Citation:

E. Dubois, On the origin of the fresh-water in the subsoil of a few shallow polders, in:
KNAW, Proceedings, 7, 1904-1905, Amsterdam, 1905, pp. 53-63

of 10 M^3 of fresh water per M^3, corresponding to $^1/_3$ to $^1/_4$ space between the grains of sand over a thickness of 30 to 40 metres. A consumption of 50 million M^3 per year being sufficient with the existing dune-water conduit for the need of the population, taking its increase into account, this quantity would be able to supply water for a hundred years; now we may presume that in a hundred years science will have so much advanced that it will be practicable then to convert any water into suitable drinking-water.

The answer to our question must in my opinion be affirmative as well as negative. Affirmative with respect to supplying water to single dwellings, to a village, or to a temporary supply in war-time such as the Engineering Corps has made at Sloten; negative with respect to a lasting demand on a large scale and this because in practice pecuniary considerations would force us to withdraw the water from a limited surface which would be impossible without causing such a diminution in pressure that certainly with a lateral afflux also water from below would flow to, so that after some time brackish water would be obtained.

Hence Prof. DUBOIS' assertion, that a sufficient quantity of drinking-water is and remains available in the ground under the shallower polders, is in my opinion entirely wrong.

Geology. — *"On the origin of the fresh-water in the subsoil of a few shallow polders"*. By Prof. EUG. DUBOIS. Communicated by Prof. BAKHUIS ROOZEBOOM.

(Communicated in the Meeting of November 28, 1903).

In the meeting of the Academy of September 26 ult. Mr. H. E. DE BRUYN, although he agreed with most of the principal conclusions about the origin and the direction of motion of the groundwater in part of our lowland, contained in my communication to the Academy of June 27, gave an elaborate exposition of the grounds on account of which he cannot accept my conclusion concerning the origin of the fresh-water in the subsoil of a few shallow polders. In my opinion this has to be sought in rain, fallen on the spot or at a relatively short distance, which Mr. DE BRUYN thinks impossible on account of considerations about the amount of the afflux in the Haarlemmermeer polder which, in his opinion proves that the layers above the diluvium, especially the "old sea-clay" transmit water to a much smaller extent than is necessary in my representation. He also supposes that part of the fresh-water which was present under our polder-land a thou-

sand years ago, is still there at the present day and that the only source from which fresh-water has been supplied to the diluvium (the subsoil) has been the dunes.

About the velocity with which water can move through our always very impure clay, which Mr. DE BRUYN rightly considers to be a cause of our difference of opinion, I will now state a few facts and at the same time point out the arguments which led me to my conception of a different origin of the deep groundwater mentioned. First however I wish to point out another possible origin which has not yet been suggested and which cannot be at once rejected, and especially a difficulty of a more serious nature even than the one objected to my representation by Mr. DE BRUYN.

If we assume the extremely slow motion ascribed to the groundwater by Mr. DE BRUYN, it might namely be that the deep fresh-water under consideration has to be considered as a remainder of what sank away there centuries ago. For not always these polders have been surrounded by brackish water only.

According to descriptions from the Roman period, Lake Flevo undoubtedly contained water from the Rhine and no salt water as the Zuiderzee does nowadays. Also the IJ was a freshwater lake communicating with the freshwater lakes Purmer, Wormer and Schermer. Moreover it is well known that the Haarlem Lake (Haarlemmermeer) arose by the union of at least four lakes: the Old Haarlem Lake, the Old Leyden Lake, the Old Lake and the Spiering Lake which were fed at least partially by one or more branches of the Katwijk Rhine. The map by Bolstra, the able land-surveyor of Rijnland. published in 1745 and incorporated in "Present state of the United Netherlands" [1]), gives us an idea of the situation of these lakes in 1531 and of their gradual union and the enlargement of the Haarlem Lake, originated in this way, down till 1740. The waves of this large lake could easily erode the steep banks, consisting of fen, as low as the same layer of clay which already formed its bottom, the circumstances for this process becoming more and more favourable, chiefly on account of the "sinking of the lands" in these parts with respect to the sea, described already a century before the draining. This erosion of land occurred at a tremendous rate at the north-east side, where the polders are situated which now have fresh-water in their underground. LE FRANCQ VAN BERKHEY [2])

[1]) Tegenwoordige staat der Vereenigde Nederlanden. Vol. 6 p. 163. Amsterdam, I. Tirion. 1746.

