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SYMPOSIUM: QUATERNARY CHANGES IN LEVEL, ESPECIALLY IN THE NETHERLANDS

# HOLOCENE MOVEMENTS OF LAND AND SEA-LEVEL IN THE COASTAL AREA OF THE NETHERLANDS

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## (I) INTRODUCTORY

This article is a rather brief digest of a manuscript, too detailed in itself for a synopsis. The complete text is intended as a university thesis. As the publication of the latter will not be delayed for long, a review of older literature will not be given here. Only those authors will be referred to whose names are indispensible for following the argumentation. Moreover, attention will mainly be drawn to new data.

## (II) THE GEOLOGICAL SUBSIDENCE OF THE COASTAL AREA IN THE NETHERLANDS

The submergence of the land in relation to the mean sea level is due to three component factors: the elevation of the level of the sea, the geological subsidence of the land and the shrinkage of the soil. The last mentioned factor can be reduced to almost negligible proportions by restricting the altitude determinations to particular sandy sections. Where such a course is impracticable, shrinkage should not be ignored.

The geological subsidence of the Western part of the Netherlands can be calculated for extensive periods using geological data such as the base of the Quaternary, the altitude of the Eemian and that of the fluviatile Lower-Terrace. The conclusion from a critical study of all available particulars concerning these three levels is that this subsidence amounts to approximately 2 or 3 cm per century for the central and the northern part of the coastal region of the Netherlands. Further south this subsidence is reduced to 0.

## (III) THE RELATIVE RISE OF SEA LEVEL DURING THE POST-GLACIAL UNTIL THE TIME OF SEDIMENTATION OF THE OLD SEA CLAY

It is generally assumed that during the last glaciation sea level wat at about 100 m below the present level. As regards the rise of sea level at the beginning of the Holocene, data can only be obtained by using the base of the lower peat as the starting point. If the lowest peat layer is true peat then that base must have been at or above the sea level of that time. The deepest peat base is to be found in Schouwen, viz. at 37,20 m — N.A.P. (ordnance datum), according to VERMEER-LOUMAN (1934). This layer of peat belongs to the Boreal and it is thus probable that sea level was below 37 m — N.A.P. during part of the Boreal age. The possibility is not excluded, however, that this layer of peat is not autochthonous.

More is known about the altitude of the contact between Boreal and Atlanticum. From the position of the lower peat at Velsen (FLORSCHÜTZ, 1944) and at Rotterdam (FLORSCHÜTZ en VAN DER VLERK, 1939) it follows that sea level during this transitional period must have been at 16 to 18 m — N.A.P.

## (IV) THE RELATIVE RISE OF SEA LEVEL AND THE TRANSGRESSIONAL PHASES DURING THE SEDIMENTATION OF THE OLD SEA CLAY

The top surface of the lower peat in the tunnel excavation at Velsen can only be used for tying-in the former sea levels if the shrinkage of the peat is allowed for. Various methods have been tried out to solve this problem. The opinion of HUIZINGA (1940) that the shrinkage may have amounted to as much as 98 % is not in accordance with modern views on soil mechanics. Our investigations have shown that the shrinkage cannot have been more than 75 to 85 %. This implies that the transgression near Velsen occurred at a level of about 14 m — N.A.P.

Near Vinkeveen, the outer limit where the lower peat is to be found as far as it is covered by a marine sediment, it can be calculated that a transgression proceeded at a sea level of 6 m — N.A.P. This level is much higher than the one calculated for Velsen. If both figures are correct, the sea must have reached Velsen about one thousand years earlier than Vinkeveen.

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The humous clay layer overlying the lower peat near Velsen and elsewhere bas been formed under water in a saline lagoon. At a level of 7 to 11 m — N.A.P. the sea encroached on the lagoon and the deposition of the sandy layers of old sea clay was started. During this sedimentation period the sea rose rather rapidly at first but later on the rise slowed down, according to HAANS (1949) who could trace various phases in the younger layers of the old sea clay, all being deposited between 5 and 4 metres — N.A.P.

These are: the Hoofddorp phase, characterized by decalcified soils, the normal old sea clay phase and the Beinsdorp phase. The normal old sea clay overlies the decalcified Hoofddorp soils, whilst the Beinsdorp soils again overlie the normal old sea clay. At spots suitable for comparisons, where the soil shows no shrinkage, it is found that the upper surface of the Hoofddorp soils is 4 m below N.A.P. and the same applies to the upper surface of the old sea clay. The facies of these two deposits, however, show a slight difference and it is not unlikely that the sea level during the formation of the old sea clay was higher than at the time when the Hoofddorp soils were formed.

The end of the old sea clay can be fixed at about 2300 B.C. The opinion of other authors who dated this era at about 1800 B.C. cannot be maintained, since the examination of Neolitic finds near Hekelingen on the island of Putten made by MODDERMAN (1953), FLORSCHÜTZ (1953) and BENNEMA (1953).

