# Mechanical Analysis, especially with a view to an agreed international classification and nomenclature.

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In many countries an initial classification and nomenclature of agricultural soils is made on the basis of the mechanical or granular composition of the soil. It is desirable to make an attempt to achieve international uniformity in this matter. The following is to be regarded merely as a first step in this direction, as was also the case with the procedure in 1923 in respect of the methods of mechanical soil analysis. On most points I have confined myself to what I have learned from my own experience and study in the Netherlands.

## §1. SOME REMARKS ON THE METHODS OF MECHANICAL SOIL ANALYSIS.

The first steps towards international co-operation in the matter of the methods of mechanical soil analysis were taken by me in 1923, in sending out a couple of Dutch soil samples to various Institutes (**1**); this was followed by the distribution of 4 soil samples by Prof. Novák (**2**). Then followed the Meeting of the First Commission of the International Society of Soil Science at Rothamsted (Harpenden, England), in October 1926, where methods A and B were formulated (**3**). Part of the meeting at Versailles in 1934 was also devoted to this subject (**4**). Finally, Novák, at the Third International Soil Science Congress at Oxford, in 1935, gave a review of the development of mechanical soil analysis (**5**). Notwithstanding all this, there are still a few points to be dealt with in regard to the method of mechanical soil analysis. I will confine myself here to the experience gained at the Institute of Soil Science at Groningen.

The decantation of the smaller particles is carried out in the Atterberg cylinders, in standing water; for settling velocities of 10 cm./7½ min. and smaller and particles smaller than 16 $\mu$, see *inter alia* §2. With these cylinders figures were invariably obtained which agreed admirably with one another. In some cases larger particles than 16 $\mu$ were separated with the Atterberg cylinders; with settling velocities of from 30 cm./60 sec. upwards the results, however, were uncertain. When Kopecký cylinders (running water) were used widely divergent results were obtained with some of the largest cylinders (internal diameter 168.5 mm.; 1 litre per 202 seconds; velocity of current 0.0222 cm. per second); this is evidently to be accounted for by defects in construction. It is necessary to check the Kopecký cylinders before use. This, by the way, should also be done in the case of the Atterberg cylinders.

At Groningen the particles larger than 16 $\mu$, remaining in the Atterberg cylinders, are dried and weighed at 105° C; this gives the sand fraction (particles of 16-2000 $\mu$). This dry sand fraction is then sieved in a "Ro-tap" testing sieve shaker with the aid of sieves, and split up into various sub-fractions. The use of sieves smaller than 0.2 mm. was condemned at Versailles. It is, however, a fact that sieves as small as 43 $\mu$ are employed for various purposes (**6**). Our experience is that it is necessary to compare the sets of sieves of the same mesh before use, with the aid of standard soil samples. When the mesh of a sieve corresponds with the position of a steep rise of the summation curve, fairly widely divergent duplicate figures are sometimes obtained. This remark also applies to the results obtained with the Atterberg cylinders.

### §2. GROUPING OF FRACTIONS.

The fraction smaller than 0.002 mm., that is, the clay fraction (Ton, argile), is determined by decantation in an Atterberg cylinder, settling velocity 10 cm./8 hours (at 20° C). With this figure as a starting point, the Stokes formula is therefore $V = 34720r^2$. With the aid of this latter formula the diameters 2r are calculated from the V values (settling velocities with Atterberg cylinders and current velocities with Kopecký cylinders). In the case of the upper limit of the silt fraction (Schluff, limon) the essential point in Atterberg's instructions was considered at Groningen to be the settling velocity, that is, 10 cm./7½ min., which gives a diameter of 0.016 mm. The silt fraction then ranges from 2 to 16 μ. Other institutes adhered to the limit of 0.020 mm. and altered the settling velocity of 10 cm./7½ min. to 10 cm./4 min. 48 sec. There are, however, some institutes which employ the Atterberg settling velocity (10 cm./7½ min.) and indicate 0.020 mm. as the upper limit of the silt fraction. This is to be condemned.

