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A. Area of the Scandinavian Glaciation

1. Pleistocene and Holocene

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With 1 figure

1. Introduction

The "Northwest-German Glaciation Area" is that part of Northwest Germany which was covered by ice during at least one glacial period during the Pleistocene. The southern and western borders of this area are generally delineated by the outer margin of the continental icesheet that proceeded farthest during the Elster- or Saale-glaciation. To the east, the border between the FRG and the GDR forms the boundary, in the North the North Sea and the Baltic Sea limit the area, though about this region only little is known at present. Within the limits of this area a periglacial climate prevailed over long periods of time during the pre-Elster period and the Weichsel cold period and also during the Elster and Saale cold period. Periglacial sediments and structures were formed and the discussion of them overlaps to a certain extent with "Periglacial Sediments and their Stratigraphy" by A. SEMMEL, another chapter in this volume. However, a regional separation has been maintained.

The statement made in "Periglacial Sediments and their Stratigraphy" applies here also: despite the progress in research during the last two decades, no satisfactory knowledge has been achieved so far. There are important reasons for this situation. Primarily, there is a lack of scientists interested in the geoscientific research of the Quaternary of Northwest Germany (except for perhaps the fields of geomorphology and palyonology) inspite of the steadily increasing economic importance of unconsolidated sediments with regard to groundwater supply, waste disposal, problems of engineering geology, e.g. coastal construction, and near-surface economic deposits. In the universities, study of the Quaternary diminishes; the governmental geoscientists are often so involved with routine work and compilation of geological and pedological maps that thorough, purely scientific work can either not be done continuously or cannot be done at all.

Additionally, scientific evaluation is possible for the data from only a small number of boreholes. True progress is no longer to be made merely by studying the near-surface strata that generally will be known within some years after the routine mapping of the entire area. Improvement may only be achieved by the study and stratigraphic division of the total Quaternary which may reach a thickness of up to 500 m. Geophysical logging of a great number flush-drilled boreholes for water supply purposes has given information on the sequence of beds. In most cases, however, no material can be obtained that allows proper petrographical and paleontological interpretation. Not before the total Quaternary has been carefully studied in detail in a dense grid of observation points and the results interpreted by various methods will it be possible to analyse with greater success such questions as the division of the glaciations, the number of basal moraines and the distance of the ice retreat between two cold phases.

For this joint report, each author has contributed a discussion of a particular area. F. GRUBE described the geology of the Quaternary in the Hamburg region. K. DUPHORN dealt with Schleswig-Holstein, K.-D. MEYER with central and northern Lower Saxony; H. STREIF was concerned with the coastal Holocene. R. VINKEN added some data regarding southern Lower Saxony not contained in the "Periglacial Sediments and their Stratigraphy", chapter moreover, he coordinated the individual contributions and orientated them towards the theme "Northwest-German Glaciation Area". The large-scale division of the contribution was effected according to stratigraphy, the division of the individual chapters in general according to regions or to genesis and facies. When this contribution was compiled, a manuscript by K. E. BEHRE and B. MENKE titled "History of Vegetation and Biostratigraphy in the Northwest-German Glaciation Area since the Pliocene" was in hand. In its entirety this manuscript is included in the chapter "History of Vegetation and Biostratigraphy".

2. Pleistocene

2.1. Early Pleistocene to the Elster glacial stage

In the Neogene the sea covered wide areas of the Northwest-German lowlands. During the time from late Tertiary to early Quaternary the sea retreated to the western coast of the Netherlands. In this area was a river system which, in general, drained towards the West and was active until the boreal continental ice sheet advanced during the Elster glacial stage. In this river system a quartz sand sequence was deposited — the so-called kaolin sand. On the Isle of Sylt its late Pliocene age is proved by intercalated lignite seams (WEYL et al. 1955, cit. GRIPP 1964, AVERDIECK 1971). Deposition of the quartz sand series extended into the early Pleistocene (see below). Its initial extent is only roughly known. Today the sequence stretches from the Isle of Sylt, where it is 40 m thick, via the Emsland as far as the Netherlands and via Schleswig-Holstein and Mecklenburg far into northern Poland.

The major source area of the Pliocene and lower Quaternary quartz sand is, from the pebble composition (blue quartz, lavender-blue Silurian chert, and quarzite), the eastern Baltic Sea between Central Sweden and the Baltic provinces. On the other hand, the presence of true lydite demonstrates the influence of the Central-German Hercynian. Particularly in the Ems area, where the "white sands" crop out, but also in other parts of Ostfriesland and of Oldenburg, lavender-blue jasper is not rare in drill holes and surface exposures. The mode of transportation of the quartz sand has been extensively discussed. Because of the size of some boulders (up to 30 cm) WIRTZ & ILLIES (1951, cit. GRIPP 1964) suggested the possibility that part of the transportation route was covered by glacial scour or drift.

In the Lieth limestone quarry on the Elmshorn (western Holstein) salt dome are several sedimentary layers which were deposited during the cold and warm periods between the late Pliocene and the Elster cold period (CROMMELIN 1954; DÜCKER & MENKE 1968, GRUBE 1968, both cit. MENKE 1970, MENKE 1970). Above the "pre-Tegelen" deposits follows a very complex early Quaternary sequence (see also chapter "History of Vegetation"). The "warm" periods are characterized particularly by the pollen from mixed forests. In the "cold" periods an arctic to boreal climate prevailed with vegetation that consisted mainly of Ericales heather mixed with herbs (details are given in the chapter "History of Vegetation").

Also in northern Lower Saxony pollen analyses (unpublished report, Niedersächsisches Landesamt für Bodenforschung, NLfB) have shown that the upper portion of the quartz sand series is of early Pleistocene age. The quartz sand encountered in drill holes in the Elbe region, e.g. near Cuxhaven, probably corresponds in part to the deposits near Lieth.

BIJLSMA and CLEVERINGA (1971) correlated fluviatile sediments in the icepushed zone of Itterbeck-Uelsen (Emsland) with the Dutch division of the early Pleistocene on the basis of pebble and heavy mineral analyses.

In southern Lower Saxony near Bilshausen a complete warm period, the Rhume interglacial, is represented in a basin clay series (LÜTTIG & REIN 1955, CHANDA 1962, H. MÜLLER 1965, cit. LÜTTIG 1965). On the basis of varve counts, H. MÜLLER estimated this warm period to have lasted 28,000 to 36,000 years. The vegetation during this period was quite different from that of the Holstein and Eem periods. The sequence of the layers, the climate- and lithostratigraphical considerations, and above all the mammal discoveries (time-equivalent to Voigtstedt, personal communication SICKENBERG) indicate that it should be assigned to the pre-Elster period.

A clear correlation with the early Pleistocene warm periods in the Netherlands or with the Cromer Forest Bed is not possible at present; it is most similar to the Westerhoven deposits in the Netherlands.

According to DUPHORN (1969) a cave loam in the Einhorn-Höhle near Scharzfeld/Harz Mountains developed during the pre-Elsterian Rhume interglacial; it contains a rich vertebrate fauna (mainly bear bones).

