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The course of the weathering processes in the marine clay deposits of Holland.

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I. The Dutch saline and alkali soils.

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In 1922 the Hungarian Academy of Sciences invited *Dr. Alexius A. J. de 'Sigmond* to prepare a monograph on the alkali soils of Hungary. At the request of *Dr. W. P. Kelley* and with the cooperation of the International Education Board, *de 'Sigmond*'s work was translated into English and issued in 1927 by the California Agricultural Experiment Station, University of California, Berkeley, under the title: „Hungarian Alkali Soils and Methods of their Reclamation". This paper, says *Dr. Kelley* in his foreword, although written with special reference to Hungary, contains important lessons for all arid or semi-arid regions. It deals with the origin and mode of formation of alkali soils in general, the distribution of the types of alkali soils found in various parts of Hungary and their natural flora, their chemical and physical properties and finally the various methods of reclamation.

Saline soils and alkali soils, the two groups known by Russian investigators as „solontchak" and „solonetz", occur in the Netherlands also. They are the kwelder-soils and the young polder-soils in the first stage after their endikening. Those who have to occupy themselves with the question of the reclamation of the Dutch kwelder-soils and young polder-soils will do well to study the work of *Prof. de 'Sigmond* carefully.

At the same time, however, the question of the reclamation of the saline soils in the humid Dutch climate has a somewhat different aspect from that of similar reclamation in the semi-arid and fully arid regions, such as those of Hungary, Southern Russia, California, etc. The annual rainfall in the Netherlands is sufficient entirely to wash the salts of the sea water out the young polder-soils to a depth of from 50 to 60 cm within a few years after their endikening, provided their permeability for water is good and the water can be properly drained off. The main thing in this process of desalting is the permeability of the soil for water. In consequence of the formation of the kwelder soil in salty water (which flocculates the clay particles) and of the grass-crop (whose roots penetrate the upper soil layer), the kwelder soil, and later the young polder soil, is extremely permeable to water.[1] This causes the salts of the sea-water to be washed out by the rains, as early as the first winter after endikening, to an appreciable depth, so that the young polder is immediately ready for cultivation. The first thing to be seen to in the reclamation of these kwelder-soils after their endikening is therefore the promotion of the good permeability of the soil for water and air, and, where this already exists, to do everything to retain it and nothing to mar it. More especially the leading-off of the surplus water by means of a good system of drainage, and further a judicious cultivation of the ground, superficial ploughing and certainly no ploughing in the wet soil, are amongst the measures most to be recommended.

Under these circumstances the transformation of the sodium clay of the kwelder soils, or rather, the transformation of the magnesia sodium clay into calcium clay under the influence of the Ca of the calcium carbonate of the soil also quickly takes place. In this transformation process this calcium carbonate must first be dissolved by means of the carbon dioxide in the form of calcium bicarbonate. For the formation of the normal calcium clay, therefore, an abundant production of carbon dioxide in the soil is of great importance, and it is obvious that in this regard also a high permeability of the soil is essential.

Whilst, therefore, in countries with an arid or semi-arid climate studies relative to the reclamation of the saline and alkali soils, as carried out by *de 'Sigmond*[2] are much more usual, in Holland, with its humid climate, the question of the subsequent weathering of the soil takes a prominent place. As with all studies, so, also, in this case, is it of great importance to find a good object of study. So far as the study of the process of weathering of the Dutch sea-clay deposits is concerned, the soils of the successively endikened Dollard polders provide an ideal object of study. These polders were endikened after the formation of the Dollard in the year 1277; the oldest polder dates approximately from the year 1550, whilst the youngest Dollard polder was endikened in the year 1926. The soil of the entire complex of Dollard polders is of a fairly homogeneous composition, consisting of very heavy clay soil with little humus (see Table 2.). Weathering has proceeded far enough to a fairly large depth. All stages are found, from the young soils, practically well saturated with bases and rich in $CaCO_3$, of the young polders to the very old soils in which not only the calcium carbonate has disappeared, but in which the adsorbing clay humus complex has also already lost a considerable amount of its bases, so that the soil now has an acid reaction (see Table 3.). The soils of this latter stage are somewhere near 400 years old, whilst as representative of the youngest stage the soils of the youngest Dollard polder, that is, the Carel Coenraadpolder, which was endikened in 1924, were investigated. This is the polder which was visited in 1926 by the Second Commission under the presidentship of Prof. *de 'Sigmond*, and in 1932 by the Sixth Commission under the presidentship of Oberbaurat *Fauser.*

II. The successively endikened Dollard polders.

The investigation related to 8 Dollard polders are mentioned in Table 1. Each profile was sampled to a depth of about one metre.

Table 1.

The successively endikened Dollard polders.