At Groningen the sand fraction, that is the particles of 16-2000μ, is separated with the aid of sieves into the following 12 sub-fractions (diameter in thousandths of a millimetre) : 16-43, 43-74, 74-104, 104-147, 147-208, 208-295, 295-417, 417-589, 589-833, 833-1168, 1168-1651, 1651-2000. By means of Zunker's formula

$$U = \frac{0,4343}{\log d_1 - \log d_2} \left(\frac{1}{d_2} - \frac{1}{d_1}\right) .$$

the specific surface U is calculated for each sub-fraction ; the sum gives the specific surface for the entire sand fraction, which is calculated on 100 grams sand fraction (16-2000μ) (U value). The limits of the first sub-fraction (16-43) are somewhat far apart for an accurate calculation of the specific surface. Where the contents of this sub-fraction are small the specific surface = 397 may be used ; for soils with high contents of this sub-fraction it is, however, necessary to sub-divide sub-fraction 1 into two parts. The division chosen was 16-32 and 32-43. The separation at 32 μ is made by means of the Atterberg cylinder or with the Kopecký cylinder (settling and current velocity 10 cm./112.5 sec.).

### RECOMMENDATIONS.

The international investigations mentioned in §1 were with regard to the particles smaller than from 16 to 20 μ. Two international methods of preliminary treatment, A and B, were agreed upon. It will be advisable also to compare the results obtained with A and B with each other. For this purpose it is especially necessary to test the sand fractions (particles from 16-20 to 2000 μ) obtained by both methods with regard to their sandy structure. Even with the heaviest clay soils this sandy fraction, according to method A, is actually without any cohesion ; it is as loose as sand. With method B this was not the case with heavy clay soils ; the "sand particles" according to method B still stuck together, which points to the presence of non-sandy material. It should also be determined whether the lower limit for the sand fraction (20 μ or 16 μ) can safely be lowered. Where particles of from 8 to 16 μ were present the sandy fraction was already found to have a certain cohesion.

It is further advisable to extend the scope of the international investigation with regard to the sandy fraction (particles from 16-2000 μ), the mechanical composition of this fraction being expressed in the U value.

### §3. THE FUNCTIONS AND SIGNIFICANCE OF MECHANICAL ANALYSIS.

In some countries the results of mechanical analysis are applied for the determination of the depth and distance of drains (7). Now these quantities depend on the permeability of the soil for water (value K), and it is only for practically pure sandy soils, with a very small percentage of non-sand (clay + humus +$CaCO_3$), that there is a connexion between the values U (mechanical composition) and K (permeability for water). For all other soils the K value is to a great extent governed by what is known as the structure of the soil, and the significance of mechanical analysis recedes more into the background. The heavy Dollard clay soils, for example (**8**), all possess practically the same mechanical composition. In the muddy stage they are still practically impermeable to water. After reclamation by " endyking " more or less broad fissures and numerous root and worm holes are formed, which give the soil a high degree of permeability for water, so that drainage can take place at distances of from 40 to 50 metres, and even more. In the older Dollard soils the fissures disappear more and more, and the permeability for water decreases, so that drainage at shorter intervals (10 metres and in some cases less) is necessary. It is evident that mechanical analysis cannot provide a basis for advice regarding drainage in the case of these soils. I am not clear as to how far the results of any method of mechanical soil analysis, and especially of that according to the International Method B, could be used in this case (**9**).

To what extent the results of mechanical analysis can be used for aggregate analysis the future will show. It is possible that this will furnish a field of work in the region of international co-operation for Commission I (**10**).