The formation of the peat on top of the old sea clay is generally considered as evidence that the level of the sea must have sunk rather considerably over a long period. This conclusion, however, may not be correct. At the beginning of the event during which the old sea clay was formed the level of the sea rose rapidly but this rise was almost equalled by the deposition of the new sediment. At the end of the old sea clay epoch the speed of this rise was retarded and at that time a coastal bar could be built up, obstructing the outlet of the hinterland to the sea. This sufficed to initiate the formation of peat. Although it is therefore not essential to assume a subsidence of sea level, a minor drop may still have taken place. Whether or not this occurred it at least did not last long, and certainly had a much shorter duration than is often assumed when a so-called subboreal regression is postulated.

## (V) THE TRANSGRESSIONAL PHASES AND THE RELATIVE RISE OF SEA LEVEL FOLLOWING THE DEPOSITION OF THE OLD SEA CLAY UNTIL SHORTLY BEFORE THE BIRTH OF CHRIST

Surely at many places the formation of peat set in after the end of the old sea clay deposition, but already during the transitional period from the Stone Age to the Bronze Age the sea has invaded the land at several other places. In the North Eastern Polder this transgressional phase has been described as the Cardium transgression, although MULLER and VAN RAADSHOVEN (1947) have wrongly associated the deposition here with the latest phase of the old sea clay sedimentation in the Western part of the Netherlands. A comparison of data pertaining to the North Eastern Polder and those of other sections in the Netherlands clearly shows that the Cardium transgression is of a more recent date than the normal old sea clay deposition in South Holland.

The immersed layer near Urk can be correlated with an immersed shallow oligotrophic layer in the peat of the Vecht region, which was examined in detail by the author. This shallow layer is to be found today at varying depths owing to irregular shrinkage. In correcting the data recorded with respect to this shrinkage effect, it becomes evident that the immersion of the landscape of the Vecht region took place, at a level of high tides of approximately 2.25 metres — N.A.P.

Apart from the examination of the neoliths of Hekelingen, already referred to above, the prehistoric IJ should be mentioned which was investigated by GÜRAY (1951). Here it was found that the peat landscape was encroached upon once more by the sea shortly after its formation, at a sea level much higher than the foregoing. Also in Waterland the terrestrial peat is covered by other brackish formations, consisting of silt and clay.

In the literature on peat formation particulars can be found on the peat areas in the north of the country before this transgressional phase set in. From an international point of view it coincides with the latest maximum of the Litorina sea (about 1800 B.C.). As to palynological evidence the Cardium transgression occurred either at the end of the Atlanticum or at the beginning of the Subboreal depending on the way in which the demarcation line between the two periods is drawn. In the West and North of the Netherlands the epoch of the Cardium transgression is characterized by a maximum of hazel (*Corylus*) vegetation.

In summarizing it can be stated that the available data with regard to the sea level during this phase point to the fact that this level must have been at approximately 3,25 m — N.A.P.

The history of our coast between the *Cardium* transgression and the Iron Age is still rather obscure, although it is clear that during this time there was no important drop of the sea level. Of importance are the conditions prevailing in Westfriesland where a soil survey is in progress at present. Here burial mounds are found on marine silty sand, dating back to about 1000 B.C. as described by VAN GIFFEN (1953). Consequently this part of Westfriesland was already inhabited in those times. The toe of the mounds is at a level of 1,5 metres — N.A.P. which is an indication that sea level was at that time considerably higher than at the end of the Cardium transgression.

With respect to Western Germany HAARNAGEL (1950) strongly stresses the point that the devastation of the peat and the formation of the sea coast took place between 700 B.C. and about 300 B.C. This dating most probably applies to Friesland and Groningen too. The devastation of the peat in the isle of Walcheren started very likely in this period as well.

In the last few centuries before the Christian era settled conditions prevailed as settlements of population existed along the coast everywhere, partly on peat soil as in Walcheren, Schouwen and the Westland, partly on marine soils as in Friesland and North Western Germany.

## (VI) THE RELATIVE RISE OF SEA LEVEL AT THE TIME OF AND JUST AFTER THE BEGINNING OF THE CHRISTIAN ERA

Encroachments of the sea on the land just before and at the time of the birth of Christ have been very numerous in Zeeland, in the islands of South Holland, in the mouths of the Maas and the Rhine and along the coast of North Holland. Thereafter a more settled period followed with extensive settlements, concluded in the third century A.D.

The effects of these encroachments were less noticeable in the north of the country as here a relatively elevated marine base level of sedimentation had been reached already.

