About the water content and shrinkage of some Dutch lacustrine and marine sediments

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Summary

In non-aerated sediments the water content is a measure for the pore space and the weight by volume. From a lot of data, especially from the bottom of the IJssellake, it appeared that there is a rather close and rectilinear connection between the clay and organic-matter contents on the one hand and the water content on the other hand. This involves that the water content of sediments with different clay content, but belonging to the same type of sediment can be compared via this clay-content/water-content relation.

In a given sediment the forecast of the shrinkage after drainage can be computed by means of this relation which also can be used for sedimentological purpose. Examples of these applications are given.

1. Introduction

Soil survey of deltaïc sediments, bay deposits and lake-bottom material before reclamation of the related areas provided a lot of data about the contents of clay, organic matter and water. From these data it appeared that there is a rather close relation between the contents of clay ($< 2\ \mu$) and organic matter on the one hand and the water content on the other hand. The higher the clay and organic-matter contents, the higher the water contents.

The majority of the data on the relation between the water content and the clay content of young marine deposits originates from the IJssellake (former Zuiderzee) area and hence attention is drawn in the first place to the sediments in that region.

In the former Zuiderzee a layer of Holocene deposits is lying over Pleistocene sands (a.o. WIGGERS, 1955). Its thickness varies from a few decimetres to about 7 metres. Its bottom layers consist partly of peat; another part is marsh clay deposited in ages of lower sea levels than today. Different subaqueous sediments were deposited on top of these layers during the last twenty centuries. The characteristic features of the more recent types of these sediments are their great uniformity over long periods of sedimentation (and hence their occurrence in rather thick layers) and over vast areas. The environment in which they were deposited was fresh to brackish (Almere deposits) up to about 1600 A.D. and afterwards brackish to saline (Zuiderzee deposits) until 1932. In that year the enclosing dam of the Zuiderzee was completed, so marine sediment could enter no longer this bay and suply of sediment generally ended that year.

In the Zuiderzee deposits a close relation exists between the contents of clay and organic matter, and so, when the water content is plotted against the clay content

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only, a close relation is got. However, when in a sediment the rate between the clay and organic-matter contents varies considerably like in the Almere deposits both the clay content and the organic-matter content have to be considered, because the water-holding capacities of clay and organic matter differ substantially.

Not only in the subaqueous sediments of the IJssellake a relation exists between the mentioned soil components, but such a relation exists also in other water-borne sediments, such as the mud flats and the salt marshes of the saline tidal area, the reed marshes and the willow coppices of the brackish- to fresh-tidal area (ZONNEVELD, 1960). For the different sediments the relation varies considerably, dependent on differences in drainage conditions.

2. Water content, pore space and volume weight of non-aerated sediments

In FIG. 1, the water contents as found in the top layer of the subaqueous sediments in the former Zuiderzee deposited in the saline period between about 1600 and 1932, are plotted against the contents of clay and organic matter. The organic matter being strongly decayed, it can be assumed that the water-holding capacity of the organic matter is 3 times as high as that of the clay. The relation between the water content and the clay and organic-matter contents appears to be close.

FIG. 1 shows that the relation between both quantities is rectilinear. The straight line can be defined by the next formula:

$$A = 20 + 2{,}25\ (L + 3\ H).$$

The symbols in this formula have the next sense:

A = grammes of water per 100 g of dry soil.
L = grammes of clay per 100 g of dry soil.
H = grammes of organic matter per 100 g of dry soil.

In general this formula runs as follows:

$$A = 20 + n\ (L + b\ H) \qquad (1)$$

in which the symbols A, L and H have the same sense as in the former formula; n means a factor indicating the number of grammes of water accompanying 1 g of clay, whereas b is a factor obtained by dividing the water-holding capacity of 1 g of organic matter by that of 1 g of clay.

