About the Plastic Properties of the Norwegian Quaternary Clays

Sur les propriétés plastiques des argiles quaternaires de la Norvège

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Summary

Statistics are given for values of liquid limit, plastic limit, plastic index, percentage of material minus 2 micron, and sorting. Further these statistics are compared with our knowledge of the occurring clay minerals.

Sommaire

L'auteur présente des données statistiques sur la limite de liquidité, la limite de plasticité, l'index de plasticité, le pourcentage des grains plus petits que 2 microns et le triage. En plus, ces données sont comparées aux connaissances que nous possédons sur la présence de minéraux d'argile dans les argiles quaternaires.

The methods of analysis for which data are given in this work are analyses of particle size distribution according to the areometer method described in A.S.T.M., and the liquid limit and plastic limit worked out in accordance with the methods therein described. All analyses have been carried out on clays dried at 110 °C unless otherwise stated. Any possible NaCl content has been removed by washing out, until dispersion is possible for the sedimentation analyses. The same dispersion-method and means of dispersion have been employed for those tests to which the data is compared.

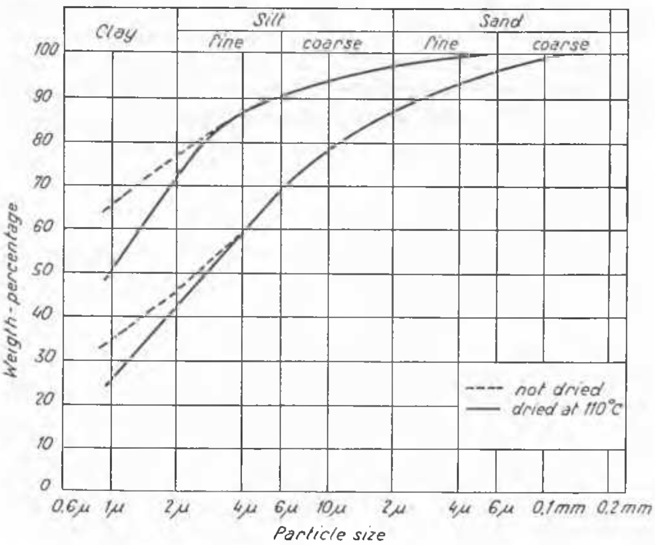

Fig. 1 Average Results of Particle Size Distribution Analyses of Sticky and Usual Norwegian Clays. Stippled Curves Indicate Clays not dried before Testing, Continuous Curves Indicate Clays dried at 110 °C
Moyenne des résultats d'analyses granulométriques obtenus sur des argiles grasses, communes en Norvège. Les courbes pointillées indiquent les argiles non séchées avant les essais, les courbes en plein indiquent les argiles passées à l'étuve à 110 °C

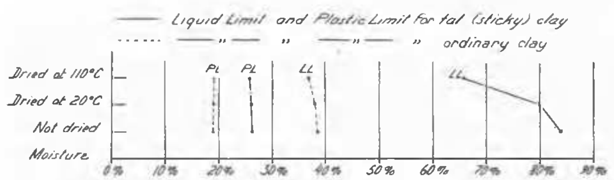

Fig. 2 Average Results on Plastic Limit and Liquid Limit of Sticky and Usual Norwegian Clays in Relation to the Degree of drying out to which the Clays have been Subject before Testing
Moyenne des résultats d'essais sur les limites de plasticité et de liquidité effectués sur des argiles grasses, communes en Norvège, en fonction du degré de dessication auquel les argiles ont été soumises avant les essais

The difference in the analysing results caused by a drying out of the clays at 110 °C before the analyses are usually quite noticeable. For information a couple of examples have been entered in Figs. 1 and 2. The drying process influences the dispersion-ability and the measurings of consistency limits, and seems to reduce the ability of the clay particles to bind an orientated film of water round themselves, at any rate for a considerable length of time. It would seem as though a serious reduction of the surface-bound water on the clay minerals in clay mineral aggregates with mutually well orientated sheet silicates (which must be regarded as very frequently occurring, due to the process of sedimentation) causes the moisture remaining between the mineral grains to assume characteristics reminiscent of those found in internally-bound water.

