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EXTREME SALT CONCENTRATIONS IN DEEP AQUIFERS IN THE NETHERLANDS

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ABSTRACT

In The Netherlands fresh water is mostly extracted from Pliocene and Quaternary aquifers and less often from Mesozoic aquifers. In these aquifers brackish groundwater is also present. A possible explanation of the salt distribution in the Pliocene and Quaternary aquifers has been given by several authors.

In this paper an attempt is made to identify the aquifer system including deeper aquifers in The Netherlands. An overview of chloride concentrations at greater depths is presented and some remarkable examples are mentioned. Attention is given to the explanation of the differences in quality which exist between the southern and northern region of the Eocene aquifer. In the southern region infiltration in the outcrop area in Belgium determines water quality. In the northern region local contact with salt diapirs which are broken through the Lower-Tertiary, leads to dissolving of salt minerals.

INTRODUCTION TO THE GROUNDWATER SITUATION IN THE NETHERLANDS

Fresh groundwater is the most important source for drinking water supply in The Netherlands. For this reason, investigation of the position of the interface between fresh and salt water and of the origin of salt water is of great importance.

Extraction of groundwater takes place from Pliocene and Quaternary aquifers and also in some parts of the country from Mesozoic aquifers. As a consequence of the geological history of The Netherlands salt water is still present in aquifers in coastal areas. In the whole country salt water is found in the less permeable beds underlying the aquifers.

According to Santing (ref. 1) the total volume of fresh groundwater is $500.10^9 m^3$. The volume of brackish and salt water might be about ten times higher because most Mesozoic, Tertiary and Quaternary deposits contain pore water. Sometimes water is also present in Paleozoic formations.

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The groundwater in the main aquifer usually flows with a velocity of some tens of metres per year. The brackish and salt water generally flows with lower velocities, because the hydraulic conductivity decreases with depth. Possible explanations for the presence of brackish groundwater at shallow depths have been given by Volker and Meinardi (refs. 2,3). The vertical chloride distribution might be explained by the theory of hydrodynamical dispersion in flowing groundwater. The presence of brackish and salt water at greater depths must be explained from geological, paleoclimatical and hydrological factors. This will be the topic of this paper.

Knowledge of the distribution of fresh and salt water and of the sources of salt water is of importance with respect to the safe extraction of fresh groundwater. The salt distribution at greater depths is also an indication of the isolating capacity of a clay layer overlying a deep aquifer. This is of importance in view of the protection of fresh aquifers against contamination with fluids, which are injected into a deep aquifer.

IDENTIFICATION OF THE AQUIFER SYSTEM

The Plio-Pleistocene main aquifer is underlain by Miocene and Oligocene clay formations with a thickness of one hundred metres and more. Below the Oligocene clay within the Eocene some aquifers can be recognised. Among these aquifers the Brussels Sand is probably the most important one.

Eocene sediments occur in two areas. One in the southwest extending into Belgium and South England and the other one in the northeast extending into North Germany. In a broad zone separating these areas the Eocene has completely been eroded during the Oligocene due to uplifting (ref. 5).

Some indication of the geohydrological properties of deep aquifers may be derived from table 1. Refs. 4, 6, 7 and 8 have been used in order to compile this table.

A cross-section through the S.W. Netherlands is presented in figure 1. This cross-section is a geohydrological interpretation of a stratigraphical section presented by Keizer and Letsch (ref. 5). The thickness of the Quaternary varies from zero till over 600 m, while the thickness of the Tertiary varies from zero till over 800 m. Of the Under-Tertiary deposits probably only the Middle-Eocene aquifer in the south-western and the north-eastern parts of the country is of interest. The Paleocene aquifer is only found in the south-west. Mesozoic aquifers are present at shallow depths in the extreme south and along the German border.

EXAMPLES OF GROUNDWATER QUALITY

In figure 2 a map is presented with chloride data of groundwater at greater depths. Most of the collected data are concerned with the Plio-Pleistocene main aquifer. Chloride contents of Under-Tertiary, Mesozoic and Paleozoic aquifers are especially

TABLE 1.

