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THE EVOLUTION OF THE COASTAL AQUIFER OF BELGIUM

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ABSTRACT

In the unconfined aquifer below the coastal area of Belgium salt water occurs under a fresh-water layer at depths that vary from 2 to more than 25 m. Radiocarbon dating of groundwater samples set the seawater encroachment in the deep parts of the aquifer back at least in the Subboreal period. A working hypothesis concerning the evolution of the aquifer is formulated.

1. INTRODUCTION

Belgium's northwestern border is formed by the southern North Sea. The coastal area stretches on the average 10 km landwards. Along the seaward edge it is bordered by a dune belt from 50 m to 2500 m wide with an average elevation of +15 to +20 m[1]. The polder area behind these dunes is almost flat, elevations varying between 2 and 5 m.

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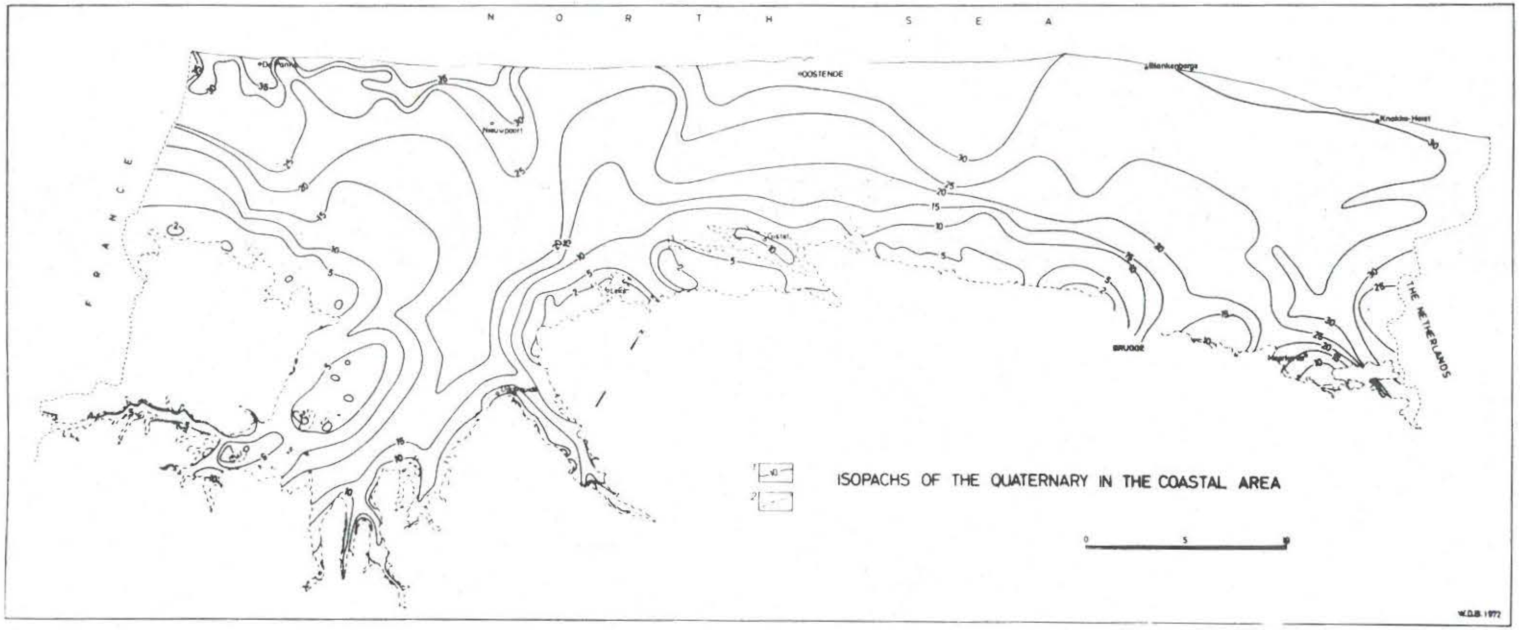