The Osterholz near Elze warm period strata which include a complete warm period sequence (GRÜGER 1967) and are overlain by a basal moraine of the Elster period (according to LÜTTIG, 1960, cit. 1964), are assigned to the "Cromer Complex" by GRÜGER as is the Bilshausen clay. He emphasizes that both occurences are not of the same age, but have to be assigned to two different warm periods of the Cromer Complex.

In situ, true glacial sediments of the pre-Elster period have not been found as yet, even in boreholes. In the Upper Muschelkalk cropping out in the Elm Mountains (southeast of Braunschweig), BEUG, GOEDEKE, and GRÜGER (1965) describe a sink hole which is said to be filled with silt and clay of the "Cromer Complex" and underlying "boulder clay of the Elbe cold period". GRÜGER (1967) concludes from the vegetation that the warm period strata are of the same age as those of Osterholz near Elze. According to LOOK (1968), the occurrence in the Elm Mountains represents a late Saale pingo structure in solifluction detritus, whereas, according to an unpublished report of H. MÜLLER (Geol. Survey of the Fed. Rep. of Germany) the warm period sediments have to be assigned to the Eem period.

Also no glacial sediments, in particular no basal moraine older than of the Elster glaciation (unpublished reports, NLfB Hannover) have been found in the up to 400 m deep channels in the Hamburg area and in northern Lower Saxony. In general, sediments of the Elster period, more rarely also of the Saale or Weichsel period, overly Tertiary beds.

It can be assumed that the glaciers of older glaciations, the existence of which has to be accepted as true, did not reach North Germany, whereas the North European ice sheet formed in the central parts of Scandinavia already during the early Pleistocene "cold periods".

Though placement of the Tertiary/Quaternary boundary is still regionally as well as internationally biostratigraphically in question, the attempt has been made in the NLfB to compile a map of base of the Quaternary sequence during the recent years. Particularly in the Hamburg region and in northeastern Lower Saxony good results have been achieved since the lithostratigraphy is relatively well known and in comparison to other areas, there is a great amount of drill-hole data to be evaluated. For northwestern and central Lower Saxony, these maps represent a first attempt to understand the distribution of the base of the Quaternary sequence.

2.2. Elster

Elster period deposits are in general know from drill-holes or deeper exposures only except for the late Elster "Lauenburg clay", a near-surface glacial sediment widely distributed between Lauenburg/Elbe and the Netherlands and of some significance as a key horizon of the Nortwest-German Quaternary. The general knowledge on the deposits of the Elster glaciation and the resulting stratigraphic and paleographic conclusions are not satisfying. Differentiation from the Saale period deposits is often difficult, as the Holstein interglacial interbeds are seldom widespread. For this reason sedimentologic methods, primarily those to identify drift material (Geschiebestatistik), are of great importance for the recognition of the strata, although many problems with the statistics of drift material remain unsolved, as will be demonstrated.

In the northwestern forelands of the Harz Mountains LÜTTIG (1954, 1958, both cit. 1964, 1970) distinguished an older Bornhausen and a younger Bockenem stage. Below the Holstein occurrence of Northeim, LÜTTIG (1960) found loess of the Elster glaciation.

According to LÜTTIG's counting of the drift material, which correspond with HESEMANN's results, the Elster sediments in this southeastern part of Lower Saxony are characterized by a comparatively high percentage of material from the eastern Scandinavian Shield. More recent still unpublished mapping of gas pipe trenches has shown, however, that part of the sediments previously assigned to the Elster period actually belong to the Saale period. Moreover, it seems to be verified that at the northern margin of the Harz Mountains the Saale glaciation and not — as has been assumed up to now — the Elster glaciation progressed farthest to the South (DUPHORN, in the press).

The composition of the drift material in the Elze section which is the stratigraphically best-substantiated occurrence of Elster period sediments, shows no distinct predominance of material from the eastern Scandinavian Shield.

In other areas of North Germany drift material originating on western Scandinavia has been found and described: HESEMANN (1937) demonstrated dominance of south Norway drift material in the boulder clay of the Elster glaciation near Wenningstedt on the Isle of Sylt; CEPEK (1962, 1969) assumed that the Elster basal moraines of Brandenburg came from the North-Northwest. As CEPEK used other methods to identify drift material and as he does not give more details of the percentage of crystalline rock fragments, his and K.-D. MEYER's (1970) results cannot directly be compared.

In the Hamburg Elbe region K. RICHTER (1962, cit. 1964) could not confirm a strong influence of the eastern Scandinavian Shield in the composition of the drift material of the Elster period.

On the basis of clast-counts of the drift material, particularly chert coefficients (among others, percentage of translucent chert) in drill-hole samples as well as in decalcification zones, RICHTER suggested a division of the Elster cold-period into 5 glacial advances separated by interstadials. According to studies of K.-D. MEYER, however, the chert coefficient is partly dependent on the grain size and the nature intensity of weathering of the components; it is not of much help in stratigraphically dividing the cold-period deposits and has only limited values as evidence for demonstrating interstadials.