The values found for material of less than 2 micron in a clay are entered in Fig. 3 as a function of the plastic limit, and in Fig. 4 as a function of the liquid limit. In addition to the natural clays, divided into clays respectively rich in humus, poor or without humus, data are given for finely crushed fresh minerals which have been separated into different fractions and reassembled so as to be graded at over 1 micron at least, corresponding to the customary graduation for natural clays. In Fig. 3 we see that humus-containing clays, crushed minerals, and clays marked poor in clay minerals have a higher plastic limit than the ordinary Norwegian clays. The latter show a relatively great extent of variation in the plastic limit with the same content of material less than 2 micron. From this diagram, little reduction seems possible for the relations between the clay-mineral contents of the various clays. For the common Norwegian clays containing more than 20% material less than 2 micron we may establish the following formula for the plastic limit:

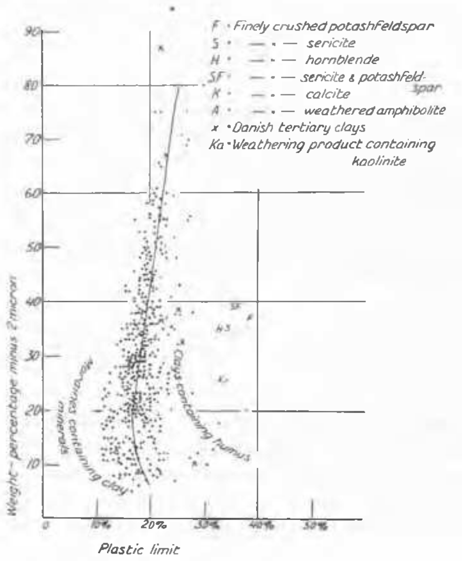

Fig. 3 Relation between Plastic Limit and Weight-Percentage of Material minus 2 Micron for various finely crushed Minerals and Norwegian Clays
Rapport entre la limite de plasticité et le pourcentage-poids du matériau inférieur à 2 microns pour différents minéraux pulvérisés et des argiles norvégiennes

$$PL = \frac{u + 98 \pm C_1}{7}$$

where u is the weight-percentage minus 2 micron, and C_1 varies between 0 and 35.

In Fig. 4 it appears that there is also a relatively great extent of variation for the liquid limit, with the same content of material less than 2 micron. The humus containing post-glacial and inter-glacial clays is distinguished by high values for the liquid limit. The finely crushed minerals and the clays poor in clay minerals are more or less grouped among the ordinary clays. For the common Norwegian clays the liquid limit may be expressed, as a function of the content of material less than 2 micron, in the following manner:

$$LL = \frac{u + 36 \pm C_2}{2}$$

where C_2 varies from 0 to 12.

The graphic representation which best differentiates the various Norwegian types of clay seems to be the plastic index entered as a function of the content of material less than 2 micron. This even in relation to other possible combinations between u, LL, PL and PI.

In Fig. 5 the plastic index is entered as a function of material less than 2 micron, and for the ordinary clays with more than 20% material less than 2 micron the plastic index may be expressed in the following manner:

$$PI = \frac{u + 11 \pm C_3}{2.8}$$

where C_3 for the ordinary clays varies between 0 and 7.

Clays in which C_3 is greater than +7 are either humus-rich clays or inter-glacial clays or sticky clays of some other special type related to the content of material less than 2 micron.

Clays in which C_3 is less than —7 are more or less of a type poor in clay minerals. The geographical distribution shows a clear connection with the petrographical composition of the