Fig. 1. Thickness of the Quaternary in the Coastal Area

1. isopach
2. polder limit

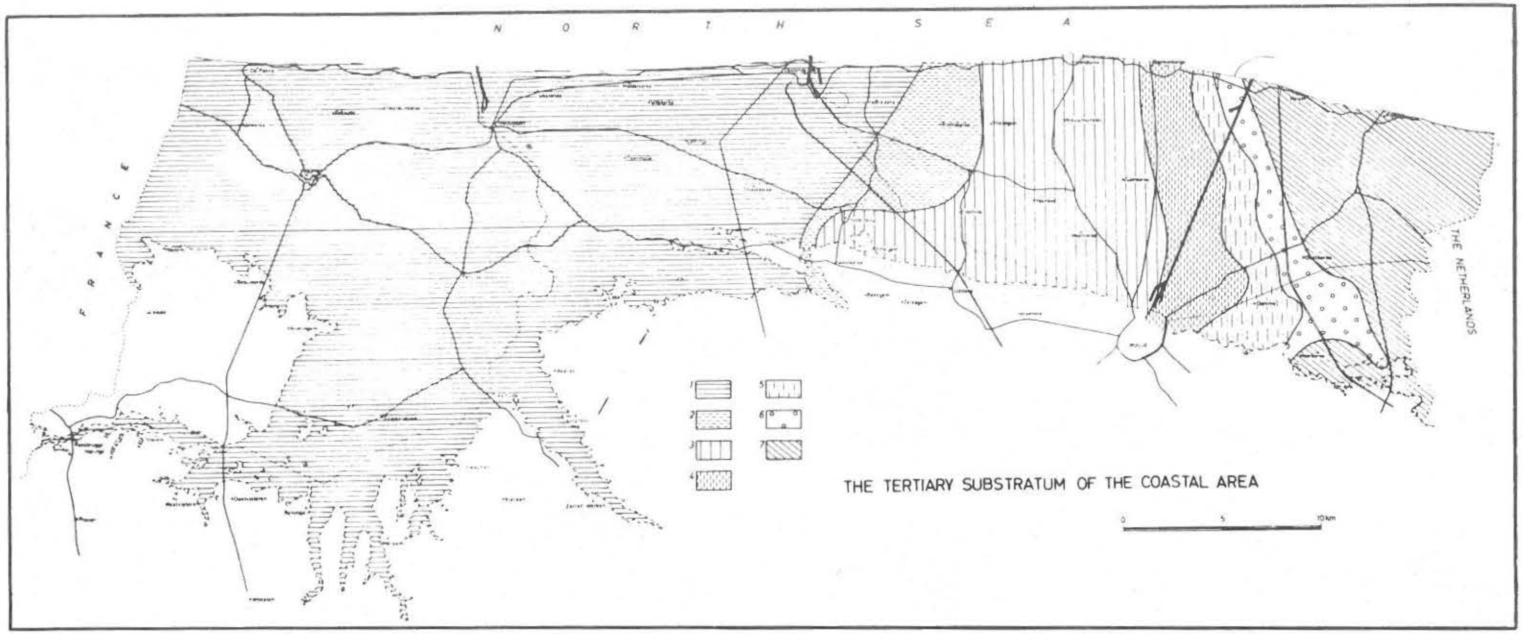

Fig. 2. The Tertiary substratum in the Coastal Area

1. Ypresian clay
2. Ypresian sand
3. Paniselian clay
4. Paniselian sand and clayey sand
5. Ledian sand
6. Wemmelian sand
7. Asschian clay