[2]) J. LE FRANCQ VAN BERKHEY. Natuurlijke Historie van Holland. Vol. I. p. 227. Amsterdam 1769.

about the middle of the 18th century describes the water of the Haarlem Lake as "fresh, but in some places, where the grounds become brackish, as near Slooten and towards Amsteldam, the water of the lake is sometimes of a saltish taste. But the abundance of water from the Rhine and the supply from so many small lakes and waters which discharge themselves into it, bring about that the brackish water can by no means get the upper hand, and so the lake has on the whole good fresh-water." Meanwhile a quantity of salt amounting to 300 milligrammes per litre is according to the latest investigations not unpalatable. An analysis by G. J. MULDER [1]) of water taken from the lake near Sloten in November 1825, shows that it contained 393 mg. chlorine per litre. Now this is the season during which it will probably have been least brackish. Hence it is improbable that the water of the Haarlem Lake was on the whole really fresh. Indeed, the lake had ample opportunity to receive salt from the IJ (which had already become salt towards the middle of the 13th century) through the upper ground of the polder-land which consisted chiefly of fen and which separated the two waters in places (near Halfweg) like a true isthmus. It is also known that at any rate towards the middle of the 18th century those grounds under which fresh-water is found, were brackish. Yet fresh-water of a much earlier period might in places have remained in the underground. Water derived not only from the north and west sides, but also from the east, may have filtered into the polders mentioned at the north-east of the present Haarlem Lake. The Amstel certainly contained for centuries perfectly freshwater, derived from the Rhine. As late as 1530 the Amsterdam canals, fed by this river, had drinkable water, but soon this supply was gradually more and more reduced by natural causes.

Is now the motion of the groundwater, not only in the finer alluvium, containing much sand, but even in the coarse and gravelly diluvial sand, which transmits water much more easily, really so slow, as Mr. DE BRUYN believes, that in three or four centuries the influence of the altered circumstances as to level and composition of superficial waters on the deep groundwater will scarcely be perceptible? I believe that numerous facts, of which I will mention a few in this communication, are at variance with this opinion.

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[1]) G. J. MULDER. Verhandeling over de wateren en lucht der stad Amsterdam. p. 66. Amsterdam 1827. LORIÉ, quoting from second hand, wrongly mentions this same analysis under two different headings and with different amounts of Cl. (Onze brakke, ijzerhoudende en alkalische bodemwateren, Verhandelingen der Kon. Akad. 2e Sectie, Dl. 6. N°. 8. 1899. p. 9).

In the first place the actual facts are incompatible with Mr. DE BRUYN'S idea that before the draining of the Haarlem Lake, some 50 years ago, "the direction of the current of the deep groundwater e.g. at Sloten, must have been exactly the reverse" of what it is now (These Proceedings VI, p. 291) and still less I can assume this for an earlier period. For near Sloten the country was not lower, but even a little higher than the level of the Haarlem Lake and not dyked in, so that the incessant washing away of the steep fenny bank of the lake could be enormously great. According to an accurate investigation, made in 1743, it amounted yearly on the average to as much as 5 to 10 Rijnland rods (about 19 to 38 metres). It is true that the upper side of the layer of fen which now forms the Rieker polder near Sloten, lies at 1.35 metres below A. P. (Amsterdam level) but its lower side is still on a level with the bottom of the Haarlemmermeer polder, as it formerly was with the bottom of the lake, and it rests on the "old sea-clay". If we now bear in mind that fen, such as that of the Rieker polder consists, when it is completely saturated, for $^{9}/_{10}$ of water, as I have found to be actually the case, and that moreover the "looseness and shiftiness" of these grounds which, as it were, rose and sank with the water, were well known in the time of the lake, it is clear, how, after the draining, in half a century, by losing over $^{1}/_{3}$ of their water, they might shrink so far below A. P. and that there can be no question of an earlier current of the deep groundwater under the Haarlem lake towards the country near Sloten. The lake certainly did not allow such a current from the dunes to pass under its bottom.

