

FRESH AND SALT GROUNDWATER IN THE DUTCH COASTAL AREA IN RELATION TO GEOMORPHOLOGICAL EVOLUTION

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ABSTRACT

De Vries, J. J. 1981 Fresh and salt water in the Dutch coastal area in relation to geomorphological evolution. *In*: A. J. van Loon (ed.): Quaternary geology: a farewell to A. J. Wiggers – Geol. Mijnbouw 363-368.

Historical sequences of encroaching seawater and recharge of fresh water under different geological and geomorphological conditions during the Quaternary are responsible for a rather complicated distribution of fresh and salt groundwater in the Dutch coastal area. A qualitative genetic model is proposed based on the Holocene landscape evolution.

INTRODUCTION

The complicated spatial distribution of fresh and salt water in the subsurface of The Netherlands in relation to the hydrogeological evolution of the coastal area, has been under discussion for a long time (e.g. VERSLUYS, 1918; VOLKER, 1961; VAN DAM & MEULENKAMP, 1967; GEIRNAERT, 1973; DE VRIES, 1974; MEINARDI, 1975; ICW, 1976; ENGELEN, 1981). These authors deal with either a particular area or with a special aspect of the processes involved. Recently more information has become available for the area between Den Helder and The Hague through systematic mapping by the Groundwater Survey (TNO), the Geological Survey and the Institute for Land and Water Management Research (ICW).

The present study is based on a combination of an overall view of the fresh-salt water² distribution, derived from the reports of the surveys mentioned above, and the hydrogeological history of the area during the Quaternary. A tentative genetic explanation is proposed for the present groundwater condition, especially based on the Holocene geomorphological evolution of the coastal district. For the Quaternary-geological history of the area one is referred to e.g. DE JONG (1967) and OELE ET AL. (1979).

GENERAL SCOPE

From a hydrogeological viewpoint, The Netherlands can be considered as a semi-circular groundwater basin, which is continuous to the west and to the north. The basin is mainly filled with coarse Pleistocene fluvial deposits with a base of fine-grained Tertiary sediments in the east and clayey Early-Pleistocene sediments in the west. The Tertiary as well as the Early-Pleistocene deposits are of marine origin and contain connate salt water. The thickness of the Pleistocene aquifer increases northwestward and shows an average value of about 200 m in the coastal area. The Pleistocene aquifer is covered in the western and northern parts of the country with Holocene clays and peat, reaching a maximum thickness of over 20 m. These deposits were formed in a tidal area with alternating salt, brackish and fresh-water character.

During the Quaternary, the western part of The Netherlands has been repeatedly invaded by the sea. Much of the Pleistocene aquifer is therefore filled with saline groundwater. The spatial distribution of fresh and salt water is caused by the historical sequences of encroaching sea water and discharge and recharge of fresh water. A relatively rapid redistribution of salt and fresh groundwater was initiated by the morphological changes that started about 1000 years ago. The lower older dune ridges on top of the coastal barriers were covered from that moment for a part by higher so-called Younger Dunes, reaching local elevations of over 30 m. The

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² In this study salt water is defined as water with a chloride content of more than 500 ppm.