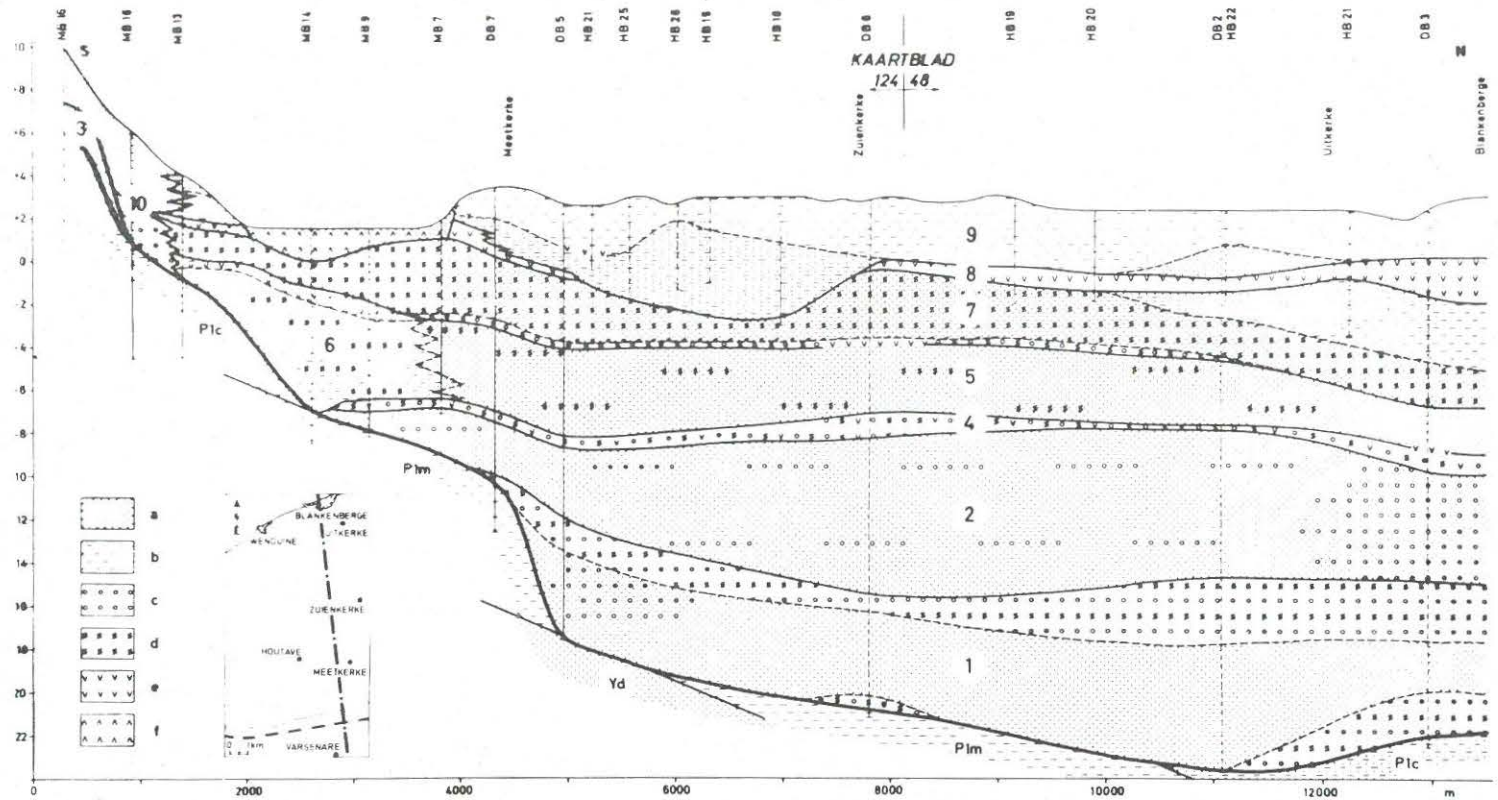

Fig. 3. South-north section from Varsenare to Blankenberge

a. sand	1 to 9 Quaternary deposits
b. clay	Plc Paniselian sandy clay
c. gravel	Plm Paniselian clay
d. shells	Yd Ypresian clayey sand
e. peat	
f. excavated peat bog	

The water-table aquifer is formed mainly by Quaternary sediments (W. DE BREUCK & G. DE MOOR, 1969), which attain a maximum thickness of 35 m (fig. 1). The Tertiary substratum consists of bedded clay and sand of Eocene age dipping gently in a northeasterly direction (fig. 2).

The deepest Quaternary deposit is formed by coarse sand of Eemian age (fig. 3) and remnants of Saalian sediments (G. DE MOOR & I. HEYSE, 1974). It is covered by sediments, mostly sandy, which are of Weichselian age. These are locally overlain by sandy tidal-flat deposits of Atlantic age. At the end of the Atlantic period peat bogs developed and continued to grow during the succeeding Subboreal period until the Dunkirk transgressions flooded the coastal area. These transgressions caused the deposition of a superficial cover of clays and sands, the distribution of which and later the influence of man have shaped the present topography of the polder landscape (J. AMERYCKX, 1959; R. TAVERNIER et al, 1970).