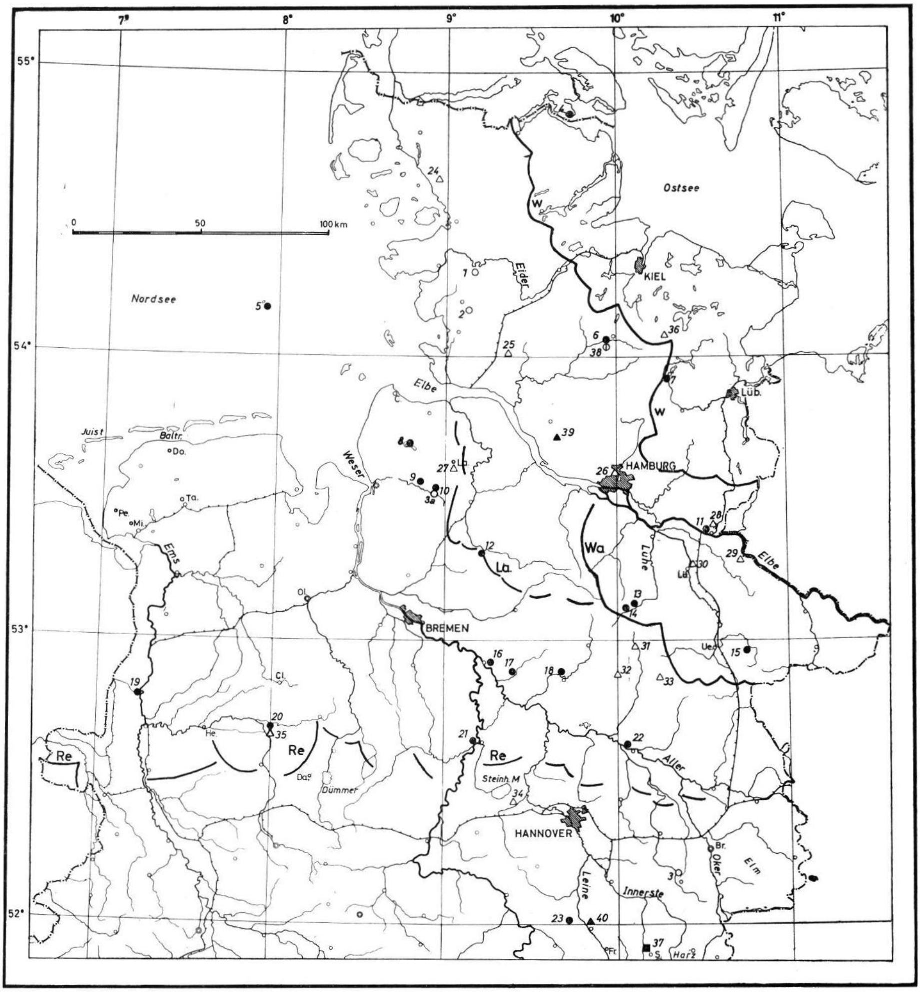

Fig. 1. Position of interstadial and interglacial deposits and of some end moraine ridges in northwestern Germany

○ Weichsel

1 Glüsing
2 Odderade
3 Lebenstedt
3a Oerel

● Eem

4 Stensigmose
5 Helgoländer Süßwasserstöck
6 Brokenlande
7 Fahrenkrug
8 Bederkesa
9 Köhlen
10 Oerel
11 Lauenburg
12 Godenstedt
13 Grevenhof + Schwindebeck
14 Hützel
15 Rosche
16 Lehringen
17 Nedden-Averbergen
18 Honerdingen
19 Haren
20 Quakenbrück
21 Liebenau
22 Gr. Hehlen
23 Wallensen

⦶ Saale

38 Brokenlande

△ Holstein

24 Bredstedt
25 Wacken
26 Hummelsbüttel
27 Nindorf
28 Lauenburg
29 Breetze
30 Lüneburg
31 Munster-Breloh
32 Hetendorf
33 Neuohe-Wiechel
34 Wunstorf
35 Quakenbrück
36 Tarbeck

■ Elster

37 Bornhausen

▲ early pleistocene fossil localities

39 Lieth
40 Osterholz

End moraines

Re Rehburg
La Lamstedt
Wa Warthe
w Weichsel

In the Hamburg area, the basal moraine of the Elster-period is locally up to 70 m thick. In surface exposures the Elster sediments could not as yet be assigned to individual stages.

In recent years the basal moraine of the Elster-period has been encountered frequently beneath the Lauenburg clay in Ostfriesland/Oldenburg (K.-D. MEYER 1970). Here, but also in the Hümmling, near Bremerhaven, and in the area of Lüneburg, the gravels of the Elster-period show a great percentage of Norvegian material, mainly rhomb porphyries.

In much of North Germany there was certainly an ice advance strongly influenced by western Scandinavia, however its relationship to the east fennoscandian related sediments described in the first part of this chapter is unclear. Of the two possible interpretations, co-existence of a "North Sea glacier" and a "Baltic Sea glacier" or one existing after the other, the latter is more probable as the differences in the drift material are considerable. A more firm interpretation would depend upon detailed study of series of samples collected according to a dense sampling grid.

Similarly, the little known western and southwestern distribution boundary of the Elster-deposits should be drawn not only according to the depth of the sediments. Also in this case the sampling grid is not dense enough to obtain conclusive data.

In recent years, a great number of hydrogeological exploration drillings has increased our knowledge considerably and resulted in abundant material that has so far not been evaluated completely. Especially worth mentioning is the substantiation of the extension to large areas of northeastern Lower Saxony and southern Schleswig-Holstein of "channels" long known from the Hamburg area. These comparatively narrow, but more than 400 m deep depressions (maximum depth = base of the Quaternary deposits so far is 502 m in a borehole near Reeßeln, LÜTTIG 1972) cut into the underlying Tertiary strata and are mainly filled with thick, Elster-period deposits. These are predominantly melt water deposits, occasionally interbedded with boulder clay and covered by the Lauenburg clay. Though often several Elster period basal moraines have been found overlying each other in boreholes, these cannot yet be correlated and assigned to individual phases with certainty.

The age and mode of development of these channels has provoked lively discussion. According to CEPEK (1967, 1968, cit. 1969) they resulted from an interlacing network of streams which drained to the North Sea and hat a pattern determined during a pre-Elster cold-period (Eburon). Also W. RICHTER et al. (1968) give a similar explanation using crustal movements to support their point of view. In our opinion, however, cross section (steep sides), course and depth, gradient of the channel bottom, and especially the channel fill predominantly of scandinavian material, are incompatible with subaerial drainage. It is probable that subglacial valleys are involved with the (partly confined) glacial meltwater for the erosive modelling of the channels more. Melting of deeply buried dead ice may have caused the down of the basal moraines, so that the stratigraphic interpretation of channel sequences has to be done with great care (compare EISSMANN 1967).

According to JOHANNSEN (1971, cit. JOHANNSEN & LÖHNERT 1971), the development of the channels is closely connected with salt tectonics in the area. The channels were mainly cut along structural strike, that is, along the deep zones themselves or along the flanks of the salt anticlines. Often a diversion of the channels by the structural trends can be observed.

2.3. Holstein

The Holstein interglacial deposits represent an important key horizon for the stratigraphic subdivision of the glacial deposits in Northwest Germany. Regrettably they are often disturbed as they were deformed by the Saale ice running over them.

Especially important are the marine deposits with their characteristic fauna. They are widely distributed as can be seen for example from the International Map of the Quaternary, scale 1 : 2 500 000, sheet 6, Copenhagen. The coast line of the Holstein Sea was irregular. The most conspicuous feature was the Lower Elbe embayment which extended inland to western Brandenburg and from western Mecklenburg far to the north-northeast. In southern Holstein was another large bay. Comparison of the configuration of the coast of the Holstein Sea with the tectonic structure and the salt structures of the subsurface shows considerable similarity. This refers in particular to the continuous trends through time of both large bays which are nearly concordant with the "Rhenish" trend of the salt structures as well as with the structural grain of the pre Cretaceous tectonics.

Though Picard (1966) suggests that Schleswig-Holstein atteined its "seaencircled" shape only during the Saale period, the present-day features of the coast already formed, according to Gripp (1964), during the Holstein interglacial. Marine Holstein depositions on the Isle of Sylt and near Esbjerg indicate the extent of the Holstein Sea to the Northwest.

The existence of the Baltic Sea during the Holstein period is shown by marine deposits near Rögle Klint on Fünen. The present-day western Baltic Sea area was at that time filled with water, at least as far as to the Oderhaff. Recently, marine Holstein sediments were drilled in Mecklenburg (Cepek 1968, cit. 1969), proving the existence of a seaway connection via the Lower Elbe bay during the Holstein-period, preceeding today's North Sea and Baltic Sea.