According to the method developed by VAN GIFFEN (1910) it is possible to determine the height of the sea level during Roman times in various places. In those times the salt-marsh had attained a level equal to N.A.P., although at some places a slightly lower level prevailed. Some higher spots existed too e.g. in Friesland, but these were located on the foreland ridges (high banks of the salt-marsh). If the salt-marshes of this period are compared with those of today, it becomes evident that during the past 1900 years the level of the sea has risen by 1.30 m or 1.40 m. For the Western coastal region we have followed the same line of reasoning which produced figures varying between 1.20 and 1.40 m. All these data demonstrate that the surface level of the land has relatively sunk by about 1.20 or 1.40 m since Roman times. Using the same methods a difference of 1.70 m was found for the Iron Age.

Along the German coastal region to the east of the Jadebusen the differences are smaller. The explanation lies partly in the fact that the absolute geological subsidence here has been less, and still further eastward even a slight absolute rise of that level, up to 2 or 3 cm per century, has been established.

## (VII) THE TRANSGRESSIONAL AND SETTLED PHASES AFTER ROMAN TIMES

A short time before 300 A.D. the sea encroached once more on the land. This phase of transgression has been described by various authors for the whole Belgian, Dutch and German coastal region.

At about the year 800 and locally at about 600 already the young marine deposits in the Belgian and South Western Dutch coastal area were reinhabited. The altitude of creek ridges reveals that these were deposited at a sea level which was about 60 or 80 cm lower than it is today.

In the northern sea clay region several "terps" (mounds) were raised. In the transgressional phase after 300 A.D. many of these "terps" were abandoned by the inhabitants (although several of them remained in use). During the ensuing settled period after the transgressional phase, however, new "terps" were raised again.

At the end of the 9th and during the 10th century the sea encroached once more on the south western sea clay region. The old landscape that had been formed soon after the Roman era was partly eroded and partly covered with young sediments. There is some proof that this period passed into a more settled one in the coastal region during the 11th century (BAKKER, 1948), whereafter the era of embankment and dike building commenced.

On account of this dike building soil conditions along our coasts after the 11th century are less representative of the fluctuations of sea level than they had been so far. The very high storm surges and the serious catastrophes during the 14th, 15th and 16th century reveal that the sea has made numerous assaults on the coastal region in this era. At the end of the 16th century a new rather settled period set in, which lasted until the middle of the 19th century (see also paragraph XII). The outset of that period is characterized by the formation of heavy clay layers on sand flats (plaatgronden).

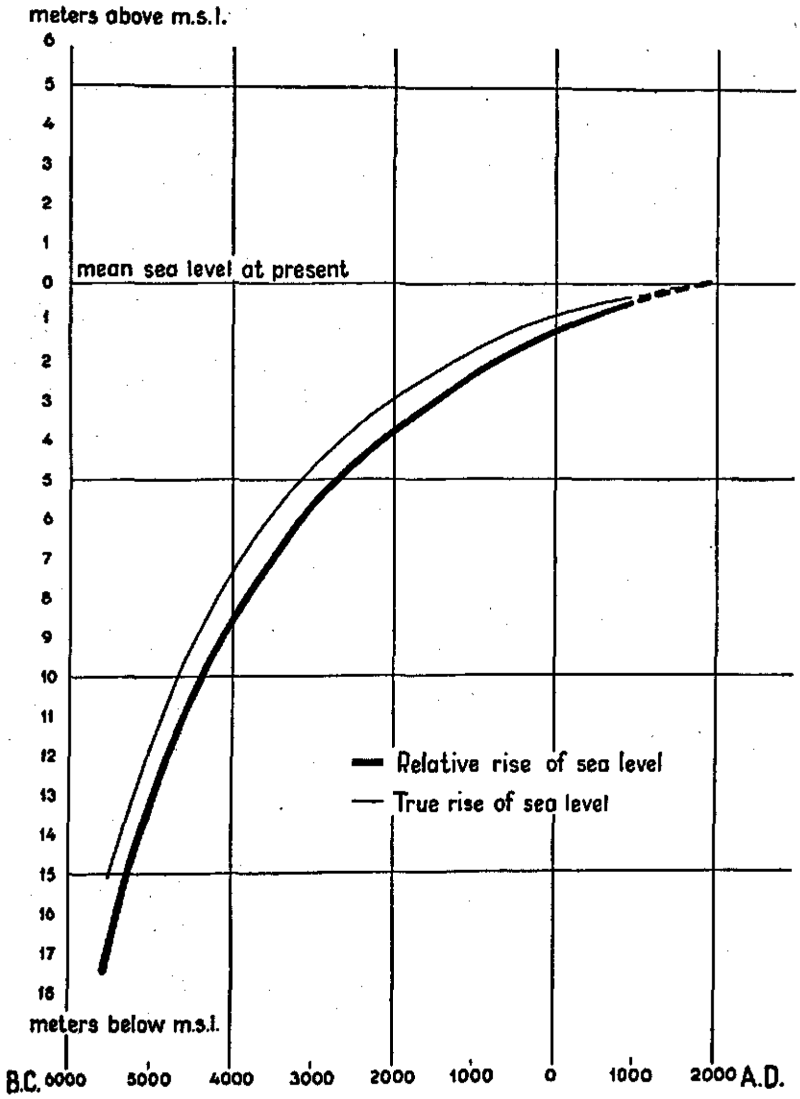


Fig. 1 — The rise of mean sea-level in the western part of the Nederlands since the beginning of the Atlanticum