Simplified lithological and hydrological characterization of aquifers

Stratigraphy		lithological characterization	hydrological characterization	indication of hydraulic conductivity (m/d)
Quaternary	Holocene	clay, peat	covering layer	-
	Pleistocene	coarse sand	main aquifer	10-50
Tertiary	Pliocene	silty sand, clay	less pervious part of the main aquifer	1-5
	Miocene	clay	base of aquifer	-
	Oligocene	clay	aquiclude	-
	Upper Eocene	clay	aquiclude	-
	Middle Eocene	sand/marl	first deep aquifer	0.1
	Under Eocene	clay	aquiclude	-
	Paleocene	sand/ clay	second deep aquifer	0.1
Mesozoic	Cretaceous	marl/claystones	third deep aquifer	2
	Jurassic	shale/claystone	aquitard	-
	Triassic	sandstone	fourth deep aquifer	0.1
Paleozoic	Permian	rocksalt/sandstone	impervious/?	
	Carboniferous	sandstone/coal	?	?

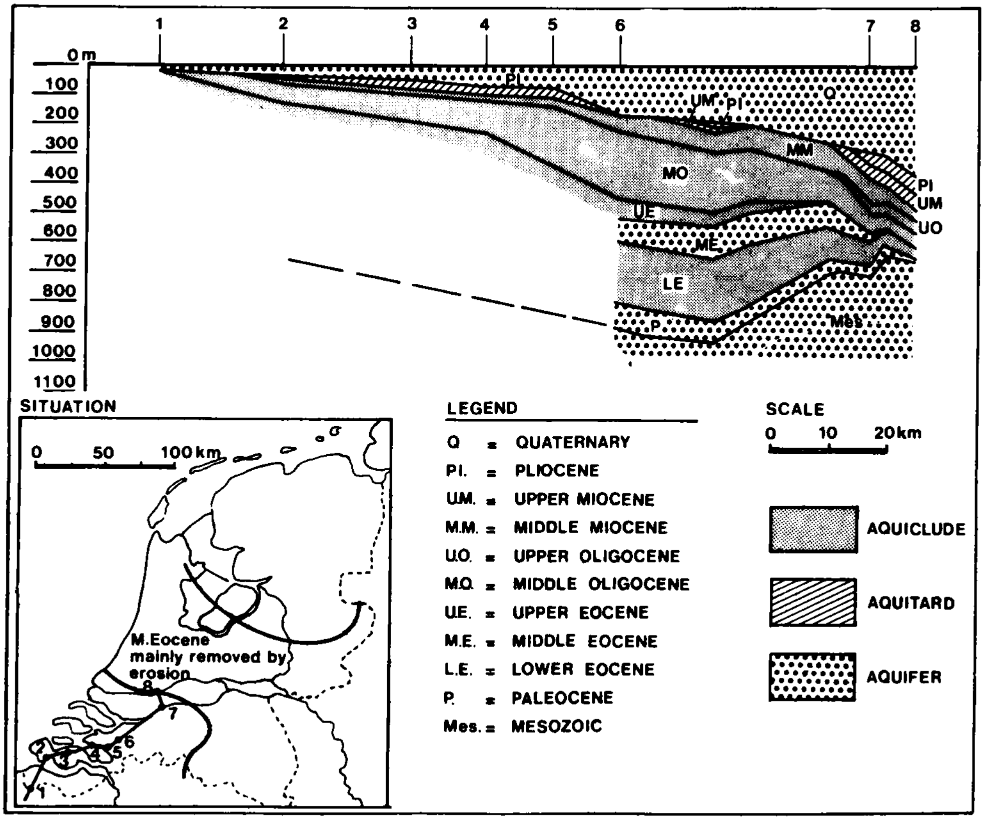

Figure 1. Schematic geohydrological section through the S.W. Netherlands (Geological data modified after Keizer and Letsch, 1963).