Though the dunes were broader and the level of the water in them higher than nowadays, the hydrostatic pressure imparted there to the deep groundwater must have been exhausted and the horizontal current stopped by the water rising in the alluvial cover, which forms an imperfect screen, long before the opposite side had been reached. For at present the difference in pressure, owing to the water-pressure being now 5 metres less in the polder than it formerly was in the lake, is certainly not less and yet already in the middle of it only a slight upward pressure remains, although pressure is directed from all sides to the middle.

Hence in the underground we only meet water that soaked the soil from above without any considerable horizontal movement in the underground.

I quite agree with Mr. DE BRUYN (p. 291) that "part of the fresh-water now present in the diluvium under the Haarlemmermeer

polder was present in it already fifty years ago", if I may consider water that contains 200 to 300 and even more milligrammes of chlorine per litre as fresh-water, as I understand he does. Only with this latter not common qualification one is entitled to say that under the Haarlemmermeer polder the diluvium has on an average more than 10 metres fresh-water, for the greater part of that polder has no fresher water in its underground than with these amounts of chlorine. Only where the higher grounds are clearly of recent origin this is different, for the rest the water in the upper diluvial layers of the Haarlemmermeer polder contains about the same amount of chlorine as the water of the former lake. Of the Wilhelmina spring, the amount of chlorine of which is over 3000 milligrammes, the depth is unknown; undoubtedly however it goes down as far as the salt water which in most places of this polder is to be found below 40.50 metres.

The most serious difficulty opposing my view of the origin of the fresh-water in the subsoil of some shallow polders is not mentioned by Mr. DE BRUYN. It is that the fresh-water in question in all seasons not only is surrounded by, but also rests on and is covered by brackish water. How can the fresh-water under these circumstances owe its origin to the rain fallen on the brackish upper ground?

The explanation of this paradoxical phenomenon I mean to have found in the peculiar hydrological condition of those polders which, like those between Amsterdam and the Haarlemmermeer polder, are themselves at a level only little below A.P. and are situated near deeper drainings. In a similar condition are the shallow polders near Purmerend and Schermerhorn. Like here towards the Haarlemmermeer polder, so yonder towards the deep polders Purmer, Wijde Wormer, Beemster and Schermer, a considerable flow exists in the coarser diluvium under the more compact alluvial cover and at the same time a vertical downward movement, while in those deeper polders the water tries to rise through the alluvial cover which forms only an imperfect screen. Consequently in boring-tubes the groundwater from the diluvium in these latter rises higher than the field, whereas in the shallow polders it remains far under it and below the level of the groundwater. These circumstances and the geological condition of the soil form in my opinion the solution of the riddle of the presence and the permanence under some shallow polders of fresh-water which on all sides is surrounded by brackish water. I arrived at this conclusion especially by studies in the Rieker polder near Sloten, in which the source for the military water-supply for

the position of Amsterdam is situated. To this I was enabled by a few experimental wells which Mr. G. VAN ROYEN, 1st lieutenant-engineer, charged with the execution of the works there, was kind enough to have made for the purpose of this investigation. At my proposal seven of these experimental wells were bored to various depths in the middle of a meadow, about 300 metres south of the Sloten road and the farm "Rustvrede", within a square of three metres side. Under the lower end of the iron tubes which were open below, gravel had been poured to a depth of half a metre. By examining the water that had risen in those tubes as to level and composition one can obtain information about the state of affairs at various depths in relation with the condition of the soil.