(VIII) A GRAPHIC REPESENTATION OF THE RISE OF SEA LEVEL

Based on the data, discussed in the preceding paragraphs, the relative rise of the sea level for the West of the Netherlands have been plotted on the chart. By subtracting 2 cm for every century from the relative rise of sea level on account of the absolute geologic subsidence of the land, the absolute rise of the level of the sea along the Westcoast of the Netherlands can be arrived at. Assuming that the shape of sea level has not changed during the times under review, this absolute rise should apply to the whole of the globe.

Contrary to most of the curves plotted by other authors, this particular graph is indicative of a gradual and progressive rise of sea level. To make any differentiation between an Atlantic transgression (Litorina transgression), a Subboreal regression and a Subatlantic transgression does not seem justified. The phenomenon as a whole should be considered as a persistant, yet decreasing Holocene transgression.

The conception that a regression has occurred in the Subboreal is usually based on two fundamental facts:

(1) The existence of many small Litorina terraces at approximately 6 m above sea level giving rise to the assumption that the sea level had sunk some 6 metres since that age.

(2) The development of a peat layer on the old sea clay being usually considered as an indication that a regression had occurred at the end of the Litorina transgression.

The existence of the small Litorina terraces can also be explained, however, by assuming that the areas where they are found, rose as quickly as did the sea level during the latter part of the Atlanticum (see GODWIN, 1945). Later on, when the rise of sea level slowed down, these terraces emerged from the sea. Other explanations are possible, however. It has already been pointed out that peat could also have developed on the old sea clay without the assumption of a considerable Subboreal regression. As a matter of fact many authors have presumed that this has been happening but they were so much struck by the simultaneousness of the phenomena that nevertheless they assumed sub-boreal regression. On the one hand this simultaneousness is to a certain extent implicated in the trend shown by the rise of the sea level, but on the other hand the simultaneousness is not quite so conspicuous as sometimes has been presumed. For instance, the development of peat on the old sea clay in the West of the Netherlands set in earlier than on the Fen clay in England.

As the sediments formed during the Cardium transgression were laid down a few centuries after the deposition of old sea clay came to an end, and as they are lying higher than the old sea clay, the conclusion can be drawn without any reserve that the assumption of a considerable regression at the beginning of the formation of the upper peat is not borne out by the facts. Yet a short phase of regression or stagnation may have had some consequences.

That the sea was exerting a greater influence than during the Subboreal notwithstanding a decline in the rate of rising of the sea level was probably due to numerous causes. The peat areas gradually developing beyond the natural coast protection were an easy pray to devastation. Deep layers of peat after being eroded, could not forthwith be replaced by fresh peat. The natural coast protection built up at the end of the Atlanticum and during the early Subboreal soon became unreliable. Changes in the prevailing climatic conditions attending the transition of the Subboreal into the Subatlanticum implied very likely that the feature of western gales as a whole became more prominent.

The tendency to associate the rise of the sea level with an accelerated melting of the glaciers is only logical. At the outset much more water was released but that quantity gradually abated again. By assuming a climatic optimum for the whole world during the Atlanticum, it will be necessary to consider the subsequent melting of ice as a sort of delaying feature demonstrating itself as long as the balance between the extent of the glaciers and the prevailing climate had not been restored. Obviously this applies in the first place to regions with an abundance of ice and therefore particularly to the Antarctic. In regions not so rich in glaciers the balance will have been restored much sooner.

## (IX) THE PERIODICITY OF THE TRANSGRESSION PHASES

In paragraphs V, VI and VII dealing with the history of our coastal region since the end of the old sea clay deposition, it was emphasized that in this history the transgression as well as the settled and regression phases played an important part and so did the noticeable general rise in the sea level.

Transgression phases are known to have occurred at about 1800 B.C., at about the birth of Christ, at 300 A.D., 900 A.D. and there are indications that similar phases must have demonstrated themselves at about 1200 B.C., 600 B.C. and 1200 to 1300 A.D. When scrutinizing these dates, a certain periodicity comes to light with calculated intervals that have lasted about 525 years. In assuming a periodicity of 525 years, the following range of dates is arrived at:

1800 B.C., 1275 B.C., 750 B.C., 225 B.C., 300 A.D., 825 A.D., 1350 A.D., which discloses the fact that the dates reasonably coincide with those of the transgression phases referred to above. The next following date after 1350 A.D. would have been 1875. As we will see in paragraph X this date is confirmed by established facts.