Ecological interpretation of the mollusc fauna (Grahle 1936) and of the microfauna (Woszidlo 1962, Lange 1962, Lafrenz 1963, cit. Menke 1970) indicates a rise in temperature in the Holstein Sea proceeding from arctic to boreal conditions; the temperature reached maximum values similar to the present only in the southern North Sea. The pollen analyses by Menke (1968, cit. 1970) confirm that the transgression of the Holstein Sea in the type area already occurred while the ice gradually melted during the late Elster period. In western Holstein the sea obviously advanced directly into the meltwater basin of the Elster glaciation where the Lauenburg clay was deposited. An early Holstein freshwater phase as has been found in some places in the southern Holstein bay, has not yet been recognized. In nearly all complete Holstein sections of the marine facies, the transition from marine to estuarine and fluviatile-terrestrial sediments, i. e. the process of regression, can be observed.

In the Hamburg area and in Lower Saxony, only a few exposures of marine facies are presently accessible. In Hamburg-Hummelsbüttel the transgression of the Holstein Sea (Mytilus clay, Cardien sands) over the lacustrine deposits of the early warm-period as well as over the Lauenburg clay can be studied (Grube 1959, Hallik 1960, cit. Grube 1967). The marine Holsteinclays, which are still accessible in the brick-works of Nindorf (west of Stade), in the icepushed moraine of Lamstedt and in the exposures near Wacken (near Itzehoe), are glacial-tectonically disturbed.

Grube, Khoo, and Weitscha are presently working in the Nindorf area. The marine Holstein interglacial deposits in the "Elba" brick-works near Lüneburg described by Benda and Michael are no longer exposed. The profile showed sand-clay lacustrine beds above the Lauenburg clay, which are in turn overlain by clay (with Mytilus); the content of foraminifers, ostracods and diatoms indicates a brackish-marine biotope. The profile ends with glazio-fluviatile sand and gravel of the Drenthe-period.

A brackish-marine influence is also to be seen in the Breetze interglacial deposits near Bleckede/Elbe. In a section recently found by K.-D. Meyer in an abandoned brickyard, two clay horizons with a diatomite up to 3.3 m thick overlie Lauenburg clay and its fine-sand facies. Paleobotanic interpretation (BENDA & MEYER, in print) shows a rather complete forest development with a climate optimum in the diatomite. The lower part of the section (lower clay and diatomite) is purely lacustrine; the upper portion, however, was deposited in a brackish-marine environment.

Though a number of Holstein occurrences are known in Northwest-Germany, few have been biostratigraphically evaluated in comparison with deposits of the Eem-interglacial. In the marine portion, only one Holstein occurrence meets present requirements for a type locality, this is the occurrence of Wacken.

Through pollen analyses MENKE (1968, cit. 1970, 1970) showed a development of vegetation typical for the "Classic" Holstein-interglacial in the marine clay deposits near Wacken. Moreover, he found for the first time in Northwest Germany an equally thermophile vegetation between the "Classic" Holstein interglacial and the Drenthe stage. DÜCKER (1969) divided the occurrence of Wacken into two warm-periods which he designated as the Muldsberg warmperiod (Holstein I) and the Wacken warm-period (Holstein II). The interbedded colder period was designated the Mehlbek cold-period (see also "History of Vegetation" chapter). A more detailed discussion of the stratigraphic classification of the "Wacken warm-period" is given by WOLDSTEDT and DUPHORN (in print). In the Hamburg area and in Lower Saxony, the division of the Holstein sequence into two separate interglacial periods could not be found in an undisturbed sequence of the marine facies (as to the Quakenbrück borehole, see below).

Concerning non-marine facies, mainly the lacustrine interglacial deposits and among them the diatomite (Kieselgur) occurrences of the Lüneburger Heide are of interest (HALLIK 1960, cit. GRUBE 1967). The Neuohe-Wiechel and Munster-Breloh deposites, which are still worked as well as the newly exposed occurrence near Hetendorf are, also with regard to their position, clearly distinguishable from the Eem-period diatomites in the Luhe valley (BEHRE 1962, cit. 1966). In connection with the now finished studies for mining purposes carried out by the NLfB, BENDA and his colleagues have succeeded in determining the entire history of the interglacial vegetation. From the varve counting of the sediments, the surprisingly short period of 12,000—15,000 years has been found to be the absolute duration of the Holstein interglacial (BENDA, K.-J. MEYER, H. MÜLLER, in print).

Newly interpreted is the well-known Quakenbrück interglacial south of Oldenburg (HARTUNG 1954, KOPP & WOLDSTEDT 1965, cit. KOPP 1968) as a result of coredrilling suggested by WOLDSTEDT and financially supported by the German Research Assocation (Deutsche Forschungsgemeinschaft) in 1967. The results are not yet available; according to a short written note, the succession is very complex: below several Weichsel interstadials follows the normally developed Eem interglacial and beneath a disconformity at a depth of 61 m, a bipartite Holstein interglacial. The drilling, which was abandoned at a depth of 100 m, did not reach the partly very thick boulder clay known from many neighbouring drillholes. Accordingly, this boulder clay has to be assigned to the Elster period. This means that the Quakenbrück Basin, which has to be regarded as the tongue basin of the Damme-Fürstenau lobe of the Rehburg phase, was formed already during the Elster period. It is strange that sediments of the Saale period are completely missing in the section drilled. Of importance is the bipartite subdivision of the Holstein interglacial. When interpreting the drilling profiles, caution is necessary because of possible dislocations, consequently we have to wait whether this bipartition will be confirmed.

2.4 Saale

With the exception of the highland ridges and the southermost part of the country, all Lower Saxony, Westphalia, and the Rhine district as far as the Ruhr area and beyond the Rhine were covered by ice during the Saale period. In the icepushed moraine ridge of

Krefeld-Kleve west of the Rhine, which marks the farthest advance of the Saale ice in West Germany, the petrographically well distinguishable deposits of the Lower Middle Terrace of the Rhine are the youngest deformed sediments. SERAPHIM (1972) dealt with the maximum extension of the Saale ice in the area between Osning and the Weser. East of the Weser as far as the foreland of the Harz Mountains, the conclusions of LÜTTIG (1954, 1958, cit. 1964) are in general still valid. In the Leine valley, the ice sheet advanced as far southward as the vicinity of Freden. In the immediate Harz foreland DUPHORN (in print) has shown with the help of the remnants of basal moraines overling the middle terraces of the Harz rivers, that in the area northwest of the Harz Mountains (on the Seesen sheet) the Saale ice advanced farther southward than the Elster ice. In the Harz Mountains proper, DUPHORN (1971) assumes local valley glaciation extending outward from the Acker Bruchberg range.

There are no recent studies of a large part of eastern Lower Saxony with regional data on the maximum extension of the Saale ice and, with the exception of the immediate margin of the Harz Mountains, on the ratio of glacial sediments to fluviatile deposits from rivers flowing in from the South. Only from the Elm area are the more detailed studies of LOOK (1968) available.