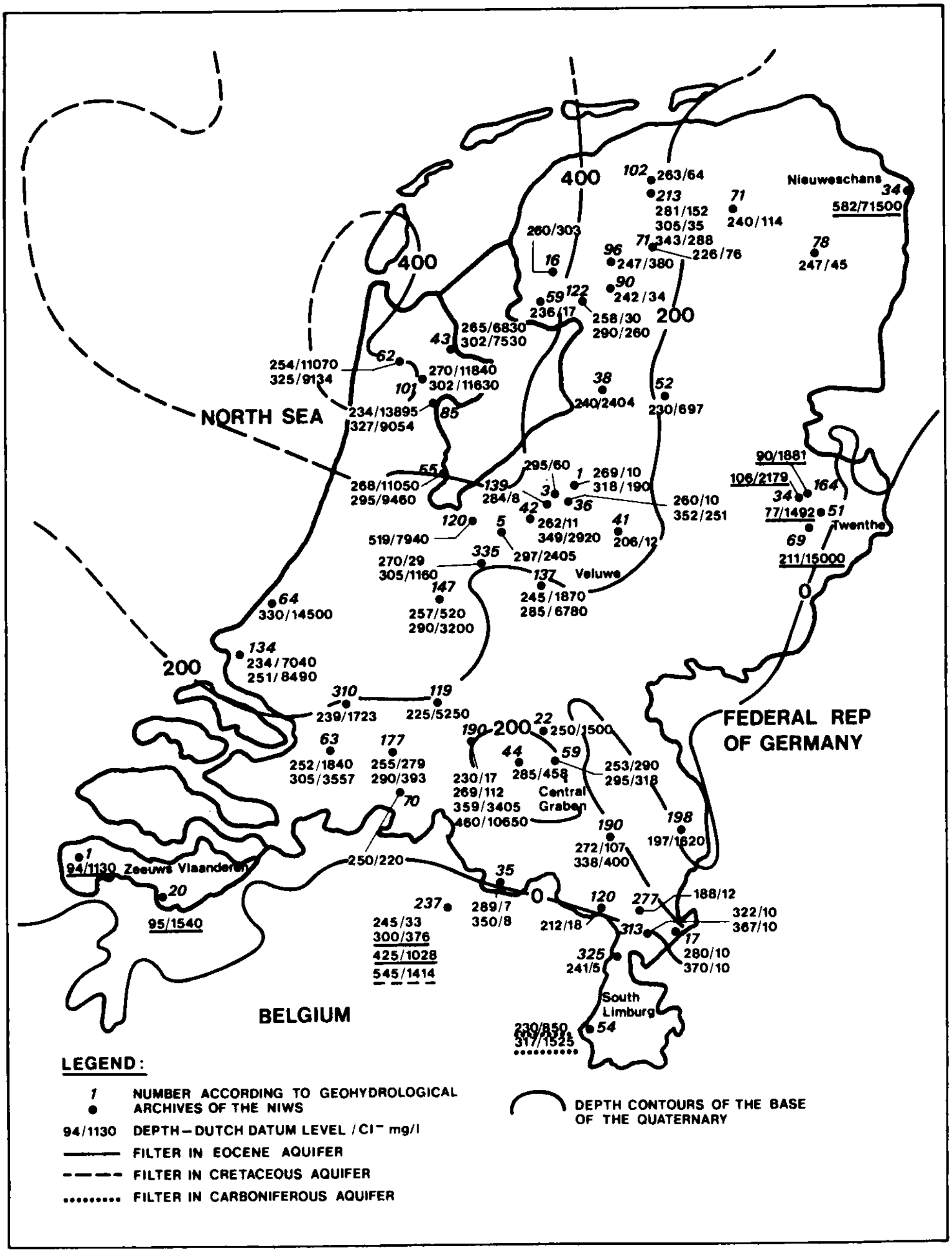

Figure 2. Chloride contents of groundwater at greater depths in The Netherlands

marked. Some remarkable areas are firstly the Veluwe in the central part of The Netherlands where fresh water is found at a depth of about 300 m, and secondly, the Central Graben in the southeast, where fresh water is also present at greater depths.

Water quality in an Eocene aquifer is known at Nieuweschans (extreme N.E.), Twenthe, Zeeuws Vlaanderen and Belgium. The quality of the groundwater in the Brussels Member shows important differences between the southern and the northern area. At Mol (Belgium) the chloride content is 376 mg/l (ref. 9), while at Nieuweschans a chloride content of 71500 mg/l has recently been analysed by the National Institute for Water Supply. Some other analysed parameters are presented in table 2. In the Eocene of Twenthe values of up to 15000 mg/l Cl^- have been found (ref. 7).

In South Limburg the quality of water within beds of Carboniferous age is known from a well at Maastricht (ref. 10) and from water out of the former coal mines. Kimpe (ref. 11) reports a chloride content of 10700 mg/l at 860 m depth but also fresh water (25 mg/l) at 500 m depth. In South Limburg the Carboniferous is overlain by Mesozoic and Tertiary strata with a thickness up to a few hundred metres which enables local infiltration.