The phases of transgression have been by no means of the same importance. Anyhow those of 1800 B.C., 300 A.D. and possibly those in the later Middle Ages, have had considerable consequences in the coastal region. The transgression phases of about the be-beginning of the Christian era and those of the 10th century have been of lesser importance. Little is known yet of the transgression phases of about 1200 B.C. and 600 B.C. but it can be gathered from data recorded in literature that the phase of 600 B.C. must have had a rather noticeable effect on the coastal regions. Possibly this may indicate that a drastic transgression phase is always succeeded by a less violent one, after an interrupting phase of regression.

Not all transgression phases were of the same duration. The one of about 900 A.D. e.g. lasted a much shorter time than the transgression phase setting in during the late Middle Ages.

Finally we wish to state that W. C. VISSER (cited after BAKKER, 1948) and BAKKER (1948) already pleaded for a periodicity of sedimentation along the Dutch coast.

The theory that the transgression phases are periodical phenomena, is substantiated by the fact that other periodical features demonstrate themselves in other parts of Europe, as will be discussed in the next paragraph.

## (X) THE RELATION BETWEEN THE TRANSGRESSION PHASES IN THE COASTAL AREA OF THE NETHERLANDS AND OTHER CLIMATIC PHENOMENA IN EUROPE

The Holocene transgression is generally explained as being a result of the melting away of the ice sheets of the last glaciation. A detailed survey of the relation between climatic fluctuations and the rise of the sea level cannot be compiled yet. There are, however, several indications that the periodicity shown by the action of the sea assumed above is closely associated with climatic fluctuations. This connection is evident from a similar periodicity shown by other phenomena, only explicable by changes of climate. The periodical features of the mountain glaciers and of the drift ice in the Arctic are too well known to be enlarged upon here.

A periodical phenomenon that only became known very recently has been revealed by the studies of WELTEN (1944) on the deposits of marsh-chalk of the Faulensee near Spiez in Switzerland. Profiles of this marsh-chalk show that beech-pollen grains increase and decrease in number at regular intervals. A high percentage of beech-pollen indicates a more oceanic climate (WELTEN, 1952). Correspondingly, WELTEN differentiates four beech phases: from 3200 to 2350 B.C., from 750 to 450 B.C., from 200 to 600 A.D. and from 850 to 1250 A.D. There are a few more of such phases but as for these the phenomenon does not show up very clearly.

Evidently the 1st, 3rd and 4th beech phases of WELTEN coincide with periods of stronger action of the sea off the Netherlands' coast.

Another study deals with the borderline horizons of the West-European peat bogs (NILSSON, 1935, 1948). Horizons can be traced between rather badly decayed mosspeat and the overlying mosspeat of a less decayed stage, the latter being formed under moister conditions. The Scandinavians have dated these horizons: 3500 B.C., 2900 B.C., 2300 B.C., 1700 B.C., 1000 B.C., 500 B.C., the birth of Christ, 400 A.D., 1300 A.D. As to the dates of the formation of some of these horizons, there is a divergence of opinion, but it appears that the dates of origin of the borderline horizons of 1700 B.C. and those thereafter synchronize remarkably with those of the transgression phases in the Netherlands.

GAMS and NORDHAGEN (1923) have been prompted to divide the Subatlanticum into a number of substages, extremely similar to the settled and the transgression phases of the coast of the Netherlands. Their periods of more rainfall are: 850 to 120 B.C., 180 to 350 A.D., 600 to 900 A.D., 1090 to 1250 A.D. Droughts prevailed from 120 B.C. to 180 A.D., 350 to 600 A.D., 900 to 1090 A.D. and 1250 to 1550 A.D. The dates apply in particular to the centre and southeastern section of Europe. Fig. 2 shows how well the dates of the various phenomena are synchronized.

The foregoing statements provide a strong argument in favour of the thesis that the transgression phases of the Young Holocene are due to climatic fluctuations.

## (XI) APPLICATION OF THE PRINCIPLE OF PERIODICITY TO THE PHASES OF TRANSGRESSION ON THE CONDITIONS OF THE COAST OF THE NETHERLANDS IN THE PAST AND AT PRESENT

In view of the fact that the difference in sea level in the Roman era and today is 1.30 metres, the difference of a few decimetres between the late Middle Ages and today appears to be rather small and from this it may be deduced that the Holocene transgression has