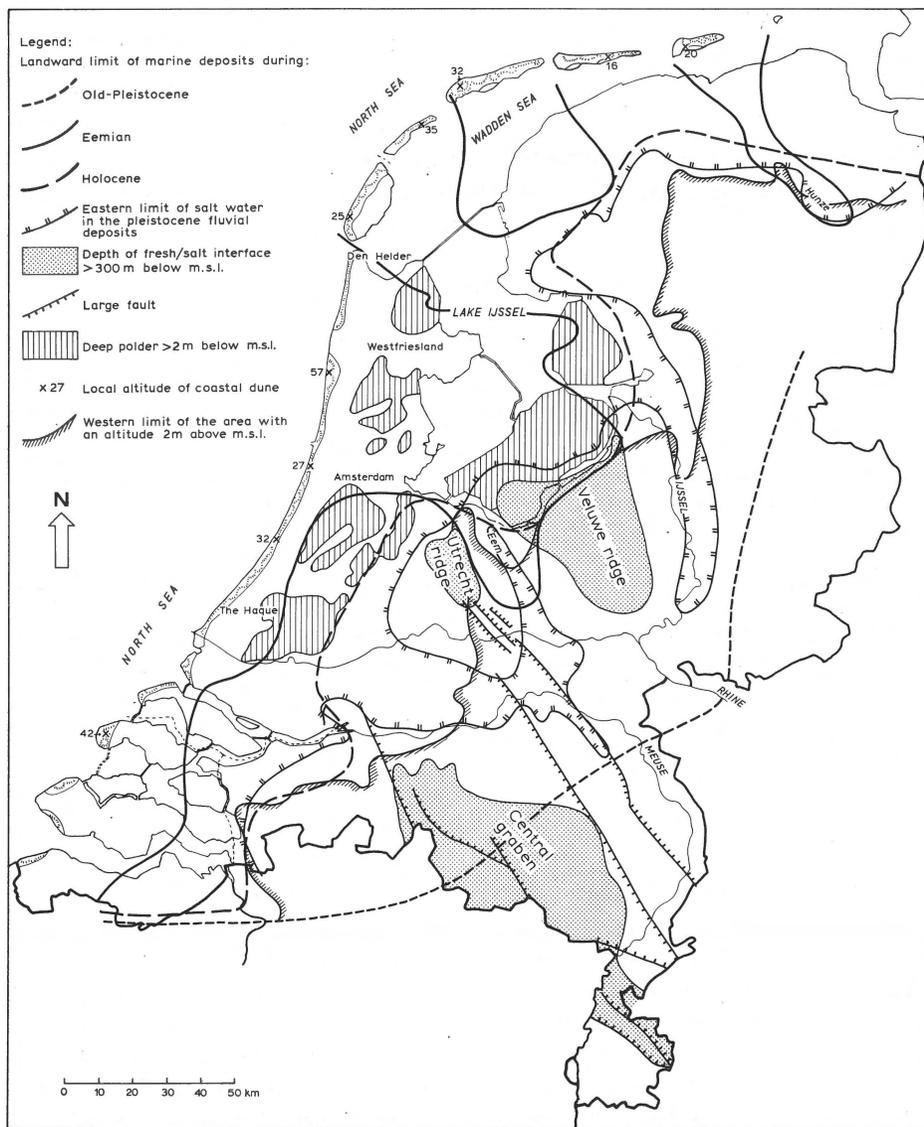


Fig. 1 Large-scale topographic and geologic structures, former coastlines and the fresh-salt water interface at greater depth.

shape and location of the initial fresh-water lenses below the dune area must have been modified by these morphological changes. About 700 years ago, the creation of the polder landscape started, initially by land drainage and later also by the reclamation of lakes. Due to the artificially maintained groundwater table in the polders and its lower elevation, a more or less continuous flow of groundwater from the higher regions to the lower ones was initiated, causing upward seepage of groundwater from the Pleistocene aquifer into the polder area. The loss of water from the Pleistocene aquifer was partly compensated for by subsurface intrusion of sea water.

Figure 1 shows the location of former Quaternary coastlines and the present interior salt/fresh-water line in the Pleistocene aquifer; table I lists the stratigraphy.

Table I Schematic stratigraphy for the Dutch coastal area. x = marine influence.

	period	approx. age
	HOLOCENE	x 10 ⁴ years BP
PLEISTOCENE	Weichselian	7 x 10 ⁴ years BP
	Eemian	x
	Saalian	
	Holsteinian	x
	Elsterian	
	Cromerian	x
		2.5 x 10 ⁶ years BP
	TERTIARY	