The constant 20 in this general formula slightly varies in reality for various sediments. These variations are due to differences in the size distribution of the sand fraction. Attention has to be given to the fact that there is a difference between the water-holding capacity of clay and that of organic matter. The water-holding capacity of organic matter is — dependent on the kind of organic matter — 3 to 8 times as high as that of clay. The more the organic matter is decayed, the lower its water-holding capacity is. In real humus, for b a value of 3 is found and in very young, not yet decayed *Sphagnum* peat it is 9 (PONS, 1961). In most sediments, the factor b is 3,0. When eroded peat material forms part of the sediment which is the case with the Almere-deposits of the IJssellake, the value of b can go up to 3,5 or 4,0.

The factor n indicating the quantity of water accompanying 1 g of clay, is independent of the clay and organic-matter contents and hence allows for comparing the water contents of various sediments differing in clay and organic-matter content. This factor n varies strongly, but is more or less characteristic for each type of sediment. If in a sediment n and b are known and, as often occurs, a constant relation exists between L and H, then the clay content (and the organic-matter content) can be computed — with the aid of formula (1) — from simple soil-moisture determinations.

As a non-aerated sediment consists of solid matter and water only, its specific volume (being the volume of 1 g of dry soil in natural packing) may be found by addition of the volume of 1 g of soil material and the volume of the accompanying water (this water content to be computed using formula (1)). The specific gravity of the mineral parts of Dutch soils being taken 2,65 g/cm^3 (HISSINK, 1935), the specific volume of 1 g of dry soil is 1 : 2,65 = 0,377 cm^3, or rounded off 0,38 cm^3. This computation does not hold for humiferous soils, the specific gravity of humus about 1,4 g/cm^3. But in soils with organic-matter contents below 12 % a value of 2,65 may be used for the specific gravity of the solid matter without introducing substantial errors (indeed, the average specific gravity of soil material containing 12 % organic matter is 2,50 g/cm^3, the volume of 1 g then being 0,40 cm^3). The volume of the water accompanying 1 g of dry soil is 0,01 A cm^3, the volume of 1 g of water taken as 1 cm^3 (differences in the specific gravity of the water caused by differences in salt content and temperature are small and not relevant for this purpose). From the foregoing it follows that the specific volume is

$$\text{s.v.} = 0{,}38 + 0{,}01 \text{ A cm}^3 \qquad (2)$$

and the weight by volume, being the weight in g of 1 cm^3 of dry soil in natural packing, is

$$\text{v.w.} = \frac{1}{0{,}38 + 0{,}01 \text{ A}}$$

It is obvious that in non-aerated soils a change in water content, *i.e.* in the value of the factor n, means a change in volume and hence shrinkage can be calculated from a decrease in the A-figures.

At the moment of deposition the very loosely packed subaqueous sediments and the muddy deposits of the tidal flats, which are not submerged during the whole day, show high values for n. In very recently deposited sediments the value of n amounts to 4 or 5. This agrees with pore spaces of 65 to 90 % (10 (n = 4) and 50 % (n = 5) of clay respectively).

After some time and mostly within a year, a consolidation takes place, the factor n decreasing to about 2,0 to 2,2. This is the normal terminal value reached in subaqueous sediments and in low-lying muds on the tidal flats. When the level of the last deposits becomes higher, which merely occurs along the shores where they are only submerged during a part of the day, this decrease of n continues, giving rise to a further consolidation of the sediment. On tidal flats only submerged for about 8 hours a day, the factor n diminishes to about 1,5 within some years. The last decrease of n and the shrinkage involved is only due to the facts that water evaporates from the surface and that some water leaks out, since no vegetation occurs on this level.

In thick layers of even rather recently deposited sediments this consolidation is related with the depth below the surface. In the tidal flats deep channels may get blocked up and then rather quickly silt up, often with sediment rich in clay. Such a channel-fill sometimes can attain a thickness of several metres. Notwithstanding the fact that the apparent weight by volume of the sediment is very low, which is caused by the very loose packing of the particles and the loss of weight brought about by the Archimedes law, the pressure exerted by the toplayers is often sufficient to compress the deeper layers in a rather considerable way.