Nr.	Soil sample	Name of polder	Year in which the polder was endikened	Age of polder in the year in which Samples were taken (1930, or 1932)
1	B 3648	Carel Coenraadpolder	1924	6
2	B 5546/47	Reiderwolderpolder	1862	70
3	B 5268/69	Finsterwolderpolder	1819	113
4	B 5560/61	Oostwolderpolder	1769	163
5	B 5574/75	Het Nieuwland..................	1701	231
6	B 3469	Nieuw Beerta (Parcel 3)	1666	264
7	B 5588/89	Het Oud Land	1626	306
8	B 3423	Nieuw Beerta (Parcel 11)........	1550	380

In addition to the various chemical constants, such as the content of calcium carbonate, clay, sand, humus, N, P_2O_5, exchangeable bases (value *S*), and the values *T*, *V*, and pH, various physical constants of the soil in its natural situation were also determined, such as the volume-weight and the permeability for water.

In this brief communication no more than a summary of a few results of the investigation of the surface soils (from 0—20 or 25 cm) is given (see Tables 2. and 3.).

I will confine myself here to a few short remarks.

As is seen by Table 2., the content of $CaCO_3$ decreases with the age. It was pointed out by *van Bemmelen*[3] that approximately 1% $CaCO_3$ was washed out from the soils of the Dollard polders in about 25 years.* The humus content of the kwelder soil, when

* An investigation carried out by *Schucht* has shown the rapidity of the washing out process of the calcium carbonate to be dependent on local conditions.[4]

Table 2.

Nr. (See table 1)	Age in years (See table 1)	Percentage of dried matter (105° Celsius) CaCO₃	Humus	Clay (fraction I+II)	Sand	Clay (+humus, calculated as clay)	Nitrogen (N)	P_2O_5 (soluble in nitric acid)	N in % of humus
*		9·5	5·4	54·2	30·2	78·7	0·294	0·208	5·4
1	6	9·4	4·8	57·5	28·3	79·3	0·258	0·217	5·4
2	70	9·3	3·3	68·9	18·5	83·9	0·215	0·193	6·5
3	113	7·5	3·4	71·9	17·2	87·4	0·228	0·210	6·7
4	163	6·9	3·3	68·8	21·0	83·8	0·209	0·222	6·3
5	231	3·0	3·6	76·8	16·6	93·2	0·226	0·169	6·3
6	264	0·3	4·3	66·5	28·9	86·0	0·260	0·202	6·0
7	306	0	3·6	71·4	25·0	87·8	0·221	0·132	6·1
8	380	0	4·7	68·5	26·8	89·9	0·285	0·195	6·1

* Kweldersoil of the kwelder in front of the Carel Coenraadpolder (Nr. B 5539/40)

the latter is grown with grass, is 5·4%. After endikening, the pasture land is converted into arable land, and the humus content diminishes to about 3·50%, after which it remains practically constant. At the same time the nitrogen-percentage of the humus rises from about 5·4 to about 6 or 6·5. The P_2O_5 content is rather high, about 0·2%, but seems to decrease in the older polders, with the exception of polders Nr. 6 and 8 (higher content of humus).

III. Exchangeable bases.

The figures of Table 3., which refer to the exchangeable bases, are very important.

Table 3.

See table 2			Exchangeable bases in milligram equivalents per 100 gr clay (+humus)				S	pH	Relative proportion of the exchangeable bases; present per 100 parts exch. bases
Nr.	Age	% $CaCO_3$	CaO	MgO	K_2O	Na_2O	Sum of exch. bases in milligram equivalents per 100 gr clay (+humus)	(water suspension)	$CaO+MgO+K_2O+Na_2O$
1	6	9·4	22·5	10·5	2·2	2·7	37·9	7·8	59+28+ 6 + 7
2	70	9·3	31·7	3·9	1·4	0·3	37·3	7·7	85+10+ 4 + 1
3	113	7·5	32·9	3·0	0·9	0·1	36·9	7·7	89+ 8+2·5+0·5
4	163	6·9	31·6	3·1	1·5	0·2	36·4	7·7	87+ 8+ 4 + 1
5	231	3·0	34·0	2·9	0·9	0·6	38·4	7·7	88+ 8+ 2 + 2
6	264	0·3	30·2	6·4	1·0	0·3	37·9	7·6	79+17+ 3 + 1
7	306	0	31·3	6·3	0·7	0·4	38·7	7·4	81+16+ 2 + 1
8	380	0	21·3	7·6	0·6	0·9	30·4	5·9	70+25+ 2 + 3

In the first place it should be noted that the figures of Table 3. are given in milligram equivalents of exchangeable bases per 100 gr.

clay + humus. In this calculation the base-adsorbing capacity of the humus substance has been estimated as being 4,545 times greater than that of the clay substance.[5] The soil of the Carel Coenraad Polder contains 57·5% clay and 4·8% humus (see Table 2.); the base-adsorbing capacity of 4·8% humus being equal to that of 21·8% clay, this soil may be considered to contain 57·5 + 21·8 = 79·3% clay + humus (calculated as clay). When calculated in this way, the richness of soils of divergent clay and humus contents may be compared.