Letter of the well.	Depth of the layer of water below the field [1]).	Layer in which the water is found.
A	1 to 1.5 M.	fen.
A'	1.7 „ 2.2 „	„
B	2.5 „ 3.0 „	Upper clay.
C	5 „ 5.5 „	Layer of sand in the clay.
C'	7.5 „ 8.0 „	Lower part of the clay.
D	10 „ 10.5 „	Between deep fen and sand
E	15 „ 15.5 „	Sand under the denser alluvium.

A well situated 30 metres to the west, 44 metres deep, IV, 13, was compared with these experimental wells.

Most of these wells were ready at the end of August ult. A' was finished about the middle of September, C' the 19th of October. The level of the water and the amount of chlorine were repeatedly examined by me. After all the wells had been left undisturbed as long as November 20, the following state of affairs was found.

	Water level in M. ÷ A.P.	Chlorine in mg. per L.
A	1.465	135
A'	1.495	202
B	1.495	617
C	1.493	780
C'	1.677	145
D	2.720	124
E	2.737	68
IV, 13	2.747	92

[1]) The level of the field is 1.33 ÷ A.P.

Of these wells C' may for the present be left out of account since a stationary condition has not yet established itself in it; having its lower end in the clay, the water still rises in it continually Well IV, 13 again has a higher and varying amount of chlorine; determinations at different times gave 114,92,190 mg. per litre. I believe that this increase and variation of the amount of chlorine has to be ascribed to the neighbourhood of the deep salt water in relation with fluctuations in atmospheric pressure and also with a proper motion of ebb and flood of the groundwater [1]).

In spite of the very considerable rainfall of the latest months, great variations in the percentage of chlorine did not occur; only in and near the clay, hence especially in C, the amount of chlorine decreased considerably, in C from 850 to 780 mg. per litre. This result does not verify my formerly stated supposition that perhaps during the wet season a continuous freshening of the water might take place.

Yet I could not agree with the idea that the fresh-water in the subsoil should have stayed there undisturbed for at least a few centuries. For why then is fresh-water in the diluvium under the Haarlemmermeer polder and the Lutkemeer polder only found at a distance not too far removed from the shallow polders near Sloten and Osdorp? Why does this layer of fresh-water end already before Halfweg, before the Great IJpolder is reached, south of Sloterdijk and also soon eastward of the Amstel? Why does the layer of Purmerend not extend further than a short distance under the Purmer and Beemster polders? Does not this limitation point to an autochthonous origin of the fresh-water in the underground of the shallow polders?

I think to have found the key of the riddle in the stated sudden fall in pressure, amounting to more than 1,20 metre, under the clay and the deep fen which is a consequence of the fact that the level of the groundwater in the Haarlemmermeer polder is almost 3.5 M. lower than in the Rieker polder. So this compressed deep fen, acting as a semi-permeable wall, can transmit to the deeper layers water, but no salt.

That fen in a compressed state and under similar conditions of

[1]) On these influences, especially on the proper ebb and flood of the groundwater, see: F. Weyde, Die Abhängigkeit des Grundwasserstandes von dem Luftdrucke, dessen Steigen und Fallen wahrend eines Tages (Flut und Ebbe), in Meteorologische Zeitschrift of August 1903. The influence of atmospheric pressure was already pointed out in my former communication. These influences become perceptible only in deep wells, because in them the water follows more easily the changing pressure of the atmosphere and gravity than it does in the neighbourhood and so is raised or depressed.

pressure as prevail in the Rieker polder, can cause osmosis, I could prove experimentally with apparatus which Mr. A. J. STOEL Jr. at Haarlem was kind enough to make for me in his workshop and with other apparatus kindly put at my disposal by Dr. HERINGA of Haarlem. The most important of these experiments is the following one.