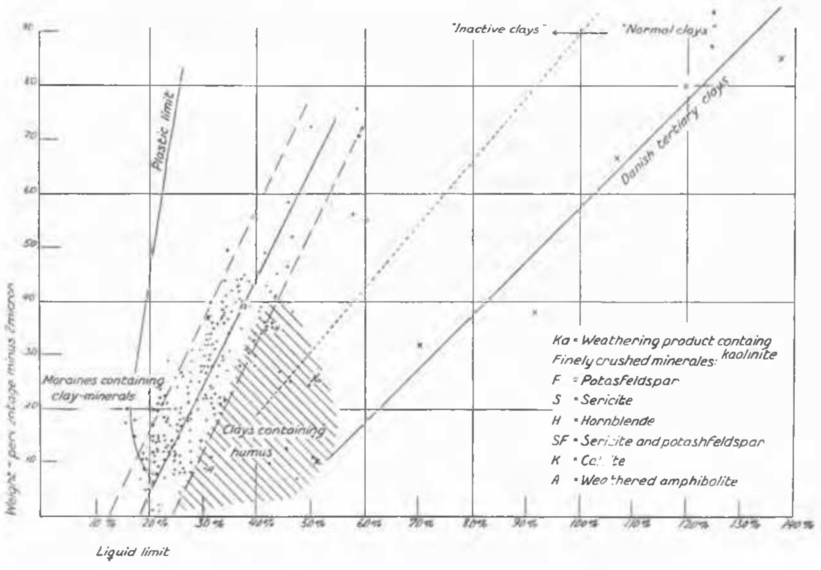

Fig. 4 Relation between Liquid Limit and Weight-Percentage of Material minus 2 Micron for various finely crushed Minerals and Norwegian Clays
Rapport entre la limite de liquidité et le pourcentage-poids du matériau inférieur à 2 microns pour différents minéraux pulvérisés et argiles de la Norvège

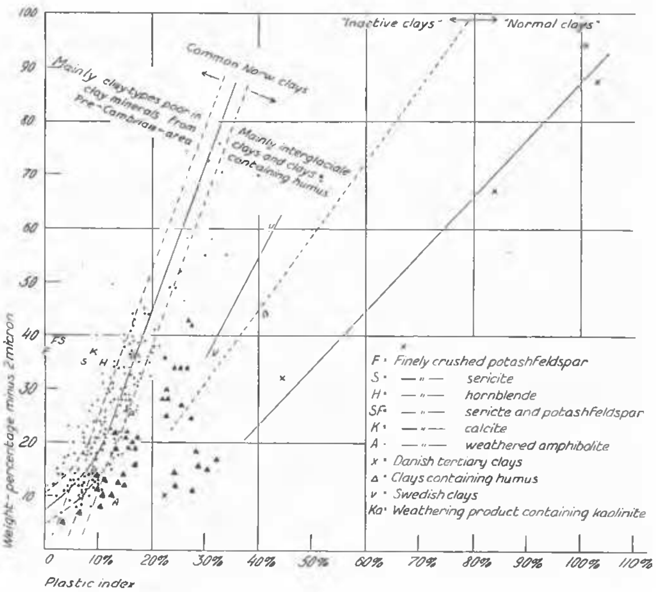

Fig. 5 Relation between Plastic Index and Weight-Percentage of Material minus 2 Micron for various finely crushed Minerals and Norwegian Clays
Rapport entre l'indice de plasticité et le pourcentage-poids du matériau inférieur à 2 microns pour différents minéraux pulvérisés et des argiles de la Norvège

rock-surface in those areas from which the clay materials must presumably have come. In the most notable cases of clays poor in clay minerals the rock-surface in the actual area is entirely dominated by rock types with a granitic and quartzitic composition. On the other hand, certain types of illite minerals seem to give a plastic index below the ordinary, although rock powder of water-free minerals does not occur in particularly great quantities. (High content of fresh mica or low content of chlorides?)

In Fig. 6 the plastic limit is entered as a function of the sorting. Sorting is then defined as $So = \log \frac{Q_{75}}{Q_{25}}$ where Q_{75} and Q_{25} are the grain size respectively for the 75% and 25% passage in the particle-size-distribution curves. The figure indicates a certain correlation between sorting and plastic limit, well-sorted types of soil having as a rule a higher plastic limit than those badly sorted. This is due, perhaps, as much toconnection between the clay mineral content and the sorting as to the porosity's and the plasticity's direct dependence on the particle size distribution.

Those types of soil which have little material less than 2 micron, and which chiefly mark the correlation in the diagram, can be divided into two types: clay-containing morainic materials and well-sorted clay-containing silt-soil-types of fluvial origin. Of the former only material less than sieve No. 40 (0.42 mm) have been used for analyses. Varieties of soil poor in clay minerals have, as already mentioned, a high plastic limit. The well-sorted types of soil of fluvial origin containing less than 20% of material less than 2 micron are also for the most part relatively poor in clay-minerals. In Fig. 6, therefore, this kind of soil appears, one might say for two reasons, high up on the diagram.