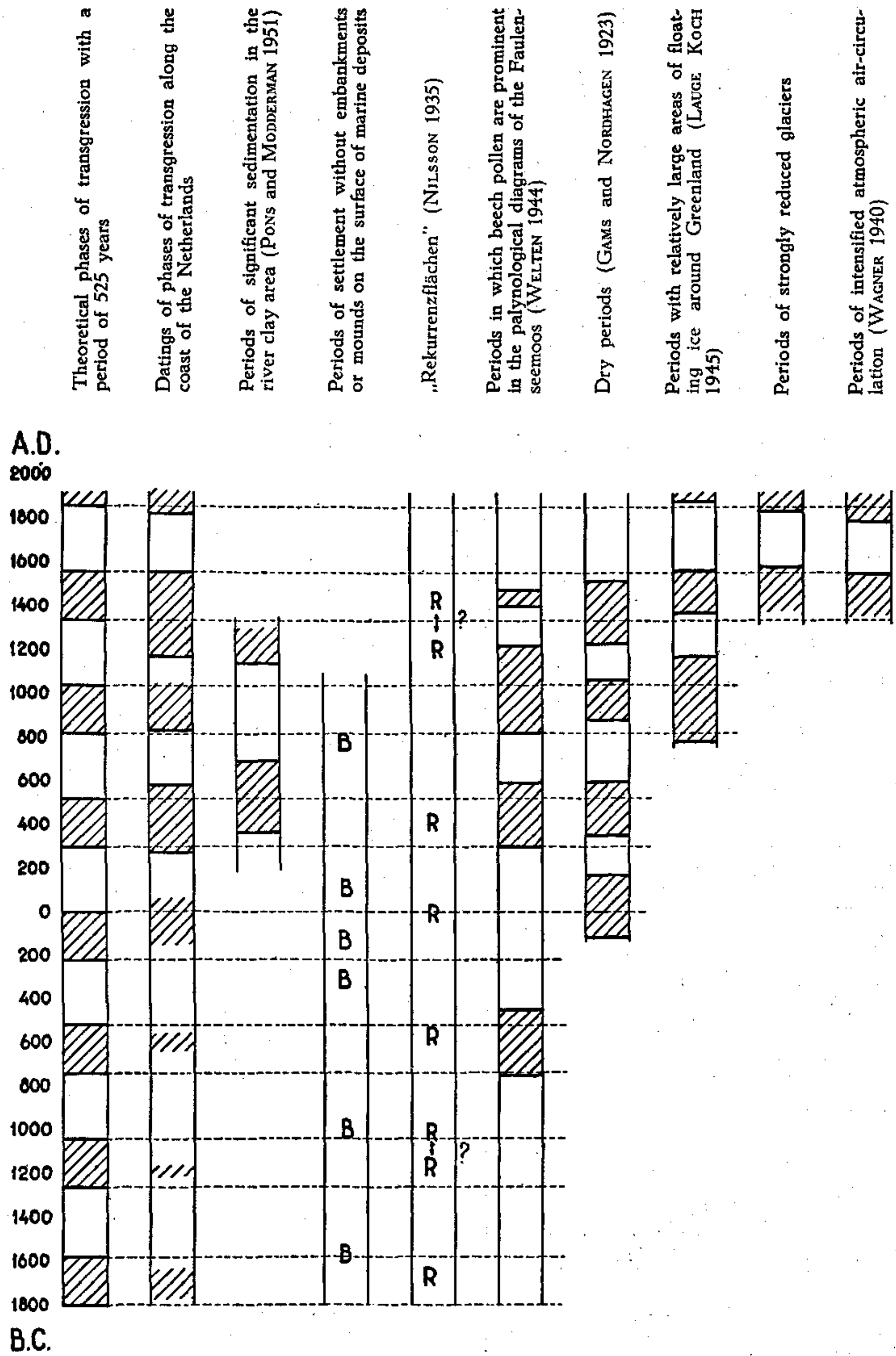


Fig. 2 — Occurrences of transgression phases in the western part of the Netherlands compared with other mainly climatically determined phenomena.

almost come to an end. The graph shows that the secular rise of sea level should only be small today. The water gauge records, however, show a larger secular rise of sea level since 1850. This excessive rise of sea level coincides with the melting away of many glaciers and a decrease of the quantity of ice in the Arctic. Before 1850 the rise of sea level was presumably less for some centuries than is in accord with the secular rise of that level. This period set in at about the end of the sixteenth century. The formation of heavy layers of clay on the sand flats might be indicative of a slight subsidence of the sea level. On the other hand it is an established fact that at about the end of the 16th century the glaciers and the ice in the Arctics were accreting. All these facts point to the outset of a settled or regression phase shortly before 1600 A.D., in concurrence with the trends of the climate (see paragraph XII), passing again into another transgression phase at about 1850. It is generally assumed that storm surges in the 15th and 16th century, therefore during the transgression phase, were much more powerful and happened more frequently than after 1600 A.D.

Unfortunately a proper comparison of the data on the height of the storm surges during the 15th and 16th century and those at later dates is not yet available.

It is only a hypothesis that the transgression phases, barring a slight rise of the sea level, could demonstrate themselves more strongly in the occurrence of relatively frequent and very high storm surges. A hypothesis which has already been mentioned by BAKKER (1948).

Whether this hypothesis is borne out by the facts is a matter of outstanding importance to our coastal regions as it involves the question whether the storm surge of 1953 must be considered as incidental or as a forerunner of more exceptionally high tides according to the scheme of periodical transgression phases, to be anticipated during the coming 175 years, of which, however, the last one hundred years might already usher in the ensuing settled phase.