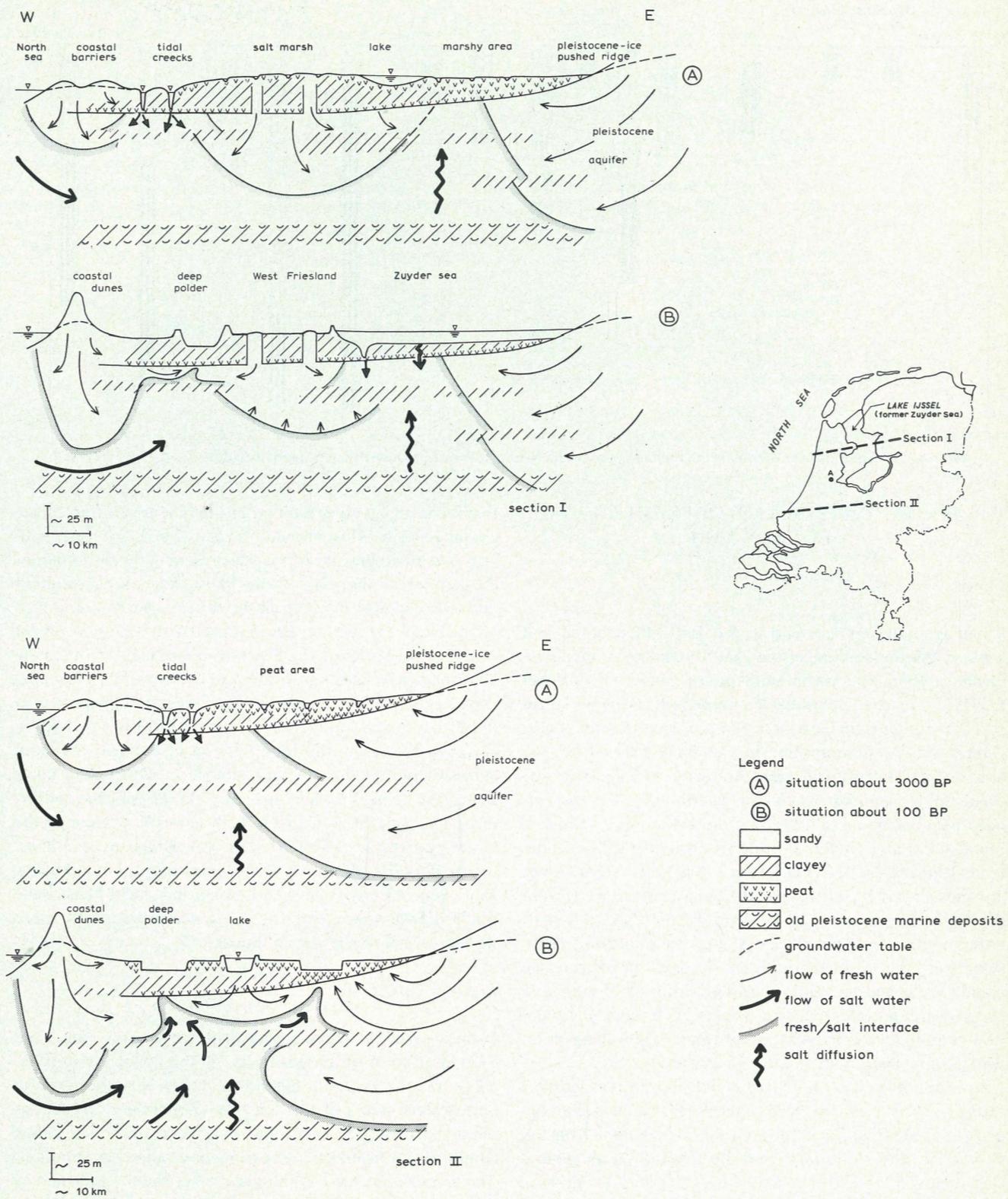


Fig. 2 Schematic hydrogeological sections through the Dutch coastal area, showing the movement of fresh and salt water in connection with the geomorphological conditions about 3000 years and 100 years before present.

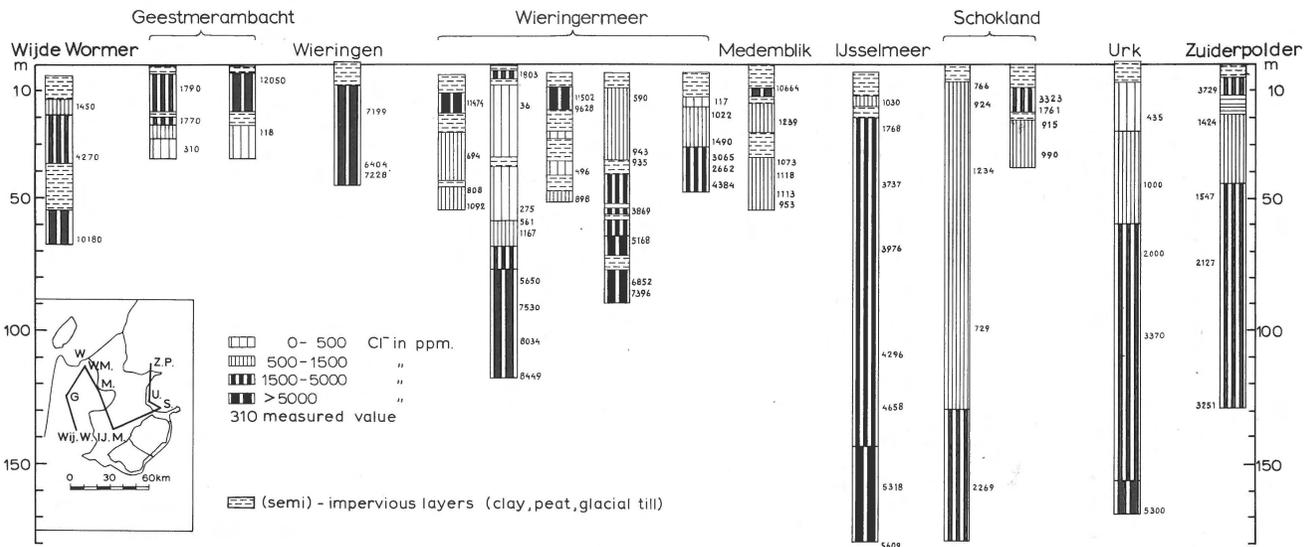


Fig. 3 Actual chloride distribution in boreholes in the Zuyder Sea area and North Holland (horizontal distances not to scale).

THE SPATIAL DISTRIBUTION OF FRESH AND SALT GROUNDWATER

General processes

Saline groundwater is found in the Early Pleistocene and Tertiary marine deposits of the lower boundary of the Pleistocene aquifer. The maximum depth of this lower salt/fresh interface is reached below the ice-pushed ridges in the central part of the country and in a large graben structure in the south. Deeply infiltrated rainwater in the high ridges (with an altitude up to 100 m), and a great thickness of fluvial deposits filling the graben may explain this distribution. The easternmost penetration of salt water in the Pleistocene aquifer is found in the large southeast-northwest oriented valleys of the rivers Rhine, Eem, Yssel and Hunze. The salt-water tongues are, most probably, the result of dragging up of salt water from the marine deposits at greater depth by the upward flow of groundwater below these valleys (Fig. 1). Other salt intrusions from the lower marine deposits into the Pleistocene aquifer are connected with (1) upward diffusion of salt into a stagnant groundwater body and dispersion through horizontal flow of groundwater at greater depth and (2) upwelling of salt water below deep polders through upward seepage.