My present purpose is to set out how far the results of mechanical soil analysis can be used for the classification and nomenclature of soils. The task of soil classification is to determine and to define the differences which occur between various soils. If a classification of this kind is to be of service to agriculture, the differences according to which soils are distinguished must have an agricultural significance. Seen from this point of view it is advisable that the classification should correspond as closely as possible with what is already known in practice. One of the most important distinctions made in practice is in the heaviness of the soil. The heaviness of the soil is an expression of the difficulty of working the soil. Besides being a property of culture this heaviness is at the same time correlative for a number of other qualities which are of prime importance in the agricultural judgement of the soil. The choice of crops, the yield, manuring, the price of the land, are all more or less closely governed by heaviness ; this correlation applies, of course, only to certain ranges of heaviness. It is therefore seen that the heaviness of the soil is a very important property in the classification of soils. It is further desirable to subdivide this heaviness into a number of gradations. These gradations have already been made in practice ; terms such as sand, sandy loam, clay, heavy clay, and so forth are already in use. The differences noted and introduced in practice are, however, unfortunately often vague and badly defined, so that they do not lend themselves at once to a generally valid classification. But there is a correlative for this heaviness of the soil which can be determined analytically with great exactitude : viz., the clay content. Furthermore there are various soil values which are connected on the one hand with this clay content, and which on the other hand govern many of the principal agricultural properties of the soil, so that there is a correlation between these properties and the clay content. In the Dutch arable marine clay soils, for instance, a fairly close relationship has been noted between the clay content and the humus content, a relationship which is maintained for hundreds of years. Clay substance and humus substance together form the seat of the adsorptive power of the soil, and in this adsorption complex the most important reactions for plants take place. This adsorption complex determines the binding power for water, partly also the water capacity, and to some extent also the nutritive value of the soil (N, $P_2O_5$, $K_2O$). In the Dutch marine clay soils the clay substance possesses a fairly homogeneous composition, which practically does not change at all in the course of centuries. The composition of the sand fraction also correlates with the clay content (see below).

All this makes a classification and a nomenclature based on the clay content quite possible from an agricultural point of view in the case of the Dutch sea-clay soils. The first question which then has to be put is: what is to be understood by the clay substance? I have defined the conception—*clay substance* as opposed to the conception—*sand fraction,* and have drawn the dividing line between clay substance and sand fraction at 16 $\mu$; that means, therefore, that I have called the particles smaller than 16 $\mu$ (fraction I + fraction II) clay substance. I am quite well aware that what I have called clay substance is in no way a uniform substance, but the question is where the upper limit of the clay substance must then be drawn, and what criteria are to be employed as a starting point. A study of four Dutch soil types **(12)** showed that the seat of the mineral base-binding capacity is, to the extent of more than 80 %, to be found in the mineral particles smaller than 0.25 $\mu$, whilst the surface of these particles forms as much up to about 90 % of the total surface of all the mineral particles. In a graph the " knee " of these two curves is more or less in the neighbourhood of 0.25 $\mu$, and certainly not, for instance, at 2 $\mu$. Robinson **(13)** has even put the question whether it may not be desirable to take the limit for clay at 0.64 $\mu$ ($\log v = -5$) in order to show up more clearly the difference between plastic substances as clay soils and materials such as kaolin which, although in a fine state of division, lack the characteristic properties of clays **(14)**.

I have made the division into 5 main groups as given below only provisionally for Dutch marine clay soils, by investigating soil samples furnished by farmers, and defined by them as very heavy, heavy, light, sandy, etc. And there is the very fortunate circumstance that the fraction (I + II) possesses a very homogeneous composition for all soils of this type. More especially is it of importance that Dutch marine clay soils possess fairly exactly 70 grammes fraction I (particles smaller than 2 $\mu$) and 30 grams fraction II (particles from 2 to 16 $\mu$) per 100 grams clay substance (fraction I + II) **(15)**. Should it later be found desirable to replace the division shown below, which is based on the clay substance (fraction I + II, particles smaller than 16 $\mu$) by one based on the clay fraction (= fraction I, particles smaller than 2 $\mu$), then the figures given below have simply to be multiplied by 0.7.