In places where the Carboniferous has been found at great depth the composition of the pore water is different from the mentioned examples in Limburg. For instance, near Emden (Germany) at about 4000 m depth the salinity is 26500 mg/l (ref. 12).

A TENTATIVE EXPLANATION OF WATER QUALITY IN THE EOCENE AQUIFERS.

To explain the large differences in salt concentrations in the Eocene aquifers the two most important factors are: 1, the hydrological system of the aquifers under consideration and 2, the interaction with solid minerals present in or at the boundary of the aquifer.

The relatively low salt concentrations at Mol can be explained by infiltration in the outcrop area further south in Belgium. The same applies in Zeeuws Vlaanderen.

A potential source of salt might be formed by Zechstein salt layers. Because these layers are present below the northeastern part of The Netherlands (fig. 3), this could be the cause of the extremely high salt content at Nieuweschans. The salt layers are covered by 1000 till 2000 m of Mesozoic strata. Only locally in Twenthe, Drenthe, Groningen and below the North Sea, rock-salt has been found at shallow depths due to halokinetic movements.

Salt diapirs have sometimes broken through the Mesozoic and through the bottom parts of the Tertiary. See for instance the salt dome of Schoonlo, Zuidwending en Winschoten (fig. 4, refs. 13, 14). The top of a salt dome which has been in contact with surface water or water in shallow aquifers with a high flow rate is usually covered with a caprock. This caprock provides some protection against further dissolving.

TABLE 2

Groundwater analysis of Nieuweschans (Brussels marl) compared to sea water.

Symbol	concentration in groundwater (mg/l)	concentration in sea water (mg/l)
Cl	71500	19000
Na	43500	10800
SO_4	1800	2712
Mg	950	1290
Ca	1250	411
K	220	392
HCO_3	183	140
CO_2	109	--
Br	140	67
Sr	165	8
F	<0.1	1.3
Li	4.6	0.170
I	2.5	0.064
Mn	3	0.0004

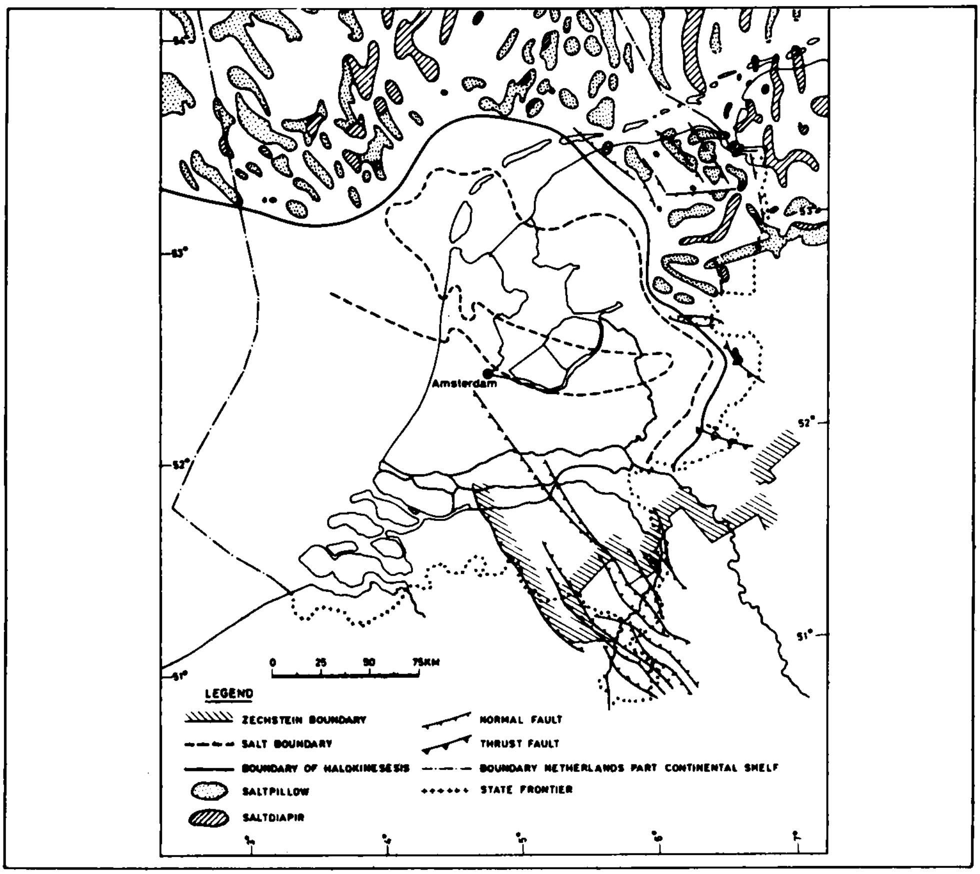

Figure 3. Extension of Zechstein basin in The Netherlands and The Netherlands part of the continental shelf (P. Heybroek, U. Haanstra, D.A. Erdman with additional data by H.M. Harsveldt)