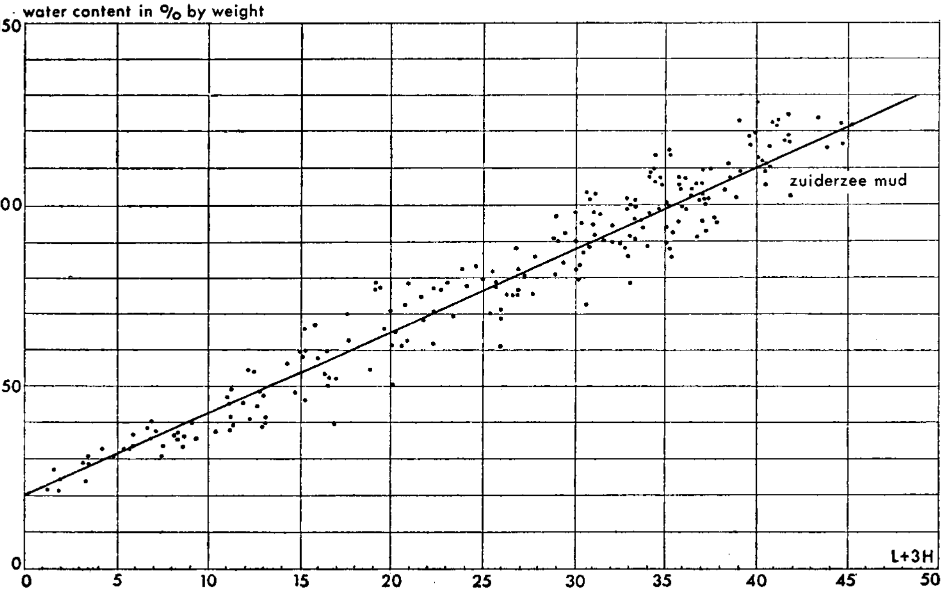
An example is given in FIG. 2 in which the values of n in such a profile, silted up in about 12 years with the profile top lying on mean sea level, are plotted against the depth below the surface. To a depth of 1 m the figures are irregular. The cause of this is not known; merely in the top layer the low value could be explained by evaporation. Below that level a very regular decrease is seen down to a value of n = 1,65. Attention is to be drawn to the fact that this is an example only. On other spots deviating figures may be found.

In the Netherlands, as mentioned already, various types of sediments deposited by water occur: Subaqueous sediments as well as tidal-shore sediments. In TABLE 1 a general view is given of the values of the factor n in the various sediments. It should also be remembered that the given figures are average values. Even in uniform sediments such as the subaqueous bay deposits of the Zuiderzee, rather considerable variations are found (FIG. 1). Still more this will be the case in the forelands where the figures are greatly influenced by differences in drainage conditions.

TABLE 1. The value of n in various reduced sediments

Type of sediment	n
Subaqueous	2,2
Low-tidal mud flats	2,2
High-tidal mud flats	1,5
Low salt marshes	1,2
Backswamps	1,9

FIG. 1. The relation between the water contents and the contents of clay and organic matter in Zuiderzee mud



