.7	*

1) A, B, C etc. indicate significant differences at 95% confidence limits; indicate the lowest mean values.

2) Probability; ** $p < 0.01$
* $p < 0.05$

Aluminium interlayering hampers the expansion and contraction of smectite and vermiculite. As aluminum interlayering occurs notably in the HB subgroup the non significant and low correlations and the low extensibilities of that subgroup are not unexpected. The high correlations in the LG subgroup are suspect, because of the limited number (4) of samples.

Table 31. Variance explained (%) in linear extensibility (LE) data of condensates by stepwise multiple regression with 9 and 5 basic explanatory variables.

	9 variables	5 variables							
GROUPING	FLUVIAL	FLUVIAL	WEICHSELIAN	HOLOCENE	HB	MB	LG	CaO	Cal
number of samples	n=55	n=55	n=30	n=25	n=9	n=17	n=4	n=11	n=14
variance explained[1)]	R^2	R^2	R^2	R^2	R^2	R^2	R^2	R^2	R^2
VARIABLE									
LE2 calc.	75	72	39	74	-	38	-	72	94
LE2 meas.	77	73	54	73	-	40	99	73	94
LE1 calc.	81	78	47	89	-	57	-	77	91
LE1 meas.	80	80	54	87	-	61	99	80	95

1) variance explained at 95% confidence limits

-: no variance explained at 95% confidence limits

Multiple regression analysis (Table 31) indicates that about 75-80% of the variance can be explained by the variables clay and organic carbon. These two variables explain more variance in the Holocene samples (about 75-90%) than in the Late Weichselian samples (about 40-55%). In the Cal subgroup, organic carbon and clay explain no less than 95% of the variance. Adding the 4 dummy variables (for differences between and within the Holocene and Late

Weichselian soil materials), the difference between Holocene and Late Weichselian (H/W=VO) significantly contributes to the variance explained in the LE2 calc. and LE1 calc. and the difference within the Holocene group (CaO/Cal=V13) contributes significantly to the variance explained in LE2 meas. This may be caused by variation not taken into account e.g. resulting from regional effects or land use effects.

The regression equations generated are given in Table 32 both in their original form and after average group values have been substituted for OC and/or CA.

Table 32. Regression equations for linear extensibility data on Fluvial, Weichselian and Holocene samples.

GROUPING	number ofsamples	REGRESSION EQUATIONS	
FLUVIAL	n=55	LE2 calc.= -4.09 + 0.18 CL + 0.92 OC + 0.13 CA	+ -2.99 + 0.18 CL
		LE2 meas.= -1.17 + 0.16 CL	
		LE1 calc.= -2.52 + 0.29 CL + 0.74 OC	+ -1.86 + 0.19 CL
		LE1 meas.= -1.53 + 0.18 CL + 0.63 OC	+ -0.97 + 0.18 CL
LATE WEICHSELIAN	n=30	LE2 calc.= 4.17 - 0.08 SA	
		LE2 meas.= -0.27 + 0.11 CL	
		LE1 calc.= -1.42 + 0.15 CL	
		LE1 meas.= -0.25 + 0.14 CL	
HOLOCENE	n=25	LE2 calc.= -1.73 + 0.16 CL	
		LE2 meas.= -1.11 + 0.16 CL	
		LE1 calc.= -1.55 + 0.15 CL + 1.32 OC	+ -0.36 + 0.15 CL
		LE1 meas.= -1.33 + 0.16 CL + 1.19 OC	+ -0.26 + 0.16 CL

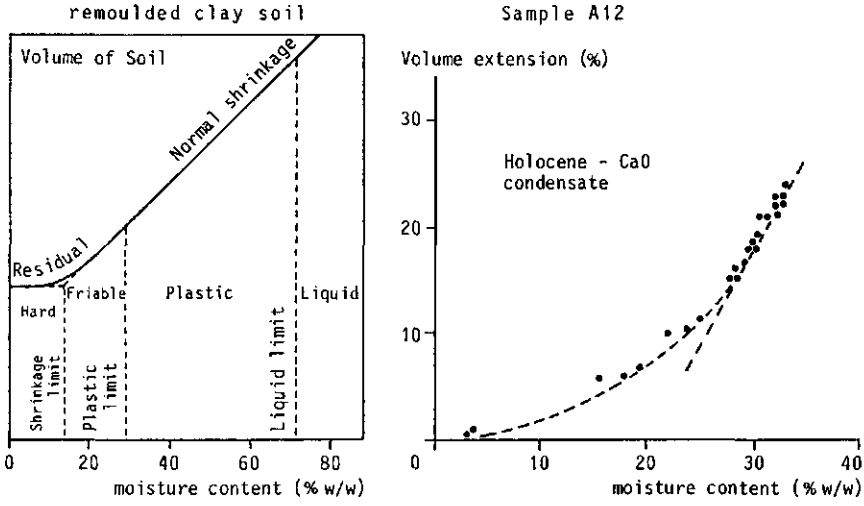


Fig. 40. Normal and residual shrinkage and an example of a measurement of volume swelling against moisture content (% w/w).

Table 33. Classification of linear extensibility data of condensates, based on discriminant analysis.

		Predicted group membership					
		Weichselian		Holocene		correct classification	
		number	%	number	%	number	%
Actual group	number of cases						
Weichselian	30	23	77	7	23		
Holocene	25	3	12	22	88		
Total	55	26		29		45	82

[4 canonical functions]		Predicted group membership											
		HB		MB		LG		CaO		Cal		correct classification	
		number	%	number	%	number	%	number	%	number	%	number	%
Actual group	number of cases												
HB	9	7	78	2	22	-	-	-	-	-	-		
MB	17	2	12	10	59	1	6	2	12	2	12		
LG	4	-	-	1	25	2	50	-	-	1	25		
CaO	11	1	9	4	36	-	-	6	55	-	-		
Cal	14	-	-	1	7	-	-	-	-	13	93		
Total	55	10		18		3		8		16		38	69

These equations indicate a fairly constant relation between linear extensibility and clay content, with a negative cut-off on the ordinate. This negative cut-off is caused by the fact that the swelling of the first few percents of clay can be accomodated in the larger pores. Comparing the linear extensibility of Late Weichselian and Holocene groups, the coefficient for CL of the Holocene group is somewhat higher, causing the linear extensibility to be slightly higher for the Holocene than for the Late Weichselian group: this may be explained by the differences in clay mineralogy mentioned earlier (section 3.2).

Discriminant analysis indicates that it is justifiable to divide the deposits into Holocene and Late Weichselian and their subgroups, on the basis of bulk densities and linear extensibilities (Table 33). The Late Weichselian/Holocene subdivision shows up correctly in about 80% of the cases based on the linear extensibilities and the bulk densities, whilst the division into 5 subgroups shows up correctly in about 70% of the cases using 4 canonical functions. The first two canonical functions, based on bulk densities and linear extensibilities respectively, cover 85% of the variance observed. The best fits are for the HB and Cal subgroups: MB is the most variable subgroup.

Conclusion

In conclusion it can be stated that:

- linear extensibility and moist bulk density of condensates are mainly a function of clay together with organic carbon.
- linear extensibility and moist bulk density of condensates are good discriminants between Late Weichselian and Holocene groups as well as for the subdivisions of these groups.
- the linear extensibility of condensates of the Late Weichselian soil material is slightly lower than that of condensates of the Holocene soil material: this echoes the differences found in clay mineralogy.

4.4.2. SHEAR STRENGTH

A direct shear strength method without loading was applied to the condensates, that were remoistened in a special way to avoid the crumbling by expansion and the occlusion of air (Koenigs *et al.*, 1976). Condensates were used to eliminate differences in natural structure. The remoistened condensates were placed in the best fitting hole of a block with a movable top part (plate) fixed on a roller skate (for the higher readings) or placed on a movable turret. The plate is attached to the top of the turret by strings to avoid friction between plate and block. When the roller skate is used the friction between plate and block is reduced by ballotini. By moving the turret or the roller skate slowly backwards shear is applied and the reaction force is followed on a balance. The shear strength at failure is measured, the diameter of the condensate is measured with a calipher and the moisture content of the condensate is determined. The shear stress is calculated by division of the recorded force at failure by the surface area. When the moisture content decreases, the volume first decreases linearly (normal shrinkage, Fig. 40). The individual particles become more densely packed and the strength will increase. When air enters the system, the loss of moisture will not correspond linearly with the shrinkage, and the increase in strength will diminish. This crucial point is very obvious from Fig. 41, which gives data on samples from each of the 5 subgroups, plus their respective clay contents. With increasing clay content the crucial point is less clear (compare HB-average 25% clay with CaO-average 46% clay:

other subgroups are intermediate). The crucial point agrees fairly well with the independently measured hygroscopic point (HP) of the Atterberg limits (section 4.4.3). Our results from Late Weichselian and Holocene fluvial soils also fit the relation between the shear strength at pF 5.5 and the clay and humus content, generated by Koenigs *et al.* (1976) for young calcareous marine soils.

Further analysis of the data below the hygroscopic point indicated that at equal strength the true Late Weichselian members (HB and MB subgroups) could be differentiated from the true Holocene members (Ca0 and Ca1 subgroups). The LG subgroup is in an intermediate position but more closely related to the Holocene members. Again was shown that the moisture content at similar clay content of the Holocene members (and LG) was higher than for the true Late Weichselian members.

The analysis suggest further that at the same strength the moisture content per 100 % clay of the HB and MB subgroups is larger than that of the Holocene group (and LG), and that its decrease with rising pF is larger. This means that the HB and MB materials need to be wetter in order to be sheared than the other materials.

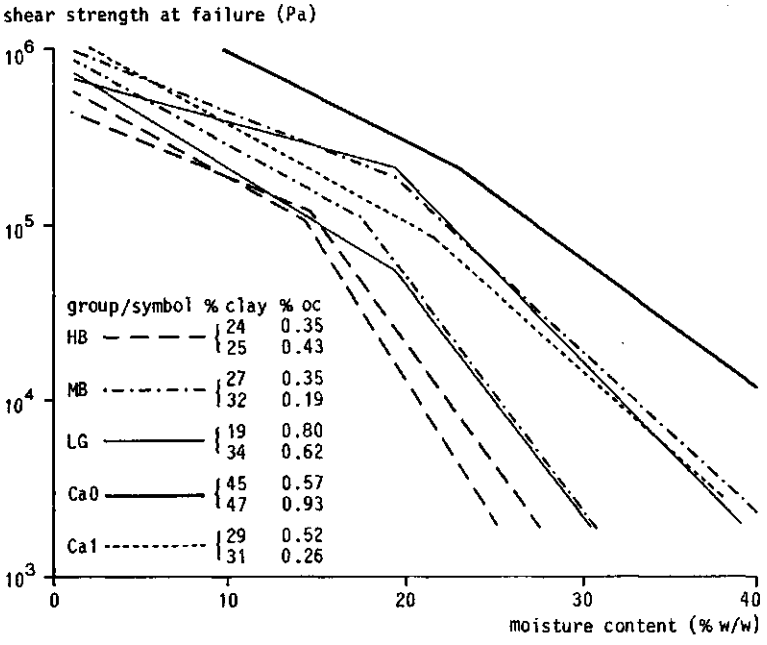


Fig. 41. Shear strength of condensates (yield value at failure).

Conclusion

The total number of samples measured (n=13) is small to allow reliable conclusions to be drawn. A large part of the differences between and within the Late Weichselian and Holocene samples are induced by differences in clay, organic carbon and derived moisture characteristic. Of the Late Weichselian samples the LG subgroup demonstrated a character more closely related to the Holocene samples. Yet, the truly Late Weichselian HB and MB materials need to be wetter in order to be sheared than the other materials.

4.4.3. ATTERBERG LIMITS

The remoulded material from which the condensates were prepared was tested for the Atterberg limits (Atterberg, 1910 a,b; 1912; Sowers, 1965). Those limits include the Upper Plastic Limit (UPL) or Liquid limit, the Sticky Point (SP), the Lower Plastic Limit (LPL) and the Hygroscopic Point (HP) or shrinkage limit (Fig. 40). The 55 samples analysed were the same as those used for the extensibility measurements. The means and standard deviations of the basic explanatory variables are given in Table 27 and ANOVA results in Table 28. The Atterberg limits are presented in Tables 34 and 35.

Table 34. Means and standard deviations (SD) of Atterberg limits (moisture content -% w/w).

GROUPING	FLUVIAL		WEICHSELIAN		HOLOCENE		HB		MB		LG		CaO		Cal	
number of samples	n=55		n=30		n=25		n=9		n=17		n=4		n=11		n=14	
VARIABLE	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
UPL [1]	35.3	11.7	29.8	7.9	41.9	12.2	21.6	2.0	32.6	7.1	36.1	5.7	46.2	12.9	38.5	10.8
SP	26.9	7.2	23.4	6.0	31.2	6.4	17.4	2.0	25.7	5.4	26.9	5.0	32.7	5.6	30.0	6.8
LPL	26.7	6.1	23.9	4.6	29.7	6.1	19.5	1.4	25.5	3.8	28.2	5.2	31.0	7.0	28.8	5.4
HP	16.0	4.8	13.9	3.3	18.6	5.2	10.9	1.1	14.9	3.2	16.5	2.8	21.2	5.0	16.5	4.4

[1] abbreviations see text.

Table 35. Results of ANOVA of Atterberg limits.

GROUPING	W	H	Ftest	probability	HB	MB	LG	CaO	Cal	Ftest	probability
VARIABLE											
UPL	A[1]	B	18.9	**[2]	A	B	BC	C	BC	11.0	**
SP	A	B	20.5	**	A	B	BC	C	BC	11.4	**
LPL	A	B	16.7	**	A	B	B	B	B	8.6	**
HP	A	B	14.8	**	A	B	BC	C	BC	10.7	**

[1] A, B, C etc. indicate significant differences at 95% confidence limits; A indicates the lowest mean values.

[2] Probability: ** $p < 0.01$

* $p < 0.05$

Table 35 demonstrates significant differences between Late Weichselian and Holocene soil material. These differences result from systematically low values for the HB group and high values for the CaO subgroup with systematic intermediate values for the MB-subgroup and intermediate to high values for the LG and Cal subgroups (Table 34). The plasticity range ('Plastizitäts-grade'-Atterberg 1910 a,b; 1912), defined as the difference between UPL and LPL and classified in three classes (I= 30-16; II= 15-8; III= 7-1), is class III for the Late Weichselian material and class II for the Holocene material, with low (2 for HB) to high (15 for CaO) values in the subgroup. The plasticity range for the Late Weichselian material is narrower than for the Holocene soil material, notably for the HB subgroups. Another important difference is that the Holocene soil material has a non-sticky plasticity (SP-LPL $\geq$ 0) whilst the Late Weichselian material remains sticky untill moisture contents fall below the LPL (SP-LPL$<$0).
Table 36 shows the results of the variance explained by stepwise multiple regression at 95% confidence limits.

Table 36. Variance explained (%) of Atterberg limits by stepwise multiple regression with 7 and 3 basic explanatory variables.

	7 variables	3 variables							
GROUPING	FLUVIAL	FLUVIAL	WEICHSELIAN	HOLOCENE	HB	MB	LG	CaO	Cal
number of samples	n=55	n=55	n=30	n=25	n=9	n=17	n=4	n=11	n=14
variance explained[1)]	R^2	R^2	R^2	R^2	R^2	R^2	R^2	R^2	R^2
VARIABLE									
UPL	92	91	82	88	-	80	-	82	98
SP	87	86	76	89	-	76	-	86	93
LPL	86	86	78	86	-	66	-	87	82
HP	85	85	77	82	-	75	-	70	73

1) Variance explained at 95% confidence limits.
-: at 95% confidence limit no variance explained.

The variance explained by clay, organic carbon and $CaCO_3$ is very high (about 85-90%) for all fluvial samples, with minor differences between the groups and subgroups (provided that the number of samples allowed determination at 95% confidence limits). Adding the dummy variables hardly improves the variance explained.

Details on the multiple regression and the correlation matrix of the Atterberg limits with 3 of the basic explanatory variables (clay, organic carbon and $CaCO_3$ content) are given in Appendix D. For FLUVIAL the correlation matrix demonstrates the expected significant (positive) correlation (R= 0.7-0.9) of the Atterberg limits and clay, and significant (positive) correlations (R= 0.3-0.6) with organic carbon. For the Holocene group, the positive correlation with OC is stronger (R= 0.5-0.7) than for the Late Weichselian group. The only significant (positive) correlation in in all of the HB, MB and LG subgroups is that of the LPL with OC, whilst the MB subgroup demonstrates in addition significant positive correlations with CL for UPL,SP and HP and with OC for SP.

Table 37 presents the classification results of Atterberg limits, based on discriminant analysis.

Table 37. Classification results of Atterberg limits, based on discriminant analysis.

		Predicted group membership					
		Weichselian		Holocene		correct classification	
		number	%	number	%	number	%
Actual group	number of cases						
Weichselian	30	26	87	4	13		
Holocene	25	10	40	15	60		
Total	55	36		19		41	75

		Predicted group membership											
[2 canonical functions]		HB		MB		LG		CaO		Cal		correct classification	
		number	%	number	%	number	%	number	%	number	%	number	%
Actual group	number of cases												
HB	9	8	89	1	11	-	-	-	-	-	-		
MB	17	2	12	10	59	-	-	2	12	3	18		
LG	4	-	-	2	50	-	-	-	-	2	18		
CaO	10	-	-	3	30	-	-	6	60	1	10		
Cal	13	-	-	5	39	-	-	1	8	7	54		
Total	53	10		21		0		7		10		31	58

The Late Weichselian group is predicted very accurately (87%) in contrast to the Holocene group (60% correct prediction). This demonstrates the characteristic behaviour of the Late Weichselian group especially of the HB subgroup whilst the MB subgroup interrelates with the HB subgroup. The sticky points (SP) is the most strongly discriminating variable. The LG subgroup has too few samples to judge. The Holocene group commonly

demonstrates overlap with the Late Weichselian MB subgroup. For the subdivision in 5 subgroups all Atterberg limits headed by SP and HP occur in function 1 which scores 67% variance explained.

Conclusion

In conclusion, the analyses of the Atterberg limits demonstrated:

- a smaller plasticity range (UPL-LPL) for the Late Weichselian material than for the Holocene material.
- Clay and organic carbon, explain practically all variation in the Atterberg limits, in both the Holocene and the Late Weichselian groups.
- the Late Weichselian material remains sticky at moisture contents equal to or below the LPL. As the LPL signifies the maximum water contents for successfull tillage, this difference is also important for agricultural practice.

4.5. PHYSICAL CHARACTERISTICS OF CORE SAMPLES

4.5.1. BULK DENSITY, PORE VOLUME AND MOISTURE CHARACTERISTIC.

The data set on core samples (CORE.DAT) is composed of results from 100 cm^3 cores from each horizon in each of the reference profiles (n=89, Appendix A) and 100 cm^3 cores taken from various depths around these reference profiles, largely within the surveyed areas (n=102). Table 24 shows the characteristics of these core samples (n=191) with regard to the 5 basic explanatory variables (clay, silt, sand, organic carbon and $CaCO_3$). Data were obtained on the following properties of the core samples: bulk density (BD); water retention at pF2 (WW2) and pF4.2 (WW42, determined from small aggregates), both as weight percentage. Air permeability (Ki) and Torvane shear strength (TV), measured only on the supplementary cores (n=102), are discussed in sections 4.5.2 and 4.5.3 respectively. With the aid of the measured particle densities (PD, section 4.3.1) the following characteristics were derived:

- pore volume ($PV = 1 - \frac{BD}{PD}$)

- volumetric water retention at pF2 and pF42 (VV2= WW2*BD*0.001; VV42= WW42*BD*0.001
- available volume of water (AM= VV2-VV42)
- air volume at pF2 and pF42 (AV2= PV-VV2; AV42= PV-VV42).

The data on these measured and derived properties are given in Table 38 as means and standard deviations. To discriminate between the different groups ANOVA was performed. The ANOVA results are presented in Table 39. The correlation matrix of these properties with the 5 basic explanatory variables is given in Appendix D. Variance explained by multiple regression at 95% confidence limits for the different groupings with 5 and 9 basic explanatory variables is presented in Table 40. Classification results based on discriminant analysis are presented in Table 41.

Table 38. Means and standard deviations (SD) of physical data on core samples.*

GROUPING	*FLUVIAL*		*WEICHSELIAN*		*HOLOCENE*		*HB*		*MB*		*LG*		*CaO*		*Cal*	
number of samples	n=191		n=130		n=61		n=44		n=68		n=18		n=38		n=23	
VARIABLE	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
BD (kg/m^3)	1485	150	1520	145	1400	115	1550	130	1545	140	1360	110	1375	120	1435	95
PV (%v/v)	44.9	5.5	43.4	5.5	48.0	4.2	41.9	4.7	42.8	5.4	49.5	3.4	48.8	4.3	46.8	3.8
WW2 (%w/w)	22.4	6.8	20.5	6.2	26.4	6.2	16.6	3.5	20.7	5.8	29.3	3.3	28.4	6.7	23.0	3.1
WW42 (%w/w)	12.0	5.9	10.6	4.9	14.8	6.9	8.3	3.0	10.8	4.8	15.6	5.3	17.6	7.1	10.2	3.0
VV2 (%v/v)	32.5	7.7	30.7	7.7	36.3	6.2	25.8	5.5	31.5	7.3	39.6	3.5	38.4	6.4	32.9	4.1
VV42 (%v/v)	17.2	7.5	15.9	6.7	20.2	8.3	13.0	5.2	16.3	6.6	21.0	7.0	23.6	8.3	14.6	4.4
AM (mm/10 cm)	15.2	4.7	14.8	4.5	16.1	5.0	12.8	3.9	15.2	4.0	18.5	4.9	14.8	4.9	18.3	4.3
AV2 (%v/v)	12.4	6.6	12.8	7.2	11.7	5.1	16.1	8.3	11.3	6.3	9.9	4.7	10.4	4.5	13.8	5.6
AV42 (%v/v)	27.7	7.2	27.6	7.3	27.9	7.2	28.9	8.8	26.5	6.1	28.4	7.2	25.3	6.7	32.2	5.9

* Rounding may cause differences in decimals

Table 39. Results of ANOVA of physical data on core samples.

GROUPING	W	H	Ftest	probability	HB	MB	LG	CaO	Cal	Ftest	probability
VARIABLE											
BD	B[1)]	A	33.3	**	B	B	A	A	A	19.6	**
PV	A	B	33.3	**	A	A	B	B	B	19.5	**
WW2	A	B	36.7	**	A	B	C	C	B	37.6	**
WW42	A	B	23.3	**	A	B	C	C	AB	23.2	**
VV2	A	B	25.4	**	A	B	C	C	B	28.7	**
VV42	A	B	15.1	**	A	BC	CD	D	AB	16.7	**
AM	A	A	3.2	*	A	B	BC	AB	C	9.4	**
AV2	A	A	1.1		B	A	A	A	AB	6.3	**
AV42	A	A	0.1		AB	A	AB	A	B	4.4	**

1) A, B, C etc. indicate significant differences at 95% confidence limits. A indicates the lowest mean values.

2) Probability: ** $p < 0.01$

* $p < 0.05$

According to the ANOVA (Table 39), all physical core characteristics except for available water (AM) and air volume at pF2 and pF4.2 (AV2 and AV42) discriminate between the Late Weichselian and Holocene groups. This discrimination is largely the result of the HB(+ MB) subgroup(s) being clearly separated from all other subgroups. Introducing the 4 dummy variables boosted the amount of explained variance by about 5%. This could have been the result of structural and microstructural differences between the groups and subgroups or other factors not taken into consideration. More variance remains unexplained for the Late Weichselian than for the Holocene group. *Bulk density* (BD) for FLUVIAL depends more on porosity than on texture; this is illustrated by the low correlations with the basic explanatory variables (Appendix D) and the low amount of variance explained by multiple regression (about 35% with 5 basic variables - Table 40).

Table 40. Variance explained (%) of physical data on core samples by multiple regression with 9 and 5 basic explanatory variables.

	9 variables	5 variables							
GROUPING	FLUVIAL	FLUVIAL	WEICHSELIAN	HOLOCENE	HB	MB	LG	CaO	Cal
number of samples	n=191	n=191	n=130	n=61	n=44	n=68	n=18	n=38	n=23
variance explained[1)]	R^2	R^2	R^2	R^2	R^2	R^2	R^2	R^2	R^2
VARIABLES									
BD	41	34	19	46	-	24	65	54	35
PV	41	35	19	47	-	25	55	54	46
WW2	80	73	64	79	61	68	71	81	74
WW42	85	84	82	82	81	83	92	76	84
VV2	78	72	68	80	67	71	62	84	52
VV42	83	82	81	81	72	86	97	74	87
AM	28	10	6	30	-	5	69	20	34
AV2	28	26	31	33	45	31	59	32	16
AV42	40	37	30	56	37	34	93	41	68

1) variance explained at 95% confidence limits.

-: no variance explained at 95% confidence limits.

The bulk density is thus a property largely unaccounted for by the 5 basic explanatory variables notably for the Late Weichselian group. As previously demonstrated (section 4.3.1.), the particle densities of Late Weichselian and Holocene material do not differ significantly, and thus for the derived variable *pore volume* (PV) the same can be said as for BD. *Water retention* at pF2 and pF4.2 strongly depends on the clay and organic carbon content of the sample, and therefore the strong positive correlations with clay and organic carbon are to be expected. Strong negative correlations exist with the sand content (Appendix D). The transformation to volume fractions (VV2, VV42) does not significantly alter this general conclusion. Multiple regression of the 5 basic explanatory variables of the FLUVIAL samples resulted in about 70-75% of the variation at pF2 and about 80-85% of the variation at pF4.2 being explained, with a systematically lower variance explained at pF2 for the Late Weichselian group and subgroups. This also indicates that there are microstructural differences in this group, because these contribute to water retention at pF2 more strongly than at pF4.2. This conclusion is supported by the correlation between BD and WW2 and WW42 (Appendix D). *Available moisture* (AM) does not adequately discriminate between the Late Weichselian and Holocene groups (because of internal compensation), but discriminates fairly well at subgroup level. The very low percentage (about 10%) of variance explained when 5 basic explanatory variables are used rises to about 30% after the 4 dummy variables connected with differences between and within Late Weichselian and Holocene groups and subgroups are introduced.
Air volume at pF2 and pF4.2 does not discriminate between the Late Weichselian and Holocene groups, although minor differences exist between the subgroups. Explained variance ranges from 30-40%.
Sand and organic carbon are the most important sources of variation in the core properties of the Late Weichselian group, whilst the combined influences of clay and organic carbon are most important in the Holocene group. Discriminant analysis (Table 41) indicates that in nearly 90% of the cases Late Weichselian samples can be correctly predicted on the basis of their properties, whereas membership of the Holocene group is predicted very poorly (only 30%). The discrimination function between Late Weichselian and Holocene is based on WW2 and BD whereas the subgroup division is based on the moisture retention and bulk density data in the first canonical function and the available moisture in the second canonical function.

Table 41. Classification of physical data on core samples, based on discriminant analysis.

		Predicted group membership					
		Weichselian		Holocene		correct classification	
		number	%	number	%	number	%
Actual group	number of samples						
Weichselian	130	115	89	15	11		
Holocene	61	42	69	19	31		
Total	191	157		34		134	70

		Predicted group membership											
[4 canonical functions]		HB		MB		LG		CaO		Cal		correct classification	
		number	%	number	%	number	%	number	%	number	%	number	%
Actual group	number of cases												
HB	44	26	59	18	42	-	-	-	-	-	-		
MB	68	9	13	50	74	2	3	4	6	3	4		
LG	18	-	-	2	11	4	22	9	50	3	17		
CaO	38	4	11	12	32	3	8	19	50	-	-		
Cal	23	1	4	14	61	-	-	-	-	8	35		
Total	191	39		97		9		32		14		107	56

Conclusion

In conclusion it can be stated that:

- properties of core samples discriminate well between the Late Weichselian and Holocene groups, especially as regards bulk density, pore volume and moisture characteristic.
- the data on the moisture characteristic are largely explained by clay and organic carbon for the Holocene group and by sand and organic carbon for the Late Weichselian group.
- the bulk density (and pore volume) is a group-specific property, largely unaccounted for by the 5 basic explanatory variables. The Late Weichselian samples notably the HB and MB subgroups have high bulk densities and low pore volumes.
- available moisture discriminates only at subgroup level, notably between the Cal subgroup (high available moisture) and the HB subgroup (low available moisture).
- the properties of Late Weichselian cores lead to a correct prediction in almost 90% of cases, whereas the properties of Holocene cores lead to a correct prediction in only 30% of cases. Bulk density and moisture characteristic are the best discriminants.

4.5.2. AIR PERMEABILITY

Air permeability at pF2 was measured in the supplementary core samples (n=102) according to the method described by Kmoch (1961). At constant pressure a known volume of air passed through the core sample with known length and cross sectional area. The time needed is recorded. With these data the intrinsic air permeability (Ki) is calculated. The characteristics of these supplementary core samples with regard to the 5 basic explanatory variables are comparable with those of all core samples. Table 42 presents data on air permeability as mean median values and standard deviations. Results of ANOVA are presented in Table 43.

Table 42. Mean median values and standard deviations (SD) of data on air permeability of core samples at pF2 ($Ki \cdot 10^{-12}$ m^2).

GROUPING	FLUVIAL		WEICHSELIAN		HOLOCENE		HB		MB		LG		CaO		Cal	
number of samples	n=102		n=69		n=33		n=22		n=36		n=11		n=21		n=12	
VARIABLE	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Ki	25	46	22	47	31	45	10	12	22	40	47	90	13	16	62	61

Table 43. Results of ANOVA of data on air permeability of core samples at pF2.

GROUPING	W	H	Ftest	Probability	HB	MB	LG	CaO	Cal	Ftest	Probability
VARIABLE											
Ki	A[1)]	A	0.8		A	AB	AB	A	B	3.9	*[2)]

[1)] A, B, C etc. significant differences at 95% confidence limits; A indicate the lowest mean values.

[2)] Probability: ** $p < 0.01$
* $p < 0.05$

The results for air permeability demonstrate very large standard deviations, despite the use of mean median values from 5 measurements. Consequently, the values for the Holocene and Late Weichselian groups are not significantly different, although the subgroups exhibit some differences. The very high means in the Cal subgroup are the result of the very high pore volumes and the continuous pores; the soils in the CaO subgroup have few interconnected pores. The data suggest that despite their high sand content, soils of the HB subgroup have a low pore volume (section 4.5) and do not have a system of continuous pores.

Correlations between the 5 basic explanatory variables and Ki are poor (Appendix D) and mostly erratic. They will not be discussed here. The occasional higher correlations can mostly be explained by local circumstances (e.g. the positive correlation between Ki and OC in the LG subgroup is because LG has undisturbed topsoils with high organic matter contents). Because correlations are poor, the percentage of variance explained by multiple regression is also poor. With the exception of the LG group explained variance does not exceed 27% (Appendix D).

Conclusion

In conclusion the air permeability of the HB and the CaO subgroups is very low and that of the Cal subgroups is very high, but statistically reliable conclusions cannot be drawn between Weichselian and Holocene groups because the standard deviations are high.

4.5.3. TORVANE SHEAR STRENGTH

A vane shear apparatus (TORVANE) was used to measure the yield value at pF2 (Sallberg, 1965) (TV in kPa). The Torvane yield value was also determined over a range of moisture contents.

Table 44. Means and standard deviations (SD) of Torvane shear strength data of core samples at pF2 (TV-kPa).

GROUPING	FLUVIAL		WEICHSELIAN		HOLOCENE		HB		MB		LG		CaO		Cal	
number of samples	n=102		n=69		n=33		n=22		n=36		n=11		n=21		n=12	
VARIABLE	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
TV	51.5	27.5	52.5	30.5	49.0	19.5	37.0	24.0	64.0	31.0	46.0	25.5	54.0	22.0	41.0	11.0

Table 45. Results of ANOVA of Torvane shear strength data of core samples at pF2.

GROUPING	W	H	Ftest probability	HB	MB	LG	CaO	Cal	Ftest	probability
VARIABLE										
TV	A[1)]	A	0.4	A	B	AB	AB	A	4.7	**[2)]

[1)] A, B, C etc indicate significant differences at 95% confidence limits. A indicates the lowest mean values.

[2)] Probability: ** p< 0.01
* p< 0.05

The results at pF2 are means of double measurements in the supplementary cores (n=102). The means, standard deviations and the ANOVA results are given in Tables 44 and 45.

The Torvane measurements also had large standard deviations. No distinction can be made between the Late Weichselian and Holocene groups on the basis of the Torvane data, but in the subgroups the MB subgroup stands out as having high values and the HB and Cal subgroups have low values because the former has a high sand content and the latter a high porosity. Correlations with clay are positive, but with the other factors, correlations are erratic. In the Cal subgroup the strong significant correlations with OC and CA are probably again the result of the influence of depth. A consistent significant negative correlation with air volume at pF2 (AV2) is as expected (Appendix D). Variance explained by clay and organic carbon ranges from 30-40%, with an additional 10% attributable to the effect of the dummy variables. Aspects of structure are probably responsible for the unexplained variance.

When the Torvane measurements are done at varying moisture contents, the increase with decreasing moisture content in the Late Weichselian samples seems to be stronger than that of the Holocene samples (Fig. 42).

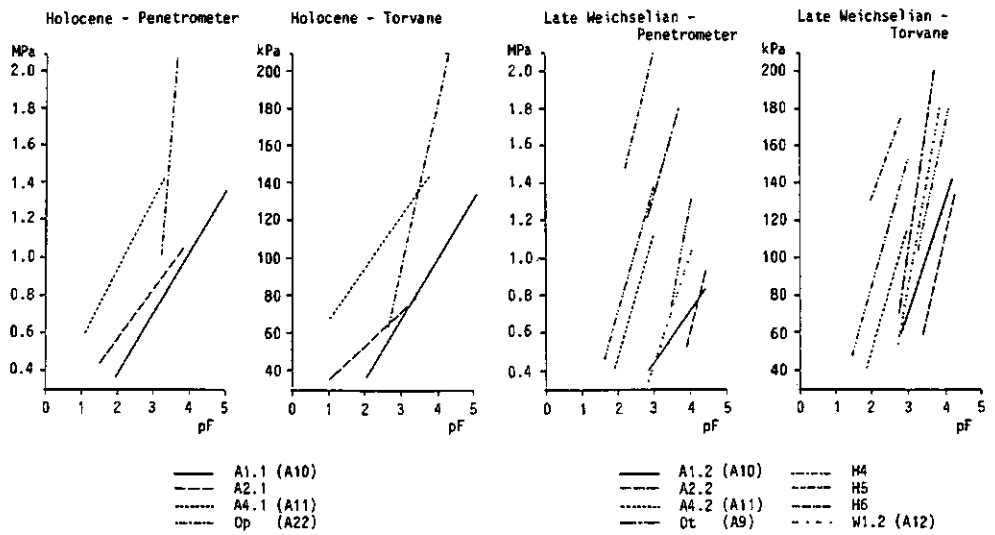


Fig. 42. Torvane shear strength and hand penetrometer resistance in relation to moisture content (pF) for Late Weichselian and Holocene core samples.

The variability of observations, however, make this conclusion tentative. The hand penetrometer data and those obtained with the Torvane give a very similar picture although the values are a factor 10 different.

Conclusion

In conclusion the Torvane measurements indicate that at pF2 moisture content the MB subgroup exhibits high yield values and the HB and Cal subgroups demonstrate low yield values. Late Weichselian samples seem to demonstrate a more pronounced increase in Torvane yield value than the Holocene samples with decreasing moisture contents. A similar picture is demonstrated by the penetrometer results.

4.6. PHYSICAL CHARACTERISTICS OF NATURAL AGGREGATES

4.6.1 BULK DENSITY, PORE VOLUME AND MOISTURE CHARACTERISTIC

The physical characteristics of natural aggregates (3.4-4.8 mm Ø) were determined on 101 samples that had been air-dried after sampling and then stored. The basic explanatory variables of these 101 samples are given in Table 46 as means and standard deviations. Results of ANOVA are given in Table 47. The results for these basic explanatory variables are essentially similar to the samples used in core characteristics (Compare Table 46 with Table 24), except for somewhat differing silt contents. The characteristics measured include dry pore volume (PV) and the moisture characteristic from pF0 to pF6 (WW0..WW6). These weight percentages have been converted to volume percentages (VV0..VV6) using the dry aggregate bulk density (BD), calculated according to BD= PD-PV*PD in which PD is the measured particle density. Available moisture (AM) is VV2-VV42.

Comparisons with various aggregate sizes (1-2 mm; 2-3.4 mm; 3.4-4.8 mm; 4.8-6.0 mm; 6.0-8.0 mm) demonstrated that the results for the 3.4-4.8 mm size class are representative for the range from 2-8 mm (De Groot, 1981).

Results are presented as means and standard deviations in Table 48. The results of ANOVA are given in Table 49. Results on aggregates that had not previously been air-dried are discussed in section 4.6.3.

Table 46. Means and standard deviations (SD) of the 5 basic explanatory variables of the investigated natural aggregates.

GROUPING		FLUVIAL		WEICHSELIAN		HOLOCENE		HB		MB		LG		CaO		Cal	
number of samples		n=101		n=61		n=40		n=23		n=32		n=6		n=17		n=23	
VARIABLE		mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Clay	(CL)	25.5	11.3	22.2	10.2	30.5	11.0	17.1	7.0	25.8	10.8	22.5	10.6	35.0	12.9	27.1	8.2
Silt	(SI)	35.4	15.3	27.9	12.8	46.8	11.3	21.5	11.4	31.5	12.6	33.3	10.2	40.8	9.7	51.3	10.4
Sand	(SA)	39.1	23.7	49.9	21.2	22.7	17.0	61.4	16.8	42.7	21.1	44.2	20.6	24.2	18.4	21.6	16.2
Org. carbon	(OC)	0.89	0.86	0.69	0.69	1.20	0.99	0.59	0.60	0.64	0.63	1.29	1.08	1.50	0.75	0.97	1.10
$CaCO_3$	(CA)	1.9	4.0	0.0	0.0	4.7	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	8.2	4.4

Table 47. Results of ANOVA of the 5 basic explanatory variables of the investigated natural aggregates.

GROUPING	W	H	Ftest	Probability	HB	MB	LG	CaO	Cal	Ftest	Probability
VARIABLE											
CL	A[1)]	B	14.9	**[2)]	A	B	AB	B	B	8.4	**
SI	A	B	57.5	**	A	B	AB	B	C	22.0	**
SA	B	A	46.1	**	C	B	ABC	A	A	16.4	**
OC	A	B	9.3	**	A	A	AB	B	AB	4.5	*
CA	A	B	49.4	**	A	A	A	A	B	66.5	**

1) A, B, C etc. indicate significant differences at 95% confidence limits; A indicates the lowest mean values.

2) Probability: ** $p < 0.01$
* $p < 0.05$

Table 48. Means and standard deviations (SD) of the physical characteristics of natural aggregates.

GROUPING	FLUVIAL		WEICHSELIAN		HOLOCENE		HB		MB		LG		CaO		Cal	
number of samples	n=101		n=61		n=40		n=23		n=32		n=6		n=17		n=23	
VARIABLE	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
PV (% v/v)	34.0	3.1	33.1	2.7	35.4	3.3	33.9	2.3	32.0	2.6	35.7	2.1	32.8	2.5	37.3	2.4
BD (kg/m^3)	1775	90	1795	80	1735	95	1770	65	1835	75	1710	80	1810	80	1685	65
VV0 (% v/v)	68.5	11.1	65.5	11.4	73.0	8.8	64.0	9.8	67.5	11.9	60.4	14.2	76.4	10.8	70.5	6.1
VV05 (% v/v)	53.3	7.3	50.4	6.6	57.7	6.2	49.3	6.5	51.1	7.2	50.7	2.4	59.8	7.4	56.1	4.8
VV1 (% v/v)	46.1	7.7	42.4	5.6	51.9	6.8	39.9	3.8	43.9	6.5	43.3	1.9	51.8	8.2	51.9	5.9
VV15 (% v/v)	41.8	9.5	36.7	7.5	49.4	6.8	32.9	5.4	38.8	8.2	40.5	3.4	49.9	7.6	49.0	6.2
VV2 (% v/v)	36.8	10.2	32.1	8.6	43.8	8.4	27.6	7.1	34.5	8.5	36.6	7.5	45.6	9.9	42.5	6.9
VV3 (% v/v)	30.9	10.5	27.1	9.1	36.7	10.0	22.2	7.0	29.4	9.1	34.4	7.3	39.0	10.8	35.0	9.1
VV42 (% v/v)	19.7	7.9	17.6	6.6	22.8	8.7	14.1	4.8	19.4	6.6	22.0	6.1	27.2	8.9	19.6	7.2
VV6 (% v/v)	4.9	3.0	4.4	3.1	5.8	2.7	2.8	1.3	5.7	3.7	3.6	0.9	7.9	2.6	4.2	1.4
AM (mm/10 cm)	17.0	4.6	14.5	3.2	21.0	3.4	13.6	3.4	15.1	3.1	14.7	3.0	18.4	2.6	22.9	2.6

Table 49. Results of ANOVA of the physical characteristics of natural aggregates.

GROUPING	W	H	Ftest	Probability	HB	MB	LC	Ca0	Cal	Ftest	Probability
VARIABLE											
PV	A[1)]	B	14.3	**[2)]	A	A	AB	A	B	17.6	**
BD	B	A	11.5	**	B	C	AB	BC	A	16.4	**
VV0	A	B	12.6	**	A	AB	AB	B	AB	4.9	**
VV05	A	B	31.0	**	A	A	A	B	B	8.9	**
VV1	A	B	58.5	**	A	A	A	B	B	16.6	**
VV15	A	B	74.7	**	A	B	B	C	C	23.2	**
VV2	A	B	46.4	**	A	B	ABC	C	C	16.1	**
VV3	A	B	24.7	**	A	B	BC	C	BC	10.7	**
VV42	A	B	11.7	**	A	B	ABC	C	BC	9.3	**
VV6	A	A	5.3	*	A	BC	AB	C	B	11.6	**
AM	A	B	95.9	**	A	A	AB	B	C	36.3	**

1) A, B, C etc. indicate significant differences at 95% confidence limits; A indicates the lowest mean values.
2) Probability: ** p< 0.01
* p< 0.05

The Late Weichselian group can clearly be separated from the Holocene group on the basis of physical characteristics of aggregates especially on the basis of available moisture (AM) and moisture retention at pF1, pF1.5 and pF2 (VV1, VV15, VV2). These characteristics (together with PV and BD) also most effectively separate the various subgroups. The fact that available moisture discriminates so effectively is striking, because this was certainly not the case for the characteristics of the core samples (Table 26). The discriminating properties of AM and VV2 are much better for the aggregate characteristics; this is probably because of microstructural aspects.

The correlation matrix (Appendix D) demonstrates few significant correlations and a rather erratic picture of positive and negative correlations for PV, BD, VV0 and VV05, part of which can be explained by phenomena in specific profiles. These phenomena will not be discussed here. Moisture retention at pF1 and above correlates significantly with clay, silt and sand. The positive correlation of water retention with organic carbon (OC) is most pronounced in the Cal subgroup; this points to the combined influences of clay and organic carbon, which was also noted in the core samples. It could also point to a better quality of OC. Available moisture correlates positively with SI content and also with moisture retention at pF1.5 through pF3.0, notably for the Late Weichselian group and subgroups and for the Ca0 subgroup, However, no such correlation is found for the Cal subgroup, probably because of the characteristics of its pore system.

Table 50 gives the results of multiple regression, in terms of the percentage of variance explained by using the 5 basic explanatory variables and the additional 4 dummy variables. Details can be found in Appendix D.

Table 50. Variance explained (%) in physical characteristics of natural aggregates by multiple regression with 9 and 5 basic explanatory variables.

	9 variables	5 variables							
GROUPING	FLUVIAL	FLUVIAL	WEICHSELIAN	HOLOCENE	HB	MB	LG	CaO	Cal
number of samples	n=101	n=101	n=61	n=40	n=23	n=32	n=6	n=17	n=23
Variance explained[1)]	R^2	R^2	R^2	R^2	R^2	R^2	R^2	R^2	R^2
VARIABLE									
PV	56	45	7	74	-[1)]	17	-	58	60
BD	59	51	26	73	-	25	46	57	59
VV0	26	23	26	10	-	47	-	22	-
VV05	38	32	11	54	18	14	49	61	77
VV1	72	71	45	70	-	59	64	71	89
VV15	85	84	76	70	62	83	72	71	89
VV2	92	92	89	88	83	92	96	88	96
VV3	90	90	89	89	85	90	97	95	88
VV42	92	92	88	95	75	94	100	91	97
VV6	59	53	53	63	62	47	96	30	92
AM	78	77	55	61	83	54	-	50	87

1) variance explained at 95% confidence limits.

- no variance explained at 95% confidence limits.

Variance in pore volume (PV) and bulk density (BD) are mainly explained by CA, OC and the dummy variables V0 (difference between Late Weichselian and Holocene) and V11 (difference MB versus HB+LG). The relation with CA is mainly the result of both PV and CA changing with depth in the Cal subgroup. In total, 55-60% of PV and BD could be explained with a 95% confidence limit. The variance explained in moisture retention is largely the result of texture characteristics and organic carbon; the explained variance is low (25-40%) at pF0 and pF0.5 (because of methodological difficulties) and high to very high (60-95%) at pF J 1.0. The dummy variables V0, V11 and V13 (V13= difference between CaO and Cal) contribute an additional 1-10% to the variance explained, indicating that there are systematic differences between the (sub)groups and these are not covered by the 5 basic explanatory variables.

The available moisture (AM) can be explained by the silt content (SI). The poorly explained variance of PV and BD in the Late Weichselian material again points to a group-specific structural property.
Table 51 presents the classification result, based on the discriminant analysis.

Table 51. Classification of physical data on natural aggregates, based on discriminant analysis.

		Predicted group membership					
		Weichselian		Holocene		correct classification	
		number	%	number	%	number	%
Actual group	number of cases						
W	61	58	95	3	5		
H	40	6	15	34	85		
Total	101	64		37		92	91

[4 canonical functions]		Predicted group membership											
		HB		MB		LG		CaO		Cal		correct classification	
		number	%	number	%	number	%	number	%	number	%	number	%
Actual group	number of cases												
HB	23	18	78	4	17	-	-	1	4	-	-		
MB	32	7	22	23	72	-	-	2	6	-	-		
LG	6	2	33	-	-	4	67	-	-	-	-		
CaO	17	2	12	3	18	-	-	12	71	-	-		
Cal	23	-	-	1	4	-	-	1	4	21	91		
Total	101	29		31		4		16		21		78	77

Predictions of group and/or subgroup membership based on the physical data on natural aggregates are very accurate for both the Late Weichselian group (95% correct prediction) and the Holocene group (85% correct prediction). Also for the the subgroup division the prediction is good (70-80%) with especially a high value for the Cal subgroup (90%). The discriminating functions are dominated by AM, VV15 and BD for the subgroup, and AM and VV15 also head the discriminating function on group level.

Conclusion

- Physical characteristics of natural aggregates discriminate very accurately between the Late Weichselian and Holocene groups. Available moisture is a good discriminant between the groups on aggregate level which was certainly not the case for the characteristics of the core samples. Pore volume, bulk density and moisture characteristic discriminate well on aggregate level as was also the case for the characteristics of core samples.
- Variance explained is high to very high for the results of moisture retention at pF > 1 resulting from clay and organic carbon influences. The variables associated with additional differences between Late Weichselian and Holocene groups and subgroups add 1-10% to the variance explained. Microstructural characteristics and the characteristics of the pore system (continuity) are thought to be responsible.
- In the Holocene Cal group notably a combined influence of clay and organic carbon as well as a better quality of the organic carbon is hypothesized.
- Pore volume and bulk density of the Late Weichselian material point to a group-specific structural property of that group, especially for the HB and MB subgroups.
- The differences in physical characteristics between the Late Weichselian and Holocene groups and subgroups are more clearly expressed on aggregate level than on core level. This points to microstructural influences. Results on aggregates from 3.4-4.8 mm are representative for the range from 2-8 mm.

4.6.2. LINEAR EXTENSIBILITY

As indicated in section 4.4., the physical characteristics determined allow the linear extensibility (LE) to be calculated according to Kuipers (1961). Data on BD, PV, PD and on VV1 and VV2 were used to calculate linear extensibility at pF1 (LE1 calc.) and pF2 (LE2 calc.) of natural aggregates (3.4-4.8 mm Ø). The results are given as means and standard deviations in Table 52. ANOVA results are presented in Table 53.

Table 52. Means and standard deviations (SD) of calculated linear extensibility data (LE) of natural aggregates.

GROUPING	FLUVIAL		WEICHSELIAN		HOLOCENE		HB		HB		LG		CaO		Cal	
number of samples	n=101		n=61		n=40		n=23		n=32		n=6		n=17		n=23	
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
VARIABLE																
LE2 calc.	0.8	3.2	-0.4	2.9	2.7	2.8	-2.2	2.6	0.7	2.6	0.2	2.8	4.0	2.8	1.7	2.3
LE1 calc.	3.8	2.2	3.0	1.7	5.2	2.1	1.9	1.3	3.8	1.7	2.5	0.9	5.9	2.3	4.6	1.8

Table 53. Results of ANOVA of calculated linear extensibility data of natural aggregates.

GROUPING	W	H	Ftest probability		HB	MB	LG	CaO	Cal	Ftest probability	
VARIABLE											
LE2 calc.	A[1)]	B	28.1	**[2)]	A	B	ABC	C	BC	15.2	**
LE1 calc.	A	B	32.9	**	A	B	AB	C	BC	15.0	**

[1)] A, B, C etc indicate significant differences at 95% confidence limits; A indicates the lowest mean values.
[2)] Probability: ** p< 0.01
* p< 0.05

From Table 53 it is clear that the calculated linear extensibility both at pF2 and at pF1 discriminates very well between the Late Weichselian and Holocene groups and subgroups.

When Tables 29 and 52 are compared the overall lower calculated linear extensibility of natural aggregates at pF2 compared to the calculated and measured linear extensibilities of condensates at pF2 is noteworthy. The obvious explanation is that the condensates do not have biopores or fissures with sizes between 30 µmand 300 µm (equivalent pore diameters at pF2 and pF1) as these have been destroyed on purpose during the preparation of the condensates. For the greater differences in the Late Weichselian group and all its subgroups the low water storage at pF2 in the very dense natural aggregates is responsible whilst in the Holocene Cal subgroup the large difference is caused by its capacity to accomodate a large part of the high water storage at pF2 in its high dry aggregate pore volume.

In the HB subgroup at pF2 complete saturation does not occur in view of the average negative values of the linear extensibility. At pF1 the differences between the extensibilities of natural aggregates and condensates are much smaller. Complete saturation occurs and the extensibilities of the natural aggregates and condensates in the various groups and subgroups are similar.

The remaining difference between the Late Weichselian and Holocene groups in measured linear extensibility of condensates has been discussed in section 4.4.1. It should be noted in this context that with the core samples the water content at pF2 (% v/v - VV2 - Table 38) is always smaller than the dry total pore volume so no swelling is calculated as the stored water could be accomodated in the interaggregate pores.

The Late Weichselian soils are so densely packed that shrinkage possibilities are limited which agrees with the limited number of cracks in the natural field structure. This was demonstrated by measurements on field columns (section 4.8; Kooistra *et al.*, 1987).

The correlation matrix of LE2 calc. and LE1 calc. with the 5 basic explanatory variables is given in Appendix D. The observations and explanation of the correlations are similar to those given in section 4.4.1 and will not be detailed here. The variance explained (%) is indicated in Table 54, based on stepwise multiple regression at 95% confidence limits.

Table 54. Variance explained (%) of calculated linear extensibility data of natural aggregates by stepwise multiple regression with 5 basic explanatory variables.

GROUPING	FLUVIAL	WEICHSELIAN	HOLOCENE	HB	MB	LG	Ca0	Ca1
number of samples	n=101	n=61	n=40	n=23	n=32	n=6	n=17	n=23
variance explained[1)]	R^2	R^2	R^2	R^2	R^2	R^2	R^2	R^2
VARIABLE								
LE2 calc.	86	82	87	67	87	88	82	93
LE1 calc.	62	47	66	-	58	-	66	84

1) variance explained at 95% confidence limits

-= no variance explained at 95% confidence limits

The main variables contributing to the variance explained both for LE2 calc. and LE1 calc., are Clay(CL) and Organic Carbon(OC) for the Fluvial and Holocene groups. For the Late Weichselian group SA with OC appears instead of CL and OC for LE2 calc. For LE1 calc. CL occurs without OC. In the Ca1 subgroup the contribution of OC surpasses the contribution of CL, again pointing to a combined influence of OC and CL. Details are given in Appendix D.

Conclusion

- The calculated linear extensibility of natural aggregates discriminates well between the Late Weichselian and Holocene groups.
- Clay and organic carbon are the main variables involved in the explanation of the observed variance. In case of the Late Weichselian samples SA instead of CL appears.
- The natural structure of aggregates with its inherent porosity and packing negatively influences the calculated swelling at pF2, because of a small water storage at pF2. In the natural field structure the shrinkage possibilities are limited because of the very dense packing thus leading to a limited number of cracks.

4.6.3. BEHAVIOUR OF THE PORE SYSTEM

Undisturbed samples (1-5 cm^3) extracted from the middle of field-moist bulk samples of 20x10x10 cm from the B-horizon (50-60 cm depth) of an MB soil (Heumen), a CaO soil (Ewijk) and a Cal soil (Kesteren) were subjected to a series of morphological and physical tests. The former tests comprised micromorphology, cryoscan electron microscopy (Tessier, 1975, 1978, 1984) and analysis of micromorphometric results from thin sections (Jongerius, 1972, 1974; Ismail, 1975), and the latter involved ascertaining the void ratio at different tensions, moisture retention characteristic and pore size distribution by mercury intrusion (Lawrence, 1977; Winslow, 1978). The objective of this study (Van Oort, 1979; 1980), performed under the guidance of Dr. D. Tessier (Versailles), was to test the hypothesis that differences in pore system and groundmass organization are responsible for the differences in field behaviour of these soils when tilled, as noted by farmers. The pore system and the organization of the solid mass were examined from macroscopic to submicroscopic levels. Thin sections were prepared after the water in the samples had been replaced by acetone (Miedema *et al.*, 1974; Kooistra, 1979; Murphy, 1982, 1986) and after oven-drying. The micromorphometric data obtained by examining these sections were analysed to give quantitative data on total pore area, pore size distribution and pore shape.

Parameters related to the pore system and the organization of the solid mass were ascertained using physical techniques. The results were combined with the data on morphology so that the pore system with diameters from nanometres to millimetres could be studied in relation to various moisture contents.

Sampling sites for the three soils were selected on the basis of previous field research and laboratory data, to try to ensure that the samples had comparable textures. A sampling depth of 50-60 cm was chosen, to avoid the influences of human activity in the topsoil and possible compaction below the ploughed zone. Heumen (MB) was sampled at the location of reference profile Heumen II (Appendix A, profile A2), Kesteren (Cal) was sampled near the location of reference profile Kesteren (Appendix A, profile A20) and Ewijk (CaO) was sampled very near to reference profile Ewijk (Appendix A, profile A17). The sample from Ewijk, however, had a much higher clay content (and also an unexpectedly high clay to silt ratio) than expected on the basis of profile A17, which was only a few metres away (Table 55). This indicates that there is strong lateral variability in texture at the sampled depth at the Ewijk site. Although comparisons between Kesteren and Heumen on one hand and Ewijk on the other hand are therefore difficult, the results and interpretations still seem to be important enough to present.

Table 55. Particle size distribution and some chemical and physical data of the investigated samples.

Sample	Age (years)	Particle size distribution (μm)			Organic Carbon (%)	pH KCl	$CaCO_3$ (%)	Particle density (kg/m^3)
		<2	2-50	>50				
KESTEREN Cal	± 500	26.1	61.5	13.4	1.6	7.5	9.6	2690
EWIJK CaO	±2000	46.9	43.2	9.9	1.6	6.7	0.4	2690
HEUMEN MB	±10000	26.5	32.1	41.1	0.6	4.4	0.0	2700

Physical analyses

The water content (Fig. 43) and the void ratio (Fig. 44) ($e = \frac{\text{volume of voids}}{\text{volume of solids}} = \frac{\text{particle density}}{\text{bulk density}} - 1.0$) are expressed in cm^3 per cm^3 of solid. This type of expression allows all physical data from samples with different particle densities to be compared in one figure (Fig. 47). Moisture retention curves (Fig. 43) were constructed from the mean values of 10 subsamples per B horizon at various pF values ($\sigma_{n-1} < 2\%$). At pF $\geq$ 4.2 the curves of Kesteren and Heumen coalesce. In contrast, at pF1, Kesteren contains 30% more water then the Late Weichselian Heumen soil. The shape of the Ewijk moisture retention curve is identical to that of Kesteren, but it is shifted upwards for about 0.1 cm^3 per cm^3 of solid.

Also indicated in Fig. 43 are the moisture contents at pF1 measured after careful and slow stepwise rehydration from air-dried samples (indicated with an arrow). Heumen arrives at the same initial water content, but Ewijk and, to a lesser extent Kesteren, arrive at lower water contents.

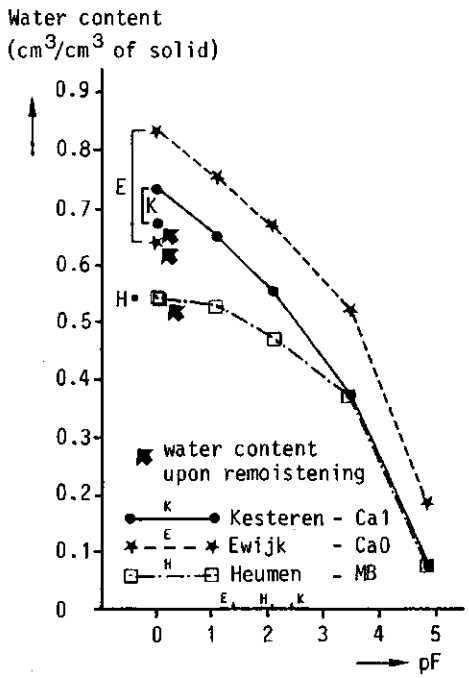


Fig. 43. Moisture retention curves of the three soil materials on desiccation. K = Kesteren; E = Ewijk; H = Heumen.

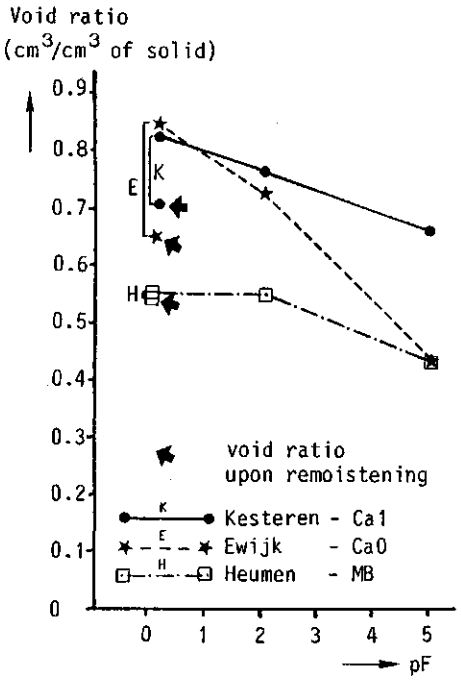


Fig. 44. Changes in pore volume of the three soil materials on desiccation. K = Kesteren; E = Ewijk; H = Heumen.

The measured void ratios (e- Fig. 44) show that Kesteren and Ewijk have an almost identical void ratio at pF1. Heumen has far fewer pores. Upon desiccation (to pF6) an important decrease (about 50%) in void ratio can be observed in the case of Ewijk. Kesteren and Heumen show a much smaller decrease upon desiccation. Note that Heumen does not show any change in void ratio between pF1 and pF3. At pF6, Ewijk and Heumen have equal ratios, whereas Kesteren shows a much higher value of e. After careful and slow stepwise rehydration to pF1, the measured void ratios were as indicated in Fig. 44 (indicated with an arrow). Heumen arrived at a slightly lower void ratio whereas Ewijk and to a lesser extent Kesteren showed clearly decreased void ratios.

The pore size distribution, measured after instantaneous deep freezing followed by sublimation, is based on the relation between mercury intrusion pressure and equivalent pore diameters. It was applied to samples previously subjected to pF1 and pF3. The maximum mercury pressure used in our experiments (100 MPa) corresponds to a lower pore size limit of 0.015 µm . The upper detection limit is about 100 µm . The total pore volume thus measured is therefore smaller than the total pore volume measured with kerosene (Fig. 47).

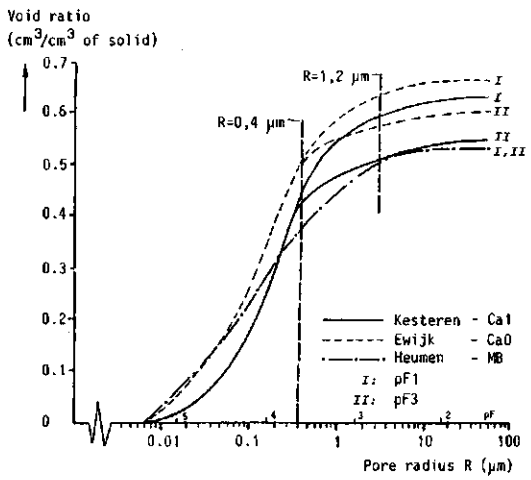


Fig. 45. Cumulative pore-size distribution curve of the three studied soil-materials at pF1 and pF3.

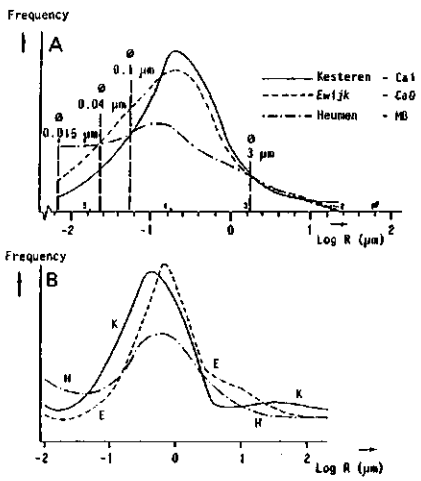


Fig. 46. Pore-size frequency curve of the three materials at pF1. (log R in µm!)
A. measured on originally field-moist samples
B. measured on originally air-dried samples

Prior to the interpretion of the results of the mercury intrusion it is necessary to discuss the pretreatment of the samples before they are

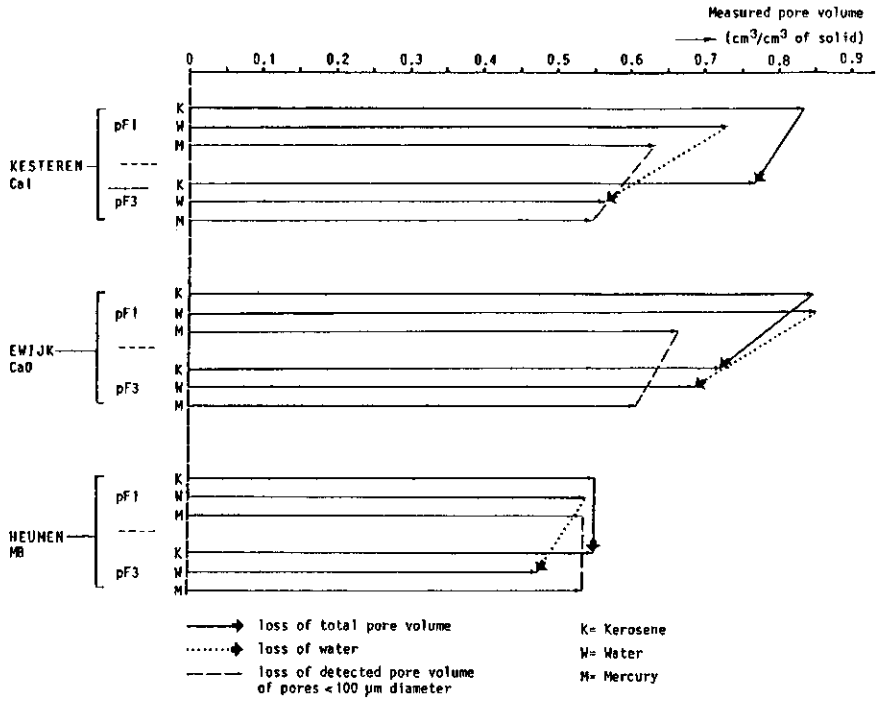
subjected to the mercury intrusion. The primary aim of the pretreatment is to fixate the microstructure at a given moisture content. For the mercury intrusion a dry sample is needed so the pretreatment aims at removing the water in the sample without disturbing the microstructre of the moist sample. This problem also occurs with morphological methods (micromorphology, Scanning Electron Microscopy) when a study of the microstructure or ultra microstructure is wanted of moist or wet soils. Two methods are widely employed to remove the water from the sample: i) freeze-drying followed by sublimation and ii) substitution of the water by an organic, less polar liquid, followed by impregnation with resin.

The sample pretreatment for the mercury intrusion utilised freeze-drying followed by sublimation of the ice. Tessier (1984), who studied the organisation at various moisture contents of pure clay separates, has discussed at length the formation of artefacts by freeze-drying followed by sublimation and changes caused by water substitution by e.g. acetone (as is used in thin section preparation from field-moist samples - Miedema *et al.*, 1974). The artefacts with freeze-drying are caused by the growth of ice crystals which exclude the clay during their formation. Liquid nitrogen, which is commonly used for freeze-drying, tends to retard the quick freezing to extremely low temperatures (Delage, 1979) and thus favours the formation of artefacts. Therefore Freon 22 (CHF_2CL) is used, cooled by liquid nitrogen. This diminishes the formation of artefacts. However, also the removal of water by substitution creates certain changes, caused by lowering of the water activity following introduction of the replacing liquid. Yet this method seems to create the least changes. According to Tessier (1984) both free-drying and acetone substitution could be used in case of kaolinite but freeze-drying created artefacts in case of illite. With smectites, except for sodium-smectites equilibrated with very diluted solutions, both methods could be used.

This analysis can lead to two lines of thought. One could argue that the structure observed (S.E.M.) and measured (mercury-intrusion) largely reflect the artefacts created by the freeze-drying and hence the interpretation of the results tells more about the artefacts created then about the naturally existing micro-structures in moist soils. Alternatively one could argue that the use of soil aggregates instead of clay separates minimises the creation of artefacts and thus the results are valid and reflect the original pore size distribution in the moist sample. This argument is strengthened by the

observation (Fig. 46B) that the mercury intrusion gives similar results when air-dried samples were treated which can not possibly have suffered from freeze-drying artefact formation. Therefore the results presented of the mercury intrusion and the discussion of the S.E.M. pictures as considered to be valid. Van Oort (1984) also found a remarkable analogy of the results from mercury intrusion and S.E.M. studies on freeze-dried soil aggregates.
Besides, at present no other methods to fixate, visualise and measure the pore system in moist soils is available. In Fig. 45 the decrease in pore volume obtained by the change from pF1 to pF3 can be seen in the Kesteren and Ewijk samples. This seems to be caused by a loss of pores with diameters between about 0.8 and 2.5 µm ($0.4 < R < 1.2$). Heumen does not show any difference in its pore size distribution curve at both pF values. According to this method, its total pore volume is smaller than those of the two Holocene soils. The frequency curves, based on the mercury intrusion results obtained at pF1 (Fig. 46A) in each soil give more details about the contribution of different pore size classes to the total pore volume. Both the Kesteren and Ewijk samples contain many more pores than the Heumen sample, the pore diameters ranging from 0.1 to 3 µm for Kesteren, and 0.04 to 3 µm for Ewijk. As well, Ewijk has more pores < 0.2 µm diameter than Kesteren. In contrast, pores with a diameter between 0.015 and 0.04 µm are most abundant in the Heumen soil. Note that these fine pores increase with increasing age of the soil.
Fig. 47 shows the simultaneous presentation of all physical analyses: the length of the lines reflects the pore volumes detected. The comparison of the kerosene line and the water line allows conclusions to be drawn about the difference between total pore volume of the samples (upper limit undefined; pore size $\tilde{=}$ 500 µm) and the water-filled pore volume smaller than the equivalent pore diameters at pF1 (300 µm) and pF3 (3 µm). The length of the mercury line indicates the total detected pore volume between 0.015 µm and about 100 µm at both pF values. Comparison of the mercury line with the water line roughly indicates the volume of pores with diameters between either $\tilde{=}$ 100 and 300 µm (pF1) or 3 and $\tilde{=}$ 100 µm (pF3).
At pF1 the very porous *Kesteren* material from an orchard soil (e = 0.83 cm^3 per cm^3 of solid) is still unsaturated despite its high water content of 0.73 cm^3 per cm^3 of solid (Figs. 43, 44, 47).

Fig. 47. Simultaneous presentation of the physical characteristics at pF1 and pF3. P = kerosone method; W = water content; M = mercury intrusion method.



The moisture content decreases sharper than the void ratio. The void ratio stops at pF6 at 0.65 cm^3 per cm^3 of solid. So the shrinkage from pF1 to air-dry amounts to 0.18 cm^3 of solid or, using the clay content given in Table 55, recalculated to 100% clay 0.69 cm^3 per cm^3 clay (Table 56). This means that a strong and wide biopore system is present, as is demonstrated also by the difference in pore volume detected at pF1 (difference between kerosene line and water line). But this pore system is also contracting and expanding so some loss in volume and moisture content is shown (void ratio has decreased from 0.83 cm^3 per cm^3 of solid to 0.70 cm^3 per cm^3 of solid after rewetting to pF1; moisture content has decreased from 0.73 cm^3 per cm^3 of solid to 0.68 cm^3 per cm^3 of solid after rewetting to pF1). This loss may be caused by the fact that during the determination of the rebound curve the soil was not allowed to swell in free water. It is therefore regarded as hysteresis. The backswelling indicates that the pores are not caused by a rigid skeleton of sand grains. The micromorphology has demonstrated that the soil constituents are very well mixed by earthworms; the clay fraction is uniformly distributed. The comparison of the water line and the mercury line (Fig. 47) indicates that 0.1 cm^3 of water per cm^3 of solid is stored in

pores with diameters between 100 and 300 μm.

At pF1 the *Ewijk* material from arable land (e = 0.84 cm^3 per cm^3 of solid) has about the same total pore volume as Kesteren (Figs. 44 and 47), but it is water saturated. The moisture content and the void ratio decrease almost identical so that at pF3 the material is still almost saturated and only then air enters the pore system. The shrinkage continues to pF6 where the void ratio ends at 0.43 cm^3 per cm^3 of solid. So the total shrinkage from pF1 to air-dry amounts to 0.41 cm^3 per cm^3 of solid or, recalculated to 100% clay (Table 55) to 0.87 cm^3 per cm^3 of clay (Table 56). Because this soil material contains 46.9 % of clay (Table 55) it can be physically regarded as a clay soil with a continuous clay plasma with embedded silt and fine sand particles. This is confirmed by the micromorphology. The properties of the clay fraction thus govern the behaviour of the Ewijk soil material, so the explanation of the water relations should primarily be based on its swelling properties. With a specific surface area of 320 m^2 per gram clay this yields a mean plate thickness of 2.3 nanometre. A rough calculation of the half distances, assuming 1/3 of the water as occluded, yields 2.8 nanometres for pF1; 2.5 nanometres for pF2; 2.2 nanometres for pF3 and 1.9 nanometres for pF 4.45. Comparison with theoretical values (Koenigs, 1961) indicate that at tensions higher than pF3 the watercontent is higher than predicted by the theory. The rebound curve from pF6 to pF2 and pF1, determined on aggregates from 6-8 mm (Van Oort, 1980) confirms the notion that this soil material has never been air-dry before i.e. that air-drying of such a material is identical to forced ripening. The losses in volume and moisture adsorption caused by internal rearrangement are considered to be permanent. The comparison of the water line and the mercury line (Fig. 47) indicates that 0.18 cm^3 of water per cm^3 of solid is stored in pores with diameters between 100 and 300 μm.

At pF1 the *Heumen* material from arable land (e = 0.55 cm^3 per cm^3 of solid) is much less porous than the Kesteren and Ewijk materials (Figs. 44 and 47) but it is nearly watersaturated. The loss in moisture towards pF3 is small (0.07 cm^3 per cm^3 of solid) whilst the decrease in void ratio is nearly absent. The packing is far denser than those from the Holocene soils as demonstrated in the micromorphology. At pF6 the void ratio ends at 0.43 cm^3 per cm^3 of solid. So the total shrinkage from pF1 to air-dry amounts to 0.12 cm^3 per cm^3 of solid or recalculated to 100% clay (Table 55) to 0.45 cm^3 per cm^3 of clay (Table 56). Comparing the shrinkage values of the Late

Weichselian and Holocene materials (Table 56) two conclusions can be drawn: i) The difference in shrinkage between the Holocene materials is not very large, in view of the fact that Ewijk has never experienced drying as far as Kesteren. ii) The shrinkage of the Heumen material is much smaller than that of the two Holocene soil materials.

Table 56. Total shrinkage from pF1 to air-dry of the three investigated soil materials.

Sample		Shrinkage cm^3 per cm^3 solid	cm^3 per cm^3 clay
Late Weichselian	Heumen (MB)	0.12	0.45
Holocene	Ewijk (CaO)	0.41	0.87
Holocene	Kesteren (Ca1)	0.18	0.69

It is further seen that the backswelling is nearly complete so the soil has ripened completely. This means that the Heumen soil material at least up to the sampled depth (50-60 cm) did become air-dry (freeze-dried) since deposition. The soil constituents have slided into a position of minimum energy, i.e. a parallel position of the clay flakes as confirmed micromorphologically (section 3.1.2). Together with the aluminium interlayering (section 3.2) this may cause the high internal load observed. The comparison of the water line and the mercury line (Fig. 47) indicates that all water is stored in pores with diameters <100 µm.

The differences in physical properties between the three soil materials are clear and can not only be related to variations in volumes of pores present, but also to variations in pore size distribution.

For instance, the Kesteren material has a high and continuous porosity. Upon a change to pF3 this material reacts by an important loss of water, whereas its change in pore volume is moderate. Its loss of stored water is even greater than the loss of water observed in the Ewijk material which has a much higher clay and silt content. Furthermore, the loss of water in the case of Ewijk is accompanied by an important internal reorganization of the pore system. Finally, the pores in the Heumen material are few and very rigid: a moderate volume of water is lost without any change in the pore system.

Optical analysis was employed to reveal the pore geometry and its variability in relation to changing moisture contents.

Optical analyses

The physical research methods revealed information about pore size up to 300 µm in diameter (equivalent pore diameter at pF1 and, by inference, some statements about the porosity with diameters > 300 µm . These pores can also be seen using optical methods, and smaller pores can be studied too. Scanning electron microscopy (S.E.M.) allows pores down to diameters of about 0.01 µm to be studied, micromorphology can study pores with diameters down to about 10 µm and micromorphometry can quantify pores down to diameters of 30 µm . The upper limit of observations of pore diameters, depending on the sample size, covers a range up to several millimetres.

Micromorphology (Fig. 48).

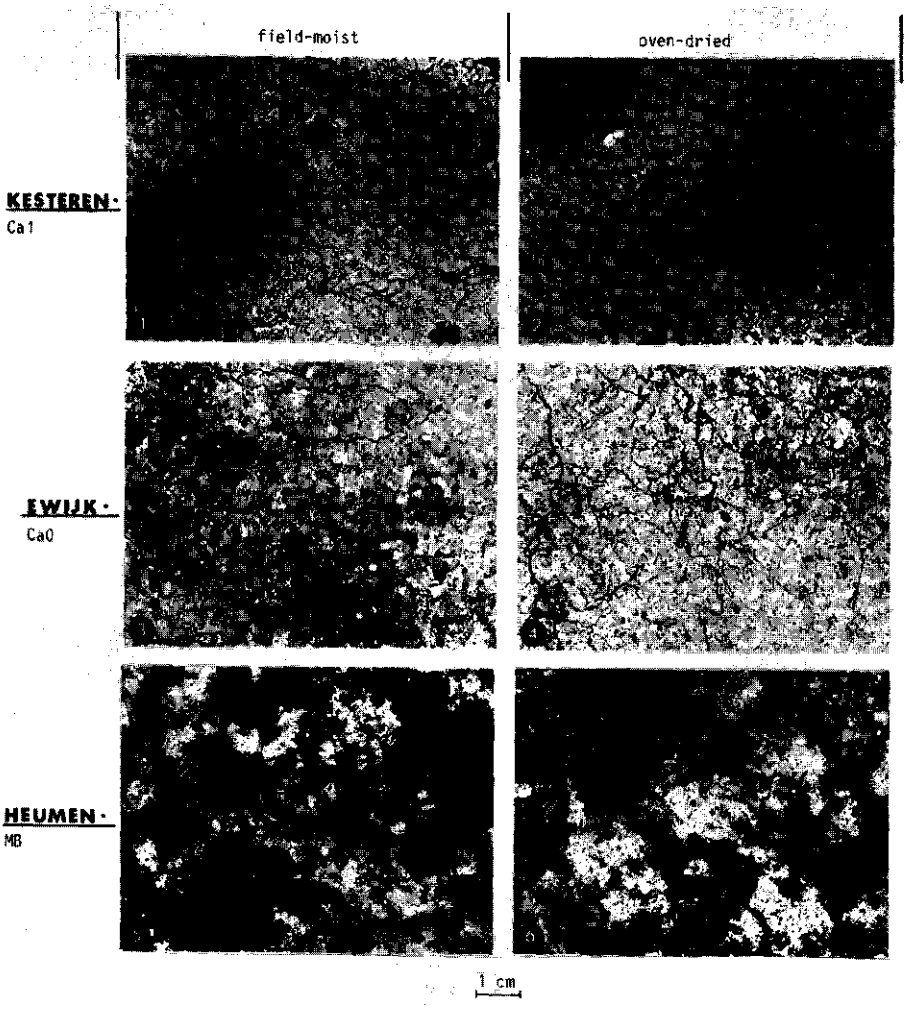
The study of the micromorphology at magnifications of 1 to 100 yields results both on the internal organization of the solid phase in the form of domains with their functional inter- and intra-domain pores, and on the number and shape of the the inter- and intra-aggregate pores in field-moist and in oven-dried material.

The recent calcareous Holocene soil material (*Kesteren*) shows a highly biogenic, very porous microhomogeneous groundmass, having moderate proportions of calcium carbonate crystallites with a particle size distribution similar to that of the sediment, whether field-moist or oven-dry. The plasmic fabric is calciasepic (Mulders, 1969). Total visible porosity is high; interconnected irregular and planar voids predominate. All pore diameter classes are well represented, notably the class with sizes larger than 3 mm in both the field-moist and the oven-dried samples (Fig. 48, photos 1 and 2).

The decalcified Holocene soil material (*Ewijk*) has a lower biogenic porosity, a moderately dense microhomogeneous groundmass which is weakly sepic and has relatively few reorientations, considering the high clay content (insepic plasmic fabric - Brewer, 1964) in both moisture states. Total visible porosity is moderately high, the pores are variable in diameter and there are clear planar voids when the material is field-moist, because of the high clay content. These planar voids widen considerably and new ones are generated when of the sample dries (Fig. 48, photos 3 and 4).

The Late Weichselian soil material (*Heumen*) has a dense, strongly microheterogeneous groundmass with appreciable reorientation in the form of an omnisepic plasmic fabric (Brewer, 1964) in both moisture states. Total visible porosity is low, with irregular and round pores of small diameter

Fig. 48. Thin sections of oven-dried and field-moist impregnated soil samples from Kesteren (Holocene-Ca1), Ewijk (Holocene-Ca0) and Heumen (Late Weichselian-MB). Thin sections used as film negatives: voids are black. White patches in Heumen result from iron-manganese mottles.



predominating in both the field-moist and the oven-dried samples. The few planar voids are wider in the oven-dried sample (Fig. 48, photos 5 and 6).

Micromorphometry (Fig. 49).

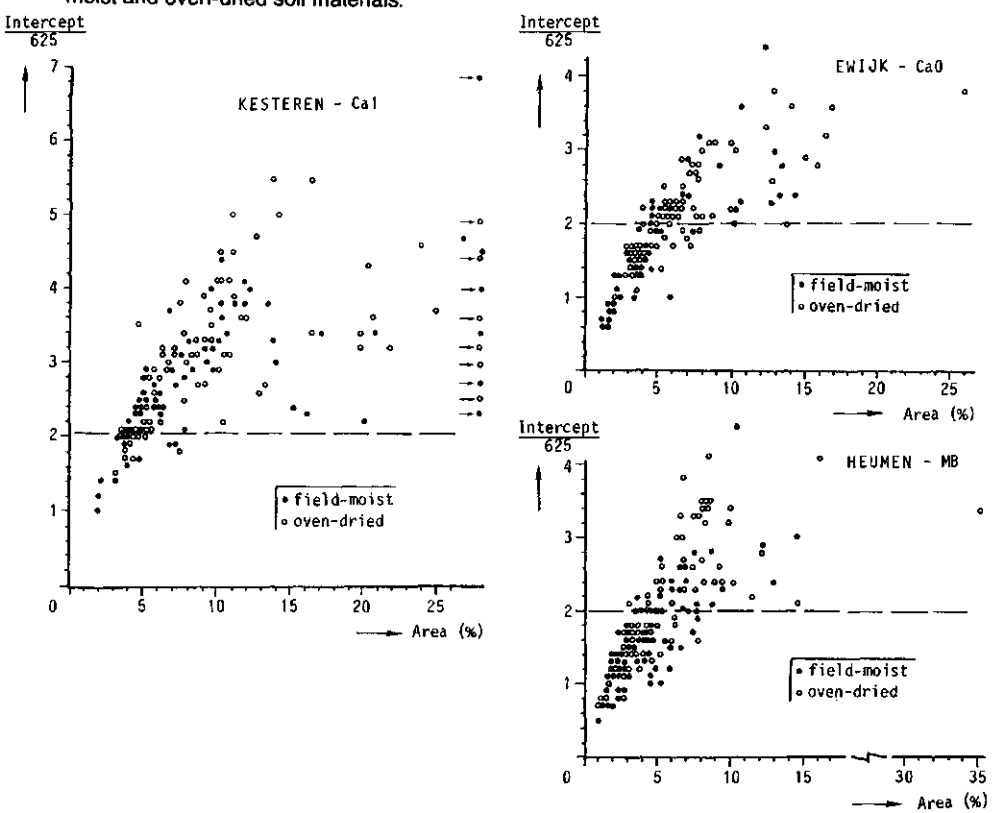
The Quantimet 720 analyses of the thin sections provide quantitative information on the area, size and shape classes of pores within a diameter range from 30 µm to > 3000 µm .

In the intercept (I/625) versus area (A) graphs (Fig. 49), the results from

scanning 72 fields of 625x625 pixels are plotted for the field-moist and the oven-dried materials. Relatively low I/625 values with a high A value correspond to large pores. This type of representation distinguishes between the very porous soil material of Kesteren, with many pores larger than 1200 µm , and the less scattered values for Ewijk and Heumen. Moreover, these graphs illustrate the natural anisotropy of such medium-textured soils.

The interpretation of the pore size distribution is based mainly on pore classes, defined by Jongerius *et al.* (1972) and Ismail (1975). The latter author stresses that certain I/625 versus A values may be indicative for

Fig. 49. Quantimet 720 results (I/625 plotted against A) of scanning of the contact prints from field-moist and oven-dried soil materials.



more than one possible combination of pore shapes. It is generally accepted that values I/625 > 2 indicate planar voids (Schoonderbeek, pers. com.). Using the form separator, the field-moist Ewijk sample, for instance, has 98 planar voids, and the oven-dried sample has 184 planar voids ($A/(PE)^2$ < 0.013), corresponding to 37% I/625 values > 2 in the field-moist sample

and 65% I/625 values ≥ 2 in the oven-dried sample.

Using this information, the void pattern in thin sections of field-moist and in oven-dried material can be interpreted. Murphy (1982) has done similar comparisons of soil materials. In all cases, drying the samples increased the percentage of planar voids; this is particularly true for the Heumen and Ewijk materials. There was only a minor increase in the Kesteren material (Table 58). The contribution of the pores of ≥ 30 µm diameter to the total porosity is smaller for Heumen; Ewijk is next, and Kesteren is by far the highest.