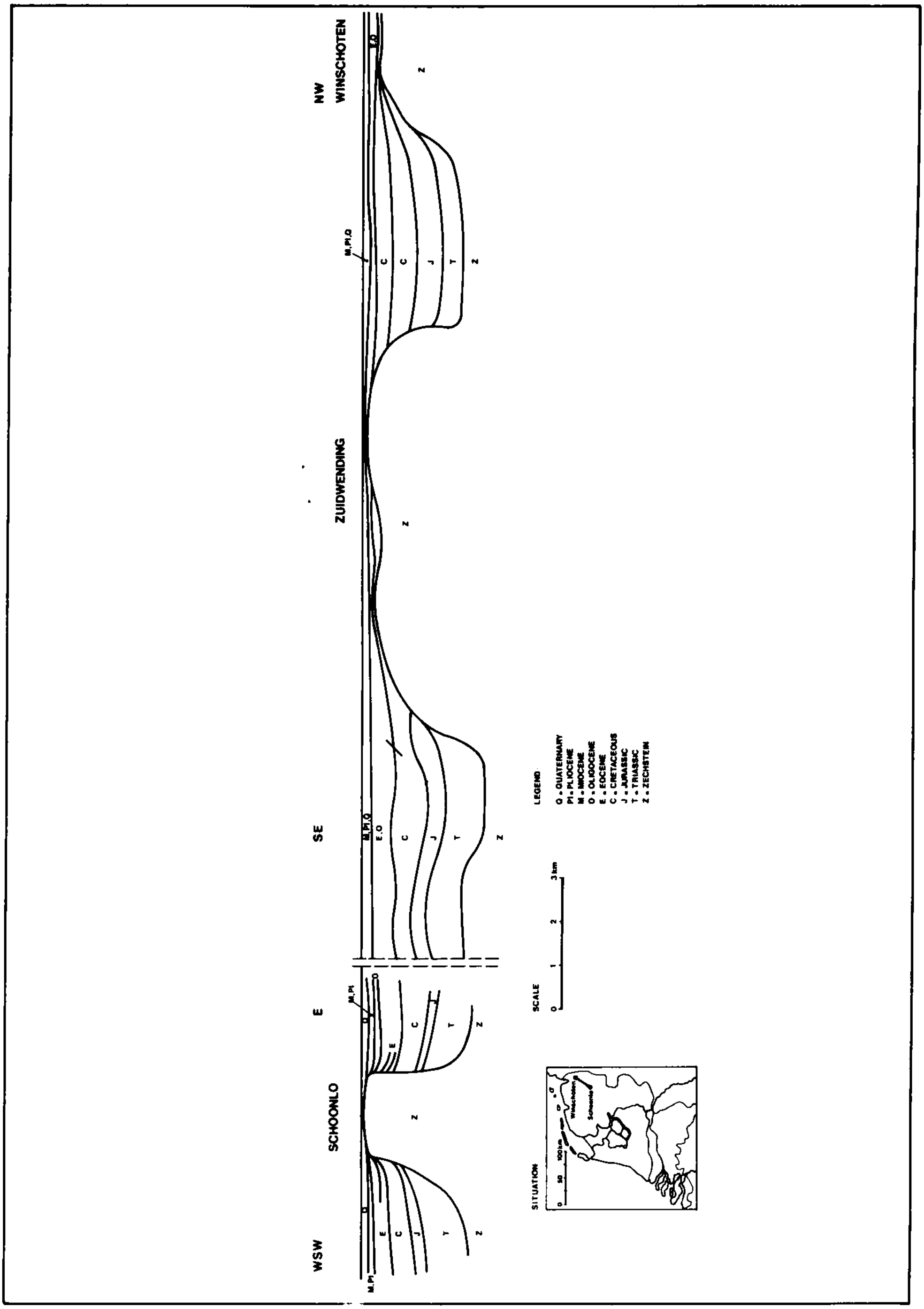

Figure 4. Profile over Schoonlo, Zuidwending and Winschoten salt-diapirs (after Mulder and Harsveldt)

Along the flanks of a diapir a contact surface between Under-Tertiary aquifers and rock-salt might be possible.