Invasion of the sea took place mainly in four periods after the Early Pleistocene: in the Cromerian, Holsteinian, Eemian and Holocene (Fig. 1 and Table I). The intruded salt from the Cromerian, the Holsteinian and the Eemian sea in general was removed from the coarse fluvial deposits by flushing during the subsequent continental Weichselian, which lasted some 70,000 years. The presence of fresh water directly below marine Eemian clay in most areas supports this idea. Exceptions occur in the northern part of Friesland and near Amsterdam, where saline water from the Cromerian/Holsteinian and

Eemian respectively are found in sandy lenses within clayey glacial deposits. Most probably a zone of brackish water with an eastward dipping interface was present in the lower part of the aquifer at the end of the Pleistocene, as a result of diffusion and dispersion of salt from below (MEINARDI, 1975).

The Holocene sedimentation started with the development of a thick peat layer on the Pleistocene surface, in front of the invading sea. Subsequently, the peat was covered by lagoonal clayey deposits. These less-pervious layers initially protected the Pleistocene aquifer from salt-water intrusion by bottom currents. However, the transgression of the sea was more aggressive during the younger Holocene. Deep tidal inlets came into being, cutting partly into the Pleistocene subsurface. This caused a relatively high chloride content in the larger part of the coastal area in both Holocene and Pleistocene deposits. But fresh-water lenses are still found below clay layers of Early Holocene, Eemian and glacial Pleistocene origin. Furthermore, extensive fresh-water lenses have been developed below the coastal dunes.

Regional conditions

In the area of Westfriesland (north of Amsterdam, Figs. 2 and 3), a large fresh-water lens occurs in the upper Pleistocene, east of the brackish zone behind the dunes. Near the northern and western limits of this lens (Wieringermeer and Geestmerambacht), fresh water has only been preserved below confining clay layers, creating an inverse salinity distribution. The Westfriesian fresh-water occurrence can be explained by the Holocene history of the area. The top of the Holocene sediments, which is slightly below mean sea-level at present, was formed about 3000 years ago at an elevation of approximately 1.5 m above mean sealevel at that time. Subsequently the area was covered by a peat layer, which has disappeared