## (XII) A FURTHER ANALYSIS OF THE PERIODICITY OF THE CLIMATE

Plenty of references in literature also of recent date are made with regard to the consistent changes of the climate which, in our opinion, may be considered as the cause of the remarkable alternation of disturbed and quiet periods which prevailed along the coast of the Netherlands.

WAGNER (1940) and PETTERSSEN (1949), amongst others, attribute the changes of climate to an increase in the general circulation of air especially the meridional circulation. According to WAGNER the period from about 1575 A.D. onward up to 1800 A.D. should be taken as a period of restricted circulation of air. Round about 1800 A.D. an era of more powerful circulation of air set in, but did not become of much consequence before 1900 A.D. They had a different effect on various parts of Europe. LABRIJN (1945) has applied this theory to the Netherlands. For a stretch of 250 years his findings check closely with those of WAGNER. As to the last half century, however, the winter temperatures exceed those of 1781—1820 by 1° C., the temperature for January is even 1.9° C. higher. The dominating direction of the wind has backed 20° to 25° (compare VAN VEEN, 1940).

## (XIII) CONCLUSIONS

1. The rise of sea level after the glaciation should be considered as a consistent, slowly dwindling transgression.
2. Of the relative rise of the sa level along the coast of South Holland a share of about 2 of 3 cm per century must be attributed to the real subsidence.
3. About 5500 B.C. the absolute rise of the sea level amounted to 75 cm per century, about 2000 B.C. the relevant rise was 13 cm per century; since the Roman era the average rise has been 4 cm per century.
4. After about 2000 B.C. the Holocene transgression has been characterized by the occurrence of transgressional and settled or regressional phases which have been of outstanding importance to the formation of the coastal region of this country and its habitability.
5. The transgressional and regressional or settled phases show a periodicity with intervals of approximately 525 years.
6. The transgressional phases are very likely characterized by slight rises in sea level and possibly by the occurrence of relatively frequent storm surges.
7. The periodicity of the transgressional and settled or regressional phases is probably related to a periodicity of climatic conditions. The latter periodicity is also apparent from the features of the peat profiles in Scandinavia

(Rekurrenzflächen) and locally of the forest vegetation.

8. The period from 1600 to 1850 A.D. is to be considered as a regressional or settled phase, the period from 1850 onward as a transgressional phase.

9. The historical phases of transgression and regression can be correlated with respect to the expansion of the polar ice sheet near Greenland and the growth of the glaciers.

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# DISCUSSION

Prof. Bakker (Amsterdam) agrees on the whole with Mr. Bennema's curve of relative rise of the sealevel, provided that minor oscillations be superimposed on it. He has found some indications suggesting that in the 500-years periodicity of transgressions, which is now also admitted by Mr. Bennema, there is a certain phase difference between the N and the S of the country, in so far that events occur somewhat earlier in the N. This applies to both the Carolingian-Early Ottonian transgression in Friesland and Groningen (± 800—950) and the Late Carolingian-Ottonian transgression (± 890—1000) in Walcheren and Flanders. The late medieval transgression started in the N about 1175—1200, whereas in the S it had its main effect after 1300. If this should also hold good for the present time the 1953-flood could be indicative of the second half of a period of floods.

As to this last remark, Prof. Thijsse (Delft) observes that a great flood, as for instance the formation of the Zuiderzee in the 12th and 13th centuries, is only an after-effect of a widening of gaps in the shore bar during the preceding centuries.

Prof. Florschütz (Leiden) makes the following observations. In order to find the height of the sealevel at the time of the formation of the "surface peat" as compared with the preceding period, a comparison may be made with the "lower peat". At that time there must have been a closed shore bar, behind which the groundwater rose, causing peat formation. Through a further rise of the sealevel the bar was broken and the sea flooded the former lagoon, forming marine sediments extending 50 km inland from the present coast. Then the sea retreated again and the "surface peat" grew up. The simplest explanation for this phenomenon is a fall of the sealevel.

Mr. Bennema, however, tries to explain it by assuming the renewed formation of a closed shore bar, in the same way as during the growth of the "lower peat". This would mean that during a continuous rise of the sealevel a shore bar was first formed, then partly destroyed, then again formed and at last broken down again, which does not seem a logical assumption.

The same succession as in the Netherlands is also found elsewhere around the North Sea. Should all these instances be explained by the formation and destruction of local shore bars? Godwin (1945) gave a summary of these submergences and emergences, and Zeuner (1952) adds that the indications of dryness in the Subboreal may be connected with a slight regression of the sea, which need not be contemporaneous everywhere. Godwin's recent publication on Jersey (1952) seems to confirm this view. Overbeck (1950) explains the peat formation in NW-Germany by a submergence, too; the late George Dubois (1924) assumed a lowering or a standstill of the sealevel between the deposition of the marine Assize de Calais and the marine Assize de Dunkerque, and also Tavernier and Moormann are of the opinion that peat formation in Belgium requires first a regression and then a rise of the water table, caused by a rise of the sealevel. Since Mr. Bennema also admits a "minor drop" of the sealevel, his views are less revolutionary than they appear at first sight.