The relative pore size distribution of the pores with diameters ≥ 30 µm remains about constant upon drying for each of the three soil materials (Table 57). However, in all cases and in both moisture states, the total percentage of these pores ≥ 30 µm diameter represents only a relatively small part of the total porosity as calculated from bulk density measurements carried out on core samples.

Table 57. Pore diameter class distribution in field-moist and oven-dried samples (% - Quantimet 720 measurements with chord sizing) and relative changes (Δ -%).

	KESTEREN Cal			EWIJK CaO			HEUMEN MB		
pore diameter classes(µm)	field moist	oven-dried	Δ	field moist	oven-dried	Δ	field moist	oven-dried	Δ
30-100	0.7	0.3	-4%	0.4	0.4	-1%	0.5	0.6	0%
100-300	2.3	2.7	0%	1.6	2.0	0%	1.4	1.9	+2%
300-500	1.5	1.9	+2%	1.2	1.6	+2%	1.0	1.3	+1%
500-1200	1.3	1.7	+2%	1.3	1.8	+3%	1.1	1.3	-1%
1200-3000	2.5	2.6	-3%	1.0	1.1	-2%	0.8	0.8	-3%
> 3000	1.0	1.5	+3%	0.2	0.1	-2%	0.1	0.2	+1%
Total porosity	9.3 + 10.7(=+15%)			5.7 + 7.0(=+23%)			4.9 + 6.1 (=+24%)		

Δ is the difference between the proportional contribution of each pore diameter class to the total areas percentage in field moist and oven-dried samples.

example:

HEUMEN, 1200-3000 µm; field moist 0.8/4.9= 16%; 0.8/6.1 = 13%: Δ =-3%

The relative increase (%) in total porosity is indicated between brackets.

The analysis of the pore shapes (Table 58) in field-moist conditions, shows that planar voids (craze planes) are most abundant in Kesteren, followed by Ewijk and Heumen. Upon drying, the Heumen and Ewijk materials show a very strong increase in planar voids. In Kesteren round voids increase at the expense of irregular voids.

Table 58. Pore shape distribution in field-moist and oven-dried samples (%) and relative changes (Δ -%).

pore shape	KESTEREN Cal field moist	KESTEREN Cal oven-dried	KESTEREN Cal Δ	EWIJK CaO field moist	EWIJK CaO oven-dried	EWIJK CaO Δ	HEUMEN MB field moist	HEUMEN MB oven-dried	HEUMEN MB Δ
ROUND	1.3	2.8	+13%	1.3	1.3	-7%	1.9	1.6	-13%
IRREGULAR	4.0	3.3.	-11%	2.4	2.0	-18%	2.5	2.4	-14%
PLANAR	4.1	4.3	-2%	2.8	3.5	-25%	0.7	2.8	+27%
Total porosity	9.4 → 10.4 (=+11%)			5.1 → 6.7(=+31%)			5.1 → 6.8(=+33%)		

Δ is the difference between the proportional contribution of each pore shape class to the total area percentage in field-moist and oven-dried samples.
The relative increase (%) in total porosity is indicated between brackets.

Scanning Electron Microscopy (Fig. 50 and 51).

The micromorphological observations enable the changes in the pore geometry for pore diameters ⩾ 10 µm to be described. S.E.M. with magnifications of 100 to 10,000 was used to study pores of sizes from about 0.01 to 10 µm and to reveal the modifications in the internal organization in the solid phase. Observations were carried out on soil samples subjected to various pF values, and after rehydration from pF6 to pF1 using Cryosan equipment. The observed features will be described, using some of the terminology proposed by Tessier and Quirk (1979) and Tessier (1984.

The S.E.M. photographs show a remarkable analogy with the mercury intrusion results, especially in the case of *Ewijk*, the most clayey soil material. At pF1 (Fig. 50, photo 2; Fig. 51, photo 11) this material is characterized by an organization in microdomains of about 5 to 10 µm thickness. On an increase to pF3 this material reacts by aggregating, forming domains with a

thickness of several tens of µm , while pore diameters decrease from about 1.5 to about 0.5 µm (Fig. 50, photo 5, Fig. 51, photo 14).

The *Kesteren* material shows a very loose groundmass, with pore sizes varying because of the arrangement of the (silt) particles (Fig. 50, photos 1, 4 and 7; Fig. 51, photo 10). The influence of an increase in pF (as suggested by the physical measurements) is less apparent than in the case of Ewijk, because of the masking effect of the high porosity.

The *Heumen* material, on the contrary, shows a very dense groundmass with large domains, between coarse sand grains (Fig. 50, photos 3 and 6; Fig. 51, photo 12). The lack of porosity is clearly visible and an increase in pF does not appear to influence the internal organization of the solid phase.

Photos 7, 8 and 9 (Fig. 50) show the pore system and the organization of the solid phase of the soil samples upon rehydration, at low magnifications. Ewijk reacts by a very strong aggregation of the material in large clay domains of some hundreds of microns. The Heumen material, in contrast, shows no apparent changes in the solid soil organization at this scale of observation. The Kesteren material does not demonstrate the changes indicated by the physical measurement (Fig. 43; Fig. 44) because of the masking effect of the high porosity. At magnifications of 2000 x (Fig. 51, photos 16, 17 and 18) the influences of desiccation are much less obvious, as at this scale short-range variation causes very different pictures.

Summarizing: the S.E.M. micrographs show that some of the soil materials react to varying pF values by changes in the organization of the solid phase. These changes are very clear, in particular at low magnification (200 x) for the Ewijk material, whereas no changes occur for the Heumen material. No changes are visible in the Kesteren material because of the masking effect of the high porosity.

Conclusion

Research was focussed on the microstructure of the soil materials, which required undisturbed field samples and a special sample treatment to prevent irreversible changes. Air drying caused irreversible changes, as shown for the Holocene Ewijk material. The Late Weichselian Heumen material remained unchanged (Fig. 43; Fig. 44). This is probably because of to the extreme drying experienced under natural field conditions during the periglacial circumstances of the Late Weichselian period. The Holocene soils have never been subjected to such conditions because they have never experienced any climate other than a temperate one. It would appear to be sensible to keep

Fig. 50. SEM micrographs (200 ×) of Kesteren (Ca1), Ewijk (Ca0) and Heumen (MB) soil samples at pF1, pF3, and rehydrated to pF1. Voids and mineral grains are black or dark grey.

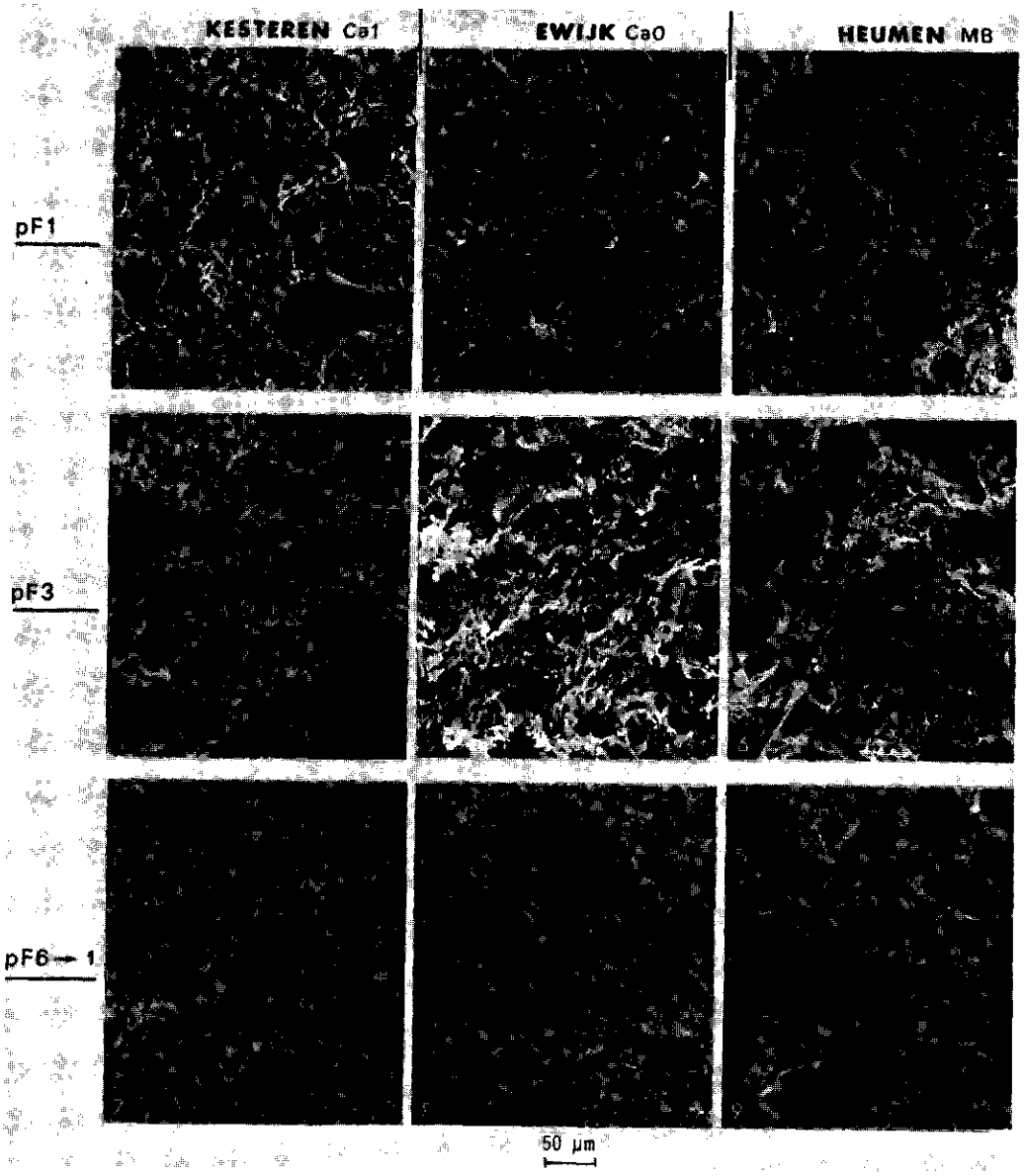
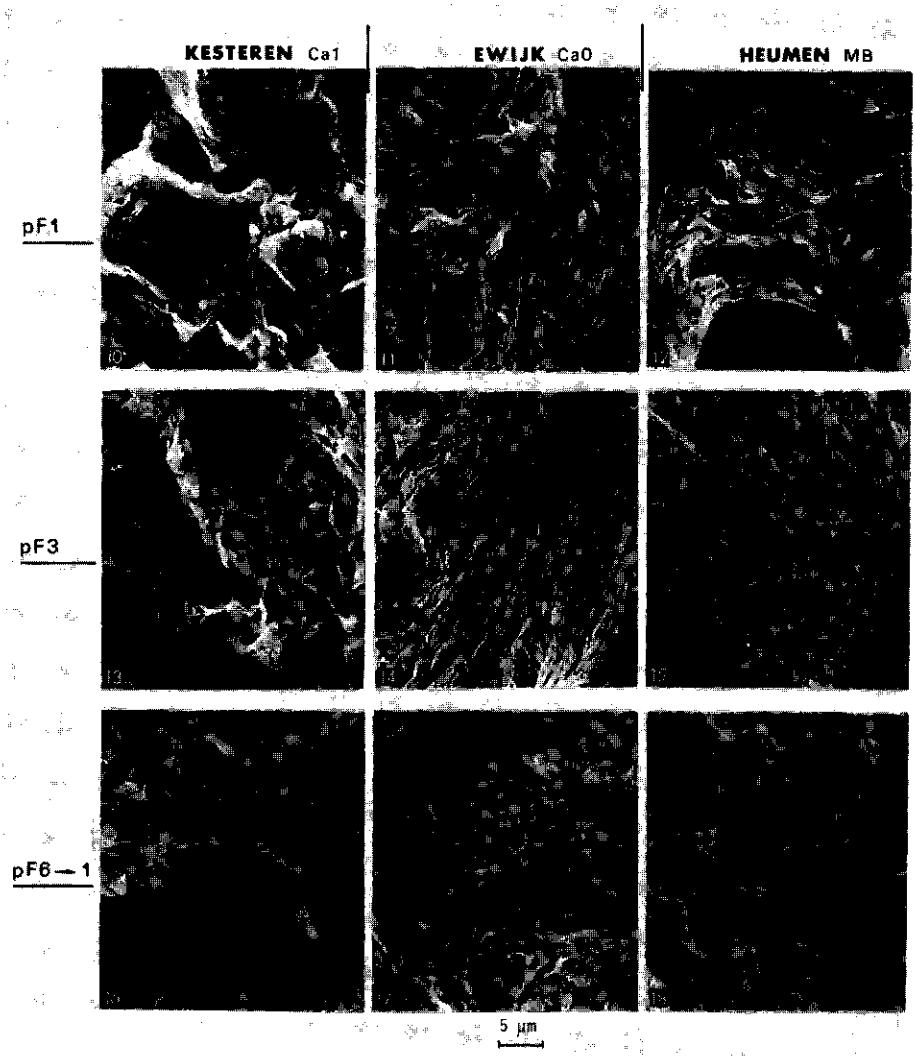


Fig. 51. SEM micrographs (2000 ×) of Kesteren (Ca1), Ewijk (Ca0) and Heumen (MB) soil samples at pF1, pF3, and rehydrated to pF1. Voids and mineral grains are black or dark grey.



soil samples within the range of moisture contents experienced under natural conditions. The same conclusion was reached by Tessier (1975; 1978; 1984), Tessier and Berrier (1979) and Tessier and Quirk (1979), pertaining to the behaviour of the clay fraction of soils.

The results obtained from the studies of the three soil materials clearly demonstrate the differences between them and are in complete agreement with the natural behaviour of the soils.

The *Kesteren* material has a high porosity with strongly varying pore diameters and many of large pores (> 3000 µm). The strong continuity of the pore system as judged from the interconnection of the pores in the vertically oriented thin sections, resulting in the loose packing of the dominantly silt sized particles, characterizes this young calcareous Holocene Cal soil material. Consequently, a considerable range in moisture content is passed during desiccation, whereas water saturation does not even occur at pF1. This explains why the tillage period of the Kesteren soil material is so long. The *Ewijk* material, with a considerably higher clay content, also shows a high porosity. Pore diameter range is much more limited, with a relative abundance of pores sizes of 0.05 - 3 µm . The continuity of the large pores is strong, judging from the interconnection of the pores in the vertically oriented thin sections. Despite the high clay content, this material is not very densely packed, and desiccation results in an important reorganization in domains. Consequently, a large range in moisture content is passed when pF increases, and this is accompanied by important volume changes. This explains why the Ewijk material also has a favourably long tillage period. Compared with Kesteren, this older decalcified Holocene CaO material has a somewhat denser microstructure.

The *Heumen* material shows a low porosity in all pore diameter classes, with a relative abundance of extremely fine pores (<0.05 µm). The continuity of the pore system is limited, judging from the thin sections. The rigid organization of the solid phase shows no volume changes on desiccation. The abundance of reorientation features favour puddling under pressure, at or near water saturation. A small loss of water corresponds to large pF changes. This explains the rapid change from moist to dry conditions and the narrow range in moisture content to produce a desirable tilth, in agreement with farmers expierence. Compared with the two Holocene materials, this Late Weichselian MB soil shows a dense microstructure that has largely been inherited from periglacial conditions in the Late Weichselian period.

4.6.4.UNCONFINED COMPRESSION TEST

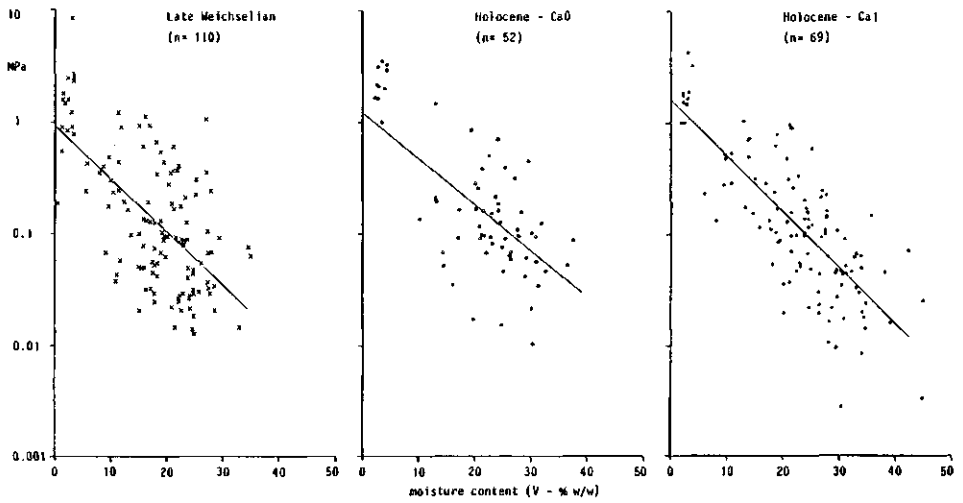
As mentioned in Chapter 1 field observations revealed that the Late Weichselian material had a larger 'stugheid' than Holocene material. This property cannot be easily connected to e.g. consistence, although the resistance to deformation is also estimated in the consistency tests by squeezing soil material between thumb and fore finger. Depending on the moisture content at determination terms like loose, friable, and firm (moist testing) and loose, soft and hard (dry testing) are used in the profile description. Schröder (1979) uses the term 'Gefüge festigkeit' which corresponds closely to our 'stugheid'.

In an attempt to quantify this 'stugheid' natural aggregates at various moisture contents at a range of suctions were shaped into cubes of varying sizes with 1-2 cm long sides. The air-dry material was dry-ground into cubic shapes, the moist material was shaped using a knife (Jacobs, 1981).

Table 59. Regression formulas for yield value of unconfined compression test with moisture content (V- %w/w; θ- %v/v).

GROUPING	REGRESSION EQUATION	R	N
LATE WEICHSELIAN	P= - 0.65V + 17.1	-0.48*	110
-MB	log P= - 0.047V + 0.97	-0.64*	110
	P= - 0.4θ + 17.5	-0.48*	110
	log P= - 0.03θ + 1.11	-0.70*	110
HOLOCENE-CaO	P= - 0.68V + 19.5	-0.65*	52
	log P= - 0.047V + 1.24	-0.72*	52
	P= - 0.408 + 20.3	-0.77*	52
	log P= - 0.029θ + 1.31	-0.79*	52
HOLOCENE-Cal	P= 0.43V + 13.1	-0.65*	69
	log P= - 0.050V + 1.21	-0.77*	69
	P= - 0.28θ + 14.1	-0.63*	69
	log P= - 0.032θ + 1.18	-0.86*	69

Fig. 52. Yield value at failure of unconfined compression test in relation to moisture content (V-%w/w).



The cubes were placed on a balance and pressure was applied manually via a flat wooden bar which was placed over the sample. The drier the material, the smaller the cube (otherwise they could not be broken). The yield value at failure was recorded and related to the clay and organic matter contents of the samples at given pF values (pF1, pF2, pF3, pF4.2 and pF6). This yielded generally a rather low correlation (R generally below 0.6) which improved when topsoils and subsoils were separated. Yet, the number of significant correlations at 95% confidence level is low. A much better relationship was found between the yield value (P) (more particularly log P) and the moisture content (weight %-V and volume % θ for each of the three investigated soil subgroups (Late Weichselian - mainly MB; Holocene - Ca0 and Holocene - Ca1). The regression formulas are given in Table 59. The given values are all significant at 95% confidence limits. The graphical presentation of the results is shown in Fig. 52.

As expected the yield value increases with decreasing moisture content, which is indicated by the negative correlations. The graphical presentation suggests that the Late Weichselan and Holocene subgroups behave similarly. In this graph the measured data are plotted, not corrected for clay or humus content. If the difference in clay content is eliminated by dividing both the yield value at failure and the moisture content by the clay content, the graphs are quite narrow above pF3 widening towards lower suctions. This is to be expected as other factors besides clay such as structural ones exert their influence. Yet, also with this approach no differences could be established between the groups.

It should be noted that near the hygroscopic point no bend is apparent like with the condensates (section 4.4.2). The individual samples demonstrated a variety of patterns (straight, bended, double bended) which could not be interpreted.

However, the moisture characteristic of the Late Weichselian material is different from that of the Holocene material (section 4.6.1.); therefore Late Weichselian material with a lower moisture content has to be compared with Holocene material with a higher moisture content. Viewed from this perspective, the field observation that the Late Weichselian material is drier even under saturated conditions would imply higher yield values because of corresponding lower moisture contents, and thus a higher 'stugheid' (resistance to deformation). This also agrees with the firm to very firm consistence noted in the profile descriptions.

Conclusion

Because of lower moisture contents at a given pF value the Late Weichselian material has a larger resistance to deformation ('stugheid') which agrees with the field observations and is in line with the firm to very firm consistence as noted in the profile descriptions.

4.7. PHYSICAL BEHAVIOUR OF NATURAL AGGREGATES

4.7.1. STRUCTURE STABILITY

Structure stability tests were carried out on air-dried and re-moistened (pF2) natural aggregates. The test included wet sieving (4.7.1.1.), end-over-end shaking (4.7.1.2.), raindrop resistance (4.7.1.3.) and slaking susceptibility (4.7.1.4.). The number of investigated samples varied from n=101 for the wet sieving of air-dried aggregates to n=13 for the end-over-end shaking. The characteristics of all subpopulations with regard to the 5 basic explanatory variables are considered to be equal to these of the whole population of 101 samples (Table 46). Details can be found in the reports of De Krey (1976), Klein Hesselink (1978), Kiliç (1979) and De Groot (1981).

4.7.1.1. WET SIEVING

The breakdown of air-dried and pF2 moist natural aggregates (6-8 mm ∅) on a set of sieves subjected to destructive forces (immersion in water) was measured after a standardized treatment of distributing the fragments by underwater sieving. The parameters used to characterize the breakdown are *mean weight diameter* (m.w.d.) in mm indicating the diameter of the fragments above and below which 50% of the total weight after treatment occurs, the *relative clod surface area* (r.c.s.a.) which demonstrates the increased specific outer surface area after treatment compared with that before treatment, and the *fraction smaller than 0.3 mm* (f03) in % (being the material lost through the sieve with the finest gauge). Large m.w.d.,

corresponding small r.c.s.a. and small f03 indicate stable material.
The wet sieving test on air-dried natural aggregates was done on all 101 samples physically characterized in section 4.6. The characteristics of the 5 basic explanatory variables can be found in Table 46 as means and standard deviations. A subpopulation (n=38) was subjected to wet sieving after careful re-moistening and desorption to pF2 to exclude the effect of air explosion which is very effective in destroying aggregates. The results for m.w.d., r.c.s.a. and f03 are presented in Table 60 as means and standard deviations. Results of ANOVA are presented in Table 61.

There were significant differences between the Late Weichselian and Holocene groups and subgroups with regard to the results of the wet sieving test, but the differences were only clear and consistent in the case of the test on air-dried natural aggregates. They largely disappeared when the natural aggregates had been carefully to a pF2 moisture content. The stability of such pF2 moist aggregates for both Late Weichselian and Holocene samples is much higher than that of air-dried aggregates (higher m.w.d., lower r.c.s.a. and f03); this has also been established for loess aggregates (Koenigs, 1975).

Table 60. Means and standard deviations (SD) for m.w.d. (mm), r.c.s.a. and f03(%) results of wet sieving of air-dried and moist (pF2) natural aggregates.

GROUPING	FLUVIAL		WEICHSELIAN		HOLOCENE		HB		MB		LG		CaO		Cal	
number of samples	n=101 resp. 38		n=61/24		n=40/14		n=23/8		n=32/11		n=6/5		n=17/6		n=23/8	
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
VARIABLE																
m.w.d. air-dry	2.25	1.75	1.76	1.51	3.00	1.86	1.37	1.45	1.88	1.41	2.62	2.01	3.96	1.61	2.29	1.73
r.c.s.a. air-dry	19.03	11.64	22.93	11.55	13.08	9.04	25.98	12.71	21.44	10.48	19.22	11.69	9.02	6.90	16.07	9.39
f03 air-dry	20.13	15.25	24.92	15.98	12.82	10.62	28.58	18.64	23.06	14.09	20.73	14.12	8.79	8.31	15.80	11.31
m.w.d. pF2	6.12	0.44	6.02	0.52	6.28	0.10	5.75	0.68	6.08	0.44	6.31	0.09	6.30	0.04	6.27	0.13
r.c.s.a. pF2	2.05	1.16	2.40	1.33	1.46	0.36	2.73	1.58	2.43	1.36	1.80	0.63	1.48	0.46	1.44	0.29
f03 pF2	1.04	1.34	1.45	1.51	0.34	0.53	1.64	1.86	1.56	1.50	0.94	0.94	0.40	0.74	0.29	0.35

Table 61. Results of ANOVA of wet sieving results of air-dried and moist (pF2) natural aggregates.

GROUPING	W	H	Ftest	Probability	HB	MB	LG	CaO	Cal	Ftest	probability
VARIABLE											
m.w.d. air-dry	A[1)]	B	13.5	**[2)]	A	A	AB	B	A	7.4	**
r.c.s.a. air-dry	B	A	20.8	**	C	BC	ABC	A	AB	7.4	**
f03 air-dry	B	A	17.7	**	C	BC	ABC	A	AB	5.8	**
m.w.d. pF2	A	A	3.5		A	A	A	A	A	2.6	
r.c.s.a. pF2	B	A	6.7	*	A	A	A	A	A	2.2	
f03 pF2	B	A	7.1	*	AB	B	AB	AB	A	2.0	

1) A, B, C etc. indicate significant differences at 95% confidence limits, A indicates the lowest mean values.
2) Probability: ** $p < 0.01$
* $p < 0.05$

The lowest structure stability is found in the sandy HB subgroup and the highest structure stability in the clayey CaO subgroup for the air-dried samples, whereas the samples at pF2 of both the CaO and Cal subgroups had high structure stability. The results of correlating of wet sieving data with the 5 basic explanatory variables (Appendix D) demonstrate positive correlations of m.w.d., especially with OC(and CL), for both Late Weichselian and Holocene samples in case of air-dried samples and for Late Weichselian samples at pF2. Negative correlations exist of OC(and CL) with r.c.s.a. and f03 being strongly reciprocal to the m.w.d. (high m.w.d. causes low r.c.s.a. and low f03). The correlation with CA is only significant in the Cal subgroup: in the air-dried samples there is a strong negative correlation with m.w.d. and hence positive correlations with r.c.s.a. and f03. Depth trends cannot be ruled out (decreasing clay content with depth,

increasing $CaCO_3$ content) but in no way can a positive influence of $CaCO_3$ on the structure stability be established. At 95% confidence limits almost all correlations for at pF2 samples are not significant, with the notable exception of OC, as mentioned previously.

Table 62 presents the variance explained (%) by multiple regression of the wet sieving results, using 5 and 9 basic explanatory variables. Multiple regression demonstrates that only the variation in m.w.d. air-dry can be explained largely by the 5 basic explanatory variables and no contribution of of the dummy variables concerning group or subgroup effects is noted. OC is the main factor in the explanation of the m.w.d. air-dry. For the data determined at pF2, only results for Fluvial, Weichselian and Holocene are presented, because for further division the number of samples is too small. Considerably less is explained for m.w.d.-pF2 than for the air-dry data.

Table 62. Variance explained (%) of wet sieving results by stepwise multiple regression with 9 and 5 basic explanatory variables.

	9 variables		5 variables																	
GROUPING	FLUVIAL		FLUVIAL		WEICHSELIAN		HOLOCENE		HB		MB		LG		CaO		Cal	
variance explained[1]		R^2		R^2		R^2		R^2		R^2		R^2		R^2		R^2		R^2
number of samples	N		N		N		N		N		N		N		N		N	
VARIABLE																		
m.w.d. air-dry	101	71	101	71	61	64	40	74	23	79	32	62	6	-	17	69	23	76
r.c.s.a. air-dry	101	53	101	53	61	42	40	70	23	56	32	38	6	-	17	-	23	82
f03 air-dry	101	43	101	43	61	31	40	58	23	41	32	27	6	-	17	-	23	85
m.w.d. pF2	38	32	38	32	24	25	14	-		*		*		*		*		*
r.c.s.a. pF2	38	43	38	43	24	43	14	34		*		*		*		*		*
f03 pF2	38	43	38	43	24	41	14	35		*		*		*		*		*

1) variance explained at 95% confidence limits

-: no variance explained at 95% confidence limits

* too few samples

Classification results of stability data, based on discriminant analysis, are given in Table 63. They are based on the results presented in the sections 4.7.1.1., 4.7.1.3. and 4.7.1.4. (wet sieving, raindrop resistance and slaking susceptibility) of samples subjected to all the mentioned tests.

Table 63. Classification results of stability data (wet sieving, raindrop, slaking), based on discriminant analysis.

		Predicted Group					
Actual group	number of cases	Weichselian number	%	Holocene number	%	correct classification number	%
Weichselian	14	11	79	3	21		
Holocene	13	2	15	11	85		
Total	27	13		14		22	81

The results of slaking, wet sieving and raindrop resistance data on air-dried aggregates dominate the function discriminating the Late Weichselian and Holocene groups. Data on aggregates at pF2 are subordinate in that function. Stability data discriminate well between the Late Weichselian and Holocene groups, with scores of 80-85% correctly predicted group membership.

4.7.1.2. END-OVER-END SHAKING

In the previous section the breakdown of natural aggregates was illustrated by the size and distribution of the resulting fragments. No information is available about the amount of released very fine fraction other than its inclusion in the f03. Natural aggregates (air-dried - with air explosion), pre-wetted natural aggregates and air-dried condensates were subjected to end-over-end shaking with water. The very fine fraction (< 40 µm) released was determined after a number of revolutions. With this relation it is possible to determine a stability index (Fig. 53), using a modified form of the method described by Koenigs (1976). Very few samples were investigated (n=13), and therefore the conclusions must be tentative (Martens, 1980). Also, the prerequisites for a proper application of the method (random distribution of clay in the aggregates and also random distribution of iron in the aggregates) are violated in the Late Weichselian samples (clay distribution inhomogeneous - section 4.3; iron distribution only homogeneous in the HB subgroup) and in the Holocene samples (notably inhomogeneous iron distribution). The results are summarized given in Fig. 53. It is clear from this figure that the HB subgroup can be differentiated from the other subgroups because it has a high iron content which is homogeneously

distributed. Stability of all subgroups strongly decreases when the natural structure is destroyed, as in the condensates. With increasing clay content, stability increases.

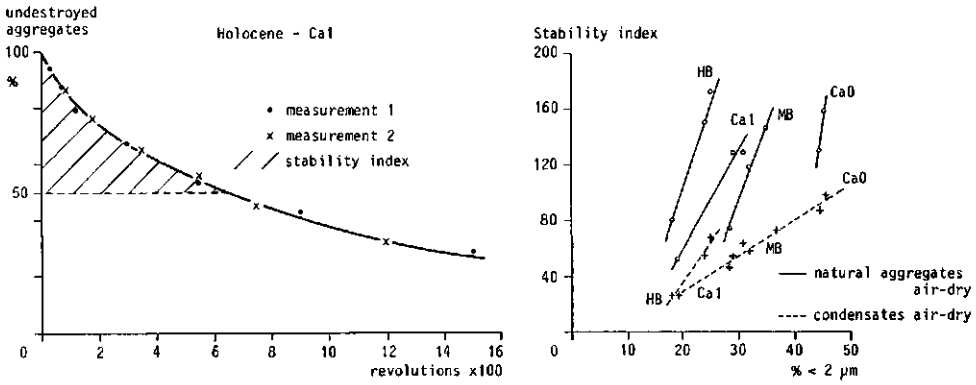


Fig. 53. Determination of the stability index with-end-over-end shaking and stability index as function of clay content.

4.7.1.3. RAINDROP RESISTANCE

Air-dried (n=69) and pF2 re-moistened (n=38) natural aggregates (6-8 mm ∅) on a sieve with a 6 mm square mesh were subjected to standardized destruction by raindrops (Low, 1954). The number of raindrops needed to reduce the size of the aggregate so that it fell through the sieve was recorded. Each measurement is the average of 5 - 10 iterations. When more than 1000 drops were needed the value 1000 is used. High values indicate stable material.

The results of the raindrop test are given in Table 64 as means and standard deviations. Results of ANOVA are presented in Table 65.

There is a significant difference between Late Weichselian and Holocene groups and subgroups with regard to the raindrop resistance of air-dried natural aggregates. Late Weichselian aggregates are less stable than

Table 64. Means and standard deviations (SD) of raindrop resistance data (number of raindrops)

GROUPING	FLUVIAL		WEICHSELIAN		HOLOCENE		HB		MB		LG		CaO		Cal	
number of samples	n=69/38		n=32/24		n=37/14		n=3/8		n=27/11		n=2/5		n=17/6		n=20/8	
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
VARIABLE																
raindrops air-dry	346	344	215	244	459	379	16	6	229	251	316	259	633	334	312	359
raindrops pF2	744	369	669	407	871	258	632	404	697	425	669	459	885	282	861	258

Table 65. Results of ANOVA of raindrop resistance data.

GROUPING	W	H	Ftest	probability	HB	MB	LG	CaO	Cal	Ftest	probability
VARIABLE											
raindrops airdry		A[1)]	B	9.8	**[2)]	A	B	ABC	C	BC	5.7	**
raindrops pF2		A	A	2.8		A	A	A	A	A	0.7	

[1)] A, B, C etc. indicate significant differences at 95% confidence limits; A indicates lowest mean values.

[2)] Probability: ** p< 0.01

* p< 0.05

Holocene aggregates. When the aggregates are carefully re-moistened and desorbed to pF2 the groups and subgroups are no longer significantly different, mainly because of large standard deviations. The increased stability of all groups and subgroups is noteworthy and is particularly spectacular for the HB subgroup: this agrees with the results of the wet sieving (section 4.7.1).

The correlations with the 5 basic explanatory variables are given in Appendix D. The correlation data show very few significant values, despite the occasionally high R values which result from the small sample numbers (especially for raindrop pF2 results).

Nevertheless, it is clear that the results, for raindrop air-dry in the Weichselian group correlate positively and significantly with CL, SI and OC, and significantly and negatively with SA. For the Holocene group, there are significant positive correlations with CL and OC, whereas SA and CA demonstrate significant negative correlations. The negative correlation with CA is the result of the Cal subgroup and demonstrates that a positive

influence of $CaCO_3$ on structure stability cannot be established: this agrees with the results of the wet sieving. For the subgroup the overall picture is not very different, although the small number of samples further reduces the number of significant correlations. For the raindrop pF2 data, OC demonstrates a significant positive correlation (together with SI) which can also be traced in the subgroups. No statistically significant correlations are present for the Holocene group.

The variance explained is given in Table 66. Because the number of samples becomes very small in the subgroup division, only the results for the groups (Weichselian, Holocene) are indicated, together with those of the fluvial samples.

Table 66. Variance explained (%) of the raindrop resistance results by stepwise multiple regression with 9 and 5 explanatory variables.

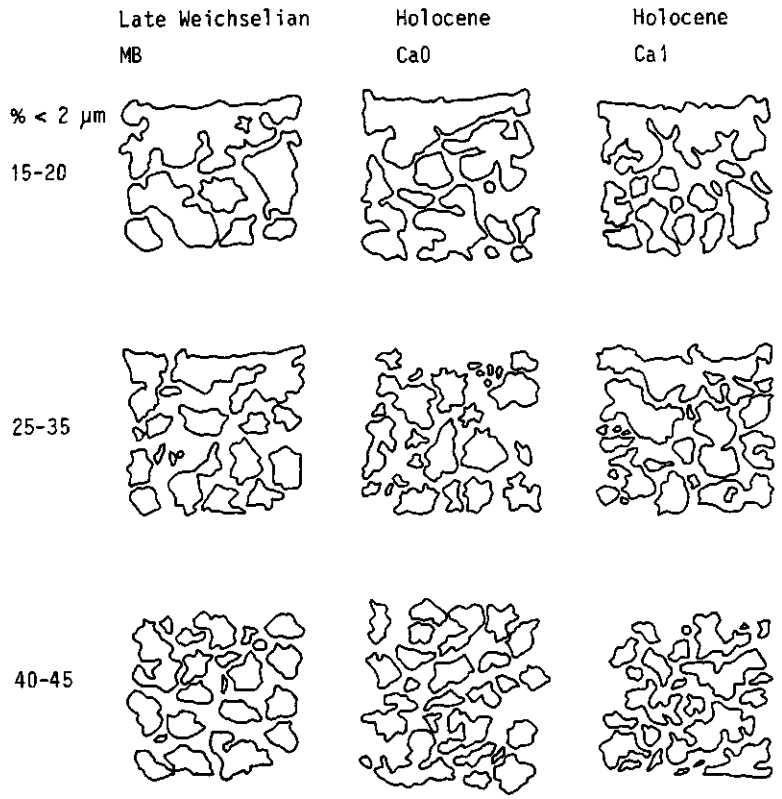
	9 variables	5 variables						
GROUPING	FLUVIAL		FLUVIAL		WEICHSELIAN		HOLOCENE	
variance explained[1]	R2		R2		R2		R2	
number of samples	n		n		n		n	
VARIABLE								
raindrop air-dry	69	79	69	77	32	76	37	76
raindrop pF2	38	27	38	27	24	29	14	-

[1] variance explained at 95% confidence limits

-: no variance explained at 95% confidence limits

The variance explained is high (about 75%) for the results obtained on the air-dry material with similar results for the Weichselian and Holocene groups. CL and OC are the variables involved and the dummy variables V0 (Weichselian, Holocene) and V13 (Ca0/Ca1) add only a small contribution (5%). For the results measured at pF2 the variance explained is much lower (25-30%) with OC as variable involved, and no contribution of the dummy variables is detected. The morphological result of raindrops on air-dry natural aggregates is shown in Fig. 54 for Late Weichselian and Holocene samples of different textures. Crusting occurs in all three soils when the soil contains 15-20% clay; in the Late Weichselian and the Ca1 subgroup still at 25-35% clay and in none at 40-45% clay. The experiment shown consisted of rainfall simulation for four days with a rainfall intensity of 25 mm per day on air-dry aggregates in sample tins (with a perforated bottom). After each day the sample was dried overnight under a burning radiator. The samples were impregnated after the 4-day treatment and the thin section studied.

Fig. 54. Crusting after raindrop test.



4.7.1.4. SLAKING TEST

This test records the reaction when natural aggregates (6-8 mm ∅) are submerged in water (Janse and Koenigs, 1963). The susceptibility to structural desintegration on sudden wetting was grouped in 6 classes, with 1 being the most susceptible class. The test was carried out with air-dry aggregates (n=69) and with carefully re-moistened and desorbed aggregates at pF2 (n=38). The results are given in Table 66 as means, and standard deviations. Results of ANOVA are given in Table 67. The classification group numbers are used in the calculations.

Table 67. Means and standard deviations (SD) of slaking test results (mean class number).

GROUPING	FLUVIAL		WEICHSELIAN		HOLOCENE		HB		MB		LG		CaO		Cal	
number of samples	n=69/38		n=32/24		n=37/14		n=3/8		n=27/11		n=2/5		n=17/6		n=20/8	
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
VARIABLE																
slaking class air-dry	3.6	2.0	2.7	2.0	4.4	1.6	1.0	0.0	2.8	2.0	3.5	2.1	5.1	1.4	3.8	1.5
slaking class pF2	5.7	0.7	5.5	0.9	6.0	0.0	5.1	1.4	5.6	0.5	6.0	0.0	6.0	0.0	6.0	0.0

Table 68. Results of ANOVA of the slaking test results.

GROUPING	W	H	Ftest probability		HB	MB	LG	CaO	Cal	Ftest probability	
VARIABLE											
slaking class air-dry	A[1)]	B	16.6	**[2)]	A	B	ABC	C	BC	6.7	**
slaking class pF2	A	B	3.7		AB	A	B	B	B	0.7	

[1)] A, B, C etc. indicate significant results at 95% confidence limits; A indicates the lowest mean values.
[2)] Probability: ** $p < 0.01$
* $p < 0.05$

It is clearly possible to discriminate between the Late Weichselian and Holocene groups on the basis of the results of the slaking test on air-dry aggregates, but not significantly on the pF2 aggregates. The Late Weichselian samples are less stable (more susceptible to slaking) than the Holocene samples, particularly for the air-dry aggregates. The HB subgroup is most susceptible to slaking whereas the CaO subgroup is least susceptible to slaking: this agrees with the sandy and clayey character of these respective subgroups. The susceptibility to slaking diminishes strongly when the aggregates are moist.

For the 'slaking class air-dry' the correlation data (Appendix D) demonstrate a significant positive correlation with CL and OC and a significant negative correlation with SA for both Weichselian and Holocene groups and subgroups. In addition, a correlation (positive) with SI for the Weichselian group and with CA(negative) for the Holocene group was found. The latter significantly negative correlation with CA is the result of the Cal subgroup and once more sheds doubt on the supposed positive influence of $CaCO_3$ on stability. In the case of the 'slaking class pF2', only the significant positive correlation with OC remains for the Weichselian group; the correlations for the Holocene group cannot be calculated because all CaO and Cal samples score class 6.

The variance explained (%) is given in Table 69. Because the number of samples becomes very small in the subgroup division, only the results for the Weichselian and Holocene groups are indicated next to those of the fluvial samples.

Table 69. Variance explained (%) of the slaking class results by stepwise regression with 9 and 5 basic explanatory variables.

	9 variables			5 variables				
Grouping		Fluvial		Fluvial		Weichselian		Holocene
Variance explained[1)]			R2		R2		R2	R2
number of samples		n		n		n		n
VARIABLE								
slaking class air-dry	69	87	69	72	32	76	37	81
slaking class pF2	38	32	38	32	24	21	14	***

1) variance explained at 95% confidence limits

*** no variance

The variance of the slaking class air-dry results is largely explained (70-80%) by CL and OC in both the Late Weichselian and Holocene groups. Dummy variables account for another 15% of the variance (V0: Weichselian/Holocene and V11: MB/HB + LG). In the case of the slaking class pF2 results, the variance explained is much lower (about 30%) and no influence of the dummy variables is found.

Conclusions based on structure stability tests

- The structure stability of Late Weichselian natural aggregates is lower than that of Holocene natural aggregates when the tests are done on air-dried material. The effect of air explosion is primarily responsible for the observed differences. The air explosion in the Late Weichselian natural aggregates results from the virtual absence of organic matter within the aggregates, the dense heterogeneous and reoriented microstructure and the non-continuous pore system. Even aggregates from Late Weichselian topsoils, having organic matter contents similar to aggregates from Holocene topsoils demonstrate a lower structure stability presumably because of the differences in distribution of the organic matter. Air-dry conditions have frequently occurred in the periglacial Late Weichselian climatic conditions after deposition of the Late Weichselian braided river sediments.

- The structure stability of the Late Weichselian and Holocene natural aggregates is not significantly different anymore when tested after careful remoistening and desorption to pF2. Care was taken to keep structure intact during the remoistening and thus this testing demonstrated the structure stability without the effects of air explosion.
- The variance in the structure stability testing results can be largely explained by OC and CL sometimes in reverse order. The inherent differences in CL and OC between Late Weichselian and Holocene soil materials, notably the low organic matter content, the poor quality and the inhomogeneous distribution of the organic matter after addition, thus explain the observed differences between the Late Weichselian and Holocene groups.
- A positive effect of $CaCO_3$ on the structure stability has not been observed. On the contrary, within the Holocene Cal subgroup negative correlations were observed between $CaCO_3$ and m.w.d., raindrop resistance and slaking susceptibility.
- Effects of differences between Late Weichselian and Holocene groups and subgroups contributed to the variance explained in case of the air-dry raindrop resistance (some 5% extra variance explained) and the air-dry slaking test results (some 15% extra explained variance). This may be due to microstructural aspects. It has to be remembered that other sources of variation (land-use, regional differences, depth) have not been taken into account, however.

4.7.2. TILLAGE TESTS

Natural aggregates (3.4-4.8 mm Ø) at various moisture contents were been subjected to simulated tillage. In the micro-tillage test (Koenigs, 1976) a hammerhead is moved over the aggregates in a standardized way. It allows the determination (Fig. 55) of the maximum moisture content for succesful tillage (the *Upper Tillage Limit* -UTL) based on the tractive force per cm thickness, visual inspection and the relative clod surface area (r.c.s.a. - section 4.7.1). In all, 45 samples were analysed (Late Weichselian MB samples n=13; Holocene *CaO* samples n=12; Holocene Cal samples n=20) (De Krey, 1976 b; Klein Hesselink, 1978; Broekhuizen, 1980). For a limited

number of samples (n=9) the results of the micro-tillage test were compared (Broekhuizen, 1980) with results obtained using the test of Perdok and Hendrikse (1982) which subjects cores with aggregates at various moisture contents to various pressures and then measures the resulting air permeability. A critical value of the resulting air permeability determines the wet workability limit (WWL). Both methods were calibrated against each other and against field conditions in the Nederlands. Statistically very similar results between these two tests over a certain range of textures (R=0.88) are reported by Terzaghi *et al.*, (1987) which agree with our results. The micro-tillage test seems to be succesful for a wide range of soils (e.g. in Uruquay - Terzaghi *et al.*, 1987, and in Kenya - Kauffman, 1975).

The results for the 5 basic explanatory variables are presented as means and standard deviations in Table 70. The results of ANOVA are presented in Table 71. In Table 72 the results of the micro-tillage test are presented as means and standard deviations of the moisture content (% w/w) at UTL (WW- UTL) and the corresponding pF value (pF-UTL) and also, using the known aggregate bulk densities (BDa, section 4.6) as volumetric moisture content (VV-UTL-%v/v).

The results of the ANOVA are presented in Table 73. The basic explanatory variables demonstrate significant differences solely in silt and calcium carbonate. Only the Cal subgroup contains calcium carbonate: it also demonstrates the highest silt content. The micro-tillage test parameters do not demonstrate significant differences other than for the bulk density of aggregates, which was noted already in section 4.6. The systematic differences (lower moisture content - % w/w and % v/v - and the highest pF value at UTL for the Late Weichselian samples) do not lead to statistically significant differences, because of the large standard deviations. Generally speaking, the Late Weichselian samples must be drier if the result of tillage is to be acceptable.

Fig. 55. Example of the determination of the UTL of the micro-tillage test.

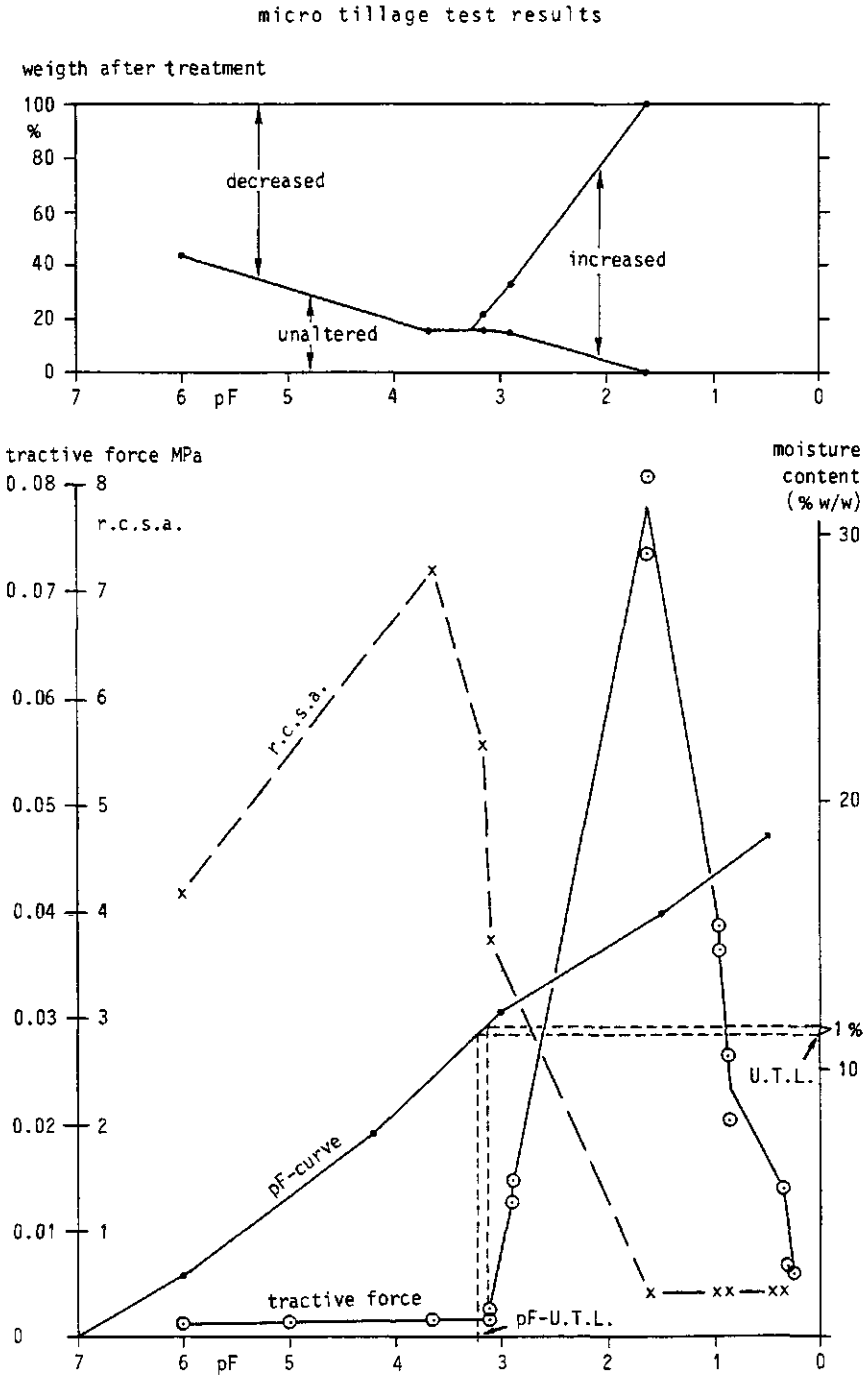


Table 70. Means and standard deviations (SD) of the 5 basic explanatory variables of samples investigated in the micro-tillage test.

GROUPING		FLUVIAL		WEICHSELIAN (MB)		HOLOCENE		CaO		Cal	
number of samples		n=45		n=13		n=32		n=12		n=20	
VARIABLES		mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Clay	(CL) %	30.7	11.3	32.8	10.0	29.8	11.8	34.3	15.0	27.2	8.9
Silt	(SI) %	43.1	11.9	35.2	10.1	46.3	11.2	40.5	10.6	49.8	10.3
Sand	(SA) %	26.2	17.7	32.0	16.2	23.9	18.0	25.2	20.3	23.0	16.9
Org. Carb.	(OC) %	0.96	0.92	0.83	0.79	1.02	0.98	1.32	0.70	0.84	1.09
$CaCO_3$	(CA) %	3.7	5.1	0.0	0.0	5.2	5.3	0.1	0.1	8.3	4.4

Table 71. Results of ANOVA of the 5 basic explanatory variables of samples investigated in the micro-tillage test.

GROUPING	W	H	Ftest	Probability	MB	CaO	Cal	Ftest	Probability
VARIABLE									
CL	A[1)]	A	0.6		A	A	A	1.8	
SI	A	B	9.5	**[2)]	A	AB	B	8.3	**
SA	A	A	2.0		A	A	A	1.0	
OC	A	A	0.4		A	A	A	1.2	
CA	A	B	12.1	**	A	A	B	42.4	**

1) A, B, C etc. indicate significant differences at 95% confidence limits; A indicates lowest mean values

2) Probability: ** $p < 0.01$ - * $p < 0.05$

Table 72. Means and standard deviations (SD) of micro-tillage test parameters.

GROUPING	FLUVIAL		WEICHSELIAN		HOLOCENE		CaO		Cal	
number of samples	n=45		n=13		n=32		n=12		n=20	
VARIABLE	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
WW-UTL (% w/w)	20.0	5.5	18.5	4.1	20.7	5.9	21.6	5.8	20.1	6.1
VV-UTL (% v/v)	35.4	9.4	33.8	6.9	36.1	10.2	39.3	10.1	34.1	10.1
pF UTL	2.9	0.4	3.1	0.4	2.9	0.4	2.7	0.5	3.0	0.3
BDa (kg/m^3)	1770	100	1840	85	1745	95	1830	85	1695	60

Table 73. Results of ANOVA of micro-tillage test parameters.

GROUPING	W	H	F test	Probability	MB	CaO	Cal	F test	Probability
VARIABLE									
WW-UTL	A[1)]	A	1.4			A	A	A	1.0
VV-UTL	A	A	0.5			A	A	A	1.5
pF-UTL	A	A	2.1			A	A	A	3.7
BDa	B	A	9.5	**[2)]		B	B	A	18.9**

1) A, B, C etc. indicate significant differences at 95% confidence limits; A indicate lowest mean values

2) Probability: ** $p < 0.01$

* $p < 0.05$

Correlations with the 5 basic explanatory variables (Appendix D) show that for the fluvial soils there are significant positive correlations between moisture content (% w/w and % v/v) at UTL and OC, CL and SI and there is a significant negative correlation with SA (% w/w) and SA and CA (% v/v). The pF only correlates significantly (and negatively) with OC. For the Late Weichselian samples the correlation with CL is no longer significant and SI dominates (% w/w); furthermore, there is no significant correlation with pF-UTL. In contrast, for the Holocene samples the correlation with CL dominates and SI is not significant (% w/w), and the correlation between pF and OC is significantly negative whereas that between pF-UTL and CA is significantly positive. The strongly negative correlation of BDa with CA, caused by the Holocene samples is, as mentioned earlier, a depth effect of both PVa (which influences BDa) and CA. The Holocene CaO subgroup only differs in the absence of significant CA correlations, and the Holocene Cal subgroup demonstrates very high positive correlations with OC and CL (both % w/w and % v/v) and negative correlations between OC and pF-UTL.
The variance explained is presented in Table 74 based on stepwise multiple regression with 5 basic explanatory variables.

Table 74. Variance explained (%) of micro-tillage test parameters by stepwise multiple regression with 5 basic explanatory variables.

GROUPING	FLUVIAL	WEICHSELIAN (MB)	HOLOCENE	CaO	Cal
number of samples	n=45	n=13	n=32	n=12	n=20
variance explained[1)]	R^2	R^2	R^2	R^2	R^2
VARIABLE					
WW-UTL	89	87	91	90	93
VV-UTL	89	85	91	90	93
pF-UTL	24	-	33	-	40
BDa	72	54	72	44	63

1) variance explained at 95% confidence limits
- no variance explained at 95% confidence limits

The variance in moisture content at UTL (% w/w; % v/v) is largely explained (85%-95%) by CL and OC, sometimes in reverse order. In the Late Weichselian samples, texture components other than CL predominate (SI, SA). The variance explained of the pF value of the UTL is much less (25-40%) and wholly attributable to the Holocene Cal samples, with OC as the only contributing variable. Variation in bulk density has already been mentioned (section 4.6), notably the influence of CA which is, in reality, a depth effect.

Conclusion

In conclusion, it can be stated that the micro-tillage test of samples of Late Weichselian and Holocene materials that are identical except for silt content and $CaCO_3$ content revealed systematic differences between the two groups that were not statistically significant at 95% confidence level because of the large standard deviations. The Late Weichselian material must be drier if the result of tillage is to be acceptable at the critical moisture content on the wet side. Differences in tillage behaviour are largely attributable to differences in clay and organic carbon.

4.8. SATURATED HYDRAULIC CONDUCTIVITY

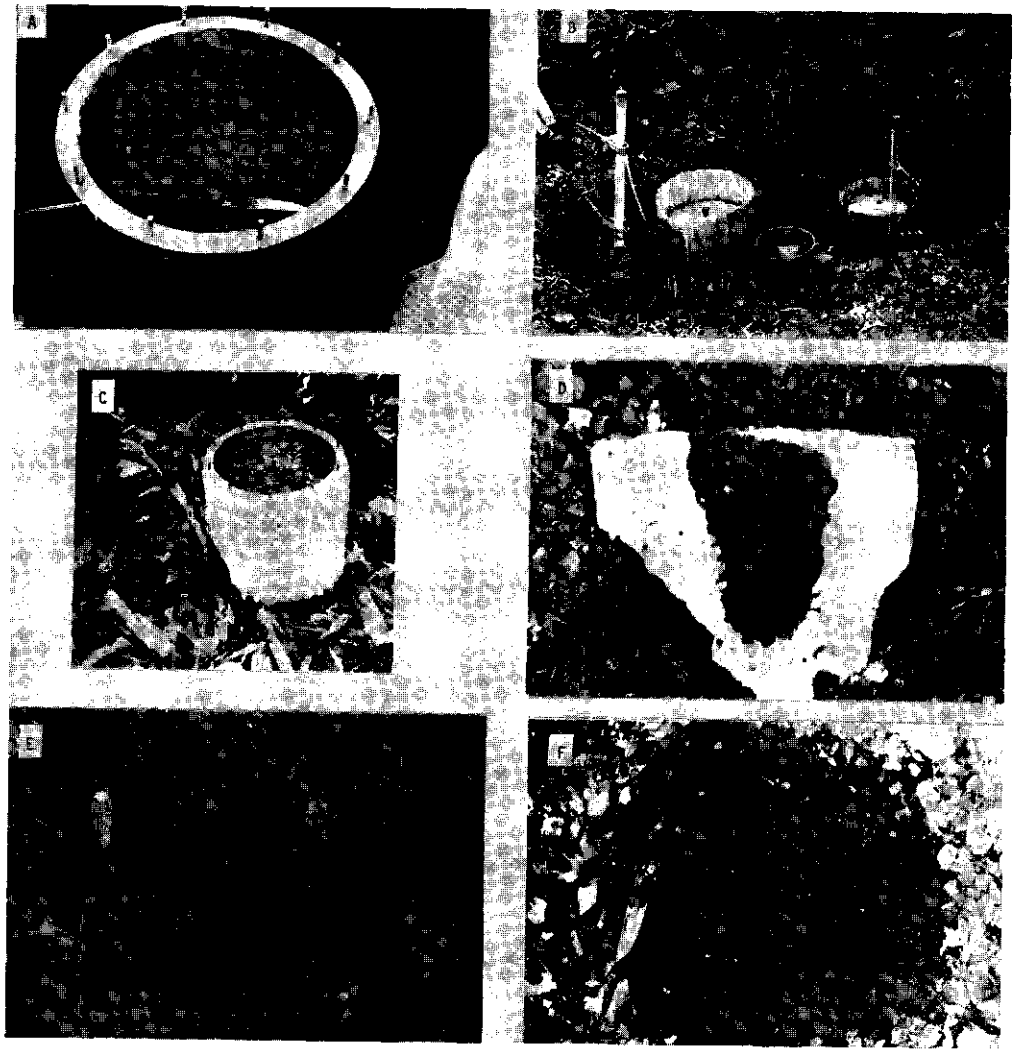
The saturated hydraulic conductivity was measured in the field using the column method and the crust test in undisturbed columns of soil with a diameter of 30 cm and a length of 30–40 cm (Fig. 56). The methods used were those described by Bouma (1977, 1983, 1984). The measurements were done with the columns in their natural position (attached) and detached from the underlying soil (Fig. 56), both without and with a crust of 25% gypsum mixed with sand. In all, 56 columns measurements were carried out (Late Weichselian n=28; Holocene n=28) at different depths. Details are reported by Du Bois and Wijntje-Bruggeman (1977), Jacobs (1978) and Van Dis and Robben (1978).

More recently, specific research on the effect of subsoil cracking on moisture deficits of Pleistocene and Holocene fluvial clay soils has been reported by Kooistra *et al.* (1987): Fig. 57 is derived from that publication, illustrating the K-h relationship including the K-macro and K-micro measurement. K-macro expresses the effect of horizontal cracking on upward flow of water, K-micro is valid for the soil between the macropores and characterizes downward flow. The effects of subsoil cracking on moisture deficits of Late Weichselian and Holocene fluvial (Rhine) clay soils were discussed in that paper and the conclusions reached were:

i) Moisture deficits in Holocene fluvial clay soils (Ca0) occur earlier during the year and are more pronounced during the summer period as compared with the deficits in Late Weichselian (MB) fluvial clay soil.

ii) Differences in moisture deficits are primarily due to more pronounced formation of horizontal planar voids in the Holocene subsoil upon

Fig. 56. Saturated hydraulic conductivity measurement and worm holes as conducting macropores.



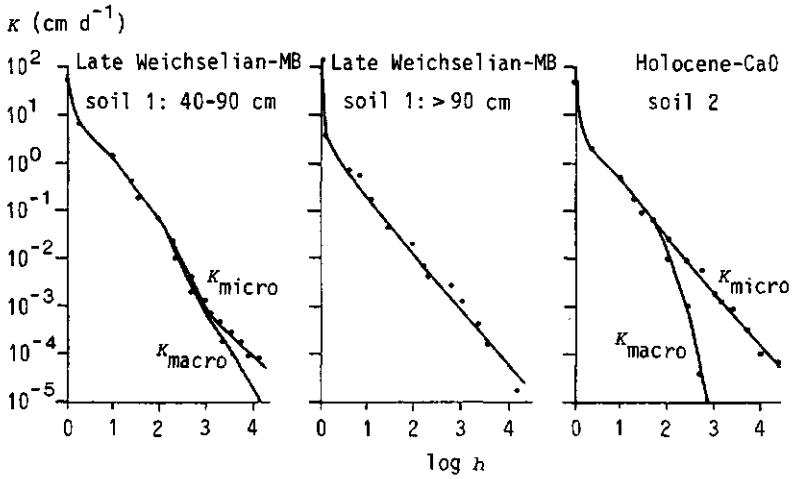
A. Field column measurement in its natural position prior to gypsum encasting. Note worm activity (near A9 - MB - grassland)
B. Simultaneous measurement of 2 columns (near A17 - Ca0 - arable land)
C. Detached field column with gypsum casing (MB - Azewijn area)
D. Worm holes as conducting macropores dyed with methylene - blue (MB - Azewijn area)
E. Conducting worm holes at 100 cm depth in a MB soil (near A5 - MB - grassland)
F. Worm activity in Late Weichselian MB soils with recently improved drainage (Asbroek area)

desiccation, as indicated by a morphological staining test. These planar voids impede upward fluxes of water.

iii) The absence of well-developed horizontal planar voids in the Late Weichselian subsoils is associated with lesser swelling and shrinking of the undisturbed soil material that has a very dense groundmass with stress features (sections 4.3 and 4.4). After disturbance, the soil material of Late Weichselian ands Holocene subsoils have identical swelling and shrinkage characteristics (needs to be amended slightly: a slightly lower linear extensibility for the Late Weichselian material, associated with clay mineralogical differences has been found - section 4.4).

iv) This study combined physical and morphological techniques to provide basic data for a similation model of the soil water regime. Both types of techniques are needed to characterize water movement in soils with macropores. Data on soil morphology were used to focus physical measurements in terms of sample location and sampling volumes and aid in explaining differences in swelling behaviour and pattern of void continuity.

Fig. 57. K-h relation for a Late Weichselian MB soil and a Holocene Ca0 soil.



The results for the measured columns are given in Table 75 in subdivisions based on *age groups* (Late Weichselian and Holocene, as usual) but also *depth classes* (D1-D3) irrespective of age (0-30/50 cm; 30/50-60/80 cm; 60/80-90/110 cm) and *land use* (LU1, LU2) irrespective of age (arable; grassland

including orchard) and land use (only for samples from depth 1: 0-30/50 cm; LU3 and LU4).

Table 75. Means and standard deviations (SD) of Ksat column measurements (m day^{-1}).

GROUPING	FLUVIAL		WEICHSELIAN (MB)		HOLOCENE(CaO)		D1[1)]		D2		D3		LU1		LU2		LU3		LU4	
number of samples	n=56		n=28		n=28		n=21		n=24		n=11		n=23		n=33		n=8		n=13	
VARIABLE	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Ksat	1.6	1.3	1.1	0.9	2.0	1.4	1.5	1.4	1.7	1.3	1.4	0.9	1.2	1.0	1.8	1.4	0.9	0.8	1.9	1.5

1) Abbreviations: see text.

Table 76. Results of ANOVA of Ksat data.

GROUPING	W	H	Ftest	Probability	D1	D2	D3	Ftest	Probability	LU1	LU2	Ftest	Probability	LU3	LU4	Ftest	Probability
VARIABLE																	
Ksat	A	A	6.4	*	A	A	A	0.2		A	A	3.4		A	A	2.9	

* $p<0.05$

From Table 76 it is clear that the Ksat of Late Weichselian and Holocene columns differs significantly ($p<0.05$) although at 95% confidence level the values are not mutually exclusive. Late Weichselian soils have a lower Ksat than Holocene soils.

But the difference in land-use irrespective of age is also important, as can be seen from the means (LU1 versus LU2) especially for the topsoils (LU3 versus LU4). Because of the large standard deviations this is not statistically significant at 95% confidence limits, however. Nevertheless, the Ksat of grassland/orchard soils is higher than that for soils under arable land (especially topsoils). Comparison of certain individual values (Appendix E) indicates striking differences. The measurement in reference profile Aaldonk (A9-arable land) resulted in a saturated hydraulic conductivity of 0.4 m/day in a column from 5-30 cm depth and a Ksat of 0.2 m/day in a column from 30-55 cm depth. In an adjacent grassland with a soil of exactly the same texture, the measurements of a column from 5-40 depth demonstrated a saturated hydraulic conductivity of 1.4 m/day and a column from 30-60 cm depth had a Ksat of 2.4 m/day. This difference is largely because the soil in the grassland parcel had many worm holes which conducted large quantities of water (with methylene blue dye - Fig. 56) to depths of some 100 cm (Fig. 56).

Such differences were recorded frequently, but because the levels of Ksat are so different there are large standard deviations in the subdivision based on land use. Also, short-range variability is very important, as

demonstrated by a measurement in an orchard near reference profile Randwijk (A19), where Ksat from columns from 5-35 cm, 35-65 cm and 65-95 cm depth were determined in two profiles only 50 cm apart. The recorded Ksat values were, respectively, in m/day: depth 5-35 cm: 4-2.4; depth 35-65 cm: 5.5-3.6 and depth 65-95 cm: 2-1.4, corresponding with the differences in number of worm holes >5 mm/700 cm^2 counted (respectively 0-0; 8-5 and 13-10 for the measured depths). In contrast, the Randwijk reference profile (A19- arable land) gave 1.1 m/day, 0.8 m/day and 2.1 m/day for the same depths, and arable land with more than 10 years zero tillage gave 1.5 m/day, 3.3 m/day and 2.7 m/day, demonstrating the effect of continuity of the macro pore system. Results from this site are also discussed in Boone *et al.* (1976).

In many cases, detached columns gave almost unmeasureable high values (>10 m/day) if macropores (notably worm holes) were continuous over the length of the column (Appendix E). If that was not the case, the values remained close to that recorded for the column in its natural position. With a crust of 25% gypsum and sand the hydraulic conductivity dropped, because large macropores could no longer contribute: reductions to 10-50% of the Ksat were commonly recorded and the hydraulic conductivity dropped to levels classed as low to very low. No differences occur between detached columns and columns in situ. Separate measurements on individual structure elements (K micro) to determine the influence of the intra-pedal system demonstrated results equal or higher than the measurement obtained in soil columns with a crust. The Holocene CaO samples demonstrated systematically higher values; this may indicate a better continuity of the pore system (more biological activity because of the higher levels of organic matter). This conclusion is tentative, however, because of the small number of samples investigated.

Conclusion

In conclusion it can be stated that:

- Late Weichselian (MB) columns demonstrated a lower Ksat than Holocene CaO columns, although the lowest recorded Ksat value (0.2 m/day) is not critically low.
- Land use differences strongly influence the Ksat, especially when individual measurements are considered. Grassland (orchard) has a markedly higher Ksat, because of the abundance of continuous macropores (worm holes).
- Measurements on individual peds suggest that peds of Holocene material have a more continuous pore system than those of Late Weichselian

material.

- Late Weichselian (MB) soils demonstrate fewer horizontal planar voids than Holocene (Ca0) soils because of packing density and swelling/shrinking. This influences the moisture deficits through its effect on upward fluxes of water. Holocene (Ca0) soil demonstrates more pronounced moisture deficits and these occur earlier in the year.

4.9. CONCLUSIONS

From the many results on physical characteristics and behaviour, the differences between Late Weichselian soils and soil material (HB, MB and LG) compared with Holocene soils and soil material (Ca0 and Ca1) are summarized in Table 77. In this table it is also indicated whether any differences

Table 77. Summary of physical characteristics and behaviour of Late Weichselian and Holocene soils and soil material

Sample:	Columns(peds)	Cores					Aggregates							Condensates		Ground fine earth		
VARIABLE:	Ksat	BD(PV)	pF	AM	Ki	TV	BD(PV)	pF	AM	Pore system	TV	Stab. dry	Stab. pF2	UTL	LE	Att.	TV	PD
GROUPING																		
Weichselian	-	-	-	0	0	0	-	-	-	-	0	-	0	(-)	-	-	-	0
Holocene	+	+	+	0	0	0	+	+	+	+	0	+	0	(+)	+	+	+	0
signific.	*	**	**	1)	1)	1)	**	**	*	n.d.	nd	**	0	0	**	**	nd	0

Key: Abbreviations
Ksat = saturated hydraulic conductivity (m/day)
BD = Bulk density (dry - kg/m^3)
PV = Pore volume (% v/v)
PD = Particle density (kg/m^3)
pF = Moisture characteristic (% w/w; % v/v)
AM = Available moisture (mm/10 cm)
Ki = Air permeability (10^{-12} m^2)
TV = strength (kPa)
Stab. = wet sieving, raindrop test, slaking test (dry and at pF2)
UTL = Upper Tillage Limit microtillage test (% w/w; % v/v; pF)
LE = linear extensibility at pF1 and pF2 (%)
Att. = Atterberg limits (% w/w)
Pore system = Micromorphology, micromorphometry, Cryoscan, mercury porosimetry
Significance: ** p<0.01
* p<0.05
0 p>0.05
Coding: + more favourable (+) systematic difference, more favourable
- less favourable (-) systematic difference, less favourable
0 no difference
1) in subgroup division significant

should be described as favourable or unfavourable. Furthermore, their statistical significance is given. Late Weichselian soils and soil material, notably the truely Late Weichselian members HB and MB, are in many respects physically less favourable than Holocene soils and soil material (with LG in intermediate position, but more closely related to the Holocene materials). The *particle density* is not significantly different between the Late Weichselian and Holocene groups and is mainly a function of clay and organic carbon. This points also to a similar mineralogical composition. In some subgroups the specific character is revealed (e.g. HB- very sandy: particle density close to that of quartz; MB with frequent iron and manganese mottles: particle density higher than expected from CL and OC contents). The *linear extensibility* is mainly a function of clay together with organic carbon. Linear extensibility discriminates well between the Late Weichselian and Holocene groups and subgroups. The linear extensibility of the Late Weichselian soil material is slightly lower than that of the Holocene soil material. This corroborates the differences found in clay mineralogy. The swelling and shrinking of the Late Weichselian soil material of natural aggregates and certainly in its field structure is hampered by the extremely dense packing as described and demonstrated in the micromorphology and the S.E.M. studies. The *shear strength* of condensates demonstrated that the true Late Weichselian materials (HB and MB) need to be wetter in order to have the same shear strength than the Holocene materials (and LG). The *Atterberg limits* are a function of clay and organic carbon and demonstrate a smaller range in plasticity (UPL-LPL) for the Late Weichselian soil material than for the Holocene soil material. Besides, the Late Weichselian soil material remains sticky at moisture contents equal to or below the LPL. As this LPL signifies the maximum water content for succesful tillage, this differences is also important for agricultural practise. The *bulk density, pore volume and moisture characteristic* determined on *core* samples discriminate well between the Late Weichselian and Holocene groups, notably between HB + MB and Ca0 + Ca1 (+LG). These properties are a function of clay and organic carbon for the Holocene group and of sand and organic carbon for the Late Weichselian group. *Available moisture between pF2 and pF4.2* only discriminates on subgroup level. The Late Weichselian physical characteristics on core samples are very specific as they lead to a correct prediction (classification) in almost 90% of cases, based on discriminant analysis. The Holocene physical characteristics on core samples are much

less specific. *Air permeability* and *Torvane shear strength* measured in cores at pF2 do not allow statistically significant conclusions because of high standard deviations. Nevertheless the results, especially for some subgroups, are quite clear. The Holocene Cal subgroup is highly porous with a pronounced continuity, yielding a very high air permeability and the HB and Ca0 subgroups demonstrated a very low air permeability. The Torvane shear strength of notably the MB subgroup was very high and the Late Weichselian samples demonstrated a more pronounced increase in yield value than the Holocene samples with decreasing moisture contents. The *bulk density, pore volume and moisture characteristic* determined on *air-dried natural aggregates* demonstrated an even better discrimination between the Late Weichselian and Holocene groups than the core sample characteristics. *Available moisture between pF2 and pF4.2* discriminates well between the Late Weichselian and Holocene groups. The differences between core sample determinations and natural aggregate determinations point to the fact that the differences between Late Weichselian and Holocene soil material in its origical structure are caused principally on the microstructure level. That is also demonstrated by the *pore system behaviour* studies using morphological and physical methods. The extremely dense, highly reoriented, rigid and microheterogeneous microstructure in the Late Weichselian causes a high bulk density, a low pore volume and consequently a low water retention. The Holocene soils are characterized by a high to moderately high continuous porosity and a semi elastic to elastic microhomogeneous microstructure resulting in low bulk densities, high pore volumes and a high water retention notably for the Holocene Cal subgroup. The *'stugheid' or resistance to deformation* of the Late Weichselian material is greater because the moisture content at a given pF value is lower and the resistance to deformation increases with decreasing moisture content. This is in line with the consistency description of the profile descriptions. The *structure stability tests* on *air-dried natural aggregates* demonstrated a clear discrimination between the Late Weichselian and the Holocene group. The stability of the Late Weichselian soil material is lower because of air explosion. This air explosion results from the virtual absence of organic matter within the Late Weichselian aggregates with their dense, highly reoriented and microheterogeneous microstructure and their non-continuous pore system. Air-dry conditions have frequently occurred in the periglacial Late Weichselian climatic conditions after deposition of the Late

Weichselian braided river sediments. The LG subgroup may not have experienced such conditions or not as frequently. The low structure stability already then has caused the above mentioned microstructure. The Holocene meandering river sediments have never become air-dry during their history. The structure stability is largely a function of OC and CL, sometimes in reverse order. For the Holocene Cal subgroup the combined effect of CL and OC (in the form of the inseparable clay/humus complex or mull humusform) has been documented. The frequently described positive influence of $CaCO_3$ on the structure stability has not been observed. On the contrary, within the Holocene Cal subgroup negative correlations of $CaCO_3$ with m.w.d., raindrop resistance and slaking susceptibility have been found. The *micro-tillage test* revealed that there are systematic differences between the Late Weichselian and Holocene groups although they are not statistically significant at 95% confidence limits because of the high standard deviations. Nevertheless the Late Weichselian soil material must be drier if the results of tillage are to be acceptable at the critical moisture content on the wet side. This corroborates the Atterberg limits and combined with the moisture characteristic explains the narrow range in moisture contents permitting acceptable tillage results ('Minutenböden'). Finally, the *hydraulic conductivity* which was reported to be very poor for the Late Weichselian soils proved to have benefitted considerably from the recently improved drainage during reallotment schemes of large areas with Late Weichselian soils. The saturated hydraulic conductivity is still significantly lower for the Late Weichselian soils but never falls below 0.1 m/day. The effect of land use is very marked and the effect of conducting macropores (worm holes) is also spectacular. An interesting result from the hydraulic conductivity studies pertains to *the land quality water availability*. Previously it was established, based on core samples and aggregates, that the amount of moisture that could be stored between pF2 and pF4.2 was lower for the Late Weichselian soils. Also capillary rise plays an important role in the land quality moisture availability, however. The less pronounced formation of horizontal planar voids because of the extremely dense packing of the Late Weichselian soil material in its undisturbed field structure allows a less interrupted supply of capillary moisture and thus moisture deficits in the Late Weichselian soils occur later in the season and are less severe than in the Holocene fluvial clay soils. Almost all of the mentioned physical characteristics depended strongly on CL and OC,

sometimes in reverse order and for the Late Weichselian soils frequently SA instead of CL. The differences in particle size distribution and organic matter content, quality and distribution between the Late Weichselian and Holocene fluvial Rhine soils are largely responsible for the observed differences in physical properties and behaviour. For agricultural use the differences in microstructure, the dense, rigid character, the chemical characteristics and the strong lateral variation of the Late Weichselian deposits add to their inferior quality compared with the Holocene fluvial soils.

5. DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

In the previous chapters, data on differences and similarities between Late Weichselian and Holocene Rhine soils have been presented. Aspects covered included differences in stratigraphy, caused by the sedimentation history (*age* and *sedimentation mechanism*). Late Weichselian braided river sediments, predominantly of pre-Allerød age, occur in the abandoned floodplains of the former northern branch of the Rhine (around Montferland) and of the former southern branch of the Rhine (Niers valley south of the Reichswald). Palynological age determinations (Koenigs, 1949; Schelling, 1951; Pons, 1957; Teunissen and Van Oorschot, 1967; Teunissen and De Man, 1981 and own results), plus the absence (even micromorphologically) of Allerød volcanic fragments in the reference profiles except for some topsoils, corroborate the conclusions concerning age of the sediments of Schelling (1951) and Pons (1957). In the present day Rhine floodplain, Allerød volcanic pumice fragments have been found in reference profile A16 (Millingen - West Germany) throughout the upper metre of 'Hochflutlehm' and in the underlying sand. Pumice fragments have been reported as far south as Bonn by Schröder (1979) and Verbraeck (1970, 1985) mentioned pumice layers covered with Holocene sediments as far west as map sheet 38 E (Gorinchem). In Germany, Brunnacker (1978) and Thoste (1974) investigated the formation and degradation of the Late Weichselian Low Terrace; Verbraeck (1985) has documented 6 phases in the Kreftenheye formation, of which the last three pertain to the Weichselian and Late Weichselian period. The non-calcareous Holocene reference soils investigated in this thesis can be assigned to a pre-Roman sedimentation phase that occurred some 2000 years ago (Pons 1957, Havinga 1969; Havinga and Op 't Hof, 1975, 1984). The calcareous Holocene soils investigated can be identified as young Rhine sediments (about 500-200 years old). However, in the fluvial area the scarcity of datable sites makes exact dating of the deposits very difficult, especially in the vicinity of a terrace crossing, where also landscape morphology is of little help.

The *stratigraphy* of the Late Weichselian deposits generally demonstrates fining upward (Reineck and Singh, 1973: Leeder, 1973). Stratified gravelly deposits (I) are overlain by stratified coarse sands (IIa) without gravel, in turn overlain by fine sands with or without clayey laminae (IIb). The overlying 'Hochflutlehm' deposits (III) are generally finer-textured and

abruptly overly deposit II. Deposit III forms the surface layer in the abandoned floodplains or is covered by a thin veneer of Holocene clayey deposits (IV) near the terrace crossing.

The *textural characteristics* of deposit III show a bimodal particle-size frequency distribution, less silt, coarser sand, a higher clay/fine silt ratio and a worse sorting than the calcareous Holocene soils. The organic matter content is very low below the topsoil and its quality is poor, being dominated by aromatic hydrocarbons. In contrast, the organic matter content below the topsoil in calcareous Holocene soils is higher and of a better quality, dominated by carbohydrates (Halma *et al.*, 1978).

Carbohydrates also dominate in topsoils of both Late Weichselian and Holocene soils, because of recent organic manuring. Presumably, the Late Weichselian sediment contained little organic matter (Schröder, 1979); this implies that recent additions of organic matter envelop microaggregates, whereas in Holocene soils mineral material and organic material are sedimented in combination, giving rise to intimate mixtures with the organic matter even between primary elements like clay platelets.

Mapping of the Late Weichselian deposits even at very detailed scales is extremely difficult, because of short-range variation in texture horizontally and with depth, caused by the sedimentation mechanism (see cross sections). The legend was based on present-day hydromorphic features, because they correspond best with the visible topography and microtopography. This leads to well-drained coarse- to medium-textured soils (HB); imperfectly drained mottled to strongly mottled medium- to fine-textured soils (MB), and poorly-drained medium to fine-textured soils (LG). This corroborates the distinctions of Schelling (1951) and Pons (1957). The recent soil maps of the Dutch Soil Survey Institute and the 'Geologisches Landesamt Nordrhein-Westfalen' also use hydrology, but at a lower level and/or as part of the recognized soil formation (Paas *et al.*, 1984); Rosing, 1984). Even on very detailed soil maps the variation within the mapping units remains considerable and influences the agricultural suitability on farm level. In order to cover these variations many Late Weichselian profiles were investigated and reported in this thesis.

To ascertain the *soil formation* of the various soils, morphological observations were made from the macroscale (profile descriptions with observations on macrostructure, macro porosity, hydromorphic features, consistency and human activity) to the microscale (micromorphology, thin

sections) and even submicroscopically (SEM). The soil-forming processes inferred from profile descriptions and thin section studies included: weathering of silicate minerals; physical reorientations resulting from stress and friction; decalcification; clay and groundmass illuviation; gleying and pseudogleying; biological activity, and human activity. A study of the *clay mineralogy* (clay minerals, Al-interlayering and total chemical analysis of the clay fraction) and of the *chemical aspects* ($CaCO_3$ content, pH-KCl, organic matter content and composition, cation exchange capacity, base saturation, complex composition and extractable iron and aluminium) in combination with the soil *morphological aspects* enables the recognition of differences and similarities between processes operative in Late Weichselian and Holocene soils and their subgroups.

Although the Late Weichselian soils are more weathered than the Holocene soils, the mineralogy of the *parent material* is similar. This is also illustrated by similar particle densities. This corroborated the data of Schröder (1979), Verbraeck (1970, 1985), Van der Meene (1978) and Berendsen (1982). Micromorphologically, the most important differences between Late Weichselian and Holocene soils are found in the *microstructure*: Holocene soils have dominantly an asepic or in case of the Cal soils a crystic plasmic fabric, which results in a friable consistence, whereas Late Weichselian soils have abundant plasma reorientations in those parts that have not been biologically reworked, leading to a firm to very firm consistence. The reason for the microstructure of the Late Weichselian soils is thought to be the periglacial circumstances during the Late Weichselian. Melting and freezing alternated and plastic flow patterns followed the melting of the frozen topsoil. Such features have been described by authors such as Fitzpatrick(1956), Van Vliet-Lanoë (1985), Van Vliet-Lanoë and Langohr (1981), Langohr and Pajares (1983), Langohr and Van Vliet-Lanoë (1979), Fox (1979, 1984) and Fox and Protz (1982) as leading to fragipans or fragipan-like densities in soil horizons (Payton, 1983; Smalley and Davin, 1982). The Holocene and Late Weichselian hydromorphic conditions which transformed several Late Weichselian soils with reasonably good drainage into the present-day mottled or even grey soils has doubtless added to the density, but are not primarily responsible for the density because the microstructural features are also still recognizable in present-day well-drained brown soils, despite their continuous strong bioturbation. The Late Weichselian soils have been completely decalcified (synsedimentarily) and

have low to very low pH-KCl values except for some local occurrences of $CaCO_3$. Jongmans and Miedema (1986b) concluded that there was *Late Weichselian decalcification* and bioturbation in Late Weichselian Rhine deposits. A similar age is postulated for lime gyttjas in coversand (Van de Westeringh, 1978, Buurman, 1970) and in Late Weichselian Rhine deposits (Van der Meene, 1978). Lime gyttjas of Late Weichselian age were also found in the palynologically analysed profiles (section 2.5.). The Holocene non-calcareous soils have been decalcified completely or to great depth, partly synsedimentarily in the finer-textured variants or through the annual rainfall surplus in autumm, winter and spring.

Clay illuviation occurs to a similar extent in both well-drained brown and imperfectly-drained mottled Late Weichselian soils. This has been documented by Miedema *et al.* (1978) for the Rhine soils, sometimes even in soils that are at present poorly-drained. For the Meuse soils the same was documented by Miedema *et al.* (1983). The *subsequent pseudogleying and gleying* covers the clay illuviation features and may even lead to ferrolysis (Brinkman, 1970, 1979). No clay illuviation features are found in Holocene soils of the Meuse (De Bakker, 1965; Miedema *et al.*, 1983) and the Rhine (this thesis). The reported clay illuviation features in the older deposits of the 'Kromme Rijn' by Van der Voorde (1963) belong to groundmass illuviation phenomena.