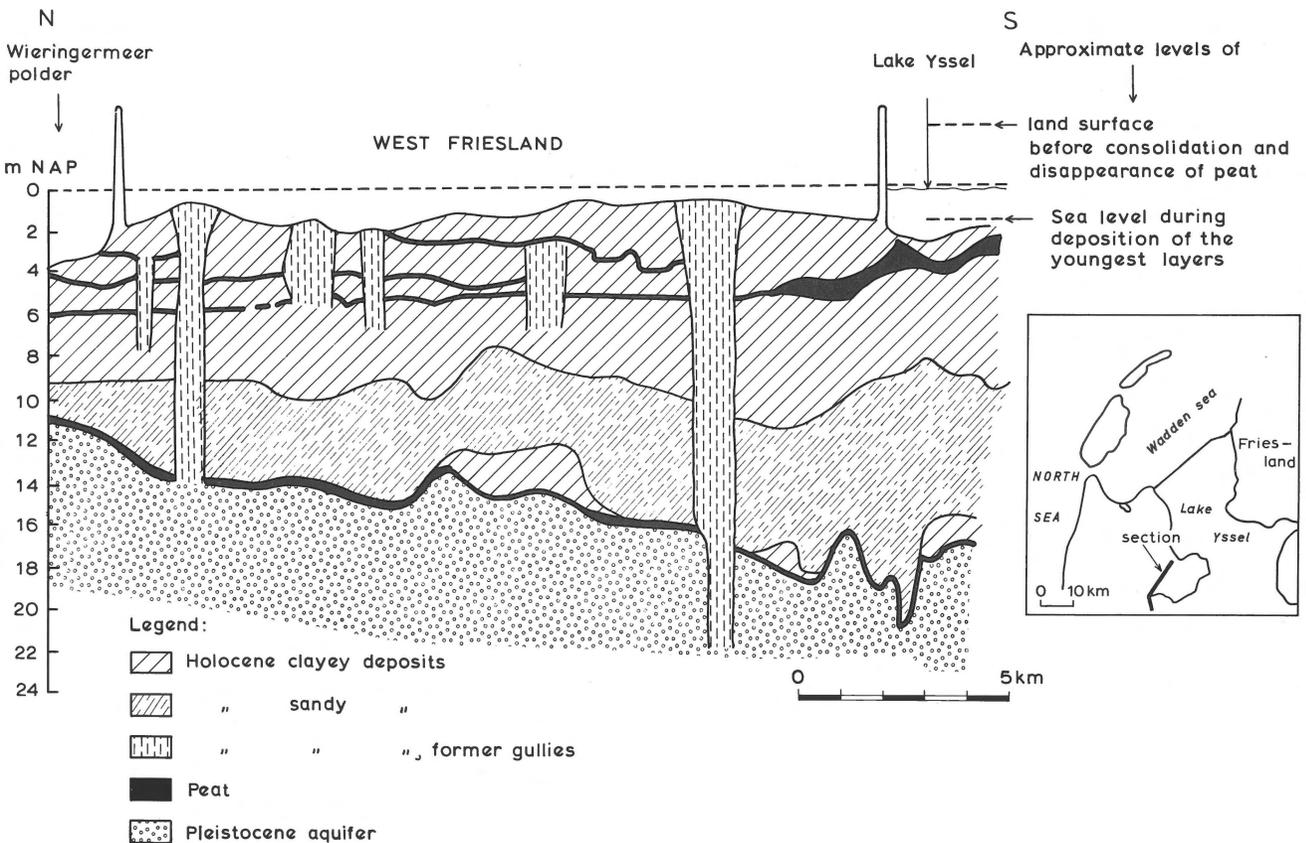


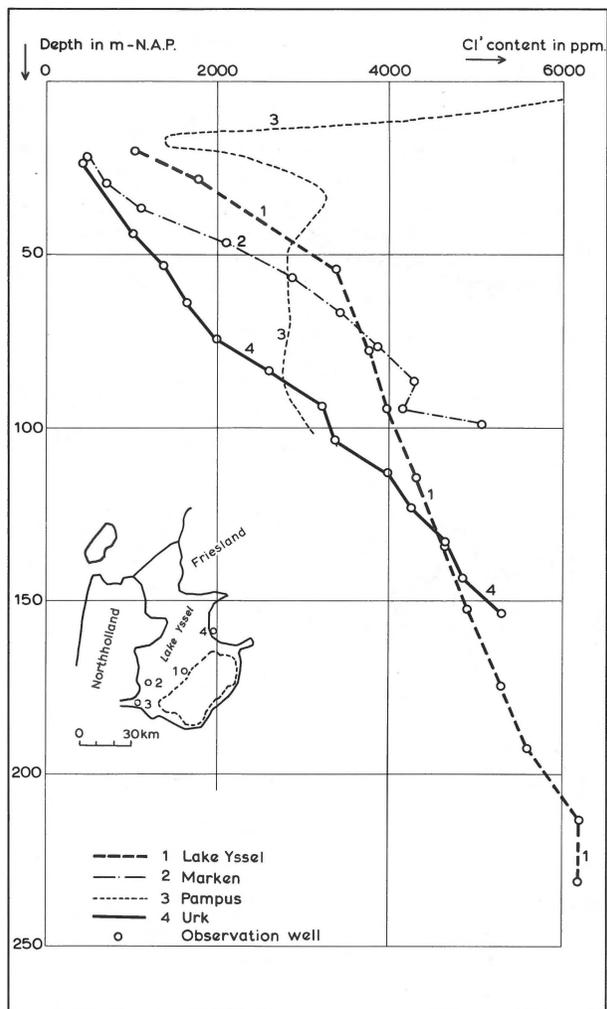
Fig. 4
Geological section showing wide and deep tidal inlets buried in the Holocene deposits of Westfriesland, and the land surface relative to former sea level (after Pons & Wiggers, 1959/1960).

since, so that Westfriesland has been some metres above sea level for more than 1000 years. The clayey tidal-flat deposits have been dissected in this area by many sand-filled channels, some of which exceed a width of 1000 m and penetrate deeply into the underlying Pleistocene (Fig. 4). The combination of a relatively permeable soil and a high elevation may have caused a deep infiltration of rainwater and the forming of a fresh-water lens, analogous to those below the coastal dunes. Evidently, this fresh-water lens is not in hydraulic equilibrium with the present sea level, and will therefore have been submitted to an upward pressure from the surrounding salt water. However, a number of deep polders have been created in the area around Westfriesland, especially in this century through the reclamation of parts of the former Zuider Sea. As a result the piezometric level in the Pleistocene aquifer has been lowered to more than 2 m below m.s.l., restoring the old equilibrium.

East of Westfriesland, the former Zuider Sea area shows neither strong Holocene salt intrusion, nor fresh-water infiltration. The chloride content in the Pleistocene deposits increases regularly with depth, indicating the predominance of diffusion from below (Figs. 3 and 5). Before the enclosure of the Zuider Sea in 1932, the chloride content in the

Holocene deposits decreased from about 6000 ppm at the top, to less than 1000 ppm at a depth of about 12 m. This vertical chloride distribution was quantitatively explained by VOLKER (1961) by downward salt diffusion from the Zuider Sea, which used to have a chloride content of about 6000 ppm. This process started in Medieval times when the Zuider Sea had come into being by destructive invasion of the sea through a tidal inlet into this former peat area. Evidently the Holocene clayey deposits prevented the salt-water intrusion into the Pleistocene by bottom currents, for there were no deeply incised tidal gullies, opening up the aquifer from above.

The morphology of the area between Amsterdam and The Hague is dominated by a central zone with deep polders, bounded by a coastal dune belt in the west and the Utrecht ice-pushed ridge in the east. Fresh groundwater from these ridges and salt groundwater from greater depth, discharge into the polder area as upward seepage. Furthermore, salt-water intrusion is observed along the northern and southern limits of the area, where Young Holocene tidal inlets and estuaries dissected the coastal barriers. Local groundwater-flow systems connected with the polder topography are superimposed on the regional systems (Fig. 2).



CONCLUSION

A reconstruction of the Quaternary geological and geomorphological history is a tool for understanding the present spatial distribution of fresh and salt water in the subsurface of a coastal area. A geological survey will however yield only qualitative models of a hypothetic nature, which need to be tested subsequently by hydraulic and hydrochemical methods. Quantitative deductions ask for rather accurate morphological reconstructions, necessary to arrive at proper boundary conditions. Until now this state has not been reached in The Netherlands, in spite of recent very intensive Quaternary-geological research and groundwater survey. A combined effort is needed; let this be a first trial.