The Subboreal must have been a dry period, as evidenced by Weber's „Grenz"layer. This dryness must have caused local shifts in vegetation zones (wood taking the place of peats, heather of woods and sand drift of heather), but these shifts are not clearly marked in pollen diagrams owing to the wide distribution of pollen grains.

Prof. Kuenen (Groningen) is not quite satisfied with Mr. Bennema's curve, as it does not show a sealevel higher than the present one, which is necessary to explain the platforms on Pacific atolls and other reefs.

Mr. Bennema, in his reply to Prof. Kuenen, suggests a general rise of the continents and islands around the oceans as belated isostatic reaction to the changes of water level. This should have continued over a vertical distance of a few metres after the rise of sealevel had slowed down.

In answer to Prof. Florschütz' observations, Mr. Bennema remarks that in accordance with the ideas of Mr. van Bendegom, the extension of peat growth can also be explained by a retardation of the rise of the sealevel and a decrease in the effect of the tides behind a shore bar, and does not require a fall of the sealevel. Once reed has settled on a tidal flat, other vegetation can follow, the growing peat affording a protection against the water, so that more peat can grow. It only requires a nearly closed shore bar. Where the shore bar was interrupted by wider gaps, no peat occurs, as e.g. in the Friesland area studied by Prof. Bakker.

So-called regressions in surrounding countries often are not contemporaneous with the beginning of the formation of peat and the supposed regression in Holland. Godwin's assumed regression coincides with the end of the Cardium transgression. Moreover his conclusions are founded on the wrong supposition that peat is subject to weathering, not to compaction, and that the gullies in the Fenlands are not deeper than the sealevel at low tide. Overbeck's regression may be considered as two or three minor regressions taken as one, and Nilsson's regressions are admittedly doubtful. Neither can drier horizons in peats far from the sea be used as arguments for a regression, and moreover it appears that drier recurrence-layers in the peat of the Eastern Netherlands do not have the same age.

On the other hand observations made by Bakker, Wiggers, Dittmer (in Slesvig-Holstein), and more or less those by Mikkelsen seem to confirm Mr. Bennema's opinion.

Prof. Mac Gillavry (Amsterdam) adds that also the phenomena at the Gulf Coast strongly speak against a regression.

Mr. Moormann (Ghent) is in favour of a slight fall of the sealevel, coinciding with the beginning of peat growth, though peat growth in itself need not be indicative of a lower sea level. He observes that in some places peat growth did not start with reed but with low lying wood peat (Stockmans, Van Hoorne), which can hardly be explained without assuming some lowering of the sealevel.

Mr. Bennema replies that the effect of tides was shut out by the shore bar, and that a drop of the sealevel cannot be observed; but a slight lowering may have occurred.

Mr. Edelman (Public Works Dept.) observes that the inner shore bar or older dune ridge, which is the oldest, is at the same time the lowest, and that the further seaward the bars are situated, the younger and higher they are. This fact is in favour of a continuously rising sealevel.

Prof. Bakker (Amsterdam) thinks that during periods of glacier advance the rivers contained less water, so that the sea could more easily penetrate into the estuaries. Therefore extension of marine sediments need not necessarily indicate a rise of sealevel.

Furthermore he observes that, besides the 500-years periodicity, there are also indications in favour of a periodicity with an interval of 1000 to 1050 years, as formerly assumed by Mr. W. C. Visser. It seems that the sedimentation periods of 200—100 B.C. and 800—1000 A.D. were less important and shorter than those of about 400 A.D. and 1200—1500 A.D. If this could be more generally applied, it would mean that the present period of floods (since 1750) belongs to the shorter ones.

Prof. Mac Gillavry (Amsterdam) remarks that the present tectonic subsidence appears to be of the order of magnitude of 1 mm per annum, which is more or less the same as that computed for the Pleistocene. He has, therefore, an idea that Mr. Bennema's curve is much more due to tectonic subsidence than to eustatic rise of sealevel.

Mr. Wemelsfelder (Public Works Dept.), for practical purposes, would like to have a figure for the most probable relative rise of sealevel in this country. He assumes that all figures, arrived at from different observations, and computed into a graph, would result in a frequency curve, the top of which would indicate the most probable figure, for instance 20 cm per century.

Dr. Pannekoek (Geol. Survey) is not in favour of this method, as the value of each figure is determined by the strength of the arguments and reasonings on which it is based. Therefore the figures are not comparable. Moreover, there will probably be a number of figures with almost equal probability, which may vary between say 5 and 30 cm per century, and they need not be the same at different places; for practical purposes the highest probable (not possible) figure should be taken, with a certain safety factor added to it.