The Late Weichselian deposits contained hardly any organic matter. Reduction of mineral deposits can only start after introduction of organic matter. The source of this organic matter must be the vegetation growing on these soils. As previously argumented these deposits data from the pre-Allerød period. In the Allerød period vegetation could develop on these soils thus providing sufficient otganic matter for reduction of the topsoils of the mineral deposits in the Late Dryas period. In this Late Dryas period the periodically melted and watersaturated topsoil underlain by frozen soil in the finer textured variants caused pseudogleying illustrated by a strong reduction in the topsoils (compare the observed albic E horizon, Fig. 36 and along the periglacial polygonal pattern , Fig. 13). When no organic matter is present, the mineral material remains oxidized even in watersaturated conditions as is illustrated in the subsoil of reference profile A7 (Siebengewald - Fig. 14B). The Holocene sediments result from deposition of riverloads consisting of erosion products mainly of topsoils containing organic matter and mineral particles. In the flowing water the suspended material, with organic matter adsorbed to the clay fraction and is oxidized.

After deposition in well-drained positions the initial reduction is followed by oxidation and biological activity homogeneously distributes the ironhydroxides, In case of deposition in poorly-drained positions intense reduction causes grey colours and oxidation(gleying) follows upon entering of air through pores resulting from vegetation.

The occurrence of the strong pseudogleying (albic E horizon, polygonal pattern- Fig 13; Fig. 36) thus points to Late Weichselian conditions, and hence clay illuviation is also Late Weichselian and fossil. This hypothesis was also put forward by Langohr and Pajares (1983) and Van Vliet-Lanoë and Langohr (1983) for silt deposits in Belgium and northern France. Hoeksema and Edelman (1960) postulated this hypothesis for the loess soils of South Limburg. Mücher (1986) considers the argillic horizon in West European loess as a Holocene soil formation following Holocene decalcification. As previously argumented it is likely that a large part of the decalcification is of Late Weichselian age. Schröder (1979) reports argillic horizons in Late Weichselian to Preboreal soils, but documents the lively controversy in German literature between the proponents of a Late Weichselian or a Holocene process of clay illuviation. Worldwide, a similar discussion has taken place: it has been reported in review articles on clay illuviation (McKeague, 1983; Fedoroff, 1972). Studies on soil formation in river-terraces are very common, because of the possibilities of relating soil formation to an established chronology. Comparisons are often hazardous because parent material and/or present or previous climatic conditions may be completely different. Yet, some recent investigations from Europe (Torrent, 1976; Chartres, 1983; Bornand, 1978; Cailler, 1977; Chrétien, 1986; Schröder, 1979) and North America (Thompson, 1983) document the presence of an argillic horizon in the low terrace deposits of Late Weichselian (Devensian, Wisconsin) age. Holocene datings of clay illuviation using archeological evidence are given by Van de Broek (1966) and Beckmann *et al.* (1986). Care should be taken, however, in interpretating the latter, as human influence may have strongly altered the original conditions (Slager and Van de Wetering, 1977). Sehgal *et al.* (1976) and Gombeer and d'Hoore (1971) demonstrated that a low dispersible clay content as well as a very low effective clay mobility occurred in udic soils in contrast to ustic soils. More such experimental pedogenetic research is needed to settle this argument. However, the farmer is not interested in knowing when the dense, reoriented microstructure was formed and the clay illuviation occurred.

He faces the problem of dealing with them.

The *clay mineralogy* of the Late Weichselian soils demonstrates smectites and vermiculites strongly interlayered with aluminium in the HB and the topsoils of the MB soils; such Al-interlayering is virtually absent in the LG and the Holocene CaO and Cal subgroups. These differences in clay mineral composition are reflected by the BaO contents of Ba-saturated clay separates, which are a measure of the *CEC of the clay fraction*. Significantly lower BaO contents also testify to the strongly Al-interlayered clays of the HB and MB subgroups. *Base saturation* is strongly variable, but averages below 80% for the Late Weichselian soils. Very low base saturations occur (below 50% or 35%) in the HB and MB soils. In agreement with the low pH-KCl values in the Late Weichselian soils, exchangeable H^+ and AL^{+++} may attain high values. Holocene soils are nearly saturated, with no exchangeable H^+ and Al^{+++}. Chemical analysis of the clay fraction substantiates the differences in clay mineralogy, CEC and base saturation. Calcareous Holocene Cal soils are characterized by high K_2O, MgO and CaO contents, low Al_2O_3 contents and a high Si/Al atomic ratio (also for the Holocene CaO). The Si/Al ratio is low for the Late Weichselian soils. The HB soils have high Al_2O_3 contents and low BaO contents.

Extractable Fe_2O_3 and Al_2O_3 contents do not allow a differentiation to be made between Holocene and Late Weichselian soils, as Schröder reported in 1979.

The *soil classification* (Soil Taxonomy, 1975; FAO-Unesco, 1974) clearly brings out the differences in soil formation. The Late Weichselian HB and MB soils are Alfisols (Luvisols) with occasionally even Ultisols (Acrisols). With hydromorphic features they belong to the aquic subgroups or even to the Aqualfs (Podzoluvisols) in case of strong pseudogleying. Most Holocene soils are Inceptisols (Cambisols); some are Mollisols (Phaeozems). Plaggen epipedons are found in Late Weichselian soils in moderately to well-drained positions, but not all sandier topsoils can be considered as plaggen epipedons (Jongmans and Miedema, 1986a; GLA, 1975 - sheet L4502 Geldern).

The *physical characteristics and behaviour* of Late Weichselian and Holocene soils and soil material demonstrate similarities and differences. Undoubtedly similar is the *particle density*, which corroborates the preceding conclusion of basically identical parent material. Clay mineralogical differences are responsible for the slightly lower *linear extensibility* (measured at pF2 and pF1 on condensates) of Late Weichselian

soil material. In natural structures (aggregates, cores, columns) the volume changes are strongly subdued in Late Weichselian soils because of their extremely dense packing as demonstrated by their microstructure (thin sections, SEM), resulting in low moisture storage at pF2. This effect was substantiated quantitatively for soil columns, in the significantly poorer development of horizontal planar voids in Late Weichselian soils, which positively influences the land quality moisture availability through uninterrupted capillary rise (Kooistra *et al.*, 1987). This contrasts with another property of Late Weichselian soils in their natural structure (aggregates/cores), where the extremely dense, rigid microstructure, reflected in a *high bulk density and low pore volume* agrees with the macroscopically observed firm to very firm consistence. This dense microstructure with a low porosity leads to a low moisture storage at pF2 for the Late Weichselian material. This microstructure is considered to be the result of the Late Weichselian conditions (freezing and thawing) as is indicated by Fitzpatrick (1956), Smalley and Davin (1983), Payton (1983), and others mentioned in the excellent review of Van Vliet-Lanoë (1985). This very dense microstructure at micro aggregate level contributes to lower moisture contents at various pF values for the Late Weichselian material, which lead to lower amounts of available moisture (AM) being stored between pF2 and pF4.2. High bulk densities have also been reported by Schröder (1979) from West Germany from well-drained Weichselian Rhine soils. These differences are very strongly discriminating, especially at the level of aggregates, and this points to the importance of microstructural aspects. When the volume of material investigated is increased (core samples) this difference is less striking, because additional influences such as biological activity and macro structural aspects influence the moisture characteristics. The improved drainage since about 1950-1960 of areas with dominantly Late Weichselian MB soils has resulted in increased worm activity and deeper rooting as well as in the development of a macrostructure as a result of stronger and more frequent drying. Although the *saturated hydraulic conductivity* of Late Weichselian soils measured in situ in field columns is still significantly lower than that of Holocene soils, the level of hydraulic conductivity in Late Weichselian soils is no longer critical, as described by Koenigs (1949), Schelling (1951) and Pons (1957).

The differences in 'stugheid' (resistance to deformation - Koenigs, 1949; Schelling, 1951 and Pons, 1957) are no doubt related to the dense

microstructure and firm consistence. The described difference has not been proved unambiguously by tests (shear strength, unconfined compression tests) quantitatively because of the small numbers of samples analysed and a lack of suitable methods to measure such a complex property. Yet, the true Late Weichselian members (HB and MB) demonstrated a certain shear strength of condensates at higher moisture contents than the Holocene materials (and LG). Additional research and improved methodology are required.

The measurements of the *structural stability of natural aggregates* (wet sieving, end-over-end shaking, raindrop resistance and slaking test) demonstrated very convincingly that Late Weichselian aggregates, when air-dried,are strongly susceptible to destruction. This is because of the effect of air explosion (Janse and Koenigs, 1963; Bolt and Koenigs, 1972; Koenigs, 1961, 1972; Stroosnijder and Koorevaar, 1972; Brewer and Blackmore, 1956; Lafeber, 1964, 1974) which is caused by a high degree of reorientation and the high aggregate bulk density, the low pore volume and the absence of sufficient amounts of stabilizing organic matter of a good quality and favourable distribution (Emerson, 1959; Halma *et al.*, 1978). When the aggregates are carefully moistened and desorbed to pF2 without structural deterioration, then the results of the same tests are no longer significantly different. This agrees with experimental results on the susceptibility to slaking and subsequent erosion of loess soils (Koenigs, 1975). The extreme drying experienced by the Late Weichselian soils in the Late Weichselian period and the repeated freezing and melting caused the extreme density as well as the reorientation patterns observed in the microstructure (Fig. 29). Methods to improve the poor structure stability include the application of sufficient organic matter of good quality but also, and equally importantly the thorough incorporation of mineral and organic material to great depth. This cannot be done mechanically, but only biologically (e.g. by earth worms - Hoeksema, 1953; Hoogerkamp *et al.*, 1983, and Van de Westeringh, 1972). The farming system thus has to maintain adequate levels of populations of the meso- and macrofauna, but this should also be supplumented by regional measures such as improving the drainage. The role of $CaCO_3$ is questionable. For the Late Weichselian soils, liming is needed to raise the low pH and to improve the cation composition on the soil complex and on the organic matter. In the Holocene calcareous soils, higher levels of $CaCO_3$ did not correlate with improved structure stability; this agrees with the result obtained by Kemper and Koch (1966).

The *soil tillage tests* (micro-tillage test, Atterberg limits) on aggregates did not all yield statistically very significant results. This is because of large variety in measurements (the result partly of differences in land use and partly of other variables, such as depth, which have not been analysed fully). Also, too few samples were investigated. The field situation needs to be monitored by field experiments, to validate the following tentative conclusions. The Atterberg limits indicate significant differences between Late Weichselian and Holocene soil material. The plasticity range for Late Weichselian material is narrower and in contrast with the Holocene soil material, this material lacks a non-sticky plasticity range. The micro-tillage test revealed systematic differences between Late Weichselian and Holocene natural aggregates which were not statistically significant at 95% level, however, because of the large standard deviations. The Late Weichselian material must be drier for acceptable tillage results at the critical moisture content on the wet side. Higher moisture contents cause puddling related to the highly reoriented microstructure. *Statistical analyses* confirmed the existence of significant differences between the Late Weichselian and Holocene soil groups and subgroups. The 5 explanatory variables (clay, silt, sand, organic carbon and $CaCO_3$) were found to contribute strongly to the variance explained. Clay and organic carbon, sometimes in alternate order and sometimes with sand instead of clay, explain 70-90% of: the variance in particle density; linear extensibility, moisture characteristic from pF1 through pF4.2, stability data (mean weight diameter, raindrop resistance, slaking class of air-dried samples); and the result of the micro-tillage test (moisture content at UTL). In general, the Holocene samples have a higher variance explained than the Late Weichselian samples. The level of variance explained in the bulk density and pore volume data of cores and aggregates is much lower (40-60%), and the difference in variance explained between Late Weichselian and Holocene samples is much larger (10-30% and 45-75%, respectively). This is the result of other factors not taken into account, e.g. level of biological activity, drainage position, depth, land use. The findings for the stability data on pF2 samples were similar. The striking differences in variance explained with regard to available moisture between pF2 and pF4.2 for core samples and aggregate samples illustrate that the material characteristics are most clearly expressed in the case of the smaller aggregate samples i.e. result from particle to particle interaction (Van Oort, 1979, 1980).

This corroborates the results of the discriminant analyses (Table 78), where discrimination between the Late Weichselian and Holocene groups based on the physical characteristics is best for the aggregates (AGGR.DAT). Aggregate stability (STAB.DAT) and linear extensibility of condensates (SWELL.DAT) also discriminate very well. The Atterberg limits (ATT.DAT) discriminate the Late Weichselian group better than the Holocene group. The core sample characteristics of the Late Weichselian group is very characteristic in contrast to that of the Holocene group (CORE.DAT).

Table 78. Correct classification (%) according to discriminant analysis of the physical data sets.

GROUPING	Weichselian	Holocene
DATA SET		
SWELL.DAT	77	88
ATT.DAT	87	60
AGGR.DAT	95	85
STAB.DAT	82	77
CORE.DAT	89	31

In conclusion, it is clear that the Late Weichselian soils and soil material differ in many aspects from the Holocene soils and soil material. Late Weichselian soils and soil materials have less favourable properties for agriculture than Holocene soils and soil material *because of differences in textural characteristics, and the quantity, quality and distribution of organic matter.*

Advanced polygenetic soil formation is responsible for differences in clay mineralogy and chemical properties such as CEC-clay , pH-KCl and base saturation. The very dense, rigid microstructure and highly reoriented plasmic fabric of the Late Weichselian deposits also result from soil formation, and negatively affect the bulk density, pore volume and water retention characteristics. These naturally compacted soils are beyond the acceptable limits of compaction (Boone, 1986). This also holds true for basal tills (Schwan *et al.*, 1977) presumably through similar mechanisms. The argillic B-horizon in the Late Weichselian soils contributes only slightly to the differences in physical properties. The structure stability (slaking susceptibility) is weak in the Late Weichselian soils, especially after prolonged dry periods and under arable land. Tillage properties of Late Weichselain soils are less favourable as regards a narrower range in moisture content for acceptable tillage results, a lack of non-sticky plasticity and at higher moisture contents puddling because of the highly reoriented plasmic fabric.

To improve the Late Weichselian soils it is imperative to supply organic matter of good quality and maintain high levels of biological activity (meso- and macrofauna) to incorporate mineral and organic matter thoroughly to great depths. Liming is needed to raise the low pH and restore a favourable complex composition. Grassland use is recommended, either permanent grassland or ley in the crop rotation for the MB soils. The HB soils have the best potential for arable cropping, as is well known and practised. Field experiments and monitoring of field situations are needed, to validate the above conclusions and to obtain data on the impact of the limitations of relevant land qualities for different land utilization systems.

6. SUMMARY

Late Weichselian braided river deposits and Holocene meandering river deposits of the Rhine in the Netherlands are studied and compared. The sedimentation profile demonstrates four different deposits: stratified very gravelly coarse sands and sandy gravels (I) from a gravelbar system are overlain by stratified coarse sands without gravels, passing into stratified finer sand sometimes with clayey laminae (II), in turn overlain by loamy sand to clay-textured deposits (III). Deposits I, II and III are Late Weichselian. The lateral and vertical variations point to braided river sediments, dated palynologically as Late Weichselian.

Detailed soil mapping (1:10,000) is very difficult because of these variations; the best results are obtained with a legend based on hydrology. This enables a distinction to be made into well-drained brown soils (HB), imperfectly drained mottled soils (MB) and poorly drained grey soils (LG) of varying textures in the Late Weichselian deposits. The Holocene clayey deposits (IV) overlie the Late Weichselian deposits close to the terrace crossing as a thin veneer, further West this deposit from a meandering river shows lateral variations between levees and backswamps, plus vertical variations, notably within the levee soils. The Holocene soils have been subdivided into somewhat older non calcareous soils (Ca0) and young calcareous soils (Ca1) varying in texture and hydrology. Based on the field investigations, 16 Late Weichselian reference profiles and 6 Holocene reference profiles are studied. For Late Weichselian soil material, particle size distribution demonstrates a bimodal frequency distribution of particle size, less silt, coarser sand, a higher ratio of clay to fine silt, and a worse sorting than in the Holocene soil material (Chapter 2).

Conclusions on soil formation are drawn from macro- and micromorphology, clay mineralogy and soil chemistry. The intensity and chronology of soil-forming processes like weathering, decalcification, clay illuviation and groundmass illuviation, pseudogleying and gleying, biological activity, human activity and physical reorientations resulting from stress and friction are documented and discussed for the Late Weichselian and Holocene reference profiles. The clay mineralogy of the Late Weichselian soils demonstrates aluminium-interlayered smectites and vermiculites in the HB profiles and in the upper layers of the MB profiles, in contrast with the LG profiles and the Holocene profiles. The Late Weichselian soils demonstrate

lower pH-KCl values (around 4.5) than the Holocene soils (6.0-7.5), low amounts of organic matter which is of poor quality and differently distributed, lower CEC and base saturation, and appreciable amounts of exchangeable Al^{+++} and H^{+}. The advanced soil formation in Late Weichselian soils has produced soils with an argillic horizon (HB and MB: Alfisols/Luvisols) with occasionally low to very low base saturation (Ultisols/Acrisols) with strong expression of pseudogleying in the MB soils (Aqualfs/Podzoluvisols). The LG soils are Aquepts/Aquolls or Eutric Cambisols/Gleysols. The Holocene soils are Inceptisols/Cambisols or Mollisols/Phaeozems (Chapter 3).

Data on the physical characteristics and behaviour of ground fine earth, natural soil aggregates, core samples and soil columns are discussed. Late Weichselian and Holocene soil material have the same particle density; this agrees with their essentially similar mineralogy. The difference noted in clay mineralogy is also reflected in the slightly lower linear extensibility of the Late Weichselian samples. However, the very dense, rigid microstructure and very firm consistence limits the volume changes and thus the elasticity of the soil; this is concluded from the measured and calculated linear extensibility of condensates and natural aggregates. In the field this leads to a better capillary rise because of less horizontal cracks and therefore the land quality moisture availability is better for the Late Weichselian soils than for the Holocene soils despite their lower available water content between pF2 and pF4.2. There are very clear quantitative differences between Late Weichselian and Holocene soil materials in their natural structure. Aggregates and cores of Late Weichselian material have high bulk densities, low pore volumes and low moisture contents at the various pF values. The differences are more marked in the natural aggregates than in the cores and relate to particle to particle interaction (microstructure). The low available moisture between pF2 and pF4.2 for the Late Weichselian aggregate samples is strongly discriminating in contrast to that of core samples. Data on structure stability indicate a lower structure stability for the Late Weichselian samples when determined from air-dried material, but hardly any difference when structure stability is determined at pF2. Air explosion has been and still is an important mechanism in the structural deterioration of Late Weichselian soils. In the periglacial conditions of the Late Weichselian extreme drying (freezing) commonly occurred followed by sudden wetting

(melting). Soil tillage characteristics demonstrate the absence of a non-sticky plasticity range and a narrower plasticity range for the Late Weichselian material, in contrast to the Holocene material. The results of the microtillage test indicate that Late Weichselian soils have to be drier to give a desirable tilth, but the large standard deviations preclude statistical significance at the 95% confidence level. Such large standard deviations are also noted for measurements of soil strength and air permeability; these also showed the less favourable character of the Late Weichselian material. The quantified differences in physical characteristics and behaviour between Late Weichselian and Holocene samples are statistically highly significant, and the variance can largely be explained by textural characteristics and organic carbon. The linear extensibility, Atterberg limits and aggregate characteristics strongly discriminate between Late Weichselian and Holocene fluvial Rhine soils, and the results from core samples are very characteristic for Late Weichselian soils as demonstrated by discriminant analysis. Saturated hydraulic conductivity is significantly recorded are no longer critical, because of the strongly increased earthworm activity following the recent improvement of the drainage of large areas (Chapter 4).

The longer period of soil formation and, even more the dramatic processes in the Late Weichselian period mean that the Late Weichselian soils have advanced soil formation (clay mineralogical changes, chemical changes, microstructure changes, clay illuviation). Their less favourable physical characteristics and behaviour (structural stability and tillage behaviour) compared to Holocene soils are caused by the differences in texture, quantity, quality and distribution of organic matter and the very dense highly reoriented microstructure. The MB soils should be used for permanent grassland or ley is recommended in the crop rotation, to increase levels of biological activity, organic matter and incorporation of mineral and organic material to greater depth. This seems the only way to lasting improvement of these imperfectly and poorly drained Late Weichselian MB soils which are compacted by natural soil-forming processes that have not been counteracted by biological activity. Very recently improved drainage of large areas of Late Weichselian MB soils has already increased the saturated hydraulic conductivity to non-critical levels through increased worm activity to 1-2 metres depth (Chapter 5).

7. SAMENVATTING

Rijnafzettingen in Nederland van een verwilderd riviersysteem uit het Laat Weichselien en van een meanderend riviersysteem uit het Holoceen zijn bestudeerd en vergeleken. Dwarsdoorsneden demonstreren 4 verschillende afzettingen: gelaagde grindige grove zanden en grofzandig grind (I) van een grindbanken systeem zijn overdekt door gelaagde grove tot fijne zanden zonder grind soms met dunne kleilenzen (II) met daarboven zandige tot kleiige afzettingen (III) uit het Laat Weichselien. De laterale en verticale variaties van de afzettingen I, II en III duiden op een verwilderd riviersysteem dat via pollenanalytisch onderzoek als Laat Weichselien is gedateerd. Bodemkartering zelfs op een schaal van 1:10.000 van deze afzettingen uit het Laat Weichselien is zeer moeilijk vanwege deze laterale en verticale variaties. De meest bevredigende resultaten zijn bereikt met een legenda gebaseerd op hydrologie. Op die wijze kan men goed gedraineerde hoge bruine gronden (HB), imperfect gedraineerde middelhoge gevlekte of bonte gronden (MB) en slecht gedraineerde lage grijze gronden (LG) van verschillende zwaartes onderscheiden binnen de gronden uit het Laat Weichselien. Dicht bij de terrassenkruising liggen dunne Holocene afzettingen (IV) op de afzettingen uit het Laat Weichselien. Verder naar het Westen wordt het Holocene pakket dikker en vertoont het de laterale differentiatie tussen oeverwallen en kommen die kenmerkend is voor afzettingen van een meanderende rivier. Binnen de stroomruggronden treden ook verticale variaties op. De bemonsterde Holocene gronden zijn te verdelen in oudere kalkloze gronden (Ca0) en jonge kalkhoudende gronden (Ca1) met variaties in zwaarte en hydrologie. Op basis van veldonderzoek zijn 16 referentieprofielen van de afzettingen uit het Laat Weichselien en 6 referentieprofielen van de Holocene afzettingen bestudeerd en vergeleken. De afzettingen uit het Laat Weichselien demonstreren een tweetoppige korrelgrootteverdeling, minder silt, grover zand, een hogere lutum/slib verhouding en een slechtere sortering in vergelijking met de Holocene afzettingen (Hoofdstuk 2).

De conclusies van de bodemvorming zijn gebaseerd op macro- en micromorfologisch, kleimineralogisch en chemisch onderzoek. De intensiteit en chronologie van bodemvormende processen als verwering, ontkalking, kleiinspoeling en grondmassa inspoeling, pseudogley en gley, biologische

activiteit, activiteit van de mens en plasma herorientaties ten gevolge van fysische processen van druk en frictie in de referentieprofielen uit het Laat Weichselien en het Holoceen zijn beschreven en besproken. De kleimineralogie van de gronden uit het Laat Weichselien toont smectiet en vermiculiet met aluminium tussenlagen in de HB profielen en de bovenste horizonten van de MB profielen, in tegenstelling tot de LG profielen en de Holocene profielen. De gronden uit het Laat Weichselien worden daarnaast chemisch gekenmerkt door lagere pH-KCl waarden (rond 4,5) dan de Holocene gronden (6,0-7,5), lagere gehalten aan organische stof van een slechtere kwaliteit en een ongunstiger verdeling dan in de Holocene gronden, een lagere CEC en basenverzadiging en aanzienlijke hoeveelheden uitwisselbaar aluminium en waterstof. De intensieve bodemvorming in de HB en MB gronden uit het Laat Weichselien heeft geleid tot gronden met een briklaag (argillic horizon). Daardoor worden deze profielen geclassificeerd als Alfisols/Luvisols, soms met een zo lage basenverzadiging dat het Ultisols/Acrisols zijn en met in de MB profielen uitgesproken pseudogley invloed (Aqualfs/Podzoluvisols). De LG profielen zijn Aquepts of Aquolls/Eutric Cambisols of Gleysols. De Holocene profielen zijn Inceptisols/Cambisols of Mollisols/Phaeozems (Hoofdstuk 3).

Data over de fysische eigenschappen en het fysisch gedrag van gemalen grond, natuurlijke bodemaggregaten, ringmonsters en bodemkolommen zijn besproken. De dichtheid van de vaste fase verschilt niet tussen bodemmateriaal uit het Laat Weichselien en het Holoceen; dit is in overeenstemming met de vergelijkbare mineralogische samenstelling. Het verschil in kleimineralogie uit zich in een iets kleinere lineaire zwel van de monsters uit het Laat Weichselien. De zeer dichte, niet elastische microstructuur en de specifieke consistentie ('firm to very firm') verhindert dat volume veranderingen tot uitdrukking komen. Dit kon worden afgeleid uit de gemeten en berekende lineaire zwel van condensaten en natuurlijke aggregaten. In het veld leidt dit tot een betere capillaire opstijging door minder horizontale scheurvorming, waardoor de vochtbeschikbaarheid van de gronden uit het Laat Weichselien beter is dan van de Holocene gronden, ondanks de geringere hoeveelheid beschikbaar vocht tussen pF2 en pF4,2. Materiaal met een natuurlijke bodemstructuur uit gronden van het Laat Weichselien en het Holoceen vertoont quantitatief duidelijk aantoonbare verschillen in fysische eigenschappen. Natuurlijke bodemaggregaten en ringmonsters van het Laat

Weichselien hebben in vergelijking met Holocene monsters een hoge dichtheid van de grond, een laag porienvolume en lage vochtgehaltes bij de verschillende pF waarden. De verschillen zijn uitgesprokener naarmate het bemonsterde volume afneemt (aggregaten t.o.v. ringmonsters) en zijn een gevolg van interacties op deeltjes niveau (microstructuur). De hoeveelheid beschikbaar vocht tussen pF2 en pF4,2 van monsters uit het Laat Weichselien is voor aggregaten duidelijk kleiner dan van monsters uit het Holoceen, terwijl een dergelijk verschil niet overtuigend kon worden aangetoond in ringmonsters. Structuurstabiliteits karakteristieken van aggregaten uit gronden uit het Laat Weichselien tonen alleen een geringere structuurstabiliteit in vergelijking met Holocene aggregaten indien deze bepaald is aan luchtdroge aggregaten. Voorzichtig voorbevochtigde aggregaten (pF2) vertonen nauwelijks verschillen. Luchtexplosie is een belangrijke oorzaak voor het structuurverval van gronden uit het Laat Weichselien reeds in de periglaciale omstandigheden van het Laat Weichselien. Extreme uitdroging door vorst en plotselinge herbevochtiging bij het smelten kwam geregeld voor in de periglaciale omstandigheden van het Laat Weichselien. De afwezigheid van plastische vervormbaarheid zonder kleef en een nauwer vochttraject van plastische vervormbaarheid bij materiaal uit het Laat Weichselien dan bij materiaal uit het Holoceen zijn van belang voor de grondbewerking. De resultaten uit de 'micro tillage test' suggereren dat het materiaal van gronden uit het Laat Weichselien verder moet uitdrogen om een aanvaardbaar grondbewerkingsresultaat te geven dan Holoceen materiaal. Door grote standaardafwijkingen kon dit echter niet met 95% betrouwbaarheid worden geconcludeerd. Door het voorkomen van grote standaardafwijkingen konden de minder gunstige eigenschappen van de gronden uit het Laat Weichselien met betrekking tot afschuifweerstand en luchtdoorlatendheid niet met 95% betrouwbaarheid worden geconcludeerd. De quantitatieve verschillen in fysische eigenschappen en fysisch gedrag van monsters van gronden uit het Laat Weichselien en uit het Holoceen zijn statistisch zeer significant en de variatie kan grotendeels worden verklaard door textuur karakteristieken en organische stof. De lineaire zwel, Atterbergse waarden en aggregaat eigenschappen discrimineren sterk tussen fluviatiele Rijnafzettingen uit het Laat Weichselien en het Holoceen, terwijl de resultaten van de ringbemonstering zeer karakteristiek zijn voor de gronden uit het Laat Weichselien zoals bleek uit discriminant analyse. De verzadigde waterdoorlatendheid, gemeten aan ongestoorde grondkolommen, van de gronden

uit het Laat Weichselien is significant lager dan die van de Holocene gronden, hoewel de gemeten minimum waarden niet meer problematisch zijn. Dit komt door de sterk toegenomen wormactiviteit na grootschalige verbetering van de ontwateringstoestand tijdens ruilverkavelingen in gebieden met imperfect gedraineerde (MB) gronden uit het Laat Weichselien (Hoofdstuk 4).

De langere periode van bodemvorming en met name de dramatische processen in het Laat Weichselien veroorzaken de intensieve polygenetische bodemvorming in de gronden ui het Laat Weichselien (veranderingen in kleimineralogie, chemische veranderingen, veranderingen in microstructuur, kleiinspoeling. De ongunstiger fysische eigenschappen en het ongunstiger fysisch gedrag vergeleken met Holocene gronden worden veroorzaakt door verschillen in textuur, hoeveelheid, kwaliteit en verdeling van organische stof en de zeer dichte, niet elastische microstructuur met veel herorientaties. De MB gronden uit het Laat Weichselien zouden gebruikt moeten worden als permanent grasland of als bouwland met regelmatige kunstweide ter bevordering van het niveau van biologische activiteit, het gehalte aan organische stof en de menging tot grote diepte van mineraal en organische materiaal. Dit lijkt de enige manier tot blijvende verbeting van deze imperfect en slecht gedraineerde MB gronden uit het Laat Weichselien die door natuurlijke bodemvormende processen verdicht zijn, terwijl biologische regeneratie niet heeft plaatsgevonden. De recentelijk verbeterde ontwateringstoestand van grote gebieden met MB gronden heeft door een verhoogde wormactiviteit tot 1-2 meter diepte de verzadigde waterdoorlatendheid al verhoogd tot niet langer problematische waarden. (Hoofstuk 5).

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APPENDICES

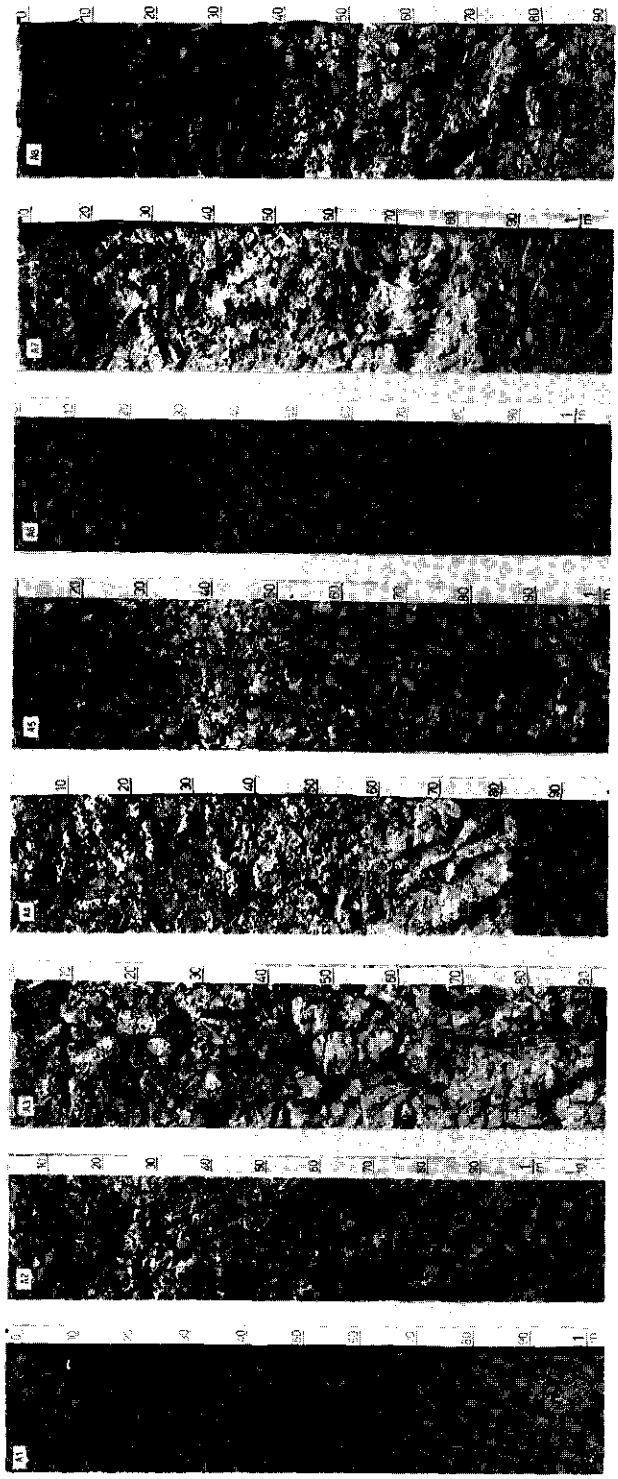


Fig. 58. Late-Weichselian reference profiles A1 t/m A8.

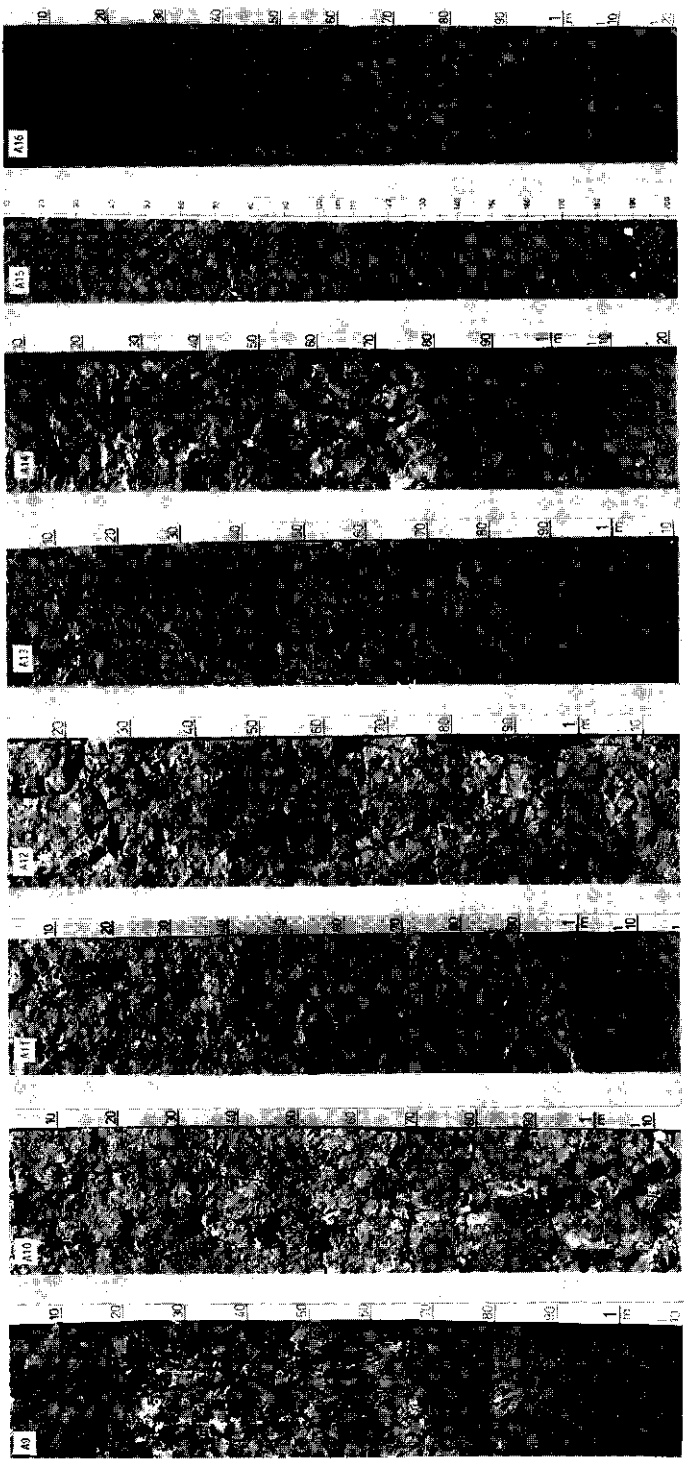


Fig. 59. Late Weichselian reference profiles A9 t/m A16.

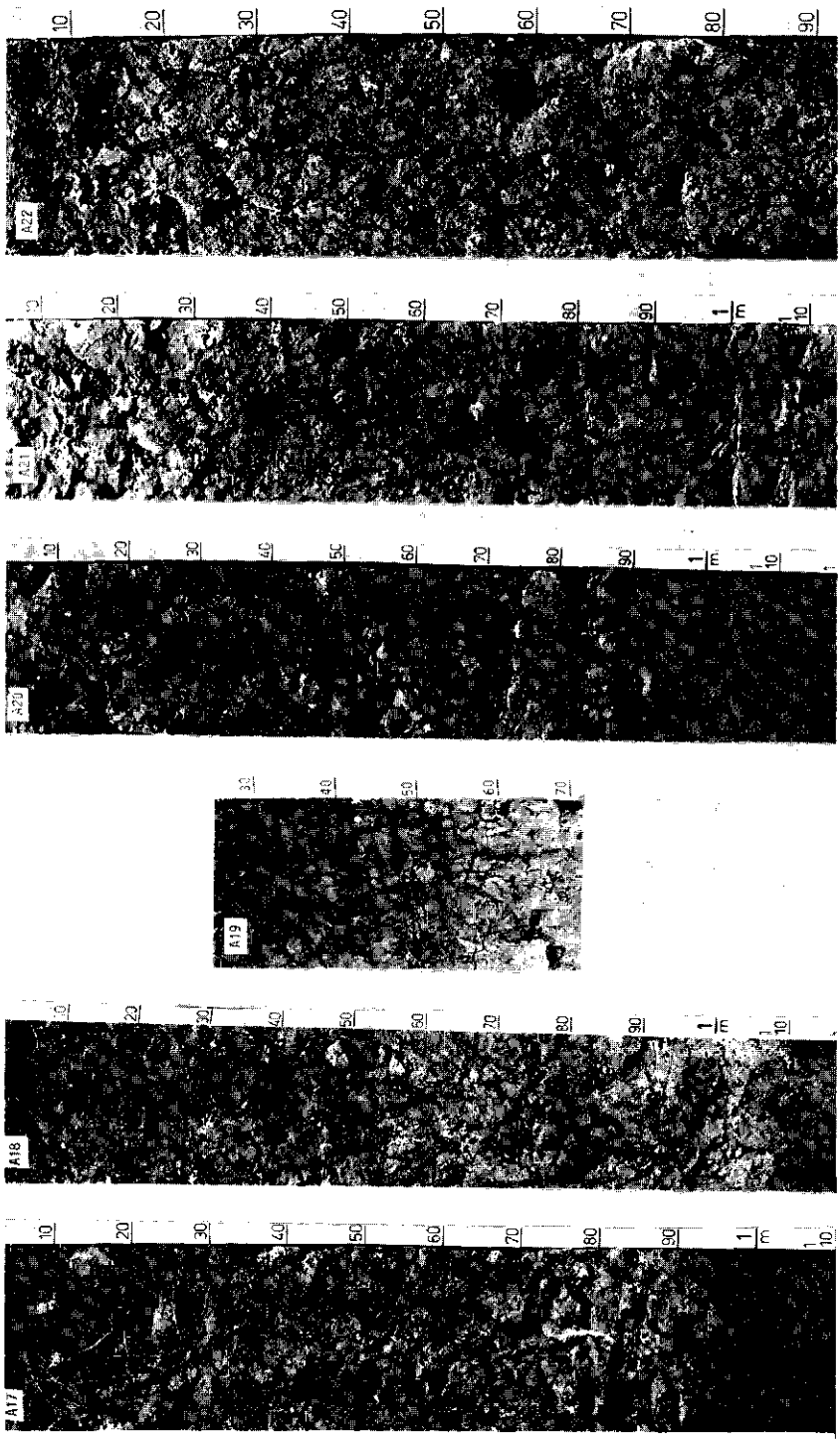


Fig. 60. Holocene reference profiles A17 t/m A22.

A P P E N D I X A

REFERENCE PROFILES

a. Profile description (according to FAO, 1977)
b. Particle size distribution
c. Chemical data (according to Begheijn, 1980)
d. Total chemical composition of the clay fraction (according to Begheijn, 1980)
e. Physical characteristics (horizon averages and averages of core samples)
f. Micromorphological observations (according to Brewer, 1964; Bullock *et al.*, 1985 was not yet available at the time of description).

Climatic data for all reference profiles.

Climatic data De Bilt (average 1951-1980)

	j	f	m	a	m	j	j	a	s	o	n	d	year
temperature (°C)	2.0	2.3	4.8	8.0	12.1	15.2	16.6	16.4	14.0	10.3	5.8	3.2	9.2
precipitation (mm)	66.6	50.3	51.3	52.3	54.1	69.5	76.8	88.2	64.9	68.9	74.7	78.6	796.2
evaporation (mm)	2	13	42	71	105	119	111	90	57	25	7	1	642

Key to semi quantitative micromorphological presentation

Symbol	term		Group of features
– – – –	faint		skeleton grains, plasma
———	distinct		reorientations, pedorelicts
▬▬▬	prominent		sedimentary relicts
– – – –	few		voids
———	common		redistributions, concentrations, bio/lithorelicts
▬▬▬	many		except illuviation phenomena
– – – –	weak	(0.3-1.0% v/v)	illuviation phenomena of
———	medium	(1.0-4.0% v/v)	clay and groundmass
▬▬▬	strong	(4.0-7.0% v/v)	components (quantified by point counting)
▬▬▬	very strong	(> 7.0% v/v)	quantitative limits cf. Miedema and Slager (1972)

A.1. HEUMEN I

a. Profile description

General data

1. Location: Topographical map of the Netherlands, scale 1:25.000 (1967), sheet 46A, coordinates: N 420.740; E 186.150.
2. Date of description: 26-8-1974.
3. Described by: Th. Pape and E. van Engelen.
4. Mapping unit: HL 1.

Soil site characteristics

1. Classification:
   a. according to FAO-Unesco (1974): Orthic Luvisol.
   b. according to the Soil Taxonomy (1975): Plaggept.
   c. according to De Bakker and Schelling (1966): Tuineerdgrond.
2. Land use: fallow during the previous month, preceded by winter barley.
3. Geology: coarse-textured Late Weichselian Rhine deposit.
4. Physiography: higher part of a weakly undulating landscape of a braided river system.
5. Relief: subnormal.
6. Slope: level to nearly level, class A.
7. Altitude: 10.5 m + NAP (Amsterdam Ordnance Datum).
8. Hydrology:
   a. Soil drainage class: well drained
   b. Groundwater level:
      presumed highest: 100 cm below the soil surface
      presumed lowest : 250 cm below the soil surface
      actual : 250 cm below the soil surface
   c. Artificial drainage: none
   d. Flooding: none
9. Evidence of human activity: charcoal, baked loam and pottery sherds from 0-70 cm

Description of the soil horizons

Ap	0-30 cm:	loamy sand; 10 YR 3/3 (moist); few charcoal, baked loam and pottery sherds, weak very fine to coarse subangular blocky structure; few large and few to common fine biopores; many very fine and few fine roots (0-10 cm), common very fine roots (10-30 cm); friable; gradual and smooth to:
Ah1	30-55 cm:	sandy loam; 10 YR 4/4 (moist); few charcoal, baked loam and pottery sherds; small dark spots (end of biopores, containing organic matter); very weak very fine to medium subangular blocky structure, tending to a sponge structure; common large and many fine biopores; common fine roots; friable; few fine gravel; high biological activity; plough pan in the upper part of the horizon; gradual and smooth to:
Ah2	55-70 cm:	sandy loam; 10 YR 4/4 (moist); few charcoal, baked loam and pottery sherds; small dark spots (ends of biopores, containing organic matter); very weak very fine to medium subangular blocky structure tending to a sponge

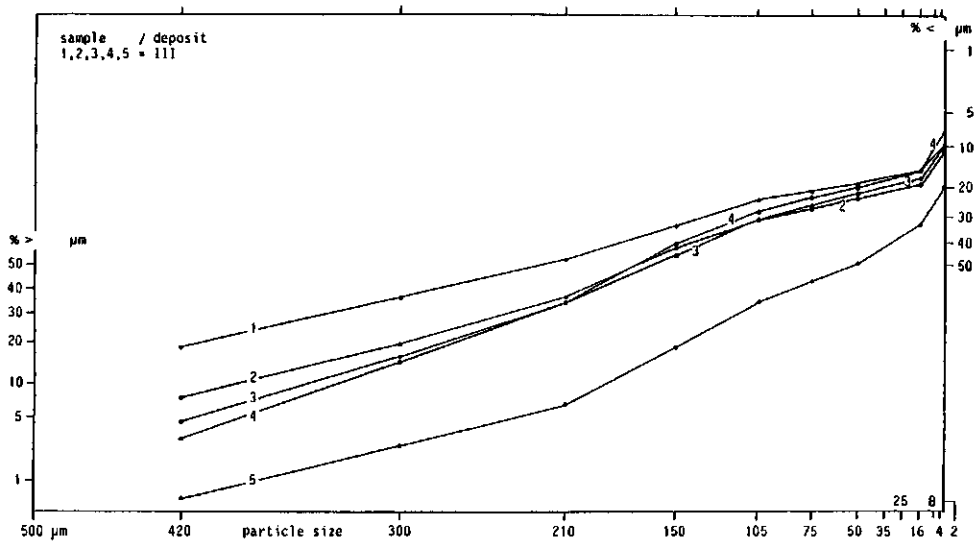
structure; common large and many fine biopores, common fine roots; friable; few fine gravel; high biological activity; gradual and smooth to:

2E 70–95 cm: loamy sand; 10 YR 4/4 (moist); light and dark parts (biological activity); small dark spots (ends of biopores, containing organic matter); very weak very fine to medium subangular blocky structure tending to a sponge structure; common large and many fine biopores; common fine roots; friable; few fine gravel; high biological activity; clear and wavy to:

2Btg 95–130 cm: stratified (partly), both sedimentary and due to clay illuviation; 10 YR 5/6 (moist); many medium to coarse faint irregular 7.5 YR 5/4 (moist) parts (presumed clay illuviation); common fine to medium faint to distinct irregular 7.5 YR 5/6 iron mottles; few fine prominent irregular 10 YR 2/1 Mn concretions; sponge structure; many fine biopores; few fine roots; firm; gravel and coarse sand at 160 cm.

b. PARTICLE SIZE DISTRIBUTION

Sample	Depth	Horizon	Particle size classes in µm																	Md 50
			<2	2-50	>50	<2	2-16	16-50	50-75	75-105	105-150	150-210	210-300	300-420	420-600	600-850	850-1200	1200-1700	<2µm <16µm	sand fraction
	cm		%			%														µm
75/84	0- 30	Ap	9.3	9.8	80.9	9.3	6.7	3.1	2.4	2.9	9.3	14.3	16.1	17.7	11.5	4.8	1.9	-	0.58	274
75/85	30- 55	Ah1	10.9	13.0	76.1	10.9	8.5	4.5	3.3	4.0	11.6	21.1	16.9	11.9	4.9	1.7	0.7	-	0.56	205
75/86	55- 70	Ah2	9.7	12.7	77.6	9.7	7.6	5.1	3.9	4.7	14.7	20.4	18.0	11.6	3.2	0.8	0.3	-	0.56	196
75/87	70- 95	2E	7.6	12.5	79.9	7.6	7.4	5.1	3.5	4.9	12.5	25.0	19.8	11.3	2.4	0.5	-	-	0.51	196
75/88	95-130	2Btg	19.4	30.4	50.2	19.4	13.1	17.3	7.8	7.9	15.8	12.0	4.2	1.9	0.6	-	-	-	0.60	132



c. CHEMICAL DATA

Sample	Depth	Horizon	Clay	Humus	$CaCO_3$	pH-	CEC/soil	CEC/clay	Exch. bases					Exch. acidity		BS	Fe_2O_3		Al_2O_3
						KCl			$1/2Ca^{2+}$	$1/2Mg^{2+}$	Na^+	K^+	Sum	$1/3\ Al^{3+}$	H^+		ox	dith	dith
	cm		%	%	%		mmol/kg	mmol/kg	mmol/kg							%	%		%
75/84	0- 30	Ap	9.3	3.1	-	5.2	50	538	43	8	-	-	51			102	0.5	1.0	0.5
75/85	30- 55	Ah1	10.9	0.8	-	4.3	22	202	4	4	-	-	8			36	0.5	1.2	0.5
75/86	55- 70	Ah2	9.7	0.5	-	4.2	19	196	-	1	-	-	1			5	0.4	1.0	0.6
75/87	70- 95	2E	7.6	0.3	-	4.2	13	171	-	1	-	-	1			6	0.4	1.0	0.7
75/88	95-130	2Btg	19.4	0.3	-	4.1	69	356	65	12	-	-	77			112	0.6	2.7	1.7

d. TOTAL CHEMICAL COMPOSITION OF THE CLAY FRACTION

Sample	Depth	Horizon	Clay	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	BaO**	$H2O^+$	CEC/clay*
	cm		%	% W/W													mmol/kg
75/84	0- 30	Ap	9.3	36.11	17.17	6.85	0.70	0.33	1.00	0.32	0.05	2.16	0.69	1.70	18.50	14.29	2410
75/85	30- 55	Ah1	10.9	43.80	21.21	8.91	0.17	0.59	1.30	0.14	0.05	2.93	0.89	1.47	8.26	10.21	1080
75/86	55- 70	Ah2	9.7	44.82	21.66	8.35	0.10	0.90	1.37	0.17	0.05	3.00	0.91	1.56	7.55	9.15	980
75/87	70- 95	2E	7.6	44.89	21.20	7.64	0.26	0.72	1.41	0.17	0.05	3.23	0.96	1.50	7.83	9.29	1020
75/88	95-130	2Btg	19.4	43.74	23.75	10.52	0.66	0.13	2.08	0.05	0.05	3.97	0.88	0.51	4.46	8.66	580

e. PHYSICAL CHARACTERISTICS (horizon averages**** and averages of 5 core samples****)

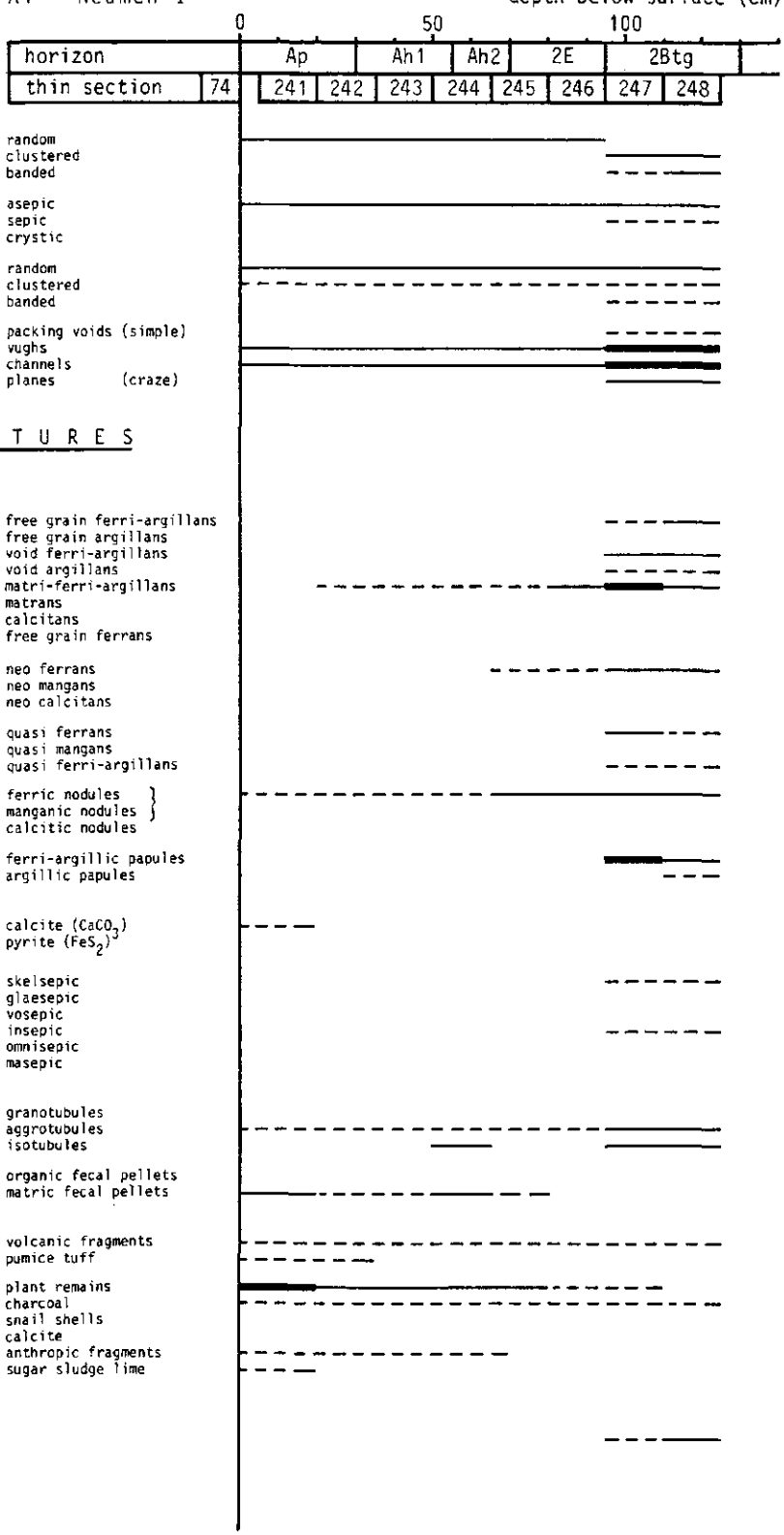
Depth	Horizon	Texture (µm)			Humus	Bulk density	Particle density	Pore volume	Moisture content				Available moisture		Air volume	
		<2	2-50	>50					pF2	pF4.2	pF2	pF4.2	VpF2-VpF4.2		pF 2	pF4.2
cm		%			%	kg/m^3	kg/m^3	%	%w/w		%v/v		mm/10cm		%	
0- 30	Ap	9.3	9.8	80.9	3.1	1510	2600	41.8	14.3	8.5	21.6	12.8	8.8		20.1	29.0
30- 55	Ah1	10.9	13.0	76.1	0.8	1530	2660	42.4	11.1	4.9	17.0	7.5	9.5		25.4	34.9
55- 70	Ah2	9.7	12.7	77.6	0.5	1430	2660	46.4	12.2	3.8	17.4	5.5	11.9		29.1	40.9
70- 95	2E	7.6	12.5	79.9	0.3	1500	2670	44.0	11.9	3.2	17.9	4.7	13.2		26.1	39.3
95-130	2Btg	19.4	30.4	50.2	0.3	1580	2720	42.0	14.3	8.2	22.8	13.0	9.8		19.2	29.0
													Σ	**140		
5- 10						1490	2600	42.6	15.6	8.5	23.3	12.8	10.5	19.3	29.0	
15- 20						1530	2600	41.0	14.4	8.5	22.0	12.8	9.2	19.0	29.0	
25- 30						1520	2600	41.7	13.0	8.5	19.6	12.8	6.8	22.1	29.0	
35- 40						1530	2660	42.4	11.1	4.9	17.0	7.5	9.5	25.4	34.9	
55- 60						1440	2660	45.8	12.2	3.8	17.6	5.5	12.1	28.2	40.9	
65- 70						1410	2660	47.1	12.2	3.8	17.2	5.5	11.7	29.9	40.9	
85- 90						1500	2670	44.0	11.9	3.2	17.9	4.7	13.2	26.1	39.3	
95-100						1530	2720	43.8	11.7	8.2	17.9	13.0	4.9	25.9	29.0	
105-110						1540	2720	43.5	14.0	8.2	21.6	13.0	8.6	21.9	29.0	
115-120						1670	2720	38.7	17.3	8.2	28.9	13.0	15.9	9.8	29.0	

* calculated from adsorbed $\frac{1}{2}Ba^{2+}$
** sum over profile depth
*** BaO figures exceptionally high, due to poor washing after Ba-saturation (?).
**** Calculations with rounded average may cause differences of some decimals.

f. MICROMORPHOLOGICAL OBSERVATIONS

A1 - Heumen I

depth below surface (cm)



A.2 HEUMEN II

a. Profile description

General data

1. Location: Topographical map of the Netherlands, scale 1:25.000 (1967), sheet 46A, coordinates: N 421.010; E 186.070.
2. Date of description: 2-9-1974.
3. Described by: Th. Pape and A.G. Jongmans.
4. Mapping unit: ML 2.

Soil site characteristics

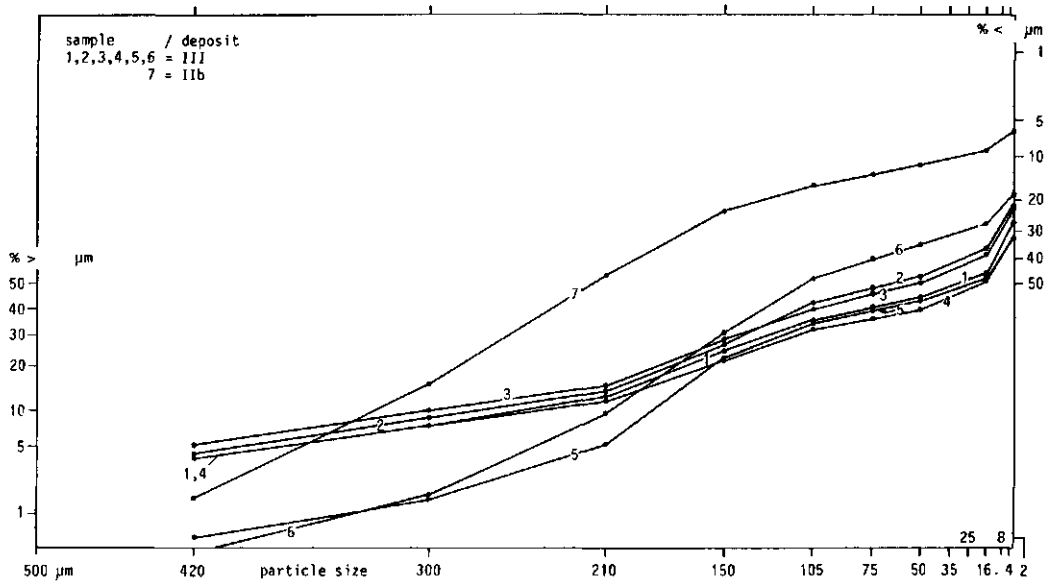
1. Classification:
   a. according to FAO-Unesco (1974): Eutric Podzoluvisol
   b. according to the Soil Taxonomy (1975): Aeric Ochraqualf.
   c. according to De Bakker and Schelling (1966): Kuilbrikgrond.
2. Land use: fallow during the previous month, preceded by winter wheat.
3. Geology: medium-textured Late Weichselian Rhine deposit
4. Physiography: lower part of a weakly undulating landscape of a braided river system.
5. Relief: flat or concave.
6. Slope: level to nearly level, class A.
7. Altitude: 9 m + NAP (Amsterdam Ordnance Datum).
8. Hydrology:
   a. Soil drainage class: imperfectly drained
   b. Groundwater level:
      presumed highest: 30 cm below the soil surface
      presumed lowest: 130 cm below the soil surface
      actual: 130 cm below the surface
   c. Artifical drainage: none
   d. Flooding: none
9. Evidence of human activity: pieces of coal in the ploughed layer, caused by earlier manuring with city refuse.

Description of the soil horizons

Ap 0-25 cm: clay loam; 10 YR 5/3 (moist); few fine to coarse prominent irregular black coal fragments; few fine to coarse distinct parts of material from the underlying horizon; strong coarse to very coarse compound prismatic subdivided into weak fine angular and subangular blocky; many large and common fine biopores; abundant fine (0-5 cm) and common fine roots (5-25 cm); firm; few gravel; worm holes, coated with darker material (10 YR 3/3); clear and smooth to;

Eg 25-40 cm: sandy clay loam; 10 YR 6/3 (moist); many coarse, prominent, irregular (locally vertically elongated) 7.5 YR 5/8 iron mottles, locally 'channel neoferrans'; few fine distinct irregular black manganese mottles; moderate to strong medium to coarse angular blocky; many to abundant large and common fine biopores; few fine roots, mainly concentrated in worm holes; firm; few gravel; big worm holes coated; clear and smooth to;

Btg1	40-50 cm:	sandy clay loam; 10 YR 6/3 (moist); many coarse prominent irregular (locally vertically elongated) 7.5 YR 5/8 iron mottles, locally 'channel neoferrans'; few fine distinct irregular black manganese mottles; moderate to strong medium to coarse angular blocky; many to abundant large and common fine biopores; few fine roots, mainly concentrated in worm holes; firm; few gravel; big worm holes coated; gradual and smooth to:
Btg2	50-90 cm:	clay loam; 5 YR 5/8 (moist) and partly 7.5 YR 5/6 (moist); 'neoferrans' locally along channels and cracks; common to many medium to coarse prominent irregular and partly elongated 10 YR 7/1 reduction parts; few fine distinct irregular black manganese mottles, locally on ped faces; moderate very coarse compound prismatic subdivided into moderate medium to coarse angular and subangular blocky and some smaller prisms; many to abundant large biopores and common fine biopores; few fine roots mainly in worm holes; coarse dead roots; firm; few gravel; worm holes coated with Ap material and biopores, filled with groundmass material (7.5 YR 6/4); gradual and smooth to:
Btg3	90-115 cm:	sandy loam; 10 YR 6/1 (wet); few, 7.5 YR 5/8, 'channel neoferrans' and few medium faint irregular 10 YR 8/6 iron mottles; macrostructureless; common large and few fine biopores; few fine roots and common dead roots; non-sticky and non-plastic; gradual and smooth to:
2Btg4	115-130 cm:	loamy sand; disturbed stratification; below 130 cm alternating layers of gravel and coarse sand.



b. PARTICLE SIZE DISTRIBUTION

Sample	Depth	Horizon	Texture (<2 mm)			Particle size classes in µm												<2µm / <16µm	Md 50 sand fraction
			<2	2-50	>50	<2	2-16	16-50	50-75	75-105	105-150	150-210	200-300	300-420	420-500	600-850	850-1200	1200-1700	
	cm		%			%													µm
75/89	0- 25	Ap	27.1	29.6	43.3	27.1	19.7	9.9	3.8	4.7	10.7	11.9	5.0	3.5	1.9	1.0	0.7	0.2	0.58	162
75/90	25- 40	Eg	21.1	26.8	52.1	21.1	15.7	11.1	5.0	5.8	14.8	12.5	5.5	4.3	2.7	1.2	0.2	-	0.57	152
75/91	40- 50	Btg1	22.6	28.3	49.1	22.6	16.8	11.5	4.3	5.4	11.6	12.9	5.1	4.8	3.2	1.2	0.6	-	0.57	165
75/92	50- 70	Btg2	31.8	29.1	39.1	31.8	18.4	10.7	3.6	3.8	10.4	9.9	4.0	3.5	2.4	1.1	0.3	-	0.63	161
75/93	70- 90	Btg2	32.0	25.8	42.2	32.0	17.1	8.7	3.8	4.4	12.0	16.9	3.5	1.0	0.5	0.1	-	-	0.65	153
75/94	90-115	Btg3	18.3	17.0	64.7	18.3	9.8	7.2	6.2	7.6	20.6	21.1	7.5	1.4	0.3	-	-	-	0.65	147
75/95	115-130	2Btg4	6.4	5.8	87.8	6.4	3.2	2.6	2.2	2.5	7.2	29.1	37.8	13.4	1.4	0.2	-	-	0.67	231

c. CHEMICAL DATA

Sample	Depth	Horizon	Clay	Humus	$CaCO_3$	pH-	CEC/soil	CEC/clay	Exch. bases					Exch.acidity		BS	Fe_2O_3		Al_2O_3
						KCl			$1/2Ca^{2+}$	$1/2Mg^{2+}$	Na^+	K^+	Sum	$1/3Al^{3+}$	H^+		ox	dith	dith
	cm		%	%	%		mmol/kg	mmol/kg	mmol/kg							%	%	%	%
75/89	0- 25	Ap	27.1	4.1	-	4.9	91	336	87	18	-	-	105	3	3	115	0.7	1.6	1.3
75/90	25- 40	Eg	21.1	0.3	-	3.9	79	374	37	10	-	1	48	11	6	61	0.8	2.1	0.6
75/91	40- 50	Btg1	22.6	0.0	-	3.7	82	363	35	15	-	1	51	12	7	62	1.1	4.0	1.1
75/92	50- 70	Btg2	31.8	0.1	-	3.7	124	390	40	31	-	1	72	15	7	58	1.3	5.7	1.6
75/93	70- 90	Btg2	32.0	0.0	-	3.6	146	456	31	47	-	5	83	23	8	57	1.2	3.7	1.4
75/94	90-115	Btg3	18.3	0.0	-	4.1	85	464	23	33	-	5	61	8	6	72	0.4	1.1	0.9
75/95	115-130	2Btg4	6.4	0.3	-	4.1	31	484	5	13	-	2	20	3	6	65	0.2	0.5	0.3

d. TOTAL CHEMICAL COMPOSITION OF THE CLAY FRACTION

Sample	Depth	Horizon	Clay	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	BaO	H_2O^+	CEC/clay*
	cm		%	%w/w												mmol/kg	
75/89	0- 25	Ap	27.1	47.53	24.72	6.51	0.64	0.02	1.14	0.21	0.05	2.31	0.98	0.49	5.27	10.69	690
75/90	25- 40	Eg	21.1	46.80	22.61	9.38	0.33	-	1.15	0.12	0.38	2.52	0.96	0.31	6.12	8.77	800
75/91	40- 50	Btg1	22.6	41.61	22.79	14.98	0.39	0.02	1.47	0.04	0.27	2.66	0.67	0.59	5.74	9.67	750
75/92	50- 70	Btg2	31.8	40.30	22.05	15.69	0.80	-	1.49	0.14	0.27	2.67	0.61	0.28	5.66	11.02	740
75/93	70- 90	Btg2	32.0	45.27	22.87	11.31	0.50	-	1.51	0.08	0.22	2.75	0.67	0.25	6.06	9.99	790
75/94	90-115	Btg3	18.3	49.45	25.34	6.83	0.41	-	1.83	0.07	0.21	3.42	0.72	0.34	5.65	8.93	740
75/95	115-130	2Btg4	6.4	47.15	25.49	6.34	0.58	-	2.17	0.05	0.26	3.72	0.67	0.40	5.60	10.01	730

e. PHYSICAL CHARACTERISTICS (horizon averages *** and averages of 5 core samples***)

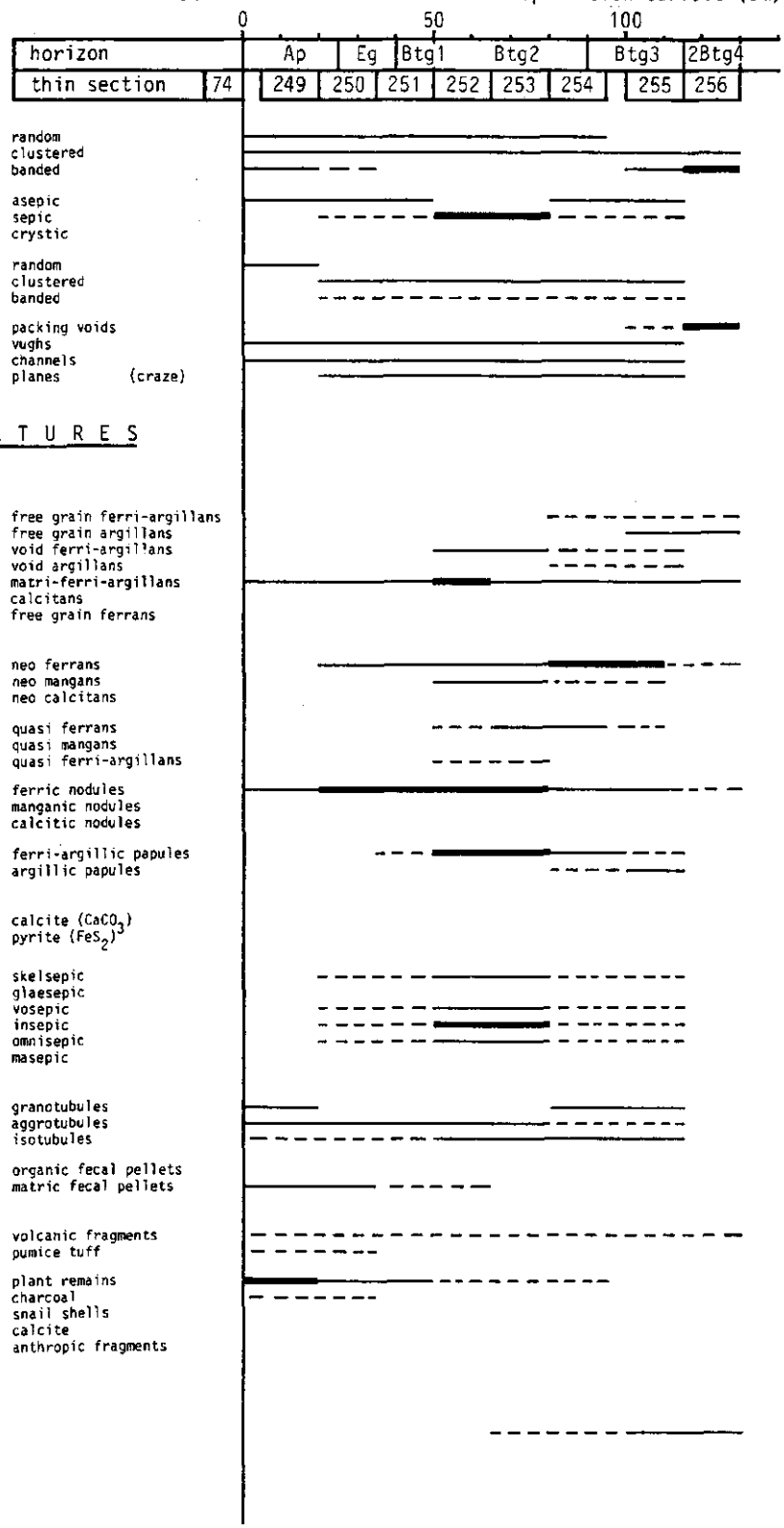
Depth	Horizon	Texture (<2 mm)			Humus	Bulk density	Particle density	Pore volume	Moisture content				Available moisture	Air volume	
		<2	2-50	>50					pF2	pF4.2	pF2	pF4.2	VpF2-VpF4.2	pF2	pF4.2
cm		%			%	kg/m³	kg/m³	%	Kw/w	%v/v		(mm/10cm)	%		
0- 25	Ap	27.1	29.6	43.3	4.1	1360	2570	47.1	26.1	15.4	35.0	21.0	14.0	12.2	26.1
25- 40	Eg	21.1	26.8	52.1	0.3	1530	2670	42.7	18.2	8.4	27.7	12.9	14.8	15.0	29.8
40- 50	Btg1	22.6	28.3	49.1	0.0	1620	2710	40.4	17.4	11.7	28.2	18.9	9.3	12.2	21.5
50- 70	Btg2	31.8	29.1	39.1	0.1	1370	2790	50.7	30.4	17.4	41.7	23.8	17.9	9.0	26.9
70- 90	Btg2	32.0	25.8	42.2	0.0	1410	2700	47.9	28.6	14.3	40.3	20.2	20.1	7.6	27.7
90-115	Btg3	18.3	17.0	64.7	0.0	1550	2690	42.5	23.3	6.3	36.2	9.8	26.4	6.4	32.7
115-130	2Btg4	6.4	5.8	87.8	0.3	1480	2660	44.2	24.7	5.9	38.6	8.8	27.8	7.6	35.4
													**245 mm		
0- 5						1250	2570	51.4	30.3	15.4	37.9	21.0	16.9	13.5	26.1
5- 20						1470	2570	42.9	21.8	15.4	32.1	21.0	11.1	10.8	26.1
25- 30						1450	2670	45.6	20.1	8.4	29.2	12.9	16.3	16.4	29.8
35- 40						1610	2670	39.8	16.3	8.4	26.2	12.9	13.3	13.6	29.8
45- 50						1620	2710	40.4	17.4	11.7	28.2	18.9	9.3	12.2	21.5
65- 70						1370	2790	50.7	30.4	17.4	41.7	23.8	17.9	9.0	26.9
75- 80						1410	2700	47.9	28.6	14.3	40.3	20.2	20.1	7.6	27.7
95-100						1530	2690	43.2	23.7	6.3	36.3	9.8	25.6	6.9	32.7
105-110						1570	2690	41.8	22.9	6.3	36.0	9.8	26.2	5.8	32.7
115-120						1480	2660	44.2	24.7	5.9	38.6	8.8	27.8	7.6	35.4

* calculated from adsorbed + Ba^{2+}
** sum over profile depth
*** Calculations with rounded average may cause differences of some decimals

f. MICROMORPHOLOGICAL OBSERVATIONS

A2 - Heumen II

depth below surface (cm)



A.3 HEUMEN III

a. Profile description

General data

1. Location: Topographical map of the Netherlands, scale 1:25.000 (1967), sheet 46A, coordinates: N 421.200; E 186.360.
2. Date of description: 17-9-1974
3. Described by: Th. Pape and A.G. Jongmans
4. Mapping unit: kLL 2

Soil site characteristics

1. Classification:
   a. according to FAO-Unesco (1974): Eutric Gleysol.
   b. according to the Soil Taxonomy (1975): Typic Haplaquept.
   c. according to De Bakker and Schelling (1966): Poldervaaggrond.
2. Land use: grassland.
3. Geology: fine-textured Late Weichselian Rhine deposit, overlain by 22 cm fine-textured Holocene Rhine deposit.
4. Physiography: border of a channel
5. Relief: flat or concave.
6. Slope: level to nearly level, class A.
7. Altitude: 8.5 m +NAP (Amsterdam Ordnance Datum).
8. Hydrology:
   a. Soil drainage class: poorly drained
   b. Groundwater level:
      presumed highest: 6 cm below the soil surface (fossil?).
      presumed lowest: 100 cm below the soil surface
      actual : 100 cm below the soil surface
   c. Artificial drainage: ditches
   d. Flooding: none
9. Evidence of human activity: none.

Description of the soil horizons

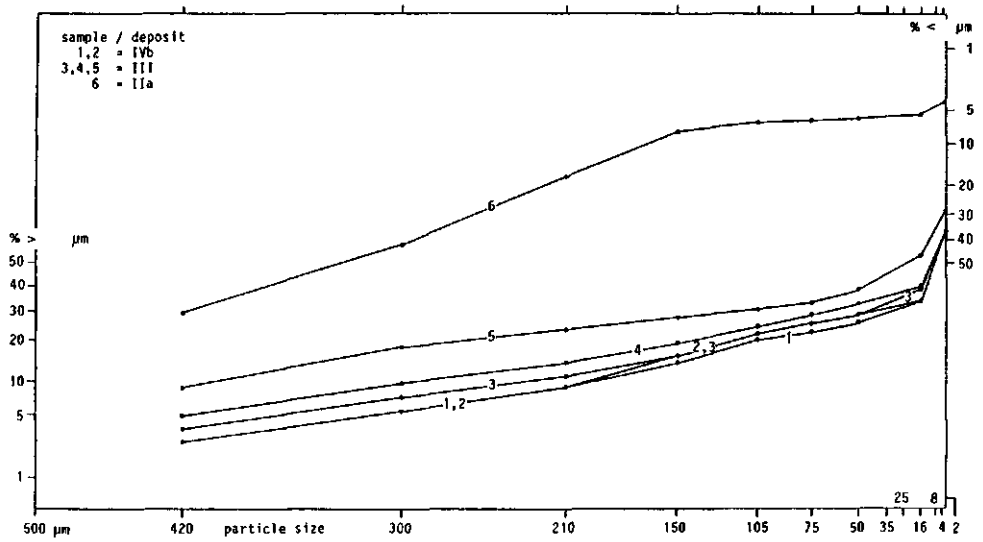
Ahg	0-8 cm:	clay loam; 10 YR 4/2 (moist); few fine faint irregular 5 YR 5/8 iron mottles and 'neoferrans'; moderate very fine to fine angular and subangular blocky; abundant large and few fine biopores; many fine roots; firm; abrupt and smooth to:
ABg	8-22 cm:	clay loam; 10 YR 4.5/3 (moist); common fine to coarse distinct irregular 7.5 YR 5/8 iron mottles; common (5-10%) fine to coarse distinct irregular, 10 YR 7/2 reduction parts; some charcoal; weak coarse compound prismatic subdivided into moderate very fine to medium angular and subangular blocky; abundant large and common fine biopores; common fine roots; firm; very few gravel; organic faecal pellets or aggrotubules in worm holes; clear and smooth to:
2Ahg	22-40/52 cm:	clay loam; 10 YR 5/2 (moist); common fine to coarse prominent 10 YR 4/8 'channel quasi- and neoferrans'; common coarse distinct irregular 10 YR 6.5/2 reduction parts; strong very coarse compound prismatic subdivided into weak medium angular blocky; rootprints

on prism faces; abundant large and common fine biopores (on and in peds); few fine roots within peds and common fine roots on peds; firm; few gravel; faecal pellets and aggrotubules in worm holes; abrupt and wavy to:

2Bwg 40/52-70 cm: clay loam; 10 YR 6/1 (wet); common fine to medium prominent 5 YR 5/8 and 2.5 YR 5/8 'channel neo- and quasiferrans'; moderate very coarse smooth prismatic; many to abundant large and common fine biopores; few fine roots within peds, somewhat more on peds and in worm holes; slightly sticky and plastic; few gravel; very few welded faecal pellets in worm holes; with increasing depth increasing amounts of coarse dead roots; gradual and smooth to:

2Cg 70-90 cm: clay loam; 10 YR 6/1 (wet); common fine to medium prominent 5 YR 5/8 and 2.5 YR 5/8 'channel neo- and quasiferrans'; half ripened macrostructureless material with some worm holes and root remnants; many to abundant large and common fine biopores; few fine roots, in worm holes somewhat more; slightly sticky and plastic; few gravel; very few welded faecal pellets in worm holes; with increasing depth, increasing amounts of coarse dead roots; clear and smooth to:

3Cr 90-120 cm: sand; 10 YR 5/1 (wet); completely reduced; undisturbed stratification; common gravel.



b. PARTICLE SIZE DISTRIBUTION

Sample	Depth	Horizon	Particle size classes in µm																Md 50
			<2	2-16	>50	<2	2-16	16-50	50-75	75-105	105-150	150-210	210-300	300-420	420-600	600-850	850-1200	1200-1700	<2µm / <16µm	sand fraction
	cm		%			%														µm
75/96	0- 8	Ahg	38.9	35.9	25.2	38.9	23.2	12.7	2.8	2.6	6.2	5.2	3.3	2.6	1.4	0.6	0.5	0.2	0.63	165
75/97	8- 22	ABg	38.8	33.0	28.2	38.8	23.1	9.9	3.0	3.3	6.2	6.8	3.5	2.7	1.5	0.6	0.6	-	0.63	160
75/98	22-40/52	2Ahg	36.7	35.4	27.9	36.7	24.8	10.6	3.1	2.9	6.2	5.0	3.7	3.4	2.2	1.2	0.3	-	0.60	175
75/99	40/52-70	2Bwg	38.5	29.0	32.5	38.5	22.1	6.9	4.2	3.9	5.3	5.3	4.2	4.8	3.0	1.3	0.5	-	0.64	180
75/100	70- 90	2Cg	28.5	33.4	38.1	28.5	18.3	15.1	3.9	3.0	4.5	3.1	5.6	9.6	5.7	2.1	0.6	-	0.61	285
75/101	90-120	3Cr	4.1	2.0	93.9	4.1	1.6	0.4	0.3	0.4	1.2	9.7	24.5	28.9	16.4	8.1	3.0	1.4	0.72	345

c. CHEMICAL DATA

Sample	Depth	Horizon	Clay	Humus	$CaCO_3$	pH-	CEC/soil	CEC/clay	Exch bases					Exch.acidity			Fe_2O_3		Al_2O_3
						KCl			$1/2Ca^{2+}$	$1/2Mg^{2+}$	Na^+	K^+	Sum	$1/3Al^{3+}$	H^+	BS	ox	dith	dith
	cm		%	%	%		mmol/kg		mmol/kg					mmol/kg		%	%		%
75/96	0- 8	Ahg	38.9	8.1	-	5.0	160	411	181	22	-	-	203	0.3	5	127	1.9	2.9	1.2
75/97	8- 22	ABg	38.8	3.6	-	4.3	150	387	103	12	-	-	115	5	6	77	1.8	3.0	1.2
75/98	22-40/52	2Ahg	36.7	1.7	-	3.9	130	354	57	16	1	2	76	22	6	58	0.7	1.2	1.0
75/99	40/52-70	2Bwg	38.5	0.0	-	3.8	136	353	30	38	2	9	79	27	5	58	0.5	1.4	1.4
75/100	70- 90	2Cg	28.5	0.1	-	3.8	111	389	25	33	1	10	69	21	5	62	0.4	1.1	1.0
75/101	90-120	3Cr	4.1	0.6	-	4.7	25	610	13	8	-	1	22	0.6	4	88	0.1	0.4	0.1

d. TOTAL CHEMICAL COMPOSITION OF THE CLAY FRACTION

Sample	Depth	Horizon	Clay	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	BaO	H_2O+	CEC/clay*
	cm		%	% w/w													mmol/kg
75/96	0- 8	Ahg	38.9	45.03	24.84	7.67	0.66	-	1.22	0.22	0.26	2.44	0.72	0.52	5.36	11.88	700
75/97	8- 22	ABg	38.8	45.06	24.24	8.59	0.79	0.02	1.23	0.30	0.27	2.51	0.75	0.40	4.83	10.77	630
75/98	22-40/52	2Ahg	36.7	45.58	26.38	5.37	0.37	0.01	1.17	0.22	0.32	2.48	0.74	0.27	5.87	10.62	770
75/99	40/52-70	2Bwg	38.5	46.96	24.56	6.20	0.41	0.01	1.63	0.19	0.27	3.46	0.71	0.23	5.39	9.28	700
75/100	70- 90	2Cg	28.5	50.92	23.99	5.15	0.44	0.01	1.61	0.11	0.32	3.83	0.84	0.21	3.85	7.99	500
75/101	90-120	3Cr	4.1	46.98	25.72	6.20	0.56	-	1.82	0.04	0.21	3.81	0.58	0.36	5.03	8.96	660

e. PHYSICAL CHARACTERISTICS (horizon averages*** and averages of 5 core samples***)

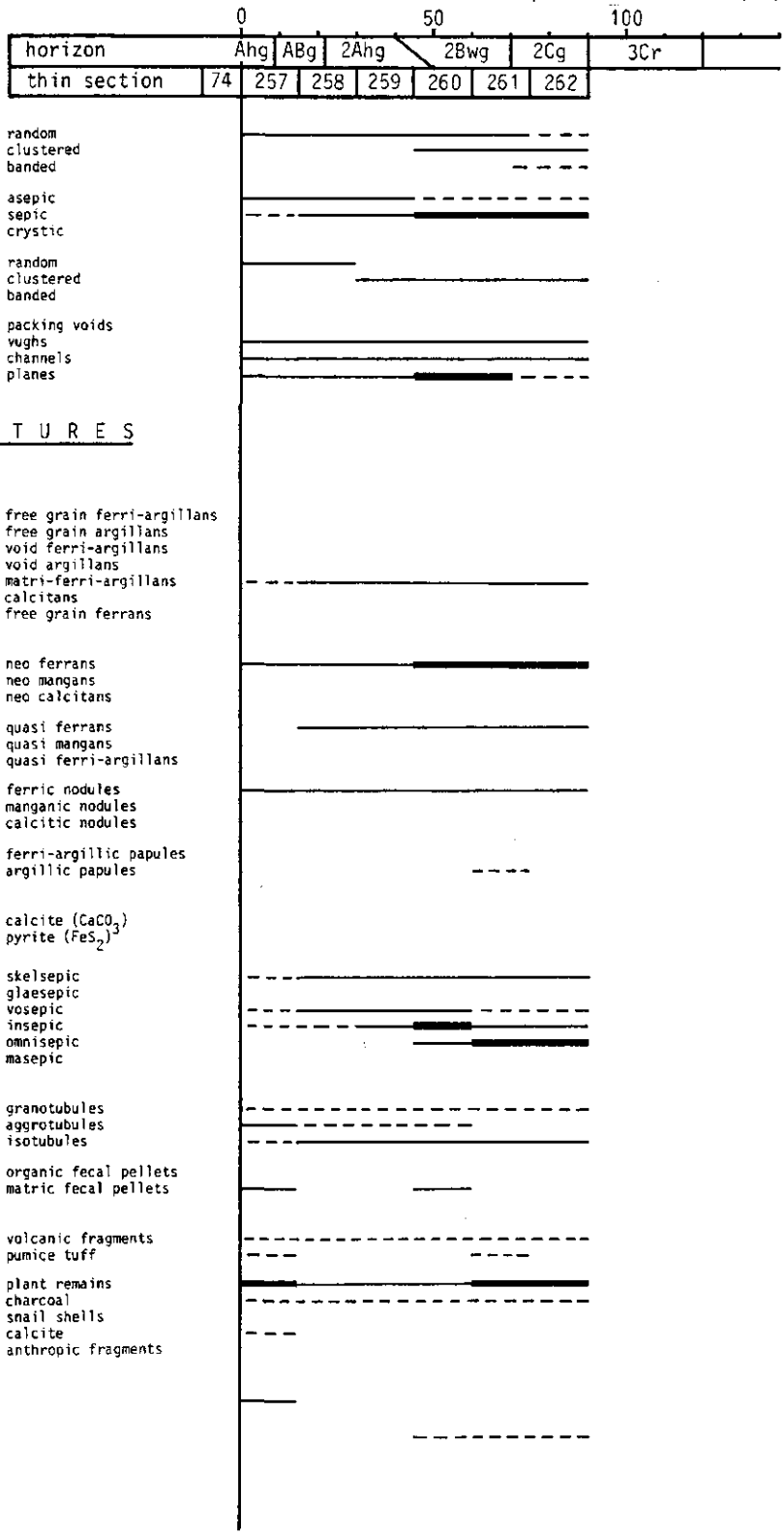
Depth	Horizon	Texture(µm)			Humus	Bulk	Particle	Pore	Moisture content				Available moisture	Air volume	
		<2	2-50	>50	%	density	density	volume	pF2	pF4.2	pF2	pF4.2	VpF2-VpF4.2	pF2	pF4.2
cm		%				kg/m³	kg/m³	%	%w/w		%v/v		mm/10cm	%	
0- 8	Ahg	38.9	35.9	25.2	8.1	1190	2490	52.4	34.4	24.4	40.9	29.0	11.9	11.5	23.4
8- 22	ABg	38.8	33.0	28.2	3.6	1240	2580	52.0	31.9	22.3	39.6	27.6	12.0	12.4	24.4
22-40/52	2Ahg	36.7	35.4	27.9	1.7	1280	2620	51.1	28.9	19.8	36.6	25.3	11.3	14.4	24.0
40/52-70	2Bwg	38.5	29.0	32.5	0.0	1420	2680	46.6	27.9	18.7	39.7	26.6	13.1	6.9	20.0
70- 90	2Cg	28.5	33.4	38.1	0.1	1500	2680	44.2	27.4	13.1	41.0	19.6	21.4	3.2	24.6
90-120	3Cr	4.1	2.0	93.90	0.6	no data	2610	no data	no data	2.1	no data	3.2	no data **130 mm	no data	no data
5-10						1190	2490	52.4	34.4	24.4	40.9	23.4	11.9	11.5	23.4
15-20						1240	2580	52.0	31.9	22.3	39.6	24.6	12.0	12.4	24.4
25-30						1170	2620	55.2	32.4	19.8	37.9	24.0	12.6	16.9	24.0
35-40						1390	2620	47.1	25.3	19.8	35.2	24.0	9.9	11.9	24.0
45-50						1430	2680	45.9	24.6	18.7	35.2	20.0	8.6	10.7	20.0
55-60						1440	2680	46.2	27.2	18.7	39.2	20.0	12.6	7.0	20.0
65-70						1400	2680	47.8	32.0	18.7	44.8	20.0	18.2	3.0	20.0
75-80						1450	2680	46.0	29.8	13.1	43.2	24.6	23.6	2.8	24.6
85-90						1550	2680	42.4	25.0	13.1	38.8	24.6	19.2	3.6	24.6

* calculated from adsorbed $\frac{1}{2}$ Ba^{2+}
** sum over profile depth
*** Calculations with rounded averages may cause differences of some decimals

f. MICROMORPHOLOGICAL OBSERVATIONS

A3 - Heumen III

depth below surface (cm)



A4. GENDRINGEN I

a. Profile description

General data

1. Location: Topographical map of the Netherlands, scale 1:25.000 (1964); sheet 41C; coordinates; N 435.250; E 220.750.
2. Date of description: 11-7-1975.
3. Described by: R. Miedema and N.G. Vlaanderen.
4. Mapping unit: ML1.