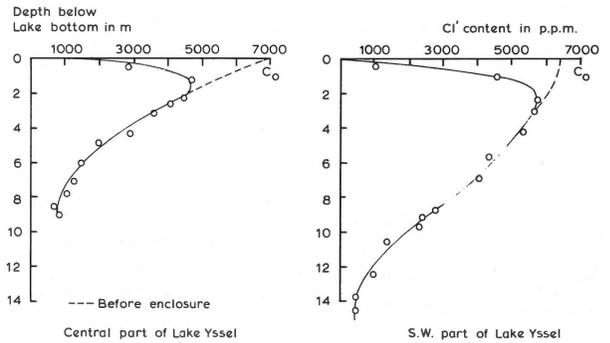


Fig. 5.
Vertical chloride distribution in the subsurface of the former Zuyder Sea area (after Volker, 1961).

ACKNOWLEDGEMENTS

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ENVIRONMENTAL CHANGES IN THE NORTHERN ANDES AND THE EXTINCTION OF MASTODON

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ABSTRACT

Van der Hammen, T. 1981 Environmental changes in the Northern Andes and the extinction of *Mastodon*. In: A. J. van Loon (ed.): Quaternary geology: a farewell to A. J. Wiggers. — Geol. Mijnbouw 60: 369-372.

The presence in the Northern Andes of a drier climatic phase between c. 21,000 and 14,000 BP resulted in contacts between open, dry vegetation types and stands of páramo vegetation. The stratigraphical position, in conjunction with the results of ¹⁴C-dating, point to the presence of large populations of *Mastodon* at that time.

When at the beginning of the Late Glacial the climate became wetter and gradually warmer, the two kinds of open vegetation became separated by montane forest and must have rapidly decreased in area. This shrinking of the *Mastodon* habitat must have reduced the population size considerably, which, together with the deleterious influence of Man, must have been the major cause of the extinction of *Mastodon* in that region.

The maximum extension of land ice in the world during the Last Glacial was apparently reached around 20,000-18,000 B.P., as is evident from a considerable number of data obtained from studies of the continents and oceans. At the same time it represents the temperature minimum of the last 50,000 years in many different places on Earth, and, moreover, often coincides with (part of) a relatively dry interval of the Last Glacial (c. 21,000-14,000 B.P.) (see, e.g., PETERSON ET AL., 1978; VAN DER HAMMEN, 1979).

Recent studies in the Colombian Cordillera Oriental (Sierra Nevada del Cocuy) showed, however, that the maximum extension of glaciers in that area has to be placed earlier (i.e., before approximately 24,000 B.P.), probably between 25,000 and 45,000 B.P. (VAN DER HAMMEN ET AL., 1980/81; VAN DER HAMMEN, 1980). The lowest position of the altitudinal forest line is found in the period between 21,000 and 14,000 B.P., however, and the annual temperatures were at a minimum then and coincided with the above-mentioned world-wide situation; this interval is also one with rather extremely low amounts of annual rainfall (VAN GEEL & VAN DER HAMMEN, 1973). On the other hand, the period before 21,000

(especially before 25,000 B.P.) shows higher lake levels on the high plains of the Cordillera Oriental (owing to a higher effective annual precipitation), later on with somewhat higher forest lines and (as mentioned above) lower reaching glaciers. It is, furthermore, noteworthy that the period before 25,000 B.P. shows the existence of a broad *Polylepis*-zone forming the upper forest line (VAN GEEL & VAN DER HAMMEN, 1973). After 21,000 B.P. this zone disappeared almost completely.

Although the generally low position of the glacier terminals during the Last Glacial was determined by the, upon the whole, much lower annual temperatures, the effect of very high and very low rainfall figures dominated apparently over the trend towards decreasing temperatures, when the period before c. 24,000 (probably between 30,000 and 25,000 B.P. and before) and that between 21,000 and 14,000 B.P. are compared.

A generalized scheme for major changes of vegetation and climate in the area may, therefore, be drawn as shown in figure 1.

For the area at the latitude of the high plain of Bogotá (c. 5°N) the probable sequence for the same time interval is shown in figure 2. The general picture is the same as that given for the Cocuy area, but, in addition, the dry vegetation types (open or half-open xerophytic vegetation and dry forest) at