Groundwater flowing along the flanks of a salt dome will take up dissolved rock-salt. Due to hydrodynamical dispersion, a broad zone downstream will become more or less saline. Calculations for this system have been made by Glasbergen (ref. 15).

The origin of the groundwater at Nieuweschans can be concluded from a comparison of the relative concentrations of the ions in the water from the Eocene aquifer with sea-water. For instance, in the groundwater the Cl- and Na- concentrations, expressed in meq/l, are the same, while in sea-water more Cl than Na is present. The Cl/Br-ratio in this groundwater is 511 while for sea-water a ratio of 284 is given. In rock-salt the average Cl/Br- ratio over a large volume is higher than in sea-water. Together with the other relative differences in concentration, the conclusion seems justified that the groundwater quality is dominated by the dissolving of rock-salt.

From the distribution of salt in the Oligocene clay and Miocene clay (fig. 5) it becomes evident that the dissolved salt has not yet passed the clay barrier.

The flow of groundwater below the Oligocene clay is difficult to explain. Infiltration in the outcrop area, approximately 90 km south of Nieuweschans, will occur. Infiltrating water could also reach deeper aquifers through fault zones around salt diapirs. The extremely high salinity, which was analyzed, would be determined in both these cases by salt dissolving from salt diapirs in the area between Twenthe and Nieuweschans.

The flow within the Eocene aquifers will be limited by the low transmissivity and a number of interruptions of these strata by salt diapirs. On the other hand, the

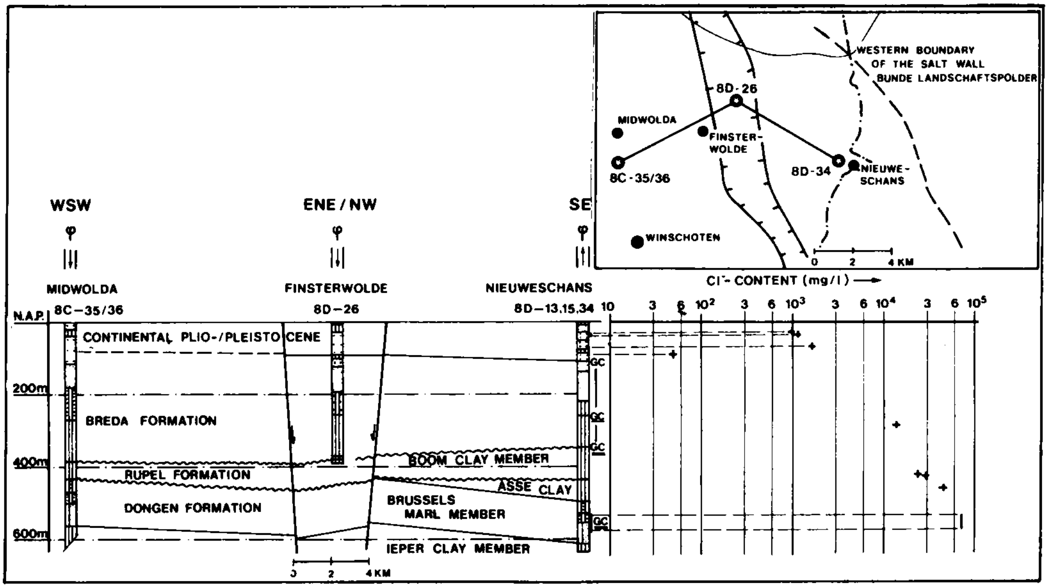

Figure 5. Geological section through Nieuweschans and vertical chloride distribution (Geological data by H.M. van Montfrans and H. Zwaan)

hydraulic gradient in the last phase of the Weichselian ice age might have been higher than the present one, due to the low sea level.

The $\delta^{18}O$-value is negative, which suggests that recharge of the aquifer still occurs or has been occurred. The carbon-isotope determination of the water extracted at Nieuweschans indicates that infiltration has taken place in the late-Pleistocene period. This age of the groundwater does not contradict the above presented hypothesis of infiltration in Twente and the northward flow of groundwater to Nieuweschans. But infiltration at shorter distances through faults seems more acceptable.

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