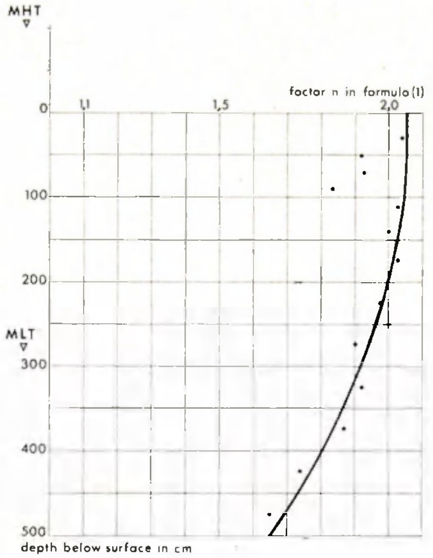
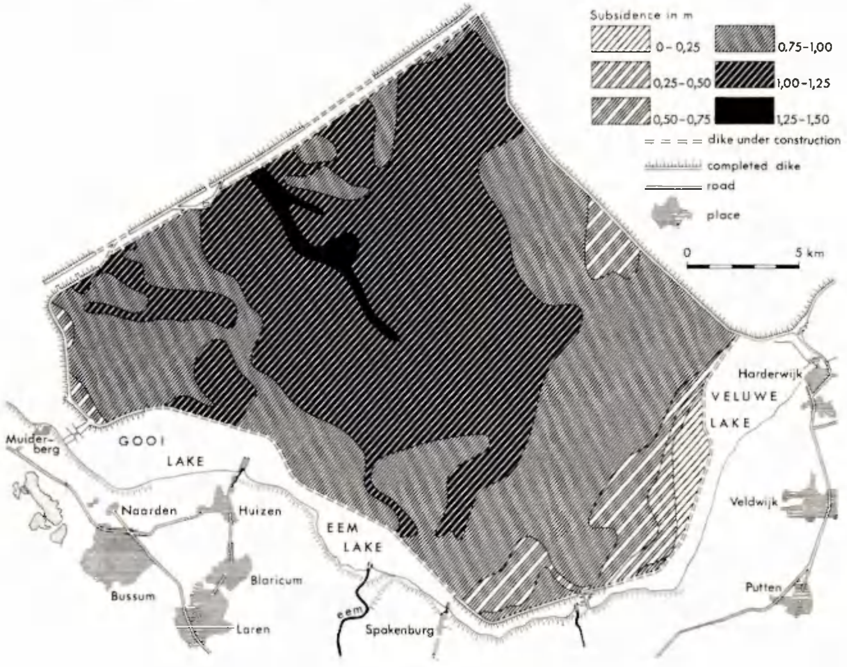


FIG. 2.
The relation between the depth below the surface and the factor n of formula (1) in a clay-rich sediment silted up in about 12 years

FIG. 3. Anticipated subsidence of the Southern Flevoland polder up to about 100 years after commencement of drainage



3. Use of data

In view of the many data gathered, it might be asked for what purpose they can be used. Important is the forecast of the subsidence of the surface after drainage of a new polder. The reverse, *viz.* calculation of the level at the commencement of drainage of an old polder, sometimes is also useful, in particular for history of sedimentation or reconstruction of former situations. But also anomalies in non-drained sediments may be traced. Compression of older sediments by the weight of younger layers is demonstrated by low n-figures, even after removal of these younger sediments by erosion.

The shrinkage can be computed directly from the specific volumes. A sediment with a s.v. of 0,95 cm^3 showing a s.v. of 0,73 after drainage, shrinks 23 % or, in another way, a layer of 10 cm shrinks to 7,7 cm. In this type of calculation it is essential to know the specific volumes at the commencement of drainage and at the time after drainage for which a forecast of the subsidence has to be given; the shrinking process takes many years, most of it occurring in the first century after reclamation.

The specific volumes of a sediment at the commencement of drainage can be calculated by means of formulae (1) and (2), supposing n and b are known. The specific volumes after reclamation can be got from older polders, taking into account the required similarity of sediment, the lapse of time for which the computations should be made and the depth below surface (the deeper the layer, the less the shrinkage).

Of course the specific volumes of older reclaimed soils cannot be determined by means of the water contents as air has penetrated the soil, so the pore space is filled partly by air and partly by water. The specific volume then can be obtained only by taking soil samples with a known volume and determining the weight contents of dry soil. From these two quantities the specific volume can be computed.

The application of the above-mentioned method is in general restricted to about the upper 1,5 m of the profile as in deeper layers the decrease of the specific volumes is of the same magnitude as the natural variations in the specific volumes. The shrinkage (which is mainly a compression) of these layers has to be computed by means of soil-mechanical formulae.