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S.N. del Cocuy

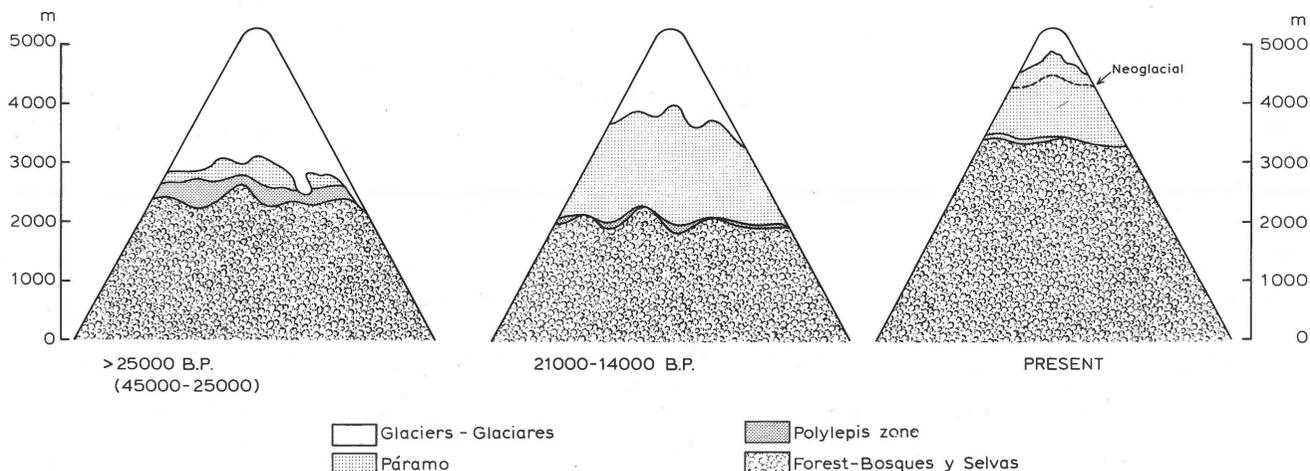


Fig. 1 Principal, successive vegetational changes in the Sierra Nevada del Cocuy (Colombia) during the last 45,000 years.

present (or originally) dominating the dry Magdalena valley and lower slopes of the Cordillera, presumably extended much farther upslopes during the period between 21,000 and 14,000 B.P. This tentative conclusion is reached on the basis of data relating to a generally very dry climate (and estimated to be less than half of the present values) and on the pollen diagram of Laguna de Pedro Palo at 2000 m on the western slopes of the Cordillera Oriental, below the 'Sabana de Bogotá' (VAN DER HAMMEN, 1974). This diagram shows a virtually tree-less stand of vegetation at the beginning of the Late Glacial, and the very low tree-pollen values suggest that no forest was present at least not until much farther downslopes (the lake in question is situated on an isolated 'saddle' with relatively steep slopes directly facing the tropical valley). Apparently during the 21,000-14,000 B.P. Upper Pleniglacial, the more or less open dry vegetation of the Magdalena valley was in contact with the open high Andean páramo vegetation, somewhere below 2000 m alt. This situation is at present known from some of the higher parts of the very dry Chicamocha valley, where around 3000 m alt. dry open vegetation types are in contact with páramo vegetation, and *Opuntia* (Cactaceae) and *Espeletia* (Compositae) grow together. In the past, therefore, they need not have been separated by a forest zone either. While before c. 25,000 B.P. the lower dry vegetation and the open cold páramo vegetation were most probably separated by a broad zone of montane forest, this was probably not the case during the 21,000-14,000 B.P. interval, both zones of more or less open vegetation being connected at that time. During the later Late Glacial, however, when the climate became less cold and considerably wetter again, a zone of montane forest must have formed which separated the two zones again. Finally, during the Holocene, the major part of the Sabana de Bogotá became forested when the páramo zone retired to the higher peaks of the mountains. However, some relatively small areas of open dry vegetation became established in the rain shadow on the

eastern slopes of the mountain bordering the high plain in the west, and persisted till the present (Fig. 2). In these dry areas of the western Sabana de Bogotá and on other high plains, and in the dry Magdalena valley, bones of *Mastodon* are frequently found in the youngest glacial successions of colluvial deposits. The first 'fluorine-dating' of a *Mastodon* tooth from Mosquera suggested a Last Interglacial to early Last Glacial age (VAN DER HAMMEN, 1965). New data on the stratigraphy of the 'Mondoñedo Formation' in which the tooth was found and several new ^{14}C -dates are mentioned in VAN DER HAMMEN ET AL. (1980). Another ^{14}C -date was published by CORREAL URREGO (1980) (see also below).

BOMBIN & HUERTAS (1980) studied the material of mastodons present in Colombian museums, and came to the conclusion that they belong to the genera *Cuvieronius*, *Haplomastodon*, *Stegomastodon* and *Notiomastodon*. However, no further documentation has been published so far, and the name '*Mastodon*' will be used here in a general sense.

The stratigraphic position of most of the *Mastodon* remains in the Mondoñedo Formation seems to be at a level between an iron-oxide crust below it and a volcanic ash layer above it. Because of the stratigraphic correlation with dated sediments, we may now accept that this level has an age between 30,000 and 14,000 B.P., possibly around 20,000 B.P. (VAN DER HAMMEN ET AL., 1980).

We now have three ^{14}C -dates directly obtained from *Mastodon* bone or from material associated with it. They are the following (determinations by the Groningen laboratory, conducted by Prof. W. Mook):

- (1) GrN-7932. Col. 254: $20,570 \pm 130$ B.P. Piece of rib of *Mastodon*. Villa de Leyva (Boyacá), Colombia. In sediments of a small river valley, at a depth of 80 cm. (Coll. Guillermo Ponton R.).
- (2) GrN-7662. Col. 243a: $16,300 \pm 150$ B.P. Shells of *Neocylotus* cf. *cingulatus*. Associated with skeleton of *Mastodon* in colluvial clays. Pubenza, Colombia.