2. HYDROGEOLOGICAL INVESTIGATIONS

A systematic geo-electric survey (W. DE BREUCK & G. DE MOOR, 1969, 1972) of more than 1700 resistivity soundings has revealed the presence of saline water (up to 30.000 ppm) all over the aquifer at depths that vary from less than 2 m to more than 25 m (fig. 4). The saline-water layer extends to the southernmost margin of the coastal area and even into its narrowest ramifications at 20 km from the seashore.

Several tens of borings have been made to check the resistivity survey and to provide the water samples for analysis. In each of the drill holes 3 or 4 independent screens of 1 m length have been installed at different depths. These depths were chosen so as to have part of the screens above and

(1) All levels are indicated in meters versus the Ostend ordnance datum (*Zéro du Dépôt de la Guerre* of the Military Geographical Institute).

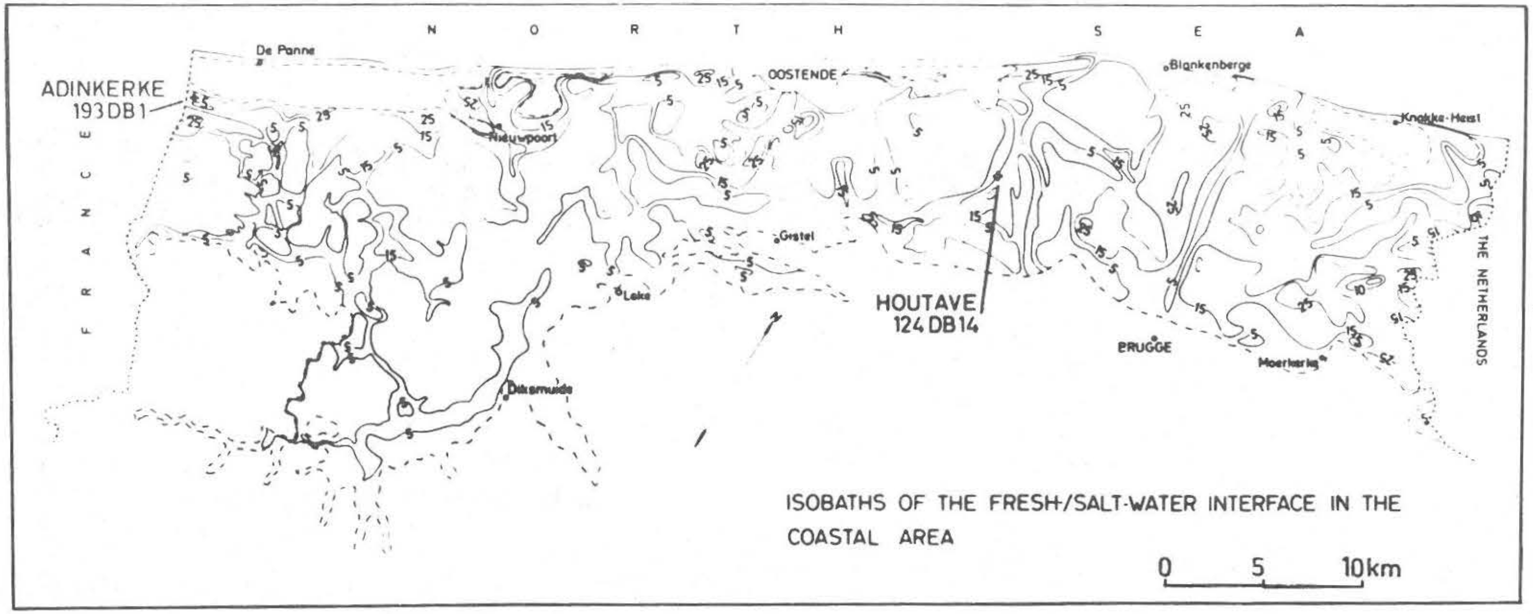

Fig. 4. Depth of the fresh-/salt-water interface and sampling sites for radiocarbon dating (Houtave, Adinkerke)

part of them below the fresh/salt-water interface. Water analyses and well logging have shown that the interface is rather sharp (fig. 5), the transition from fresh to salt water being limited to a zone of a few meters (W. DE BREUCK & G. DE MOOR, 1972). The vertical and horizontal distribution of the different water types in the aquifer shed a light upon its origin and evolution, which is to be related to the recent Quaternary history of the area.