Soil site characteristics

1. Classification:
   a. according to FAO-Unesco (1974): Orthic Luvisol.
   b. according to the Soil Taxonomy (1975): Typic Hapludalf.
   c. according to De Bakker and Schelling (1966): Daalbrikgrond.
2. Land use: grassland, former arable land.
3. Geology: medium-textured Late Weichselian Rhine deposit.
4. Physiography: higher part of the weakly undulating landscape of a braided river.
5. Relief: Subnormal.
6. Slope: level to nearly level, class A.
7. Altitude: 13.5 m +NAP (Amsterdam Ordnance Datum).
8. Hydrology:
   a. Soil drainage class: Moderately well drained.
   b. Groundwater level:
      presumed highest: 45 cm below the soil surface
      presumed lowest: >170 cm below the soil surface
      actual: at 170 cm below the soil surface
   c. Artifical drainage: Tile drains and widely spaced ditches; drainage considerably improved since 1968 (reallotment scheme)
   d. Flooding: none.
9. Evidence of human activity: Ap-horizon to 18 cm with impurities from nearby ditch and liming with sugar sludge lime.

Description of the soil horizons

Ap	0-18 cm:	loam; 10 YR 4/3 (moist): few fine faint round 7.5 YR 4/4 iron mottles; many spots of greyish and brownish mottled clayey material from neighbouring ditch; moderate fine subangular blocky structure (0-10 cm) and moderate fine rough prismatic structure; many fine and very fine roots; firm; slightly calcareous (fertilizer); clear and smooth to:
Eg	18-40 cm:	sandy loam; 10 YR 5/6 (moist); few fine distinct round 10 YR 5/8 iron mottles and common fine and medium round 5 YR 2/1 iron-manganese concretions; weak fine subangular blocky structure, tending to sponge structure; common large and many fine biopores; some large mole holes; common fine and very fine roots; firm; clear and smooth to:
Btg1	40-80 cm:	sandy loam; 10 YR 6/4 (moist); many medium distinct irregular 7.5 YR 5/8 iron mottles and many medium prominent round and irregular 5 YR 2/2 rather soft iron-manganese concretions; weak medium and coarse subangular blocky structure; common large and many fine biopores;

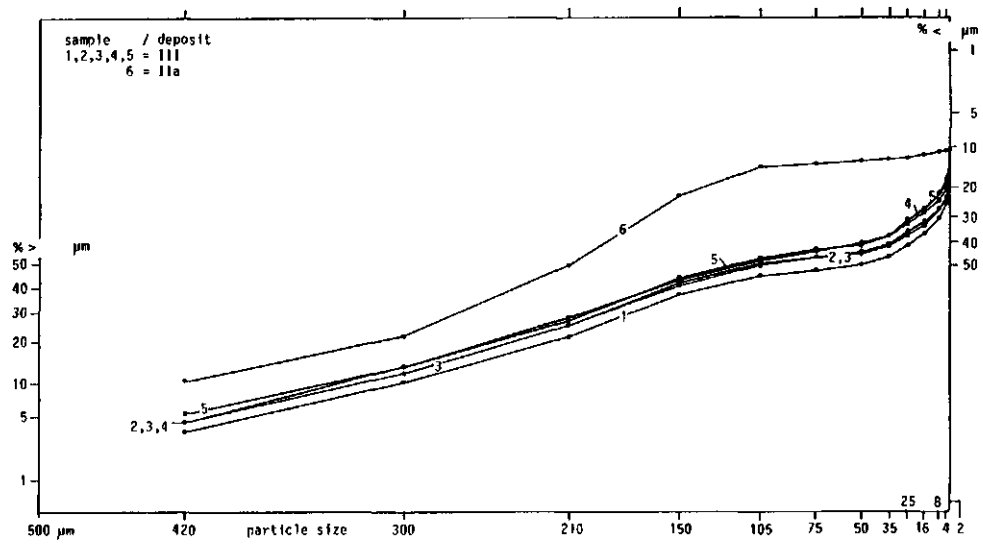
few fine roots; very firm; clear and smooth to:

Btg2 80-100 cm: sandy loam; 10 YR 7/2 (moist); many medium and coarse prominent round and irregular 7.5 YR 5/8 iron concretions and common medium and coarse prominent round and irregular 10 YR 2/2 iron-manganese concretions with an outer rim of iron; macrostructureless; few large and common fine biopores; very few fine roots; friable; abrupt and wavy to:

2Btg3 100-120 cm: loamy sand; 10 YR 5/6 (70%, moist) and 6/6 (moist); many coarse horizontally elongated cemented laminae of iron-manganese with an iron rim, a 2.5 YR 3/6 centre and cemented manganese concretions; few medium distinct round 7.5 YR 5/8 iron mottles; macrostructureless, locally single grain; few large and fine biopores; no roots; very friable; very hard and cemented.

b. PARTICLE SIZE DISTRIBUTION

Sample	Depth	Horizon	Particle size classes in µm																				Md 50 sand fraction µm
	cm		<2	2-50	>50	<2	2-4	4-8	8-16	16-25	25-35	35-50	50-75	75-105	105-150	150-210	210-300	300-420	420-600	600-850	850-1200	1200-1700	<2µm <16µm
			%			%																	
75/307	0- 18	Ap	20.3	30.1	49.6	20.3	5.4	5.1	5.8	4.8	5.0	4.0	2.4	2.3	7.8	15.1	11.9	6.6	2.3	0.7	0.3	0.2	0.55	199
75/308	18- 40	Eg	18.4	26.3	55.3	18.4	5.4	6.0	5.1	4.0	4.6	3.2	2.2	2.1	8.2	14.9	14.5	9.1	3.2	0.8	0.3	-	0.56	211
75/309	40- 60	Btg1	19.4	25.3	55.3	19.4	4.5	5.6	4.3	4.0	5.0	3.9	2.4	2.9	8.4	15.8	13.6	7.7	3.0	0.9	0.6	-	0.61	203
75/310	60- 80	Btg1	17.0	24.5	58.5	17.0	4.1	3.5	4.0	4.0	5.0	3.9	2.7	2.9	9.8	14.8	14.6	9.2	3.1	0.9	0.5	-	0.59	205
75/311	80-110	Btg2	15.3	25.6	59.1	15.3	4.0	3.6	4.2	4.1	5.3	4.4	2.6	3.2	9.1	16.4	14.2	8.3	3.2	1.1	0.7	0.3	0.56	202
75/312	100-120	2Btg3	9.4	4.0	86.6	9.4	1.7	0.3	0.2	0.7	0.6	0.5	0.5	0.8	7.4	27.3	27.9	12.1	3.9	3.7	2.8	0.2	0.81	234



c. CHEMICAL DATA

Sample	Depth	Horizon	Clay	Humus	$CaCO_3$	pH-	CEC/soil	CEC/clay	Exch.bases					Exch.acidity			Fe_2O_3		Al_2O_3
						KCl			1/2Ca^{2+}	1/2Mg^{2+}	Na^+	K^+	Sum	1/3 Al^{3+}	H^+	BS	ox.	dith	dith
	cm		%	%	%		mmol/kg	mmol/kg	mmol/kg						mmol/kg	%	%	%	%
75/307	0- 18	Ap	20.3	4.4	1.1	7.0	108	532	98	10	-	-	108	-	-	100	0.7	1.9	1.0
75/308	18- 40	Eg	18.4	1.6	0.1	6.2	83	451	77	6	-	-	83	-	-	100	0.7	1.9	1.0
75/309	40- 60	Btg1	19.4	0.5	-	4.5	70	361	58	6	-	-	64	0.2	2.3	91	0.5	1.7	1.0
75/310	60- 80	Btg1	17.0	0.2	-	4.2	50	294	29	6	-	-	35	2.2	3.9	70	0.4	1.8	1.0
75/311	80-100	Btg2	15.3	0.3	-	4.3	51	333	29	6	-	-	35	1.1	3.4	69	0.3	1.8	1.0
75/312	100-120	2Btg3	9.4	0.2	-	4.5	44	468	43	5	-	-	48	0.9	2.6	109	0.5	1.7	0.8

d. TOTAL CHEMICAL COMPOSITION OF THE CLAY FRACTION

Sample	Depth	Horizon	Clay	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	BaO	H_2O^+	CEC/clay*
	cm		%	% w/w													mmol/kg
75/307	0- 18	Ap	20.3	47.51	22.69	8.30	0.95	0.13	1.83	0.17	0.30	3.03	1.06	0.66	4.21	8.64	550
75/308	18- 40	Eg	18.4	47.23	23.00	8.17	0.86	0.30	1.81	0.19	0.27	2.74	1.09	0.64	4.19	9.01	550
75/309	40- 60	Btg1	19.4	47.83	24.25	8.18	0.77	0.27	1.71	0.08	0.27	2.67	1.03	0.54	3.92	8.73	510
75/310	60- 80	Btg1	17.0	47.24	24.33	7.96	0.87	0.16	1.64	0.05	0.21	2.78	1.02	0.47	3.91	8.71	510
75/311	80-100	Btg2	15.3	47.86	24.27	8.35	0.81	0.09	1.64	0.04	0.21	3.00	1.03	0.41	3.85	8.26	500
75/312	100-120	2Btg3	9.4	43.81	24.16	9.83	0.53	0.28	1.74	0.03	0.15	2.99	0.83	0.60	4.56	8.97	590

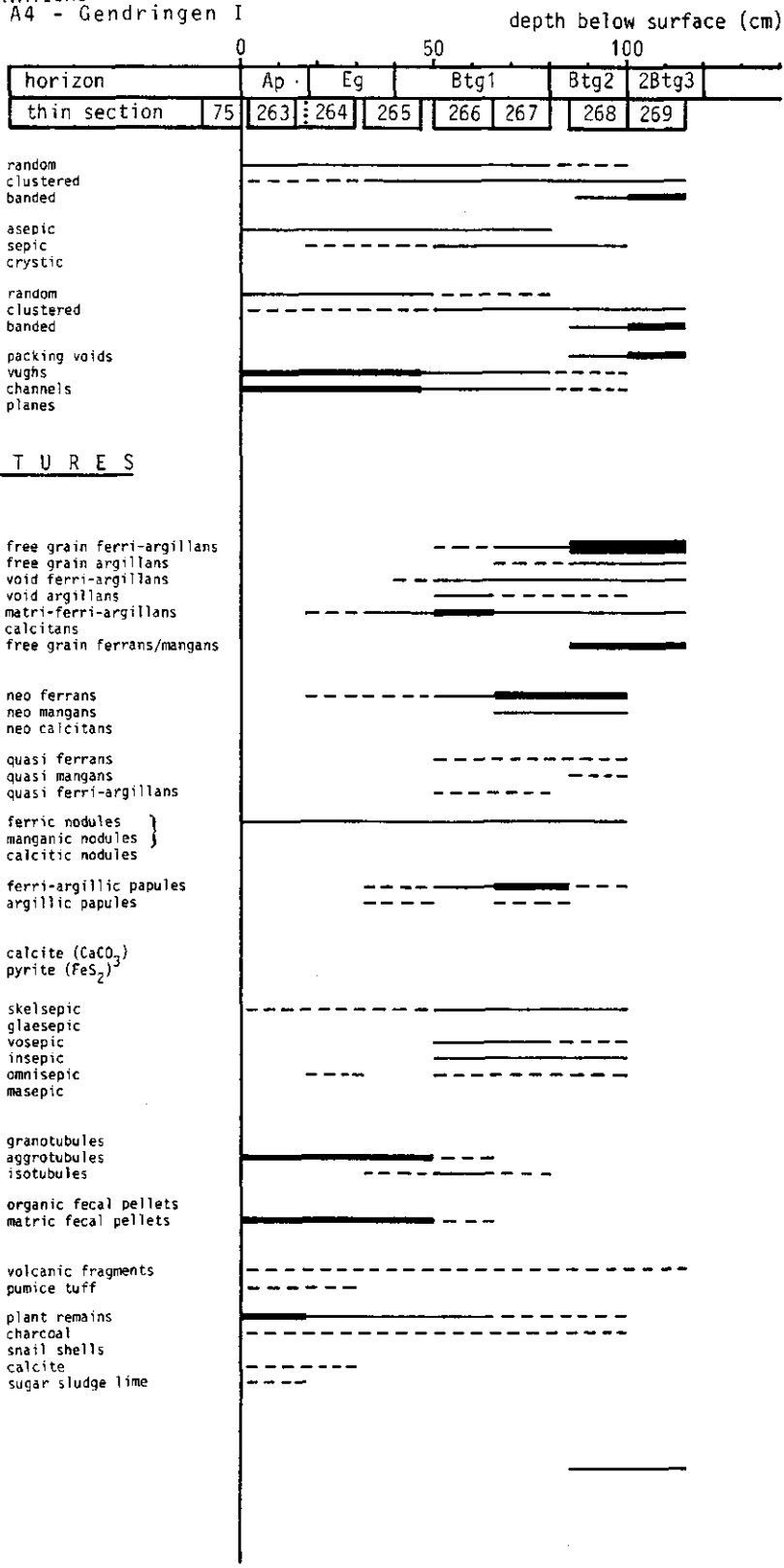
e. PHYSICAL CHARACTERISTICS (horizon averages and averages*** of 3 core samples***)

Depth	Horizon	Texture (µm)			Humus	Bulk density	Particle density	Pore volume	Moisture content				Available moisture	Air volume	
		<2	2-50	>50					pF2	pF4.2	pF2	pF4.2	VpF2-VpF4.2	pF2	pF 4.2
cm		%			%	kg/m³	kg/m³	%	%w/w		%w/v		mm/10 cm	%	
0- 18	Ap	20.3	30.1	49.6	4.4	1470	2660	44.8	26.9	11.1	39.5	16.3	23.2	5.3	28.5
18- 40	Eg	18.4	26.3	55.3	1.6	1450	2680	46.1	21.8	6.7	31.6	9.7	21.9	14.5	36.4
40- 60	Btg1	18.2	24.9	56.9	0.4	1580	2700	41.5	17.0	6.6	26.8	10.4	16.4	14.7	31.1
80-100	Btg2	15.3	25.6	59.1	0.3	1690	2710	37.5	15.3	6.0	25.9	10.1	15.8	11.6	27.4
100-120	2Btg3	9.4	4.0	86.6	0.2	1590	2690	40.9	13.2	2.8	21.0	4.5	17.5	19.9	36.4
													** 220 mm		
2- 7						1470	2660	44.8	26.9	11.1	39.5	16.3	23.2	5.3	28.5
20- 25						1450	2680	46.1	21.8	6.7	31.6	9.7	21.9	14.5	36.4
40- 45						1530	2690	43.1	18.1	6.6	27.7	10.1	17.6	15.4	33.0
60- 65						1620	2700	39.9	15.9	6.6	25.8	10.7	15.1	14.1	29.2
80- 85						1690	2710	37.5	15.3	6.0	25.9	10.1	15.8	11.6	27.4
100-105						1620	2690	39.9	13.6	2.8	22.0	4.5	17.5	17.9	35.4
115-120						1560	2680	41.9	12.8	2.8	20.0	4.4	15.6	21.9	37.5

* calculated from adsorbed $\frac{1}{2}$ Ba^{2+}
** sum over profile depth
*** Calculation with rounded averages may cause difference of some decimals

f. MICROMORPHOLOGICAL OBSERVATIONS

A4 - Gendringen I



A5. GENDRINGEN II

a. Profile description

General data

1. Location: Topographical map of the Netherlands, scale 1:25.000 (1964); sheet 41C; coordinates: N 429.410; E 222.560.
2. Date of description: 21-7-1975.
3. Described by: R. Miedema and N.G. Vlaanderen.
4. Mapping unit: kML2.

Soil site characteristics

1. Classification:
   a. according to FAO-Unesco (1974): Orthic Luvisol.
   b. according to the Soil Taxonomy (1975): Aquic Hapludalf.
   c. according to De Bakker and Schelling (1966): Daalbrikgrond.
2. Land use: grassland, former arable land.
3. Geology: fine- to medium-textured Late Weichselian Rhine deposit overlain by 28 cm fine-textured Holocene Rhine deposit.
4. Physiography: higher part of the weakly undulating landscape of a braided river.
5. Relief: subnormal.
6. Slope: level to nearly level, class A.
7. Altitude: 15.0 m +NAP (Amsterdam Ordnance Datum).
8. Hydrology:
   a. Soil drainage class: imperfectly drained
   b. Groundwater level:
      presumed highest: 40 cm below the soil surface
      presumed lowest: 120 cm below the soil surface
      actual: 120 cm below the soil surface
   c. Artificial drainage: widely spaced ditches
   d. Flooding: none.
9. Evidence of human activity: Ap horizon to 28 cm and liming with sugar sludge lime.

Description of soil horizons

Ap	0-28 cm:	clay loam; 10 YR 4/3 (moist); few fine distinct round iron-manganese concretions; strong compound fine smooth prismatic structure subdivided into moderate medium angular blocky structure and from 0-10 cm strong medium angular blocky structure; few large and common fine biopores; common fine and very fine roots; firm; very few gravel; slightly calcareous (fertilizer); abrupt and irregular to:
2Eg	28-40 cm*:	clay loam; 10 YR 6/3.5 (moist); common medium distinct round and irregular 7.5 YR 5/8 iron mottles and many medium prominent round 10 YR 2/1 iron-manganese concretions; moderate compound fine smooth prismatic structure subdivided into moderate fine angular blocky structure; common large and fine biopores; few fine roots; firm; gradual and smooth to:
2Btg1	40-70 cm*	
2Btg2	70-90 cm:	sandy clay loam; 2.5 Y 7/2 (wet); abundant coarse irregular 7.5 YR 5/8 iron mottles and few fine distinct round 10 YR 2/1 manganese mottles; very weak very coarse smooth prismatic structure; few large and common fine

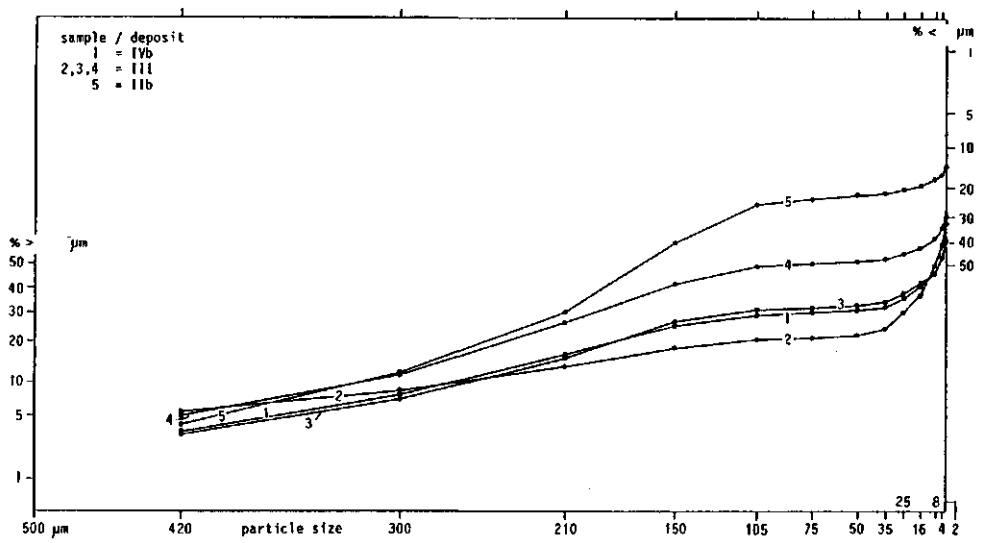
biopores; slightly sticky and plastic; clear and smooth to:

3Btg3 90-120 cm: sandy loam; 10 YR 7/1 (wet); common coarse distinct irregular 10 YR 5/8 iron mottles and 7.5 YR 2/1 manganese mottles; undisturbed stratification to macrostructureless; few fine biopores; slightly sticky and plastic.

* Subdivision based on micromorphological investigation.

b. PARTICLE SIZE DISTRIBUTION

Sample	Depth cm	Horizon	<2 %	2-50 %	>50 %	Particle size classes in µm: <2 %	2-4 %	4-8 %	8-16 %	16-25 %	25-35 %	35-50 %	50-75 %	75-105 %	105-150 %	150-210 %	210-300 %	300-420 %	420-600 %	600-850 %	850-1200 %	1200-1700 %	<2µm <16µm	Md 50 sand fraction µm
75/313	0- 28	Ap	32.5	36.5	31.0	32.5	9.5	6.9	8.5	4.8	3.2	1.6	0.9	0.9	3.7	9.2	8.5	4.5	2.0	0.7	0.4	0.2	0.55	219
75/314	28- 40	2Eg	32.2	45.4	22.4	32.2	9.7	9.9	10.6	7.3	5.8	2.1	1.0	0.6	2.6	4.7	5.0	2.9	1.7	1.4	1.6	0.9	0.52	251
75/315	40- 70	2Btg1	37.9	29.1	33.0	37.9	8.0	6.7	5.7	3.9	3.2	1.6	0.9	0.9	4.5	10.9	8.7	3.9	1.6	0.8	0.6	0.2	0.65	206
75/316	70- 90	2Btg2	29.6	18.6	51.8	29.6	5.2	3.7	3.5	2.5	2.4	1.3	1.2	1.1	8.2	15.7	14.2	7.4	2.8	0.8	0.4	-	0.70	209
75/317	90-120	3Btg3	14.0	8.6	77.4	14.0	2.3	1.5	1.4	1.2	1.3	0.9	1.0	2.0	14.5	29.9	18.2	7.8	2.9	0.8	0.3	-	0.73	193



c. CHEMICAL DATA

Sample	Depth	Horizon	Clay	Humus	$CaCO_3$	pH-	CEC/soil	CEC/clay	Exch.bases					Exch.acidity		BS	Fe_2O_3		Al_2O_3
						KCl			$1/2Ca^{2+}$	$1/2Mg^{2+}$	Na^+	K^+	Sum	$1/3\ Al^{3+}$	H^+		ox.	dith	dith
	cm		%	%	%		mmol/kg	mmol/kg	mmol/kg							%		%	%
75/313	0- 28	Ap	32.5	2.7	-	5.9	154	474	161	14	-	-	175			114	0.9	3.1	1.5
75/314	28- 40	2Eg	32.2	0.5	0.1	5.4	153	475	116	11	-	-	127			83	0.7	4.1	1.6
75/315	40- 70	2Btg1	37.9	0.0	0.1	5.4	172	454	149	21	-	-	170			99	0.4	4.5	1.8
75/316	70- 90	2Btg2	29.6	0.0	0.1	5.5	134	453	117	19	-	-	136			101	0.3	3.6	1.1
75/317	90-120	3Btg3	14.0	0.2	0.1	5.4	82	586	72	13	-	-	85			104	0.3	1.7	0.4

d. TOTAL CHEMICAL COMPOSITION OF THE CLAY FRACTION

Sample	Depth	Horizon	Clay	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	BaO	H_2O^+	CEC/clay*
	cm		%	% w/w													mmol/kg
75/313	0- 28	Ap	32.5	46.87	22.97	7.64	0.69	0.22	1.79	0.18	0.20	3.18	1.11	0.57	4.53	8.98	590
75/314	28- 40	2Eg	32.2	48.20	24.04	7.67	0.79	0.19	1.66	0.06	0.23	3.00	1.14	0.36	3.64	8.42	470
75/315	40- 70	2Btg1	37.9	47.67	23.42	8.03	0.73	0.12	1.65	0.03	0.23	3.44	0.94	0.27	4.20	8.28	550
75/316	70- 90	2Btg2	29.6	46.12	23.24	10.01	0.53	0.11	1.69	0.02	0.19	3.11	0.84	0.31	4.72	8.77	620
75/317	90-120	3Btg3	14.0	46.88	24.09	8.94	0.40	0.14	1.63	0.03	0.23	2.89	0.84	0.40	5.29	8.96	690

e. PHYSICAL CHARACTERISTICS (horizon averages*** and averages of 3 core samples***)

Depth	Horizon	Texture (µm)			Humus	Bulk density	Particle density	Pore volume	Moisture content				Available moisture	Air volume	
		% <2	2-50	>50					pF2	pF4.2	pF2	pF4.2	VpF2-VpF4.2	pF2	pF4.2
cm					%	kg/m³	kg/m³	%	%w/w		%v/v		mm/10 cm	%	
0- 28	Ap	32.5	36.5	31.0	2.7	1560	2690	41.9	24.5	12.0	38.2	18.7	19.5	3.7	23.2
28- 40	2Eg	32.2	45.4	22.4	0.5	1590	2750	42.0	21.3	11.5	33.9	18.3	15.6	8.1	23.7
40- 70	2Btg1	37.9	29.1	33.0	0.0	1530	2780	38.2	25.8	12.9	39.5	19.7	19.8	5.6	25.4
70- 90	2Btg2	29.6	18.6	51.8	0.0	1630	2780	41.1	21.6	11.0	35.2	17.9	17.3	5.9	23.2
90-120	3Btg3	14.0	8.6	77.4	0.2	1660	2690	38.2	14.9	6.9	24.7	11.5	13.2	13.5	26.7
													** 205 mm		
7- 12						1560	2690	41.9	24.5	12.0	38.2	18.7	19.5	3.7	23.2
32- 37						1590	2750	42.0	21.3	11.5	33.9	18.3	15.6	8.1	23.7
51- 56						1530	2780	45.1	25.8	12.9	39.5	19.7	19.8	5.6	25.4
75- 80						1630	2780	41.1	21.6	11.0	35.2	17.9	17.3	5.9	23.2
90- 95						1650	2690	38.7	17.4	6.9	28.7	11.4	17.3	10.0	27.3
100-115						1670	2680	37.8	12.4	6.9	20.7	11.5	9.2	17.1	26.3

* Calculated from adsorbed $\frac{1}{2}$ Ba^{2+}

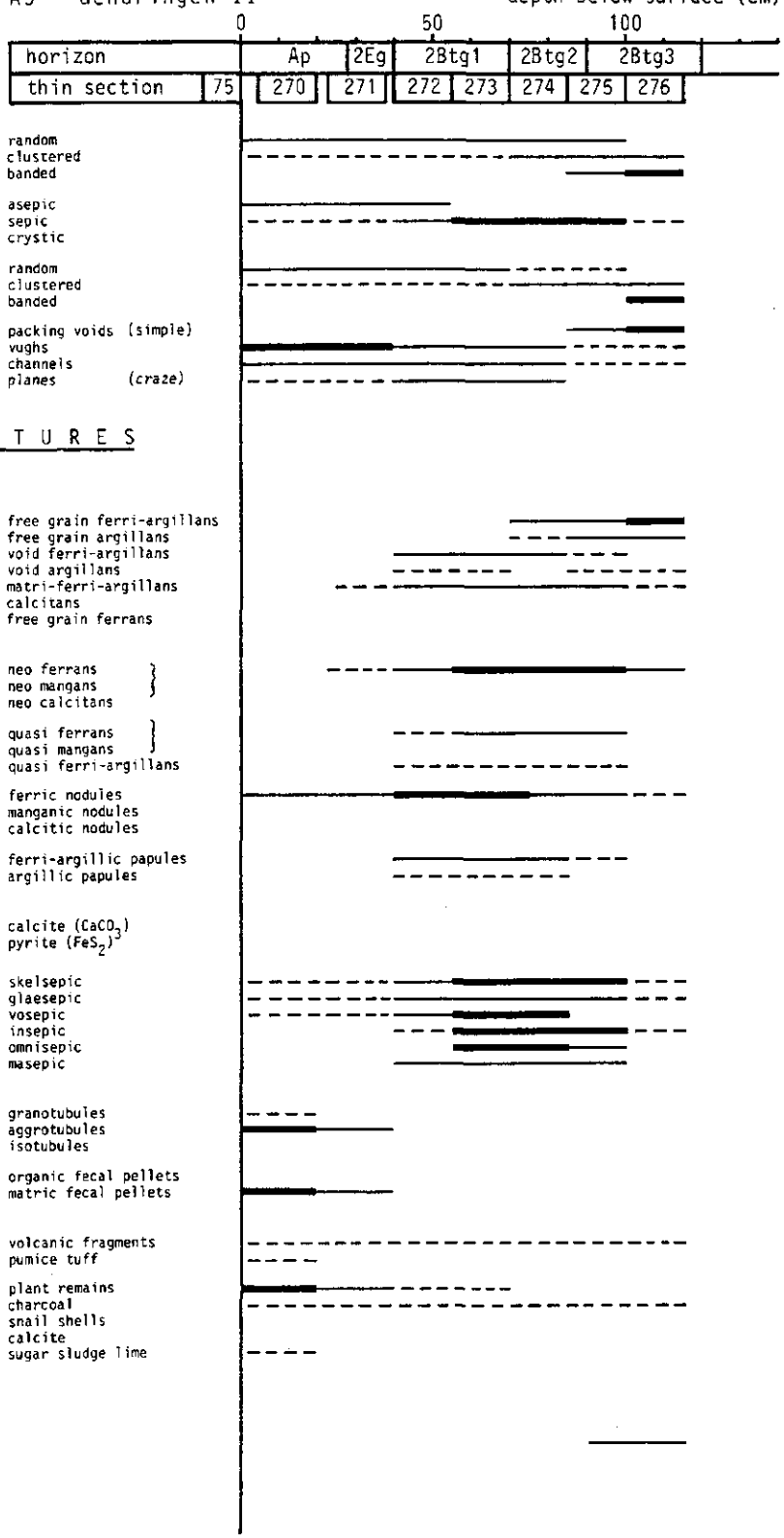
** sum over profile depth

*** Calculation with rounded averages may cause difference of some decimals

f. MICROMORPHOLOGICAL OBSERVATIONS

A5 - Gendringen II

depth below surface (cm)



A.6. OTTERSUM

a. Profile description

General data

1. Location: Topographical map of the Netherlands, scale 1:25.000 (1967), sheet 46B + E; coordinates: N 413.630; E 196.360.
2. Date of description: 14-6-1978.
3. Described by: A.E.C. van Dis and J.J.R. Robben.
4. Mapping unit: HL1.

Soil site characteristics

1. Classification:
   a. according to FAO-Unesco (1974): Luvic Phaeozem.
   b. according to the Soil Taxonomy (1975): Humic Hapludult.
   c. according to De Bakker and Schelling (1966): Radebrikgrond.
2. Land use: grassland, former arable land.
3. Geology: medium- to coarse-textured Late Weichselian Rhine deposit.
4. Physiography: plateau bordered in the north by a major channel and in the south by the Niers valley.
5. Relief: subnormal.
6. Slope: level to nearly level, class A.
7. Altitude: 13.5 m +NAP (Amsterdam Ordnance Datum).
8. Hydrology:
   a. Soil drainage class: Well drained.
   b. Groundwater level:
      presumed highest: >150 cm below the soil surface
      presumed lowest: >150 cm below the soil surface
      actual: > 150 cm below the soil surface
   c. Artificial drainage: none
   d. Flooding: none
9. Evidence of human activity: Ap-horizon to 26 cm with some anthropogenic relicts.

Description of the soil horizons

Ap	0-26 cm:	sandy loam; 10 YR 3/3 (moist); few fine and medium distinct irregular 10 YR 4/4 spots of the underlying horizon; weak fine subangular blocky structure; in worm holes locally granular structure (aggrotubules); few large and many fine biopores; common fine roots; firm; very few fresh gravel and very few brick fragments; abrupt and smooth to:
E	26-55 cm:	loam; 10 YR 4/4 (moist); common medium distinct totally and/or partly filled up worm holes with 10 YR 3/3 Ap-material; few fine faint 10 YR 2/1 manganese mottles; weak very fine subangular blocky structure tending to sponge structure; many worm holes coated with Ap-material and in worm holes sometimes granular structure; common large and many fine biopores; few fine roots; friable; very few gravel; gradual and smooth to:
Bt1	55-72 cm:	loam; 7.5 YR 4/4 (moist); few fine distinct 10 YR 2/1 round manganese mottles; weak fine subangular blocky structure tending to sponge structure; many worm holes coated with Ap-material and in some a granular structure; many large and many fine biopores; few fine roots;

friable; gradual and smooth to:

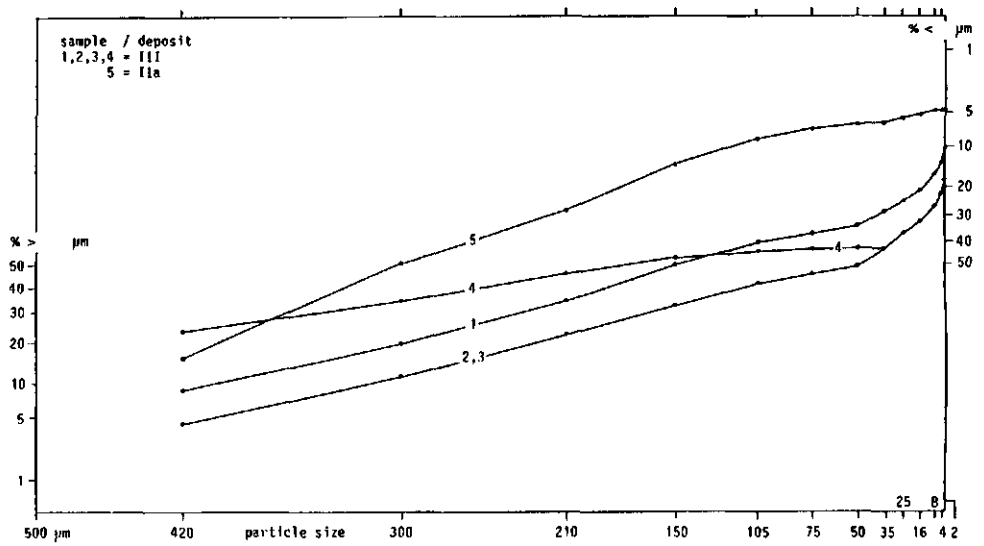
Bt2 72-98 cm: sandy loam; 5 YR 4/8 (moist); few fine and medium distinct round manganese mottles; weak subangular blocky structure tending to sponge structure; common large and common fine biopores; very few fine roots; friable; clear and smooth to:

2Bt3 98-120 cm: loamy sand/sand (banded); matrix colour is an alternation of 5 YR 4/6 (loamy sand, Bt ± 80%) and 10 YR 6/7 (sand, C ± 20%); undisturbed stratification; sand: loose and loamy sand: friable; slightly hard and cemented; no biopores; no roots; clear and smooth to:

2CB120 - 135 cm: coarse sand; 10 YR 8/4 (moist); undisturbed stratification; some thin laminae of loamy sand (Bt); loose.

A6: OTTERSUM
b. PARTICLE SIZE DISTRIBUTION

Sample	Depth cm	Horizon	<2	2-50	>50	<2	2-4	4-8	8-16	16-25	25-35	35-50	50-75	75-105	105-150	150-210	210-300	300-420	420-600	600-850	850-1200	1200-1700	<2µm 16µm	Md 50 sand fraction µm
			%			Particle size classes in µm																		
78/248	0- 26	Ap	10.4	23.6	66.0	10.4	3.0	3.6	4.1	4.0	3.6	5.3	3.1	3.6	9.5	15.2	15.0	10.8	5.3	2.2	1.0	0.3	0.49	217
78/249	26- 55	E	17.4	33.2	49.4	17.4	4.1	5.0	5.2	5.0	6.5	7.4	3.9	3.8	8.5	10.6	11.0	7.2	3.1	0.8	0.2	0.1	0.55	198
78/250	55- 72	Bt1	18.1	32.5	49.4	18.1	4.0	4.9	5.4	5.0	5.4	7.8	3.8	3.9	8.0	11.2	10.9	7.1	3.2	1.0	0.3	-	0.56	198
78/251	72- 98	Bt2	19.7	23.6	56.7	19.7	2.5	4.2	5.8	4.5	6.5	0.1	0.3	0.9	3.2	7.0	11.3	10.6	6.3	5.4	3.8	7.4	0.61	365
78/252	98-120	2Bt3	4.7	2.1	93.2	4.7	0.1	0.1	0.3	0.5	0.8	0.3	0.4	1.3	5.6	14.5	21.5	34.7	12.7	1.2	0.5	0.8	0.90	311



c. CHEMICAL DATA

Sample	Depth	Horizon	Clay	Humus	$CaCO_3$	pH-	CEC/soil	CEC/clay	Exch. bases					Exch. acidity			Fe_2O_3		Al_2O_3
						KCl			$1/2Ca^{2+}$	$1/2Mg^{2+}$	Na^+	K^+	Sum	$1/3\ Al^{3+}$	H^+	BS	ox	dith	dith
	cm		%	%	%		mmol/kg	mmol/kg	mmol/kg							%	%		%
78/248	0- 26	Ap	10.4	3.4	-	6.1	67	644	56	10	-	-	66	2	1	99	0.5	1.3	0.6
78/249	26- 55	E	17.4	1.0	-	4.3	43	247	7	6	-	-	13	27	2	30	0.5	1.7	1.1
78/250	55- 72	Bt1	18.1	0.7	-	4.0	50	276	7	2	-	-	9	28	4	18	0.5	1.8	1.2
78/251	72- 98	Bt2	19.7	0.3	-	3.9	50	254	14	2	-	-	16	36	5	32	0.3	1.9	1.5
78/252	98-120	2Bt3	4.7	0.3	-	4.3	37	787	29	2	-	-	31	11	1	84	0.2	1.1	0.6

d. TOTAL CHEMICAL COMPOSITION OF THE CLAY FRACTION

Sample	Depth	Horizon	Clay	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	BaO	H_2O^+	CEC/clay*
	cm		%	% w/w													mmol/kg
78/248	0- 26	Ap	10.4	48.64	22.89	9.10	0.74	0.18	1.51	0.10	0.28	2.82	1.07	1.55	4.08	8.55	530
78/249	26- 55	E	17.4	48.08	24.72	9.07	0.62	0.30	1.80	0.03	0.26	2.84	1.05	0.52	2.44	8.30	320
78/250	55- 72	Bt1	18.1	47.42	25.35	8.91	0.78	0.28	1.86	0.02	0.24	2.85	1.01	0.42	2.71	8.75	350
78/251	72- 98	Bt2	19.7	47.86	25.26	8.74	0.83	0.17	2.01	0.01	0.18	3.17	0.99	0.26	2.62	8.16	340
78/252	98-120	2Bt3	4.7	44.66	25.56	10.45	0.60	0.16	2.31	0.02	0.18	3.33	0.76	0.39	3.02	9.04	390

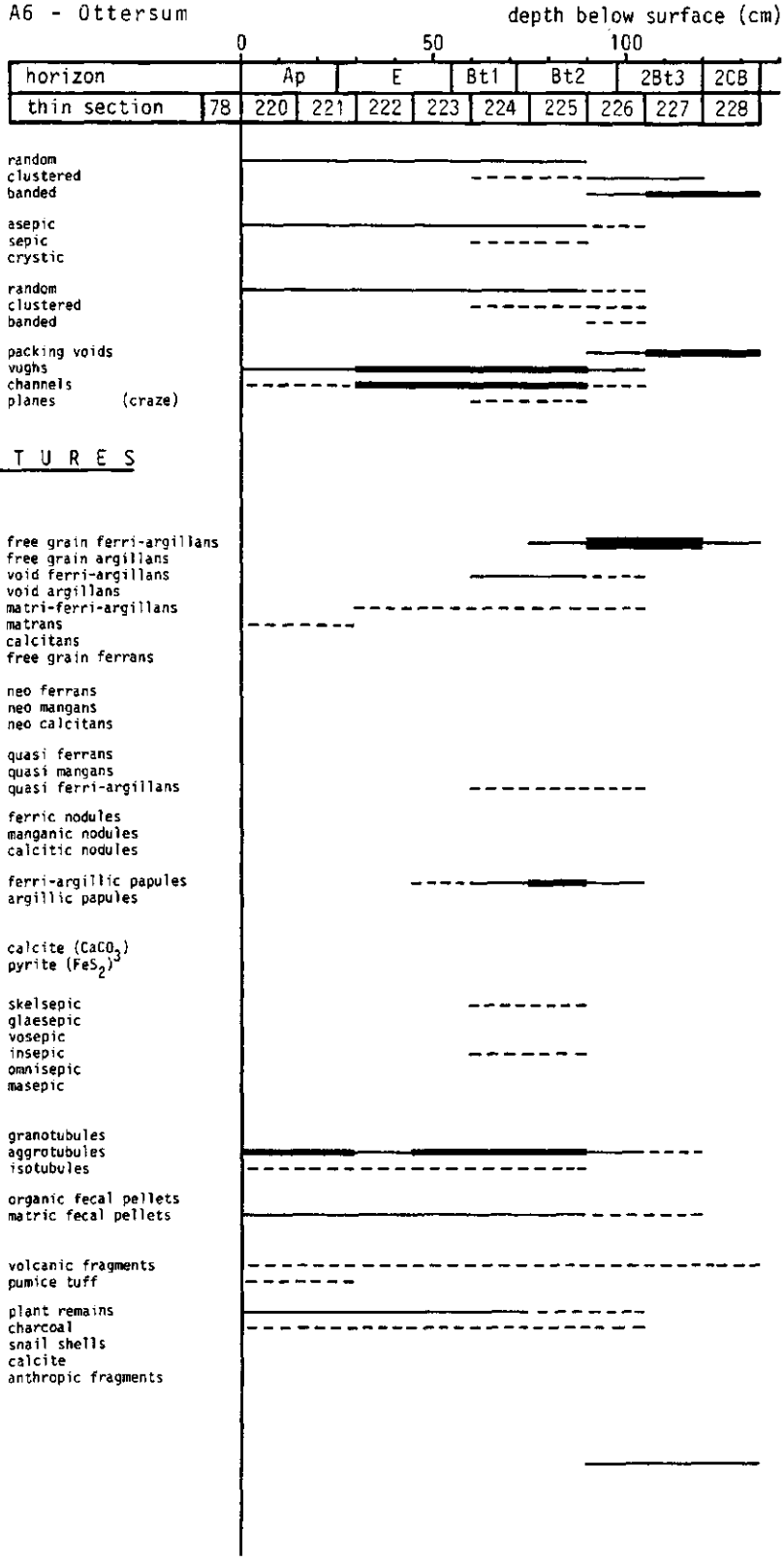
e. PHYSICAL CHARACTERISTICS (horizon averages*** and averages of 5 core samples***)

Depth	Horizon	Texture (mm)			Humus	Bulk density	Particle density	Pore volume	Moisture content				Available moisture	Air volume	
		<2	2-50	>50					pF2	pF4.2	pF2	pF4.2	VpF2-VpF4.2	pF2	pF4.2
cm		%			%	kg/m^3	kg/m^3	%	%w/w		%v/v		mm/10 cm	%	
0- 26	Ap	10.4	23.6	66.0	3.4	1610	2630	38.9	17.7	7.2	28.5	11.6	16.9	10.4	27.3
26- 55	E	17.4	33.2	49.4	1.0	1360	2660	49.1	18.1	7.2	24.6	9.8	14.8	24.5	39.3
55- 72	Bt1	18.1	32.5	49.4	0.7	1370	2680	48.7	18.0	8.0	24.7	11.0	13.7	24.0	37.7
72- 98	Bt2	19.7	23.6	56.7	0.3	1340	2700	50.2	17.2	7.5	23.0	10.1	12.9	27.2	38.6
98-120	2Bt3	4.7	2.1	93.2	0.3	1370	2670	48.6	8.9	3.2	12.2	4.4	7.8	36.4	44.2
													** 160 cm		
10- 15						1590	2630	39.5	17.6	7.2	28.0	11.4	16.6	11.5	28.1
18- 23						1620	2630	38.3	17.7	7.2	28.7	11.7	17.0	9.6	26.6
32- 37						1360	2660	49.1	18.1	7.2	24.6	9.8	14.8	24.5	39.3
55- 60						1370	2680	48.7	18.0	8.0	24.7	11.0	13.7	24.0	37.7
80- 85						1340	2700	50.2	17.2	7.5	23.0	10.1	12.9	27.2	38.6
100-105						1370	2670	48.6	8.9	3.2	12.2	4.4	7.8	36.4	44.2

* Calculated from adsorbed + Ba^{2+}
** Sum over profile depth
*** Calculations with rounded averages may cause difference of some decimals

f. MICROMORPHOLOGICAL OBSERVATIONS

A6 - Ottersum



A.7. SIEBENGEWALD

a. Profile description

General data

1. Location: Topographical map of the Netherlands, scale 1:25.000 (1967), sheet: 46G; coordinates: N 407.600; E 204.220.
2. Date of description: 23-6-1978.
3. Described by: A.E.C. van Dis and J.J.R. Robben.
4. Mapping unit: ML1.

Soil site characteristics

1. Classification:
   a. according to FAO-Unesco (1974): Gleyic Luvisol
   b. according to the Soil Taxonomy (1975): Aeric Ochraqualf.
   c. according to De Bakker and Schelling (1966): Daalbrikgrond.
2. Land use: arable land.
3. Geology: medium- to coarse-textured Late Weichselian Rhine deposit.
4. Physiography: plateau bordered by depressions (infilled former shallow channels).
5. Relief: subnormal.
6. Slope: level to nearly level, class A.
7. Altitude: 15.9 m +NAP (Amsterdam Ordnance Datum).
8. Hydrology:
   a. Soil drainage class: Imperfectly drained.
   b. Groundwater level:
      presumed highest: 25 cm below the soil surface
      presumed lowest: 120 cm below the soil surface
      actual: 120 cm below the soil surface
   c. Artificial drainage: widely spaced ditches and tile drainage
   d. Flooding: none
9. Evidence of human activity: Ap-horizon to 25 cm.

Description of the soil horizons

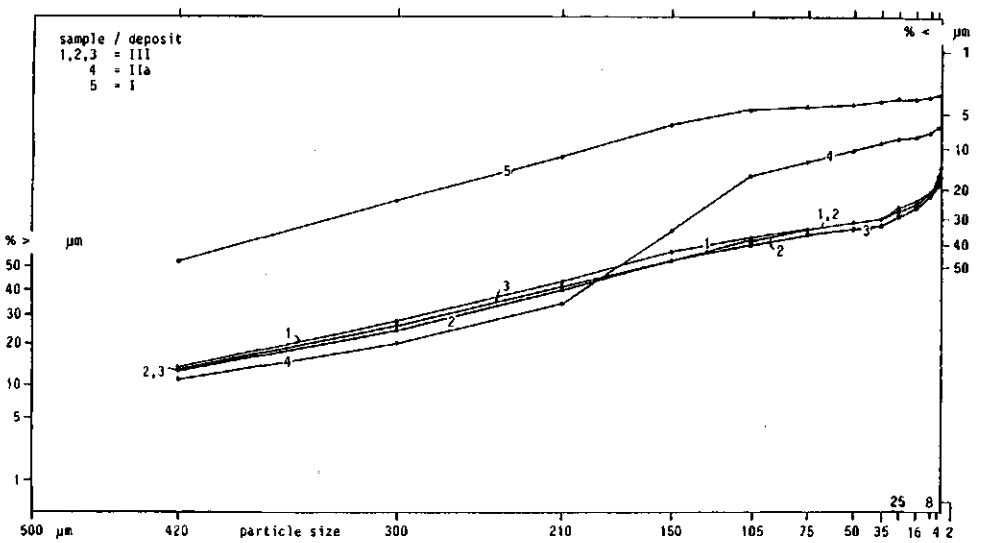
Ap	0-25 cm:	sandy loam; 10 YR 4/3 (moist); few medium distinct 10 YR 5/6 spots of material from the underlying horizon; few fine distinct iron and manganese mottles; weak medium subangular blocky structure; few large and common fine biopores; few fine roots; friable; very few gravel; abrupt and wavy to:
Eg	25-30 cm:	sandy loam; 10 YR 5/6 (moist); few fine distinct black manganese mottles; many medium and coarse prominent 7.5 YR 5/8 iron mottles; common medium distinct spots of material from the overlying horizon; strong medium subangular blocky structure; few large and common fine biopores; few very fine roots; firm; very few gravel; clear and smooth to:
Btg1	30-60 cm:	sandy loam; 7.5 YR 5/8 (70% moist) and 10 YR 7/1 (30% moist); few medium distinct patches of material from the overlying horizon; abundant medium distinct iron mottles; few fine and medium prominent Mn-mottles; strong coarse subangular blocky structure; firm; few very fine roots; slightly gravelly; clear and smooth to:
2Btg2	60-84 cm:	sand; 7.5 YR 5/8 (70%, moist) and 10 YR 7/1 (30%, moist); macrostructureless; loose; few medium roots; slightly

gravelly; abrupt and smooth to:
remark: below the Btg2 a gravel layer of ± 2 cm thickness occurs followed by a 2 cm-thick gravelly iron pan.

3Btg3 84–105 cm: gravelly coarse sand; 5 YR 3/5 (moist); macrostructureless; loose.

b. PARTICLE SIZE DISTRIBUTION

Sample	Depth cm	horizon	<2	2–50	>50	Particle size classes in µm: <2	2–4	4–8	8–16	16–25	25–35	35–50	50–75	75–105	105–150	150–210	210–300	300–420	420–600	600–850	850–1200	1200–1700	<2µm / <16µm	Md 50 sand fraction µm
			%			%																		
78/253	0– 25	Ap	14.0	18.0	68.0	14.0	2.5	3.9	3.6	2.5	3.3	2.2	2.1	3.1	6.5	13.3	15.9	13.2	6.8	3.0	1.8	2.3	0.58	260
78/254	25– 30	Eg	16.1	15.3	68.6	16.1	2.6	2.9	3.5	2.5	2.7	1.1	3.1	4.5	8.4	13.0	14.7	11.9	5.6	1.7	1.8	3.9	0.64	242
78/255	30– 60	Btg1	15.3	19.0	65.7	15.3	3.9	3.5	3.7	2.8	4.5	0.6	2.4	3.8	7.3	12.0	14.6	12.5	4.9	2.0	1.9	4.3	0.58	255
78/256	60– 84	2Btg2	6.4	4.5	89.1	6.4	0.6	0.7	0.6	0.2	1.0	1.4	2.1	3.8	10.2	31.0	14.1	8.9	5.8	2.9	1.5	0.8	0.77	189
78/257	84–105	3Btg3	3.1	1.0	95.9	3.1	0.1	0.2	0.1	0.2	0.2	0.2	0.2	0.5	1.8	5.6	12.0	23.9	26.5	16.4	7.3	1.7	0.89	457



c. CHEMICAL DATA

Sample	Depth	Horizon	Clay	Humus	$CaCO_3$	pH-KCl	CEC/soil	CEC/clay	Exch. bases $1/2Ca^{2+}$	$1/2Mg^{2+}$	Na^+	K^+	Sum	Exch. acidity $1/3\ Al^{3+}$	H^+	BS	Fe_2O_3 ox	Fe_2O_3 dith	Al_2O_3 dith
	cm		%	%	%		mmol/kg	mmol/kg			mmol/kg				mmol/kg	%	%	%	%
78/253	0- 25	Ap	14.0	3.2	-	4.9	106	757	43	4	-	-	47			44	0.3	1.4	0.9
78/254	25- 30	Eg	16.1	0.8	-	4.8	56	348	42	4	-	-	46			82	0.2	1.5	0.9
78/255	30- 60	Btg1	15.3	0.3	-	4.9	50	327	43	4	-	-	47			94	0.2	1.9	1.0
78/256	60- 84	2Btg2	6.4	0.4	-	4.9	31	484	28	4	-	-	32			103	0.2	0.6	0.5
78/257	84-105	3Btg3	3.1	0.2	-	5.1	25	806	28	4	-	-	32			128	0.1	0.4	0.2

d. TOTAL CHEMICAL COMPOSITION OF THE CLAY FRACTION

Sample	Depth	Horizon	Clay	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	BaO	H_2O^+	CEC/clay*
	cm		%	% w/w													mmol/kg
78/253	0- 25	Ap	14.0	50.19	24.43	6.84	0.77	0.09	1.46	0.05	0.25	2.64	1.08	0.42	3.40	8.88	440
78/254	25- 30	Eg	16.1	49.30	24.65	8.33	0.79	0.09	1.64	0.03	0.21	2.91	0.98	0.11	2.81	8.63	370
78/255	30- 60	Btg1	15.3	50.86	25.14	7.24	0.64	0.25	1.71	0.02	0.22	3.19	1.05	0.07	2.41	7.84	310
78/256	60- 84	2Btg2	6.4	47.91	25.49	7.94	0.62	0.03	1.90	0.04	0.25	3.00	0.82	0.17	3.42	8.67	450
78/257	84-105	3Btg3	3.1	47.80	26.15	7.23	0.43	0.11	2.40	0.02	0.12	3.23	0.58	0.20	3.43	8.92	450

e. PHYSICAL CHARACTERISTICS (horizon averages*** and averages of 5 core samples***)

Depth	Horizon	Texture (mm) <2	2-50	>50	Humus	Bulk density	Particle density	Pore volume	Moisture content pF2	pF4.2	pF2	pF4.2	Available moisture VpF2-VpF4.2	Air volume pF2	pF4.2
cm		%			%	kg/m^3	kg/m^3	%	%w/w		%v/v		mm/10 cm	%	
0- 25	Ap	14.0	18.0	68.0	3.2	1430	2640	45.6	17.2	7.5	24.6	10.7	13.9	21.0	34.9
25- 30	Eg	16.1	15.3	68.6	0.8	1860	2660	30.2	13.0	6.2	24.2	11.5	12.7	6.0	18.7
30- 60	Btg1	15.3	19.0	65.7	0.3	1770	2690	34.2	13.3	6.5	23.5	11.5	12.0	10.7	22.7
60- 84	2Btg2	6.4	4.5	89.1	0.4	1670	2680	37.8	12.5	3.1	20.9	5.2	15.7	16.9	32.6
84-105	3Btg3	3.1	1.0	95.9	0.2	1700	2670	36.3	8.9	2.0	15.1	3.4	11.7	21.2	32.9
													** 140 cm		
10- 15						1310	2660	50.3	17.4	7.5	22.8	9.8	13.0	27.5	40.5
18- 23						1550	2630	40.9	16.9	7.5	26.1	11.6	14.5	14.8	29.3
25- 30						1860	2660	30.2	13.0	6.2	24.2	11.5	12.7	6.0	18.7
40- 45						1770	2690	34.2	13.3	6.5	23.5	11.5	12.0	10.7	22.7
70- 75						1670	2680	37.8	12.5	3.1	20.9	5.2	15.7	16.9	32.6
85- 90						1700	2670	36.3	8.9	2.0	15.1	3.4	11.7	21.2	32.9

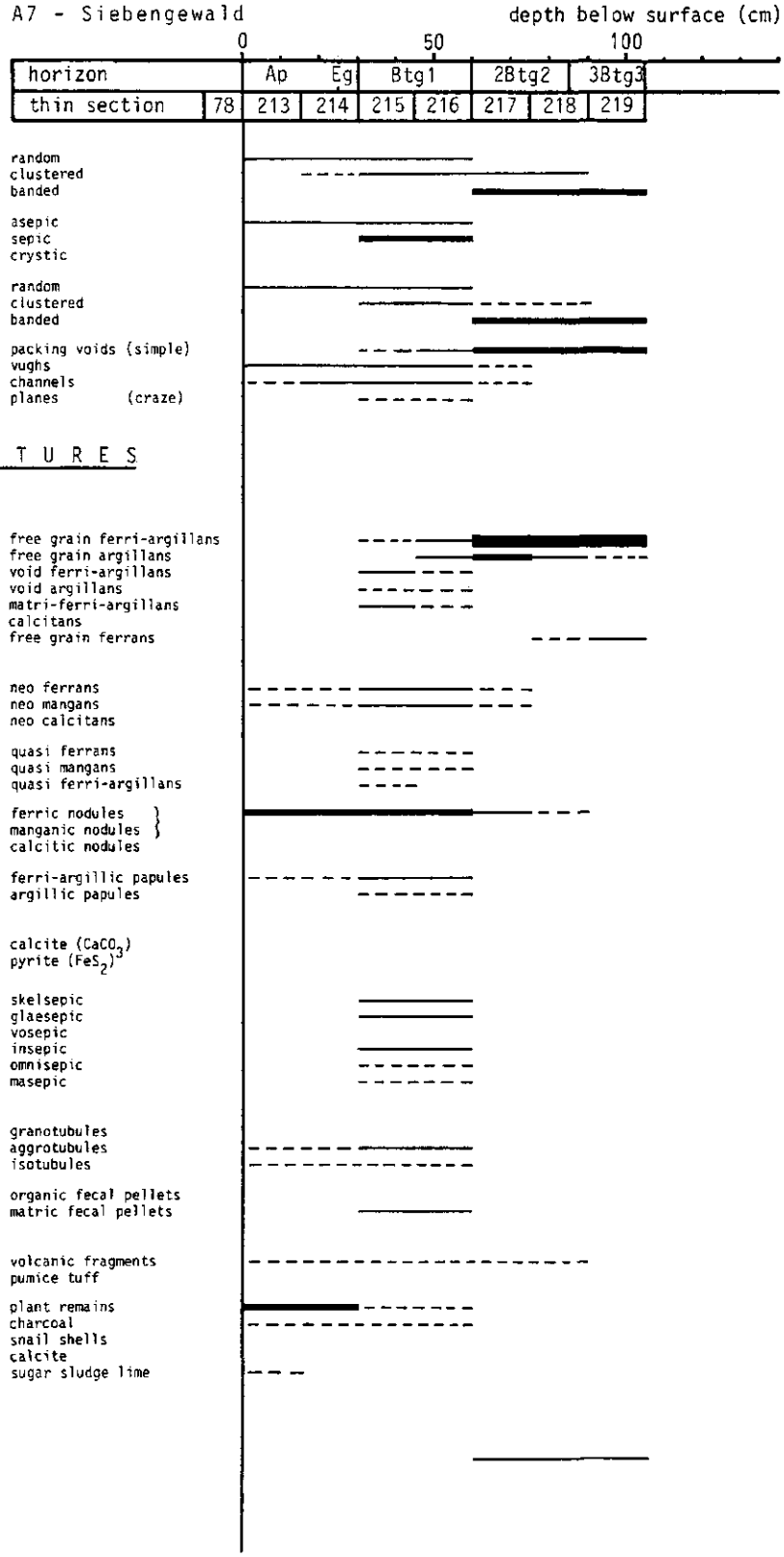
* Calculated for adsorbed $\frac{1}{2}Ba^{2+}$

** Sum over profile depth

*** Calculation with rounded averages may cause differences of some decimals

f. MICROMORPHOLOGICAL OBSERVATIONS

A7 - Siebengewald



A.8. MILSBEEK

a. Profile description

General data

1. Location: Topographical map of the Netherlands, scale 1:25.000 (1967), sheet 46B + E; coordinates; N 416.530; E 194.590.
2. Date of description: 20-6-1978.
3. Described by: A.E.C. van Dis and J.J.R. Robben.
4. Mapping unit: LL2.

Soil site characteristics

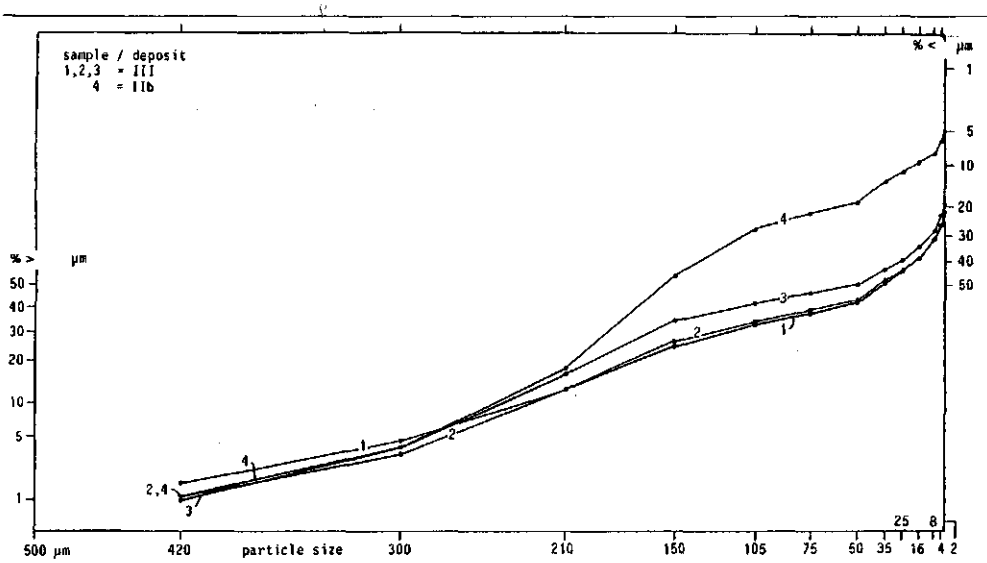
1. Classification:
   a. according to FAO-Unesco (1974): Mollic Gleysol.
   b. according to the Soil Taxonomy (1975): Fluvaquentic Haplaquoll
   c. according to De Bakker and Schelling (1966): Leekeerdgrond
2. Land use: grassland.
3. Geology: medium-textured Late Weichselian Rhine deposit.
4. Physiography: lower part alluvial plain near shallow infilled channels.
5. Relief: flat or concave
6. Slope: level to nearly level, class A.
7. Altitude: 11.8 m +NAP (Amsterdam Ordnance Datum).
8. Hydrology:
   a. Soil drainage class: imperfectly drained.
   b. Groundwater level:
      presumed highest: 40 cm below the soil surface
      presumed lowest: 70 cm below the soil surface
      actual: 70 cm below the soil surface
   c. Artificial drainage: ditches
   d. Flooding: sometimes in winter.
9. Evidence of human activity: soils in the area have been used for making pottery.

Description of the soil horizons

Ahg	0-25 cm:	loam; 10 YR 3/3 (moist); few fine distinct sharply bounded 5 YR 5/8 iron mottles; moderate strong fine subangular blocky structure; firm; few fine to coarse biopores, many very fine biopores: many very fine to fine roots; clear and smooth to:
Bwg	25-38 cm:	loam; 10 YR 4/1 (moist); few fine distinct round and vertically elongated 5 YR 5/8 iron mottles; strong coarse, smooth prismatic structure; few fine to coarse biopores, many very fine biopores; common very fine to fine roots; clear and wavy to: remark: the horizon contains many coarse dead roots.
Cg	38-65 cm:	loam; 5 Y 5/2 (wet); common medium distinct to faint iron mottles; weak medium subangular blocky structure; non-sticky, slightly plastic; few medium to coarse biopores, common very fine biopores; clear and smooth to: remark: the horizon contains many coarse dead roots.
2Cr	65-90 cm:	loamy sand, with laminae of sandy clay: 5 YR 5/1 (wet); macrostructureless; non-sticky, non-plastic. remark: the horizon contains many coarse dead roots.

b. PARTICLE SIZE DISTRIBUTION

Sample	Depth	Horizon	Particle size classes in µm																			Md 50 sand fraction
			<2	2-50	>50	<2	2-4	4-8	8-16	16-25	25-35	35-50	50-75	75-105	105-150	150-210	210-300	300-420	420-600	600-850	850-1200	1200-1700	<2µm <16µm	µm
	cm		%			%																		
78/258	0- 25	Ahg	22.3	35.8	41.9	22.3	4.2	5.0	7.3	5.1	6.2	8.0	4.5	4.1	8.1	12.5	8.1	2.9	1.2	0.4	0.1	-	0.57	170
78/259	25- 38	Bwg	22.0	35.4	42.6	22.0	4.8	5.0	7.2	4.9	4.9	8.6	3.8	4.5	7.4	14.1	9.4	2.2	0.8	0.3	-	0.1	0.56	174
78/260	38- 65	Cg	19.1	31.6	49.3	19.1	4.3	4.6	6.2	5.9	3.5	7.1	3.8	3.5	7.3	18.3	12.6	2.8	0.7	0.2	0.1	-	0.56	183
78/261	65- 90	2Cr	5.0	14.0	81.0	5.0	1.1	1.9	1.6	2.0	2.2	3.2	3.5	5.6	17.9	36.7	13.5	2.7	0.7	0.2	0.1	0.1	0.52	172



c. CHEMICAL DATA

Sample	Depth	Horizon	Clay	Humus	$CaCO_3$	pH-KCl	CEC/soil	CEC/clay	Exch. bases					Exch. acidity		BS	Fe_2O_3	Al_2O_3
									1/2Ca^{2+}	1/2Mg^{2+}	Na^+	K^+	Sum	1/3 Al^{3+}	H^+		ox	dith
	cm		%	%	%		mmol/kg	mmol/kg	mmol/kg						mmol/kg	%	%	%
78/258	0- 25	Ahg	22.3	3.6	-	4.5	155	695	85	39	-	3	127			82	0.2	0.9	1.1
78/259	25- 38	Bwg	22.0	0.9	-	4.4	123	559	56	51	-	5	112			91	0.2	1.1	1.1
78/260	38- 65	Cg	19.1	1.3	-	4.5	91	476	55	43	-	4	102			112	0.1	0.9	0.9
78/261	65- 90	2Cr	5.0	1.3	1.0	4.4	35	700	40	6	-	-	46			131	0.1	0.4	0.4

d. TOTAL CHEMICAL COMPOSITION OF THE CLAY FRACTION

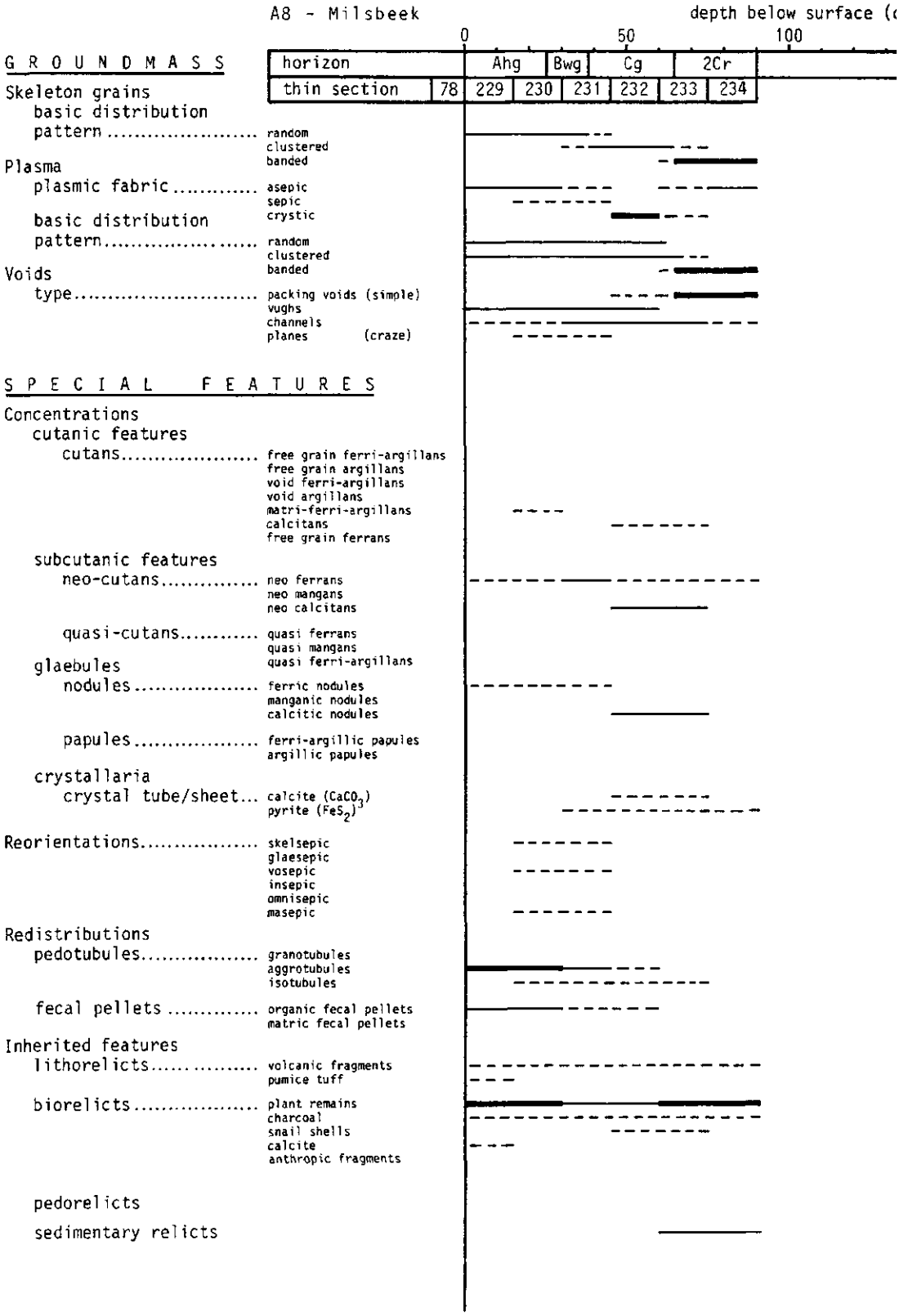
Sample	Depth	Horizon	Clay	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	BaO	H_2O^+	CEC/clay*
	cm		%	% w/w													mmol/kg
78/258	0- 25	Ahg	22.3	50.33	25.15	5.36	0.92	0.02	2.18	0.20	0.21	2.43	0.80	0.12	4.96	8.09	650
78/259	25- 38	Bwg	22.0	49.30	24.79	5.54	1.06	0.02	2.25	0.34	0.16	2.42	0.73	0.09	5.08	8.40	660
78/260	38- 65	Cg	19.1	51.13	24.46	5.71	1.14	0.03	2.54	0.18	0.20	2.86	0.82	0.07	4.46	7.13	580
78/261	65- 90	2Cr	5.0	49.70	22.55	5.41	1.32	0.02	2.90	0.19	0.23	3.61	0.84	0.14	5.56	7.62	730

e. PHYSICAL CHARACTERISTICS (horizon averages*** and averages of 5 core samples***)

Depth	Horizon	Texture (µm)			Humus	Bulk density	Particle density	Pore volume	Moisture content				Available moisture	Air volume	
		<2	2-50	>50					pF2	pF4.2	pF2	pF4.2	VpF2-VpF4.2	pF2	pF4.2
cm		%			%	kg/m³	kg/m³	%	%w/w			%v/v	mm/10 cm	%	
0- 25	Ahg	22.3	35.8	41.9	3.6	1160	2590	55.2	34.1	17.6	39.6	20.4	19.2	15.6	34.8
25- 38	Bwg	22.0	35.4	42.6	0.9	1380	2660	48.1	25.9	13.0	35.7	17.9	17.8	12.4	30.2
38- 65	Cg	19.1	31.6	49.3	1.3	1460	2700	46.1	25.6	9.9	38.8	14.5	24.3	7.3	31.6
65- 90	2Cr	5.0	14.0	81.0	1.3	1360	2680	49.3	25.8	7.0	35.1	9.5	25.6	14.2	39.8
													** 200 mm		
10- 15						1170	2670	56.5	35.7	17.6	41.8	20.6	21.2	12.7	33.9
18- 23						1150	2600	55.8	32.5	17.6	37.4	20.2	17.2	18.4	35.6
30- 35						1380	2660	48.1	25.9	13.0	35.7	17.9	17.8	12.4	30.2
42- 47						1530	2700	43.3	25.1	9.9	38.4	15.1	23.3	4.9	28.2
50- 55						1380	2700	48.9	28.2	9.9	38.9	13.7	25.2	10.0	33.2
68- 73						1360	2680	49.3	25.8	7.0	35.1	9.5	25.6	14.2	39.8

* Calculated from adsorbed $\frac{1}{2}Ba^{2+}$
** Sum over profile depth
*** Calculations with rounded average may cause differences of some decimals

f. MICROMORPHOLOGICAL OBSERVATIONS



A.9 AALDONK

a. Profile description

General data

1. Location: Topographical map of the Netherlands, scale 1:25.000 (1976), sheet: 46B + E, coordinates: N 414.680; E 197.510
2. Date of description: 14-7-1977.
3. Described by: J. Wijntje and G. du Bois.
4. Mapping unit ML2.

Soil site characteristics

1. Classification:
   a. according to FAO-Unesco (1974): Gleyic Podzoluvisol
   b. according to the Soil Taxonomy (1975): Aeric Ochraquult
   c. according to De Bakker and Schelling (1966): Kuilbrikgrond.
2. Land use: arable land - potatoes.
3. Geology: medium- to fine-textured Late Weichselian Rhine deposit.
4. Physiography: lower part of a weakly undulating alluvial plain of a braided river system.
5. Relief: flat or concave
6. Slope: level to nearly level, class A.
7. Altitude: 12.7 m +NAP (Amsterdam Ordnance Datum).
8. Hydrology:
   a. Soil drainage class: imperfectly drained
   b. Groundwater level:
      presumed highest: 70 cm below soil surface
      presumed lowest: 120 cm below the soil surface
      actual: 120 cm below the soil surface
   c. Artificial drainage: none
   d. Flooding: none.
9. Evidence of human activity: Ap to 20 cm.