In an iron tube of 1 M. length and 154 mm. internal diameter newly dug fen from the superficial layer in the Rieker polder was compressed by means of a lever until no further compression was observed. The pressure was gradually raised to 2,8 kilogrammes per square centimetre, a pressure equal to that which is found in a soil of sand or clay at a depth of 14 metres; the layer of fen was three centim. thick. Of water, containing a quantity of sodium chloride corresponding to an amount of chlorine of 1000 mg. per litre, this layer of fen, which on account of its slight thickness, can by no means be so perfect a semi-permeable wall as the deep layer of fen in the Rieker polder which has an average thickness of a metre, water was transmitted which contained temporarily at the utmost 750 mg. chlorine per litre; hence at least 250 milligrammes were retained.

Now the deep fen in the Rieker polder occurs as an almost coherent layer, extending from Haarlem, right through the Haarlemmermeer polder as far as Mijdrecht and from Sloten by Amsterdam as far as Zaandam and Uitdam. This layer is missed in the north-western corner of the Haarlemmermeer polder, i.e. in the place of the former Lake Spiering and farther south. The lower side of this deep layer of fen lies at about 11 to 13 metres below A.P. Still deeper at Sloten in some three borings, parts of a second old layer of fen were found and also repeatedly at Amsterdam and Zaandam. This layer must be distinguished from the former with which it was formerly identified. As a fairly coherent layer this deeper fen can be traced above the diluvium, to the north by Purmerend as far as Hoorn and Enkhuizen, to the west by Wormerveer, Beverwijk, and Velzen to IJmuiden. The upper one of these deep layers of fen can reach a thickness of about 1 M., the lower one is rarely $^1/_2$ metre thick.

So we may understand how the underground may have derived in former times and may still derive its fresh-water from the upper ground although this latter always carries brackish water itself.

But will the "layer of clay" which is 7 M. thick be permeable enough to render it possible that in the half century, elapsed after the draining of the Haarlem lake, under the polders to the north-

east of this drainage a layer of fresh-water of at least 50 M. thick may have accumulated? This means a yearly increase of at least one metre, or, if we take into account the interstices between the grains of sand, of about 0.30 M. pure water a year. Now this amount is pretty much the same as of the rain that can penetrate into the earth, while also all the other surface-water can furnish fresh-water to the underground, by which also the fresh-water, flown off to the deep polder, can be accounted for. In my former communication I already pointed out that the power of clay to transmit water is commonly underrated. The clay in our alluvial grounds is generally very impure, consists mostly of very fine sand and according as the percentage of this increases, its "permeability" becomes greater. The fattest clay of the Rieker polder at Sloten lies as a thin bank immediately under the superficial layer of fen and contains 30% real clay. From the 7 M. "clay" in the Rieker polder, one has to subtract first a couple of metres of sand, the rest is also much richer in sand than the fat upper layer mentioned. Now SPRING has proved that a layer of Hesbay's loam of 7 M. thickness admitted in 24 hours a movement of water of at least 0.036 to 0.045 M. [1]) which is ten to fifteen times more than the velocity calculated for the Rieker polder. A sample of loam, kindly sent me by that scientist, proved, on analysis by Dr. N. SCHOORL, to contain 21.5% clay i.e. about as much as our ordinary, pretty fat alluvial clay contains on an average. Experiments with fatter clay under pressure, as it is in nature, give me a much smaller velocity which however is still sufficient to explain the hydrological condition of the Rieker polder. Of these experiments I intend to give an account on a future occasion.

I wish to draw attention to a result of the experiments of SPRING already mentioned in my former communication, according to which, when the thickness of a layer of sand becomes very great with respect to the pressure-column of the water, the rate of filtration may by no means be taken inversely proportional to the thickness of the filter. On the contrary, SPRING found in this case the rate independent of the thickness of the filter. I can confirm this for clay and for this substance the pressure may even be relatively great and the thickness of the layer hundreds of times smaller on account of the so much greater resistance of clay than of sand. A layer of the fattest clay, obtained in the same way as the compressed fen, by squeezing out the water, having a thickness of

[1]) In this time namely a layer of water of 12 to 15 mm. thickness was transmitted.