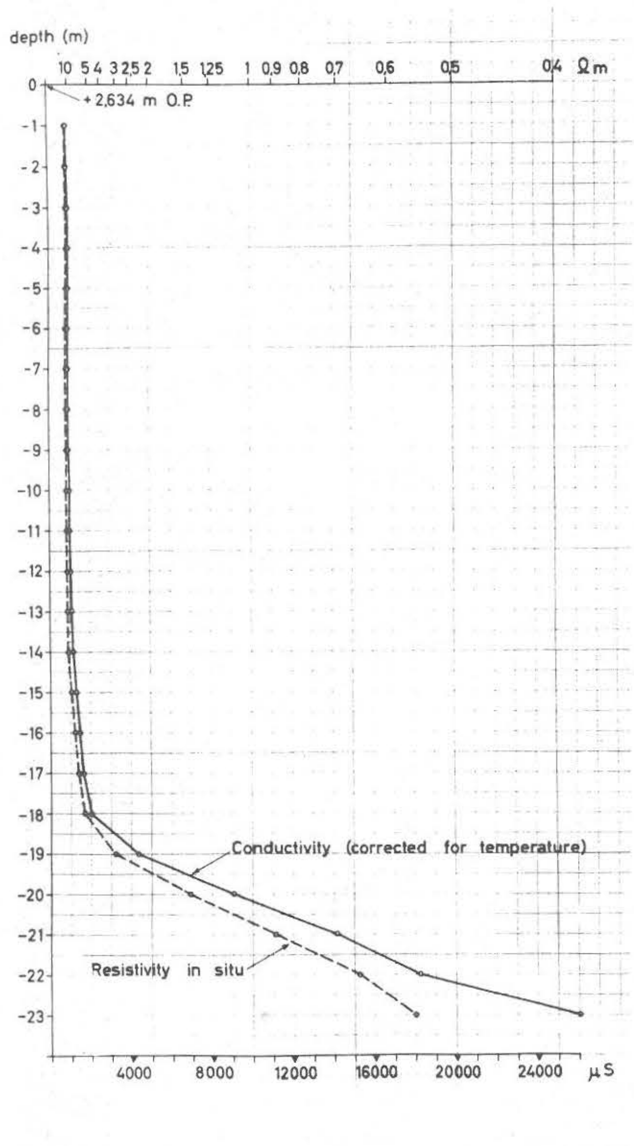

Fig. 5. Variation with depth of the resistivity and the conductivity of the groundwater at well site 48DB8.

The present active seawater encroachment is determined by the nature of the Tertiary substratum and by the relief and the dimensions of the dune belt; it seems to be confined to a very narrow zone along the coast extending not farther than 2 km landwards. The canals also influence, in a minor way though, the general pattern.

3. SAMPLING SITES FOR GROUNDWATER DATING

Two sampling sites have been selected in areas where apparently no active seawater encroachment is taking place. Pumping was performed at a very low yield so as to obtain water solely from a very restricted zone in the aquifer. The pump was of a rotation press type. The suction pipe was lowered to the screen level so that mixture with other water or air would be minimal. Two samples of 50 liters were pumped from the well after a conductivity test showed no more variation.

Samples were taken on two different occasions at Vlissegem from a depth of 23 m (fig. 4). The well is situated at 6 km from the seashore. The surface elevation is +3. Vlissegem is located in a part of the polders which show a typical inversion relief (J. AMERYCKX, 1958). The well itself has been drilled on a creek ridge. The sample 124DB14WAD1 was taken on May 15, 1972 and the sample 124DB14WAD2 on January 13, 1973.

The second site was chosen in the western coastal area at Adinkerke near the French border (fig. 4). A distance of approximately 3 km separates the well from the seashore. The coastal dune belt attains here a width of more than 2 km and elevations reach over +20. The Tertiary substratum is composed by impervious Ypresian clay and lies at a depth of 29 m at the well site. Surface elevation attains +3. The well is located

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Table 1 - Water analyses.