Description of soil horizons

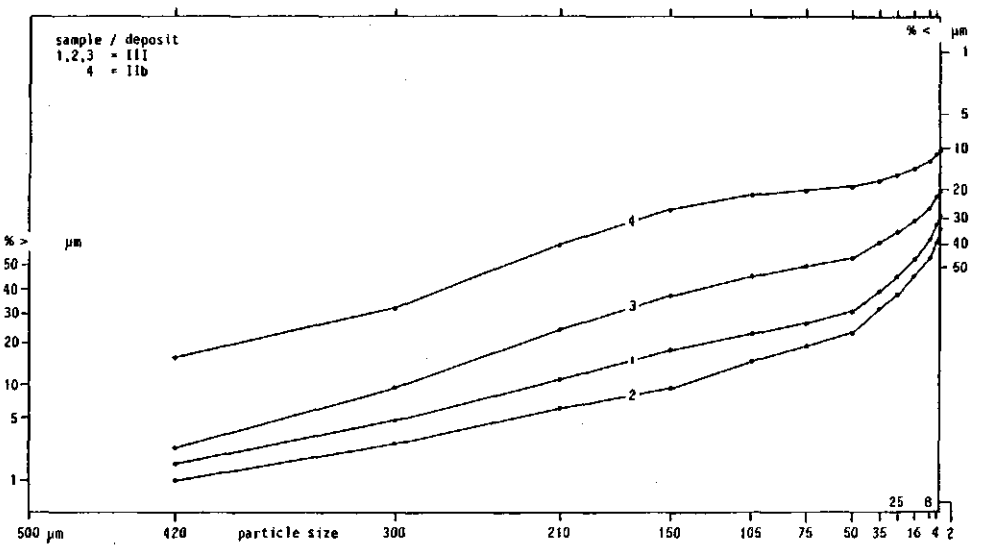
Ap	0-20 cm:	loam: 10 YR 4/3 (moist); weak fine subangular blocky structure; firm; common large and fine biopores; common fine roots; abrupt and smooth to:
Btg1	20-52 cm:	clay loam: 10 YR 5/3 (moist) on ped faces, 7.5 YR 5/8 (moist) in peds; few fine faint Mn-mottles; strong medium compound rough prismatic structure, subdivided into weak coarse subangular blocky structure; common medium distinct 2.5 Y 7/2 reduction spots; many rootprints; firm; few large biopores, many fine pores in peds, common fine pores on ped faces; few fine roots; gradual and smooth to:
Btg2	52-69 cm:	sandy clay loam; mottled 2.5 Y 7/1 (45%), 7.5 YR 5/8 (40%), 7.5 YR 5/4 (10%), and 5 YR 5/8 (5%) (moist); moderate medium compound rough prismatic structure, subdivided into weak coarse subangular blocky structure; friable; common rootprints; on ped faces 10 YR 5/3 material; common fine biopores in peds, few on ped faces; few fine roots; gradual and tongued to
2Btg3	69-94 cm:	loamy sand to sandy loam; mottled 2.5 Y 7/2 (60%), 7.5 YR 6/8 (30%), 5 YR 4/8 (10%) (moist); single grain structure; very friable; very few fine biopores; no

roots; clear and smooth to

2Btg4 94-130 cm: loamy sand; stratified 2.5 Y 7/2, 7.5 YR 6/3, 7.5 YR 6/8 (wet), undisturbed stratification; loose; non-sticky, non-plastic.

b. PARTICLE SIZE DISTRIBUTION

Sample	Depth	Horizon	<2	2-50	>50	Particle size classes in µm: <2	2-4	4-8	8-16	16-25	25-35	35-50	50-75	75-105	105-150	150-210	210-300	300-420	420-600	600-850	850-1200	1200-1700	<2µm / <16µm	Md 50 sand fraction
	cm		%			%				%														µm
77/571	0-20	Ap	24.4	44.8	30.8	24.4	7.7	7.0	8.4	7.2	6.1	8.4	4.0	3.5	5.1	7.0	6.4	3.1	1.2	0.4	0.1	-	0.51	174
77/572	20-52	Btg1	33.8	42.4	23.8	33.8	6.0	6.8	8.1	7.8	4.8	8.9	4.5	4.0	5.9	3.2	3.4	1.8	0.8	0.2	-	-	0.62	131
77/573	52-69	Btg2	21.2	25.1	53.7	21.2	2.3	3.5	1.2	4.6	4.0	6.5	4.2	4.3	7.8	12.6	15.4	6.9	2.1	0.4	-	-	0.88	200
77/574	69-94	2Btg3	10.9	8.9	80.2	10.9	0.7	1.6	2.0	1.6	1.2	1.8	1.2	1.3	5.2	13.4	26.8	16.3	8.9	4.8	2.3	-	0.72	275



c. CHEMICAL DATA

Sample	Depth	Horizon	Clay	Humus	$CaCO_3$	pH-KCl	CEC/soil	CEC/clay	Exch. bases $1/2Ca^{2+}$	Exch. bases $1/2Mg^{2+}$	Na^+	K^+	Sum	Exch. acidity $1/3\ Al^{3+}$	Exch. acidity H^+	BS	Fe_2O_3 ox	Fe_2O_3 dith	Al_2O_3 dith
	cm		%	%	%		mmol/kg	mmol/kg			mmol/kg				mmol/kg	%	%	%	%
77/571	0-20	Ap	24.4	1.5	-	5.7	126	516	55	17	-	-	72	1	2	57	0.5	1.4	0.8
77/572	20-52	Btg1	33.8	0.9	-	3.8	142	420	-	12	-	-	12	56	11	8	0.6	3.5	1.1
77/573	52-69	Btg2	21.1	0.0	-	3.7	110	519	-	6	-	-	6	56	9	5	0.5	2.3	0.2
77/574	69-94	2Btg3	10.9	0.0	-	3.9	55	505	-	4	-	-	4	27	8	7	0.2	0.3	0.2

d. TOTAL CHEMICAL COMPOSITION OF THE CLAY FRACTION

Sample	Depth	Horizon	Clay	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	BaO	H_2O^+	CEC/clay*
	cm		%	% w/w													mmol/kg
77/571	0-20	Ap	24.4	48.24	25.67	6.52	0.58	0.07	1.82	0.12	0.32	3.11	0.98	0.43	3.13	8.89	410
77/572	20-52	Btg1	33.8	46.74	24.45	11.03	0.47	0.03	1.88	0.05	0.22	3.28	0.81	0.23	3.80	8.27	500
77/573	52-69	Btg2	21.2	46.55	24.78	9.29	0.32	0.03	1.85	0.05	0.21	3.18	0.74	0.18	4.31	8.37	560
77/574	69-94	2Btg3	10.9	50.17	26.39	5.65	0.25	0.02	1.80	0.05	0.22	3.32	0.80	0.16	3.68	8.28	480

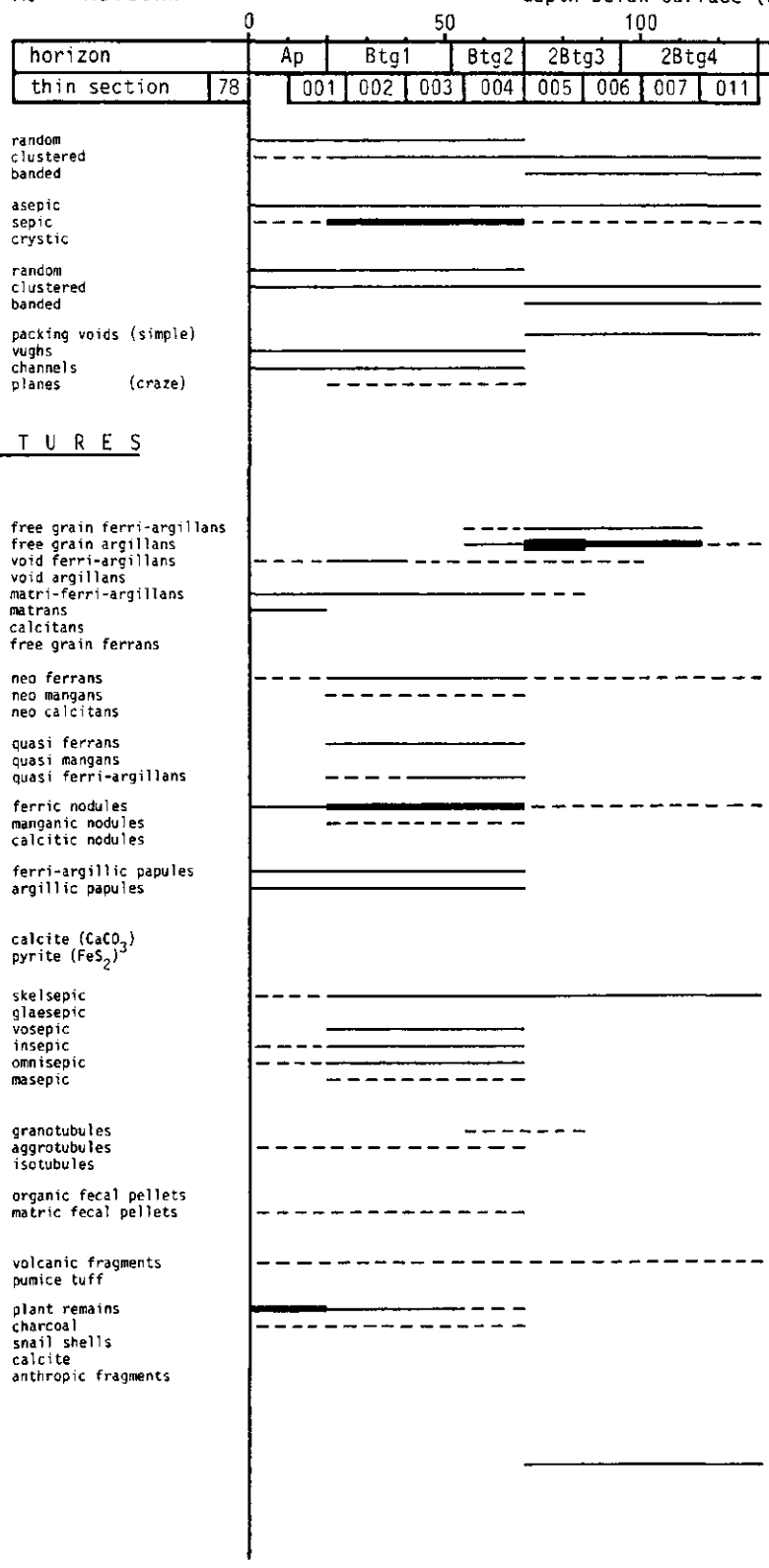
e. PHYSICAL CHARACTERISTICS (horizon averages and averages of 5 core samples)

Depth	Horizon	Texture (μm) <2	2-50	>50	Humus	Bulk density	Particle density	Pore volume	Moisture content pF2	pF4.2	Available moisture pF2	pF4.2	Available moisture $Vp_{F2}-Vp_{F4.2}$	Air volume pF2	pF4.2
cm		%			%	kg/dm^3	kg/m^3	%	% w/w		% v/v		mm/10 cm	%	
0-20	Ap	24.4	44.8	30.8	1.5	1560	2690	42.0	21.7	10.6	33.8	16.5	17.3	8.2	25.5
20-52	Btg1	33.8	42.4	23.8	0.9	1630	2710	40.1	22.4	12.3	36.5	20.0	16.5	3.6	20.1
52-69	Btg2	21.2	25.1	53.7	0.0	1610	2720	41.0	23.4	10.4	37.7	16.7	21.0	3.3	24.3
69-94	2Btg3	10.9	8.9	80.2	0.0	1570	2670	41.6	14.0	6.0	22.0	9.4	12.6	19.6	32.2
													** 153 mm		
5-10						1560	2690	42.0	21.7	10.6	33.8	16.5	17.3	8.2	25.5
20-25						1660	2690	38.3	20.8	12.3	34.5	20.4	14.1	3.8	17.9
35-40						1590	2730	41.9	23.9	12.3	38.0	19.6	18.4	3.9	22.3
60-65						1610	2720	41.0	23.4	10.4	37.7	16.7	21.0	3.3	24.3
80-85						1570	2670	41.6	14.0	6.0	22.0	9.4	12.6	19.6	32.2

* Calculated from adsorbed $\%Ba^{2+}$
** Sum over profile depth
*** Calculations with rounded averages may cause differences of some decimals

f. MICROMORPHOLOGICAL OBSERVATIONS

A9 - Aaldonk



A.10 AZEWIJN I

a. Profile description

General data

1. Location: Topographical map of the Netherlands, scale 1:25.000 (1966) sheet 40H, coordinates: N 433.820; E 219.520.
2. Date of description: 2-5-1977
3. Described by: Th. Pape.
4. Mapping unit: KML2

Soil site characteristics

1. Classification:
   a. according to FAO-Unesco (1974): Gleyic Cambisol
   b. according to the Soil Taxonomy (1975): Thapto Ochraqualfic Dystric Fluventic Eutrochrept
   c. according to De Bakker and Schelling (1966): Poldervaaggrond (Kuilbrikgrond)
2. Land use: grassland near clay excavation.
3. Geology: fine-textured Late Weichselian Rhine deposit overlain by 50 cm fine-textured Holocene Rhine deposit
4. Physiography: basin area with some microlief.
5. Relief: flat or concave
6. Slope: level to nearly level, class A.
7. Altitude: 14.0 m +NAP (Amsterdam Ordnance Datum)
8. Hydrology:
   a. Soil drainage class: imperfectly drained
   b. Groundwater level:
      presumed highest: 40 cm below soil surface
      presumed lowest: 180 cm below soil surface
      actual: 140 cm below soil surface
   c. Artificial drainage: ditches
   d. Flooding: none
9. Evidence of human activity: somewhat compacted topsoil; clay excavation.

Description of soil horizons

Ahg	0-15 cm:	silty clay; 10 YR 4/2 (moist); few fine faint 10 YR 5/8 iron mottles; weak to moderate very fine to medium angular and subangular blocky structure; very firm; distinct very fine rootprints; few very fine biopores; many very fine roots; gradual and smooth to:
ABg	15-40 cm:	silty clay; 10 YR 4/3 (moist); few fine faint 10 YR 5/6 iron mottles, few 10 YR 2/1 manganese mottles and concretions (hard); strong coarse rough prismatic structure subdivided into weak medium subangular blocky structure; firm; distinct very fine rootprints; few large and few very fine biopores; common very fine roots; gradual and smooth to:
Bwg	40-50 cm:	clay; 10 YR 5/4 (moist); common fine distinct 10 YR 5/8 iron mottles, few fine prominent hard manganese concretions; strong coarse rough prismatic structure subdivided into weak medium angular and subangular blocky structure, sometimes fine prismatic; firm; few

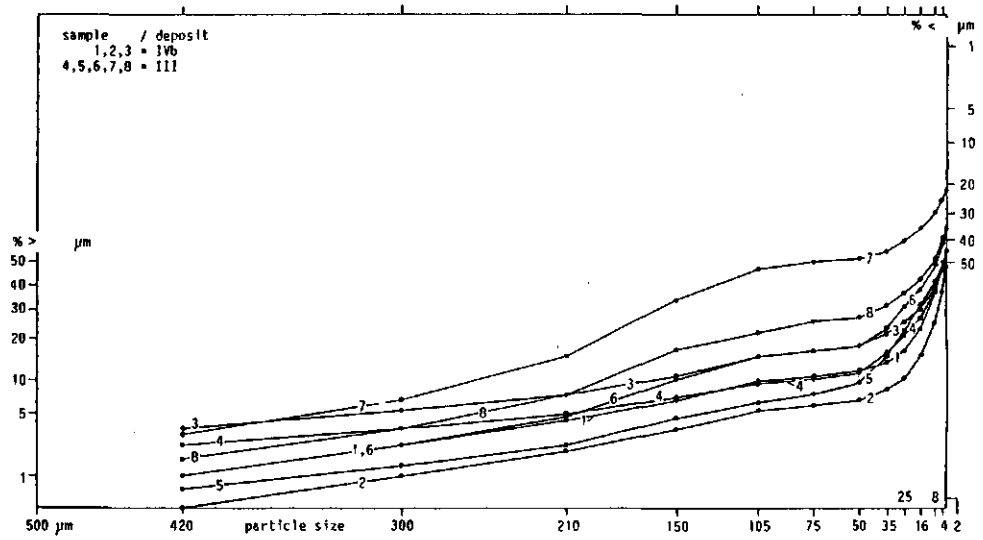
fine rootprints; few large and common fine and few very fine biopores; few very fine roots; clear and smooth to:

2Btg 50-110 cm: silty clay; 10 YR 5/2 (moist); common to many fine and medium distinct 10 YR 5/8 iron mottles, common fine prominent 10 YR 2/1 manganese mottles; moderate coarse rough prismatic structure; very firm; prominent very fine rootprints; common fine and few very fine biopores; few very fine roots; clear and wavy to:

2Cgk/2Cg 110-130 cm: clay loam; 10 YR 5/1 (moist); common fine distinct 10 YR 5/8 iron mottles, many fine distinct 10 YR 8/2 $CaCO_3$ mottles; macrostructureless; firm; few prominent rootprints; few fine biopores, few fine dead rootrests (fossil?); strongly calcareous from 110-120 cm, from 120-130 cm weakly calcareous.

b. PARTICLE SIZE DISTRIBUTION

Sample	Depth cm	Horizon	<2	2-50	>50	Particle size classes in µm: <2	2-4	4-8	8-16	16-25	25-35	35-50	50-75	75-105	105-150	150-210	210-300	300-420	420-600	600-850	850-1200	1200-1700	<2µm <16µm	MH 50 sand fraction µm
			%			%																		
77/552	0- 15	Ahg	41.1	46.9	12.0	41.1	9.3	12.3	13.9	6.3	3.1	2.0	1.1	1.0	3.1	2.6	1.9	1.3	0.6	0.3	0.1	-	0.54	169
77/553	15- 40	ABg	52.0	41.2	6.8	52.0	12.7	10.0	9.7	5.1	2.1	1.6	0.8	0.7	1.8	1.5	1.0	0.6	0.3	0.1	-	-	0.62	154
77/554	40- 50	Bwg	45.6	35.7	18.7	45.6	8.0	7.0	8.5	4.5	3.6	4.1	1.6	1.6	4.4	3.4	2.3	1.8	1.3	1.1	0.8	0.2	0.66	181
77/555	50- 70	2Btg1	46.2	41.9	11.9	46.2	8.4	8.1	10.1	5.7	5.3	4.3	1.2	1.1	2.5	2.2	1.5	1.1	0.8	0.8	0.5	0.2	0.63	181
77/556	70- 85	2Btg2	43.3	47.3	9.4	43.3	7.0	9.1	9.2	8.9	7.3	5.8	1.7	1.1	2.0	2.3	1.0	0.6	0.4	0.2	0.1	-	0.63	148
77/557	85-110	2Btg3	36.6	44.8	18.6	36.6	6.1	9.0	9.7	7.3	6.9	5.8	1.8	1.5	4.7	5.8	2.5	1.3	0.7	0.2	0.1	-	0.60	163
77/558	110-120	2Cgk	21.9	26.4	51.7	21.9	3.6	4.4	6.0	4.7	4.6	3.1	1.4	3.0	13.2	18.7	8.6	3.8	2.0	0.8	0.2	-	0.61	177
77/559	120-130	2Cg	35.3	37.0	27.7	35.3	5.8	7.5	9.0	5.2	5.2	4.3	1.6	3.5	5.4	10.0	3.7	1.8	1.0	0.4	0.2	0.1	0.61	170



c. CHEMICAL DATA

Sample	Depth	Horizon	Clay	Humus	$CaCO_3$	pH-KCl	CEC/soil	CEC/clay	Exch. bases					Exch. acidity		BS	Fe_2O_3		Al_2O_3
									1/2Ca^{2+}	1/2Mg^{2+}	Na^+	K^+	Sum	1/3 Al^{3+}	H^+		ox	dith	dith
	cm		%	%	%		mmol/kg	mmol/kg	mmol/kg							%	%		%
77/552	0- 15	Ahg	41.1	6.6	-	4.4	298	725	166	44	-	-	210			70	1.0	4.0	1.5
77/553	15- 40	ABg	52.0	1.8	-	4.8	258	496	196	53	-	-	249			97	0.8	4.1	1.5
77/554	40- 50	Bwg	45.6	0.9	-	5.1	236	518	194	48	-	-	242			103	0.6	5.0	1.5
77/555	50- 70	2Btg1	46.2	0.0	0.1	5.4	222	481	178	37	-	-	215			97	0.5	4.9	1.4
77/556	70- 85	2Btg2	43.3	0.0	-	5.5	253	584	225	37	-	-	262			104	0.2	4.3	1.3
77/557	85-110	2Btg3	36.6	0.0	-	5.7	211	577	198	25	-	-	223			106	0.3	3.9	1.2
77/558	110-120	2Cgk	21.9	0.7	12.5	7.5	163	744	150	13	-	-	163			100	0.2	2.2	0.8
77/559	120-130	2Cg	35.3	0.3	0.8	7.1	218	618	198	20	-	-	218			100	0.3	3.3	1.1

d. TOTAL CHEMICAL COMPOSITION OF THE CLAY FRACTION

Sample	Depth	Horizon	Clay	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	BaO	H_2O^+	CEC/clay*
	cm		%	%w/w													mmol/kg
77/552	0- 15	Ahg	41.1	48.83	23.48	7.95	0.72	0.11	2.50	0.26	0.25	3.03	0.89	0.26	3.86	8.79	500
77/553	15- 40	ABg	52.0	49.32	24.48	8.29	0.42	0.16	2.60	0.12	0.20	2.89	0.82	0.21	4.19	8.04	550
77/554	40- 50	Bwg	45.6	49.30	24.52	8.40	0.37	0.20	2.20	0.18	0.22	2.41	0.86	0.16	4.30	8.35	560
77/555	50- 70	2Btg1	46.2	48.68	24.03	9.06	0.15	0.39	2.01	0.07	0.23	2.46	0.87	0.14	4.17	8.35	540
77/556	70- 85	2Btg2	43.3	47.97	23.99	9.07	0.22	0.18	2.20	0.07	0.21	3.04	0.73	0.09	4.11	7.76	540
77/557	85-110	2Btg3	36.6	48.69	23.89	9.31	0.31	0.19	2.34	0.07	0.22	3.19	0.70	0.09	4.16	7.59	540
77/558	110-120	2Cgk	21.9	49.14	22.98	9.00	0.36	0.04	2.29	0.13	0.20	2.81	0.64	0.13	5.04	7.34	660
77/559	120-130	2Cg	35.3	48.06	22.77	9.82	0.38	0.16	2.36	0.05	0.25	3.16	0.68	0.13	4.33	7.43	560

e. PHYSICAL CHARACTERISTICS (*horizon averages*** *and averages of 5 core samples*****)

Depth	Horizon	Texture (m)			Humus	Bulk density	Particle density	Pore volume	Moisture content				Available moisture		Air volume	
		<2	2-50	>50					pF2	pF4.2	pF2	pF4.2	VpF2-VpF4.2		pF2	pF4.2
cm		%			%	kg/m³	kg/m³	%	%w/w		%v/v		mm/10 cm		%	
0- 15	Ahg****	41.1	46.9	12.0	6.6	1200	2660	54.9	37.3	17.4	45.0	20.9	24.1		8.9	34.0
15- 40	ABg	52.0	41.2	6.8	1.8	1180	2730	56.8	38.1	19.4	45.0	22.9	22.1		11.8	33.9
40- 50	Bwg	45.6	35.7	18.7	0.9	1290	2730	52.7	30.2	19.4	38.9	25.0	13.9		13.8	27.7
50- 70	2Btg1	46.2	41.9	11.9	0.0	1480	2770	46.6	26.6	16.5	39.3	24.4	14.9		7.3	22.2
70- 85	2Btg2	40.0	46.0	14.0	0.0	1470	2770	46.9	29.5	16.5	43.4	24.3	19.1		3.5	22.6
													** 165 mm			
21- 28						1180	2730	56.8	38.1	19.4	45.0	22.9	22.1		11.8	33.9
40- 45						1290	2730	52.7	30.2	19.4	38.9	25.0	13.8		13.8	27.7
55- 60						1480	2770	46.6	26.6	16.5	39.3	24.4	14.9		7.3	22.2
70- 75						1470	2770	46.9	29.5	16.5	43.4	24.3	19.1		3.5	22.6

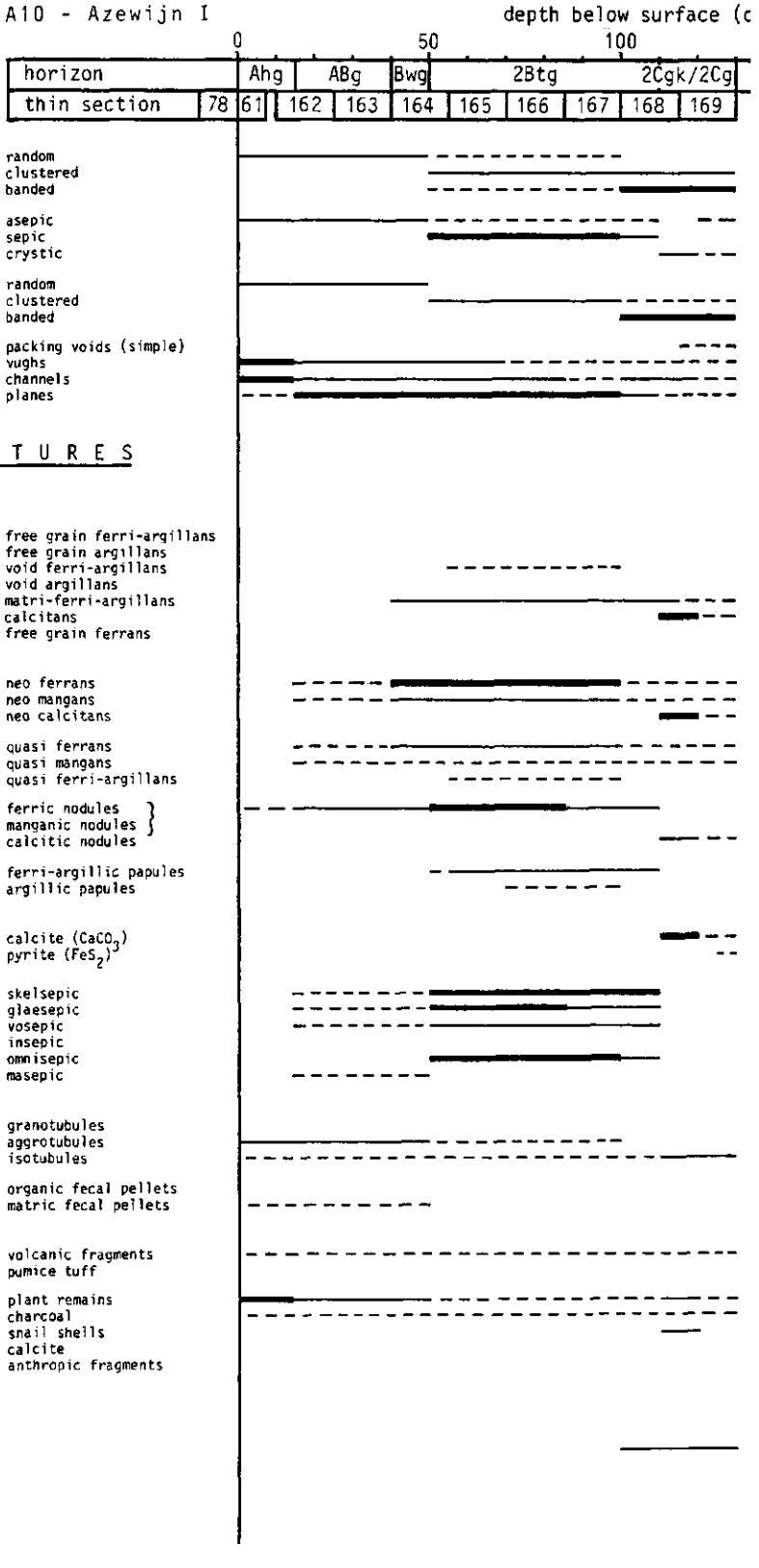
* *Calculated from adsorbed* Ba^{2+}

** Sum over profile depth.

*** Calculation with rounded averages may cause differences of some decimals

**** Data based on results from similar profile

f. MICROMORPHOLOGICAL OBSERVATIONS



A.11 AZEWIJN IV

a. Profile description

General data

1. Location: Topographical map of the Netherlands, scale 1:25.000 (1966) sheet 40H, coordinates: N 432.840; E 219.820
2. Date of description: 15-7-1977
3. Described by: R. Miedema.
4. Mapping unit: kHL3.

Soil site characteristics

1. Classification:
   a. according to FAO-Unesco (1974): Orthic Luvisol
   b. according to the Soil Taxonomy (1975): Mollic Hapludalf
   c. according to De Bakker and Schelling (1966): Daalbrikgrond
2. Land use: grassland near clay excavation
3. Geology: medium-textured Late Weichselian Rhine deposit overlain by 30 cm medium-textured Holocene Rhine deposit.
4. Physiography: small summit in basin area with some microrelief
5. Relief: flat or concave
6. Slope: level to nearly level, class A
7. Altitude: 14.3 m +NAP (Amsterdam Ordnance Datum)
8. Hydrology:
   a. Soil drainage class: moderately well drained
   b. Groundwater level:
      presumed highest: 75 cm below the soil surface
      presumed lowest: 180 cm below the soil surface
      actual: 180 cm below the soil surface
   c. Artificial drainage: ditches
   d. Flooding: none
9. Evidence of human activity: compacted topsoil; clay excavation.

Description of soil horizons

Ahg	0-10 cm:	loam; 10 YR 5/2 (moist); many fine red Fe-mottles around roots; strong fine to medium angular and subangular blocky structure, tending to weak medium rough prismatic structure; very firm; few large and common fine pedotubules; common medium and many fine roots; few quartz gravel; clear and smooth to:
Bw	10-30 cm:	loam; 10 YR 4/3 (moist); common fine hard Mn-concretions; moderate medium rough prismatic structure, subdivided into moderate subangular blocky structure; firm; common medium and fine biopores; common large pedotubules; common medium and fine roots; few quartz gravel; clear and smooth to:
2Bt	30-40 cm:	sandy clay loam; 7.5 YR 4/4 (moist); many medium hard Mn-concretions, few fine faint red Fe-mottles; weak fine compound rough prismatic structure, subdivided into moderate very porous subangular blocky structure; slightly firm; many medium and fine biopores; common large coated worm holes; common fine roots; few gravel; clear and smooth to:
2Btg1	40-60 cm:	sandy loam; 7.5 YR 4/6 (moist); common fine faint irregular Fe-mottles, many medium distinct slightly hard round Mn-concretions; sponge structure; friable;

many medium and fine biopores; common large coated worm holes; common fine roots; gradual and smooth to:

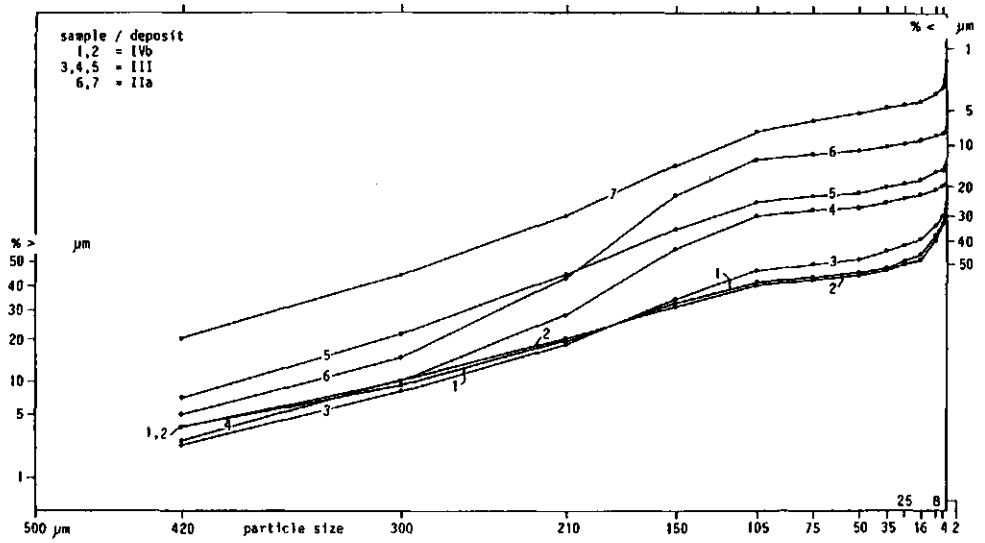
2Btg2 60–80 cm: sandy loam; 7.5 YR 5/6 (moist); few medium distinct 7.5 YR 5/8 Fe-mottles, common medium distinct Mn-mottles; sponge structure; friable; common medium and fine biopores; common large coated worm holes; few fine roots; clear and smooth to:

3Btg3 80–110 cm: stratified sand to loamy sand; 10 YR 5/8 (moist); common medium and fine Mn-mottles 7.5 YR 5/8 Fe in bands (<1/2 cm), clay-illuviation band at about 105 cm (7.5 YR 4/4); macrostructureless; friable; few large and many medium and fine pores; few fine roots; abrupt and smooth to:

3Btg4 110–130 cm: stratified sand; 10 YR 7/3 (moist); single grain structure; loose.

b. PARTICLE SIZE DISTRIBUTION

Sample	Depth cm	Horizon	<2	2–50	>50	<2	2–4	4–8	8–16	16–25	25–35	35–50	50–75	75–105	105–150	150–210	210–300	300–420	420–600	600–850	850–1200	1200–1700	<2µm / <16µm	Md 50 sand fraction µm
			%			%																		
77/560	0– 10	Ahg	25.6	29.0	45.4	25.6	6.3	6.6	7.8	2.6	3.3	2.4	1.5	2.4	7.9	13.7	10.6	5.6	2.6	0.7	0.3	0.1	0.55	198
77/561	10– 30	Bw	25.8	29.7	44.5	25.8	7.8	7.0	8.0	2.0	2.4	2.5	1.6	2.1	8.7	11.6	10.4	6.3	2.6	0.8	0.4	–	0.53	201
77/562	30– 40	2Bt	27.6	20.8	51.6	27.6	3.3	3.7	4.8	3.0	2.3	3.7	2.5	2.8	11.4	15.9	10.8	5.7	2.0	0.4	0.1	–	0.70	184
77/563	40– 60	2Btg1	19.0	8.3	72.7	19.0	1.5	0.9	1.7	1.5	1.2	1.5	1.2	2.0	12.7	28.1	18.5	7.4	2.4	0.4	–	–	0.82	193
77/564	60– 80	2Btg2	14.7	7.6	77.7	14.7	1.4	0.4	2.1	1.4	0.6	1.7	1.2	2.0	9.7	20.0	22.8	14.8	5.8	1.2	0.2	–	0.79	234
77/565	80–110	3Btg3	7.5	3.9	88.6	7.5	0.9	0.5	0.7	0.4	0.6	0.8	0.7	1.3	9.7	33.2	28.3	10.4	3.5	1.1	0.4	–	0.78	209
77/566	110–130	3Btg4	1.6	3.9	94.5	1.6	1.4	0.4	0.6	0.4	0.3	0.8	0.8	1.7	6.8	15.5	25.1	23.9	14.0	4.8	1.7	0.2	0.40	290



c. CHEMICAL DATA

Sample	Depth	Horizon	Clay	Humus	$CaCO_3$	pH-KCl	CEC/soil	CEC/clay	Exch. bases $1/2Ca^{2+}$	$1/2Mg^{2+}$	Na^+	K^+	Sum	Exch. acidity $1/3\ Al^{3+}$	H^+	BS	Fe_2O_3 ox	Fe_2O_3 dith	Al_2O_3 dith
	cm		%	%	%		mmol/kg	mmol/kg			mmol/kg				mmol/kg	%	%	%	%
77/560	0- 10	Ahg	25.6	4.3	0.1	5.5	143	559	117	17	-	-	134			94	0.8	2.6	1.0
77/561	10- 30	Bw	25.8	2.7	-	4.8	137	531	112	16	-	-	133			97	0.6	2.7	1.1
77/562	30- 40	2Bt	27.6	0.6	-	4.4	124	449	102	21	-	-	123			99	0.3	2.2	1.1
77/563	40- 60	2Btg1	19.0	0.4	-	4.5	104	547	80	19	-	-	99			95	0.2	2.1	1.0
77/564	60- 80	2Btg2	14.7	0.5	-	4.5	110	748	65	13	-	-	78			71	0.3	1.4	0.7
77/565	80-110	3Btg3	7.5	0.5	-	4.3	58	773	34	8	-	-	42			72	0.2	1.1	0.4
77/556	110-130	3Btg4	1.6	0.5	0.1	5.6	32	2000	18	4	-	-	22			69	0.1	0.4	0.2

d. TOTAL CHEMICAL COMPOSITION OF THE CLAY FRACTION

Sample	Depth	Horizon	Clay	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	BaO	H_2O^+	CEC/clay*
	cm		%	% w/w													mmol/kg
77/560	0- 10	Ahg	25.6	46.44	23.45	8.25	0.70	0.18	2.44	0.20	0.25	2.97	0.85	0.39	4.15	8.69	540
77/561	10- 30	Bw	25.8	48.17	23.92	8.27	0.69	0.22	2.45	0.14	0.25	3.09	0.87	0.33	3.78	8.08	490
77/562	30- 40	2Bt	27.6	47.53	24.68	8.70	0.61	0.20	2.25	0.09	0.23	2.95	0.75	0.30	3.92	8.09	510
77/563	40- 60	2Btg2	19.0	46.70	25.07	9.04	0.54	0.15	2.32	0.04	0.21	2.88	0.66	0.31	4.28	8.07	560
77/564	60- 80	2Btg3	14.7	46.43	24.92	8.97	0.50	0.16	2.45	0.11	0.23	2.82	0.64	0.37	4.54	8.41	590
77/565	80-110	3Btg3	7.5	46.38	25.06	9.71	0.49	0.15	2.49	0.05	0.21	2.78	0.64	0.44	4.26	8.66	560
77/566	110-130	3Btg4	1.6	no data													

e. PHYSICAL CHARACTERISTICS (horizon averages**** and averages of 4 core samples****)

Depth	Horizon	Texture (mm) <2	2-50	>50	Humus	Bulk density	Particle density	Pore volume	Moisture content pF2	pF4.2	pF2	pF4.2	Available moisture VpF2-VpF4.2	Air volume pF2	pF4.2
cm		%			%	kg/m³	kg/m³	%	%w/w		%v/v		mm/10 cm	%	
0- 10	Ahg	25.6	29.0	45.4	4.3	no data									
10- 30	Bw	25.8	29.7	44.5	2.7	1450	2680	45.9	24.8	15.8	35.9	22.9	13.0	10.0	23.0
30- 40	2Bt	27.6	20.8	51.6	0.6	no data									
40- 60	2Btg1	19.0	8.3	72.7	0.4	no data									
60- 80	2Btg2	14.7	7.6	77.7	0.5	1530	2680	42.9	17.4	7.1	26.6	10.9	15.7	16.3	32.0
80-110	3Btg3	7.5	3.9	88.6	0.5	no data									
110-130	3Btg4	1.6	3.9	94.5	0.5	no data									
15- 20	(profile	36	39	25	2.9	1390	2700	48.5	27.0	17.7	37.5	24.6	12.9	11.0	23.9
30- 35	DAAS III)*	30	32	38	1.4	1590	2730	41.8	19.8	13.4	31.5	21.3	10.2	10.5	20.5
45- 50	"	29	34	37	0.9	1620	2710	40.2	18.8	11.9	30.5	19.3	11.2	9.7	20.9
60- 65	"	21	18	61	0.5	1590	2700	41.1	20.8	9.5	33.0	15.1	17.9	8.1	26.0
75- 80	"	13	8	79	0.5	1620	2680	39.6	18.2	6.0	29.5	9.2	19.8	10.1	29.9
90- 95	"	7	11	82	0.5	1570	2650	40.8	15.9	4.7	25.0	7.4	17.6	15.8	33.4
													*** 145 mm		

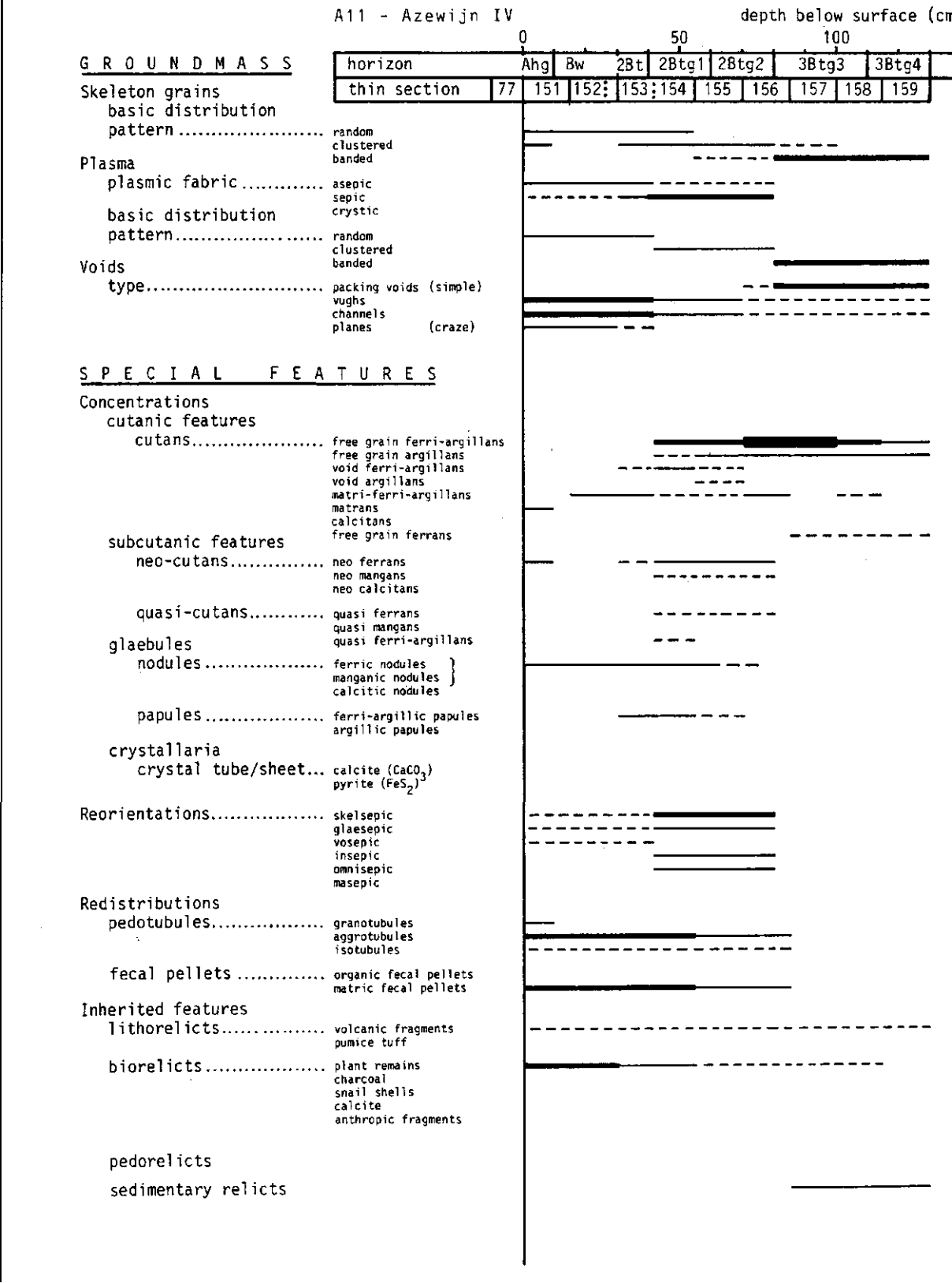
* results from a nearby, similar but somewhat finer textured profile.

** Calculated from adsorbed Ba^{2+}

*** Sum of profile DAAS III till 100 cm depth.

**** Calculations with rounded averages may cause differences of some decimals

f. MICROMORPHOLOGICAL OBSERVATIONS



A.12 WOEZIK

a. Profile description

General data

1. Location: Topographical map of the Netherlands, scale 1:25.000, sheet 40C (1966) coordinates: N 428.420; E 181.680.
2. Date of description: 18-5-1977
3. Described by: J. Wijntje, G. du Bois.
4. Mapping unit: kML2.

Soil site characteristics

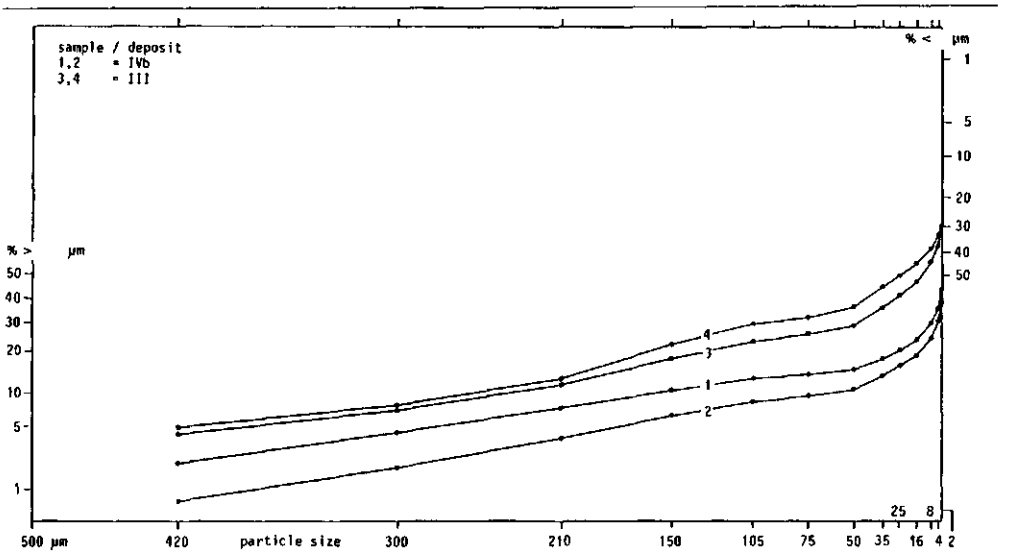
1. Classification:
   a. According to FAO-Unesco (1974): Gleyic Luvisol
   b. according to the Soil Taxonomy (1975): Aquollic Hapludalf
   c. according to De Bakker and Schelling (1966): Kuilbrikgrond.
2. Land use: grassland.
3. Geology: medium- to fine-textured Late Weichselian Rhine deposit overlain by 30 cm fine-textured Rhine deposit.
4. Physiography: basin area with some microrelief.
5. Relief: flat or concave.
6. Slope: level to nearly level, class A.
7. Altitude: 7m +NAP (Amsterdam Ordnance Datum)
8. Hydrology:
   a. Soil drainage class: poorly drained
   b. Groundwater level:
      presumed highest: 40 cm below soil surface
      presumed lowest: 120 cm below soil surface
      actual: 110 cm below soil surface
   c. Artificial drainage: ditches
   d. Flooding: none
9. Evidence of human activity: Ap-horizon

Description of soil horizons

Apg	0-10 cm:	clay; 5 YR 3/2 (moist); few iron mottles along roots; weak medium angular blocky structure; firm; common fine biopores; common fine roots; clear and smooth to:
Bwg	10-30 cm:	clay; 2.5 Y 4/2 (moist); common fine distinct Fe-mottles, few fine hard round FeMn-concretions; moderate coarse prismatic structure; firm; few large and very fine biopores; few medium and common very fine roots along ped faces; gradual and tongued to:
2Btg1	30-50 cm:	clay loam; mottled 10 YR 5/3 and 7.5 YR 4/6 (moist); abundant medium hard round FeMn-concretions; moderate very coarse angular blocky structure; firm; common very fine biopores; few very fine roots; few round quartz gravel; gradual and wavy to:
2Btg2	50-75 cm:	clay loam; 7.5 YR 5/8 (moist); common fine distinct 10 YR 6/1 (moist) reduction parts; moderate coarse angular blocky structure; friable; common fine biopores; few very fine roots; few round quartz gravel; clear and wavy to:
2Btg3	75-110 cm:	sandy loam; 2.5 YR 5/2 (wet); few medium faint 7.5 YR 5/6 Fe mottles; macrostructureless; very friable, slightly sticky, slightly plastic; few very fine biopores; common coarse dead roots.

b. PARTICLE SIZE DISTRIBUTION

Sample	Depth	Horizon	Particle size classes in µm																			Md 50 sand fraction
	cm		<2	2-50	>50	<2	2-4	4-8	8-16	16-25	25-35	35-50	50-75	75-105	105-150	150-210	210-300	300-420	420-600	600-850	850-1200	1200-1700	<2µm <16µm	µm
			%			%																		
77/567	0-10	Apg	56.5	28.0	15.5	56.5	7.2	6.3	5.7	3.4	2.7	2.7	1.3	1.0	2.5	3.3	3.1	2.3	1.2	0.5	0.3	-	0.75	202
77/568	10-30	Bwg	61.4	27.7	10.9	61.4	7.7	5.6	5.8	2.7	2.8	3.1	1.4	0.9	2.1	2.6	2.0	1.2	0.5	0.2	-	-	0.76	174
77/569	30-50	2Btg1	29.3	40.8	2.93	29.9	7.4	6.5	8.9	5.8	5.0	7.2	3.0	2.5	5.3	6.7	4.7	3.0	2.1	1.3	0.5	0.1	0.57	185
77/570	50-75	2Btg2	29.2	33.9	36.9	29.2	4.1	5.0	6.5	5.2	5.1	8.0	4.1	2.7	7.1	10.0	5.1	3.0	2.0	1.4	1.5	-	0.65	178



c. CHEMICAL DATA

Sample	Depth	Horizon	Clay	Humus	$CaCO_3$	pH-KCl	CEC/soil	CEC/clay	Exch. bases $1/2Ca^{2+}$	$1/2Mg^{2+}$	Na^+	K^+	Sum	Exch. acidity $1/3\ Al^{3+}$	H^+	BS	Fe_2O_3 ox	Fe_2O_3 dith	Al_2O_3 dith
	cm		%	%	%		mmol/kg	mmol/kg	mmol/kg							%	%	%	%
77/567	0-10	Apg	56.5	6.6	-	4.6	352	623	280	39	-	-	329			93	1.3	3.6	1.3
77/568	10-30	Bwg	61.4	0.9	-	4.5	383	624	251	43	-	-	294			77	0.5	3.9	1.5
77/569	30-50	2Btg1	29.9	0.8	0.1	5.7	209	699	175	20	-	-	195			93	0.4	4.7	1.2
77/570	50-75	2Btg2	29.2	0.6	-	5.1	189	647	171	23	-	-	194			103	0.5	6.7	1.2

d. TOTAL CHEMICAL COMPOSITION OF THE CLAY FRACTION

Sample	Depth	Horizon	Clay	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	BaO	H_2O^+	CEC/clay*
	cm		%	Gw/w													mmol/kg
77/567	0-10	Apg	56.5	49.70	24.32	6.95	0.50	0.06	1.78	0.28	0.23	1.92	0.81	0.22	4.51	8.98	590
77/568	10-30	Bwg	61.4	50.20	25.37	6.87	0.45	0.09	1.91	0.15	0.21	2.08	0.77	0.13	4.54	8.48	590
77/569	30-50	2Btg1	29.9	47.91	24.05	10.36	0.22	0.48	2.01	0.05	0.22	2.91	0.82	0.23	3.76	7.48	490
77/570	50-75	2Btg2	29.2	45.30	22.74	12.64	0.51	0.07	2.11	0.06	0.21	2.94	0.71	0.28	4.01	7.68	520

e. PHYSICAL CHARACTERISTICS (horizon averages*** and averages of 4 core samples***)

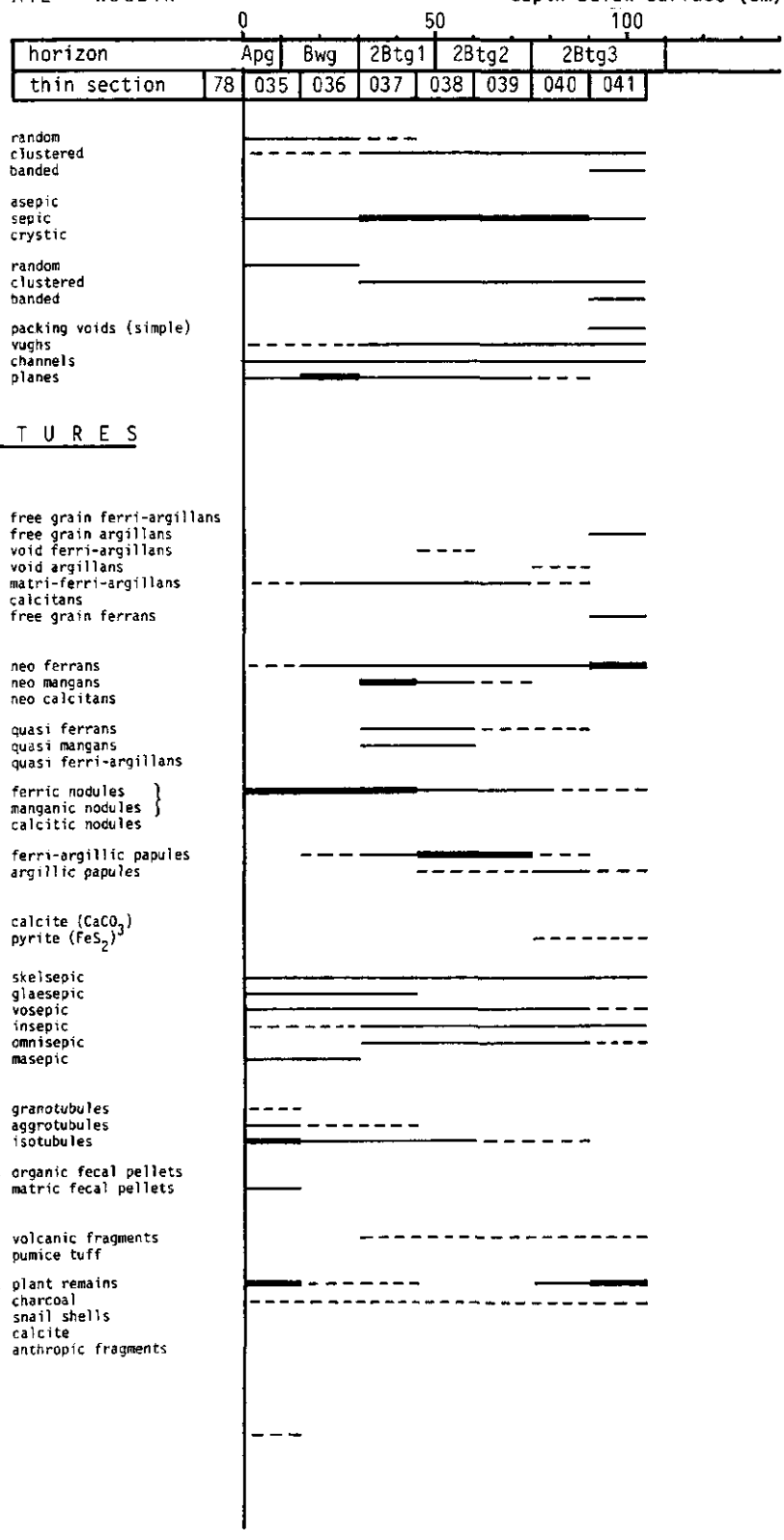
Depth	Horizon	Texture (µm) <2	2-50	>50	Humus	Bulk density	Particle density	Pore volume	Moisture content pF2	pF4.2	Available moisture pF2	pF4.2	Air volume pF2	pF4.2
cm		%			%	kg/m³	kg/m³	%	%w/w		%v/v		VpF2-VpF4.2 mm/10 cm		%	
0-10	Apg	56.5	28.0	15.5	6.6	1350	2650	49.1	35.5	24.9	47.9	33.6	14.3	1.2	15.5
10-30	Bwg	61.4	27.7	10.9	0.9	1390	2750	49.5	31.9	20.8	44.4	28.9	15.5	5.1	20.6
30-50	2Btg1	29.9	40.8	29.3	0.8	1400	2760	49.3	24.0	14.4	33.6	20.2	13.4	15.7	29.1
50-75	2Btg2	29.2	33.9	36.9	0.6	1250	2770	54.9	28.2	14.4	35.2	18.0	17.2	19.7	36.9
													** 115 mm		
5-10						1350	2650	49.1	35.5	24.9	47.9	33.6	14.3	1.2	15.5
22-27						1390	2750	49.5	31.9	20.8	44.4	28.9	15.5	5.1	20.6
33-38						1460	2750	46.9	23.9	14.4	34.9	21.0	13.9	12.0	35.9
45-50						1340	2770	51.6	24.0	14.4	37.1	19.3	12.8	19.5	32.3
55-60						1250	2770	54.9	28.2	14.4	35.2	18.0	17.2	19.7	36.9

* Calculated from adsorbed Ba^{2+}
** Sum over profile depth
*** Calculations with rounded averages may cause differences of some decimals

f. MICROMORPHOLOGICAL OBSERVATIONS

A12 - Woezik

depth below surface (cm)



A.13 ASBROEK

a. Profile description

General data

1. Location: Topographical map of the Netherlands, scale 1:25.000 (1966), sheet 44C; coordinates: N 430.370; E 221.850.
2. Date of description: 10-11-1978.
3. Described by: A.G. Jongmans, J. Broekhuizen, G.F. Epema.
4. Mapping unit: HL1.

Soil site characteristics

1. Classification:
   a. According to FAO-Unesco (1974): Chromic Luvisol.
   b. according to the Soil Taxonomy (1975): Typic Hapludalf
   c. according to De Bakker and Schelling (1966): Radebrikgrond
2. Land use: grassland.
3. Geology: medium-textured Late Weichselian Rhine deposit.
4. Physiography: the profile is situated on a small ridge.
5. Relief: subnormal
6. Slope: level to nearly level, class A.
7. Altitude: 15 m +NAP (Amsterdam Ordnance Datum)
8. Hydrology:
   a. Soil drainage class: well drained
   b. Groundwater level:
      presumed highest: >120 cm below the soil surface
      presumed lowest: >120 cm below the soil surface
      actual: >120 cm below the soil surface
   c. Artificial drainage: none
   d. Flooding: none
9. Evidence of human activity: 0-33 cm Ap-horizon.

Description of the soil horizons

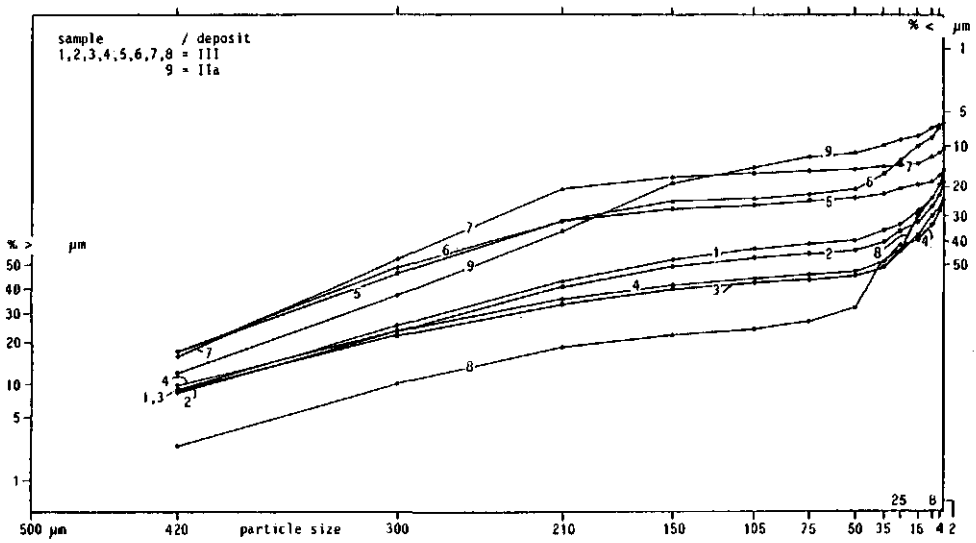
Ap	0-30 cm:	sandy loam; 10 YR 4/3 (moist); few charcoal, few patches of the underlying horizons; moderate very fine subangular blocky structure; common large and few fine biopores; many fine roots; few ortho aggrotubules, (granular structure); very few gravel; clear and smooth to:
EB	30-50 cm:	sandy loam; 7.5 YR 5/4 (moist); very few very fine faint sharply bounded round 10 YR 2/1 FeMn mottles; firm; weak very coarse rough prismatic structure subdivided into moderate fine angular to subangular blocky structure; common fine roots; very firm; worm holes plastered with Ap material; few ortho aggrotubules (granular structure); very few gravel; clear and smooth to:
Bt	50-83 cm:	loam; 5 YR 4/4 (moist); common very fine distinct sharply bounded 10 YR 2/1 FeMn mottles; firm; few medium diffusely bounded Fe-mottles in the lower part of the horizon; moderate smooth very coarse compound prismatic subdivided into medium and fine angular and subangular blocky; cutans on ped faces; many large and many fine biopores; worm holes plastered with Ap material; few ortho aggrotubules; few fine roots; extremely firm; diffuse and wavy to:

2Btg1 83–110 cm: sandy loam; 5 YR 4/6 (moist); common fine distinct FeMn mottles inside peds; vertically elongated tongues (7.5 YR 6/4) of 2–10 cm wide, surrounded by an iron band (5 YR 5/8) with a diffuse boundary; weak very coarse prismatic structure; extremely firm; few worm holes coated with Ap material; in worm holes only few fine roots; gradual and smooth to:

2Btg2 110–140 cm: loamy sand; 7.5 YR 6/4 (wet); common reduction spots (<2–20 cm diameter, 5 YR 7/2) surrounded by iron band; from 135–138 cm sedimentation band of loam (10 YR 7/1, moist) with few fine biopores and surrounded by iron band; macrostructureless; slightly sticky, non plastic.

b. PARTICLE SIZE DISTRIBUTION

Sample	Depth cm	Horizon	<2	2-50	>50	Particle size classes in µm: <2	2-4	4-8	8-16	16-25	25-35	35-50	50-75	75-105	105-150	150-210	210-300	300-420	420-600	600-850	850-1200	1200-1700	<2µm / <16µm	Md 50 sand fraction µm
			%			%																		
78/285	0- 30	Ap	14.8	25.1	60.1	14.8	4.3	4.9	4.0	5.0	2.8	4.1	1.6	1.7	4.8	9.6	16.6	16.8	7.0	1.5	0.5	-	0.53	277
78/286	30- 50	EB	18.7	25.2	56.1	18.7	4.0	4.2	5.6	3.5	4.4	3.5	1.3	1.8	3.6	9.3	16.5	15.2	6.4	1.5	0.5	-	0.58	276
78/287	50- 70	Bt1	24.6	30.4	45.0	24.6	3.9	6.2	6.6	3.0	6.5	4.2	1.7	1.1	2.9	5.7	11.4	13.3	6.8	1.5	0.6	-	0.60	298
78/288	70- 83	Bt2	23.4	30.0	46.6	23.4	5.1	4.9	5.9	3.7	5.5	4.9	1.4	1.5	2.6	6.0	12.0	13.4	7.3	2.0	0.4	-	0.60	298
78/289	83-110	2Btg1	15.2	8.8	76.0	15.2	1.9	1.4	1.0	1.1	2.0	1.4	0.8	0.7	1.6	4.3	22.0	29.4	12.7	3.6	0.9	-	0.78	335
78/290[1]	83-110	hor.t.	6.7	13.9	79.4	6.7	0.5	1.1	2.0	2.6	3.5	4.2	2.0	1.7	0.5	6.5	20.6	31.1	14.1	2.5	0.4	-	0.65	333
78/291[2]	83-110	vert.t.	10.9	4.3	84.8	10.9	0.9	0.5	1.4	0.2	0.4	0.9	0.5	0.5	1.0	3.6	26.3	36.4	14.3	1.8	0.4	-	0.80	335
78/292[3]	135-138	sed.l.	16.4	51.6	32.0	16.4	3.3	3.5	11.4	6.7	7.7	19.0	4.9	2.8	1.8	3.7	8.7	7.5	2.2	0.4	-	-	0.47	239
78/293	110-140	2Btg2	7.3	4.2	88.5	7.3	0.4	0.3	0.5	0.4	1.3	1.3	0.9	2.5	4.1	17.0	27.5	24.5	9.0	2.2	0.6	0.2	0.86	275



c. CHEMICAL DATA

Sample	Depth	Horizon	Clay	Humus	$CaCO_3$	pH-KCl	CEC/soil	CEC/clay	Exch. bases $1/2Ca^{2+}$	$1/2Mg^{2+}$	Na^+	K^+	Sum	Exch. acidity $1/3\ Al^{3+}$	H^+	BS	Fe_2O_3 ox	Fe_2O_3 dith	Al_2O_3 dith
	cm		%	%	%		mmol/kg	mmol/kg			mmol/kg				mmol/kg	%		%	%
78/285	0- 30	Ap	14.8	2.6	0.1	5.4	71	480	43	8	-	5	56			79	0.5	1.5	0.6
78/286	30- 50	EB	18.7	0.8	-	5.1	52	278	43	12	-	-	55			106	0.6	1.6	0.9
78/287	50- 70	Bt1	24.6	0.3	-	4.9	65	264	86	16	-	-	102			157	0.6	2.3	1.2
78/288	70- 83	Bt2	23.4	0.3	-	4.8	116	496	86	18	-	-	104			90	0.5	2.1	1.1
78/289	83-110	2Btg1	15.2	0.3	-	4.7	58	382	43	10	-	-	53			91	0.3	1.5	0.9
78/290[1]	83-110	hor.t	6.7	0.3	-	4.9	no data												
78/291[2]	83-110	vert.t	10.9	0.4	-	4.7	24	220	21	4	-	-	25			104	0.3	0.9	2.9
78/292[3]	83-110	sed.l.	16.4	0.3	-	4.7	46	280	43	12	-	-	55			120	0.4	1.2	1.1
78/293	110-140	2Btg2	7.3	0.2	-	4.8	71	973	64	12	-	-	76			107	0.3	1.1	0.8

d. TOTAL CHEMICAL COMPOSITION OF THE CLAY FRACTION

Sample	Depth	Horizon	Clay	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	BaO	H_2O^+	CEC/clay*
	cm		%	%w/w													mmol/kg
78/285	0- 30	Ap	14.8	44.68	23.26	8.31	0.19	0.14	2.01	0.07	0.25	3.41	0.84	1.05	5.72	9.12	750
78/286	30- 50	EB	18.7	46.23	24.46	8.62	0.83	0.23	2.02	0.05	0.39	3.33	0.83	0.76	4.67	8.41	610
78/287	50- 70	Bt1	24.6	46.06	24.66	8.84	0.85	0.21	2.06	0.04	0.24	3.25	0.78	0.55	4.02	8.51	520
78/288	70- 83	Bt2	23.4	46.06	24.65	9.15	0.87	0.12	2.14	0.02	0.23	3.26	0.73	0.43	4.02	8.22	520
78/289	83-110	2Btg1	15.2	44.75	24.93	9.64	0.63	0.24	2.05	0.02	0.27	3.18	0.68	0.55	3.95	8.84	520
78/290[1]	83-110	hor.t.	6.7	46.04	25.07	7.89	0.79	0.08	2.27	0.05	0.34	3.22	0.71	0.60	4.09	8.48	530
78/291[2]	83-110	vert.t.	10.9	46.44	23.91	7.70	0.92	0.08	2.09	0.06	0.32	3.19	0.76	0.56	5.16	8.48	670
78/292[3]	83-110	sed.l.	16.4	48.70	25.21	6.63	0.70	0.05	2.08	0.05	0.26	3.28	0.87	0.48	4.38	7.99	540
78/293	110-140	2Btg2	7.3	44.92	25.21	9.63	0.65	0.25	2.34	0.02	0.29	3.00	0.59	0.57	3.19	9.27	420

e. PHYSICAL CHARACTERISTICS (horizon averages*** and averages of 5 core samples***)

Depth	Horizon	Texture (mm) <2	2-50	>50	Humus	Bulk density	Particle density	Pore volume	Moisture content pF2	pF4.2	pF2	pF4.2	Available moisture VpF2-VpF4.2	Air volume pF2	pF4.2
cm		%			%	kg/m³	kg/m³	%	%w/w		%v/v		mm/10 cm	%	
0- 30	Ap	14.8	25.1	60.1	2.6	1810	2670	32.2	15.2	11.9	27.5	21.5	6.0	4.7	10.7
30- 50	EB	18.7	25.2	56.1	0.8	1690	2670	36.7	16.3	10.6	27.5	17.9	9.6	9.2	18.8
50- 70	Bt1	24.6	30.4	45.0	0.3	1700	2700	37.0	15.6	10.3	26.5	17.5	9.0	10.5	19.5
70- 83	Bt2	23.4	30.0	46.6	0.3	1700	2700	37.0	15.6	10.3	26.5	17.5	9.0	10.5	19.5
83-110	2Btg1	15.2	8.8	76.0	0.3	1740	2690	35.3	13.0	8.2	22.6	14.3	8.3	12.7	21.0
													** 90 mm		
10- 15						1810	2670	32.2	15.2	11.9	27.5	21.5	6.0	4.7	10.7
35- 40						1690	2670	36.7	16.3	10.6	27.5	17.9	9.6	9.2	18.8
60- 65						1700	2700	37.0	15.6	10.3	26.5	17.5	9.0	10.5	19.5
85- 90						1700	2700	36.8	14.4	12.0	26.0	21.1	4.9	8.8	13.7
100-105						1710	2680	36.2	11.2	4.4	19.2	7.5	11.7	17.0	28.7

* Calculated from adsorbed H_2O

** Sum over profile depth.

*** Calculations with rounded averages may cause differences of some decimals

1 horizontal tongues

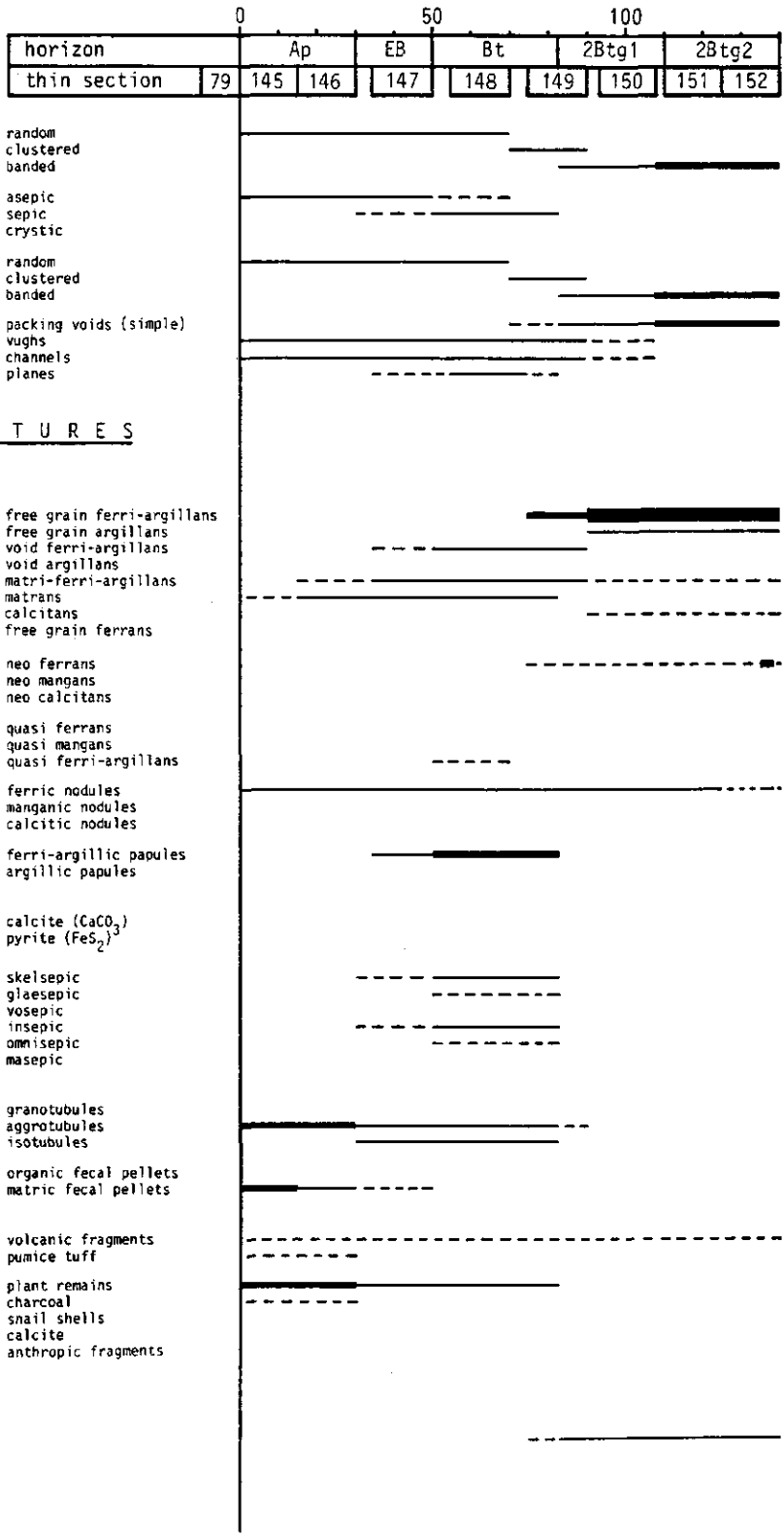
2 vertical tongues

3 sedimentation lamina

f. MICROMORPHOLOGICAL OBSERVATIONS

A13 - Asbroek

depth below surface (cm)



A.14 MEGCHELEN

a. Profile description

General data

1. Location: Topographical map of the Netherlands, scale 1:25.000 (1966); sheet 41C; coordinates: N 427.520; E 225.080.
2. Date of description: 08-11-1978.
3. Described by: R. Miedema, J. Broekhuizen, G.F. Epema, J.J.R. Robben.
4. Mapping unit: HL2.

Soil site characteristics

1. Classification:
   a. According to FAO-Unesco (1974): Orthic Acrisol.
   b. according to the Soil Taxonomy (1975): Typic Hapludalf.
   c. according to De Bakker and Schelling (1966): Daalbrikgrond.
2. Land use: not used, grass and weeds (thistles and Urtica dioica).
3. Geology: medium-textured Late Weichselian Rhine deposit.
4. Physiography: the profile occupies a shallow depression area within a high ridge.
5. Relief: subnormal
6. Slope: level to nearly level, class A
7. Altitude: 17 m +NAP (Amsterdam Ordnance Datum)
8. Hydrology:
   a. Soil drainage class: moderately well drained.
   b. Groundwater level:
      presumed highest: 55 cm below the soil surface (due to pseudogley)
      presumed lowest: 300 cm below the soil surface
      actual: 300 cm below the soil surface.
   c. Artificial drainage: none
   d. Flooding: none
9. Evidence of human activity: of abrupt Ap-boundary indicates ploughing; very dense topsoil caused by tractor traffic and addition of human garbage (coal, charcoal, bricks, stones, scrap iron, plastic).

Description of the soil horizons

Apg 0-25 cm: sandy loam; 10 YR 3.5/3 (moist); strong medium angular blocky tending to a medium platy structure; few medium faint Fe-mottles around roots and on ped faces due to man-induced very dense character of Ap-horizon; few fine and very fine biopores, few coated and partly excrement-filled worm holes and occasional mole holes; very few medium roots (concentrated on ped faces), few fine and very fine roots; firm; many anthropic coarse fragments (coal, charcoal, bricks, rubble, plastic, scrap iron); non calcareous matrix with some strongly calcareous anthropic coarse fragments; abrupt and wavy (due to human influence) to:

E 25-35 cm: sandy loam; 10 YR 4.5/4 (moist); weak medium subangular blocky structure tending to sponge structure; few fine faint Fe and Mn mottles; common fine and very fine biopores, common to many large coated and partly

excrement-filled worm holes; few fine roots; friable; gradual and smooth to:

Bt 35-55 cm: loam; 10 YR 5/6 (moist); weak subangular blocky structure tending to sponge structure; few fine faint Fe and Mn mottles; many fine and very fine biopores, many large coated and partly excrement-filled worm holes; few fine roots; friable; clear and tongued to:

Btg1 55-80 cm: sandy clay loam; 10 YR 5/6 (moist) tongues of material from overlying horizon; 10 YR 5.5/4 (moist) with irregular and tonguing 10 YR 6/3 (moist) material, irregular round and rectangular 7.5 YR 5/5 (moist) material with a clear concentration of Mn mottles mainly in lower part of horizon; sponge structure; many medium irregular round 7.5 YR 5/8 (moist) Fe mottles; abundant fine and very fine biopores, common large coated and partly excrement-filled worm holes and occasional mole holes filled with material from overlying horizon; few fine roots; slightly firm and hard to very hard when dry; clear and smooth to:
Remark 1: the percentual distribution of the various colours in this horizon along the wall of the excavation differs.
Remark 2: near the boundary with the sand lenses described in the next horizon, series of thin brown horizontal bands sometimes occur.

2Btg2 80-100 cm: sand; 10 YR 5/7 (moist); occurs as lenses and is locally absent; thin horizontal laminae of Fe and Mn; single grain structure; very few coated large worm holes

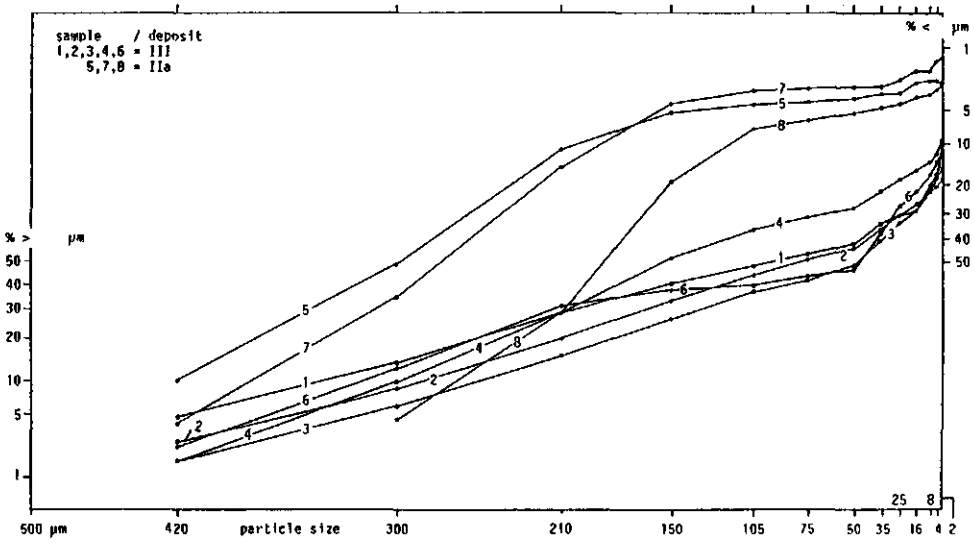
2Btg3 100-110 cm: loam; 10 YR 6/2.5 (moist); weak medium subangular blocky structure; at top horizontal laminae of Fe; at the bottom horizontal laminae of Mn; many medium distinct 7.5 YR 5/8 Fe mottles; common fine biopores; very few large coated worm holes; friable; frequent decomposing root remains of a former vegetation; continuously occurring along wall; abrupt and smooth to:

2Btg4 110-130 cm: sand; 10 YR 6.5/6 (moist); undisturbed stratification (thinly bedded); few medium distinct Fe-mottles around old root channels and bordering the overlying horizon a thin horizontal band of Fe; occasional worm holes (large biopores); abrupt and smooth to:
Remark: in the same position underlying the grey silt loam layer various sedimentary structures have been observed (bed sets, scour marks) indicating a fluvial sediment.

2Btg5 130-155 cm: sand; 10 YR 6/4 (moist); undisturbed stratification; occasional Fe-mottles around old root channels and a browner layer from 135-137 cm depth; loose
Remark 1: on other parts of the wall in this horizon occasional bleached tongues (old tree roots) with a lining of Fe.
Remark 2: round completely filled dung-beetle holes occasionally observed.

b. PARTICLE SIZE DISTRIBUTION

Sample	Depth	Horizon	<2	2–50	>50	Particle size classes in µm																	Md 50 sand fraction
	cm		%			<2	2-4	4-8	8-16	16-15	25-35	35-50	50-75	75-105	105-150	150-210	210-300	300-420	420-600	600-850	850-1200	1200-1700	<2µm <16µm	µm
78/277	0- 25	Apg	9.2	33.4	57.4	9.2	8.0	3.1	8.5	1.6	3.2	9.0	4.3	5.4	7.3	12.3	14.4	9.0	3.4	0.9	0.4	-	0.32	207
78/278	25- 35	E	15.7	28.7	55.6	15.7	3.0	3.8	4.5	3.7	4.7	9.0	4.8	6.7	10.4	13.7	11.7	5.8	1.9	0.4	0.2	-	0.58	176
78/279	35- 55	Bt	18.2	33.0	48.8	18.2	3.1	1.2	6.7	4.1	7.6	10.3	6.7	4.9	10.4	11.3	9.4	4.4	1.3	0.3	0.1	-	0.62	163
78/280	55- 80	Btg1	10.2	17.9	71.9	10.2	2.0	1.8	1.9	2.2	3.8	6.1	3.4	4.9	11.8	23.6	18.3	8.2	1.4	0.3	-	-	0.64	190
78/281	80-100	2Btg2	2.6	1.3	96.1	2.6	0.0	0.0	0.1	0.7	0.1	0.4	0.3	0.3	0.8	6.3	40.2	38.2	8.6	1.2	0.2	-	0.36	301
78/282	100-110	2Btg3	11.4	40.8	47.8	11.4	2.6	3.1	5.1	5.6	9.5	14.9	4.9	2.8	1.9	7.1	18.6	9.9	2.0	0.4	0.2	-	0.51	245
78/283	110-130	2Btg4	1.4	1.6	97.0	1.4	0.2	0.4	0.0	0.6	0.3	0.1	0.1	0.1	1.1	11.2	50.0	30.6	3.7	0.4	-	-	0.70	235
78/284	130-155	2Btg5	2.7	2.9	94.4	2.7	0.4	0.3	0.4	0.5	0.5	0.8	0.6	1.5	11.6	41.5	34.8	4.3	0.1	0.0	-	-	0.71	198



c. CHEMICAL DATA

Sample	Depth	Horizon	Clay	Humus	$CaCO_3$	pH-KCl	CEC/soil	CEC/clay	Exch. bases $1/2Ca^{2+}$	$1/2Mg^{2+}$	Na^+	K^+	Sum	Exch. acidity $1/3\ Al^{3+}$	H^+	BS	Fe_2O_3 ox	Fe_2O_3 dith	Al_2O_3 dith
	cm		%	%	%		mmol/kg	mmol/kg	mmol/kg						mmol/kg	%	%		
78/277	0- 25	Apg	9.2	4.3	0.2	6.2	84	913	55	22	-	7	84			100	0.6	1.7	0.7
78/278	25- 35	E	15.7	2.3	0.3	6.0	64	408	21	8	-	1	30			47	0.5	1.7	0.9
78/279	35- 55	Bt	18.2	0.9	-	4.0	84	462	21	6	-	-	27			32	0.5	1.9	1.0
78/280	55- 80	Btgl	10.2	0.8	-	4.1	52	510	21	4	-	-	25			48	0.3	1.4	0.7
78/281	80-100	2Btg2	2.6	0.4	-	4.7	19	731	11	1	-	-	12			63	0.2	0.7	0.4
78/282	100-110	2Btg3	11.4	0.6	-	4.1	46	404	32	8	-	-	40			87	0.5	1.6	1.0
78/283	110-130	2Btg4	1.4	0.3	-	4.7	13	929	11	2	-	-	13			100	0.4	0.7	0.3
78/284	130-155	2Btg5	2.7	0.6	-	4.5	10	370	11	2	-	-	13			130	0.3	0.8	0.5

d. TOTAL CHEMICAL COMPOSITION OF THE CLAY FRACTION

Sample	Depth	Horizon	Clay	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	BaO	H_2O^+	CEC/clay
	cm		%	% w/w													mmol/kg
78/277	0- 25	Apg	9.2	44.15	23.45	8.61	1.13	0.08	1.99	0.20	0.37	3.08	0.81	1.95	4.95	9.14	650
78/278	25- 35	E	15.7	46.47	23.71	8.64	1.07	0.15	2.02	0.04	0.41	2.91	0.91	0.51	4.50	8.22	590
78/279	35- 55	Bt	18.2	45.39	25.23	9.96	0.86	0.17	2.16	0.02	0.32	3.01	0.84	0.38	3.71	8.74	480
78/280	55- 80	Btgl	10.2	45.39	24.91	10.05	0.91	0.15	2.16	0.03	0.33	3.11	0.87	0.33	3.59	8.67	470
78/281	80-100	2Btg2	2.6	44.45	24.53	10.65	0.64	0.30	2.07	0.04	0.27	2.86	0.78	0.66	3.90	9.57	510
78/282	100-110	2Btg3	11.4	48.69	24.38	8.89	0.39	0.17	2.06	0.02	0.31	3.48	0.82	0.22	3.39	7.70	440
78/283	110-130	2Btg4	1.4	42.23	23.48	14.45	0.60	0.18	1.83	0.05	0.23	2.65	0.82	0.58	3.69	9.14	480
78/284	130-155	2Btg5	2.7	44.24	24.36	11.26	0.91	0.09	1.96	0.09	0.39	2.80	0.84	0.66	3.62	9.55	470

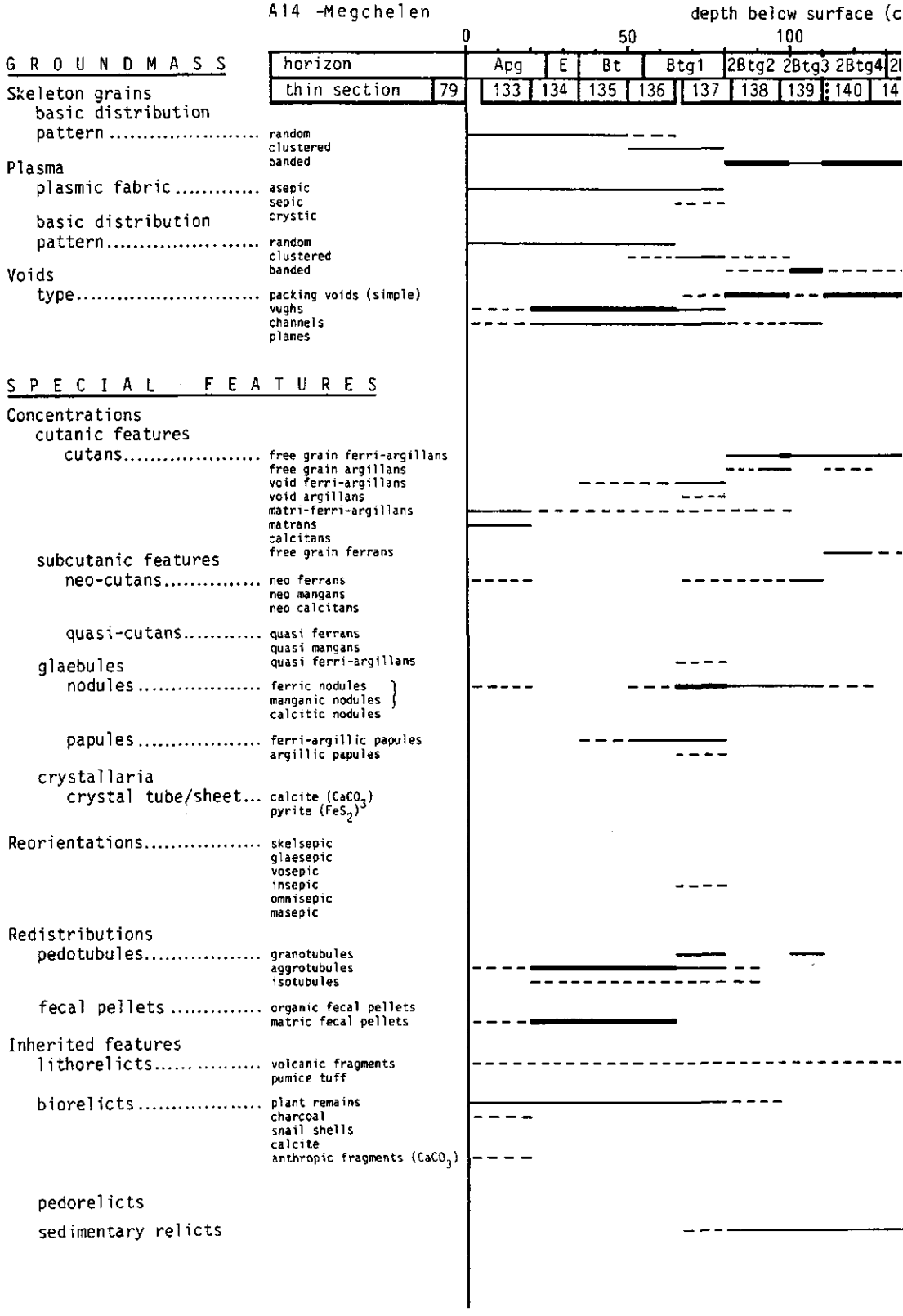
e. PHYSICAL CHARACTERISTICS (horizon averages*** and averages of 5 core samples***)

Depth	Horizon	Texture (mm) <2	2-50	>50	Humus	Bulk density	Particle density	Pore volume	Moisture content pF2	pF4.2	pF2	pF4.2	Available moisture VpF2-VpF4.2	Air volume pF2	pF4.2
cm		%			%	kg/m^3	kg/m^3	%	% w/w		% v/v		mm/10 cm	%	
0- 25	Apg	9.2	33.4	57.4	4.3	1500	2610	42.5	25.0	15.5	37.5	23.3	14.2	5.0	19.2
25- 35	E	15.7	28.7	55.6	2.3	1520	2660	42.9	21.8	14.6	33.2	22.2	11.0	9.7	20.7
35- 55	Bt	18.2	33.0	48.8	0.9	1470	2670	44.9	19.4	7.8	28.5	11.5	17.0	16.4	33.4
55- 80	Btgl	10.2	17.9	71.9	0.8	1570	2680	41.4	17.1	6.5	26.8	10.2	16.6	14.6	31.2
80-100	2Btg2	2.6	1.3	96.1	0.4	no data									
100-110	2Btg3	11.4	40.8	47.8	0.6	1610	2690	40.1	16.3	5.5	6.2	8.9	17.3	13.9	31.2
													** 125 mm		
5- 10						1500	2610	42.5	25.0	15.5	37.5	23.3	14.2	5.0	19.2
30- 35						1520	2660	42.9	21.8	14.6	33.2	22.2	11.0	9.7	20.7
50- 55						1470	2670	44.9	19.4	7.8	28.5	11.5	17.0	16.4	33.4
70- 75						1570	2680	41.4	17.1	6.5	26.8	10.2	16.6	14.6	31.2
100-105						1610	2690	40.1	16.3	5.5	26.2	8.9	17.3	13.9	31.2

* Calculated from adsorbed $\frac{1}{2}Ba^{2+}$
** Sum over profile depth.
*** Calculations with rounded averages may cause differences of some decimals

f. MICROMORPHOLOGICAL OBSERVATIONS

A14 -Megchelen



A.15 VEN-ZELDERHEIDE

a. Profile description

General data

1. Location: Topographical map of the Netherlands, scale 1:25.000 (1967); sheet: 46B+E; coordinates: N 413.970; E 199.150.
2. Date of description: 10-5-1979.
3. Described by: A.G. Jongmans
4. Mapping unit: HL1.