15 cm., under a pressure of 80 cm. transmitted no less water than a layer of the same compressed clay of only 4 cm. thickness. Calculations like those on page 294 of Mr. DE BRUYN's communication, in which the rate of filtration through 9000 M. sand from the dunes is simply assumed to be $^1/_{9000}$ of the rate found in an experiment with 1 M. of the same sand lead consequently to erroneous conclusions. I also want to point out that in the coarse diluvial sand which forms the principal way for the horizontal movements of the water, the velocity of motion is about ten times as great as in sand from the dunes.

Under these circumstances I believe to be justified in maintaining my opinion that the water in the underground of some shallow polders is of autochthonous origin.

It is also clear now, how in many places in the Haarlemmermeer polder water can spring up which is as fresh as water from the dunes. So in the farm "het Botervat" on the Y road near the Kruisweg; in it I found as well in the driest periods as after much rain a quantity of chlorine of 35 to 37 mg. per litre, whereas in the same farm a well has been bored reaching just below the deep fen, in which the water contains an amount of chlorine of 235 mg. per litre. At numerous other spots of the Haarlemmermeer polder the presence of fresh-water in wells (which proved to be no rainwater, as I believed for some time) could be stated; it is also found at about one kilometre east of the just mentioned farm, besides on the Kruisweg between the Sloten road and the Sloter Tocht, on the Sloten road near the Slaperdijk. On the other hand the water in wells in the north-western part of that polder, in which the deep layer of fen is entirely absent, is brackish everywhere.

The water flowing under the compact alluvial cover from the higher environs of the Haarlemmermeer polder has there, as I showed in my former communication, a tendency to rise and so the salt-retaining property of the fen can here act in an opposite direction as in the shallower polders in which the vertical component of the water is directed downward.

As the old fen forms, as it were, a filter for sodium chloride, so in the shallower polders the "old sea-clay" by its high percentage of iron, keeps the water in the underground relatively free from sulphuric acid. The superficial fen in the Rieker polder contains so much compounds of sulphur that it has a very strong smell of sulphuretted hydrogen, when freshly dug. Water squeezed out from it proved on analysis by Dr. SCHOORL to contain no less than 408 mg.

SO_3 per litre, while that from a well, 44 M. deep, near the place where the fen had been taken, contained only 17 mg. SO_3 per litre. Already immediately below the clay, at a depth of ten metres below the meadow, the amount of SO_3 has become so small. In the iron-containing layer of clay, pyrites is namely formed by the well-known minerogenetic process, with previous reduction of the SO_3 compounds in the fen, which reduction takes place here with the help of sulphur-bacteria by which the freshly denuded fen is coloured yellowish.

Pyrites can indeed be shown to occur in the clay. And so this difference in the amount of SO_3 between the upper water and the deep groundwater is a proof for the origin of the latter from above instead of against it, as has been supposed.

Chemistry. — Prof. C. A. LOBRY DE BRUYN also in the name of Dr. S. TYMSTRA Bz. read a paper: "*The mechanism of the salicylacid synthese.*"

(This paper will not be published in these Proceedings).

Chemistry. — Prof. C. A. LOBRY DE BRUYN presents a paper of Dr. J. J. BLANKSMA: "*On the intramolecular oxydation of a SH-group bound to benzol by an orthostanding NO_2-group.*"

(This paper will not be published in these Proceedings).

Chemistry. — Prof. C. A. LOBRY DE BRUYN presents a paper of J. M. M. DORMAAR: "*The inversion of carvon and eucarvon in carvacrol and its velocity.*"

(This paper will not be published in these Proceedings).

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