(3) GrN-9375. Col. 275: $11,740 \pm 110$ B.P.

Piece of charred bone (*Mastodon*) from a depth of approximately 110 cm. in an excavation near Tibitó (Coll. Gonzalo Correal).

There is still another date related to a *Mastodon* skeleton found in the South of the Sabana de Bogotá, but it gives only a *terminus post quem*:

(4) GrN-4657. Col. 60: $42,200 \pm \frac{2600}{2000}$ B.P.

Charcoal from a peaty clay layer, directly below a *Mastodon* skeleton in lighter coloured clay layer.

Additional fluorine analyses of *Mastodon* bone from different sites give values between 1.4% and 0.1%. The ^{14}C -dated bone of Villa de Leyva gave 0.86%. The highest fluorine value from the Pubenza bone was 0.61%, but other fragments of bone from that site gave values between 0.15% and 0.4%. The highest values seem to be well in accordance with the age. All data together (using maximum fluorine percentages of each site) seem to indicate that although mastodons lived in the area of the high plains in the Cordillera Oriental and in the tropical Magdalena valley during much of the Last Glacial period, most remains have a Pleniglacial and Late Glacial age, somewhere between 25,000 and 11,000 B.P. Relatively low fluorine percentages of a number of bones from the Sabana de Bogotá, Socotá, Soatá and Garzon, are from dry areas and their low fluorine content might be caused by the fact that they were not continuously in contact with groundwater. However, the possible occurrence of some younger (Holocene) remains cannot entirely be ruled out.

Most *Mastodon* remains seem to be of Upper Pleniglacial age, so that apparently a particularly large population must have existed in the area at that time. In the high plain they lived apparently in the open dry páramos of that interval, and in the Magdalena valley in dry, more or less open vegetation. As was suggested above (Fig. 2), both vegetation types were probably in contact and formed an immense area of partly open to open vegetation types, which apparently formed the biotope of *Mastodon*, and hence, this may have been the time when conditions were favourable for a greater and continuous area of distribution of the *Mastodon* population. Direct contacts between the lowland and upland population must have been possible.

As mentioned above, at the beginning of the Late Glacial, when the climate became wetter and gradually warmer, the two areas of open vegetation became separated by montane forest, and must have rapidly decreased in size: the southern part of the Magdalena valley proper, the small areas of 'dry' vegetation in the western part of the high plains, and some longitudinal interandean valleys such as the Chicamocha valley. Here *Mastodon* seems to have lived on during the Late Glacial in very much depleted populations. It was by the beginning of the Late Glacial that Man appeared in the area, and the latest data from the excavations in the Tibitó area (western Sabana de Bogotá), render it probable that Man hunted *Mastodon* (CORREAL, 1980). The age of the bones of that site is that of the Guantiva Interstadial (see above).

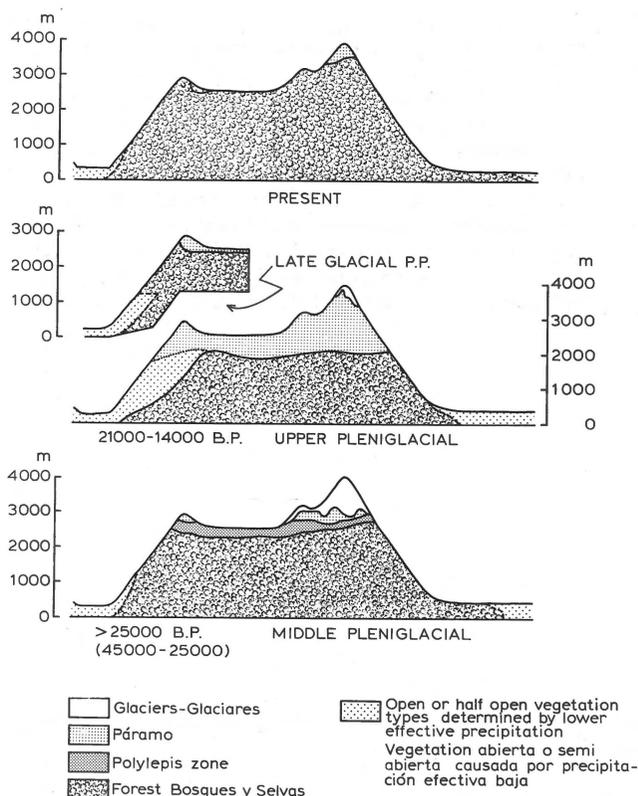


Fig. 2

Principal, successive vegetational changes in the Colombian Cordillera Oriental (W-E section, at ca. 5° N. latitude). Partly tentative.

Hence, it seems probable that the appreciable decrease of the area of the *Mastodon* habitat attributable to the climatical change by the beginning of the Holocene, also much reduced the population size. If this considerable reduction in the habitat and population size indeed took place, the influence of Man as a predator of *Mastodon* may have given the final blow and led to its extinction. This may have happened in the Late Glacial, but the possible occurrence of a very much reduced population in the Magdalena valley area during part of the Holocene cannot be ruled out altogether. A representation of an elephant-like animal on one of the ancient stone statues of the San Augustine culture (c. 2600-1000 B.P.) suggests that these people had knowledge of the last survivors of *Mastodon*.

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