**Table.**

**Classification of Dutch marine clay deposits according to the content of clay substance (fraction I + fraction II).**

| Name. | | Content of clay substance (fraction I + II = particles smaller than 16 $\mu$) in % per 100 clay + sand | Specific surface (value U) of the sandy fraction | s. d. value of the sand fraction (in thousandths of a millimetre) |
|---|---|---|---|---|
| Dutch | English translation | | | |
| I. zware tot zeer zware kleigronden | heavy to very heavy clay soils | larger than 60 | comparatively fairly uniform with the clay content ranging from 250 to 350 | of approx. 40 to 30 |
| II. kleigronden | clay soils | 60-40 | | |
| III. lichte kleigronden tot zware zavelgronden | light clay soils to heavy silt soils | 40-20 | | |
| IV. lichte zavelgronden | light silt soils | 20-10 | Approx. 275 to 175 | Approx. 36 to 57 |
| V. zandige gronden | sandy soils | smaller than 10 | Approx. 175 to approx. 60-50 | Approx. 57 to approx. 167-200 |

It is now more than 10 years since I made the above division into 5 main groups. It has since been found that main group IV (light silt soils) especially contains soils which from an agricultural point of view perhaps differ too widely to be kept in one group; soils with 12-13 % clay are too far removed from soils with 17-18 % clay. It has been suggested that main group III should range from 40 to 25 % clay; that this group should be followed by a main group IVa from 25 to 15 % clay (light silt soils), and a main group IVb from 15 to 8 % clay (very light silt soils), whilst main group V of the sandy soils should begin at 8 % clay. This division would also seem to apply to the loam soils, so that main group IVa would comprise the light silt and light loam soils, and main group IVb the very light silt and very light loam soils.

A word more as to the *sand fraction (particles from 0.016 — 2 mm.)*. In the heavier clay soils, from about 30 to 35 % clay, the subfractions from 16-43$\mu$ and 43-74$\mu$ dominate to such an extent that the U value of the sand fraction (calculated on 100 grams of the sand fraction) does not fall below about 300. For the marine deposits of 0 to 30 % clay substance Ir. Zuur (**16**) has made a curve in which the contents of clay, sand subfractions 16-43, 43-74, 74-104, 104-147 and larger than 147 $\mu$, as also the contents of humus + $CaCO_3$, are set up on the y axis and the clay soils on the x axis. This graph shows that the fineness of the sand decreases with the fall of the clay content. Yet the sand, even in the marine sandy soils with only 1 to 2 % clay substance (dune sand), remains still fairly fine; the U value does not fall below from 60 to 50. Even in the practically pure marine sand, particles larger than 0.2 mm. diameter only occur in very small percentages.

The other Dutch soil types have not yet been sufficiently studied to permit of our proceeding to a general classification and nomenclature. So far as the loam soils are concerned, these investigations lead in the same direction as that of Ed. Jouis (**17**), who calls the "limons proprement dits, les sols contenant de 5 à 15 % argile (fraction I) et 70 % minimum de limon (fraction II) et de sable fin réunis; ils sont pauvres en sable grossier et contiennent 95 à 100 % de terre fine." The sandy fraction of the Dutch loam soils investigated, and also those of the loess soils may be very rich in particles from 22.6-43 $\mu$ (71 % and 72 % respectively of the total sand fraction in the loam soils and in the loess soils) and especially in particles from 32-43 $\mu$ (57 % and 47 % of the total sand fraction); the U values being very high (329 and 271 respectively).

I think I have shown that for the Dutch marine clay deposits—and possibly also for all Dutch soils—*an initial classification and nomenclature according to the clay content is to be recommended.* Subsequently, classification may take place with the aid of other soil values ($CaCO_3$, humus, etc.).