Soil site characteristics

1. Classification:
   a. According to FAO-Unesco (1974): Orthic Acrisol.
   b. according to the Soil Taxonomy (1975): Typic Hapludult
   c. according to De Bakker and Schelling (1966): Radebrikgrond.
2. Land use: grassland
3. Geology: coarse-textured Late Weichselian Rhine deposit.
4. Physiography: river terrace forming a broad ridge near a former major channel of the braided river system
5. Relief: subnormal
6. Slope: level to nearly level, class A.
7. Altitude: 13.8 m +NAP (Amsterdam Ordnance Datum)
8. Hydrology:
   a. Soil drainage class: well drained
   b. Groundwater level:
      presumed highest:>2 m below the soil surface
      presumed lowest: >2 m below the soil surface
      actual: >2 m below the soil surface
   c. Artificial drainage: none
   d. Flooding: none
9. Evidence of human activity: Ap to 30 cm.

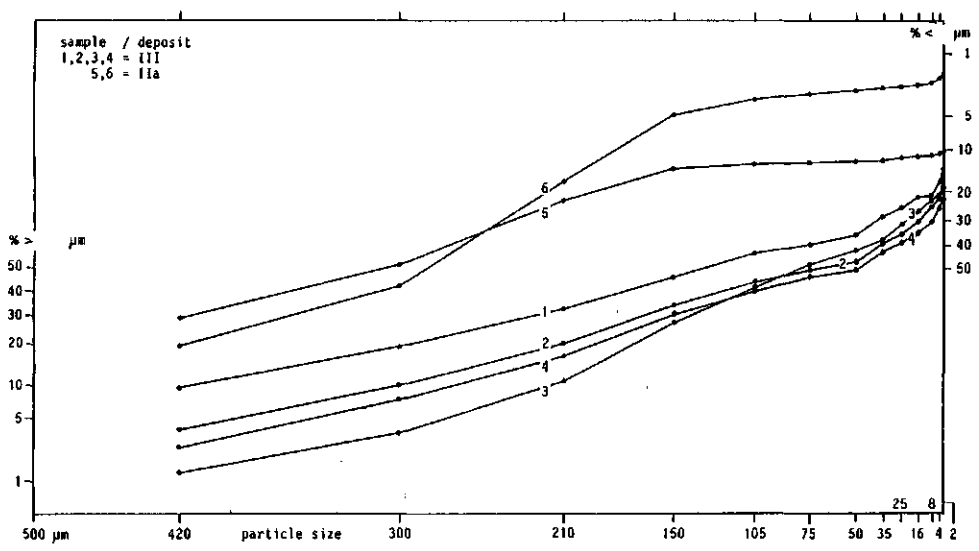
Description of the soil horizons

Ap	0-30 cm:	slightly gravelly sandy loam; 10 YR 4/2 (moist); few fine bricks, few charcoal; few fine and coarse patches of the underlying horizon, sharply bounded; moderate fine subangular blocky structure changing with depth into weak fine angular blocky structure and common strong granular structure, matric aggrotubules Ø 1/2-1 cm; common large and fine biopores; many fine roots; friable with depth changing into slightly firm; very few round gravel; abrupt and smooth, locally broken to:
E	30-50 cm:	slightly gravelly sandy loam; 7.5 YR 4/4 changing with depth into 7.5 YR 5/6 (moist); few very fine sharply bounded FeMn nodules, in the upper part common medium patches of the underlying horizon; sponge structure; cutans consisting of Ap-material along worm holes, common meta aggrotubules with strong granular structure in clusters; many large and fine biopores; common fine roots; friable; very few round gravel; diffuse and smooth to:
Bt1	50-107 cm:	coarse sandy loam changing with depth into loam; 5 YR 5/6 (moist); few fine irregular FeMn nodules; few fine channel neomangans; sponge structure; cutans consisting

of Ap-material along worm holes, locally meta aggrotubules partly filled; common large and many fine biopores; few fine roots mainly in worm holes; friable; gradual and smooth to:

2Bt2 207-170 cm: this horizon consists of an alternation of bands of loamy sand (5 YR 4/4, moist) and sand (10 YR 7/6 (moist)); loamy sand bands ± 3 cm thick decreasing with depth to ± 1 cm mainly parallel to the soil surface following the geogenic stratification, locally bands inclined to the soil surface not following the geogenic stratification; macrostructureless; few fine biopores; friable; common round gravel;
sand bands: undisturbed stratification (single grain structure); loose, common round gravel; gradual and smooth to:

3CB 170-200 cm: very gravelly coarse sand; few loamy sand bands of 1/2 - 1 cm thick (5 YR 4/4, moist); undisturbed stratification (single grain structure).



b. PARTICLE SIZE DISTRIBUTION

Sample	Depth	Horizon	<2	2-50	>50	Particle size classes in µm: <2	2-4	4-8	8-16	16-25	25-35	35-50	50-75	75-105	105-150	150-210	210-300	300-420	420-600	600-850	850-1200	1200-2000	<2 µm / <16 µm	Md 50 sand fraction
	cm		%			%																		µm
79/132	0- 30	Ap	15.1	21.1	63.8	15.1	2.6	4.5	0.2	3.6	2.7	7.5	4.1	3.6	10.7	13.0	13.4	10.1	5.1	2.7	1.0	0.6	0.67	213
79/133	30- 50	E	17.6	29.2	53.2	17.6	5.2	2.6	5.2	4.7	3.5	8.0	4.0	5.6	9.6	13.4	10.5	6.2	2.5	1.4	-	-	0.58	184
79/134	50- 80	Bt1	18.6	19.4	62.0	18.6	3.0	1.7	3.7	3.5	1.1	6.4	4.2	6.0	10.2	14.2	16.4	7.4	2.3	1.1	0.2	-	0.69	195
79/137	80-107	Bt1	22.2	28.0	49.8	22.2	2.9	5.3	4.4	3.9	3.8	7.7	4.3	5.3	9.7	13.5	9.2	4.9	1.7	0.8	0.3	0.1	0.64	175
79/135	107-120	2Bt2	10.6	1.8	87.6	10.6	0.2	0.2	0.3	0.2	0.6	0.3	0.2	0.3	1.2	8.8	25.8	22.3	15.9	9.3	2.9	0.9	0.94	340
79/136	120-170	2Bt2	1.6	1.0	97.4	1.6	0.2	0.2	0.1	0.2	0.2	0.1	0.2	0.3	1.6	12.3	40.7	22.2	15.3	3.7	0.7	0.2	0.76	286

c. CHEMICAL DATA

Sample	Depth	Horizon	Clay	Humus	$CaCO_3$	pH-KCl	CEC/soil	CEC/clay	Exch. bases: $1/2Ca^{2+}$	$1/2Mg^{2+}$	Na^+	K^+	Sum	Exch. acidity: $1/3\ Al^{3+}$	H^+	BS	Fe_2O_3 ox	Fe_2O_3 dith	Al_2O_3 dith
	cm		%	%	%		mmol/kg	mmol/kg	mmol/kg					mmol/kg		%	%	%	%
79/132	0- 30	Ap	15.1	2.4	-	4.7	50	331	43	4	-	2	45			90	0.6	1.3	1.9
79/133	30- 50	E	17.6	1.5	0.8	5.4	50	284	7	4	-	2	13			26	0.5	1.6	1.9
79/134	50- 80	Bt1	18.6	0.7	-	4.1	57	306	14	4	-	-	18			32	0.3	1.9	2.1
79/137	80-107	Bt1	22.2	0.6	-	4.7	57	257	28	4	-	-	32			56	0.4	2.4	2.3
79/135	107-120	2Bt2	10.6	0.1	-	4.0	44	415	14	2	-	-	16			36	0.3	1.3	1.6
79/136	120-170	2Bt2	1.6	0.0	-	4.4	6	375	14	1	-	-	15			250	0.4	1.1	1.3

d. TOTAL CHEMICAL COMPOSITION OF THE CLAY FRACTION

Sample	Depth	Horizon	Clay	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	BaO	H_2O^+	CEC/clay*
	cm		%	%w/w													mmol/kg
79/132	0- 30	Ap	15.1	47.91	23.21	8.73	0.67	0.17	1.61	0.08	0.41	2.88	1.02	0.99	4.14	9.38	540
79/133	30- 50	E	17.6	47.90	23.50	8.17	0.80	0.13	1.66	0.06	0.36	2.66	0.96	0.49	4.26	9.15	560
79/134	50- 80	Bt1	18.6	44.94	24.47	9.99	0.67	0.09	2.16	0.02	0.19	3.00	0.80	0.28	4.19	10.06	550
79/137	80-107	Bt1	22.2	46.35	24.42	9.34	0.83	0.12	2.07	0.02	0.21	3.25	0.87	0.24	3.22	9.36	420
79/135	107-120	2Bt2	10.6	43.67	25.19	10.99	0.48	0.14	2.08	0.01	0.14	3.12	0.70	0.39	3.84	9.86	500
79/136	120-170	2Bt2	1.6	no data													

PHYSICAL CHARACTERISTICS

No determinations of this profile, but similar to profile OTTERSUM (Appendix A.6.)

* Calculated from adsorbed + Ba^{2+}

f. MICROMORPHOLOGICAL OBSERVATIONS

A15 - Ven-Zelderheide

depth below surface (c

		0	50	100
	horizon	Ap	E	Bt1	2Bt2
	thin section	80	011 012 013 014 015 016 018	

G R O U N D M A S S

Skeleton grains	
basic distribution pattern	random clustered banded
Plasma	
plasmic fabric	asepic sepic crystic
basic distribution pattern	random clustered banded
Voids	
type	packing voids (simple) vughs channels planes

S P E C I A L F E A T U R E S

Concentrations	
cutanic features	
cutans	free grain ferri-argillans free grain argillans void ferri-argillans void argillans matri-ferri-argillans calcitans free grain ferrans
subcutanic features	
neo-cutans	neo ferrans neo mangans neo calcitans
quasi-cutans	quasi ferrans quasi mangans quasi ferri-argillans
glaebules	
nodules	ferric nodules manganic nodules calcitic nodules
papules	ferri-argillic papules argillic papules
crystallaria	
crystal tube/sheet	calcite ($CaCO_3$) pyrite (FeS_2)
Reorientations	skelsepic glaesepic vosepic insepic omnisepic masepic
Redistributions	
pedotubules	granotubules aggrotubules isotubules
fecal pellets	organic fecal pellets matric fecal pellets
Inherited features	
lithorelicts	volcanic fragments pumice tuff
biorelicts	plant remains charcoal snail shells calcite anthropic fragments
pedorelicts	
sedimentary relicts	

A.16 MILLINGEN

a. Profile description

General data

1. Location: Topografische Karte Nordrhein-Westfalen 1:50.000 (1978), Blatt L4104 (Bocholt), N 57.420; E 25.280.
2. Date of description: 17-4-1980.
3. Described by: R. Miedema and Th. Pape.
4. Mapping unit: HL1.

Soil site characteristics

1. Classification:
   a. According to FAO-Unesco (1974): Chromic Luvisol
   b. according to the Soil Taxonomy 1975: Typic Hapludalf
   c. according to De Bakker and Schelling 1966: Radebrikgrond.
2. Land use: former arable land, now grassland (building site).
3. Geology: medium- to fine-textured Late Weichselian Rhine deposit.
4. Physiography: river terrace plateau
5. Relief: subnormal
6. Slope: level to nearly level, class A.
7. Altitude: 17.0 m +NAP (Amsterdam Ordnance Datum)
8. Hydrology:
   a. Soil drainage class: well drained
   b. Groundwater level:
      presumed highest:>150 cm below the soil surface
      presumed lowest: >150 cm below the soil surface
      actual: >150 cm below the soil surface
   c. Artificial drainage: none
   d. Flooding: none
9. Evidence of human activity: Ap-horizon from 0-27 cm.

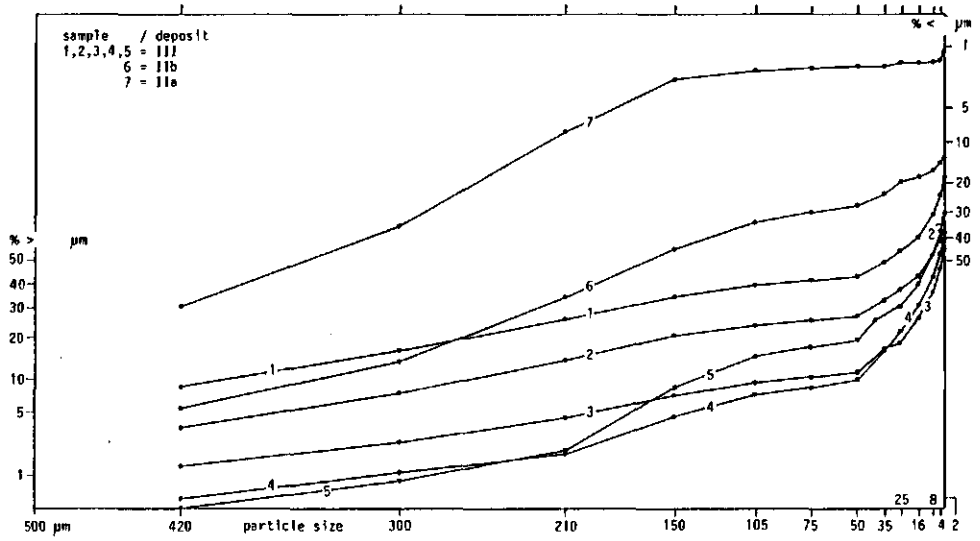
Description of the soil horizons

Ap	0-27 cm:	loam; 10 YR 4/3 (moist); moderate medium subangular blocky structure, locally granular in common pedotubules (worm holes and mole holes); friable; common large and fine biopores; many fine and medium roots; common anthropogenic relicts as coal, charcoal, brick fragments, gravel; clear and smooth to:
E	27-40 cm:	clay loam; 10 YR 4/4 (moist); moderate medium and coarse subangular blocky, locally granular in common pedotubules (worm holes); friable; many fine and common large biopores; many fine and common medium roots; gradual and smooth to:
Bt1	40-50 cm:	silty clay; 7.5 YR 4/4 (moist); strong medium angular blocky; common pedotubules (worm holes); slightly firm; many fine and many large biopores; clear pedcutans (moist shiny faces); common fine roots; gradual and smooth to:
Bt2	50-64 cm:	silty clay; 7.5 YR 5/6 (moist); strong medium compound smooth prismatic subdivided into moderate to strong medium angular blocky; common pedotubules (wormholes); firm; many fine and many large biopores; clear pedcutans (moist shiny faces); common fine roots; common fine distinct black mottles (concretions) of Mn/Fe; gradual and smooth to:

Bt3 64–90 cm: silty clay loam; 7.5 YR 5/6 (moist); strong to moderate coarse compound smooth prismatic subdivided into moderate coarse angular blocky; few pedotubules (worm holes); firm; many worm holes and mole holes); friable; common large and fine biopores; many fine and medium roots; common anthropogenic relicts as coal, charcoal, brick fragments, gravel; clear and smooth to:

2Bt4 90–120 cm: sandy loam; 5 YR 4/4 (moist) illuviation bands with 7.5 YR 4/4 (moist) loamy sand interlayers 1–2 cm thick occasionally also finer textured thin sedimentation laminae; macrostructureless; friable; occasional pedotubules (worm holes); common fine biopores and few large biopores; very few fine roots; clear and smooth to:

2CB 120–150 cm: sedimentary stratified sand with thin gravel layers and occasional thin illuviation bands (<1 cm thick).



b. PARTICLE SIZE DISTRIBUTION

Sample	Depth cm	Horizon	Particle size classes in µm																			Md 50 sand fraction µm
			<2	2-50	>50	<2	2-4	4-8	8-16	16-25	25-35	35-50	50-75	75-105	105-150	150-210	210-300	300-420	420-600	600-850	850-1200	1200-1700	<2µm / <16µm	
			%			%																		
80/588	0- 27	Ap	18.1	38.6	43.3	18.1	5.6	7.1	8.7	6.0	4.7	6.5	1.8	1.9	4.6	8.6	9.9	7.8	5.0	2.2	1.5	-	0.46	253
80/589	27- 40	E	30.1	42.2	27.7	30.1	7.6	8.7	9.4	6.0	4.5	6.0	1.5	1.8	3.4	6.8	6.5	4.1	2.3	0.8	0.5	-	0.54	215
80/590	40- 50	Bt1	44.9	43.5	11.6	44.9	8.6	9.3	10.2	8.1	1.9	5.4	1.2	1.0	2.2	2.7	1.9	1.3	0.8	0.5	-	-	0.62	181
80/591	50- 64	Bt2	40.8	49.2	10.0	40.8	7.1	8.8	11.5	9.2	6.1	6.5	1.4	1.3	2.6	2.8	0.8	0.5	0.3	0.2	0.1	-	0.60	145
80/592	64- 90	Bt3	36.3	44.3	19.4	36.3	6.0	4.7	13.3	8.2	5.2	6.9	2.0	2.4	6.4	6.6	1.1	0.5	0.3	0.1	-	-	0.60	142
80/593	90-120	2Bt4	13.6	13.7	72.7	13.6	1.3	1.4	1.9	1.5	3.8	3.8	2.4	3.8	11.3	20.6	20.7	8.3	4.0	1.1	0.5	-	0.75	205
80/594	120-150	2CB	1.1	0.7	98.2	1.1	0.3	0.1	0.1	0.0	0.2	0.0	0.1	0.1	0.6	5.5	27.0	34.1	21.0	7.5	1.7	0.6	0.69	356

c. CHEMICAL DATA

Sample	Depth cm	Horizon	Clay %	Humus %	$CaCO_3$ %	pH-KCl	CEC/soil mmol/kg	CEC/clay mmol/kg	Exch. bases $1/2Ca^{2+}$	$1/2Mg^{2+}$	Na^+	K^+	Sum	Exch. acidity $1/3\ Al^{3+}$	H^+	BS %	Fe_2O_3 ox %	Fe_2O_3 dith %	Al_2O_3 dith %
									mmol/kg						mmol/kg				
80/588	0- 27	Ap	18.1	1.7	-	4.8	59	326	60	7	-	1	68			115	0.6	1.9	0.7
80/589	27- 40	E	30.1	0.4	-	4.0	74	246	58	10	-	1	69			93	0.8	2.5	1.5
80/590	40- 50	Bt1	44.9	0.0	-	3.8	123	274	83	18	-	1	102			83	0.5	3.6	2.1
80/591	50- 64	Bt2	40.8	0.2	-	3.8	162	397	116	21	-	-	137			85	0.6	3.9	2.2
80/592	64- 90	Bt3	36.3	0.1	-	3.8	145	399	124	24	-	-	148			102	0.4	3.4	2.1
80/593	90-120	2Bt4	13.6	0.2	-	4.0	69	507	47	13	-	-	60			87	0.2	1.5	1.1
80/594	120-150	2CB	1.1	0.3	-	4.8	5	455	3	1	-	1	5			100	0.1	0.3	0.2

d. TOTAL CHEMICAL COMPOSITION OF THE CLAY FRACTION

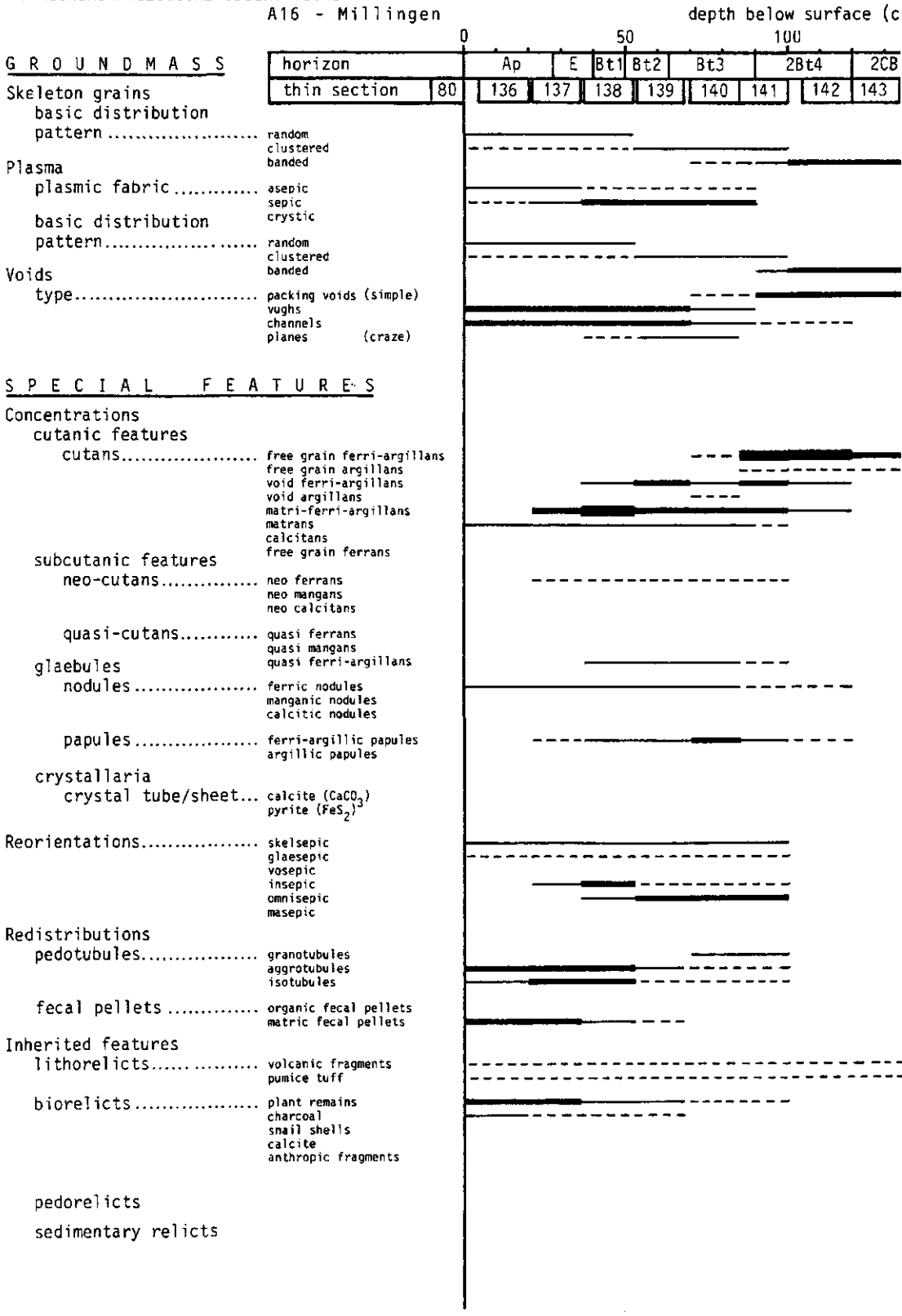
Sample	Depth cm	Horizon	Clay %	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	BaO	H_2O^+	CEC/clay* mmol/kg
				Xu/w													
80/588	0- 27	Ap	18.1	50.29	23.04	7.55	1.03	0.06	2.08	0.06	0.26	3.79	1.08	0.53	1.68	8.13	220
80/589	27- 40	E	30.1	49.36	23.24	7.46	1.03	0.05	1.98	0.04	0.25	3.71	1.00	0.31	2.28	7.85	300
80/590	40- 50	Bt1	44.9	49.07	23.78	8.24	0.94	0.05	2.07	0.02	0.23	3.53	0.91	0.27	2.69	8.35	350
80/591	50- 64	Bt2	40.8	47.69	24.01	8.82	0.82	0.05	2.00	0.01	0.21	3.46	0.86	0.20	3.05	8.81	400
80/592	64- 90	Bt3	36.3	47.65	24.48	9.04	0.71	0.05	2.12	0.03	0.21	3.42	0.74	0.31	3.38	8.88	440
80/593	90-120	2Bt4	13.6	48.11	23.05	8.16	0.70	0.06	2.08	0.03	0.20	3.26	0.87	0.22	2.85	9.28	370
80/594	120-150	2CB	1.1	no data													

e. PHYSICAL CHARACTERISTICS

No determinations of this profile.

* Calculated from adsorbed $\frac{1}{2}Ba^{2+}$.

f. MICROMORPHOLOGICAL OBSERVATIONS



A.17 EWIJK

a. Profile description

General data

1. Location: Topographical map of the Netherlands, scale 1:25.000 (1966), sheet 39H, coordinates N 430.780; E 179.620.
2. Date of description: 1-10-1975.
3. Described by: R. Miedema and C. de Kreij.
4. Mapping unit: KML2.

Soil site characteristics

1. Classification:
   a. according to FAO-Unesco (1974): Eutric Gleysol
   b. according to the Soil Taxonomy (1975): Thapto Hapludalfic Aeric Haplaquept
   c. according to De Bakker and Schelling (1966): Poldervaaggrond (Daalbrikgrond)
2. Land use: harvested maize field
3. Geology: medium- to fine-textured Holocene Rhine deposit overlying redeposited (?) medium- to fine-textured Late Weichselian Rhine deposit.
4. Physiography: flat levee.
5. Relief: subnormal
6. Slope: level to nearly level, class A.
7. Altitude: 7 m +NAP (Amsterdam Ordnance Datum)
8. Hydrology:
   a. Soil drainage class: imperfectly drained
   b. Groundwater level:
      presumed highest: 45 cm below the soil surface
      presumed lowest: 130 cm below the soil surface
      actual: 120 cm below the soil surface
   c. Artificial drainage: ditches round the parcel
   d. Flooding: none
9. Evidence of human activity: Ap 0-25 cm

Description of soil horizons

Apg	0-25 cm:	loam; 10 YR 3.5/3 (moist); few fine faint round 10 YR 5/8 Fe-mottles; few fine distinct round N 2/ Mn-concretions; moderate compound fine smooth prismatic structure, subdivided into medium subangular and angular blocky structure; common fine and common large biopores; common fine roots; friable; local concentrations of organic material and silt spots; clear and smooth to: Remark: the layer 23-28 cm below the soil surface is more dense (plough pan) than rest of Apg and Bwg
Bwg1	25-47 cm:	loam; 10 YR 4/3 (moist); mottling and concretions see Ap; medium moderate subangular blocky structure; few large biopores (some filled with worm excrements) and many fine biopores; common (to few) fine roots; friable; few coatings on ped faces; gradual and smooth to:
Bwg2	47-64 cm:	clay loam; 10 YR 4/2 (moist) ; common fine distinct round 7.5 YR 5/8 Fe-mottles and common fine distinct round Mn-concretions; strong compound fine smooth prismatic subdivided into strong, medium angular blocky structure;

few large biopores and many fine biopores inside peds and common fine biopores on ped faces; few fine roots; firm; locally some coarse fragments; few coatings on ped faces; clear and smooth to:

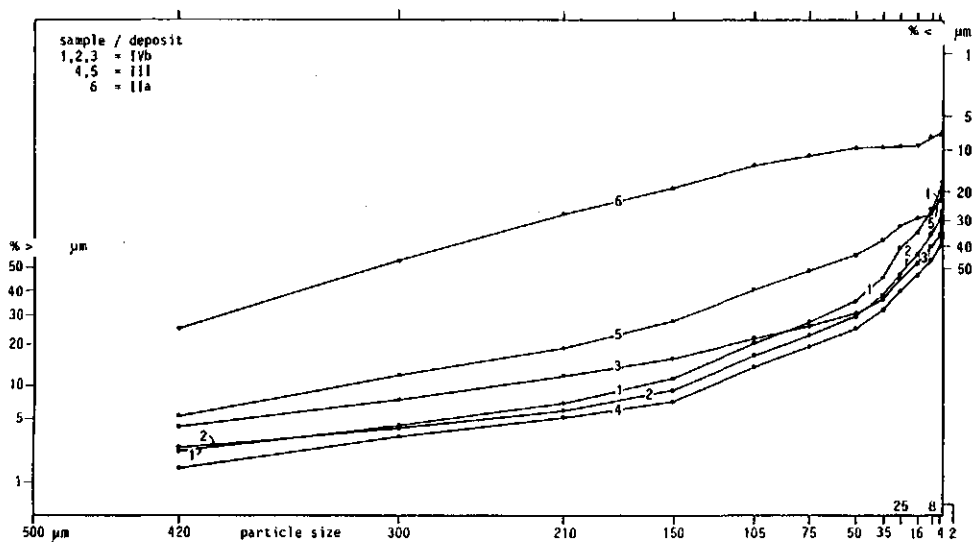
2Btg1 64-87 cm: clay loam; 10 YR 5/2.5 (moist); many medium distinct round 7.5 YR 5/8 Fe-mottles and many medium distinct round N2/ Mn-concretions; moderate single medium smooth prismatic structure; biopores see Bwg; very few fine roots; firm; few coatings on ped faces; clear and smooth to:

2Btg2 87-99 cm: sandy loam; 10 YR 5/3 (moist); many medium distinct round 7.5 YR 5/8 Fe-mottles; macrostructureless; common fine biopores; very friable; clear and smooth to:

3Btg3 99-120 cm: sand; 10 YR 5/3 (wet); few fine faint round Fe-mottles; single grain structure; non sticky, non plastic; many gravel.

b. PARTICLE SIZE DISTRIBUTION

Sample	Depth cm	Horizon	<2	2-50	>50	Particle size classes in µm: <2	2-4	4-8	8-16	16-25	25-35	35-50	50-75	75-105	105-150	150-210	210-300	300-420	420-600	600-850	850-1200	1200-1700	<2µm <16µm	Md 50 sand fraction µm
			%			%																		
75/441	0- 25	Apg	17.7	46.2	36.1	17.7	3.6	5.1	8.3	5.5	14.3	9.4	8.0	7.1	9.1	4.8	2.7	2.1	1.2	0.6	0.5	-	0.51	120
75/442	25- 47	Bwg1	26.9	43.0	30.1	26.9	4.5	4.5	8.4	7.7	10.0	7.9	6.9	6.1	7.8	3.3	2.0	1.7	1.1	0.6	0.8	-	0.61	115
75/443	47- 84	Bwg2	31.0	37.7	31.3	31.0	4.7	4.5	7.1	6.5	9.0	5.9	4.6	4.2	5.7	4.6	4.3	3.6	1.9	1.2	0.8	0.3	0.66	165
75/444	84- 87	2Btg1	36.5	37.5	26.0	36.5	4.8	5.1	6.0	6.4	8.6	6.6	5.9	5.5	6.8	2.5	1.8	1.8	0.8	0.4	0.4	-	0.58	115
75/445	87- 97	2Btg2	20.4	23.8	55.8	20.4	2.1	5.3	1.2	2.8	6.1	6.3	7.1	8.2	11.8	9.5	7.1	6.8	3.2	1.3	0.5	0.3	0.70	155
75/446	97-120	3Btg3	7.1	2.8	90.1	7.1	0.3	0.6	1.1	0.6	0.1	0.1	1.4	2.1	5.8	8.5	18.8	27.7	14.8	6.5	3.0	1.5	0.78	335



c. CHEMICAL DATA

Sample	Depth	Horizon	Clay	Humus	$CaCO_3$	pH-KCl	CEC/soil	CEC/clay	Exch. bases					Exch. acidity			BS	Fe_2O_3		Al_2O_3
									1/2Ca^{2+}	1/2Mg^{2+}	Na^+	K^+	Sum	1/3 Al^{3+}	H^+			ox	dith	dith
	cm		%	%	%		mmol/kg	mmol/kg	mmol/kg								%	%		%
75/441	0- 25	Apg	17.7	2.0	0.1	5.3	97	548	45	27	1	4	77	-	-		79	0.6	1.9	1.0
75/442	25- 47	Bwg1	26.9	0.4	-	4.7	162	602	80	34	2	5	121	-	-		75	0.7	2.7	1.0
75/443	47- 64	Bwg2	31.0	0.2	-	4.8	195	629	108	38	-	6	152	-	-		78	0.7	2.9	1.3
75/444	64- 87	2Btg1	36.5	0.0	-	5.2	238	652	153	36	-	2	191	-	-		80	0.6	3.8	1.5
75/445	87- 97	2Btg2	20.4	0.0	-	5.3	107	525	82	21	-	3	106	-	-		99	0.4	2.1	1.0
75/446	97-120	3Btg3	7.1	0.1	0.1	5.6	37	521	24	7	-	1	32	1	1		86	0.2	1.0	0.3

d. TOTAL CHEMICAL COMPOSITION OF THE CLAY FRACTION

Sample	Depth	Horizon	Clay	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	BaO	H_2O^+	CEC/clay*
	cm		%	%w/w													mmol/kg
75/441	0- 25	Apg	17.7	49.01	21.31	8.89	0.60	0.31	1.71	0.15	0.93	3.54	0.87	0.79	5.36	8.22	700
75/442	25- 47	Bwg1	26.9	48.65	21.58	9.27	0.43	0.32	1.77	0.12	0.96	3.33	0.81	0.60	5.90	7.85	770
75/443	47- 64	Bwg2	31.0	49.52	22.59	8.84	0.55	0.13	1.79	0.07	0.91	3.15	0.81	0.37	5.41	8.58	710
75/444	64- 87	2Btg1	36.5	48.06	22.96	8.90	0.58	0.07	1.74	0.05	0.98	3.08	0.79	0.29	4.87	8.58	640
75/445	87- 97	2Btg2	20.4	48.31	23.07	8.84	0.47	0.02	1.79	0.06	0.93	3.18	0.71	0.38	5.65	7.62	740
75/446	97-120	3Btg3	7.1	47.27	21.67	9.26	0.54	0.17	1.77	0.16	1.16	3.30	0.68	0.58	5.51	7.74	720

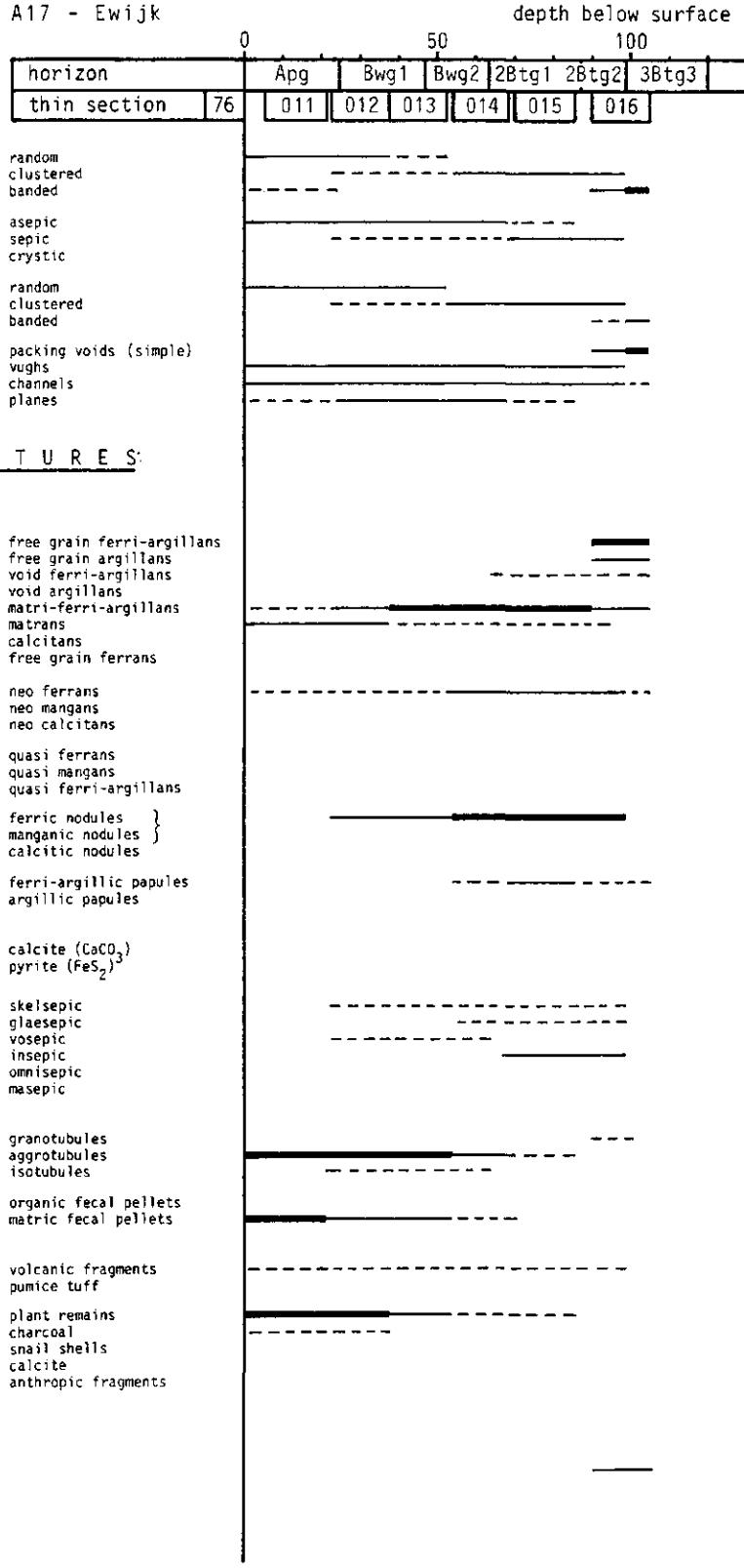
e. PHYSICAL CHARACTERISTICS (horizon averages*** and averages of 5 core samples***)

Depth	Horizon	Texture (mm)			Humus	Bulk density	Particle density	Pore volume	Moisture content				Available moisture	Air volume	
		<2	2-50	50					pF 2	pF4.2	pF2	pF4.2	VpF2-VpF4.2	pF2	pF4.2
cm		%			%	kg/m^3	kg/m^3	%	%w/w		%v/v		mm/10 cm	%	
0- 25	Apg	17.7	46.2	36.1	2.0	1490	2620	43.1	23.1	8.5	34.4	12.7	21.7	8.7	30.4
25- 47	Bwg1	26.9	43.0	30.1	0.4	1480	2700	45.2	21.7	10.6	32.1	15.7	16.4	13.1	29.5
47- 64	Bwg2	31.0	37.7	31.3	0.2	1510	2710	44.3	22.5	11.7	34.0	17.7	16.3	10.3	26.6
64- 87	2Btg1	36.5	37.5	26.0	0.0	1550	2760	43.8	22.1	13.5	34.3	20.9	13.4	9.5	22.9
87- 97	2Btg2	20.4	23.8	55.8	0.0	1690	2700	37.4	17.5	7.1	29.6	12.0	17.6	7.8	25.4
90-120	3Btg3	7.1	2.8	90.1	0.1	1650	2670	38.2	6.7	1.8	11.1	3.0	8.1	27.1	35.2
													** 185 mm		
5- 10						1490	2620	43.1	23.1	8.5	34.4	12.7	21.7	8.7	30.4
35- 40						1480	2700	45.2	21.7	10.6	32.1	15.7	16.4	13.1	29.5
55- 60						1510	2710	44.3	22.5	11.7	34.0	17.7	16.3	10.3	26.6
70- 75						1550	2760	43.8	22.1	13.5	34.3	20.9	13.4	9.5	22.9
90- 95						1690	2700	37.4	17.5	7.1	29.6	12.0	17.6	7.8	25.4
105-110						1650	2670	38.2	6.7	1.8	11.1	3.0	8.1	27.1	35.2

* Calculated from adsorbed Ba^{2+}
** Sum over profile depth.
*** Calculation with rounded averages may cause differences of some decimals

f. MICROMORPHOLOGICAL OBSERVATIONS

A17 - Ewijk



GROUNDMASS

Skeleton grains
- basic distribution pattern ..... random, clustered, banded

Plasma
- plasmic fabric ..... asepic, sepic, crystic
- basic distribution pattern ..... random, clustered, banded

Voids
- type ..... packing voids (simple), vughs, channels, planes

SPECIAL FEATURES

Concentrations
- cutanic features
  - cutans ..... free grain ferri-argillans, free grain argillans, void ferri-argillans, void argillans, matri-ferri-argillans, matrans, calcitans, free grain ferrans
- subcutanic features
  - neo-cutans ..... neo ferrans, neo mangans, neo calcitans
  - quasi-cutans ..... quasi ferrans, quasi mangans, quasi ferri-argillans
- glaebules
  - nodules ..... ferric nodules, manganic nodules, calcitic nodules
  - papules ..... ferri-argillic papules, argillic papules
- crystallaria
  - crystal tube/sheet ... calcite ($CaCO_3$), pyrite (FeS_2)

Reorientations ..... skelsepic, glaesepic, vosepic, insepic, omnisepic, masepic

Redistributions
- pedotubules ..... granotubules, aggrotubules, isotubules
- fecal pellets ..... organic fecal pellets, matric fecal pellets

Inherited features
- lithorelicts ..... volcanic fragments, pumice tuff
- biorelicts ..... plant remains, charcoal, snail shells, calcite, anthropic fragments
- pedorelicts
- sedimentary relicts

A.18 WEURT

a. Profile description

General data

1. Location: Topographical map of the Netherlands, scale 1:25.000 (1966), sheet 40C, coordinates: N 429.700; E 183.920
2. Date of description: 7-10-1975
3. Described by: R. Miedema and Th. Pape.

Soil site characteristics

1. Classification:
   a. According to FAO-Unesco (1974): Eutric Cambisol
   b. according to the Soil Taxonomy (1975): Fluventic Eutrochrept
   c. according to De Bakker and Schelling (1966): Hofeerdgrond.
2. Land use: grassland
3. Geology: coarse- to medium-textured Holocene Rhine deposit
4. Physiography: flat levee
5. Relief: subnormal
6. Slope: level to nearly level, class A.
7. Altitude: 9 m +NAP (Amsterdam Ordnance Datum)
8. Hydrology:
   a. Soil drainage: moderately well drained
   b. Groundwater level:
      presumed highest: 60 cm below the soil surface
      presumed lowest: 120 cm below the soil surface
      actual: 120 cm below the soil surface
   c. Artificial drainage: none
   d. Flooding: none
9. Evidence of human activity: pieces of charcoal, baked loam from 0-40 cm

Description of soil horizons.

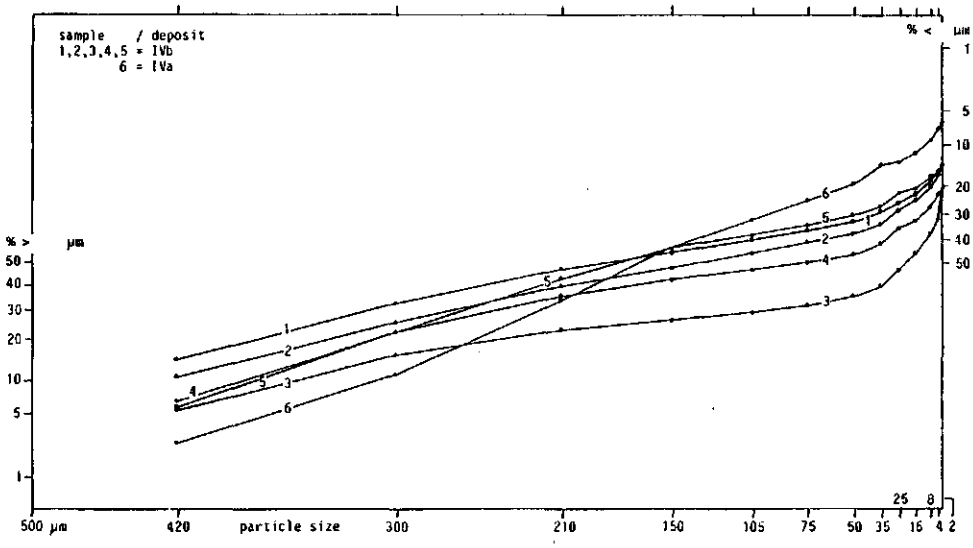
Ap	0-25 cm:	sandy loam; 10 YR 3/3 (moist); weak medium subangular blocky structure; common large and common fine biopores; common fine roots; friable; few round gravel (Ø 1-2 cm); few charcoal; slightly calcareous (spotwise); clear and smooth to:
Bw	25-56 cm:	sandy loam; 10 YR 4/3 (moist); weak medium subangular blocky structure, tending to sponge structure; common to many large and many fine biopores; common fine roots; friable; few round gravel (Ø 1-2 cm); few charcoal; slightly calcareous (spotwise); clear and smooth to:
Bwg	56-83 cm:	loam; 10 YR 4.5/3 (moist); common fine distinct very coarse compound rough prismatic structure subdivided into moderate medium subangular blocky structure; many large and many fine biopores; few fine roots; firm; slightly calcareous; clear and smooth to:
Bwgkl	83-99 cm:	sandy clay loam; 10 YR 6/3 (moist); common fine distinct round 10 YR 5/8 Fe-mottles, common fine distinct 2.5 Y 8/3 mottles of secondary $CaCO_3$; hole structure tending to sponge structure; many large and many fine biopores; friable; strongly calcareous (primary and secondary); gradual and smooth to:

Bwgk2 99-120 cm: sandy loam; 10 YR 5/8 (moist); common fine distinct round 10 YR 5/8 Fe-mottles, common fine distinct round N2/Mn-mottles; common fine distinct 2.5 Y 8/3 $CaCO_3$-mottles ; sponge structure; few large and many fine biopores; friable; strongly calcareous (primary and secondary); layered; clear and smooth to:

2Cg 120-130 cm: loamy sand; 10 YR 6/3 (moist); many coarse horizontally elongated Mn- and Fe-mottles; undisturbed stratification; loose; strongly calcareous.

b. PARTICLE SIZE DISTRIBUTION

Sample	Depth cm	Horizon	<2 %	2-50 %	>50 %	Particle size classes in µm: <2 %	2-4 %	4-8 %	8-16 %	16-25 %	25-35 %	35-50 %	50-75 %	75-105 %	105-150 %	150-210 %	210-300 %	300-420 %	420-600 %	600-850 %	850-1200 %	1200-1700 %	<2µm / <16µm	Md 50 sand fraction µm
75/447	0- 25	Ap	12.9	19.9	67.2	12.9	2.1	3.5	4.0	3.2	3.3	3.8	3.3	3.0	6.2	7.8	14.4	10.1	9.0	3.2	1.5	0.7	0.57	293
75/448	25- 56	Bv	14.7	23.1	62.2	14.7	2.7	3.1	4.4	3.4	5.5	4.0	3.8	4.0	6.5	8.5	13.8	14.8	6.8	2.3	1.0	0.7	0.59	264
75/449	56- 83	Bvg	21.0	43.6	35.4	21.0	10.6	5.5	8.6	7.4	7.0	4.5	3.3	2.3	3.0	3.6	7.1	10.5	4.3	0.8	0.3	-	0.46	279
75/450	83- 99	Bvgk1	21.3	25.0	53.7	21.3	1.6	4.6	5.0	2.9	6.6	4.1	3.8	2.9	4.4	7.6	12.8	15.6	5.6	0.8	0.1	-	0.66	267
75/451	99-120	Bvgk2	13.9	16.8	69.3	13.9	2.0	2.1	3.0	1.2	4.9	3.6	3.6	3.8	5.6	13.8	20.2	16.6	5.1	0.6	0.1	-	0.66	245
75/452	120-130	2Cg	6.8	12.9	80.3	6.8	0.9	1.6	2.4	2.0	0.7	5.3	5.7	6.6	12.4	21.8	22.7	8.7	2.2	0.3	0.1	-	0.58	193



c. CHEMICAL DATA

Sample	Depth	Horizon	Clay	Humus	$CaCO_3$	pH-KCl	CEC/soil	CEC/clay	Exch. bases					Exch. acidity		BS	Fe_2O_3 ox	Fe_2O_3 dith	Al_2O_3 dith
									$1/2Ca^{2+}$	$1/2Mg^{2+}$	Na^+	K^+	Sum	$1/3\ Al^{3+}$	H^+				
	cm		%	%	%		mmol/kg	mmol/kg	mmol/kg							%	%	%	%
75/447	0- 25	Ap	12.9	3.4	0.3	6.7	81	628	63	13	1	4	81			100	0.4	1.5	0.5
75/448	25- 56	Bw	14.7	1.2	0.3	6.9	75	510	61	11	-	3	75			100	0.4	1.5	0.4
75/449	56- 83	Bwg	21.0	1.1	0.1	6.4	152	724	116	22	-	1	139			91	0.7	2.7	1.6
75/450	83- 99	Bwgk1	21.3	0.4	0.4	7.2	155	728	132	22	-	1	155			100	0.5	2.1	1.3
75/451	99-120	Bwgk2	13.9	0.2	4.6	7.6	65	468	50	13	1	1	65			100	0.3	1.4	0.8
75/452	120-130	2Cg	6.8	0.5	8.5	7.9	9	132	1	6	1	1	9			100	0.3	0.9	0.3

d. TOTAL CHEMICAL COMPOSITION OF THE CLAY FRACTION

Sample	Depth	Horizon	Clay	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	BaO	H_2O^+	CEC/clay*
	cm		%	Gew%													mmol/kg
75/447	0- 25	Ap	12.9	46.20	20.93	9.18	0.68	0.27	1.73	0.39	0.43	4.00	0.85	1.38	5.69	8.21	740
75/448	25- 56	Bw	14.7	47.15	21.31	9.19	0.60	0.31	1.76	0.26	0.42	3.89	0.83	0.80	6.01	8.27	760
75/449	56- 83	Bwg	21.0	48.71	23.13	9.36	0.48	0.21	1.84	0.09	0.32	3.75	0.79	0.37	5.12	8.16	670
75/450	83- 99	Bwgk1	21.3	47.87	22.00	9.15	0.57	0.07	1.86	0.14	0.36	3.34	0.72	0.34	4.76	8.23	620
75/451	99-120	Bwgk2	13.9	47.25	21.98	9.33	0.55	0.12	1.88	0.14	0.33	3.52	0.84	0.41	4.87	8.12	640
75/452	120-130	2Cg	6.8	45.05	20.66	11.42	0.60	0.40	1.74	0.38	0.43	3.39	0.81	0.89	5.33	8.90	700

e. PHYSICAL CHARACTERISTICS (horizon averages and averages of 5 core samples)

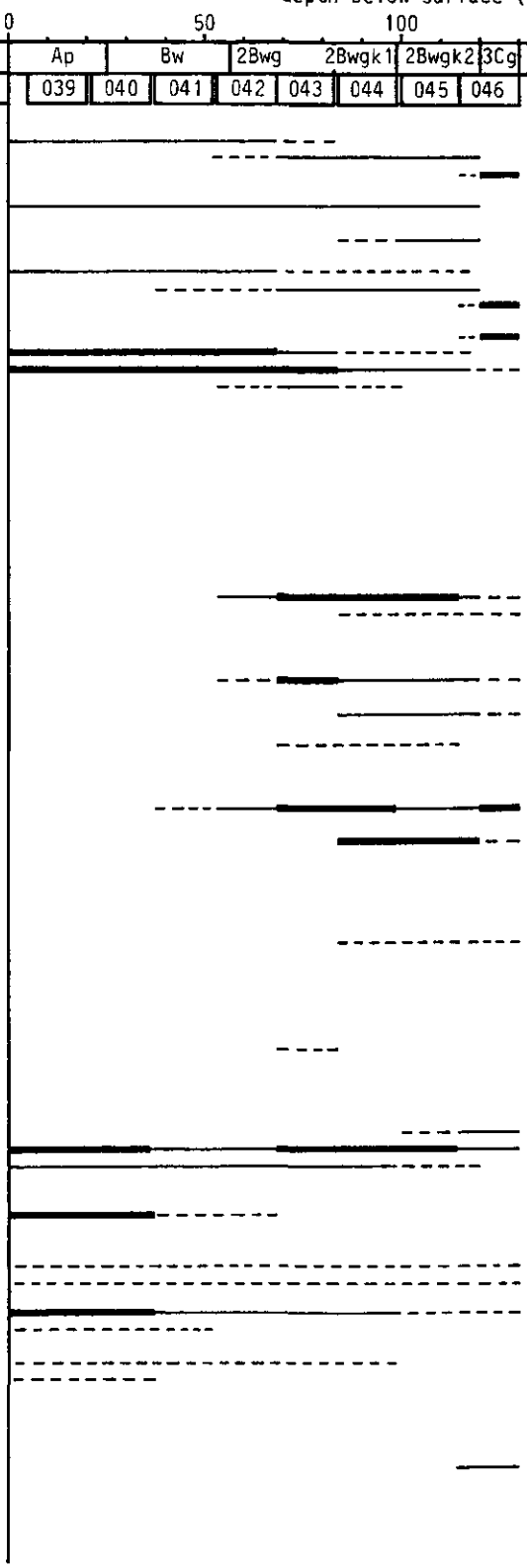
Depth	Horizon	Texture (mm)			Humus	Bulk density	Particle density	Pore volume	Moisture content				Available moisture	Air volume	
		<2	2-50	>50					pF2	pF4.2	pF2	pF4.2	VpF2-VpF4.2	pF2	pF 4.2
cm		%			%	kg/m³	kg/m³	%	Gew%		Vol%		mm/10 cm	%	
0- 25	Ap	12.9	19.9	67.2	3.4	1450	1620	44.7	20.9	8.1	30.3	11.7	18.6	14.4	33.0
25- 50	Bw	14.7	23.1	62.2	1.2	1500	2670	43.8	15.1	6.1	22.7	9.2	13.5	21.1	34.6
56- 83	Bwg	21.0	43.6	35.4	1.1	1510	2710	44.3	19.2	11.2	29.0	16.9	12.1	15.3	32.2
83- 99	Bwgk1	21.3	25.0	53.7	0.4	1560	2700	42.2	18.7	8.7	29.2	13.6	15.6	13.0	28.6
99-120	Bwgk2	13.9	16.8	69.3	0.2	1540	2700	43.0	14.9	5.5	22.9	8.5	14.4	20.1	34.5
120-130	2Cg	6.8	12.9	80.3	0.5	1470	2670	44.9	16.6	4.4	24.4	6.5	17.9	20.5	38.4
													** 200 cm		
10- 15						1450	2620	44.7	20.9	8.1	30.3	11.7	18.6	14.4	33.0
43- 48						1500	2670	43.8	15.1	6.1	22.7	9.2	13.5	21.1	34.6
70- 75						1510	2710	44.3	19.2	11.2	29.0	16.9	12.1	15.3	32.2
87- 92						1560	2700	42.2	18.7	8.7	29.2	13.6	15.6	13.0	28.6
105-110						1540	2700	43.0	14.9	5.5	22.9	8.5	14.4	20.1	34.5
122-127						1470	2670	44.9	16.6	4.4	24.4	6.5	17.9	20.5	38.4

* Calculated from adsorbed Ba^{2+}
** Sum over profile depth.
*** Calculations with rounded averages may cause differences of some decimals

f. MICROMORPHOLOGICAL OBSERVATIONS

A18 - Weurt

depth below surface (c



GROUNDMASS

Skeleton grains
- basic distribution pattern ..... random, clustered, banded

Plasma
- plasmic fabric ..... asepic, sepic, crystic
- basic distribution pattern ..... random, clustered, banded

Voids
- type ..... packing voids (simple), vughs, channels, planes (craze)

SPECIAL FEATURES

Concentrations
- cutanic features
  - cutans ..... free grain ferri-argillans, free grain argillans, void ferri-argillans, void argillans, matri-ferri-argillans, calcitans, free grain ferrans
- subcutanic features
  - neo-cutans ..... neo ferrans, neo mangans, neo calcitans
  - quasi-cutans ..... quasi ferrans, quasi mangans, quasi ferri-argillans
- glaebules
  - nodules ..... ferric nodules, manganic nodules, calcitic nodules
  - papules ..... ferri-argillic papules, argillic papules
- crystallaria
  - crystal tube/sheet ... calcite ($CaCO_3$), pyrite (FeS_2)

Reorientations ..... skelsepic, glaesepic, vosepic, insepic, mosepic, omnisepic, masepic

Redistributions
- pedotubules ..... granotubules, aggrotubules, isotubules
- fecal pellets ..... organic fecal pellets, matric fecal pellets

Inherited features
- lithorelicts ..... volcanic fragments, pumice tuff
- biorelicts ..... plant remains, charcoal, snail shells, calcite, anthropic fragments
- pedorelicts
- sedimentary relicts

A.19 RANDWIJK

a. Profile description

General data

1. Location: Topographical map of the Netherlands, scale 1: 25.000 (1966); sheet: 39 F, coordinates: N 439.850; E 176.750.
2. Date of description: 9-10-1975
3. Described by: R. Miedema and C. de Kreij.

Soil site characteristics

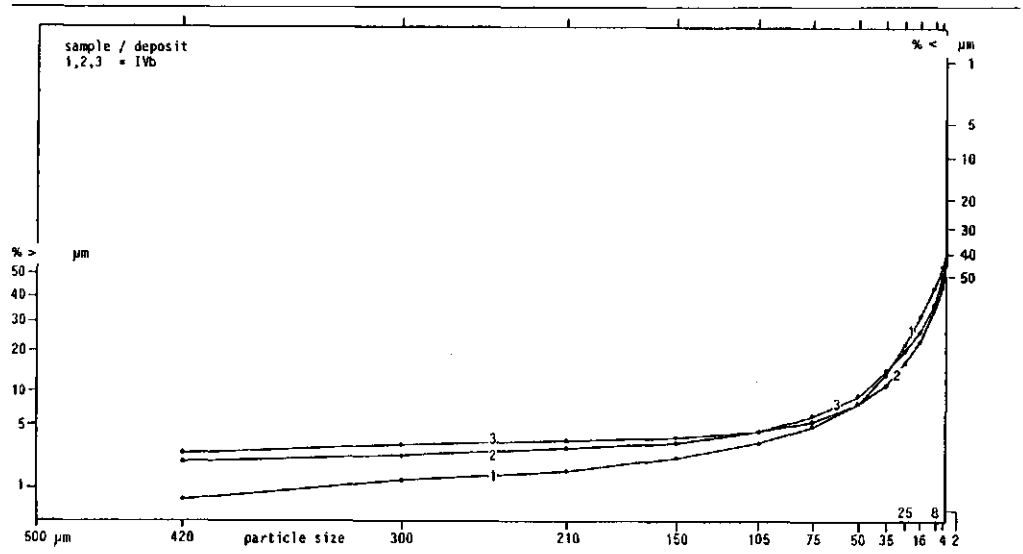
1. Classification:
   a. according to FAO-Unesco (1974): Eutric Gleysol
   b. according to the Soil Taxonomy (1975): Typic Haplaquept
   c. according to De Bakker and Schelling (1966): Poldervaaggrond.
2. Land use: harvested potato field
3. Geology: fine-textured Holocene Rhine deposit
4. Physiography: backswamp-levee transition
5. Relief: flat or concave
6. Slope: level to nearly level, class A
7. Altitude: 7.5 m +NAP (Amsterdam Ordnance Datum)
8. Hydrology:
   a. Soil drainage class: imperfectly drained
   b. Groundwater level:
      presumed highest: 30 cm below the soil surface
      presumed lowest: 120 cm below the soil surface
      actual: 70 cm below the soil surface
   c. Artificial drainage: tile drainage
   d. Flooding: none
9. Evidence of human activity: Ap 0-30 cm.

Description of soil horizons

Ap	0-30 cm:	silty clay loam; 10 YR 4/3 (moist); few fine distinct Fe-concretions; weak medium angular blocky structure; few fine biopores; few fine roots; friable; slightly calcareous patches; clear and smooth to:
Bwg	30-70 cm:	silty clay; 10 YR 5/2 (moist); common fine and medium distinct irregular 5 YR 5/8 Fe-mottles and common fine distinct round N2/ Mn-concretions; moderate single medium smooth prismatic structure; few fine biopores; few fine roots; firm; non-calcareous.

b. PARTICLE SIZE DISTRIBUTION

Sample	Depth	Horizon	<2	2-50	>50	Particle size classes in µm: <2	2-4	4-8	8-16	16-25	25-35	35-50	50-75	75-105	105-150	150-210	210-300	300-420	420-600	600-850	850-1200	1200-1700	<2µm / <16µm	Md 50 sand fraction
	cm		%			%																		µm
75/453	0-30	Ap	39.2	52.3	8.0	39.2	7.0	9.1	11.5	10.2	8.8	6.2	3.0	1.5	1.1	0.6	0.5	0.5	0.3	0.5	-	-	0.59	95
75/454	30-50	Bwg	45.7	46.3	8.0	45.7	8.6	9.5	11.3	7.1	5.7	4.1	2.5	1.3	0.8	0.4	0.4	0.5	0.6	0.6	0.7	0.2	0.61	115
75/455	50-70	Bwg	45.1	45.3	9.6	45.1	6.9	9.9	10.1	7.1	5.8	5.5	3.1	1.8	1.6	0.4	0.3	0.3	0.7	0.8	0.9	0.3	0.61	100



c. CHEMICAL DATA

Sample	Depth	Horizon	Clay	Humus	$CaCO_3$	pH-KCl	CEC/soil	CEC/clay	Exch. bases 1/2Ca^{2+}	1/2Mg^{2+}	Na^+	K^+	Scm	Exch. acidity 1/3 Al^{3+}	H^+	BS	Fe_2O_3 ox	Fe_2O_3 dith	Al_2O_3 dith
	cm		%	%	%		mmol/kg	mmol/kg			mmol/kg				mmol/kg	%	%	%	%
75/453	0-30	Ap	39.2	1.1	0.2	6.6	227	579	136	36	-	4	176			78	1.1	3.5	2.4
75/454	30-50	Bwg	45.7	0.2	0.2	6.5	292	639	232	47	-	-	279			96	0.7	3.7	2.4
75/455	50-70	Bwg	45.1	0.2	0.2	6.3	285	632	209	47	-	-	256			90	0.6	4.1	2.4

d. TOTAL CHEMICAL COMPOSITION OF THE CLAY FRACTION

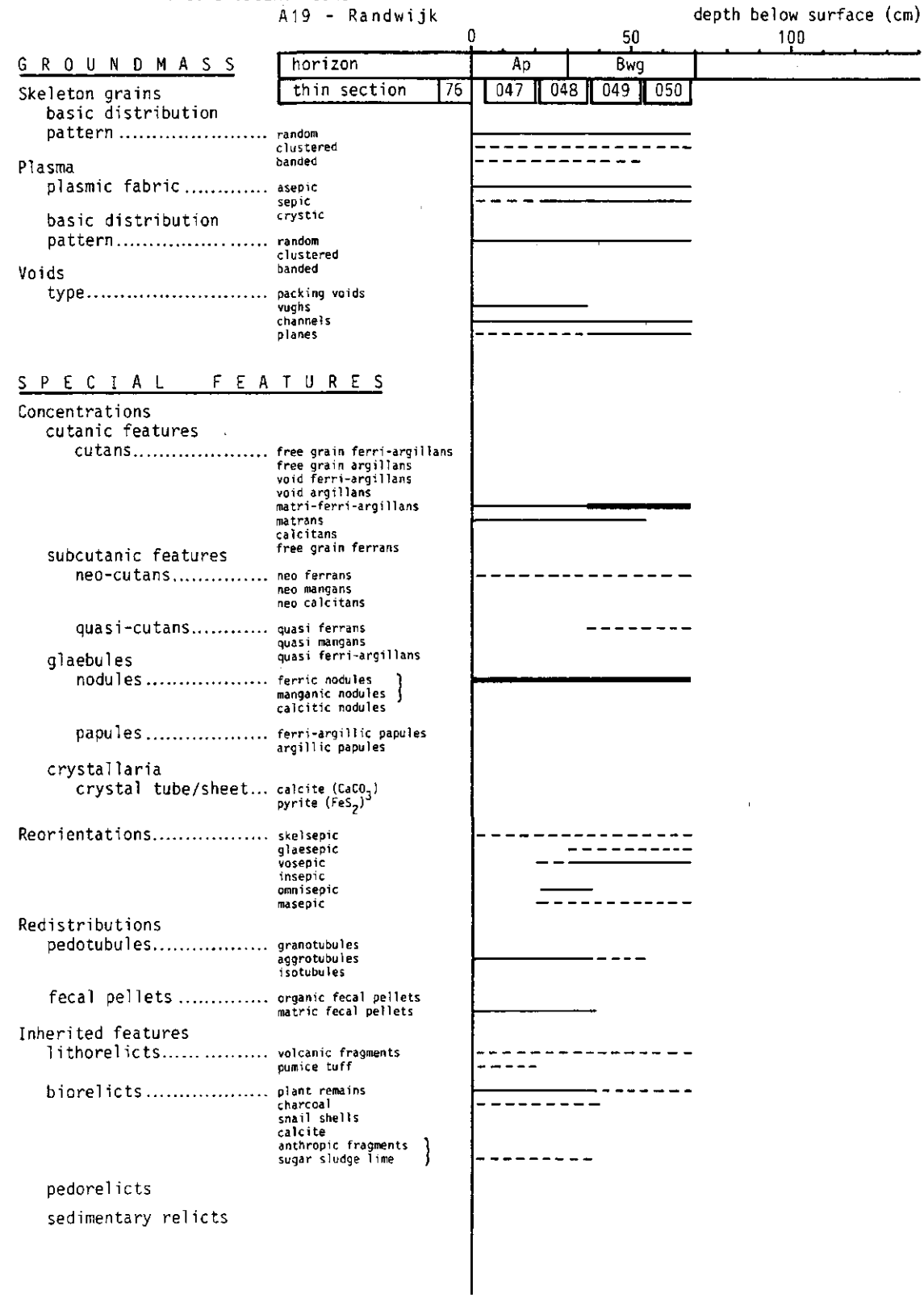
Sample	Depth	Horizon	Clay	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	BaO	H_2O^*	CEC/clay*
	cm		%	%w/w													mmol/kg
75/453	0-30	Ap	39.2	46.92	22.16	9.22	0.65	0.12	1.72	0.12	0.27	3.41	0.84	0.36	4.82	8.86	630
75/454	30-50	Bwg	45.7	48.75	23.33	8.71	0.42	0.30	1.72	0.04	0.27	3.12	0.93	0.21	5.32	8.38	690
75/455	50-70	Bwg	45.1	47.89	22.52	8.43	0.54	0.05	1.70	0.05	0.27	3.20	0.92	0.23	5.12	8.28	670

e. PHYSICAL CHARACTERISTICS (horizon averages*** and averages of 5 core samples***)

Depth	Horizon	Texture (µm) <2	2-50	>50	Humus	Bulk density	Particle density	Pore volume	Moisture content pF2 %w/w	pF4.2 %w/w	pF2 %v/v	pF4.2	Available moisture VpF2-VpF4.2	Air volume pF2	pF4.2
cm		%			%	kg/m³	kg/m³	%					mm/10 cm	%	
0-30	Ap	39.2	52.8	8.0	1.1	1470	2740	46.4	25.3	13.9	37.2	20.4	16.8	9.2	26.0
30-70	Bwg	45.4	45.8	8.8	0.2	1450	2790	48.0	30.2	16.5	43.8	23.9	19.9	4.2	24.1
													** 130		
12-17						1470	2740	46.4	25.3	13.9	37.2	20.4	16.8	9.2	26.0
50-55						1450	2790	48.0	30.2	16.5	43.8	23.9	19.9	4.2	24.1

* Calculated from adsorbed Ba^{2+}
** Sum over profile depth.
*** Calculations with rounded averages may causs differences of some decimals

f. MICROMORPHOLOGICAL OBSERVATIONS



A.20 KESTEREN

a. Profile description

General data

1. Location: Topographical map of the Netherlands 1:25.000 (1966); sheet 39 E; coordinates; N 439.200; E 168.160.
2. Date of description: 29-10-1976.
3. Described by: R. Miedema and A.G. Jongmans

Soil site characteristics

1. Classification:
   a. according to FAO-Unesco (1974): Calcaric Phaeozem
   b. according to the Soil Taxonomy (1975): Fluventic Hapludoll
   c. according to De Bakker and Schelling (1966): Hofeerdgrond.
2. Land use: harvested sugarbeets field.
3. Geology: coarse- to medium-textured Holocene Rhine deposit
4. Physiography: slightly undulating river levee
5. Relief: subnormal
6. Slope: level to nearly level, class A.
7. Altitude: 7.0 m +NAP (Amsterdam Ordnance Datum)
8. Hydrology:
   a. Soil drainage class: moderately well drained
   b. Groundwater level:
      presumed highest: 50 cm below the soil surface
      presumed lowest: 130 cm below the soil surface
      actual: 130 cm below the soil surface
   c. Artificial drainage: ditches around the field
   d. Flooding: none
9. Evidence of human activity: Ap 0-26 cm

Description of soil horizons

Ap	0-26 cm:	loam; 10 YR 3/2 (moist); weak very fine subangular blocky, locally angular blocky structure; few fine and few large biopores; few fine roots; friable; calcareous with shells and some biogenic calcite; few gravels, bricks and coal; abrupt and smooth to:
Bw	26-50 cm:	silt loam to silty clay loam; 10 YR 4/4 (moist); strong fine subangular blocky, locally granular (mole holes) structure; few fine and common large biopores in the plowpan (26-33 cm); many to abundant fine and many large biopores below; common fine roots; firm in plough pan, below slightly firm; calcareous with shells and some biogenic calcite; clear and smooth to: Remark: clear dense plough pan from 26-33 cm; pedotubules and coated (10 YR 3/2) worm holes
Bwg	50-81 cm:	loam; 10 YR 7/4 (dry); sponge structure locally disturbed stratification; common medium distinct irregular, in lower part horizontally elongated 5 YR 5/8 (mainly) locally 2.5 YR 3/4 Fe-mottles (some distinct neoferrans), few fine distinct round Mn-mottles; many fine and large biopores; few fine roots; hard; calcareous with shells; clear and smooth to: Remark: pedotubules; mole holes sometimes with sandy filling; coated worm holes.

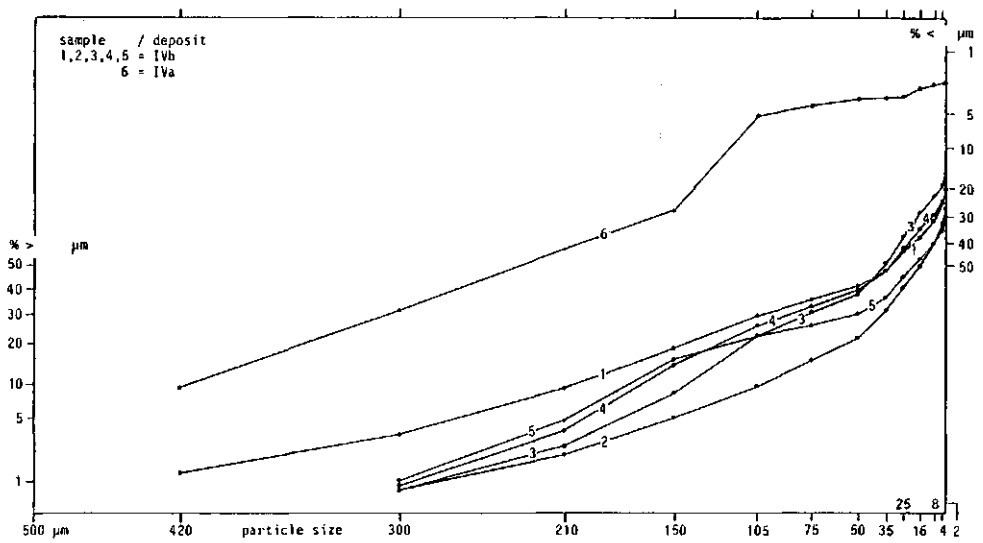
Cgl 81-87 cm: loam; 10 YR 7/2 (dry); disturbed stratification; common medium and coarse distinct irregular and horizontally elongated 2.5 YR 3/4 and 5 YR 5/8 Fe-mottles (some distinct neoferrans); few fine distinct round Mn-mottles; common fine and large biopores; few fine roots; hard; calcareous with shells; abrupt and smooth to:
Remark: lower boundary locally perforated by worm holes.

Cgk 87-90 cm: clay loam; 10 YR 6/3 (dry); sponge structure; common fine distinct irregular 2.5 YR 3/4 Fe-mottles; few fine distinct Mn-mottles; many fine and few large biopores; common fine roots; slightly hard; calcareous with shells, secondary lime (neocalcitans) and hard calcitic nodules; abrupt and smooth to:

2Cg 90-120 cm: sand; 10 YR 7/4 (moist); undisturbed stratification; few coarse distinct irregular and horizontally elongated 7.5 YR 5/8 mottles; loose; calcareous.

b. PARTICLE SIZE DISTRIBUTION

Sample	Depth cm	Horizon	<2	2-50	>50	Particle size classes in µm: <2	2-4	4-8	8-16	16-25	25-35	35-50	50-75	75-105	105-150	150-210	210-300	300-420	420-600	600-850	850-1200	1200-1700	<2µm / <16µm	Md 50 sand fraction µm
			%			%																		
77/13	0- 26	Ap	20.2	38.8	41.0	20.2	4.7	5.9	6.4	5.8	9.2	6.8	5.5	6.2	12.7	7.5	5.8	2.0	0.9	0.3	0.1	-	0.54	136
77/14	26- 50	Bw	27.0	51.4	21.6	27.0	6.4	7.2	9.2	8.8	10.6	9.2	6.4	5.8	4.4	3.0	1.3	0.4	0.2	0.1	-	-	0.54	98
77/15	50- 81	Bwg	16.0	46.2	37.8	16.0	2.9	4.0	6.0	8.5	12.3	12.5	7.7	8.0	13.9	5.6	1.9	0.4	0.2	0.1	-	-	0.35	115
77/16	81- 87	Cg1	20.4	40.3	39.3	20.4	3.7	4.7	5.9	7.6	10.6	7.8	6.4	7.3	11.5	10.4	2.9	0.5	0.2	0.1	-	-	0.59	128
77/17	87- 90	Cgk	29.2	40.9	29.9	29.2	5.0	6.1	7.4	7.1	9.1	6.2	4.1	3.7	6.4	11.0	3.7	0.7	0.3	-	-	-	0.61	154
77/18	90-120	2Cg2	2.4	1.2	96.4	2.4	0.1	0.1	0.2	0.4	0.2	0.2	0.3	1.2	22.2	15.4	26.2	21.7	7.1	1.6	0.4	0.1	0.86	241



c. CHEMICAL DATA

Sample	Depth	Horizon	Clay	Humus	$CaCO_3$	pH-KCl	CEC/soil	CEC/clay	Exch. bases					Exch. acidity		BS	Fe_2O_3		Al_2O_3
									1/2Ca^{2+}	1/2Mg^{2+}	Na^+	K^+	Sum	1/3 Al^{3+}	H^+		ox	dith	dith
	cm		%	%	%		mmol/kg	mmol/kg	mmol/kg							%	%		%
77/13	0- 26	Ap	20.2	2.6	3.9	7.2	132	653	114	12	4	2	132			100	0.6	2.2	1.0
77/14	26- 50	Bw	27.0	1.2	9.4	7.3	145	537	118	21	4	2	145			100	0.8	2.7	1.3
77/15	50- 81	Bwg	16.0	0.9	13.9	7.5	63	394	31	21	8	3	63			100	0.7	2.0	0.9
77/16	81- 87	Cg1	20.4	0.8	15.9	7.5	37	181	4	23	7	3	37			100	0.6	1.8	0.8
77/17	87- 90	Cgk	29.2	1.0	17.1	7.6	88	299	49	25	9	5	88			100	0.8	2.2	1.1
77/18	90-120	2Cg2	2.4	0.4	5.8	7.5	9	375	1	4	2	2	9			100	0.2	0.5	0.2

d. TOTAL CHEMICAL COMPOSITION OF THE CLAY FRACTION

Sample	Depth	Horizon	Clay	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	BaO	H_2O^+	CEC/clay*
	cm		%							%w/w							mmol/kg
77/13	0- 26	Ap	20.2	46.39	21.85	9.36	0.83	0.11	2.78	0.37	0.23	3.89	0.84	0.59	4.61	8.48	600
77/14	26- 50	Bw	27.0	46.36	22.21	9.52	0.70	0.14	2.78	0.27	0.22	3.77	0.85	0.39	4.42	8.09	580
77/15	50- 81	Bwg	16.0	46.20	21.91	9.24	0.69	0.14	2.74	0.35	0.23	3.65	0.86	0.42	4.68	8.83	610
77/16	81- 87	Cg1	20.4	47.24	22.60	8.75	0.80	0.11	2.88	0.46	0.22	3.75	0.85	0.42	4.42	8.39	580
77/17	87- 90	Cgk	29.2	48.51	22.40	7.87	0.76	0.10	2.96	0.38	0.22	3.80	0.86	0.31	4.42	8.05	580
77/18	90-120	2Cg2	2.4	no data		8.77	0.71	n.d.	1.77	n.d.	0.22	no data					

e. PHYSICAL CHARACTERISTICS (horizon averages and averages of 5 core samples)

Depth	Horizon	Texture (µm)			Humus	Bulk density	Particle density	Pore volume	Moisture content				Available moisture	Air volume	
		<2	2-50	>50					pF2	pF4.2	pF2	pF4.2	VpF2-VpF4.2	pF2	pF4.2
cm		%			%	kg/m^3	kg/m^3	%	%w/w		%v/v		mm/10 cm	%	
0-26	Ap	20.2	38.8	41.0	2.6	1540	2650	41.9	22.9	9.2	35.3	14.2	21.1	6.6	27.7
26-50	Bw	27.0	51.4	21.6	1.2	1340	2700	50.4	25.5	9.5	34.2	12.7	21.5	16.2	37.7
50-81	Bwg	16.0	46.2	37.8	0.9	1320	2710	51.3	26.0	7.7	34.3	10.2	24.1	17.0	41.1
													** 175 cm		
5-10						1540	2650	41.9	22.9	9.2	35.3	14.2	21.1	6.6	27.7
27-32(plowpan)						1540	2700	43.0	20.7	9.6	31.9	14.8	17.1	11.1	28.2
40-45						1340	2700	50.4	25.5	9.5	34.2	12.7	21.5	16.2	37.7
60-65						1320	2710	51.3	26.0	7.7	34.3	10.2	24.1	17.0	41.1

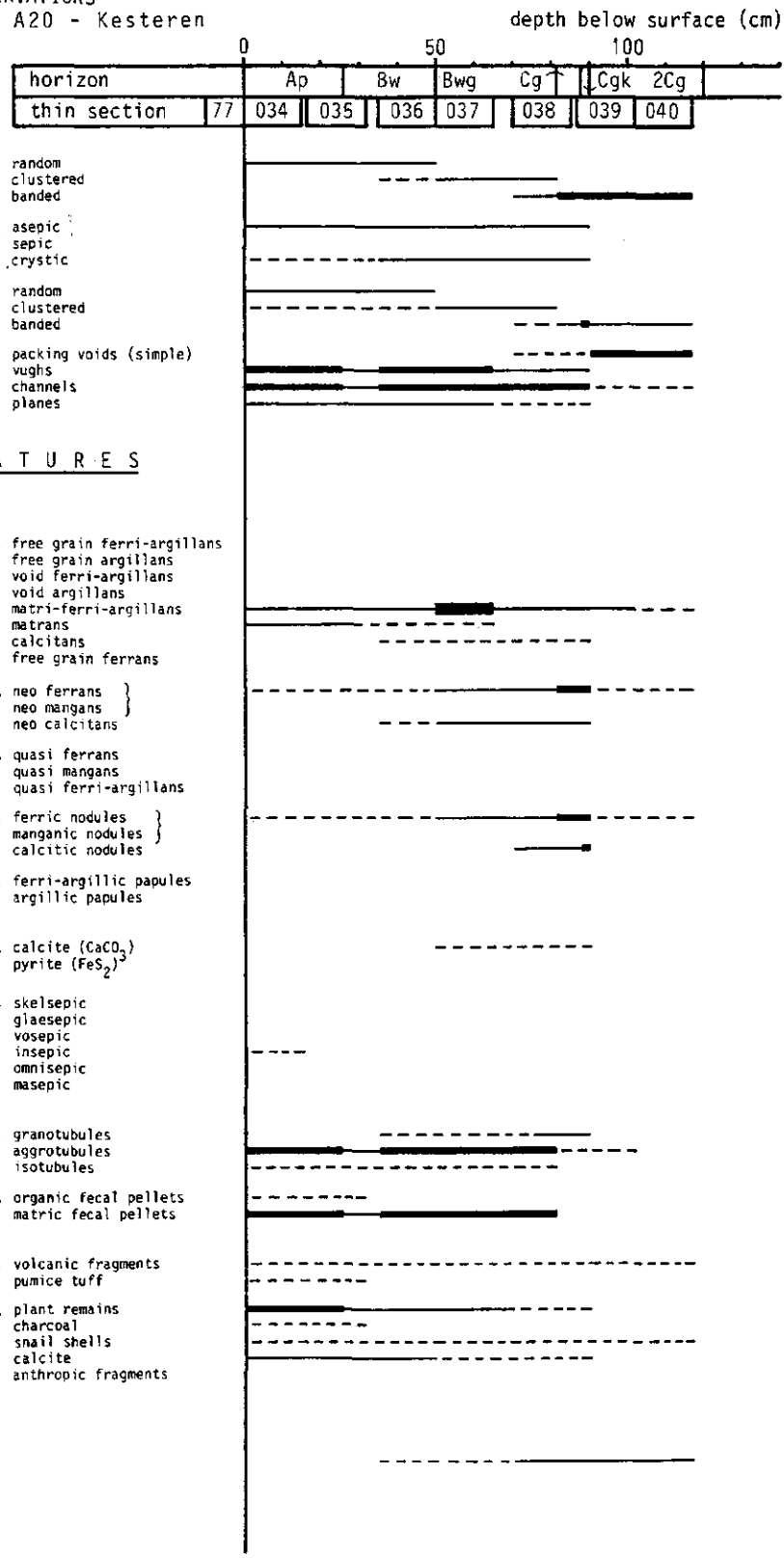
* Calculated from adsorbed $\frac{1}{2}Ba^{2+}$

** Sum over profile depth (80cm).

*** Calculations with rounded averages may cause differences of some decimals

f. MICROMORPHOLOGICAL OBSERVATIONS

A20 - Kesteren



A.21 LIENDEN

a. Profile description

General data

1. Location: Topographical map of the Netherlands, 1:25.000 (1966); sheet 39 E; coordinates; N 440.340; E 165.530.
2. Date of description: 28-10-1976
3. Described by: R. Miedema and A.G. Jongmans.