For example, on the map of FIG. 3 the result is shown of the calculation of the predicted subsidence of the polder Southern Flevoland (a future polder in the southern part of the IJssellake) computed with the method of the specific volumes for the upper 1,5 m of the profiles after shrinkage, whereas the compaction of the deeper layers was computed with the aid of soil-mechanical formulae. In that way the future level of the polder can be determined, which is of importance for the design of the polder, the construction (depth) of sluices, pumpingstations (capacity) and so on.

By means of the formulae also the shrinkage before draining can be computed. As mentioned before, the factor n decreases with increasing depth in thick layers of sediment. Assuming that in the example given in FIG. 2 the first consolidation at all levels has taken place a year after sedimentation (so that the factor n was 2,2), the appeared shrinkage ranges from about 20 % at a depth of 5 m to 5 % about 1 m below the surface after some years. So, notwithstanding the very low grain pressures the stability of these very loosely packed sediments is so small that a considerable shrinkage can take place in the deepest layers.

When sandy sediments are deposited on top of the soft sediments a further shrinkage appears, of course including a decrease of n. This is due to the greater apparent weight by volume of sand compared with that of sediments rich in clay, these weights by volume being 0,84 and 0,40 kg/dm^3 respectively. This difference causes greater grain pressures in the subsoil which leads to a greater shrinkage as will be made clear by the next example.

Supposing that the whole profile consists of clay, then the grain pressure on the 4 m level below the surface is 16,0 kg/dm^2. If the upper metre of the profile consists of sand instead of clay the grain pressure at the same level will be 20,4 kg/dm^2. From soil-mechanical laws it follows that the compressing of the bottom metre of the profile under a sandy toplayer is about 100 % as high as that under a toplayer of clay. The water content is then strongly decreased, the value of n diminishing to about 1,2.

For some purposes it is useful to know the subsidence of the surface of an older polder. As an example, a reconstruction is given of the original thickness of the IJ-clay cover in the IJ-polders, drained in 1875. In 1950 the thickness of this clay cover varied from 40 to 100 cm (GÜRAY, 1952). Data on the specific volumes in about that year were also available.

Assuming that the factor n had a value of 2,2 in 1875 (this supposition is likely as the IJ-clay is a subaqueous deposit comparable with the Zuiderzee deposits), the specific volumes at that time can be calculated by means of the formulae (1) and (2). As the specific volumes at both moments and the thickness of the layer in 1950 as well are known, the thickness in 1875 can be calculated. The result is given in TABLE 2.

TABLE 2. The thickness of the IJ-clay cover in 1950 and the corresponding thickness at commencement of drainage

Thickness (cm) in	
1950	1875
0—30	0— 66
0—40	0— 88
0—50	0—107
0—60	0—125
0—70	0—142
0—80	0—159

From this table it appears that a considerable shrinkage has taken place, the IJ-clay cover being reduced too less than the half of its original thickness (from covers thicker than 80 cm, which for the rest occur rarely, no calculation could be made by lack of data). From the data of TABLE 2 it also appears that the sedimentation rate stated by GÜRAY as 0,2 cm a year is too low. It has gone up to more than 0,3 cm a year at the sites with the thickest cover.

LITERATURE

GÜRAY, A. R.	1952	De bodemgesteldheid van de IJ-polders. *Boor en Spade. 2,* 5 : 1—28.
HISSINK, D. J.	1935	De bodemkundige gesteldheid van de achtereenvolgens ingedijkte Dollardpolders. Versl. Landbk. Onderz. No. 41 B.
PONS, L. J.	1961	De veengronden. In : Bodemkunde. 's-Gravenhage, 1961. 173—193.
WIGGERS, A. J.	1955	De wording van het Noordoostpoldergebied. *Van Zee tot Land.* No. 14.
ZONNEVELD, I. S.	1960	De Brabantse Biesbosch. Thesis. Wageningen, 1960.