## §4. FURTHER CLASSIFICATION AND NOMENCLATURE OF SANDY SOILS.

In collaboration with a Dutch Commission for the classification and nomenclature of soils (President W. F. J. M. Krul) a *detailed investigation of the mechanical composition of sandy soils in the Netherlands* was instituted. The main point to be decided was at what content of clay substance (fractions I and II) the dividing line between the sandy soils and the other soils (loamy and clayey soils) is to be drawn. Here the limit of 10 % clay substance (per 100 mineral substance), already adopted for the marine deposits, was adhered to. The objections inherent in every boundary figure are also obviously applicable to this figure. The criteria adopted here were in the first place the workability of the soil and the dependence of the soil properties on the rainfall and other agricultural criteria, such as amount of manure required etc.

The classification of the sandy soils was further made in accordance with the U value (specific surface). For those to whom this value at first seems somewhat strange, the value s.d. (specific diameter) was introduced, which is defined as $\text{s.d.} = \frac{1}{U}\ \text{cm.} = \frac{1000}{U}\ \mu$. The following U values refer in all cases to 100 grams of the sand fraction (particles from 16 to 2000 $\mu$ diameter). The boundary between the fine sandy soils and the coarse sandy soils is assumed to be U = 50, i.e. s.d. = 200 $\mu$. The first group is subdivided into fairly fine (U from 50 to 80; s.d. of 200-125$\mu$); medium fine (U from 80 to 120; s.d. from 125 to 83 $\mu$) and very fine or extremely fine (U larger than 120; s.d. smaller than 83 $\mu$); the second group into fairly coarse (U from 50 to 30; s.d. from 200 to 333 $\mu$); medium coarse (U from 30 to 20; s.d. from 333 to 500 $\mu$) and very coarse to extremely coarse (U smaller than 20; s.d. larger than 500 $\mu$). The U values of the dune sand along the coast of the Netherlands lie between 50 and 70. It is therefore a fairly fine sand. During the classification of the dune sand a difference of opinion occurred between those members of the Commission who regarded the matter more from the geological and hydrological points of view and the Soil Science Institute at Groningen. This Institute originally desired to place the dune sand, on the strength of its agricultural properties (mainly its dependence on the rainfall) in the class of fairly coarse sandy soils; for the geologists and hydrologists, who approach the sandy region from the side of gravel, the dune sand belongs rather to the finer sands.

Of this classification of the Dutch sandy soils on the basis of the U values it may also be said that it is to be regarded as a first step. In addition to the value U, other factors, more especially the humus content, may have a great and even predominant influence on the agricultural properties.

It may be pointed out here that the sandy soils were further classified according to the homogeneity of their sand fraction. The Dutch dune sand, of which about 75 to 90 % comes within the subfraction 150 to 300 $\mu$, or 100 to 200 $\mu$, is the type of a very homogeneous sand.

## §5 FINAL REMARKS.

The conclusion to which I have come is therefore that an initial classification of the Dutch soils on the basis of their mechanical composition, and more especially of their clay content, should be made. But the classification in accordance with the content of clay substance can obviously no more be applied to all soils than is the case with the method for mechanical soil analysis, whether in its A form or in its B form. This will partly be due to the fact that what I have called the clay substance (particles smaller than 16$\mu$) may have a different composition in different soil types. I have already pointed this out in 1915, in connexion with a discussion of Java soils (**18**). These were clay soils which were rich in finely divided iron oxide, and, partly owing to this, possessed a very high content of particles smaller than 2$\mu$, whilst they nevertheless belonged to the agriculturally less heavy soils. Without doubt a purely mechanical investigation gives an erroneous picture of the agricultural properties of this type of soils. This remark, however, also applies to other soil values, such, for instance, as the hygroscopicity figures of these $Fe_2O_3$—containing soils. In this connexion I would further call attention to a publication by Frosterus (**19**), in which he describes a soil (No. 6; table 1, page 12-13), the fraction I (particles smaller than 2 $\mu$) of which consisted to a great extent of fine quartz powder; this soil consequently possessed quite different properties from soils with an equally high content of fraction I. And in a lecture recently given (meeting of Commission V, Vienna, September 2nd, 1937) Prof. Till called attention to the occurrence in Austria of soils with a high content of silt (fraction II), which soils are also said to have agricultural properties differing from the usual type.