As the clay-containing plastic morainic material is principally composed of rock-varieties having a high content of sheet silicates, the resultant product usually gives for this reason great possibilities for a relatively high clay mineral content in these badly sorted types of soil. In addition to this there is the close packing of the soil in question. Both these factors seem to induce a low plastic limit. But when the content of material less than 2 micron is less than 10% of material which has passed through sieve No. 40 (0.42 mm), the plastic limit is again relatively higher. This will appear in Fig. 3, being the diagram for the plastic limit and material less than 2 micron, and seems to become evident in connection with the fact that the content of clay minerals is, as already stated, a function of rock-varieties of which the morainic material is composed. In Fig. 7 the liquid limit is entered as a function of the sorting. It is difficult to discern any clear correlation between sorting and liquid limit. None the less it appears from this diagram and the one for liquid limit and material less than 2 micron that the morainic soil types rich in clay have a relatively low liquid limit (as well as plastic limit), so that, to a certain extent, a correlation exists.

The diagram for the plastic index and material less than 2 micron seems, therefore, to be the most informative one regarding the relative content of clay minerals in those types of soil which have a low content of material less than 2 micron. But the function for the common Norwegian clays regarding material of less than 20% of material below 2 micron takes another cause, as the water-free minerals gradually take on more importance in relation to the clay minerals above the

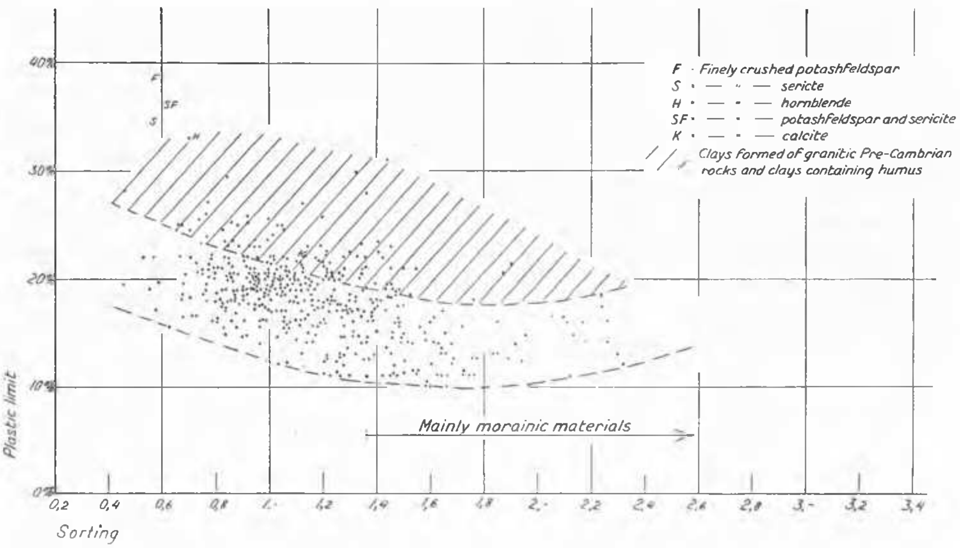

Fig. 6 Relation between Plastic Limit and Sorting for various finely crushed Minerals and Norwegian Clays. Sorting is defined as $\log \frac{Q_{75}}{Q_{25}}$ where Q_{75} and Q_{25} are the Grain Size respectively for the 75% and the 25% Passage in the Particle Size Distribution Curves
Rapport entre la limite de plasticité et le «triage» obtenu pour différents minéraux pulvérisés et argiles Norvégiennes. Le triage est défini par $\log \frac{Q_{75}}{Q_{25}}$, Q_{75} et Q_{25} étant respectivement le diamètre des grains correspondant aux 75% et 25% du matériau tamisé dans les courbes de répartition granulométrique

consistency limit measurements, and because Norwegian plastic types of soil with little material less than 2 micron (20%) generally have a relatively low clay mineral content. Further, even here the occurring variations in illite mineral types give diffuse bounds.

Clay minerals occurring in Norwegian clays have been but little examined by means of modern investigation methods, but certain main features are apparent from what has been done.