Soil site characteristics

1. Classification:
   a. according to FAO-Unesco (1974): Calcic Cambisol
   b. according to the Soil Taxonomy (1975): Fluventic Eutrochrept
   c. according to De Bakker and Schelling (1966): Ooivaaggrond
2. Land use: harvested maize-field
3. Geology: medium-textured Holocene Rhine deposit
4. Physiography: river levee.
5. Relief: subnormal
6. Slope: level to nearly level, class A.
7. Altitude: 7.0 m +NAP (Amsterdam Ordnance Datum)
8. Hydrology:
   a. Soil drainage class: moderately well drained
   b. Groundwater level:
      presumed highest: 50 cm below the surface
      presumed lowest: 150 cm below the surface
      actual: 120 cm below the surface
   c. Artificial drainage: ditches around the field
   d. Flooding: none
9. Evidence of human activity: Ap 0-30 cm

Description of soil horizons

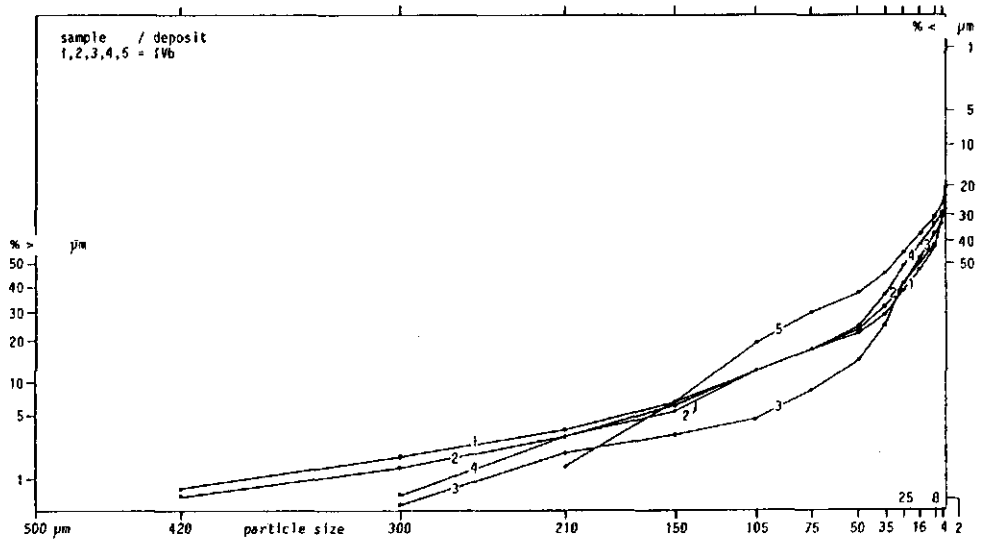
Ap	0-30 cm:	clay loam; 10 YR 4/3 (moist); moderate fine angular and subangular blocky structure; few fine and very few large biopores; common fine and medium roots; firm; calcareous with shells and some biogenic carbonate; few gravel brick fragments coal; abrupt and smooth to: Remark: rather dense
Bw	30 - 50 cm:	clay loam; 10 YR 4/4 (moist); very weak compound coarse rough prismatic structure subdivided into strong fine angular blocky structure, locally granular structure in mole holes and pedotubules; many fine and abundant large biopores; common fine and medium roots; friable; strongly calcareous with shells and some biogenic carbonate; clear and smooth to:
Bwg1	50-80 cm:	silt loam; 10 YR 5/3 (moist); very weak compound coarse rough prismatic structure subdivided into weak medium angular blocky structure; common medium faint irregular 7.5 YR 5/8 Fe-mottles with diffuse boundaries; few fine faint soft Mn-nodules; many fine and large biopores; few fine and medium roots; friable; strongly calcareous with shells; clear and smooth to: Remark: some pedotubules.
Bwg2	80-95 cm:	silt loam; 10 YR 6/3 (moist); sponge structure; common medium distinct irregular 10 YR 5/8 Fe-mottles with

diffuse boundaries; few fine distinct soft Mn-nodules; many fine and common large biopores; few fine roots; friable; strongly calcareous with shells; clear and smooth to:

Cg 95-130 cm: stratified loam/sandy loam; 10 YR 6/2 (wet); disturbed stratification; many medium and coarse distinct irregular 7.5 YR 5/8 Fe-mottles with diffuse boundaries; common medium distinct soft Mn-nodules; common fine and few large biopores; slightly plastic and non-sticky; strongly calcareous.

b. PARTICLE SIZE DISTRIBUTION

Sample	Depth cm	Horizon	>2	2-50	50<	<2	2-4	4-8	8-16	16-25	25-35	35-50	50-75	75-105	105-150	150-210	210-300	300-420	420-600	600-850	850-1200	1200-1700	<2µm <16µm	Md 50 sand fraction µm
			%			%																		
77/8	0- 30	Ap	27.8	49.9	22.3	27.8	6.2	9.0	9.4	9.1	9.3	6.9	5.0	5.0	5.5	3.1	1.8	1.1	0.5	0.2	0.1	-	0.53	114
77/9	30- 50	Bw	27.7	48.2	24.1	27.7	6.0	7.3	8.6	8.7	8.9	8.3	6.3	5.6	6.9	2.4	1.7	0.8	0.3	0.2	0.1	-	0.55	107
77/10	50- 80	Bwg1	25.7	59.4	14.9	25.7	5.2	6.8	10.0	12.8	13.8	10.8	6.4	3.8	1.6	1.1	1.5	0.4	0.1	-	-	-	0.54	83
77/11	80- 95	Bwg2	23.0	52.7	24.3	23.0	5.0	5.3	8.4	8.8	13.1	12.1	7.3	4.8	6.1	3.1	2.4	0.4	0.1	0.1	-	-	0.55	105
77/12	95-130	Cg	20.4	42.5	37.1	20.4	5.1	5.2	6.6	7.2	9.6	8.8	7.3	10.6	12.6	5.0	1.3	0.2	0.1	-	-	-	0.55	107



c. CHEMICAL DATA

Sample	Depth	Horizon	Clay	Humus	$CaCO_3$	pH-KCl	CEC/soil	CEC/clay	Exch. bases $1/2Ca^{2+}$	$1/2Mg^{2+}$	Na^+	K^+	Sum	Exch. acidity $1/3\ Al^{3+}$	H^+	BS	Fe_2O_3 ox	Fe_2O_3 dith	Al_2O_3 dith
	cm		%	%	%		mmol/kg	mmol/kg	mmol/kg							%	%		%
77/8	0- 30	Ap	27.8	2.7	3.2	7.1	168	604	129	32	4	3	168			100	0.7	2.6	1.3
77/9	30- 50	Bv	27.7	2.9	5.9	7.1	124	448	82	35	4	3	124			100	0.7	2.8	1.5
77/10	50- 80	Bvg1	25.7	1.2	15.0	7.3	81	315	46	26	4	5	81			100	0.6	2.3	1.2
77/11	80- 95	Bvg2	23.0	1.0	17.6	7.5	101	439	65	27	7	2	101			100	0.7	2.3	1.1
77/12	95-130	Cg	20.4	1.0	17.1	7.6	76	373	45	25	4	2	76			100	0.7	1.5	0.7

d. TOTAL CHEMICAL COMPOSITION OF THE CLAY FRACTION

Sample	Depth	Horizon	Clay	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	BaO	H_2O^+	CEC/clay*
	cm		%	% w/w													mmol/kg
77/8	0- 30	Ap	27.8	46.55	22.39	8.78	1.02	0.10	2.77	0.38	0.14	3.69	0.82	0.42	4.48	8.85	580
77/9	30- 50	Bv	27.7	46.88	22.51	8.77	0.88	0.11	2.59	0.20	0.14	3.58	0.82	0.30	4.76	8.36	620
77/10	50- 80	Bvg1	25.7	46.93	21.96	8.76	0.89	0.13	2.76	0.28	0.13	3.60	0.85	0.32	4.82	8.27	630
77/11	80- 95	Bvg2	23.0	47.73	21.88	8.96	0.70	0.13	2.68	0.39	0.23	3.55	0.86	0.34	4.60	8.15	600
77/12	95-130	Cg	20.4	48.45	21.63	9.14	0.85	0.15	2.53	0.50	0.26	3.44	0.84	0.41	4.36	7.88	570

e. PHYSICAL CHARACTERISTICS (horizon averages*** and averages of 5 core samples***)

Depth	Horizon	Texture (μm) <2	2-50	>50	Humus	Bulk density	Particle density	Pore volume	Moisture content pF2	pF4.2	pF2	pF4.2	Available moisture VpF2-VpF4.2	Air volume pF2	pF4.2
cm		%			%	kg/m³	kg/m³	%	% w/w		% v/v		mm/10 cm	%	
0- 30	Ap	27.8	49.9	22.3	2.7	1530	2690	43.1	23.9	11.5	36.6	17.6	19.0	6.5	25.5
30- 50	B21	27.7	48.2	24.1	2.9	1350	2700	50.0	22.0	11.3	29.7	15.3	14.4	20.3	34.7
50- 80	B22g	25.7	59.4	14.9	1.2	1320	2720	51.5	25.2	11.3	33.3	14.9	18.4	18.2	36.6
80- 95	C1g	23.0	52.7	24.3	1.0	1380	2700	48.9	26.7	7.7	36.8	10.6	26.2	12.1	38.3
95-130	C2g	20.4	42.5	37.1	1.0	1460	2690	45.7	21.9	5.5	32.0	8.0	24.0	13.7	37.7
													** 240 mm		
5- 10						1530	2690	43.1	23.9	11.5	36.6	17.6	19.0	6.5	25.5
30- 35						1420	2690	47.2	20.4	11.1	29.40	15.8	13.2	18.2	31.4
40- 45						1290	2710	52.8	23.5	11.4	30.1	14.6	15.5	22.7	38.2
55- 60						1320	2720	51.5	25.2	11.3	33.3	14.9	18.4	18.2	36.6
80- 85						1380	2700	48.9	26.7	7.7	36.8	10.6	26.2	12.1	38.3
95-100						1460	2690	45.7	21.9	5.5	32.0	8.0	24.0	13.7	37.7

* Calculated from adsorbed H_2O

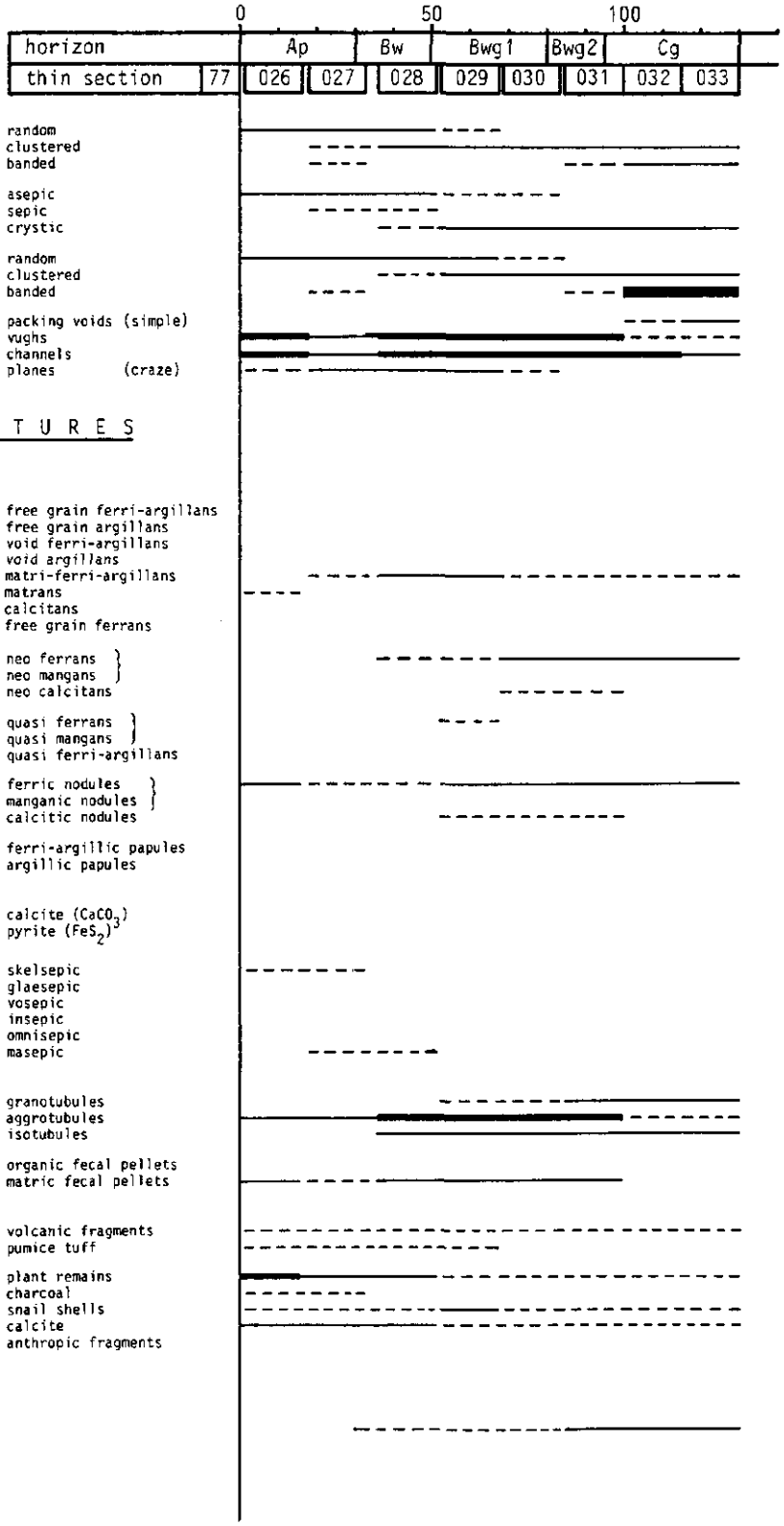
** Sum over profile depth.

*** Calculations with rounded averages may cause differences of some decimals

f. MICROMORPHOLOGICAL OBSERVATIONS

A21 - Lienden

depth below surface (cm)



A.22 OPHEUSDEN

a. Profile description

General data

1. Location: Topographical map of the Netherlands, 1:25.000 (1966); sheet 39F; coordinates; N 438.950; E 171.950.
2. Date of description: 27-10-1976
3. Described by: R. Miedema and A.G. Jongmans.

Soil site characteristics

1. Classification:
   a. according to FAO-Unesco (1974): Calcic Cambisol
   b. according to the Soil Taxonomy (1975): Fluventic Eutrochrept
   c. according to De Bakker and Schelling (1966): Hofeerdgrond
2. Vegetation/land use: fallow with some weeds, former grassland
3. Geology: fine-textured Holocene Rhine deposit
4. Physiography: foreland, very slightly undulating
5. Relief: flat or concave
6. Slope: level to nearly level, class A.
7. Altitude: 7.5 m +NAP (Amsterdam Ordnance Datum)
8. Hydrology:
   a. Soil drainage class: moderately well drained
   b. Groundwater level:
      presumed highest: 35 cm below the soil surface
      presumed lowest: 130 cm below the soil surface
      actual: 130 cm below the soil surface
   c. Artificial drainage: none
   d. Flooding: occurs irregularly in spring
9. Evidence of human activity: clay excavation

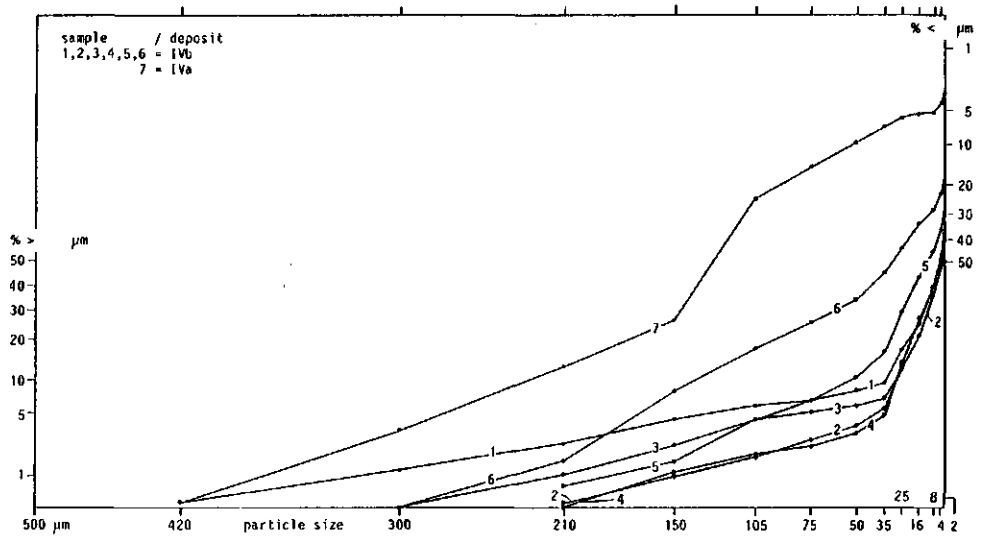
Description of soil horizons

Ah	0-17 cm:	silty clay loam; 10 YR 3/2 (moist); weak compound very coarse rough prismatic structure subdivided into strong fine angular blocky structure; few fine distinct white round patches of biogenic carbonate; few fine and few large biopores; many fine and very few medium roots; friable; slightly calcareous; clear and smooth to:
Bw	17-75 cm:	silty clay loam; 10 YR 4/3 (moist); strong compound very coarse rough prismatic structure subdivided into strong fine and medium angular and subangular blocky structure; few fine faint irregular 5 YR 5/8 Fe-mottles increasing with depth; few fine distinct white round spots of biogenic carbonate; abundant fine biopores in peds, common on peds and many large biopores; some pedotubules; common fine and common medium roots; firm; calcareous with snail shells; coated worm holes (10 YR 3/2), locally also on ped faces; gradual and smooth to:
Bwg1	75-95 cm:	silty clay loam; 10 YR 5/4 (dry); strong compound very coarse rough prismatic structure subdivided into weak fine subangular blocky structure; common fine faint irregular 7.5 YR 5/8 Fe-mottles; few fine faint round black Mn-mottles; few fine distinct round white biogenic carbonate; abundant fine biopores in, common on peds; few large biopores; few fine and very few medium roots; hard;

strongly calcareous with snail shells; clear and smooth to:

Bwg2 95–102 cm: loam; 10 YR 7/4 (dry); sponge structure; common fine distinct irregular 7.5 YR 5/8 Fe-mottles; common fine distinct round to irregular black Mn-mottles; abundant fine and very few large biopores; few fine roots; slightly hard; strongly calcareous with snail shells; abrupt and smooth to:

2Cg 102–130 cm: stratified sand; 10 YR 8/3 (dry); disturbed stratification passing into single grain structure; common fine distinct, especially in layers horizontally elongated and irregular 7.5 YR 5/8 Fe-mottles; very few large biopores, many fine in loamy sand layers, none in sand layers; soft/loose; strongly calcareous.
Remark: Clayey depositional bands in top 10 cm of this horizon.



b. PARTICLE SIZE DISTRIBUTION

Sample	Depth	Horizon	Particle size classes in µm																			Md 50
			<2	2-50	50-2000	<2	2-4	4-8	8-16	16-25	25-35	35-50	50-75	75-105	105-150	150-210	210-300	300-420	420-600	600-850	850-1200	1200-1700	<2µm <16µm	sand fraction
	cm		%			%																		µm
77/1	0- 17	Ah	39.7	52.3	8.0	39.7	10.2	12.2	12.5	8.5	7.7	1.5	1.1	1.9	1.6	1.8	1.4	0.7	0.3	0.1	-	0.1	0.53	163
77/2	17- 40	Bw	39.8	56.4	3.8	39.8	10.6	12.6	15.0	9.5	6.7	2.0	1.0	0.8	1.0	0.5	0.2	0.1	0.1	0.1	-	-	0.51	110
77/3	40- 60	Bw	40.7	53.3	6.0	40.7	10.5	12.9	14.4	8.3	6.2	1.0	0.9	0.8	2.0	1.2	0.7	0.3	0.1	-	-	-	0.52	134
77/4	60- 75	Bw	37.8	59.1	3.1	37.8	10.1	12.3	13.7	12.6	8.6	1.8	0.7	0.5	0.8	0.7	0.3	0.1	-	-	-	-	0.51	125
77/5	75- 95	Bwg1	29.8	59.9	10.3	29.8	6.1	9.5	11.4	13.9	12.8	6.1	3.5	2.5	2.8	0.9	0.5	0.2	-	-	-	-	0.52	95
77/6	95-102	Bwg2	18.8	47.0	34.2	18.8	3.7	5.8	4.8	10.2	11.0	11.5	8.4	8.2	9.6	6.4	1.2	0.3	0.1	-	-	-	0.57	107
77/7	102-130	2Cg	3.4	6.8	89.8	3.4	0.7	1.1	0.1	0.6	1.6	2.7	5.0	9.5	48.7	13.8	9.5	2.8	0.4	0.1	-	-	0.64	133

c. CHEMICAL DATA

Sample	Depth	Horizon	Clay	Humus	$CaCO_3$	pH-KCl	CEC/soil	CEC/clay	Exch. bases				Exch. acidity			BS	Fe_2O_3		Al_2O_3
									1/2Ca^{2+}	1/2Mg^{2+}	Na^+	K^+	Sum	1/3 Al^{3+}	H^+		ox	dith	dith
	cm		%	%	%		mmol/kg		mmol/kg						mmol/kg	%	%		%
77/1	0- 17	Ah	39.7	9.8	1.4	6.7	300	756	242	52	4	2	300			100	1.2	3.4	1.8
77/2	17- 40	Bw	39.8	3.2	6.4	7.0	228	573	178	43	4	3	228			100	1.1	3.2	1.8
77/3	40- 60	Bw	40.7	2.0	6.1	7.1	202	496	158	37	4	3	202			100	1.0	3.2	1.8
77/4	60- 75	Bw	37.8	1.6	8.1	7.2	171	452	123	37	7	4	171			100	0.9	3.1	1.8
77/5	75- 95	Bwg1	29.8	1.2	13.2	7.3	101	339	68	25	4	4	101			100	0.7	2.6	1.5
77/6	95-102	Bwg2	18.8	0.9	14.5	7.6	44	234	13	24	4	3	44			100	0.6	1.7	0.9
77/7	102-130	2Cg	3.4	0.5	11.0	7.6	19	559	3	11	2	3	19			100	0.3	1.0	0.4

d. TOTAL CHEMICAL COMPOSITION

Sample	Depth	Horizon	Clay	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	H_2O^+	CEC/clay*
	cm		%	% w/w													mmol/kg
77/1	0- 17	Ah	39.7	46.76	23.04	8.36	1.02	0.06	2.87	0.16	0.23	1.69	0.83	0.46	4.27	8.86	560
77/2	17- 40	Bw	39.8	47.19	23.16	8.15	0.90	0.09	3.00	0.14	0.06	3.91	0.83	0.27	4.22	8.15	550
77/3	40- 60	Bw	40.7	46.61	22.75	8.48	0.85	0.09	2.93	0.13	0.13	3.85	0.83	0.26	4.25	8.51	550
77/4	60- 75	Bw	37.8	47.20	23.63	8.51	0.85	0.10	2.91	0.15	0.14	3.91	0.86	0.26	4.12	8.42	540
77/5	75- 95	Bwg1	29.8	45.86	22.79	8.98	0.78	0.13	2.92	0.21	0.14	3.89	0.86	0.29	4.36	8.43	570
77/6	95-102	Bwg2	18.8	46.43	22.36	9.05	0.88	0.13	2.80	0.30	0.25	3.87	0.87	0.33	4.18	8.44	570
77/7	102-130	2Cg	3.4	45.01	20.95	8.98	0.95	0.14	2.76	0.52	0.21	3.82	0.85	0.45	4.31	8.50	560

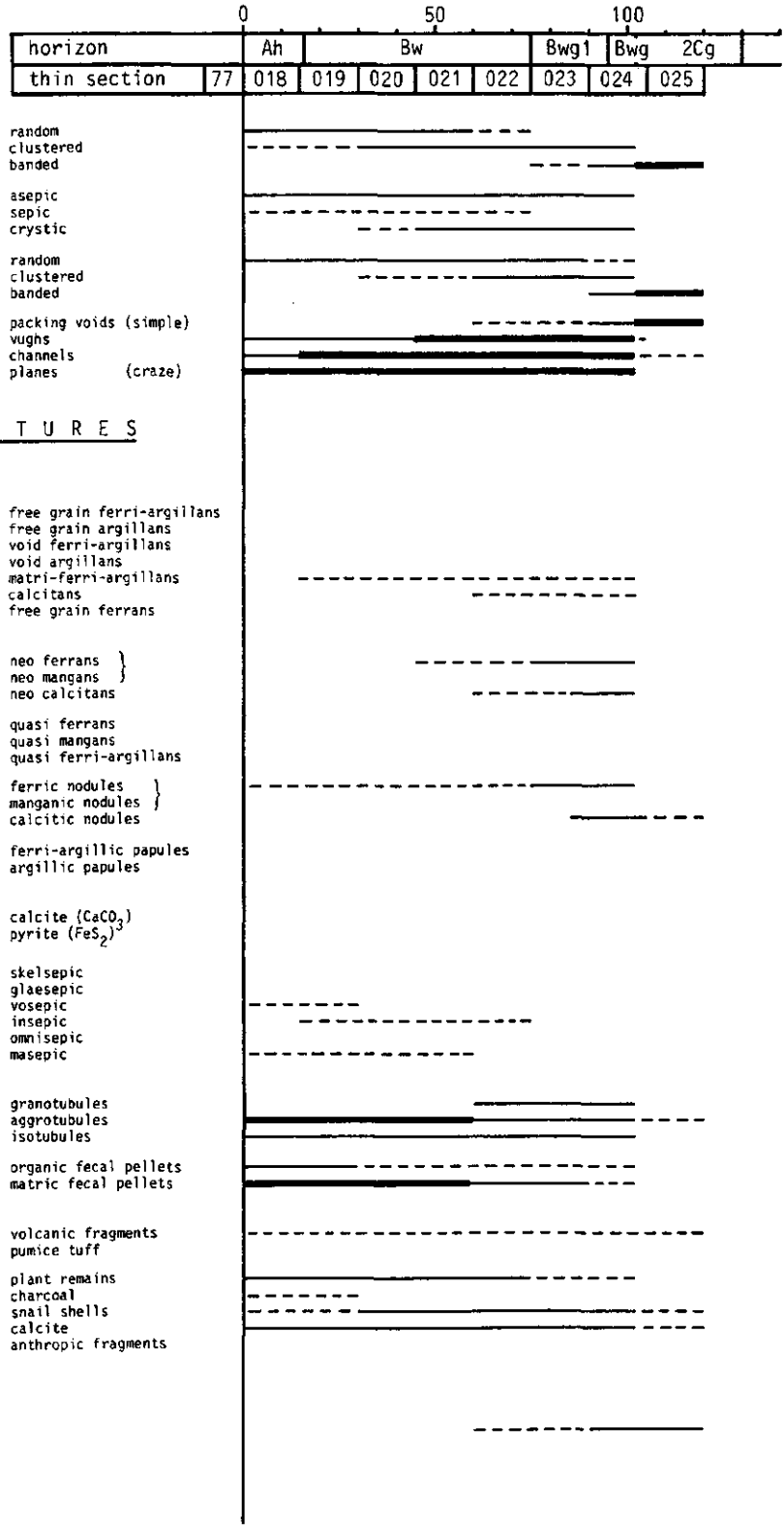
e. PHYSICAL CHARACTERISTICS
No data on core samples available

* Calculated from adsorbed $4Na^{2+}$

f. MICROMORPHOLOGICAL OBSERVATIONS

A22 - Opheusden

depth below surface (cm)



APPENDIX B

CLAY MINERALOGICAL CHARACTERISTICS

OF REFERENCE PROFILES

Key: K = kaolinite
M = mica
S = smectite
M-S = mica-smectite interstratifications
S-int = aluminium interlayered smectite
V = vermiculite
V-int = aluminium interlayered vermiculite
C = chlorite

\- = absent
(+) = traces
\+ = moderate amounts
+(+) =
++ = fair amounts
++(+) =
+++ = large amounts

n.d. = no data

CLAY MINERALOGY

Group	Ref. Prof.	Deposit	Horizon	Sample No.	K	M	S	M-S	S-int	V	V-int	C	CEC-clay (mmol $\frac{1}{2}Ba^{2+}$/kg)
HB	A01	III	Ap	75084	++	+(+)	-	-	+	-	+(+)	+	2410
	(Heumen I)	III	Ah1	75085	++	+(+)	-	(+)	+	-	+(+)	+	1080
		III	Ah2	75086	++	++	-	-	-	-	+(+)	+(+)	980
		III	2E	75087	++	++	-	(+)	-	-	(+)	+(+)	1020
		III	2Btg	75088	++	++	+	(+)	-	-	+(+)	+	580
HB	A06	III	Ap	78248	++	+(+)	-	(+)	+(+)	-	+(+)	(+)	530
	(Otterloum)	III	E	78249	++	+	-	(+)	+	-	++	(+)	320
		III	Bt1	78250	++	+	-	(+)	+	-	++	+	350
		III	Bt2	78251	++	++	(+)	(+)	+	-	+(+)	+	340
		IIa	2Bt3	78252	++	++	(+)	(+)	+(+)	-	+	-	390
HB	A13	IVb	Ahg	77560	++	+	(+)	(+)	+	-	+(+)	(+)	540
	(Azewijn IV)	IVb	Bw	77561	++	+	(+)	(+)	+(+)	-	++	(+)	490
		III	2Bt	77562	++	++	(+)	(+)	+(+)	-	++	(+)	510
		III	2Btg1	77563	++	++	(+)	(+)	+(+)	-	++	(+)	560
		III	2Btg2	77564	++	++	(+)	(+)	+(+)	-	++	(+)	590
		IIa	3Btg3	77565	++	++	+	(+)	-	-	++	-	560
		IIa	3Btg4	77566	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
HB	A13	III	Ap	78285	++(+)	++(+)	-	+	+	-	+	(+)	750
	(Asbroek)	III	EB	78286	++	++	-	(+)	+(+)	-	+	(+)	610
		III	Bt1	78287	++	++	-	(+)	+(+)	-	+	-	520
		III	Bt2	78288	++	++	-	(+)	+	-	+	(+)	520
		III	2Btg1	78289	++	++(+)	-	(+)	+	-	+	-	520
		III	2Btg1	78290	++	++	(+)	(+)	+	-	+	+	530
		III	2Btg1	78291	++	++	-	(+)	+	-	+	+	670
		III	2Btg1	78292	++	++(+)	+	(+)	(+)	-	+	-	540
		IIa	2Btg2	78293	++	++(+)	-	+	+(+)	-	+	-	420
HB	A14	III	Apg	78277	++	++	-	+	(+)	-	+(+)	(+)	650
	(Hegchelen)	III	E	78278	++	++	-	+	-	-	+(+)	+	590
		III	Bt	78279	++	++	-	(+)	-	-	++	(+)	480
		III	Btg1	78280	++	++	-	(+)	(+)	-	++	(+)	470
		IIa	2Btg2	78281	++	++	-	(+)	-	-	++	(+)	510
		III	2Btg3	78282	++	++	(+)	(+)	-	-	+(+)	(+)	440
		IIa	2Btg4	78283	+(+)	++	-	(+)	(+)	-	+	(+)	480
		IIa	2Btg5	78284	+(+)	++	-	(+)	(+)	-	+	(+)	470
HB	A15	III	Ap	79132	++	++	-	+	-	-	(+)	+	540
	(Von-Zelderhaida)	III	E	79133	++	+(+)	-	(+)	-	-	(+)	+(+)	560
		III	Bt1	79134	++	++	-	(+)	-	-	+	+	550
		III	Bt1	79137	++	++	-	(+)	+	-	+	+	420
		IIa	2Bt2	79135	++	++	-	(+)	+	-	-	(+)	500
		IIa	2Bt2	79136	++	++	-	(+)	+	-	-	+	n.d.
HB	A16	III	Ap	80588	++	++	(+)	(+)	(+)	(+)	(+)	+	220
	(Millingen)	III	E	80589	++	++	-	(+)	(+)	-	-	+(+)	300
		III	Bt1	80590	++	++	(+)	+	(+)	-	-	+	350
		III	Bt2	80591	++	++	+	(+)	(+)	-	-	+(+)	400
		III	Bt3	80592	++	++	+	(+)	(+)	-	+(+)	(+)	440
		IIb	2Bt4	80593	++	++	+	(+)	(+)	-	+(+)	-	370
		IIa	2C	80594	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
HB	A02	III	Ap	75089	++	+	-	-	+	-	++(+)	+	690
	(Heumen II)	III	Eg	75090	++	+(+)	-	-	+(+)	-	+(+)	-	800
		III	Btg1	75091	++	++	(+)	(+)	-	++	-	(+)	750
		III	Btg2	75092	++	++	+	(+)	-	++	-	-	740
		III	Btg2	75093	++	++	+(+)	(+)	-	+(+)	-	+	790
		III	Btg3	75094	++	++	++	(+)	-	(+)	-	+	740
		IIb	2Btg4	75095	++	++	+(+)	(+)	-	+(+)	-	+	730

Key: K = kaolinite
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V-int = aluminium interlayered vermiculite
C = chlorite

\- = absent
(+) = traces
\+ = moderate amounts
+(+) =
++ = fair amounts
++(+) =
+++ = large amounts

n.d. = no data

Group	Ref.Prof.	Deposit	Horizon	Sample No.	K	M	S	M-S	S-int	V	V-int	C	CEC-clay (mmol Ba^{2+}/kg)
MB	A04	III	Ap	75307	++	++	(+)	-	+(+)	-	++	+	550
	(Gendringen I)	III	Eg	75308	++	+(+)	-	-	+	-	+(+)	+	550
		III	Btg1	75309	++	+	-	-	+	-	++	+(+)	510
		III	Btg1	75310	++	+	-	-	+	-	++	+(+)	510
		III	Btg2	75311	++	++	+	-	+	-	+(+)	+	500
		IIa	2Btg3	75312	++	++	-	-	(+)	++	+	(+)	590
MB	A05	IVb	Ap	75313	++	+(+)	-	-	+(+)	-	+(+)	+	590
	(Gendringen II)	III	2Eg	75314	++	+(+)	-	-	+(+)	-	++	+	470
		III	2Btg1	75315	++	+(+)	+	-	++	++	+	+	530
		III	2Btg2	75316	++	++	+	-	++	+(+)	(+)	(+)	620
		IIb	3Btg3	75317	++	++	+	-	+	+(+)	-	(+)	690
MB	A07	III	Ap	78253	++(+)	+	-	(+)	(+)	-	++(+)	+	440
	(Siebengewald)	III	Eg	78254	++	++	-	(+)	+	-	++	+	370
		III	Btg1	78255	++	++	-	(+)	+	-	+(+)	+	310
		IIa	2Btg2	78256	++	++	-	+	+	-	+(+)	+	450
		I	3Btg3	78257	++	++	+	+	+(+)	-	+	-	450
MB	A09	III	Ap	77571	++	++	-	-	+	-	+(+)	+	610
	(Asdonk)	III	Btg1	77572	++	++	+	(+)	(+)	(+)	-	+	500
		III	Btg2	77573	++	++	+	(+)	+	+	(+)	+	560
		IIb	2Btg3	77574	++	++	+	(+)	+	(+)	-	(+)	480
MB	A10	IVb	Ahg	77552	++	+(+)	(+)	-	+(+)	-	++	+	500
	(Asselijn I)	IVb	ABg	77553	++	+(+)	(+)	-	+(+)	-	+(+)	+	550
		IVb	Bwg	77554	++	+	(+)	-	+(+)	-	++	(+)	560
		III	2Btg1	77555	++	+(+)	(+)	-	+(+)	-	++	(+)	540
		III	2Btg2	77556	++	++	+	(+)	+(+)	++	-	-	540
		III	2Btg3	77557	++	++	+	(+)	+(+)	++	-	-	540
		III	2Cgk	77558	++	++	++	-	(+)	++	-	(+)	660
		III	2Cg	77559	++	++	+(+)	-	-	++	-	-	560
MB	A12	IVb	Apg	77567	++	+	(+)	-	++	-	++	(+)	590
	(Woezik)	IVb	Bwg	77568	++	+	(+)	-	++	-	++	(+)	590
		III	2Btg1	77569	++	++	+	(+)	+(+)	+(+)	-	(+)	490
		III	2Btg2	77570	++	++	+(+)	(+)	+	+(+)	-	(+)	520
CaO MB	A17 (Zwijk)	IVb	Apg	75441	++	+(+)	-	-	++	-	-	(+)	700
		IVb	Bwg1	75442	++	+(+)	+(+)	-	+	++	-	(+)	770
		IVb	Bwg2	75443	++	+(+)	+(+)	-	+(+)	+(+)	-	(+)	710
		III	2Btg1	75444	++	+	-	(+)	++	++	-	(+)	640
		III	2Btg2	75445	++	+	(+)	-	++	++	-	(+)	740
		IIa	3Btg3	75446	++	+	+	-	++	++	-	(+)	720
LC	A03	IVb	Ahg	75096	++	++	(+)	(+)	-	-	++	(+)	700
	(Neumen III)	IVb	ABg	75097	++	++	(+)	(+)	+	-	++	+	630
		III	2Ahg	75098	++	++	(+)	-	-	-	++	+	770
		III	2Bwg	75099	++	++	++	-	-	-	-	+	700
		III	2Cg	75100	++	++	+(+)	(+)	-	(+)	-	+	500
		IIa	3Cr	75101	++	++(+)	+	-	+	+	-	+	660
LC	A08	III	Ahg	78258	+	(+)	++	-	++	-	+	(+)	650
	(Milsbeek)	III	Bwg	78259	+	(+)	++	-	++	-	(+)	(+)	660
		III	Cg	78260	++	+(+)	++	(+)	+(+)	-	+	(+)	580
		IIb	2Cr	78261	++	++	++	-	+	-	(+)	(+)	730
CaO Cal	A18 (Weurt)	IVb	Ap	75447	++	++(+)	(+)	(+)	+	(+)	-	(+)	740
		IVb	Bw	75448	++	++	-	-	++	-	-	+	780
		IVb	Bwg	75449	++	++	+(+)	-	(+)	+(+)	-	(+)	670
		IVb	Bwgk1	75450	++	++	+	-	+(+)	++	-	(+)	620
		IVb	Bwgk2	75451	++	+	+	-	+(+)	+(+)	-	(+)	640
		IVa	2Cg	75452	++	++	+(+)	-	+	+(+)	-	(+)	700

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+(+) =
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++(+) =
+++ = large amounts

n.d. = no data

Group	Ref.Prof.	Deposit	Horizon	Sample No.	K	M	S	M-S	S-int	V	V-int	C	CEC-clay (mmol $\frac{1}{2}Ba^{2+}$/kg)
CaO	A19	IVb	Ap	75453	++	++	(+)	-	+	+(+)	-	+	630
	(Rendwijk)	IVb	Bwg	75454	++	+(+)	+(+)	-	-	+(+)	-	(+)	690
		IVb	Bwg	75455	++	++	+(+)	-	-	+(+)	-	-	670
Cal	A20	IVb	Ap	77013	++	++	(+)	-	+	+(+)	-	(+)	600
	(Kesteren)	IVb	Bw	77014	++	++	(+)	-	++	+(+)	-	(+)	580
		IVb	Bwg	77015	++	++	+	-	+(+)	+(+)	-	+	610
		IVb	Cgl	77016	++	++	+	-	+(+)	+	-	+	580
		IVb	Cgk	77017	++	++	+	-	+(+)	+(+)	-	+	580
		IVa	2Cg2	77018	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cal	A21	IVb	Ap	77008	++	++	(+)	-	+(+)	+(+)	-	-	580
	(Lieoden)	IVb	Bw	77009	++	++	+	-	+(+)	+(+)	-	(+)	620
		IVb	Bwg1	77010	++	++	(+)	-	-	++	-	(+)	630
		IVb	Bwg2	77011	++	++	+	-	(+)	+	-	+	600
		IVb	Cg	77012	++	++	(+)	-	++	+(+)	-	(+)	570
Cal	A22	IVb	Ah	77001	++	++	-	-	-	-	-	(+)	560
	(Opheusden)	IVb	Bw	77002	++	++	(+)	-	+(+)	+	-	(+)	550
		IVb	Bw	77003	++	++	(+)	-	+(+)	+	-	(+)	550
		IVb	Bw	77004	++	++	(+)	-	(+)	+(+)	-	(+)	540
		IVb	Bwg1	77005	++	++	-	-	-	-	-	+	570
		IVb	Bwg2	77006	++	++	(+)	-	+(+)	+	-	(+)	570
		IVa	2Cg	77007	++	++	-	-	-	-	-	(+)	560

Key:

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APPENDIX C

PHYSICAL DATA SETS

* SWELL.DAT = Data on Linear extensibility condensates

* ATT.DAT = Data on Atterberg Limits

* CORE.DAT = Data from core samples

* AGGR.DAT = Data from natural aggregates

* STAB.DAT = Data on Stability of natural aggregates

file: SWELL.DAT

		<basic explanatory variables>												
nr.	gr.	clay	silt	sand	org.C	CaCO3	le21	le22	ve2	BD 2	le11	le12	ve1	BD 1	BD dry
1	111	10	24	66	1.76	0.0	-1.1	0.6	1.8	1690	0.6	1.1	3.5	1660	1700
2	111	15	9	76	0.16	0.0	0.7	1.7	5.2	1800	2.8	3.2	10.0	1720	1900
3	111	15	25	60	1.55	0.0	1.2	2.4	7.2	1700	3.4	3.9	12.1	1640	1760
4	111	17	33	50	0.86	0.0	-1.0	0.8	2.4	1780	-0.3	0.9	2.8	1780	1830
5	111	18	33	49	0.30	0.0	-1.7	0.8	2.5	1810	-0.4	0.9	2.6	1800	1850
6	111	19	25	56	0.92	0.0	0.4	1.4	4.1	1750	1.6	2.0	6.3	1710	1830
7	111	20	23	57	0.14	0.0	-1.8	1.4	4.3	1790	-0.1	1.7	5.0	1770	1860
8	111	24	30	46	0.35	0.0	0.5	1.5	4.4	1830	1.2	1.6	4.9	1810	1900
9	111	25	17	58	0.43	0.0	-1.1	2.7	8.2	1700	1.5	2.6	8.0	1710	1830
10	112	17	28	55	0.37	0.0	-1.5	1.0	3.0	1780	-0.5	1.3	3.8	1770	1850
11	112	18	17	65	0.14	0.0	-2.5	1.8	5.6	1740	0.3	2.0	6.2	1710	1830
12	112	18	41	41	1.44	0.0	0.7	1.3	3.7	1680	1.6	2.1	6.2	1640	1730
13	112	21	29	50	0.39	0.0	0.3	2.6	7.8	1580	1.9	3.2	9.8	1530	1700
14	112	23	29	48	0.28	0.0	2.0	3.1	9.7	1650	3.4	4.3	13.2	1590	1800
15	112	24	41	35	2.32	0.0	1.2	1.8	5.4	1550	2.6	3.0	9.2	1500	1640
16	112	25	46	29	1.16	0.1	1.4	2.3	7.1	1650	2.5	2.8	8.4	1630	1760
17	112	26	47	27	0.52	0.0	0.7	2.3	7.1	1640	1.5	2.4	7.5	1640	1770
18	112	27	32	41	0.35	0.0	3.5	3.7	11.5	1670	4.8	4.8	15.1	1620	1870
19	112	28	37	35	1.77	0.0	2.6	3.2	9.8	1570	4.4	4.8	14.9	1500	1730
20	112	31	36	33	2.09	0.0	3.3	4.0	12.5	1460	4.7	4.7	14.5	1440	1650
21	112	32	44	24	1.56	0.0	3.0	3.7	11.4	1550	4.0	5.6	17.6	1470	1750
22	112	32	46	22	0.19	0.0	2.9	3.9	12.2	1640	3.2	4.1	12.9	1630	1850
23	112	34	30	36	0.32	0.1	4.0	4.5	14.0	1720	4.6	5.0	15.7	1690	1970
24	112	35	48	17	0.40	0.0	2.9	3.6	11.2	1660	3.8	4.3	13.5	1630	1860
25	112	36	29	35	0.26	0.0	-1.9	1.6	4.8	1650	4.1	5.6	17.8	1470	1740
26	112	37	41	22	0.29	0.0	2.1	3.0	9.1	1730	3.0	3.8	11.7	1690	1890
27	113	19	32	49	0.80	0.0	0.6	2.2	6.6	1690	0.7	3.1	9.4	1640	1800
28	113	22	36	42	3.39	0.0	1.7	3.0	9.2	1440	2.4	3.3	10.1	1430	1580
29	113	22	35	43	1.30	0.0	0.5	2.7	8.3	1590	1.7	3.4	10.5	1560	1730
30	113	34	41	25	0.62	0.0	2.3	3.7	11.4	1590	3.0	4.1	12.5	1580	1790
31	124	18	52	30	1.00	0.0	1.5	2.2	6.8	1600	3.2	3.8	11.9	1530	1700
32	124	25	32	43	2.11	0.0	3.2	3.4	10.4	1700	4.5	4.4	13.8	1650	1910
33	124	26	48	26	0.53	0.0	2.8	3.4	10.6	1620	3.9	4.4	13.7	1570	1790
34	124	30	30	40	0.83	0.0	1.4	1.6	4.8	1800	2.6	2.6	8.1	1750	1850
35	124	33	39	28	1.77	0.0	3.7	4.2	13.0	1590	4.8	5.2	16.2	1550	1800
36	124	40	55	5	1.19	0.0	3.9	4.6	14.5	1670	5.8	6.1	19.6	1600	1950
37	124	41	51	8	1.91	0.0	2.7	3.2	9.9	1760	6.6	6.7	21.3	1590	1930
38	124	45	49	6	0.57	0.0	5.2	6.1	19.4	1610	6.9	7.8	25.2	1530	1880
39	124	47	43	10	0.93	0.4	6.6	7.0	22.6	1590	7.5	8.1	26.1	1540	1950
40	124	52	35	13	0.54	0.0	5.1	5.9	18.7	1470	6.1	7.1	22.3	1430	1750
41	124	57	31	12	1.87	0.0	9.3	10.0	33.1	1340	10.4	11.1	37.1	1300	1790
42	125	11	21	68	0.04	13.9	-0.1	1.2	3.5	1610	1.0	1.2	3.6	1610	1670
43	125	19	64	17	0.18	13.6	1.8	2.3	7.0	1580	2.3	2.5	7.8	1570	1700
44	125	20	40	40	1.14	3.9	2.3	2.9	8.9	1580	2.6	3.6	11.3	1550	1740
45	125	25	56	19	0.01	17.1	1.4	2.1	6.5	1560	2.0	2.5	7.6	1540	1660
46	125	25	45	30	0.44	5.8	2.4	2.9	8.8	1650	3.4	4.0	12.3	1600	1800
47	125	28	52	20	1.05	4.0	3.3	4.0	12.5	1590	3.4	4.3	13.5	1580	1810
48	125	28	51	21	0.32	8.0	2.5	2.9	9.1	1580	3.0	3.3	10.0	1570	1730
49	125	29	67	4	0.52	8.8	3.1	3.7	11.6	1590	3.2	3.8	11.8	1590	1780
50	125	30	51	19	0.35	4.2	3.7	4.2	13.0	1620	4.0	4.4	13.9	1600	1830
51	125	31	52	17	0.45	8.6	3.5	3.8	11.7	1600	3.6	4.2	13.1	1570	1800
52	125	31	60	9	0.26	15.0	2.7	3.2	10.1	1590	2.8	3.3	10.1	1590	1750
53	125	41	56	3	1.42	6.8	5.9	6.4	20.3	1450	7.1	7.9	25.5	1380	1740
54	125	41	53	6	0.82	7.2	4.0	4.7	14.7	1540	5.0	5.7	18.1	1490	1770
55	125	42	53	5	2.09	3.5	7.9	8.5	27.8	1330	9.2	9.9	32.9	1280	1710

nr. = number
gr. = grouping : 111 = HB
112 = HB
113 = LG
124 = Ca0
125 = Cal

le21 = linear extensibility at pF 2 (calculated) (%)
le22 = linear extensibility at pF 2 (measured) (%)
ve2 = volume extensibility at pF 2 (measured) (%)
BD 2 = Bulk Density at pF 2 (kg/m3)
le11 = linear extensibility at pF 1 (calculated) (%)
le12 = linear extensibility at pF 1 (measured) (%)
ve1 = volume extensibility at pF 1 (measured) (%)
BD 1 = Bulk Density at pF 1 (kg/m3)
BD dry Bulk Density dry (kg/m3)

file: ATT.DAT

nr.	gr.	<basic expl. var.> clay	org.C	CaCO3	UPL	SP	LPL	HP
1	111	10.4	1.76	0.0	19.7	16.1	20.4	10.5
2	111	14.8	1.55	0.0	23.1	20.7	22.1	11.5
3	111	15.2	0.16	0.0	22.6	19.6	18.1	12.1
4	111	17.4	0.86	0.0	17.8	16.4	18.5	9.6
5	111	18.1	0.30	0.0	21.1	16.8	18.8	10.5
6	111	18.7	0.92	0.0	21.0	19.8	19.2	11.0
7	111	19.7	0.14	0.0	21.6	16.1	18.6	9.3
8	111	24.3	0.35	0.0	23.3	19.7	19.4	12.6
9	111	25.0	0.43	0.0	24.3	15.6	21.2	10.8
10	112	16.8	0.37	0.0	19.2	16.6	-1.0	9.3
11	112	18.0	0.14	0.0	21.5	16.4	19.1	8.0
12	112	18.0	1.44	0.0	26.2	23.9	25.2	12.0
13	112	21.1	0.39	0.0	28.5	22.7	26.2	13.1
14	112	23.0	0.28	0.0	27.9	23.1	20.0	14.0
15	112	24.1	2.32	0.0	31.2	28.4	28.3	15.9
16	112	25.0	1.16	0.1	28.8	26.3	-1.0	14.4
17	112	26.0	0.52	0.0	31.4	24.5	23.4	15.0
18	112	26.5	0.35	0.0	30.2	22.5	22.1	14.2
19	112	27.8	1.77	0.0	33.7	36.2	29.1	16.5
20	112	30.9	2.09	0.0	39.5	35.0	31.1	18.7
21	112	31.4	1.56	0.0	38.3	31.4	30.9	19.4
22	112	32.0	0.19	0.0	42.4	28.1	28.4	18.0
23	112	34.0	0.32	0.1	36.1	25.7	23.1	15.0
24	112	35.4	0.40	0.0	42.5	28.2	27.8	18.7
25	112	36.3	0.26	0.0	34.4	22.2	22.2	14.8
26	112	37.0	0.29	0.0	42.8	26.5	25.5	17.0
27	113	19.1	0.80	0.0	29.9	22.5	25.2	15.4
28	113	22.0	1.30	0.0	32.7	23.3	24.8	14.0
29	113	22.3	3.39	0.0	41.4	33.3	35.8	20.4
30	113	34.0	0.62	0.0	40.5	28.4	27.0	16.3
31	124	18.5	1.00	0.0	29.5	27.6	23.5	16.0
32	124	25.0	2.11	0.0	37.5	31.1	29.8	18.1
33	124	26.3	0.53	0.0	32.6	27.3	24.6	17.2
34	124	30.0	0.83	0.0	36.5	26.1	25.2	16.2
35	124	33.2	1.77	0.0	38.5	31.5	29.6	17.2
36	124	39.6	1.19	0.0	43.6	32.6	29.5	20.0
37	124	41.0	1.91	0.0	50.1	41.5	38.8	25.6
38	124	44.9	0.57	0.0	63.4	32.4	30.0	22.5
39	124	46.9	0.93	0.4	54.2	33.1	30.7	27.5
40	124	52.0	0.54	0.0	52.2	32.2	31.0	21.7
41	124	57.0	1.87	0.0	69.8	44.2	48.1	31.0
42	125	11.4	0.04	13.9	22.7	20.6	23.6	8.7
43	125	19.1	0.18	13.6	28.7	26.4	26.8	16.3
44	125	19.5	1.14	3.9	30.6	24.6	23.9	13.0
45	125	24.9	0.44	5.8	31.0	27.4	25.6	11.7
46	125	25.1	0.01	17.1	32.4	26.6	26.1	13.0
47	125	27.8	0.32	8.0	36.7	29.5	28.9	14.2
48	125	27.9	1.05	4.0	36.2	26.9	26.2	-1.0
49	125	29.0	0.52	8.8	38.3	29.3	28.9	21.4
50	125	29.7	0.55	4.2	36.3	26.6	25.5	16.7
51	125	30.5	0.26	15.0	38.3	28.9	26.1	16.8
52	125	30.6	0.45	8.6	38.4	30.0	28.2	16.5
53	125	40.8	0.82	7.2	51.1	33.8	33.2	20.4
54	125	41.3	1.42	6.8	58.1	42.4	36.4	21.1
55	125	41.8	2.09	3.5	59.8	46.4	43.1	24.2

nr. = number
gr. = grouping : 111 = HB
: 112 = MB
: 113 = LG
: 124 = Ca0
: 125 = Ca1

UPL = Upper Plastic Limit (moisture content, %W/W)
SP = Sticky Point (moisture content, %W/W)
LPL = Lower Plastic Limit (moisture content, %W/W)
HP = Hygroscopic Point (moisture content, %W/W)

-1.0 = missing value

file: CORE.DAT

nr.	gr.	<basic explanatory variables> clay	silt	sand	org.C	CaCO3	BD	PD	PV	SV	E= PV/SV	WV2	WV4.2	WV2	WV4.2	AM	AV2	AV4.2
1	111	4.7	2.1	93.2	0.20	0.0	1370	2670	48.6	51.4	0.95	8.9	3.2	12.2	4.4	7.8	36.4	44.2
2	111	7.0	5.0	88.0	0.07	0.0	1370	2670	48.7	51.3	0.95	8.9	3.2	12.2	4.4	7.8	36.5	44.3
3	111	7.0	11.0	82.0	0.29	0.0	1570	2650	40.8	59.2	0.69	16.2	5.1	25.5	8.0	17.5	15.3	32.8
4	111	7.0	11.0	82.0	0.29	0.0	1530	2670	42.7	57.3	0.75	12.4	5.2	18.9	8.0	10.9	23.8	34.7
5	111	7.6	12.5	79.9	0.20	0.0	1500	2670	44.0	56.0	0.79	11.9	3.2	17.9	4.7	13.2	26.1	39.3
6	111	9.0	25.0	66.0	1.71	0.1	1620	2630	38.4	61.6	0.62	17.7	7.2	28.7	11.7	17.0	9.7	26.7
7	111	9.2	33.4	57.4	2.50	0.2	1500	2610	42.5	57.5	0.74	25.0	15.5	37.5	23.3	14.2	5.0	19.2
8	111	9.3	9.8	80.9	1.80	0.0	1510	2600	41.8	58.2	0.72	14.3	8.5	21.6	12.8	8.8	20.1	29.0
9	111	9.7	12.7	77.6	0.30	0.0	1430	2660	46.4	53.6	0.87	12.2	3.8	17.4	5.5	11.9	29.1	40.9
10	111	10.0	24.0	66.0	1.80	0.1	1590	2630	39.5	60.5	0.65	17.6	7.2	28.0	11.4	16.6	11.5	28.1
11	111	10.0	11.0	79.0	0.23	0.0	1710	2680	36.2	63.8	0.57	11.2	4.4	19.2	7.5	11.7	17.0	28.7
12	111	10.2	17.9	71.9	0.50	0.0	1570	2680	41.4	58.6	0.71	17.1	6.5	26.8	10.2	16.6	14.6	31.2
13	111	10.4	23.6	66.0	2.00	0.0	1610	2630	38.9	61.1	0.64	17.7	7.2	28.5	11.6	16.9	10.4	27.3
14	111	10.9	13.0	76.1	0.50	0.0	1530	2660	42.4	57.6	0.74	11.1	4.9	17.0	7.5	9.5	25.4	34.9
15	111	11.4	40.8	47.8	0.30	0.0	1610	2690	40.1	59.9	0.67	16.3	5.5	26.2	8.9	17.3	13.9	31.2
16	111	13.0	18.0	69.0	0.29	0.0	1620	2680	39.6	60.4	0.66	18.2	6.5	29.5	10.5	19.0	10.1	29.1
17	111	14.0	35.0	51.0	0.86	0.0	1360	2660	48.9	51.1	0.96	18.1	7.2	24.6	9.8	14.8	24.3	39.1
18	111	14.7	7.6	77.7	0.30	0.0	1530	2680	42.9	57.1	0.75	17.4	7.1	26.6	10.9	15.7	16.3	32.0
19	111	14.8	25.1	60.1	1.50	0.1	1810	2670	32.2	67.8	0.47	15.2	11.9	27.5	21.5	6.0	4.7	10.7
20	111	15.0	28.0	57.0	1.04	0.0	1690	2670	36.7	63.3	0.58	16.3	10.6	27.5	17.9	9.6	9.2	18.8
21	111	15.0	20.0	65.0	2.26	0.2	1500	2610	42.5	57.5	0.74	25.0	10.7	37.5	16.0	21.5	5.0	26.5
22	111	15.0	8.0	77.0	0.30	0.0	1530	2680	42.9	57.1	0.75	17.4	7.1	26.6	10.9	15.7	16.3	32.0
23	111	15.2	8.8	76.0	0.20	0.0	1740	2690	35.3	64.7	0.55	13.0	8.2	22.6	14.3	8.3	12.7	21.0
24	111	15.7	28.7	55.6	1.30	0.3	1520	2660	42.9	57.1	0.75	21.8	14.6	33.2	22.2	11.0	9.7	20.7
25	111	16.0	35.0	49.0	1.22	0.3	1520	2660	42.9	57.1	0.75	21.8	11.5	33.2	17.5	15.7	9.7	25.4
26	111	16.0	26.0	58.0	0.87	0.1	1810	2670	32.2	67.8	0.47	15.2	11.9	27.5	21.5	6.0	4.7	10.7
27	111	16.0	28.0	56.0	0.23	0.0	1570	2680	41.4	58.6	0.71	17.1	6.5	26.8	10.2	16.6	14.6	31.2
28	111	17.0	38.0	45.0	0.30	0.0	1370	2680	48.9	51.1	0.96	18.0	8.0	24.7	11.0	13.7	24.2	37.9
29	111	17.4	33.2	49.4	0.60	0.0	1360	2660	49.1	50.9	0.96	18.1	7.2	24.6	9.8	14.8	24.5	39.3
30	111	18.1	32.5	49.4	0.40	0.0	1370	2680	48.7	51.3	0.95	18.0	8.0	24.7	11.0	13.7	24.0	37.7
31	111	18.2	33.0	48.8	0.50	0.0	1470	2670	44.9	55.1	0.81	19.4	7.8	28.5	11.5	17.0	16.4	33.4
32	111	18.7	25.2	56.1	0.50	0.0	1690	2670	36.7	63.3	0.58	16.3	10.6	27.5	17.9	9.6	9.2	18.8
33	111	19.0	39.0	42.0	0.46	0.0	1470	2620	43.9	56.1	0.78	19.4	8.5	28.5	12.5	16.0	15.4	31.4
34	111	19.0	34.0	47.0	0.14	0.0	1340	2700	50.4	49.6	1.02	17.2	7.5	23.0	10.1	12.9	27.4	40.3
35	111	19.4	30.4	50.2	0.20	0.0	1580	2720	42.0	58.0	0.72	14.3	8.2	22.8	13.0	9.8	19.2	29.0
36	111	19.7	23.6	56.7	0.20	0.0	1340	2700	50.2	49.8	1.01	17.2	7.5	23.0	10.1	12.9	27.2	40.1
37	111	21.0	18.0	61.0	0.35	0.0	1590	2700	41.1	58.9	0.70	20.8	10.1	33.0	16.0	17.0	8.1	25.1
38	111	22.0	35.0	43.0	0.35	0.0	1760	2700	34.8	65.2	0.53	14.8	12.0	26.0	21.1	4.9	8.8	13.7
39	111	23.0	35.0	42.0	0.46	0.0	1700	2700	37.0	63.0	0.59	15.6	10.3	26.5	17.5	9.0	10.5	19.5
40	111	23.4	30.0	46.6	0.20	0.0	1700	2700	37.0	63.0	0.59	15.6	10.3	26.5	17.5	9.0	10.5	19.5
41	111	24.6	30.4	45.0	0.20	0.0	1700	2700	37.0	63.0	0.59	15.6	10.3	26.5	17.5	9.0	10.5	19.5
42	111	29.0	34.0	37.0	0.52	0.0	1620	2710	40.2	59.8	0.67	18.8	11.7	30.5	19.0	11.5	9.7	21.2
43	111	30.0	33.0	37.0	0.75	0.0	1590	2730	41.8	58.2	0.72	19.8	13.8	31.5	22.0	9.5	10.3	19.8
44	112	3.1	1.0	95.9	0.10	0.0	1700	2670	36.3	63.7	0.57	8.9	2.0	15.1	3.4	11.7	21.2	32.9
45	112	5.0	5.0	90.0	0.08	0.0	1700	2670	36.3	63.7	0.57	8.9	2.0	15.1	3.4	11.7	21.2	32.9
46	112	6.4	5.8	87.8	0.20	0.0	1480	2660	44.2	55.8	0.79	24.7	5.9	36.6	8.8	27.8	7.6	35.4
47	112	6.4	4.5	89.1	0.20	0.0	1670	2680	37.8	62.2	0.61	12.5	3.1	20.9	5.2	15.7	16.9	32.6
48	112	7.1	2.8	90.1	0.10	0.1	1650	2670	38.2	61.8	0.62	6.7	1.8	11.1	3.0	8.1	27.1	35.2
49	112	9.4	4.0	86.6	0.10	0.0	1590	2690	40.9	59.1	0.69	13.2	2.8	21.0	4.5	17.5	19.9	36.4
50	112	10.0	9.0	81.0	0.09	0.0	1670	2680	37.7	62.3	0.61	12.5	3.1	20.9	5.2	15.7	16.8	32.5
51	112	10.9	8.9	80.2	0.00	0.0	1570	2670	41.6	58.4	0.71	14.0	6.0	22.0	9.4	12.6	19.6	32.2
52	112	11.0	9.0	80.0	0.10	0.0	1560	2670	41.6	58.4	0.71	14.0	6.0	21.8	9.4	12.4	19.8	32.2
53	112	13.0	17.0	70.0	0.01	0.0	1440	2670	46.1	53.9	0.86	17.3	9.9	24.9	14.3	10.6	21.2	31.8
54	112	13.0	23.0	64.0	1.77	0.0	1310	2640	50.4	49.6	1.02	17.4	7.5	22.8	9.8	13.0	27.6	40.6
55	112	13.0	22.0	65.0	1.49	0.1	1550	2630	41.1	58.9	0.70	16.9	7.5	26.2	11.6	14.6	14.9	29.5
56	112	14.0	18.0	68.0	1.90	0.0	1430	2640	45.6	54.4	0.84	17.2	7.5	24.6	10.7	13.9	21.0	34.9
57	112	14.0	8.6	77.4	0.10	0.1	1660	2690	38.2	61.8	0.62	14.9	6.9	24.7	11.5	13.2	13.5	26.7
58	112	15.3	19.0	65.7	0.20	0.0	1770	2690	34.2	65.8	0.52	13.3	6.5	23.5	11.5	12.0	10.7	22.7
59	112	15.3	25.6	59.1	0.20	0.0	1690	2710	37.5	62.5	0.60	15.3	6.0	25.9	10.1	15.8	11.6	27.4
60	112	16.0	25.0	59.0	0.19	0.0	1770	2690	34.2	65.8	0.52	13.3	6.5	23.5	11.5	12.0	10.7	22.7
61	112	16.0	23.0	61.0	0.68	0.0	1860	2660	30.1	69.9	0.43	13.0	6.2	24.2	11.5	12.7	5.9	18.6
62	112	16.1	15.3	68.6	0.50	0.0	1860	2660	30.2	69.8	0.43	13.0	6.2	24.2	11.5	12.7	6.0	18.7
63	112	17.0	28.0	55.0	0.37	0.0	1780	2700	34.1	65.9	0.52	14.0	7.7	24.9	13.7	11.2	9.2	20.4
64	112	17.0	24.5	58.5	0.10	0.0	1620	2700	39.9	60.1	0.66	15.9	6.6	25.8	10.7	15.1	14.1	29.2
65	112	18.3	17.0	64.7	0.00	0.0	1550	2690	42.5	57.5	0.74	23.3	6.3	36.2	9.8	26.4	6.4	32.7
66	112	18.4	26.3	55.3	0.90	0.1	1450	2680	46.1	53.9	0.86	21.8	6.7	31.6	9.7	21.9	14.5	36.4
67	112	19.4	25.3	55.3	0.30	0.0	1530	2690	43.1	56.9	0.76	18.1	6.6	27.7	10.1	17.6	15.4	33.0
68	112	20.0	30.0	50.0	0.18	0.0	1640	2670	38.6	61.4	0.63	16.3	8.7	26.7	14.3	12.4	11.9	24.3
69	112	20.3	30.1	49.6	2.60	1.1	1470	2660	44.8	55.2	0.81	26.9	11.1	39.5	16.3	23.2	5.3	28.5
70	112	20.4	23.8	55.8	0.00	0.0	1690	2700	37.4	62.6	0.60	17.5	7.1	29.6	12.0	17.6	7.8	25.4
71	112	21.0	29.0	50.0	0.39	0.0	1530	2710	43.5	56.5	0.77	20.5	10.7	31.4	16.4	15.0	12.1	27.1
72	112	21.0	25.0	54.0	0.20	0.0	1610	2720	40.8	59.2	0.69	23.4	10.4	37.6	16.7	20.9	3.2	24.1
73	112	21.0	32.0	47.0	0.43	0.0	1390	2710	48.7	51.3	0.95	21.3	12.6	29.6	17.5	12.1	19.1	31.2

nr. = number
gr. = grouping : 111 = HB
: 112 = MB
: 113 = LB
: 124 = Ca0
: 125 = Cal

BD = Bulk Density (kg/m3)
PD = Particle Density (kg/m3)
PV = Pore Volume (%)
SV = Solid Volume (%)
WV2/4.2 = moisture content at pF2/42 (%W/W)
VV2/4.2 = moisture content at pF2/42 (%V/V)
AM = Available Moisture (VV2 - VV4.2) (mm/10cm)
AV2/4.2 = Air Volume at pF2/4.2 (%)

file: CORE.DAT

nr.	gr.	<basic explanatory variables> clay	silt	sand	org.C	CaCO3	BD	PD	PV	SV	E= PV/SV	WV2	WV4.2	WV2	WV4.2	AM	AV2	AV4.2
74	112	21.0	35.0	44.0	0.30	0.0	1380	2710	49.1	50.9	0.96	21.3	12.7	29.4	17.5	11.9	19.7	31.6
75	112	21.1	26.8	52.1	0.20	0.0	1530	2670	42.7	57.3	0.75	18.2	8.4	27.7	12.9	14.8	15.0	29.8
76	112	21.2	25.1	53.7	0.00	0.0	1610	2720	41.0	59.0	0.69	23.4	10.4	37.7	16.7	21.0	3.3	24.3
77	112	22.6	28.3	49.1	0.00	0.0	1620	2710	40.4	59.6	0.68	17.4	11.7	28.2	18.9	9.3	12.2	21.5
78	112	24.0	32.0	44.0	0.18	0.0	1340	2710	50.6	49.4	1.02	21.1	13.1	28.3	17.5	10.8	22.3	33.1
79	112	24.0	45.0	31.0	1.16	0.0	1560	2690	42.0	58.0	0.72	21.7	10.6	33.8	16.5	17.3	8.2	25.5
80	112	24.0	41.0	35.0	2.32	0.0	1340	2630	49.1	50.9	0.96	26.6	11.7	35.7	15.7	20.0	13.4	33.4
81	112	24.4	44.8	30.8	0.90	0.0	1560	2690	42.0	58.0	0.72	21.7	10.6	33.8	16.5	17.3	8.2	25.5
82	112	26.0	12.0	62.0	0.17	0.0	1670	2700	38.2	61.8	0.62	17.1	7.7	28.5	12.9	15.6	9.7	25.3
83	112	27.1	29.6	43.3	2.40	0.0	1360	2570	47.1	52.9	0.89	26.1	15.4	35.0	21.0	14.0	12.2	26.1
84	112	28.0	37.0	35.0	1.77	0.0	1470	2660	44.7	55.3	0.81	21.5	10.9	31.6	16.0	15.6	13.1	28.7
85	112	29.2	33.9	36.9	0.30	0.0	1250	2770	54.9	45.1	1.22	28.2	14.4	35.2	18.0	17.2	19.7	36.9
86	112	29.6	18.6	51.8	0.00	0.1	1630	2780	41.1	58.9	0.70	21.6	11.0	35.2	17.9	17.3	5.9	23.2
87	112	29.9	40.8	29.3	0.50	0.1	1400	2760	49.3	50.7	0.97	24.0	14.4	33.6	20.2	13.4	15.7	29.1
88	112	31.0	36.0	33.0	2.09	0.0	1400	2610	46.4	53.6	0.87	27.1	15.2	37.9	21.3	16.6	8.5	25.1
89	112	31.8	29.1	39.1	0.10	0.0	1370	2790	50.7	49.3	1.03	30.4	17.4	41.7	23.8	17.9	9.0	26.9
90	112	32.0	25.8	42.2	0.00	0.0	1410	2700	47.9	52.1	0.92	28.6	14.3	40.3	20.2	20.1	7.6	27.7
91	112	32.0	44.0	24.0	1.56	0.0	1530	2690	43.1	56.9	0.76	25.2	13.6	38.6	20.8	17.8	4.5	22.3
92	112	32.2	45.4	22.4	0.30	0.1	1590	2750	42.0	58.0	0.72	21.3	11.5	33.9	18.3	15.6	8.1	23.7
93	112	33.8	42.4	23.8	0.50	0.0	1630	2710	40.1	59.9	0.67	22.4	12.3	36.5	20.0	16.5	3.6	20.1
94	112	34.0	33.0	33.0	0.52	0.0	1620	2730	40.7	59.3	0.69	22.8	17.3	37.0	28.0	9.0	3.7	12.7
95	112	34.0	39.0	27.0	0.35	0.0	1550	2760	43.8	56.2	0.78	24.7	13.5	38.3	20.9	17.4	5.5	22.9
96	112	34.0	42.0	24.0	0.50	0.0	1660	2690	38.3	61.7	0.62	20.8	12.3	34.5	20.4	14.1	3.8	17.9
97	112	35.0	48.0	17.0	0.40	0.0	1510	2760	45.3	54.7	0.83	23.2	13.3	35.0	20.1	14.9	10.3	25.2
98	112	36.0	31.0	33.0	0.70	0.0	1600	2720	41.2	58.8	0.70	22.5	16.6	36.0	26.5	9.5	5.2	14.7
99	112	36.0	29.0	35.0	0.26	0.0	1570	2730	42.5	57.5	0.74	20.6	9.8	32.4	15.4	17.0	10.1	27.1
100	112	36.5	37.5	26.0	0.00	0.0	1550	2760	43.8	56.2	0.78	22.1	13.5	34.3	20.9	13.4	9.5	22.9
101	112	37.0	41.0	22.0	0.29	0.0	1270	2770	54.2	45.8	1.18	27.7	20.9	35.2	26.6	8.6	19.0	27.6
102	112	37.0	29.0	34.0	0.30	0.1	1760	2730	35.5	64.5	0.55	19.2	13.1	33.8	23.1	10.7	1.7	12.4
103	112	37.0	29.0	34.0	0.30	0.1	1690	2730	38.1	61.9	0.62	21.0	13.7	35.5	23.1	12.4	2.6	15.0
104	112	37.0	32.0	31.0	0.49	0.0	1290	2710	52.4	47.6	1.10	26.7	15.7	34.5	20.2	14.3	17.9	32.2
105	112	37.9	29.1	33.0	0.00	0.1	1530	2780	45.1	54.9	0.82	25.8	12.9	39.5	19.7	19.8	5.6	25.4
106	112	40.0	46.0	14.0	0.00	0.0	1470	2770	46.9	53.1	0.88	29.5	16.5	43.4	24.3	19.1	3.5	22.6
107	112	43.0	47.0	10.0	0.30	0.0	1470	2770	46.9	53.1	0.88	29.5	16.5	43.4	24.3	19.1	3.5	22.6
108	112	44.0	39.0	17.0	0.35	0.0	1430	2790	48.8	51.2	0.95	28.0	18.9	40.0	27.0	13.0	8.8	21.8
109	112	46.0	47.0	7.0	0.31	0.0	1440	2780	48.2	51.8	0.93	28.6	17.0	41.2	24.5	16.7	7.0	23.7
110	112	46.0	42.0	12.0	0.50	0.1	1480	2770	46.6	53.4	0.87	26.6	16.5	39.3	24.4	14.9	7.3	22.2
111	112	46.2	41.9	11.9	0.00	0.1	1480	2770	46.6	53.4	0.87	26.6	16.5	39.3	24.4	14.9	7.3	22.2
112	112	49.0	32.0	19.0	1.28	0.0	1380	2740	49.6	50.4	0.98	30.1	23.2	41.5	32.0	9.5	8.1	17.6
113	113	4.0	26.0	70.0	0.45	0.0	1360	2680	49.3	50.7	0.97	25.8	7.0	35.1	9.5	25.6	14.2	39.8
114	113	5.0	14.0	81.0	0.80	1.0	1360	2680	49.3	50.7	0.97	25.8	7.0	35.1	9.5	25.6	14.2	39.8
115	113	12.0	27.0	61.0	0.54	0.0	1380	2700	48.9	51.1	0.96	28.2	9.9	38.9	13.7	25.2	10.0	35.2
116	113	19.0	37.0	44.0	1.30	0.0	1380	2660	48.1	51.9	0.93	25.9	13.0	35.7	17.9	17.8	12.4	30.2
117	113	19.0	37.0	44.0	1.06	0.0	1530	2700	43.3	56.7	0.76	25.1	9.9	38.4	15.1	23.3	4.9	28.2
118	113	19.0	40.0	41.0	3.21	0.0	1170	2570	54.5	45.5	1.20	35.7	17.6	41.8	20.6	21.2	12.7	33.9
119	113	19.1	31.6	49.3	0.80	0.0	1460	2700	46.1	53.9	0.86	26.6	9.9	38.8	14.5	24.3	7.3	31.6
120	113	20.0	40.0	40.0	3.56	0.0	1150	2600	55.8	44.2	1.26	32.5	17.6	37.4	20.2	17.2	18.4	35.6
121	113	22.0	35.4	42.6	0.50	0.0	1380	2660	48.1	51.9	0.93	25.9	13.0	35.7	17.9	17.8	12.4	30.2
122	113	22.3	35.8	41.9	2.10	0.0	1160	2590	55.2	44.8	1.23	34.1	17.6	39.6	20.4	19.2	15.6	34.8
123	113	28.5	33.4	38.1	0.10	0.0	1500	2680	44.2	55.8	0.79	27.4	13.1	41.0	19.6	21.4	3.2	24.6
124	113	33.0	42.0	25.0	1.20	0.0	1270	2650	52.1	47.9	1.09	31.3	20.9	39.8	26.5	13.3	12.3	25.6
125	113	36.7	35.4	27.9	1.00	0.0	1280	2620	51.1	49.9	1.02	28.9	19.8	36.6	25.3	11.3	14.4	24.0
126	113	38.5	29.0	32.5	0.00	0.0	1420	2680	46.6	53.4	0.87	27.9	18.7	39.7	26.6	13.1	6.9	20.0
127	113	46.0	41.0	13.0	0.52	0.0	1430	2780	48.6	51.4	0.95	32.2	20.6	46.0	29.5	16.5	2.6	19.1
128	113	51.0	39.0	10.0	0.64	0.0	1430	2780	48.6	51.4	0.95	30.4	21.0	43.5	30.0	13.5	5.1	18.6
129	113	52.0	41.0	7.0	0.52	0.0	1380	2800	50.7	49.3	1.03	33.3	21.7	46.0	30.0	16.0	4.7	20.7
130	113	52.0	41.0	7.0	0.58	0.0	1400	2820	50.4	49.6	1.02	30.7	22.5	43.0	31.5	11.5	7.4	18.9
131	124	12.9	19.9	67.2	2.00	0.3	1450	2620	44.7	55.3	0.81	20.9	8.1	30.3	11.7	18.6	14.4	33.0
132	124	13.0	25.0	62.0	0.82	0.1	1500	2670	43.8	56.2	0.78	15.1	6.1	22.7	9.2	13.5	21.1	34.6
133	124	14.0	26.0	60.0	2.57	0.1	1450	2620	44.7	55.3	0.81	20.8	8.1	30.2	11.8	18.4	14.5	32.9
134	124	14.7	23.1	62.2	0.70	0.3	1500	2670	43.8	56.2	0.78	15.1	6.1	22.7	9.2	13.5	21.1	34.6
135	124	17.7	46.2	36.1	1.20	0.1	1490	2620	43.1	56.9	0.76	23.1	8.5	34.4	12.7	21.7	8.7	30.4
136	124	18.0	52.0	30.0	1.00	0.0	1490	2620	43.1	56.9	0.76	23.2	8.5	34.5	12.7	21.8	8.6	30.4
137	124	21.0	43.6	35.4	0.60	0.1	1510	2710	44.3	55.7	0.80	19.2	11.2	29.0	16.9	12.1	15.3	32.2
138	124	25.8	29.7	44.5	1.60	0.0	1450	2680	45.9	54.1	0.85	24.8	15.8	35.9	22.9	13.0	10.0	23.0
139	124	26.0	48.0	26.0	0.53	0.0	1480	2700	45.2	54.8	0.82	21.8	10.6	32.2	15.7	16.5	13.0	29.5
140	124	26.0	30.0	44.0	1.60	0.0	1450	2680	45.9	54.1	0.85	24.8	15.8	35.9	22.9	13.0	10.0	23.0
141	124	26.9	43.0	30.1	0.20	0.0	1480	2700	45.2	54.8	0.82	21.7	10.6	32.1	15.7	16.4	13.1	29.5
142	124	31.0	37.7	31.3	0.10	0.0	1510	2710	44.3	55.7	0.80	22.5	11.7	34.0	17.7	16.3	10.3	26.6
143	124	32.5	36.5	31.0	1.60	0.0	1560	2690	41.9	58.1	0.72	24.5	12.0	38.2	18.7	19.5	3.7	23.2

nr. = number
gr. = grouping : 111 = HB
: 112 = MB
: 113 = LS
: 124 = CaO
: 125 = Cal

BD = Bulk Density (kg/m3)
PD = Particle Density (kg/m3)
PV = Pore Volume (%)
SV = Solid Volume (%)
WV2/4.2 = moisture content at pF2/42 (%V/V)
VV2/4.2 = moisture content at pF2/42 (%V/V)
AM = Available Moisture (VV2 - VV4.2) (mm/10cm)
AV2/4.2 = Air Volume at pF2/4.2 (%)

file: CORE.DAT

nr.	gr.	(basic explanatory variables) clay	silt	sand	org.C	CaCO3	BB	PD	PV	SV	E= PV/SV	WV2	WV4.2	VV2	VV4.2	AM	AV2	AV4.2
144	124	33.0	39.0	28.0	1.77	0.0	1440	2670	46.1	53.9	0.86	24.6	12.6	35.4	18.1	17.3	10.7	28.0
145	124	37.0	40.0	23.0	1.74	0.0	1390	2700	48.5	51.5	0.94	27.3	15.1	38.0	21.0	17.0	10.5	27.5
146	124	38.8	33.0	28.2	2.10	0.0	1240	2580	52.0	48.0	1.08	31.9	22.3	39.6	27.6	12.0	12.4	24.4
147	124	38.9	35.9	25.2	4.70	0.0	1190	2490	52.4	47.6	1.10	34.4	24.4	40.9	29.0	11.9	11.5	23.4
148	124	39.2	52.8	8.0	0.60	0.2	1470	2740	46.4	53.6	0.87	25.3	13.9	37.2	20.4	16.8	9.2	26.0
149	124	40.0	35.0	25.0	2.67	0.0	1270	2670	52.4	47.6	1.10	35.0	29.1	44.4	36.9	7.5	8.0	15.5
150	124	41.0	51.0	8.0	1.91	0.0	1140	2660	57.1	42.9	1.33	35.6	25.8	40.6	29.4	11.2	16.5	27.7
151	124	41.1	46.9	12.0	3.80	0.0	1200	2660	54.9	45.1	1.22	37.5	17.4	45.0	20.9	24.1	9.9	34.0
152	124	43.0	34.0	23.0	2.09	0.0	1240	2670	53.6	46.4	1.16	35.5	29.8	44.0	36.9	7.1	9.6	16.7
153	124	44.0	42.0	14.0	4.26	0.0	1390	2720	48.9	51.1	0.96	28.8	20.5	40.0	28.5	11.5	8.9	20.4
154	124	45.0	49.0	6.0	0.57	0.0	1450	2790	48.0	52.0	0.92	30.3	16.5	43.9	23.9	20.0	4.1	24.1
155	124	45.0	43.0	12.0	3.77	0.0	1150	2650	56.6	43.4	1.30	44.3	32.6	51.0	37.5	13.5	5.6	19.1
156	124	45.0	43.0	12.0	2.32	0.0	1350	2710	50.2	49.8	1.01	29.6	22.6	40.0	30.5	9.5	10.2	19.7
157	124	45.4	45.8	8.8	0.10	0.2	1450	2790	48.0	52.0	0.92	30.2	16.5	43.8	23.9	19.9	4.2	24.1
158	124	45.6	35.7	18.7	0.50	0.0	1290	2730	52.7	47.3	1.11	30.2	19.4	38.9	25.0	13.9	13.8	27.7
159	124	46.0	36.0	18.0	0.80	0.0	1290	2730	52.8	47.2	1.12	30.2	19.4	38.9	25.0	13.9	13.9	27.8
160	124	48.0	43.0	9.0	1.51	0.0	1350	2750	50.9	49.1	1.04	31.1	20.0	42.0	27.0	15.0	8.9	23.9
161	124	49.0	44.0	7.0	1.33	0.0	1360	2740	50.4	49.6	1.02	29.8	21.0	40.5	28.5	12.0	9.9	21.9
162	124	50.0	36.0	14.0	0.87	0.0	1400	2730	48.7	51.3	0.95	27.9	19.3	39.0	27.0	12.0	9.7	21.7
163	124	52.0	41.0	7.0	1.40	0.0	1180	2730	56.8	43.2	1.31	38.1	19.4	45.0	22.9	22.1	11.8	33.9
164	124	52.0	41.2	6.8	1.00	0.0	1180	2730	56.8	43.2	1.31	38.1	19.4	45.0	22.9	22.1	11.8	33.9
165	124	52.0	35.0	13.0	0.54	0.0	1460	2750	46.9	53.1	0.88	23.9	21.3	34.9	31.1	3.8	12.0	15.8
166	124	56.5	28.0	15.5	3.80	0.0	1350	2650	49.1	50.9	0.96	35.5	24.9	47.9	33.6	14.3	1.2	15.5
167	124	57.0	31.0	12.0	1.87	0.0	1390	2670	47.9	52.1	0.92	33.7	31.4	46.8	43.6	3.2	1.1	4.3
168	124	61.4	27.7	10.9	0.50	0.0	1390	2750	49.5	50.5	0.98	31.9	20.8	44.4	28.9	15.5	5.1	20.6
169	125	6.8	12.9	80.3	0.30	8.5	1470	2670	44.9	55.1	0.81	16.6	4.4	24.4	6.5	17.9	20.5	38.4
170	125	13.9	16.8	69.3	0.10	4.6	1540	2700	43.0	57.0	0.75	14.9	5.5	22.9	8.5	14.4	20.1	34.5
171	125	16.0	46.2	37.8	0.50	13.9	1320	2710	51.3	48.7	1.05	26.0	7.7	34.3	10.2	24.1	17.0	41.1
172	125	17.0	35.0	48.0	0.01	15.9	1460	2690	45.7	54.3	0.84	21.8	6.7	31.9	9.8	22.1	13.8	35.9
173	125	19.0	64.0	17.0	0.18	13.6	1320	2710	51.3	48.7	1.05	26.1	9.5	34.4	12.5	21.9	16.9	38.8
174	125	20.0	40.0	40.0	1.14	3.9	1540	2650	41.9	58.1	0.72	22.9	10.5	35.3	16.2	19.1	6.6	25.7
175	125	20.2	38.8	41.0	1.50	3.9	1540	2650	41.9	58.1	0.72	22.9	9.2	35.3	14.2	21.1	6.6	27.7
176	125	20.4	42.5	37.1	0.60	17.1	1460	2690	45.7	54.3	0.84	21.9	5.5	32.0	8.0	24.0	13.7	37.7
177	125	21.3	25.0	53.7	0.20	0.4	1560	2700	42.2	57.8	0.73	18.7	8.7	29.2	13.6	15.6	13.0	28.6
178	125	23.0	52.7	24.3	0.60	17.6	1380	2700	48.9	51.1	0.96	26.7	7.7	36.8	10.6	26.2	12.1	38.3
179	125	25.0	45.0	30.0	0.44	5.8	1540	2700	43.0	57.0	0.75	20.7	11.0	31.9	16.9	15.0	11.1	26.1
180	125	25.0	56.0	19.0	0.01	17.1	1380	2700	48.9	51.1	0.96	24.8	8.9	34.2	12.3	21.9	14.7	36.6
181	125	25.7	59.4	14.9	0.79	15.0	1320	2720	51.5	48.5	1.06	25.2	11.3	33.3	14.9	18.4	18.2	36.6
182	125	27.0	51.4	21.6	0.70	9.4	1340	2700	50.4	49.6	1.02	25.5	9.5	34.2	12.7	21.5	16.2	37.7
183	125	27.7	48.2	24.1	1.70	5.9	1350	2700	50.0	50.0	1.00	22.0	11.3	29.7	15.3	14.4	20.3	34.7
184	125	27.8	49.9	22.3	1.60	3.2	1530	2690	43.1	56.9	0.76	23.9	11.5	36.6	17.6	19.0	6.5	25.5
185	125	28.0	51.0	21.0	0.32	8.0	1340	2700	50.4	49.6	1.02	25.4	11.9	34.1	15.9	18.2	16.3	34.5
186	125	28.0	52.0	20.0	1.05	4.0	1530	2690	43.1	56.9	0.76	23.9	14.0	36.6	21.4	15.2	6.5	21.7
187	125	30.0	51.0	19.0	0.55	4.2	1420	2690	47.2	52.8	0.89	20.4	13.7	28.9	19.5	9.4	18.9	27.7
188	125	31.0	60.0	9.0	0.26	15.0	1320	2720	51.5	48.5	1.06	25.1	14.2	33.1	18.8	14.3	18.4	32.7
189	125	31.0	52.0	17.0	0.45	8.6	1290	2710	52.4	47.6	1.10	23.3	15.0	30.1	19.4	10.7	22.3	33.0
190	125	34.0	62.0	4.0	0.70	8.4	1570	2730	42.5	57.5	0.74	24.2	13.0	38.0	20.4	17.6	4.5	22.1
191	125	42.0	55.0	3.0	0.52	7.4	1500	2730	45.1	54.9	0.82	26.8	13.6	40.2	20.4	19.8	4.9	24.7

nr. = number
gr. = grouping : 111 = HB
: 112 = MB
: 113 = LB
: 124 = Ca0
: 125 = Cal