For the last two decades a great number of authors has dealt with the subdivision of the deposits of the Saale period in Northwest Germany; it is not possible to refer to all of them in more detail here. Following demonstration that the Weichsel ice did not cross the Elbe (the recent suggestion that the Weichsel ice advanced southward past the Elbe must be regarded as speculation) of increasing importance has been the question of the order of successions, the extent of the individually distinguishable advances, and the role of the dividing intervals. It had to be established if the Saale cold period must be subdivided into two or several individual cold periods separated by true interglacials. Present-day authors are largely unanimous in denying such a subdivision. The great number of boreholes and exposures that have been studied during the last few years, and mainly the excellent cross-sections of the Elbe side canal which is presently under construction from Artlenburg in the North and the "Mittellandkanal" near Gifhorn in the South have not given any indications as to true intra-Saale interglacials.

Existence of the "Treene warm period" postulated as occurring between the Drenthe and Warthe period by PICARD (latest in 1970) and STREMME (1960, cit. in 1964) based on fossil soils, has not remained uncontradicted and has not been biostratigraphically substantiated by palynological methods as yet. The diatomite (Kieselgur) deposit of the "Ohe warm period" (v. D. BRELIE 1955) could be assigned palynologically to the Holstein period by HALLIK (1960, cit. by GRUBE 1967); this result is confirmed by recent investigations (L. BENDA, K.-J. MEYER & H. MÜLLER, in print). An interglacial occurrence discovered in the Gerdau valley near Linden which is not identical with the "Gerdau interstadial" (LÜTTIG 1958, cit. 1964) was definitely assigned to the Eem period by BENDA, LÜTTIG & SCHNEEKLOTH (1966). Proof is also missing from the marine facies. Though Northwest Germany was free of ice between the individual longer phases of advance and retreat of the ice, a warming in connection with a peak sea level of "interglacial character" has not yet been demonstrated (KOPP & WOLDSTEDT 1965, cit. KOPP 1968).

There is general agreement on the fact the Drenthe and Warthe stage are subdivided into several phases, but not on the number and the order of the phases and the extent of the ice advances during these phases. This uncertainty is due to the great number of individual advances from various directions and of differing intensity; partly they overlapped each other and mainly in the Lüneburger Heide, formed a rather undecipherable confusion of glacier margin deposits (compare Table 7 in LÜTTIG 1964). There is great difficulty in satisfactorily assigning the ground moraines to specific marginal moraines. This frequently encountered and actually normal discrepancy between the number of ground moraines and the number of the various mostly morphologically distinguishable, "marginal moraines" ("Endmoränen") may have several causes.

One possibility is the erosion and removal of the ground moraines by the next-younger ice advance (LÜTTIG 1964). On the other hand, there is no certainty that each glacier margin marked by "marginal moraine" must be attributed to an advance phase with characteristic ground moraine and that in the different phases the ice retreated rather far, returned causing new glacio-fluviatile accumulation and finally left its ground moraine at the top of these meltwater deposits. It increasingly appears that there were partial halts in the advance of the ice which occassionally caused the development of distinct ridges; that means that the ice did not retreat and that thus no splitting up of the ground moraine is to be expected. For the same reasons there are difficulties concerning the stratigraphical subdivision of the locally rather thick glacio-fluviatile deposits of the Drenthe stage. The processes taking place in connection with the "stagnation" of large masses of continental ice and the possible reactivation of these ice masses in case of supraregional climatic changes complicate the genetic and stratigraphic interpretation of the data obtained in exposures and drillings. Almost unknown is also the drainage pattern of the individual phases of the Saale glaciation (cf. also "Warthe-sandurs"), mainly because of the lack of statistical data from widespread measurements of the cross-bedding in sedimentary bodies of definately uniform age.

"Marginal moraine stratigraphy" which considers only morphological criteria involves some serious faults. Accordingly, the attempt has be to check and complete it by a "ground moraine stratigraphy" in spite of the uncertainties. A locally valid stratigraphy can be applied to larger regions only with great caution so that ground moraine layers which owe their existence to minor oscillations of the glacier margin are not overrated. In applying glacial till statistics as an auxiliary method in ground moraine stratigraphy, it must be checked whether differences in the till composition indicate always true stratigraphical differences or only facies differences in a rock succession of about the same age.

LÜTTIG has published a series of papers on the Drenthe stage in central and southern Lower Saxony (1954, 1958, 1960, all. cit. 1964, 1965, 1968). According to his findings, the Drenthe stage consists of quite a number of phases, these again are divided into "Staffeln" which are separated by intervals (and/or "Etappen"). The southermost advance took place during the "Hameln" phase. In southern Lower Saxony the ground moraine from this advance overlies in general wide areas of the Middle Terrace complex of the Weser, Leine, Innerste and Oker rivers which transported material from the south. From their position at the very bottom of these ground moraine, the loesses and fluvio-periglacial as well as solifluidal-periglacial sediments, for example east of Hildesheim, can definitely be assigned to the early Drenthe period (VINKEN 1969). In the same stratigraphic position in the more proximal Hannover area, the material of the Middle Terrace complex transported from the South interfingers and is mixed the glacio-fluviatile deposits of the advancing Drenthe ice sheet. This mixing or transition-zone shows here a N-S-extent of approximately 40 km. In the area north of the "Wiehengebirge" as well as on the Weser terraces south of the Porta Westfalica recent, namely petrographical investigations on the interfingering of sediments transported from the south by the Weser river and meltwater deposits drifted from the North, despite the comprehensive studies e. g. of WORTMANN (1968), did not yet yield conclusive results as to the course of the Weser during the Saale period. Detritus from the Weser can be traced as far as the Netherlands; it is, however mostly exposed in icepushed moraines, so that the stratigraphic relations are often unclear.

According to LÜTTIG, the "Rehburg" phase preceded the "Hameln" phase. The Rehburg "end moraines", designated by WOLDSTEDT (1928) the "Rehburger Stadium, probably the most important and most distinctive marginal moraine of Northwest Germany" extend as individual cresents and patches from the Dutch border in an east-west direction as far as the area east of Braunschweig. Within the Drenthe stage the actual time and development of this ridge which shows a strong glacio-tectonic imbricate structure, has been discussed extensively. WOLDSTEDT concluded that, because no sandurs are developed and the ground moraine overlies the Middle Terrace in the forelands, probably a "phase of advance rather than a phase of retreat" is concerned here. This opinion was substantiated by him in 1954. The idea that such a distinct end moraine was overrun by the ice has been previously questioned. R. RICHTER (1955, 1958, 1968) reached the modified view that overlapping took place at the boundary between the active and the "dead" ice. Reconnaissance mapping by the NLfB during the last few years, which covered also the entire area from the "Rehburger Berge" to the "Fürstenauer Berge", showed remnants of ground moraine on the crests of the end moraines and chiefly, over a wide area, at their southern outer margin. As a result it can no longer be denied that the ice overran the end moraines. In the immediate hinterland no doubling of the Drenthe ground moraine was found. The ice could not have retreated considerably towards the North after the ridge material has been pushed; it must have advanced further southward after a short halt. LANG (1964) reached similar conclusions with regard to the "Mellendorfer Berge" north of Hannover; they were likewise deposited and overrun during the "Rehburg" phase. According to the evidence from the glacio-tectonic structures and morphological observations, however, the "Brelinger Berge" deposits immediately adjacent in the North, were contorted during a younger phase (according to LANG during the "Heisterberg" phase) when the ice retreated.