Microscopic investigations and chemical analyses show that the prevailing rocks of the region in question characterize the mineral composition of the coarser fractions of the clays as mentioned in the case of morainic soils. An enrichment of

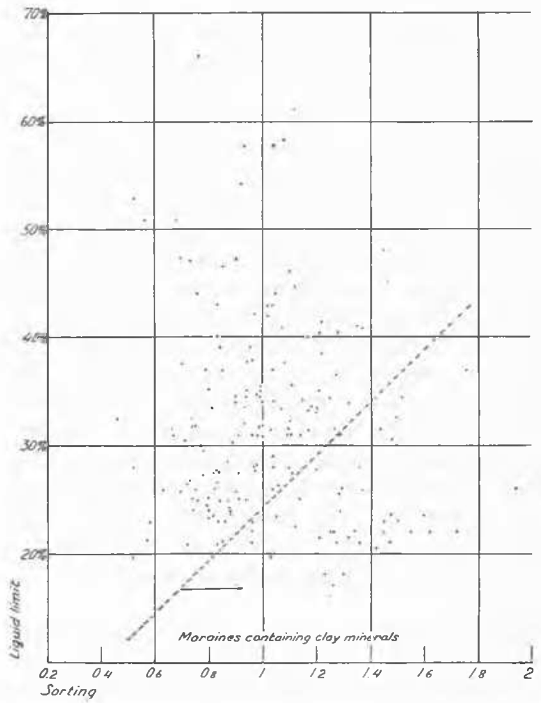

Fig. 7 Relation between Liquid Limit and Sorting for Norwegian Clays
Rapport entre la limite de liquidité et le triage pour certaines argiles norvégiennes

sheet silicates is found in material under 2 micron. As the particles decrease in size, the biotite becomes chloritized, and under 10 micron only chlorite- and sericite-like metamorphic products of the biotite are found. In material between 2 and 10 micron, feldspar usually predominates. The weathering towards mica-like minerals has occurred to a highly varying degree (*Krogh*, 1923; *Hougen*, *Klüver*, *Løkke*, 1925; *Rove*, 1926; *Goldschmidt*, 1922 and 1926). Electron-microscopic investigations of some clays from Østfold, Norway, indicate that the fraction under 2 micron primarily consists of particles between 0.2 and 0.05 micron (*Ackermann*, 1948). *H. G. Byers* has investigated fat (sticky) clays from Østfold. By means of modern analytical methods it was found that the material under 1 micron was made up prevailingly of hydrous mica (*Brudal*, 1940). In clay from Strøm which is very fat, according to Norwegian conditions, *Rosenqvist* indicates (based upon X-ray, differential thermal, benzidine, and dehydration analyses) that in the fraction under 2 micron the hydrous mica (illite) makes up nearly half of the material, the balance being muscovite and water-free minerals (*Rosenqvist*, 1942).

It has not been possible to prove that Norwegian clays contain any appreciable amount of minerals belonging to the montmorillonite group.

Chemical weathered zones in the rock surface containing kaolinite or montmorillonite are of unfrequent occurrence in Norway. Generally the clay mineral content in the existing weathered rocks is so low that the mineral in question has not been clearly identified. Further, it is reasonable to assume that the unmetamorphic Cambrian-Silurian shales of the Oslo region, as in Sweden, contain illite.

Based upon our present knowledge of common Norwegian clays there is every reason to assume that the low percentage amounts of existing clay minerals in the Norwegian soils belong to the illite group (illite, diff. hydrous mica, chlorite, vermiculite) and that clay minerals of the montmorillonite group and the kaolinite group sometimes constitute insignificant amounts, which in some cases are due to pre-glacial weathering of underlying rock. Regionally it should be taken into account that within the minus 2 micron fraction considerable variations occur in the ratio of the content of various illite minerals to that of sericite, chlorite and water-free minerals.

For one thing this seems to be borne out by the plastic condition of Norwegian clays, particularly by the diagram of material minus 2 micron and plastic index. This variation in the mineral content of the clay fraction as well as the variations in illite minerals also seems to depend upon the typical regional changes in the mineralogical composition of the underlying rock, and upon conditions governing the transportation and sedimentation of the clay minerals and the age and chemical conditions of the deposits.

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