It is, of course, possible that soils of this kind do not fit into the system of classification outlined above. This will, however, have to be demonstrated by means of statistical material. The question must then be put forward how far such deviating soil types occur to such an extent as to render it necessary to build up an entirely new system of classification based on other criteria. And finally those who have done this latter will have to show that the criteria selected by them in actual fact deserve the preference.

Groningen, November 1937.

## Notes.

(1) Actes de la IV ième Conférence Internationale de Pédologie, Rome, 12-19 mai, 1924, Vol. II, page 11-38.

(2) Proceedings and Papers of the Second International Congress of Soil Science, Leningrad-Moscow, USSR, July 20-31, 1930 ; Vol. I., Commission I, pp. 14-40 ; and pp. 196-261.

(3) See note (2), pp. 17-18, and pp. 262-304.

(4) Comptes Rendus de la Conférence de la Première Commission (Physique du Sol), Versailles, 2-5 juillet 1934.

(5) Transactions of the Third International Congress of Soil Science, Oxford, England, 1935, Vol II, pp. 24-37.

(6) The Groningen Institute uses sieves supplied by the firm W. S. Tyler Company, Cleveland, Ohio, U.S.A., and shakes these in a Ro-tap testing sieve shaker. As proposed by a Netherlands Commission sieves down to 0.050 mm diameter mesh are made and used.

(7) See Novàk (note 5), page 34.

(8) De bodemkundige gesteldheid van de achtereenvolgens ingedijkte Dollardpolders, door Dr. D. J. Hissink ; Verslagen van Landbouwkundige Onderzoekingen, No. **41,** B,1935 ; pp. 1-126 ; see especially Table II, page 138.

(9) Russian Congress (see note 2), Vol. I, Commission I ; joint meeting of the I and VI Commissions, page XXI.

(10) See Novàk (note 5), page 35.

(11) D. J. Hissink : Bijdragen tot de nomenclatuur en de klassificatie van de minerale gronden in Nederland. 1. Definitie van de begrippen klei, leem, zand ; Verslagen van Landbouwkundige Onderzoekingen, No. **30** (1925), pp. 169-202, with an English summary (Definition of the terms clay, loam and sand).

(12) D. J. Hissink, S. B. Hooghoudt en Jac. van der Spek : Der mineralische Bodenkomplex, Bodenkundliche Forschungen, Band V (1936) pp. 21-56.

(13) G. W. Robinson : The form of mechanical composition curves of soils, clays, and other granular substances ; The Journal of Agricultural Science ; Vol. XIV, 1924, page 631.

(14) Robinson states as the lower limit of particle size : of *clay* log v = -7, i.e., 0.064 $\mu$ and of *kaolin* log v = -5, i.e., 0.64 $\mu$. Our investigations (see paper note 12) show this limit as 0.03 $\mu$ for the clay particles and approx. 0.13 to 0.24 $\mu$ for the kaolin particles.

(15) Bodemkundig Instituut Groningen ; Twintig Jaar Bodemkundig Onderzoek (1916-1936), Tien Jaar Bodemkundig Instituut (1926-1936) ; page 34.

(16) Ir. A. J. Zuur : Over de bodemkundige gesteldheid van de Wieringermeer. Directie van den Wieringermeerpolder, Afdeeling onderzoek (1936).

(17) Bulletin de l' Association Française pour l' Étude du Sol, Tome III, No. 2. juin 1937, page 122'.

(18) Beschrijving der grondsoorten in Banjoemas. Cultura, 1915, 27ste Jrg.

(19) Zur Frage nach der Einteilung der Böden in Nordwest-Europas Moränengebieten, I-V, von Benj. Frosterus und K. Glinka, Helsingfors, 1913 ; III, pages 1-125.