In the northwestern part of Lower Saxony the situation is in general simpler. Distinct ice-margin deposits (end moraines) do not occur, and only one ground moraine of the Drenthe period has been found. Concerning the glacial till, the ground moraine shows in general the usual compositional spectrum of the Drenthe period with predominantly material from South and Central Sweden.

In the Cloppenburg - Vechta - Herzlake area, however, there is a sudden and considerable change. The percentage of east-Baltic material (mainly rapakivi) increases abruptly. The percentage of flintstone decreases to a minimum, the clay content increases considerably, and the moraine aquires a red colour. According to K. RICHTER (1961) this red moraine is equivalent to the older of the two boulder clays of the Drenthe stadial of the Saale glaciation.

In mapping and particularly by recording km-long exposures (gas pipe trenches), however, it became obvious that the "Red Drenthe Moraine" (which is also known in the Netherlands) is extensive and always near the surface. It is not separated from the underlying "normal", grey, more sandy Drenthe-moraine by beds of glacio-fluviatile character, but always overlies it directly. Reworked deposits of an older Drenthe period till cannot be concerned here, and definitely not an Elster period moraine. The extension towards the East past the area described above has not yet been discovered. Although there remains difficulty in the glaciologic interpretation because of the great differences in the composition of the glacial till, we hold the opinion, according to the data available, that the "Red Drenthe Moraine" represents a facies of the one Drenthe period moraine.

In the area between the Weser and the Elbe are several Saale period ground moraines. However, these cannot be assigned in each case to particular icemargin deposits and the end moraine cresents going along with them. In the northern part of the Lüneburger Heide and in the area near Lauenburg (K.-D. MEYER 1965, cit. 1970), two ground moraines of the Saale period have been definitely found so far, (the older "Drenthe Main Moraine" and the "Younger Drenthe Moraine") as well as a ground moraine of the Warthe stage. The Younger Drenthe Moraine, according to the mapping of the NLfB, locally consists of two units; this is probably due to a local oscillation of the glacier and does not necessarily mean that another phase took place. The division set up by GRUBE (1967) for the area of Hamburg with its great number of excellent exposures is comperable with this sequence.

The "Drenthe Moraine" of GRUBE corresponds to the "Drenthe Main Moraine" of MEYER, and the „Niendorfer Moraine" is, according to all its characteristics, identical with the "Younger Drenthe Moraine". GRUBE's "Fuhlsbütteler Moraine" is, also according to K.-D. MEYER's studies of the glacial till, assignable to the Warthe-stage.

Recently, GRUBE (1971) identified above the "Fuhlsbütteler Moraine" (or Fuhlsbüttel I) and separated from this by glacio-fluviatile and glacio-lacustrine sediments, a fourth Saale moraine (Fuhlsbüttel II), which is correlated with the "Vasdorfer Red Warthe Moraine" (GAUGER and K.-D. MEYER 1970) of the Lüneburg area. According to MEYER it is, however, possible that in case of the Fuhlsbüttel-I-Moraine a facies of the Younger-Drenthe-Niendorfer Moraine is concerned, while the Fuhlsbüttel-II-Moraine corresponds to the actual Warthe Moraine; the "Vasdorfer Red Warthe Moraine" being only a different facies of the last one. It is hoped that the study of glacial till in additional exposures in the Hamburg area and especially the interpretation of the data obtained in the large exposures and core-drilling for the Elbe-side canal will clear up this problem and a full understanding will be reached in the near future.

The "Younger Drenthe- or Niendorfer Moraine" is most probably the ground moraine corresponding to the Lamstedter end moraine (west of Stade). The Lamstedter end moraine, one of the most important ones in northern Lower Saxony, for morphological reasons and because of the composition of its glacial till should not to be assigned to the Warthe-stage (ILLIES 1955, cit. LÜTTIG 1964, K. RICHTER 1955), but to the Drenthe-stage (LÜTTIG 1964); this is confirmed by recent sedimentological studies by K.-D. MEYER. According to KOPP (1968), also the soil development is definitely more similar to that of the Drenthe stage than to that of the Warthe stage. In his paper, which is interesting also in the methods used, MARCZINSKI (1968) indicates that the Lamstedter (and Stader) advance took place during the "late Drenthe period to early Warthe period". This dissertation based on the sedimentological studies of K. RICHTER, descriebes an "Uthleder glacial till community" of the early Drenthe period followed by one "Meyenburger" advance and two "glaciers of the main Drenthe period", namely, one "earlier advance of the main Drenthe period" (only in drillings) and the "Late Bremer advance". The paper deals with comprehensive observations; nevertheless there arises the possibility of a stratigraphic overinterpretation.

In the course of several years' mapping, PICARD (most recently 1970) succeeded in drawing a detailed picture of the glacier margine of the Saale period in Schleswig-Holstein. However, it has not been possible so far to connect the corresponding glacier margins in the Hamburg area and in Lower Saxony.

One of the central problems of the Saale glaciation in northeastern Lower Saxony is still the Warthe stage (WOLDSTEDT 1927, cit. 1954). Originally designated as the "Warthe glaciation", WOLDSTEDT pointed out again and again that the Warthe is separated from the Weichsel by a genuine interglacial period but not from the "Saale" and/or Drenthe and consequently represents a younger stage of the Saale glaciation. As has been described above, in Lower Saxony, from palynological studies, there is so far no basis for assuming an acute warm period within the Saale glaciation between the Drenthe and Warthe. As concerns the sedimentology, the content of glacial till that is characterized by material from the eastern Baltic shield and differs considerably from that of the Drenthe, suggests a major retreat of the ice, but the petrographic uniqueness does not prove the existence of a glaciation.

The ground moraine with its unmistakeable till content, determines also the distribution boundary of the Warthe stage ice. It corresponds to the morphological boundary described by WOLDSTEDT, i. e. it extends via the Fläming-Uelzen basin margin — Wilseder Berg — Harburger Berge past the Elbe into Schleswig-Holstein. The outermost „Warthe" end moraines are partly built up of older, dominantly Drenthe stadial, glaciofluviatile material, the ridges of which the Warthe ice ran up against, as has already been suggested by K. RICHTER (1958) and, for some localities, also by other scientists. Under these circumstances it is not surprising that the "Warthe sandurs" lying in front of these "Warthe" end moraines, contain no glacial till of the Warthe but only of the Drenthe period. This applies e.g. to the "sandur" at the western margin of the "Harburger Berge" and the "Sprakensehler sandur" south of Uelzen. Both "sandurs" are overlain by a ground moraine of the late Drenthe period as recent mapping of the NLfB has shown. On the other hand, also fluvial sediments of the Weichsel period are to be found in the sandurs, as can be seen from the intercalated sediments of the Eem interglacial (e.g. in the "Wümme sandur" (LANG 1971)).