BB = Bulk Density (kg/m3)
PD = Particle Density (kg/m3)
PV = Pore Volume (%)
SV = Solid Volume (%)
WV2/4.2 = moisture content at pF2/42 (%W/W)
VV2/4.2 = moisture content at pF2/42 (%V/V)
AM = Available Moisture (VV2 - VV4.2) (mm/10cm)
AV2/4.2 = Air Volume at pF2/4.2 (%)

file: AGGR.DAT

nr.	gr.	<basic expl. variables> cl	si	sa	org.C	CaCO3	PD	PV	SV	PV/SV	BD	WV 0	WV 0.5	WV 1	WV 1.5	WV 2	WV 3	WV 4.2	WV 6	AM
1	111	5	2	93	0.07	0.0	2670	32.30	67.70	0.48	1810	66.1	61.7	40.4	24.3	14.1	8.5	5.8	1.3	8.3
2	111	6	3	91	0.23	0.0	2670	33.86	66.14	0.51	1770	72.6	63.0	44.4	23.7	15.4	8.3	6.2	1.6	9.2
3	111	9	5	86	0.20	0.0	2660	34.71	65.29	0.53	1740	69.4	52.4	41.1	25.9	13.9	9.6	6.1	1.6	7.8
4	111	9	33	58	2.17	0.0	2610	37.02	62.98	0.59	1640	65.9	48.7	42.8	43.3	39.5	29.0	17.9	3.0	21.6
5	111	10	24	66	1.76	0.0	2630	32.25	67.75	0.48	1780	64.1	40.6	35.1	32.6	29.9	22.8	12.8	2.3	17.1
6	111	13	9	78	0.21	0.0	2680	34.50	65.50	0.53	1760	67.4	51.7	44.2	31.7	20.2	14.4	9.3	2.3	10.9
7	111	15	9	76	0.16	0.0	2700	30.99	69.01	0.45	1860	70.5	51.2	37.4	33.3	30.9	27.0	18.2	3.3	12.7
8	111	15	25	60	1.55	0.0	2670	31.22	68.78	0.45	1840	74.3	53.9	39.7	39.1	32.9	27.4	17.5	2.4	16.4
9	111	15	21	64	1.55	0.0	2630	33.53	66.47	0.5	1750	45.2	41.1	34.1	31.2	27.5	22.9	11.4	2.1	16.1
10	111	16	7	77	0.41	0.0	2680	35.56	64.44	0.55	1730	63.3	52.8	42.4	32.4	24.0	17.3	12.1	3.1	11.9
11	111	17	33	50	0.86	0.0	2660	34.64	65.36	0.53	1740	47.7	41.8	36.4	31.7	27.8	23.7	12.5	2.1	15.3
12	111	18	29	53	0.84	0.0	2680	37.57	62.43	0.6	1710	49.1	42.6	35.9	29.2	27.4	24.5	12.8	2.2	14.6
13	111	18	33	49	0.42	0.0	2660	36.93	63.07	0.59	1680	58.1	43.2	38.6	34.3	29.9	23.7	13.6	2.5	16.3
14	111	18	33	49	0.30	0.0	2680	35.34	64.66	0.55	1730	61.9	41.5	37.4	32.7	28.2	24.2	13.8	1.9	14.4
15	111	19	25	56	0.92	0.0	2670	30.83	69.17	0.45	1850	62.7	47.4	37.6	34.2	31.5	25.2	13.7	2.2	17.8
16	111	19	19	62	0.23	0.0	2700	38.35	61.65	0.62	1660	49.8	48.0	39.0	30.7	26.6	21.2	17.3	2.8	9.3
17	111	20	23	57	0.14	0.0	2700	34.17	65.83	0.52	1780	71.7	47.5	37.6	31.5	26.9	21.0	13.4	2.0	13.5
18	111	20	20	60	0.06	0.0	2690	30.52	69.48	0.44	1870	75.4	51.6	39.5	27.7	23.2	16.8	12.5	2.6	10.7
19	111	22	28	50	0.17	0.0	2710	31.57	68.43	0.46	1850	54.4	44.2	37.2	33.3	30.3	27.0	16.7	3.7	13.6
20	111	23	21	56	0.30	0.0	2700	33.53	66.47	0.5	1790	64.4	50.1	46.4	41.9	30.8	24.7	16.5	4.7	14.3
21	111	24	30	46	0.35	0.0	2700	31.18	68.82	0.45	1860	51.9	50.0	38.9	32.6	30.9	26.8	17.3	2.8	13.6
22	111	25	17	58	0.43	0.0	2690	33.44	66.56	0.5	1790	70.9	48.2	43.0	35.3	29.4	26.1	18.3	3.8	11.1
23	111	37	46	17	0.35	0.0	2730	36.35	63.65	0.57	1740	84.7	61.6	49.6	45.1	43.0	37.8	27.7	7.8	15.3
24	112	3	1	96	0.08	0.0	2670	30.36	69.64	0.44	1860	60.0	54.3	35.3	17.7	8.6	5.4	3.7	1.3	4.9
25	112	6	5	89	0.09	0.0	2680	33.29	66.71	0.5	1790	71.2	67.8	47.4	31.7	21.8	8.6	5.5	1.8	16.3
26	112	14	18	68	1.63	0.0	2640	31.81	68.19	0.47	1800	49.3	41.9	35.6	33.3	27.2	20.7	13.5	2.3	13.7
27	112	15	19	66	0.19	0.0	2690	27.98	72.02	0.39	1940	58.0	49.3	32.2	27.0	22.7	18.8	12.6	1.9	10.1
28	112	16	15	69	0.68	0.0	2660	27.91	72.09	0.39	1920	56.4	37.6	32.8	25.7	21.9	18.8	11.9	2.1	10.0
29	112	17	28	55	0.37	0.0	2700	26.92	73.08	0.37	1970	62.1	44.3	36.6	31.1	27.0	24.0	15.2	4.5	11.8
30	112	17	31	52	0.18	0.0	2670	28.42	71.58	0.4	1910	57.5	40.3	37.1	29.0	27.3	24.1	14.3	2.3	13.0
31	112	18	41	41	1.44	0.0	2670	34.45	65.55	0.53	1720	55.0	45.4	40.9	41.3	37.0	31.5	16.5	6.4	20.5
32	112	18	17	65	0.14	0.0	2670	32.75	67.25	0.49	1800	53.1	46.4	39.4	33.3	29.0	25.7	16.0	4.5	13.0
33	112	20	27	53	0.24	0.0	2670	27.61	72.39	0.38	1930	46.9	38.6	33.4	29.7	28.6	26.4	14.7	1.9	13.9
34	112	20	25	55	0.43	0.0	2710	34.78	65.22	0.53	1770	67.8	48.5	44.1	37.2	32.9	28.6	17.5	4.1	15.4
35	112	21	29	50	0.39	0.0	2710	35.86	64.14	0.56	1740	70.8	51.2	46.6	40.2	33.1	27.0	18.6	5.4	14.5
36	112	23	29	48	0.28	0.0	2690	33.67	66.33	0.51	1780	68.7	48.6	41.5	36.1	33.5	28.1	18.5	3.4	15.0
37	112	24	37	39	0.28	0.0	2710	35.41	64.59	0.55	1750	48.7	48.5	44.6	38.9	36.2	32.2	20.8	4.4	15.4
38	112	24	41	35	2.32	0.0	2630	34.71	65.29	0.53	1720	75.5	56.4	49.7	48.2	38.2	30.8	20.1	6.5	18.1
39	112	25	46	29	1.16	0.1	2650	30.93	69.07	0.45	1830	59.8	45.9	41.4	37.7	37.3	32.0	19.4	3.1	17.9
40	112	25	43	32	1.16	0.0	2670	30.93	69.07	0.45	1840	54.8	48.0	43.2	39.0	37.5	32.2	19.7	3.5	17.8
41	112	26	47	27	0.52	0.0	2700	35.47	64.53	0.55	1740	67.9	52.9	42.6	39.3	37.2	33.2	21.4	3.5	15.8
42	112	26	12	62	0.17	0.0	2700	29.46	70.54	0.42	1900	74.3	48.1	41.2	35.9	29.8	21.7	14.6	7.0	15.2
43	112	27	32	41	0.35	0.0	2710	31.83	68.17	0.47	1850	75.1	55.1	45.0	38.9	36.4	29.8	20.2	3.9	16.2
44	112	28	37	35	1.77	0.0	2660	32.30	67.70	0.48	1800	68.4	56.3	50.2	46.4	38.9	36.9	19.6	9.9	19.3
45	112	31	36	33	2.09	0.0	2610	34.74	65.26	0.53	1700	73.3	59.8	53.6	49.5	42.8	38.8	25.8	10.7	17.0
46	112	32	44	24	1.56	0.0	2690	33.59	66.41	0.51	1790	79.1	59.8	49.2	49.6	42.8	41.0	24.3	15.0	18.5
47	112	32	46	22	0.19	0.0	2720	35.26	64.74	0.54	1760	76.6	53.7	46.3	42.2	40.3	35.4	23.4	4.4	16.9
48	112	34	39	27	0.35	0.0	2760	29.37	70.63	0.42	1950	89.9	57.9	52.8	49.3	44.5	34.3	26.3	12.9	18.2
49	112	34	30	36	0.32	0.1	2730	30.69	69.31	0.44	1890	68.8	46.1	41.6	38.2	35.7	31.6	23.1	3.8	12.6
50	112	35	48	17	0.40	0.0	2760	34.24	65.76	0.52	1810	73.3	51.6	46.2	43.1	40.0	37.1	24.1	13.2	15.9
51	112	36	29	35	0.26	0.0	2730	30.78	69.22	0.44	1890	67.7	48.4	45.5	37.4	33.5	22.3	18.5	7.6	15.0
52	112	37	41	22	0.29	0.0	2770	33.28	66.72	0.5	1850	70.5	52.5	48.8	42.7	40.7	36.1	26.6	5.7	14.1
53	112	45	42	13	0.27	0.1	2770	33.02	66.98	0.49	1860	75.9	55.2	50.0	47.6	45.6	40.5	30.7	6.5	14.9
54	112	46	47	7	0.31	0.0	2780	32.30	67.70	0.48	1880	93.6	64.9	55.5	53.6	47.9	45.5	32.0	11.8	15.9
55	112	51	26	23	0.52	0.0	2750	30.86	69.14	0.45	1900	90.3	59.3	55.5	50.2	47.3	42.4	32.1	6.8	15.2

nr. = number
gr. = grouping : 111 = HB
112 = MB
113 = LB
124 = CaO
125 = Cal

cl = clay, si = silt, sa = sand
PD = Particle Density (kg/m3)
PV = Pore Volume (%)
SV = Solid Volume (%)
BD = Bulk Density (kg/m3)
AM = Available Moisture = WV2 - WV4.2 (mm/10cm)

WV 0 = moisture content at pF 0 (%V/V)
WV 0.5 = " " " pF 0.5 "
WV 1 = " " " pF 1 "
WV 1.5 = " " " pF 1.5 "
WV 2 = " " " pF 2 "
WV 3 = " " " pF 3 "
WV 4.2 = " " " pF 4.2 "
WV 6 = " " " pF 6 "

file: AGGR.DAT

nr.	gr.	<basic expl. variables> cl	si	sa	org.C	CaCO3	PB	PV	SV	E= PV/SV	BD	VV 0	VV 0.5	VV 1	VV 1.5	VV 2	VV 3	VV 4.2	VV 6	AM
56	113	5	14	81	0.45	0.0	2680	37.57	62.43	0.6	1670	50.4	52.6	40.2	33.9	21.9	20.7	11.7	1.8	19.2
57	113	19	32	49	0.80	0.0	2700	32.23	67.77	0.48	1830	84.7	51.2	42.5	41.5	36.2	32.4	18.1	3.3	18.1
58	113	22	35	43	1.30	0.0	2660	35.63	64.37	0.55	1710	70.8	51.8	44.3	42.1	39.3	36.4	22.2	4.1	17.1
59	113	22	36	42	3.39	0.0	2590	38.13	61.87	0.62	1600	53.3	52.2	44.8	42.7	41.6	41.3	28.2	4.0	13.4
60	113	33	42	25	1.20	0.0	2650	36.03	63.97	0.56	1700	49.5	46.2	42.7	39.8	39.3	36.9	26.5	4.1	12.8
61	113	34	41	25	0.62	0.0	2680	34.85	65.15	0.53	1750	53.7	50.4	45.3	42.9	41.3	38.7	25.0	4.0	16.3
62	124	13	25	62	0.82	0.1	2670	30.97	69.03	0.45	1840	65.9	48.8	39.4	38.5	26.1	15.5	11.2	4.4	14.9
63	124	14	26	60	2.57	0.1	2620	30.58	69.42	0.44	1820	68.6	58.4	39.9	39.7	29.5	23.3	14.7	7.8	14.8
64	124	18	52	30	1.00	0.0	2620	32.43	67.57	0.48	1770	68.9	60.9	47.3	46.7	37.9	27.3	15.0	5.5	22.9
65	124	25	32	43	2.11	0.0	2640	34.85	65.15	0.53	1720	76.9	48.3	44.5	41.8	39.0	33.9	23.7	4.5	15.3
66	124	26	48	26	0.53	0.0	2700	29.07	70.93	0.41	1920	84.1	54.7	52.4	48.6	42.2	30.0	20.4	8.6	21.8
67	124	30	37	33	2.27	0.0	2680	34.83	65.17	0.53	1750	94.3	58.1	48.1	46.9	45.7	39.4	27.7	5.1	18.0
68	124	30	30	40	0.83	0.0	2690	31.84	68.16	0.47	1830	51.1	47.4	41.0	38.6	37.5	32.8	23.4	5.9	14.1
69	124	33	39	28	1.77	0.0	2670	31.69	68.31	0.46	1820	77.4	57.1	47.7	48.2	40.6	37.1	22.8	12.4	17.8
70	124	39	41	20	2.02	0.0	2670	34.83	65.17	0.53	1740	71.2	65.6	59.2	56.4	56.5	47.0	36.9	6.6	19.6
71	124	40	55	5	1.19	0.0	2740	29.35	70.65	0.42	1940	93.1	65.4	54.9	55.5	47.1	41.1	27.0	11.3	20.1
72	124	41	51	8	1.91	0.0	2660	36.42	63.58	0.57	1690	81.3	65.2	54.6	54.2	49.0	44.6	29.4	9.5	19.6
73	124	42	49	9	1.74	0.0	2730	34.80	65.20	0.53	1800	80.3	67.5	58.5	55.3	55.5	49.7	34.9	7.9	20.6
74	124	43	50	7	2.91	0.0	2690	37.43	62.57	0.6	1680	67.9	63.7	58.0	54.3	55.0	48.4	38.3	8.9	16.7
75	124	45	49	6	0.57	0.0	2790	30.32	69.68	0.44	1940	89.6	63.8	58.0	58.2	50.4	46.6	32.0	11.8	18.4
76	124	47	43	10	0.93	0.4	2720	31.34	68.66	0.46	1870	75.2	60.0	53.5	51.2	50.7	44.3	30.5	5.2	20.2
77	124	52	35	13	0.54	0.0	2750	32.23	67.77	0.48	1860	73.7	56.2	52.8	48.7	48.4	43.9	31.1	8.2	17.3
78	124	57	31	12	1.87	0.0	2670	34.29	65.71	0.52	1750	79.5	75.1	70.7	66.2	64.2	58.6	43.6	10.9	20.6
79	125	11	21	68	0.04	13.9	2700	39.93	60.07	0.66	1620	69.0	53.0	48.9	43.9	33.7	21.5	10.2	2.3	23.5
80	125	17	35	48	0.01	15.9	2690	38.49	61.51	0.63	1650	82.7	59.1	50.8	46.2	33.2	23.1	9.8	2.5	23.4
81	125	19	42	39	0.91	5.7	2650	36.31	63.69	0.57	1690	58.3	52.1	47.5	47.8	39.4	18.1	15.4	3.4	24.0
82	125	19	64	17	0.18	13.6	2710	40.37	59.63	0.68	1620	76.5	54.8	51.7	45.7	39.2	26.2	12.5	2.9	26.7
83	125	20	42	38	1.05	4.9	2650	35.75	64.25	0.56	1700	62.1	51.2	49.8	47.3	39.3	34.9	17.2	3.2	22.1
84	125	20	40	40	1.14	3.9	2650	33.59	66.41	0.51	1760	65.5	52.6	49.1	44.4	38.0	34.8	16.2	3.7	21.8
85	125	21	52	27	0.26	8.4	2700	37.92	62.08	0.61	1680	67.5	52.4	48.7	46.5	38.5	31.9	14.4	3.2	24.1
86	125	25	56	19	0.01	17.1	2700	40.70	59.30	0.69	1600	77.6	54.9	53.3	51.2	40.3	29.0	12.3	3.4	28.0
87	125	25	45	30	0.44	5.8	2700	34.93	65.07	0.54	1760	70.9	51.7	47.7	42.8	38.0	32.2	16.9	4.2	21.1
88	125	25	51	24	0.31	9.0	2710	37.03	62.97	0.59	1710	62.4	52.3	47.0	45.5	39.0	33.0	17.4	4.1	21.6
89	125	26	60	14	2.44	4.3	2650	39.02	60.98	0.64	1620	79.5	63.7	55.6	53.5	48.3	39.9	21.9	3.4	26.4
90	125	27	64	9	0.99	12.1	2710	40.18	59.82	0.67	1620	71.6	58.3	49.6	46.8	43.6	34.3	19.0	3.1	24.6
91	125	27	60	13	2.15	5.3	2660	39.60	60.40	0.66	1610	74.7	64.1	55.1	53.1	47.7	39.3	21.9	3.5	25.8
92	125	28	52	20	1.05	4.0	2690	30.99	69.01	0.45	1860	75.5	58.4	52.1	50.6	43.0	40.7	21.4	5.2	21.6
93	125	28	51	21	0.32	8.0	2700	38.30	61.70	0.62	1670	70.1	52.3	48.1	42.8	37.4	30.9	15.9	3.8	21.5
94	125	29	67	4	0.52	8.8	2730	36.46	63.54	0.57	1730	67.0	54.1	47.6	46.2	43.6	36.8	20.4	3.8	23.2
95	125	30	51	19	0.55	4.2	2690	34.60	65.40	0.53	1760	67.9	55.4	47.0	44.0	38.4	33.3	19.5	4.6	18.9
96	125	31	52	17	0.45	8.6	2710	37.31	62.69	0.6	1700	71.4	54.1	48.8	45.6	40.5	33.3	19.4	4.4	21.1
97	125	31	60	9	0.26	15.0	2720	39.07	60.93	0.64	1660	69.6	53.8	50.6	49.1	42.7	34.0	18.8	4.5	23.9
98	125	41	52	7	4.88	1.9	2580	36.40	63.60	0.57	1640	77.6	69.5	72.0	69.9	64.1	60.0	38.5	7.7	25.6
99	125	41	56	3	1.42	6.8	2720	37.39	62.61	0.6	1700	62.9	55.1	55.9	52.4	49.0	44.4	30.3	6.5	18.7
100	125	41	53	6	0.82	7.2	2730	36.58	63.42	0.58	1730	72.5	55.7	53.8	51.4	46.5	42.7	28.0	6.1	18.5
101	125	42	53	5	2.09	3.5	2660	37.05	62.95	0.59	1670	69.3	62.1	63.6	60.3	55.1	49.8	33.9	7.0	21.2

nr. = number
gr. = grouping : 111 = HB
112 = MB
113 = LG
124 = CaO
125 = Cal

cl = clay, si = silt, sa = sand
PB = Particle Density (kg/m3)
PV = Pore Volume (%)
SV = Solid Volume (%)
BD = Bulk Density (kg/m3)
AM = Available Moisture = VV2 - VV4.2 (mm/10cm)

VV 0 = moisture content at pF 0 (%V/V)
VV 0.5 = " " pF 0.5 "
VV 1 = " " pF 1 "
VV 1.5 = " " pF 1.5 "
VV 2 = " " pF 2 "
VV 3 = " " pF 3 "
VV 4.2 = " " pF 4.2 "
VV 6 = " " pF 6 "

file: STAB.DAT

nr.	gr.	<basic explanatory variables> clay	silt	sand	org.C	CaCO3	< m.w.d.	air-dry r.c.s.a.	> f 0.3	< m.w.d.	pF 2.0 r.c.s.a.	> f 0.3	air-dry nr. of raindrops	pF 2.0	air-dry slaking	pF2.0 cl.
1	111	5	2	93	0.07	0.0	0.58	25.5	23.7	-	-	-	-	-	-	-
2	111	6	3	91	0.23	0.0	0.57	25.0	23.4	-	-	-	-	-	-	-
3	111	9	5	86	0.20	0.0	0.27	51.1	69.6	-	-	-	-	-	-	-
4	111	9	33	58	2.17	0.0	4.18	5.9	4.0	-	-	-	-	-	-	-
5	111	10	24	66	1.76	0.0	3.69	9.5	8.3	-	-	-	-	-	-	-
6	111	13	9	78	0.21	0.0	0.28	49.3	65.9	-	-	-	-	-	-	-
7	111	15	9	76	0.16	0.0	0.42	35.4	40.0	-	-	-	-	-	-	-
8	111	15	21	64	1.55	0.0	4.64	6.1	4.6	6.36	1.2	0.0	-	1000	-	6
9	111	15	25	60	1.55	0.0	4.74	6.8	6.6	6.34	1.3	0.2	-	1000	-	6
10	111	16	7	77	0.41	0.0	0.86	24.2	23.0	-	-	-	9	-	1	-
11	111	17	33	50	0.86	0.0	0.88	21.6	19.7	-	-	-	-	-	-	-
12	111	18	29	53	0.84	0.0	0.70	23.0	19.6	-	-	-	-	-	-	-
13	111	18	33	49	0.30	0.0	0.66	37.4	47.5	5.90	2.5	1.6	-	380	-	5
14	111	18	33	49	0.42	0.0	1.05	17.9	14.6	-	-	-	-	-	-	-
15	111	19	19	62	0.23	0.0	0.59	30.6	32.1	5.58	5.3	5.2	-	325	-	2
16	111	19	25	56	0.92	0.0	1.16	22.2	22.5	6.31	1.7	0.8	-	1000	-	6
17	111	20	20	60	0.06	0.0	0.69	22.1	20.1	-	-	-	-	-	-	-
18	111	20	23	57	0.14	0.0	0.32	46.9	62.2	-	-	-	-	-	-	-
19	111	22	28	50	0.17	0.0	0.46	28.9	27.9	-	-	-	-	-	-	-
20	111	23	21	56	0.30	0.0	2.25	23.0	27.0	4.52	5.0	3.5	17	285	1	5
21	111	24	30	46	0.35	0.0	0.55	27.9	28.9	5.97	2.6	1.8	-	1000	-	6
22	111	25	17	58	0.43	0.0	0.97	35.7	44.8	-	-	-	21	-	1	-
23	111	37	46	17	0.35	0.0	0.97	21.5	21.4	4.99	2.2	0.0	-	64	-	5
24	112	3	1	96	0.08	0.0	0.87	17.8	14.0	-	-	-	-	-	-	-
25	112	6	5	89	0.09	0.0	0.37	40.9	49.8	-	-	-	-	-	-	-
26	112	14	18	68	1.63	0.0	3.63	8.4	6.5	-	-	-	-	-	-	-
27	112	15	19	66	0.19	0.0	0.77	28.4	29.8	-	-	-	-	-	-	-
28	112	16	15	69	0.68	0.0	1.35	19.6	17.5	-	-	-	-	-	-	-
29	112	17	28	55	0.37	0.0	0.59	33.2	36.0	4.98	5.3	4.3	47	92	1	5
30	112	17	31	52	0.18	0.0	0.70	26.9	26.2	-	-	-	31	-	1	-
31	112	18	17	65	0.14	0.0	0.33	42.5	52.8	-	-	-	9	-	1	-
32	112	18	41	41	1.44	0.0	4.46	9.4	10.1	6.35	1.6	0.6	124	1000	2	6
33	112	20	25	55	0.43	0.0	0.90	23.0	23.1	-	-	-	29	-	1	-
34	112	20	27	53	0.24	0.0	1.29	16.8	12.4	-	-	-	31	-	1	-
35	112	21	29	50	0.39	0.0	0.96	24.4	25.1	6.13	3.1	2.8	40	1000	1	6
36	112	23	29	48	0.28	0.0	0.87	42.2	56.9	6.37	1.3	0.2	18	102	1	5
37	112	24	37	39	0.28	0.0	1.37	18.2	17.1	-	-	-	20	-	1	-
38	112	24	41	35	2.32	0.0	3.27	15.4	16.7	6.29	1.7	0.9	422	1000	5	6
39	112	25	43	32	1.16	0.0	1.12	20.0	19.2	-	-	-	132	-	2	-
40	112	25	46	29	1.16	0.1	0.90	26.8	28.9	6.38	1.2	0.0	112	1000	2	6
41	112	26	12	62	0.17	0.0	1.76	20.0	20.1	-	-	-	10	-	1	-
42	112	26	47	27	0.52	0.0	0.57	35.3	41.8	5.94	2.7	1.7	33	145	1	5
43	112	27	32	41	0.35	0.0	0.69	31.7	37.2	5.56	4.4	3.8	35	323	1	5
44	112	28	37	35	1.77	0.0	1.94	17.4	16.4	6.21	2.5	2.0	394	1000	5	6
45	112	31	36	33	2.09	0.0	5.25	7.2	7.6	6.34	1.4	0.4	482	1000	5	6
46	112	32	44	24	1.56	0.0	2.36	16.3	16.2	-	-	-	380	-	5	-
47	112	32	46	22	0.19	0.0	0.94	35.2	44.8	-	-	-	110	-	2	-
48	112	34	30	36	0.32	0.1	2.18	19.1	21.4	-	-	-	139	-	2	-
49	112	34	39	27	0.35	0.0	2.69	12.0	11.8	-	-	-	418	-	5	-
50	112	35	48	17	0.40	0.0	2.63	16.4	17.8	6.34	1.5	0.4	456	1000	5	6
51	112	36	29	35	0.26	0.0	1.59	18.9	19.0	-	-	-	41	-	1	-
52	112	37	41	22	0.29	0.0	1.45	21.0	22.0	-	-	-	437	-	5	-
53	112	45	42	13	0.27	0.1	4.69	4.7	3.6	-	-	-	740	-	6	-
54	112	46	47	7	0.31	0.0	3.14	11.6	11.5	-	-	-	807	-	6	-
55	112	51	26	23	0.52	0.0	4.66	5.5	4.7	-	-	-	694	-	6	-

nr. = number
gr. = grouping
m.w.d. = mean weight diameter (mm)
r.c.s.a. = relative clod surface area
f 0.3 = fraction < 0.3 mm (%)
- = not determined

file: STAB.DAT

nr.	gr.	<basic explanatory variables> clay	silt	sand	org.C	CaCO3	< m.w.d.	air-dry r.c.s.a.	> f 0.3	< m.w.d.	pF 2.0 r.c.s.a.	> f 0.3	air-dry nr. of raindrops	pF 2.0	air-dry slaking	pF2.0 cl.
56	113	5	14	81	0.45	0.0	1.08	24.7	24.6	-	-	-	-	-	-	-
57	113	19	32	49	0.80	0.0	0.67	35.8	42.4	6.15	2.8	2.4	-	74	-	6
58	113	22	35	43	1.30	0.0	2.28	23.0	26.8	6.32	2.0	1.3	-	270	-	6
59	113	22	36	42	3.39	0.0	5.09	7.1	7.7	6.38	1.2	0.0	-	1000	-	6
60	113	33	42	25	1.20	0.0	5.16	4.5	3.3	6.34	1.5	0.5	499	1000	5	6
61	113	34	41	25	0.62	0.0	1.45	20.2	19.6	6.36	1.5	0.5	133	1000	2	6
62	124	13	25	62	0.82	0.1	2.14	10.4	6.6	-	-	-	152	-	2	-
63	124	14	26	60	2.57	0.1	5.34	5.2	4.3	-	-	-	390	-	5	-
64	124	18	52	30	1.00	0.0	1.00	28.1	30.8	6.30	1.2	0.0	133	1000	2	6
65	124	25	32	43	2.11	0.0	3.38	15.8	19.3	-	-	-	390	-	5	-
66	124	26	48	26	0.53	0.0	1.54	14.7	15.7	6.28	1.4	0.2	227	310	4	6
67	124	30	30	40	0.83	0.0	2.56	12.3	12.3	-	-	-	249	-	4	-
68	124	30	37	33	2.27	0.0	5.76	2.9	2.1	6.27	2.4	1.9	447	1000	5	6
69	124	33	39	28	1.77	0.0	4.11	12.9	14.9	6.35	1.2	0.0	627	1000	6	6
70	124	39	41	20	2.02	0.0	5.78	2.4	1.4	-	-	-	950	-	6	-
71	124	40	55	5	1.19	0.0	3.24	9.8	8.9	6.34	1.3	0.1	1000	1000	6	6
72	124	41	51	8	1.91	0.0	6.09	1.7	0.0	-	-	-	874	-	6	-
73	124	42	49	9	1.74	0.0	4.90	2.9	1.3	-	-	-	1000	-	6	-
74	124	43	50	7	2.91	0.0	6.06	1.4	0.3	-	-	-	1000	-	6	-
75	124	45	49	6	0.57	0.0	4.40	5.2	4.2	-	-	-	1000	-	6	-
76	124	47	43	10	0.93	0.4	2.56	9.8	8.6	6.25	1.4	0.2	1000	1000	6	6
77	124	52	35	13	0.54	0.0	4.18	12.9	14.9	-	-	-	646	-	6	-
78	124	57	31	12	1.87	0.0	4.25	5.0	3.8	-	-	-	675	-	6	-
79	125	11	21	68	0.04	13.9	0.62	33.8	39.6	-	-	-	49	-	1	-
80	125	17	35	48	0.01	15.9	0.46	33.1	36.6	-	-	-	36	-	1	-
81	125	19	42	39	0.91	5.7	3.60	15.2	16.2	6.29	1.2	0.0	228	433	4	6
82	125	19	64	17	0.18	13.6	0.68	27.3	29.6	-	-	-	124	-	3	-
83	125	20	40	40	1.14	3.9	1.28	20.5	19.5	6.28	1.6	0.7	118	1000	4	6
84	125	20	42	38	1.05	4.9	0.96	21.3	22.3	-	-	-	118	-	4	-
85	125	21	52	27	0.26	8.4	2.60	14.1	12.7	-	-	-	146	-	3	-
86	125	25	45	30	0.44	5.8	1.32	18.9	18.1	-	-	-	129	-	4	-
87	125	25	51	24	0.31	9.0	0.92	22.3	22.7	-	-	-	149	-	3	-
88	125	25	56	19	0.01	17.1	0.58	30.7	34.2	-	-	-	45	-	1	-
89	125	26	60	14	2.44	4.3	3.26	7.0	4.4	-	-	-	-	-	-	-
90	125	27	60	13	2.15	5.3	3.38	6.2	3.5	-	-	-	-	-	-	-
91	125	27	64	9	0.99	12.1	1.78	11.5	8.2	6.38	1.2	0.0	-	1000	-	6
92	125	28	51	21	0.32	8.0	1.93	19.8	13.6	5.98	1.5	0.2	125	1000	4	6
93	125	28	52	20	1.05	4.0	2.30	16.3	15.0	6.30	1.2	0.0	236	1000	4	6
94	125	29	67	4	0.52	8.8	1.05	18.8	17.8	-	-	-	310	-	4	-
95	125	30	51	19	0.55	4.2	2.60	12.3	11.1	-	-	-	148	-	4	-
96	125	31	52	17	0.45	8.6	0.99	12.9	10.9	6.33	1.6	0.6	140	453	4	6
97	125	31	60	9	0.26	15.0	0.99	19.9	19.2	-	-	-	137	-	4	-
98	125	41	52	7	4.88	1.9	6.50	2.2	1.5	-	-	-	1000	-	6	-
99	125	41	53	6	0.82	7.2	4.50	5.4	3.7	6.39	1.2	0.0	1000	1000	6	6
100	125	41	56	3	1.42	6.8	5.10	3.4	1.8	-	-	-	1000	-	6	-
101	125	42	53	5	2.09	3.5	5.20	2.7	1.2	6.21	2.0	0.8	1000	1000	6	6

nr. = number
gr. = grouping

m.w.d. = mean weight diameter (mm)
r.c.s.a. = relative clod surface area
f 0.3 = fraction < 0.3 mm (%)
- = not determined

APPENDIX D

CORRELATION MATRICES AND STEPWISE MULTIPLE REGRESSION OF PHYSICAL DATA

1. R - Particle Density Data - 5 basic explanatory variables
2. MLINREGR(stepwise) - PD - 5 basic explanatory variables

3. R - Linear Extensibility Data condensates - 5 basic explanatory variables
4. MLINREGR(stepwise) - LE - 5 basic explanatory variables
5. MLINREGR(stepwise) - LE - 9 basic explanatory variables
6. R - Atterberg Limits Data - 3 basic explanatory variables
7. MLINREGR(stepwise) - Atterberg Limits Data 3 basic explanatory variables
8. MLINREGR(stepwise) - Atterberg Limits Data 7 basic explanatory variables
9. R - Selected Core Data - 5 basic explanatory variables
10. MLINREGR(stepwise) - Selected Core Data - 5 basic explanatory variables
11. MLINREGR(stepwise) - Selected Core Data - 9 basic explanatory variables
12. R - Torvane, Air Permeability Cores at pF2 - 5 basic explanatory variables
13. R - Selected natural Aggregate Data - 5 basic explanatory variables
14. MLINREGR(stepwise) - Selected natural Aggregate Data - 5 basic explanatory variables
15. MLINREGR(stepwise) - Selected natural Aggregate Data - 9 basic explanatory variables
16. R - Stability Data natural Aggregates - 5 basic explanatory variables
17. MLINREGR(stepwise) - Stability Data natural Aggregates - 5 basic explanatory variables
18. MLINREGR(stepwise) - Stability Data natural Aggregates - 9 basic explanatory variables
19. R - Micro Tillage Test Data - 5 basic explanatory variables
20. MLINREGR(stepwise) - Micro Tillage Test Data - 5 basic explanatory variables

1. Correlation coefficient (R) of Particle Density (PD) with the 5 basic explanatory variables clay (CL), silt (SI), sand (SA), organic carbon (OC) and $CaCO_3$ (CA).

GROUPING number of samples	Fluvial n=191	Weichselian n=130	Holocene n=61	HB n=44	MB n=68	LG n=18	CaO n=38	Cal n=23
CORRELATED VARIABLES								
PD-CL	.51	.66	.33	.60	.66	.61	.42	.55
PD-SI	.28	.33	.29	(.17)	.44	(.13)	.28	.53
PD-SA	-.44	-.54	+.42	+.36	-.58	-.50	-.47	-.58
PD-OC	-.36	-.59	-.41	+.73	-.52	+.65	-.66	-.37
PD-CA	*	*	*	*	*	*	*	(-.34)

( ) not significant at 95 % confidence limits
* correlation not possible ($CaCO_3$ =0) and groups with many $CaCO_3$ =0 values

2. Stepwise multiple regression of PD with the 5 basic explanatory variables at 95 % confidence limits.

GROUPING	Number of samples	step	Entered VARIABLE	R² (%)	F test
FLUVIAL	191	1	OC	31	86.7
		2	CL	72	237.1
WEICHSELIAN	130	1	CL	44	100.0
		2	OC	74	178.7
HOLOCENE	61	1	OC	38	35.5
		2	CL	68	62.0
HB	44	1	OC	33	48.1
		2	CL	74	58.9
MB	68	1	CL	44	51.1
		2	OC	77	106.1
LG	18	1	OC	42	11.6
		2	CL	63	12.8
CaO	38	1	OC	44	28.4
		2	CL	70	40.5
Cal	23	1	SA	33	10.5
		2	OC	57	13.2

3. Correlation coefficient (R) of linear extensibility (LE) calculated or measured at pF2 and pF1 on condensates (LE2 calc; LE2 meas; LE1 calc; LE1 meas) with the 5 basic explanatory variables.

GROUPING number of samples		Fluvial n=55	Weichselian n=30	Holocene n=25	HB n=9	MB n=17	LG n=4	CaO n=11	Cal n=14
CORRELATED VARIABLES									
LE2 calc	-CL	0.79	0.59	0.86	(-0.08)	0.53	(0.82)	0.85	0.89
	-SI	0.50	0.53	(-0.02)	(-0.28)	0.51	(0.88)	(-0.28)	(0.38)
	-SA	-0.75	-0.63	-0.61	(0.27)	-0.61	(-0.85)	-0.56	-0.69
	-OC	0.31	(0.24)	0.56	(0.24)	(0.26)	(0.16)	(0.13)	0.88
	-CA	*	*	*	*	*	*	*	-0.60
LE2 meas	-CL	0.85	0.75	0.85	(0.48)	0.64	0.94	0.85	0.87
	-SI	0.36	0.40	(-0.04)	(+0.52)	(0.23)	0.99	(-0.23)	(0.31)
	-SA	-0.89	-0.61	-0.59	(0.20)	-0.48	-0.96	-0.61	-0.64
	-OC	0.26	(0.06)	0.52	(-0.12)	(-0.02)	(0.01)	(0.09)	0.90
	-CA	*	*	*	*	*	*	*	-0.59
LE1 calc	-CL	0.85	0.69	0.88	(-0.10)	0.75	(0.83)	0.88	0.86
	-SI	0.36	(0.30)	(-0.07)	-0.60	(0.24)	0.95	(-0.09)	(0.27)
	-SA	-0.69	-0.53	-0.58	(0.35)	-0.55	(-0.88)	-0.72	-0.61
	-OC	0.34	0.16	0.67	(0.24)	(0.18)	(0.23)	(0.26)	0.88
	-CA	*	*	*	*	*	*	*	-0.57
LE1 meas	-CL	0.87	0.74	0.89	(0.01)	0.78	0.99	0.89	0.86
	-SI	0.32	(0.29)	(-0.05)	-0.65	(0.10)	0.96	(-0.06)	(0.26)
	-SA	-0.87	-0.54	+0.60	(0.54)	-0.47	-0.99	-0.75	-0.60
	-OC	0.32	(0.09)	0.63	(0.08)	(0.07)	(-0.36)	(0.16)	0.91
	-CA	*	*	*	*	*	*	*	-0.60

( ) not significant at 95 % confidence limits
* correlation not possible ($CaCO_3$ = 0) and groups with many $CaCO_3$ = 0 values

4. Stepwise multiple regression of LE data with the 5 basic explanatory variables at 95 % confidence limits.

GROUPING	n	VARIABLE	step	VARIABLE	R² (%)	F test
FLUVIAL	55	LE2 calc	1	CL	63	90.4
			2	OC	67	53.5
			3	CA	72	44.7
		LE2 meas	1	CL	73	139.9
		LE1 calc	1	CL	72	138.8
			2	OC	78	91.1
		LE1 meas	1	CL	76	166.7
			2	OC	80	106.0
WEICHSELIAN	30	LE2 calc	1	SA	39	18.3
		LE2 meas	1	CL	34	32.7
		LE1 calc	1	CL	47	24.8
		LE1 meas	1	CL	54	33.1
HOLOCENE	25	LE2 calc	1	CL	74	64.3
		LE2 meas	1	CL	73	62.2
		LE1 calc	1	CL	78	82.1
			2	OC	89	88.7
		LE1 meas	1	CL	79	87.0
			2	OC	87	75.4
HB	9	—				
MB	17	LE2 calc	1	SA	38	9.0
		LE2 meas	1	CL	40	10.1
		LE1 calc	1	CL	57	19.6
		LE1 meas	1	CL	61	23.7
LG	4	LE2 meas	1	SI	99	?
		LE1 meas	1	CL	99	?
CaO	11	LE2 calc	1	CL	72	22.8
		LE2 meas	1	CL	73	24.2
		LE1 calc	1	CL	77	30.8
		LE1 meas	1	CL	80	35.1
Cal	14	LE2 calc	1	CL	78	43.4
			2	OC	94	87.2
		LE2 meas	1	OC	80	48.8
			2	CL	94	91.8
		LE1 calc	1	OC	77	39.7
			2	CL	91	57.4
		LE1 meas	1	OC	82	55.3
			2	CL	95	107.2

5. Stepwise multiple regression of LE data with 9 basic explanatory variables at 95% confidence limits.

GROUPING	n	VARIABLE	step	VARIABLE	R² (%)	F test
FLUVIAL	55	LE2 calc	1	CL	63	90.4
			2	V0	70	61.0
			3	OC	75	50.8
		LE2 meas	1	CL	73	139.9
			2	OC	75	77.5
			3	V13	77	56.5
		LE1 calc	1	CL	72	138.8
			2	OC	78	91.1
			3	V0	81	74.0
		LE1 meas	1	CL	76	166.7
			2	OC	80	106.0

V0 = difference Late Weichselian - Holocene
V11= difference MB - HB+LG
V12= difference HB - LG
V13= difference CaO - Cal

6. Correlation coefficient (R) of Atterberg limit data (upper plastic limit - UPL; sticky point - SP; lower plastic limit - LPL; hygroscopic point - HP) with 3 of the 5 basic explanatory variables at 95% confidence limits.

GROUPING number of samples		Fluvial n=55	Weichselian n=30	Holocene n=25	HB n=9	MB n=17	LG n=4	CaO n=11	Cal n=14
CORRELATED VARIABLES									
UPL-CL		.92	.84	.94	(-.52)	.91	(-64)	.92	.96
UPL-OC		.30	(.22)	.51	(-.33)	(.09)	(-51)	(-07)	.78
UPL-CA		*	*	*	*	*	*	*	(-.42)
SP-CL		.76	.60	.78	(-.41)	.52	(.33)	.71	.88
SP-OC		.52	.55	.71	(.28)	.68	(-76)	.57	.79
SP-CA		*	*	*	*	*	*	*	(-.38)
LPL-CL		.73	.48	.77	(-.14)	(.32)	(-.03)	.74	.82
LPL-OC		.36	.65	.67	.65	.69	.92	.56	.77
LPL-CA		*	*	*	*	*	*	*	(-.35)
HP-CL		.86	.71	.88	(.15)	.79	(.03)	.85	.85
HP-OC		.42	.42	.58	(-.05)	(.36)	(-84)	(.24)	.68
HP-CA		*	*	*	*	*	*	*	(-.38)

( ) not significant at 95% confidence limits
* correlation not possible ($CaCO_3$ = 0) and groups with many $CaCO_3$ = 0 values

7. Stepwise multiple regression of Atterberg limits data with 3 of the 5 basic explanatory variables at 95% confidence limits.

GROUPING	n	VARIABLE	step	VARIABLE	R^2(%)	F test
FLUVIAL	55	UPL	1	CL	85	271.6
			2	OC	88	178.8
			3	CA	91	155.3
		SP	1	CL	57	65.5
			2	OC	75	72.6
			3	CA	86	93.7
		LPL	1	CL	53	54.2
			2	OC	75	73.9
			3	CA	86	93.6
		MP	1	CL	74	138.3
			2	OC	83	118.9
			3	CA	85	86.7
WEICHSELIAN	30	UPL	1	CL	70	60.2
			2	OC	82	56.9
		SP	1	CL	34	13.5
			2	OC	76	38.7
		LPL	1	OC	42	19.1
			2	CL	78	43.5
		MP	1	CL	49	24.7
			2	OC	77	40.7
HOLOCENE	25	UPL	1	CL	88	147.0
		SP	1	CL	60	31.9
			2	OC	79	36.9
			3	CA	89	49.8
		LPL	1	CL	57	27.4
			2	OC	73	27.0
			3	CA	86	37.4
		MP	1	CL	78	75.5
			2	OC	82	46.7
RB	9	UPL	-			
		SP	-			
		LPL	-			
		MP	-			
MB	17	UPL	1	CL	80	50.5
		SP	1	OC	48	12.1
			2	CL	76	18.6
		LPL	1	OC	47	11.6
			2	CL	66	11.3
		MP	1	CL	34	15.5
			2	OC	75	18.1
LC	4	UPL	-			
		SP	-			
		LPL	-			
		MP	-			
CaO	11	UPL	1	CL	82	36.8
		SP	1	CL	46	6.9
			2	OC	86	21.1
		LPL	1	CL	48	7.4
			2	OC	87	23.5
		MP	1	CL	70	18.9
Cal	14	UPL	1	CL	92	120.2
			2	OC	97	145.2
			3	CA	98	174.5
		SP	1	CL	78	39.8
			2	OC	89	41.6
			3	CA	93	41.6
		LPL	1	CL	69	24.2
			2	OC	82	22.2
		MP	1	CL	73	29.5

- no variables entered at 95% confidence limits

8. Stepwise multiple regression of Atterberg limits data with 7 basic explanatory variable at 95% confidence limits.

GROUPING	n	VARIABLE	step	VARIABLE	R^2(%)	F test
FLUVIAL	55	UPL	1	CL	85	271.6
			2	OC	88	178.8
			3	CA	91	155.3
			4	V12	92	131.0
		SP	1	CL	57	65.5
			2	OC	75	72.6
			3	CA	86	93.7
			4	V11	87	78.2
		LPL	1	CL	53	54.2
			2	OC	75	73.9
			3	CA	86	93.6
		MP	1	CL	74	138.3
			2	OC	83	118.9
			3	V0	85	86.2

V0 = difference Late Weichselian - Holocene
V11 = difference MB - RB + LC
V12 = difference MB - LC

9. Correlation coefficient (R) of selected core sample data (bulk density -BD; pore volume -PV; moisture content (% W/W) at pF2 and pF4.2 -WW2, WW42) with the 5 basic explanatory variables.

GROUPING / Number of samples	Fluvial n=191	Weichselian n=130	Holocene n=60	RB n=44	MB n=68	LC n=18	CaO n=38	Cal n=23
CORRELATED VARIABLES								
CL-BD	-.39	-.22	-.49	(.23)	-.37	(.18)	-.53	(-.08)
SI-BD	-.41	-.33	(-.15)	(.05)	-.41	(-.18)	(-.12)	-.46
SA-BD	.45	.30	.45	(-.12)	.42	(-.07)	.49	(.35)
OC-BD	-.44	-.34	-.47	(.06)	-.33	-.81	-.36	(.21)
CA-BD	*	*	*	*	*	*	*	-.59**
CL-PV	.48	.33	.56	(-.15)	.47	(.01)	.66	(.14)
SI-PV	.46	.39	(.21)	(+.03)	.47	(.28)	(.20)	.50
SA-PV	-.55	-.39	-.55	(.08)	-.50	(-.10)	-.61	-.40
OC-PV	.35	.24	.35	(-.16)	.23	.56	.41	(-.24)
CA-PV	*	*	*	*	*	*	*	.60**
CL-WW2	.75	.68	.79	.37	.79	.44	.76	.54
SI-WW2	.61	.68	(.16)	.55	.72	.59	(.25)	.86
SA-WW2	-.77	-.73	-.68	-.53	-.80	-.53	-.72	-.80
OC-WW2	.50	.35	.58	.52	.28	.56	.53	(.15)
CA-WW2	*	*	*	*	*	*	*	.45
CL-WW42	.86	.85	.84	.61	.90	.88	.78	.86
SI-WW42	.51	.73	(-.03)	.56	.77	.75	(.06)	.68
SA-WW42	-.77	-.85	-.60	-.64	-.88	-.91	-.65	-.79
OC-WW42	.48	.26	.59	.44	.20	(.14)	.48	(.27)
CA-WW42	*	*	*	*	*	*	*	(-.28)
BD-WW2	-.72	-.63	-.79	(-.09)	-.70	-.65	-.87	-.46
BD-WW42	-.54	-.43	-.63	.39	-.58	(-.28)	-.73	(-.15)
PV-WW2	.73	.67	.79	(.06)	.75	.76	.89	.50
PV-WW42	.58	.49	.64	-.39	.65	.43	.75	(.18)

( ) not significant at 95% confidence limits
* correlation not possible ($CaCO_3$) and groups with many $CaCO_3$ = 0 values
** is in reality a depth function

10. Stepwise multiple regression of selected core sample data with the 5 basic explanatory variables at 95% confidence limits.

GROUPING	n	VARIABLE	step	VARIABLE	R²(%)	F test
FLUVIAL	191	BD	1	SA	21	49.3
			2	OC	33	45.6
			3	CA**	34	32.8
		PV	1	SA	28	74.1
			2	OC	34	47.6
			3	CA**	35	33.3
		WW2	1	SA	59	272.6
			2	OC	70	223.8
			3	CL/SI	73	167.7
		WW42	1	CL	74	526.0
			2	OC	83	469.2
			3	CA	84	317.6
		AM	1	CA	10	20.5
WEICHSELIAN	130	BD	1	OC	12	16.7
			2	SA	19	14.6
		PV	1	SA	15	23.0
			2	OC	19	15.2
		WW2	1	SA	54	149.3
			2	OC	62	103.2
			3	CL/SI	63	72.8
			4	CA*	64	56.6
		WW42	1	SA	73	340.3
			2	OC	76	201.2
			3	CL/SI	82	197.4
		AM	1	CA*	6	7.4
HOLOCENE	61	BD	1	CL	24	18.5
			2	OC	35	15.4
			3	CA**	46	16.0
		PV	1	CL	32	27.6
			2	CA**	39	18.4
			3	OC	47	16.7
		WW2	1	CL	62	95.1
			2	OC	74	82.1
			3	CA	78	68.1
			4	SI/SA	79	53.1
		WW42	1	CL	70	139.9
			2	OC	82	127.8
		AM	1	CA	22	16.3
			2	CL	26	10.4
			3	SI/SA	30	8.1
MB	44	BD	-			
		PV	-			
		WW2	1	CA*	30	18.8
			2	SA	53	23.9
			3	OC	61	20.8
		WW42	1	SA	41	28.8
			2	CA*	63	35.2
			3	CL/SI	73	36.6
			4	OC	81	40.8
		AM	-			
HB	68	BD	1	SA	17	13.8
			2	OC	24	10.2
		PV	1	SA	25	22.0
		WW2	1	SA	64	115.4
			2	OC	65	60.9
			3	CL/SI	68	45.8
		WW42	1	CL	81	281.6
			2	OC	83	136.7
		AM	1	CA*	5	3.6
LG	18	BD	1	OC	65	30.1
		PV	1	OC	55	19.9
		WW2	1	SI	35	8.7
			2	OC	51	7.7
			3	CL/SA	71	11.2
		WW42	1	SA	83	80.7
			2	OC	88	56.6
			3	CL/SI	92	56.2
		AM	1	SA	69	35.0
CaO	38	BD	1	OC	31	16.3
			2	SA	54	20.1
		PV	1	CL	43	27.2
			2	OC	54	20.5
		WW2	1	CL	58	49.9
			2	OC	77	59.1
			3	SI/SA	81	47.9
		WW42	1	CL	60	54.8
			2	OC	76	54.3
		AM	1	SI	9	3.7
			2	CL/SA	20	4.4
Cal	23	BD	1	CA**	35	11.4
		PV	1	CA**	36	12.0
			2	SI	46	8.4
		WW2	1	SA	74	58.3
		WW42	1	CL	73	57.3
			2	CA	77	32.7
			3	SI/SA	84	33.6
		AM	1	CA	34	10.9

\- no variable entered at 95% confidence limits
* should be excluded because $CaCO_3$ = 0 for group except for exceptional erratic $CaCO_3$ content
** is in reality a depth function

11. Stepwise multiple regression of selected core sample data with 9 basic explanatory variables at 95 % confidence limits.

GROUPING	n	VARIABLE	step	VARIABLE	R² (%)	F test
FLUVIAL	191	BD	1	SA	21	49.3
			2	OC	33	45.6
			3	V12	36	35.0
			4	V13	41	31.7
		PV	1	SA	28	74.1
			2	OC	34	47.6
			3	V12	37	36.8
			4	V11	41	32.2
		WW2	1	SA	59	272.6
			2	OC	70	223.8
			3	V12	77	209.7
			4	CL/SI	79	175.0
			5	V11	80	151.6
		WW42	1	CL	74	526.1
			2	OC	83	469.3
			3	V11	84	323.3*
			4	V0	85	255.7
			5	V12	85	213.8
		AM	1	V12	12	23.0
			2	CA	20	23.4
			3	CL	25	26.4
			4	SI/SA	28	18.0

V0 = difference Late Weichselian - Holocene
V1 = difference MB + HB + LG
V12 = difference HB + LG
V13 = difference CaO + Cal

12. Correlation coefficient (R) of Torvane shear strength (TV) and air permeability measurements (Ki) in cores at pF2 with the 5 basic explanatory variables.

GROUPING number of samples	Fluvial n=102	Weichselian n=69	Holocene n=33	HB n=22	HF n=36	LG n=11	CaO n=21	Cal n=12
CORRELATED VARIABLES								
TV -CL	.50	.56	.65	.40	.45	.84	.66	(.13)
-SI	(.14)	.33	(-.28)	(-.07)	.45	.66	(.01)	(-.48)
-SA	-.37	-.50	-.35	(-.12)	-.49	-.85	-.53	(-.24)
-OC	(-.08)	(-.17)	(.20)	(.19)	(-.18)	(-.45)	(-.10)	.76
-CA	"	"	"	"	"	"	"	-.72
-AV2	-.45	-.45	-.51	-.64	-.30	-.63	-.58	(-.42)
Ki -CL	(-.08)	(-.03)	-.33	(-.23)	(-.04)	(-.25)	-.32	(-.16)
-SI	.26	(.17)	.45	(.11)	(.07)	(.25)	(.18)	(.22)
-SA	(-.10)	(-.07)	(-.03)	(.02)	(-.02)	(.14)	(.33)	(-.22)
-OC	(.13)	.38	-.41	(-.34)	(-.01)	.80	(-.18)	(-.16)
-CA	"	"	"	"	"	"	"	(.13)
-AV2	.43	.35	.70	.86	.47	.73	.71	.77

( ) not significant at 95% confidence limits
* correlation not possible ($CaCO_3$ = 0) and groups with many $CaCO_3$ = 0 values

13. Correlation coefficient (R) of selected natural aggregate data (bulk density - BD; pore volume - PV; moisture content (%v/v) at pF2 and pF4.2 - WV2, WV42; available moisture - AM) with the 5 basic explanatory variables.

GROUPING number of samples	Fluvial n=101	Weichselian n=61	Holocene n=40	HF n=23	HB n=32	LG n=6	CaO n=17	Cal n=23
CORRELATED VARIABLES								
CL-BD	(.10)	.23	.28	(.13)	(.09)	(.17)	(-.00)	(.15)
SI-BD	-.33	(-.10)	-.31	(-.20)	(-.28)	(.14)	(.10)	(-.11)
SA-BD	.17	(-.06)	(.03)	(.08)	(.12)	(-.15)	(-.06)	(-.01)
OC-BD	-.33	-.46	(-.09)	(-.26)	-.50	(-.68)	-.76	(-.14)
CA-BD	"	"	"	"	"	"	"	.67**
CL-PV	(-.03)	(-.04)	(-.19)	(.06)	(.18)	(-.23)	(.29)	(-.17)
SI-PV	.42	(.18)	.41	(.24)	.41	(-.27)	(.08)	(.19)
SA-PV	-.28	(-.09)	(-.15)	(-.19)	-.34	(.26)	(-.24)	(-.06)
OC-PV	.18	.27	(-.09)	(.06)	(.27)	(.51)	.69	(-.14)
CA-PV	"	"	"	"	"	"	"	-.49**
CL-WV2	.85	.83	.85	.63	.88	.85	.98	.79
SI-WV2	.77	.85	.29	.82	.82	.95	.43	.44
SA-WV2	-.90	-.91	-.74	-.82	-.94	-.91	-.86	-.69
OC-WV2	.53	.37	.58	.46	.29	(.49)	(.19)	.89
CA-WV2	"	"	"	"	"	"	"	-.50
CL-WV42	.91	.90	.91	.80	.95	.84	.91	.90
SI-WV42	.54	.78	(.05)	.69	.75	.90	(.28)	(.35)
SA-WV42	-.78	-.90	-.62	-.80	-.93	-.88	-.78	-.68
OC-WV42	.51	.25	.62	(.13)	.13	(.64)	(.27)	.80
CA-WV42	"	"	"	"	"	"	"	-.62
CL-AM	.33	.38	(-.24)	(.17)	.41	(.41)	(.33)	-.39
SI-AM	.78	.69	.59	.72	.67	(.51)	.71	(.22)
SA-AM	-.67	-.60	(-.23)	-.56	-.61	(-.46)	-.60	(.06)
OC-AM	.32	.49	(-.15)	.77	.51	(-.09)	(-.22)	(.17)
CA-AM	"	"	"	"	"	"	"	.38
BD-WV2	-.21	(-.05)	(+.01)	(+.08)	(-.22)	(.05)	(+.22)	(-.14)
BD-WV42	(-.00)	(.01)	(.22)	(.01)	(-.07)	(+.28)	(-.27)	(.11)
BD-AM	-.46	(-.14)	-.60	(-.17)	-.47	(.70)	(.11)	-.69
PV-WV2	.28	(.15)	(.03)	(.09)	.42	(.21)	.48	(-.04)
PV-WV42	(.08)	(.13)	(-.21)	(.09)	.32	(.13)	.54	(-.25)
PV-AM	.49	(.13)	.63	(.06)	.48	-.80	(-.04)	.59

( ) not significant at 95% confidence limits
* correlation not possible ($CaCO_3$ = 0) and groups with many $CaCO_3$ = 0 values
** is in reality a depth function

14. Stepwise multiple regression of selected natural aggregate data with the 5 basic explanatory variables at 95% confidence limits.

GROUPING	n	VARIABLE	step	VARIABLE	R^2(%)	F test
FLUVIAL	101	BD	1	CA**	29	39.6
			2	OC	46	42.4
			3	CL	51	33.6
		PF	1	CA**	32	59.0
			2	OC	45	39.9
		VV2	1	SA	81	422.3
			2	OC	88	365.6
			3	CL/SI	91	323.4
			4	CA	92	260.4
		VV42	1	CL	83	473.6
			2	OC	91	510.4
			3	CA	92	378.3
		AM	1	SI	63	166.5
			2	CA	72	126.1
			3	OC	77	107.6
WEICHSELLIAN	61	BD	1	OC	21	15.8
			2	CL	26	10.1
		PF	1	OC	7	4.7
		VV2	1	SA	84	301.7
			2	OC	88	207.6
			3	CL/SI	89	153.2
		VV42	1	SA	82	261.6
			2	CL/SI	85	167.3
			3	OC	88	146.1
		AM	1	SI	47	53.0
			2	OC	55	35.6
HOLOCENE	40	BD	1	CA**	44	29.9
			2	OC	73	50.6
		PF	1	CA**	58	53.0
			2	OC	74	52.8
		VV2	1	CL	72	99.0
			2	OC	88	87.4
			3	CA	86	76.4
			4	SI/SA	88	62.0
		VV42	1	CL	83	183.3
			2	OC	94	305.8
		AM	1	CA	43	28.2
			2	SI	57	25.0
			3	OC	61	18.4
HB	23	BD	-			
		PF	-			
		VV2	1	SA	67	42.8
			2	OC	80	40.0
			3	CL/SI	83	30.4
		VV42	1	SA	64	37.9
			2	CL/SI	69	22.2
			3	OC	75	19.4
		AM	1	OC	60	31.3
			2	SI	83	49.8
MB	32	BD	1	OC	25	9.8
		PF	1	SI	17	6.0
		VV2	1	SA	88	225.9
			2	CL/SI	89	122.4
			3	OC	92	101.2
		VV42	1	CL	90	263.9
			2	SI/SA	94	218.4
		AM	1	SI	44	24.0
			2	OC	54	17.1
LG	6	BD	1	OC	46	3.4
		PF	-			
		VV2	1	SI	91	39.4
			2	CL/SA	96	40.4
		VV42	1	SI	83	17.9
			2	OC	96	40.4
			3	CL/SA	100	178.7
		AM	-			
CaO	17	BD	1	OC	57	20.0
		PF	1	OC	48	13.7
			2	CL	58	9.6
		VV2	1	CL	80	60.8
			2	OC	85	39.9
			3	SI/SA	88	33.0
		VV42	1	CL	82	68.2
			2	OC	91	75.0
		AM	1	SI	50	15.2
Cal	23	BD	1	CA**	24	6.5
			2	OC	59	14.4
		PF	1	CA**	45	17.5
			2	OC	60	15.3
		VV2	1	OC	80	81.6
			2	CL	94	148.9
			3	CA	96	139.6
			4	SI/SA	96	122.4
		VV42	1	CL	81	91.4
			2	OC	96	247.0
			3	SI/SA	97	188.4
		AM	1	CL	15	3.7
			2	SI/SA	38	6.3
			3	OC	63	10.6
			4	CA	87	29.9

- no variables entered at 95% confidence limits
** is in reality a depth function

15. Stepwise multiple regression of selected natural aggregate data with 9 basic explanatory variables at 95% confidence limits.

GROUPING	n	VARIABLE	step	VARIABLE	R^2(%)	F test
FLUVIAL	101	BD	1	CA**	29	39.6
			2	OC	46	41.4
			3	V11	53	36.8
			4	V0	59	35.1
		PF	1	CA**	37	59.0
			2	V11	45	40.2
			3	OC	51	33.4
			4	V0	54	26.3
			5	SI	56	24.6
		VV2	1	SA	81	422.3
			2	OC	88	365.6
			3	CL/SI	91	323.4
			4	CA	92	260.4
		VV42	1	CL	83	473.6
			2	OC	91	510.4
			3	CA	92	378.3
			4	V12	92	295.8
		AM	1	SI	63	166.5
			2	CA	72	126.1
			3	OC	77	107.6
			4	V0	78	84.4

V0 = difference Late Weichselian - Holocene
V11 = difference MB-HB+LG
V12 = difference HB-LG
V13 = difference CaO-Cal
** is in reality a depth function

16a. Correlation coefficient (R) of data on natural aggregate stability (m.w.d., r.c.s.a, f03 of air-dried samples) with the 5 basic explanatory variables.

GROUPING number of samples	Fluvial n=101	Weichselian n=41	Holocene n=40	HB n=23	MB n=32	LG n=6	CaO n=17	Cal n=23
CORRELATED VARIABLES								
m.w.d.-CL	.53	.34	.60	(-.19)	.55	(.43)	(.38)	.74
m.w.d.-SI	.33	.34	(-.11)	(.24)	(.29)	(.50)	(.03)	(.19)
m.w.d.-SA	-.46	-.37	-.32	(-.08)	-.45	(-.47)	(-.28)	-.50
m.w.d.-OC	.76	.69	.77	.89	.52	.74	.73	.78
m.w.d.-CA	*	*	*	*	*	*	*	-.64
r.c.s.a.-CL	-.52	-.32	-.64	(.06)	-.43	(-.47)	-.43	-.80
r.c.s.a.-SI	-.44	-.36	(-.06)	-.39	(-.22)	(-.46)	(.01)	-.65
r.c.s.a.-SA	.53	.37	.46	(.24)	.36	(.47)	(.29)	.70
r.c.s.a.-OC	-.83	-.56	-.68	-.75	-.63	(-.59)	-.51	-.69
r.c.s.a.-CA	*	*	*	*	*	*	*	.72
f03-CL	-.46	-.27	-.61	(.03)	-.36	(-.45)	(-.38)	-.78
f03-SI	-.42	-.31	(-.12)	-.37	(-.16)	(-.40)	(.02	-.50
f03-SA	.49	.31	.47	(.24)	(.28)	(.43)	(.26)	.72
f03-OC	-.56	-.49	-.63	-.64	-.39	(-.51)	-.65	-.66
f03-CA	*	*	*	*	*	*	*	.71

16b. Correlation coefficient (R) of data on natural aggregate stability (raindrop resistance and slaking class of air-dried samples) with the 5 basic explanatory variables.

GROUPING number of samples	Fluvial n=69	Weichselian n=32	Holocene n=37	HB n=3	MB n=27	LG n=2	CaO n=17	Cal n=20
CORRELATED VARIABLES								
no.raindrops-CL	.79	.80	.81	.99	.81	*	.76	.85
no.raindrops-SI	.38	.49	(.13)	(.82)	.44	*	.32	(.27)
no.raindrops-SA	-.70	-.75	-.62	(-.91)	-.76	*	-.81	-.61
no.raindrops-OC	.57	.32	.60	(-.03)	(.27)	*	(.22)	.71
no.raindrops-CA	*	*	*	*	*	*	*	-.67
slaking class-CL	.73	.74	.81	**	.74	*	.78	.83
slaking class-SI	.47	.52	(.11)	**	.47	*	(.25)	.41
slaking class-SA	-.72	-.74	-.60	**	-.75	*	-.68	-.68
slaking class-OC	.56	.44	.61	**	.40	*	(.34)	.65
slaking class-CA	*	*	*	*	*	*	*	-.75

16c Correlation coefficient (R) of data on natural aggregate stability (m.w.d., r.c.s.a., f03, raindrop resistance, slaking class of pF2-moist samples) with the 5 basic explanatory variables.

GROUPING number of samples	Fluvial n=38	Weichselian n=24	Holocene n=14	HB n=8	MB n=11	LG n=5	CaO n=6	Cal n=8
m.w.d.-CL	(.11)	(-.03)	(.05)	-.66	(.40)	(.55)	(-.18)	(.07)
m.w.d.-SI	.36	(.27)	(.13)	(-.24)	(.47)	(.68)	(.37)	(.20)
m.w.d.-SA	-.29	(-.16)	(-.11)	(.45)	(-.51)	(-.60)	(-.08)	(-.15)
m.w.d.-OC	.45	.30	(.18)	.68	(.45)	(.46)	(.39)	(.16)
m.w.d.-CA	*	*	*	*	*	*	*	(.17)
r.c.s.a.-CL	(-.26)	(-.21)	(.15)	(.14)	(-.38)	(-.57)	(-.02)	(.37)
r.c.s.a.-SI	-.55	-.46	(-.36)	(-.33)	-.55	(-.71)	(-.38)	(-.14)
r.c.s.a.-SA	.48	.38	(.11)	(.12)	.55	(.62)	(.39)	(-.15)
r.c.s.a.-OC	-.40	-.53	.58	-.72	-.46	(-.34)	(.66)	(.51)
r.c.s.a.-CA	*	*	*	*	*	*	*	(-.40)
f03-CL	-.31	(-.28)	(.05)	(-.10)	(-.37)	(-.55)	(-.05)	(.19)
f03-SI	-.58	-.49	(-.44)	(-.49)	-.58	(-.70)	(-.59)	(-.29)
f03-SA	.55	.43	(.23)	(.33)	.57	(.61)	(.41)	(.06)
f03-OC	-.34	-.48	.59	-.83	(-.41)	(-.36)	(.71)	(.43)
f03-CA	*	*	*	*	*	*	*	(-.41)
no.raindrops-CL	(.24)	(.08)	(.32)	(-.62)	(.30)	(.74)	(.30)	(.36)
no.raindrops-SI	.27	(.14)	(.09)	(-.41)	(.39)	.83	(-.16)	(.33)
no.raindrops-SA	-.29	(-.13)	(-.29)	(.53)	(-.41)	(-.78)	(-.17)	(-.39)
no.raindrops-OC	.52	.34	(.43)	.72	.63	(.36)	(.58)	(.33)
no.raindrops-CA	*	*	*	*	*	*	*	(-.10)
slaking class-CL	(.20)	(.13)	**	(-.08)	(.26)	**	**	**
slaking class-SI	.42	.36	**	(.20)	(.38)	**	**	**
slaking class-SA	-.37	-.29	**	(.08)	(-.39)	**	**	**
slaking class-OC	.61	.46	**	(.33)	.64	**	**	**
slaking class-CA	*	*	**	*	*	**	**	**

( ) not significant at 95% confidence level
* correlation not possible ($CaCO_3$ = 0) or n=2 and groups with many $CaCO_3$ = 0 values
** no variance

17a. Stepwise multiple regression of data on natural aggregate stability (m.w.d., r.c.s.a., fD3 of air-dried samples) with the 5 basic explanatory variables at 95% confidence limits.

GROUPING	n	VARIABLE	step	VARIABLE	R^2(%)	F test
FLUVIAL	101	m.w.d.	1	OC	58	134.0
			2	CL	70	114.8
		r.c.s.a.	1	OC	39	64.3
			2	CL	53	56.9
		fD3	1	OC	32	45.5
			2	SA	43	36.2
WEICHSELLAN	61	m.w.d.	1	OC	48	53.7
			2	CL	60	43.5
			3	SI/SA	64	34.3
		r.c.s.a.	1	OC	31	26.9
			2	CL	42	21.4
		fD3	1	OC	24	18.4
			2	CL	31	13.2
HOLOCENE	40	m.w.d.	1	OC	60	56.4
			2	CL	74	51.9
		r.c.s.a.	1	OC	46	31.2
			2	CL	66	33.2
			3	CA	70	28.2
		fD3	1	OC	40	25.5
			2	CL	58	15.9
RB	23	m.w.d.	1	OC	79	77.6
		r.c.s.a.	1	OC	56	26.4
		fD3	1	OC	41	14.6
MB	32	m.w.d.	1	CL	28	11.8
			2	OC	54	17.2
			3	SI/SA	62	15.3
		r.c.s.a.	1	CL	20	7.6
			2	OC	38	8.7
		fD3	1	OC	15	5.2
			2	CL	27	5.5
LG	6	m.w.d.	-			
		r.c.s.a.	-			
		fD3	-			
CaO	17	m.w.d.	1	OC	53	16.6
			2	CL	69	15.4
		r.c.s.a.	-			
		fD3	-			
Cal	23	m.w.d.	1	OC	61	33.5
			2	CL	76	31.3
		r.c.s.a.	1	CL	64	36.9
			2	CA	82	45.2
		fD3	1	CL	61	33.2
			2	CA	80	39.1
			3	SI/SA	85	34.5

- no variables entered at 95% confidence limits

17b. Stepwise multiple regression of data on natural aggregate stability (raindrop resistance and slaking class of air-dried samples) with the 5 basic explanatory variables at 95% confidence limits.

GROUPING	n	VARIABLE	step	VARIABLE	R^2(%)	F test
FLUVIAL	69	no.raindrops	1	CL	65	112.1
			2	OC	77	101.4
		slaking class	1	CL	53	75.3
			2	OC	67	67.9
			3	SI/SA	72	55.6
WEICHSELLAN	32	no.raindrops	1	CL	64	53.5
			2	OC	76	46.1
		slaking class	1	CL	55	36.4
			3	OC	76	46.7
HOLOCENE	37	no.raindrops	1	CL	66	67.5
			2	OC	76	54.9
		slaking class	1	CL	65	66.4
			2	CA	78	58.7
			3	OC	81	46.8
RB	3	no.raindrops	1	CL	99	88.5
		slaking class	-			
MB	27	no.raindrops	1	CL	66	47.9
			2	OC	78	41.4
		slaking class	1	SA	56	31.9
			2	OC	64	21.1
			3	CL/SI	78	26.8
LG	2	no.raindrops	-			
		slaking class	-			
CaO	17	no.raindrops	1	SA	65	28.5
		slaking class	1	CL	61	23.7
			2	OC	75	21.0
Cal	20	no.raindrops	1	CL	72	46.1
			2	OC	79	31.7
		slaking class	1	CL	69	39.2
			2	CA	87	38.9

- no variables entered at 95% confidence limits

11c. Stepwise multiple regression of data on natural aggregate stability (m.w.d., r.c.s.a., f03, raindrop resistance, slaking class of pF2-moist samples) with the 5 basic explanatory variables at 95% confidence limits.

GROUPING	n	VARIABLE	step	VARIABLE	R^2(%)	F test
FLUVIAL	38	m.w.d.	1	OC	20	9.2
			2	SI	32	8.1
		r.c.s.a.	1	SI	30	15.4
			2	OC	43	13.3
		f03	1	SI	34	18.5
			2	OC	43	13.2
		no.raindrops	1	OC	27	13.2
		slaking class	1	SI	18	7.7
			2	OC	32	8.3
WEICHSELLIAN	24	m.w.d.	1	OC	25	7.5
		r.c.s.a.	1	OC	28	8.6
			2	SI	43	7.8
		f03	1	SI	24	6.9
			2	OC	41	7.2
		no.raindrops	1	OC	29	9.0
		slaking class	1	OC	21	5.9
HOLOCENE	14	m.w.d.	-			
		r.c.s.a.	1	OC	34	6.2
		f03	1	OC	33	6.3
		no.raindrops	-			
		slaking class	*			
NB	8	m.w.d.	-			
		r.c.s.a.	1	OC	51	6.4
			2	SI	85	14.4
		f03	-			
		no.raindrops	1	OC	52	6.4
		slaking class	-			
MB	11	m.w.d.	-			
		r.c.s.a.	-			
		f03	-			
		no.raindrops	1	OC	49	8.6
			2	CL	81	17.4
		slaking class	1	OC	40	6.1
LG	5	m.w.d.	-			
		r.c.s.a.	-			
		f03	-			
		no.raindrops	-			
		slaking class	*			
CaO	6	m.w.d.	-			
		r.c.s.a.	-			
		f03	-			
		no.raindrops	-			
		slaking class	*			
Cal	8	m.w.d.	-			
		r.c.s.a.	-			
		f03	-			
		no.raindrops	-			
		slaking class	*			

- no variables entered at 95% confidence limits
* no variance

18. Stepwise multiple regression of data on natural aggregate stability with 9 basic explanatory variables at 95% confidence limits.

GROUPING	n	VARIABLE	step	VARIABLE	R^2(%)	F test
FLUVIAL	101	m.w.d.-air-dry	1	OC	58	134.0
			2	CL	70	114.8
			3	SI/SA	71	80.1
	101	r.s.c.a.-air-dry	1	OC	39	64.3
			2	CL	55	36.3
	101	f03-air-dry	1	OC	34	45.5
			2	SA	43	34.2
	69	no.raindrops-air-dry	1	CL	63	112.1
			2	OC	76	107.4
			3	YD	79	83.0
	69	slaking class-air-dry	1	CL	53	75.3
			2	OC	69	67.9
			3	YD	74	52.9
	38	m.w.d.-pF2	1	OC	20	9.2
			2	SI	32	8.1
	38	r.c.s.a.-pF2	1	SI	30	15.4
			2	OC	43	13.3
	38	f03-pF2	1	SI	34	18.5
			2	OC	43	13.2
	38	no.raindrops-pF2	1	OC	27	13.2
	38	slaking class-pF2	1	SI	18	7.7
			2	OC	32	8.3

YD = difference Late Weichselian - Holocene

19. Correlation coefficient (R) of selected micro tillage test data (upper tillage limit as moisture content % w/w = UTL.WW and as pF value = UTL.pF with the 5 basic explanatory variables at 95% confidence limits.

GROUPING number of samples	Fluvial n=43	Weichselian n=13	Holocene n=32	CaO n=12	Cal n=20
CORRELATED VARIABLES					
UTL.WW-CL	.66	(.40)	.76	.82	.78
UTL.WW-SI	.31	.73	(.15)	(.19)	(.23)
UTL.WW-SA	-.63	-.70	-.59	-.70	-.55
UTL.WW-OC	.73	.62	.75	(.31)	.82
UTL.WW-CA	*	*	*	*	-.54
UTL.pF-CL	(.13)	(.36)	(.03)	(.42)	(-.26)
UTL.pF-SI	(.12)	(.10)	(.29)	(.05)	(.26)
UTL.pF-SA	(-.16)	(-.29)	(-.20)	(-.34)	(-.02)
UTL.pF-OC	-.49	(-.15)	-.57	-.52	-.63
UTL.pF-CA	*	*	*	*	(.25)

( ) not significant at 95% confidence limits
* correlation not possible ($CaCO_3$ = 0) and groups with many $CaCO_3$ = 0 values

20. Stepwise multiple regression of selected micro tillage test data with the 5 basic explanatory variables at 95% confidence limits.

GROUPING	n	VARIABLE	step	VARIABLE	R^2(%)	F test
FLUVIAL	43	UTL.WW	1	OC	53	47.6
			2	SA	83	99.6
			3	CL/SI	86	87.3
			4	CA	89	82.3
		UTL..pF	1	OC	24	13.5
WEICHSELLIAN(NB)	13	UTL.WW	1	SI	53	12.4
			2	OC	71	12.4
			3	CL/SA	87	19.6
		UTL..pF	-			
HOLOCENE	32	UTL.WW	1	CL	58	42.1
			2	OC	87	99.1
			3	CA	91	98.1
		UTL..pF	1	OC	33	14.7
CaO	12	UTL.WW	1	CL	67	20.6
			2	OC	90	40.8
		UTL..pF	-			
Cal	20	UTL.WW	1	OC	84	92.0
			2	CL	93	108.8
		UTL..pF	1	OC	40	12.0

- no variables entered at 95% confidence limits

APPENDIX E

SELECTED DATA ON SATURATED HYDRAULIC CONDUCTIVITY

sample location	age of sediment	land use	depth (cm)	attached to subsoil: without crust K(m/day)	attached to subsoil: with 25% gypsum crust K(m/day)	detached from subsoil: with 25% gypsum crust K(m/day)	detached from subsoil: without crust K(m/day)	worm holes > 5 mm ø (number/700cm²)	worm holes 2-5 mm ø (number/100cm²)	biopores < 2 mm ø (number/cm²)
Azewijn	Holocene on Late Weichselian	grassland	10-30	1.7	1.30*	n.d.	n.d.	4-5	4-5	10
			22-45	2.4	1.40*	n.d.	n.d.	2-3	5-6	5-10
			40-70	1.0	0.50*	n.d.	n.d.	0	6-7	10
			30-60	1.7	0.60**	n.d.	n.d.	0	6-7	10
			70-100	1.1	0.20**	n.d.	n.d.	2	3	10-15
Azewijn	Holocene on Late Weichselian	arable land	5-35	0.4	0.03	0.02	n.d.	0	0	0-5
			40-70	0.1	0.01	n.d.	n.d.	0	0	0-5
			70-100	0.4	0.10	n.d.	n.d.	0	0	0-5
Asbroek	Late Weichselian	grassland	5-35	0.4	0.05	0.03	27	4	6	10
			40-70	0.6	0.02	0.03	30	6	6	10
			70-100	0.5	0.20	0.50	n.d.	0	1-2	5
Asbroek	Late Weichselian	arable land	10-40	0.6	0.07	n.d.	0.7	0	1-2	0-5
			40-70	0.5	0.20	0.30	1.0	0	1-2	5
			70-100	0.3	0.20	0.40	0.6	0	0	5-10
Aaldonk	Late Weichselian	grassland	5-40	1.4	0.30	0.30	6.7	0	6-7	0-5
			30-60	2.4	0.02	0.02	4.9	0	9-10	0-5
Aaldonk	Late Weichselian	arable land	5-30	0.4	0.20	0.60	0.7	0	1-2	0-5
			30-55	0.2	0.06	0.10	0.2	0	1-2	0-5
Ewijk	Holocene	orchard	10-40	6.1	n.d.	n.d.	n.d.	0	2-3	0-5
			40-70	1.5	0.03	0.05	30	0	2-3	0-5
			65-95	1.2	0.60	0.70	5.5	0	2-3	5
Ewijk	Holocene	arable land	10-40	0.1	0.03	0.07	0.04	0	1	n.d.
			40-70	1.3	0.02	n.d.	n.d.	0	4	0-5
			65-95	0.4	0.10	0.80	2.8	0	1-5	0-5
Randwijk	Holocene	orchard	5-35	4.0	0.04	n.d.	7.6	0	3-4	10
			35-65	5.5	0.08	0.05	20	8	15	15
			65-95	2.0	0.01	0.10	75	13	15	5-10
Randwijk	Holocene	orchard	5-35	2.4	0.09	0.12	30	0	2-3	15
			35-65	3.6	0.09	0.12	15	5	15	15
			65-95	1.4	0.01	0.02	50	10	15	5-10
Randwijk	Holocene	arable land (tilled)	5-35	1.1	0.01	0.03	n.d.	0	0-2	0-5
			35-65	0.8	0.01	0.02	n.d.	0	1	0-5
			65-95	2.1	0.03	n.d.	2.8	1	5-10	10-15
Randwijk	Holocene	arable land (zero till.)	5-35	1.5	0.01	0.01	1.2	0	5-15	5-10
			35-65	3.3	0.01	0.01	3.1	0	5	0-5
			65-95	2.7	0.04	0.03	9.5	6	10-15	10-15

Key: * with 10% gypsum crust
** with 15% gypsum crust
n.d. no determination

CURRICULUM VITAE

Rienk Miedema werd geboren op 25 December 1945 te Stiens (Fr.). Na de lagere school te Stiens (1952-1958) werd de RHBS-B te Leeuwarden bezocht (1958-1963), waarna aan de Landbouwhogeschool te Wageningen Bodemkunde en Bemestingsleer werd gestudeerd (1963-1972). Tijdens die studie werden diverse student-assistentschappen vervuld op de Vakgroepen Bodemkunde en Geologie en Bodemkunde en Plantevoeding. Sinds zijn afstuderen (met lof) is de auteur verbonden aan de Vakgroep Bodemkunde en Geologie, als veldbodemkundige met als specialisatie de bodemmacro- en micromorfologie. Sedert Januari 1981 is hij hoofd van de afdeling Bodemmorfologie. Van 1982-1986 vervulde hij het secretariaat van subcommissie B: Micromorfologie van de Internationale Bodemkundige Vereniging (ISSS).

Hij is (co)-auteur van een 25-tal wetenschappelijke publicaties op het gebied van de bodemkunde. Momenteel is hij onderwijscoördinator en lid van de Formatieplancommissie van de Vakgroep Bodemkunde en Geologie en lid van de Richtingsonderwijscommissie voor de studierichting Bodemkunde. Zijn huidige onderwijsactiviteiten omvatten colleges en (veld)practica op het gebied van de regionale bodemkunde en bodemmicromorfologie voor zowel LU-studenten als voor studenten van de MSc cursus Bodem en Water. De huidige onderzoekactiviteiten liggen op het gebied van de bodemvariabiliteit en de bodemvorming van gronden op rivierterrassen van de Allier en de Dore in de Limagneslenk in Frankrijk alsmede (micro)morfologische bijdragen aan andere onderzoekprojecten van de Vakgroep.