In Table 3. the soil of the kwelder is not included, as the method for the determination of the exchangeable bases in saline soils which also contain calcium carbonate, has not yet been fixed. In several former communications I have endeavoured to indicate an approximate method,[6] but I am quite willing to admit that there is much to criticize in this method. Judging by the figures obtained by this method, the Dutch kwelder soils are to be regarded as magnesia sodium clay soils. The soil of the kwelder-soils contains approximately 30 to 40 CaO, 45 to 35 MgO, 6 K_2O, and 15 Na_2O per 100 parts exchangeable bases. As has already been pointed out, the salts of the sea-water are, if the drainage is good, very quickly washed out of the upper layers. The upper layer of the 6-year old Carel Coenraadpolder was therefore free from salt. As is shown in Table 3., the relative proportion in the young Carel Coenraadpolder is already 59 + 28 + 6 + 7, i. e., a great part of the exchangeable MgO and Na_2O originally present in the kwelder soil has been replaced by lime from the $CaCO_3$. This process of replacing of the exchangeable MgO and Na_2O by CaO proceeds fairly rapidly, so that the 70-year old soil of the Reiderwolderpolder is already a true calcium clay soil, with a relative proportion of 85 + 10 + 4 + 1.

As long as the soil still contains sufficient calcium carbonate, a slight rise in the content of CaO is to be observed, from 31·7 milligram equivalents (mE) per 100 parts clay (+ humus) in polder Nr. 2. (70 years old, with 9·3% $CaCO_3$) to 34·0 mE CaO in polder Nr. 5. (231 years old with 3·0% $CaCO_3$). In judging these figures it must not be lost sight of that the calculation of the CaO content per 100 parts clay + humus (calculated as clay) yields figures which are only approximately correct.

In all these soils (polders Nrs. 2., 3., 4. and 5.) the relative proportion of the exchangeable bases remains nearly constant; that is to say, the exchangeable CaO is greatly predominant, whilst the exchangeable MgO, K_2O, and Na_2O are quite put in the shade (average: 87 + 9 + 3 + 1).

In the case of the soil of the 264-year old polder „Nieuw-Beerta“ (Nr. 6), which now contains no more than 0·3% $CaCO_3$, we see a decrease of the exchangeable CaO, which, however, is accompanied by a practically equally large rise of the exchangeable MgO. The same phenomenon is observable in the 306 years old soil of the polder „Het Oud Land“ (Nr. 7), from which the calcium carbonate has just disappeared. In this stage of the weathering process the exchangeable CaO washed out seems to be replaced by MgO from the inner parts of the clay particles. In my first long paper[7] I pointed out the possibility of the change of the bases from the acid-soluble form into the exchangeable or adsorptively-bound form. In this paper and elsewhere[8] I also pointed out that among the acid-soluble bases of the Dutch clay soils magnesia ranks first. I found an average of 0·08 gr. exchangeable MgO and 1·34 gr. acid-soluble MgO per 100 gr. soil. From the stage in which the old Dollard clay soils contain little or no $CaCO_3$, we see the MgO again becoming more prominent, as was the case in the kwelder stage and in the first stage, immediately after the endikening. See polders Nrs. 6 and 7 with a relative proportion of 79 + 17 + 3 + 1 and 81 + 16 + 2 + 1.

With further weathering the content of exchangeable CaO falls still farther, but no further rise of the content of exchangeable MgO occurs; see the soil of the 380-year old polder „Nieuw Beerta" (Nr. 8), with 21·3 CaO and 7·6 MgO and a relative proportion 70 + 25 + 2 + 3.

A further point of great importance is a consideration of the S-values from Table 3. These S-values have also been calculated on 100 parts clay (+ humus), and therefore give an indication of the richness in adsorptively bound bases of the clay-humus substance. There must be a connection between the S-value per 100 parts clay + humus and my V-value (degree of saturation); I will revert to this point later on.

There must also be a connection between these two values, S per 100 gr. clay (+ humus) and V, and the pH-value. As the soil grows older, if the degree of saturation decreases, the pH-value must also fall.