Several phases and/or "Staffeln" may be distinguished on geomorphological bases within the Warthe stage; their namens and stratigraphic terminology changes with the different authors (HÖVERMANN 1956, LÜTTIG 1958, cit. 1964, K. RICHTER 1958). Also here, as at the outer margin, older end moraines of the Drenthe period, partly overran by the ice, seem to be concerned here.

Under these conditions it is easy to understand that correlation with neighbouring areas meets with difficulties; an example will explain this further. Among the three Saale ground moraines recognized by CEPEK (most recently in 1969) in the area of the northern G.D.R., the S_2-moraine representing the ground moraine of the Fläming glacial within the Saale period is characterized by a very high percentage of early Paleozoic calcereous and dolomitic glacial till. Since in the Hamburg area also three Saale ground moraines were know in 1967 (GRUBE 1967), CEPEK assumes that an examination of the percentage of dolomitic glacial till "... would essentially support the formal correlation very much". Regrettably, this assumption cannot be confirmed. The middle Saale moraine of GRUBE (Niendorfer Moraine = Younger Drenthe Moraine) is characterized by a very high percentage of cretaceous limestone. The Silurian limestone content is not nearly as high as in the S_2-moraine of CEPEK, but, particularly, dolomitic glacial till is essentially missing. On the other hand, high dolomitic-percentages (25 % in the maximum) are to be observed in the Lüneburger Heide in the uppermost Saale moraine, i.e. in the Warthe ground moraine (Vasdorfer Red Warthe Moraine) (GAUGER & K.-D. MEYER 1970). This Warthe ground moraine undoubtedly overlies the Younger Drenthe Moraine (large exposures in the Elbe-side canal) both moraine complexes being separated from each other by thick glacio-fluviatile sediments. There is rather little doubt that the S_2-moraine of CEPEK hat the same age as the Warthe moraine of our area, although CEPEK does not take into consideration any key drift material ("Leitgeschiebe") in its proper sense. This correlation would imply that the Warthe moraine cropping out in eastern Lower Saxony is overlain by another ground moraine farther to the East, i.e. the S_3-moraine of CEPEK, that represents a second Warthe moraine or perhaps (in the North) already a Weichsel moraine. Assuming this classification is correct, the stratigraphic position of the Rügen period of CEPEK would have to be reconsidered (see also Chapter "History of Vegetation", p. 251). In Lower Saxony the S_1-moraine of CEPEK could then be divided into the Drenthe Main Moraine and the Younger Drenthe (Niendorfer) Moraine.

The only known complete profile of the Saale late glacial period was found by MENKE & ROSS (1967, cit. MENKE 1970) near Brokenlande south of Neumünster. Below diatomite and claymud of the Eem interglacial up to 7 m thick, siltclay basin sediments of the late Saale period are deposited. This period, in contrast to the Weichsel late glacial period represented obviously only a short transition phase with a continuously improving climate without recognizable climatic deterioration.

2.5. Eem

The number of Saale/Weichsel interglacial occurrences known and investigated during the last two decades is so large, that here only the most important ones can be mentioned. WOLDSTEDT, REIN and SELLE gave a general outline in 1951. In 1962, SELLE described the interglacial periods of Oerel, Godenstedt, Grevenhof, Mengebostel, Honerdingen and Nedden-Averbergen. H. MÜLLER (1958) studied the interglacial deposits of Rosche and Liebenau. The kieselgur (diatomite) beds of the Eem period in the Luhe valley were studied by BEHRE (1962, cit. 1966); BENDA and collaborators will soon publish a paper on the mining-geological investigations of these occurrences. As one result of these studies, H. MÜLLER, by counting the annual layers, came to the conclusion that the absolute duration of the Eem period was 10,000 to 12,000 years. BENDA & SCHNEEKLOTH (1965) describe a nearly complete section from Köhlen (Kreis Wesermünde). HALLIK has published several papers on the Hamburg area (1953, 1957 et al. cit. 1957) and included the distribution of the known Eem occurrences of this area on a map with a scale of 1 : 50 000 (1971). For Schleswig-Holstein, AVERDIECK (1967, cit. 1971) and MENKE (1967, cit. 1970)have carried out a series of investigations.

The studies as a total give a rather complete description of the development of the Eem vegetation. Details about the development of the forest, the attempts to divide the Eem period according to plant-evolution, and the development of the climate are described in this volume by MENKE and BEHRE in the chapter on "History of Vegetation and Biostratigraphy".

In contrast to the continental Eem occurrences that are often accessible in surface exposures, one mostly has to rely on drillholes when studying the marine Eem-sediments since the sea level of the Eem period did not exceed — 7 m NN (DECHEND 1959, SINDOWSKI 1965). In the central part of the Deutsche Bucht the base of the Eem deposits, according to SINDOWSKI (1970) hat an elevation from — 37 to — 62 m, whereas the Eem upper surface varies between — 33 and — 54 m. Within the area of the North Sea and the Baltic Sea, marine sediments are mainly to be found beyond the present coastline. Only in some narrow channels in the Marshlands of Lower Saxony, in the lowlands between the Eider and the Danish/German border and in the Lübeck Bay did the sea advance into the present land. The marine Eem sediments are locally bounded above and below by lacustrine-telmatic strata. Here, the maximum duration of the Eem-transgression can be limited by pollen-analyses (V. D. BRELIE 1954, cit. 1955; GRIPP 1964). The coincidence of the climatic optimum during the warm-period, maximum retreat of the glaciers and highest sea level have been substantiated for the Eem interglacial period.

In comparison with floral studies, the treatment of the fauna materials is lagging. As the kieselgur is nowadays worked by machines, vertebrate-remains are only occasionally found in the mines; the freshwater marl mines that formerly yielded abundant material, since long have been abandoned. For this reason, the study of the mammal fauna in the limy marls of Lehringen, the most "productive" locality of the Eem period sediments (SICKENBERG 1969), and the attempts to study the Eem profiles entomologically (ULLRICH, in preparation) are most welcome.

2.6. Weichsel

Before the Weichsel pleniglacial, two important interstadial periods can be demonstrated in the Weichsel early glacial period: the Brørup interstadial and the "Odderade-interstadial". Only few organogenic deposit were found so far in the Weichsel pleniglacial sediments of Northwest Germany. The development of vegetation and the problem of correlation with the neighbouring areas are described by MENKE and BEHRE in the chapter "History of Vegetation and Biostratigraphy" of this volume.