Sample	Depth	Conduct.18°C µS/cm	Dis.solids mg/l	Cations mé/l	Na^{+} mé/l	K^{+} mé/l	Ca^{++} mé/l	Mg^{++} mé/l
124DB14WAD1	23	33696	28305	477,9	365,3	7,2	22,4	80,2
124DB14WAD2	23	34492	27733	460,7	336,2	7,3	28,1	87,6
193DB1WAD1	28	28150	21958	377,8	285,5	6,1	22,2	62,7
seawater	0	36115	34794	604,9	462,5	9,9	23,1	109,4

Sample	$Fe^{++} + Fe^{+++}$ mé/l	Anions mé/l	Cl^{-}	SO_4^{--}	HCO_3^{-}	SAR
124DB14WAD1	1,1	483,5	434,5	18,1	30,7	51
124DB14WAD2	1,0	470,5	420,2	18,1	32,1	44
193DB1WAD1	0,9	370,1	322,9	31,2	15,8	44
seawater	0,0	602,3	586,3	42,4	2,7	57

on an outcrop of Atlantic tidal-flat deposits (F.R. MOORMANN & G. T'JONCK, 1960). A water sample was pumped from a depth of 28 m on January 12, 1973.

4. Laboratory results

The water samples have been submitted to an extensive analysis. Some of the results are shown in table 1. A recent analysis of a seawater sample has been included for comparison. The three waters show a dissolved-solids content very similar to that of the present seawater, although the total ion content is somewhat smaller. This may be due to the admixture of fresh water.

The radiocarbon dating has been performed at the "Institut Royal du Patrimoine Artistique" (I.R.P.A.) of Brussels (M. DAUCHOT-DEHON & J. HEYLEN, 1973).

The carbondioxide of the water has been transformed into methane, which has been counted in a proportional counter by anticoincidence (HOUTERMANS-OESCHGER). The results of the radiocarbon measurements are given in table 2.

Table 2 - Radiocarbon dating of water samples (I.R.P.A.).

Sample	Depth	Age (years BP)	Age (years BP)
		T = 5570 years	T = 5730 years
124DB14WAD1	23	3880 ± 180	4000 ± 180
124DB14WAD2	23	3720 ± 152	3920 ± 150
193DB1WAD1	28	3476 ± 224	3580 ± 160

5. DISCUSSION

No data on the stable-isotope composition of the waters are available at the present time, so that the first series of ages must be interpreted with the greatest care. Nonetheless they provide new evidence for an earlier advanced hypothesis on the evolution of the hydrologic conditions in this area (W. DE BREUCK & G. DE MOOR, 1969).

Although the Vlissegem well is situated on a creek ridge, in areas which have been inundated by the Dunkirk-2 transgression, and the Adinkerke well in a non-covered tidal-flats area, the water of both sites show comparable ages. The fact that the former is situated at 6 km from the sea as compared to 3 km for the latter may be mere coincidence rather than explain the difference in age. On the other hand the total ion content at Vlissegem is approximately 80% of that of present-day seawater while the latter amounts to only 63%. This could mean that at both sites the seawater was fixed at approximately the same time.

Since both sampling sites are located in areas where present seawater cannot penetrate it had formerly been assumed that the deeper salt-water layer has been introduced during the Subatlantic Dunkirk transgressions (J. DE PAEPE & W. DE BREUCK, 1958). The radiocarbon measurements set the date of the seawater encroachment further back into the Subboreal period.

Both wells have their screens installed in Eemian deposits. It is easily understood that the subsequent lowering of the sea level during the last glaciation has resulted in a complete flushing of the salt pore water. The ensuing rise of the sea level during the postglacial period has caused the Flandrian transgression and the salinization of the older deposits. Opinions diverge (J.R. CURRAY, 1965; S. JELGERSMA, 1966; A.L. BLOOM, 1971) about the pace of rise to its present level. Some maintain that the sea reached its present level

3000 to 5000 years ago, others proclaim that there has been a slow and continuous rise until very recently. The rising sea level and the tidal movements (H.H. COOPER et al., 1964) must have created a continuous subterranean inflow of salt groundwater.

From the chemical analysis it seems evident to consider the samples as seawater, although slightly mixed with fresh water. The fresh-water supply may have occurred in the Subboreal period or later. When contemporaneous of the intrusion of the seawater the radiocarbon measurements indicate approximately the true age. Whenever the fresh-water supply was more recent the dating of the water is giving too young an age for the seawater encroachment. The seawater would then have been entrapped at an earlier stage in the Subboreal or even in the Atlantic period. One may also consider the possibility of the mixture of older Weichselian fresh water with Atlantic seawater.