As has already been pointed out, the kwelder stage has not been included in Table 3. A few kwelder soils have been investigated, but — as stated above — the method employed is open to certain objections. With this proviso I may now say that for the soil in the kwelder stage an S-value of about 31 was found. This is a somewhat lower value than that of the soil of the youngest Dollard polder (Table 3, Nr. 1 with $S = 37·9$). That the kwelder soil, notwithstanding the lower S-value, has pH-values of 7·5 to 8, is to be acounted for by the fact that among the exchangeable bases the Na_2O takes a more prominent place. It is not impossible that the lower S-values are connected with the smaller binding-power of the clay substance for sodium.[9] After endikening, not only part of the MgO and Na_2O, but also of the H, is replaced by the CaO of the $CaCO_3$, which results in a small rise of the S-value, and in consequence of the V-value. As long as there is any $CaCO_3$ left in the soil, these S-values remain at pretty much the same height (about 37—38). And even in the first years after the disappearance of the $CaCO_3$ there is no decrease in the S-values, owing to the adsorptively bound base material being replenished from the supply of acid-soluble MgO. Even after the disappearance of the $CaCO_3$, therefore, the clay substance remains for a time at the same degree of saturation, and that notwithstanding that the content of adsorptively bound CaO falls. In consonance with this, the pH-values do not yet decrease either; the upper layers of the polders Nrs. 6 and 7 still possess S-values of 37·9 and 38·7, and pH-values of 7·6 and 7·4.

With still further weathering (see the soil of the 380-year old polder „Nieuw-Beerta", Nr. 8) a fall of the S-value is *now* seen to occur, to $S = 30{\cdot}4$; these are again the values of the kwelder period. Since, however, the relative proportion is now 70 + 25 + + 2 + 3 (table 3, Nr. 8) and the exchangeable Na_2O has therefore receded entirely into the background, this 380-year old soil already shows a fairly strong acid reaction (pH = 5·9). Further weathering stages of Dollard clay soils do not, as far as I am aware, occur.

IV. Physical character of the soil.

A further point of great interest is the study of the effect of weathering on the physical character of the soil. It is, however, more difficult to express this in figures than is the case with the chemical character of the soil. So far only two physical soil constants of the Dollard clay soils have been determined, viz., the volume weight and the permeability for water.[10] An attempt has further been made at least to some extent to estimate by the eye and by the sense of touch the physical character of the successively endikened Dollard polders. This brought more especially to light the fact that the Dutch sea clay soils show broad fissures up to a depth of 100 cm and more, and that these fissures last for a very long time. It is obvious that this formation of fissures contributes to a great extent to the permeability of the soil for water, with which again is connected the fact that these soils quickly allow of the water draining off. How long these sea clay polder soils can retain their good structure is proved by the Oostwolderpolder, which was endikened in 1769 (Nr. 4 of Table 1); a piece of land, 40 metres broad, along the sides of which ditches had been dug, needed no other drainage system up to as late as in the year 1932. Up to a depth of more than 100 cm broad fissures still occured even in this approximately 160-year old formation. It may be added that the worm-holes present in the soil also contribute to the good permeability of the soil for water.

I hope shortly to be in a position to publish the detailed results of this investigation, with the addition of the *(T—S), T,* and *V*-values, etc., as also those of the layers to a depth of 100 cm. That I now give this short summary is due principally to my not wishing to be absent from the commemoration of the jubilee of my friend, Prof. Dr. *Alexius A. J. de 'Sigmond.*

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A holland tengeri agyaglerakódások kilúgozásának folyamata.

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A holland tengerpartokon is találhatók szikes és sós talajok, még pedig a tengeri lerakódások — *a kwelderek* — és a körülgátolás után, a fiatal *polderek.* Úgy a kwelderek, mint polderek vízáteresztők és így a hollandiai csapadékviszonyok mellett ezeknek javítása nem okoz nehézséget, amennyiben a talajokban felhalmozott sók csakhamar a mélyebb szintekbe mosódnak, feltéve azonban, hogy permeabilitásuk fenntartásáról és megfelelő alagcsövezésükről gondoskodás történik.

Nyolc ilyen, különböző időben, 6—380 évvel ezelőtt körülgátolt polder-talaj vizsgálatából kitűnt, hogy mészben és humuszban idővel elszegényednek, míg a körülzárás után a nitrogéntartalom valamivel emelkedik; foszforban eléggé gazdagok (0·2%) ezek a talajok.

Amíg $CaCO_3$-t tartalmaznak, kicserélhető bázisaik között a Ca játssza a vezérszerepet és csak 200—300 év mulva, amidőn a $CaCO_3$ mennyisége néhány tized százalékra csökken, válik érezhetővé a kicserélhető Ca mennyiségének csökkenése. Helyét a körülgátolás utáni első időben Mg foglalja el, míg a K és Na csak igen alárendelt szerepet játszik. A pH-érték, a Ca mennyiségének csökkenésével, természetesen szintén csökken és idővel 6 alá esik.

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19.895. — Kir. Magyar Egyetemi Nyomda, Budapest.