Since at present we have no evidence neither for a younger nor an older fresh-water supply one can assume that the seawater was entrapped sometime in the Subboreal period, when the area was already covered by peat bogs.

This could be explained by two facts. The coastal dune belt had not grown high enough yet to develop a fresh-water lens that could inhibit the subterranean seawater flow, and the sea still had access to the coastal plain during spring and storm tides through existing creeks which also drained the run-off from the higher peat bogs and the back land. In the end the expanding dune-water lens curtailed and finally stopped the salt-groundwater movement (fig. 6). The creeks gradually drained fresher water, thus flushing the salt groundwater in their immediate vicinity. The salt water beneath the peat-bog areas, though, was not expelled since almost all of the precipitation was retained by the peat or immediately drained by the creek system.

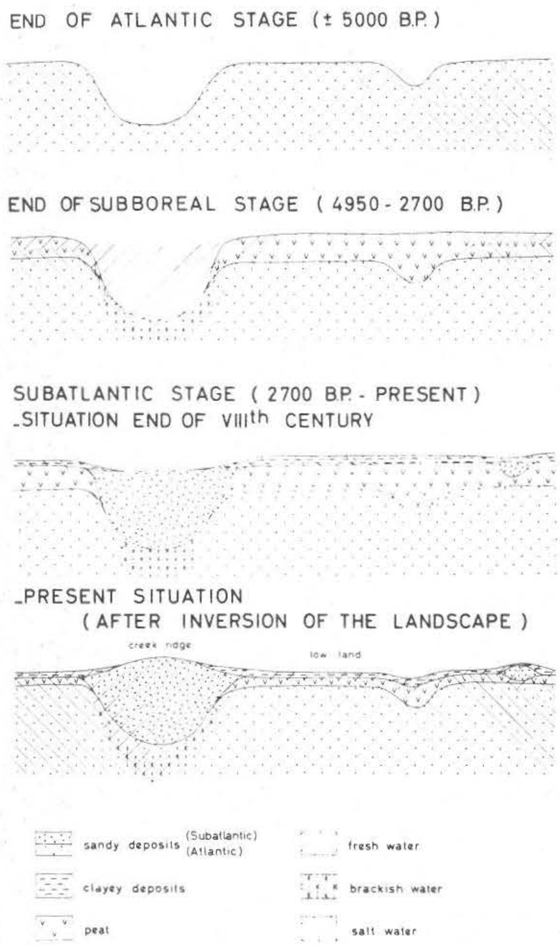

Fig. 6. Evolution of the hydrochemistry of the groundwater and the morphology in the coastal plain.

A large part of this creek system probably served for the drainage of the areas when the sea flooded the coastal plain during the Dunkirk transgressions. The breaches were probably cut through the dune belt at its lowest parts, where the creeks debouched into the sea. Some areas, especially around the breaches, may have been eroded by the force of the in and out flowing water currents. When finally the sea retreated the water in the creeks became fresh again. Underneath them the brackish water was expelled.

The creek system was gradually filled up by sandy deposits, while on the higher peat bogs only clay was deposited. When the region was reclaimed the dewatering resulted in a differential settling of the clay-covered peat areas and the sandy creeks, the latter becoming the higher parts. Due to their higher elevation and their composition the creek ridges developed a fresh-water lens beneath them.

The rainwater barely penetrated into the clay-covered peat areas and was almost continuously evacuated through ditches and canals. Hence the saline water beneath these areas was not replaced.

The relatively old age of the waters furthermore suggests that the deeper groundwater in the unconfined aquifer moves at an extremely slow speed or does not move at all. This is probably the case for large parts of the coastal region. From the present data it can be assumed that the salinization effect of the Dunkirk transgression has been restricted to the top layers.

6. CONCLUSION

The radiocarbon dating of the deep saline water in the coastal aquifer of Belgium indicates that the seawater encroachment in large parts of the coastal area, dates back at least from the Subboreal period. These measurements also suggest that movement in the deeper parts in the aquifer, if any takes place, is extremely slow. These preliminary findings are to be confirmed by a more detailed investigation, which includes the determination of the stable isotopes.

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