The Scandinavian ice sheet did not cross the Elbe line during the pleniglacial period of the Weichsel glaciation. As detailed studies of DUPHORN (1968), particularly in the Oder valley, have definitively shown a valley glaciation took place in the Harz Montains during the Weichsel period. Almost entire Lower Saxony and the western part of Schleswig-Holstein were thus exposed to a periglacial climate during the Weichsel period; evidence is given by the widespread occurrence of permafrost structures and periglacial sediments. Accordingly, the deposits of the older glacial and interglacial periods in the lowlands and of the Mesozoic in the mountains regions are concealed by an almost complete but thin cover of eolian, fluvial and solifluction sediments.

Solifluction sediments are widely distributed in the mountain areas. A subdivision into a basal unit which is free from loess material and consists of rocks originating from the pre-Quaternary basement and an upper unit which contains in addition a more or less large amount of redeposited loess material can be mapped over wide areas. The percentage of loess material, however, is nearly always distinctly lower than in the Holocene loam which is deposited on the slopes and may cover the solifluction strata of the Weichsel period. Part of these solifluction sediments are overlain, with a gradual transition, by loess in situ. In these cases the solifluction sediments in the sequence must certainly be assigned to the Weichsel glaciation ("pre-loess") or beginning of the loess sedimentation), as can also be concluded from the local interfingering with the Low Terrace (Niederterrasse) sediments. On the other hand, there are occurrences of solifluction sediments with the same facies and stratigraphic sequence which must be assigned to the Drenthe period (VINKEN 1969), because of being overlain by the Drenthe boulder clay. A division and stratigraphic classification without any datable intecalated or underlying and overlying beds may therefore lead to errors (compare BARTELS 1967).

The loess of the Weichsel period in Lower Saxony mainly belongs to the late Pleniglacial of the Weichsel period; in areas of only little relief it is about 2 m thick, in the uplands, however, the thickness varies considerably (up to 15 m). MERKT (1968) has compiled a map of the loess distribution in southern Lower Saxony. The uncertainties of loess-stratigraphy, chiefly of that of the middle and late Weichsel period, are described by SEMMEL in Chapter "Periglacial Sediments and their Stratigraphy" in this volume. Near the northern loess boundary, a number of occurrences of loesses with thin sandy interbeds and similar strata have been mapped; these have so far not been studied in detail, so that their stratigraphic and genetic relation to the actual loesses on one hand and the wind-blown sands and the sandloesses ("Flottlehm") in the northern foreland on the other hand, has not yet been clarified.

In comparison with the upland deposits, lowland solifluction sediments are of minor importance due to the less distinct relief. Particularly in case of sandy areas, only a few decimeters beneath the surface the old sedimentary structure is still intact. In case of loamy material, especially ground moraines, the lower boundary of the periglacial influence cannot be identified as easily. Except for deep fissures caused by frost action ("Frostspalten"), the so-called "cryoturbated sand cover" ("Geschiebedecksand"), which is here interpreted as a periglacially affected weathering product of the ground moraine, extends to an average depth of 75 cm; different original material and the relief cause variations the extent of which, however, is only little known. On the whole, knowledge about the solifluction sediments in the lowlands, in comparison to the results obtained in the neighbouring areas, is unsatisfactory.

The fluvial sediments of the Weichsel period are from several meters to tens of meters thick. To them belong the typical Low Terraces (Niederterrassen) of the rivers and moreover, at least part of the deposits in the lowlands formerly designated as "Talsand". These last mentioned, mostly fine-sandy sediments are obviously not homogeneous neither genetically nor with regard to their age. On one hand, they grade without any distinct boundary into the alluvial fans of the ridges, on the other hand, eolian and/or "niveo-fluvial" processes must have contributed to the development of these strata. Part of the sections may have to be assigned to the Warthe period. The interfingering with the Low Terrace and intercalated organogenic sediments proves, however, that the main body of strata developed during the last cold-period. A more exact classification will not be possible before the age of the frequently occurring organogenic sediments is determined (e.g. BEHRE 1966).

During the Weichsel period, the sandy loess ("Flottlehm" and/or "Flottsand") was deposited as a facies of the loess over wide areas of the lowlands north of the loess boundary. Little is known about the period of deposition of the sandy loess; ROESCHMANN (1963) has shown that the sandy loess was locally deposited already before the latest glacial temperature fluctuations. VIERHUFF (1967) distinguished two development periods of sand-loess separated by an erosion phase, which he correlated with the "Older Coversands" in the Netherlands.

The sand-loess interfingers often with wind-blown sand. From this wellknown fact it can be derived that at least large quantities of wind-blown sand have to be assigned to the Weichsel period. This is confirmed by the intercalated organogenic sediments of the Bölling- and Alleröd-interstadial (DÜCKER & MAARLEVELD 1958, ERBE 1959, BEHRE 1966). The Alleröd-horizon in particular often occurs, partly in form of the Usselo-soil-horizon. Later redeposition during the Holocene as is caused by wind-blowing over young moorlands and/or culture horizons, is to be assumed for some widely distributed areas. Except for the areas adjacent to those of Holocene dunes, however, sediments of only minor thickness were deposited. In addition to the above mentioned papers, also further individual data are available, but modern comprehensive studies of the cover of wind-blown sand are still missing. Because of their wide distribution particularly in northwestern Lower Saxony, such studies would, however, be desirable.

In Schleswig-Holstein the glaciation was preceded by a period of approx. 50,000 years during which periglacial processes dominated the geolocical scence. In the pleniglacial period the young moraine landscape of the eastern part of the country got its characteristic features; the good state of preservation allows, for example, the study of the details of the marginal zone of a continental glacier. GRIPP (1964) distinguishes three main icemargin deposits: one outer marginal deposit with several zones (A-end moraines), a second marginal deposit, also with several zones (M-end moraines), which in the North partly forms the outer marginal deposit, and finally the third innermost marginal deposit of the I-moraines near to the coast of the Baltic Sea and conforming with the coastal line.

WOLDSTEDT & DUPHORN (in print) connect the A-end moraines in eastern Holstein with the "Frankfurt" stage and the M- and I-end moraines with the "Pommern" stage in Mecklenburg, whereas in Holstein the "Brandenburg" stage cannot be identified glacial-morphologically.

In the northern part of Schleswig-Holstein, the connecting of the individual ice-margin deposits is in general more difficult, since they pinch together here and it is not known if they bifurcate or cross one another. Different opinions are also held concerning the morphogenesis of some surface forms. This refers in particular to the subglacial tunnel valleys (GRIPP 1964, HORMANN 1969, GRUBE 1969, cit. HOMCI 1972) and to the inland sandurs (A. HERRMANN 1971). GRIPP (1964), SCHLENGER et. al. (1969) and WOLDSTEDT & DUPHORN (in print) discussed the glacial-morphological and stratigraphic problems in more detail. According to recent work of K. PICARD (1970), loess was occasionally deposited also in Schleswig-Holstein.

Through pollen analyses the course of plant evolution (literature and discussion — cf. BEHRE, in this volume, Chapter ...) and the stratigraphic division of the late- and post-glacial period in Northwest Germany have become well known. Recently, a pre-Bölling-interstadial improvement of the climate was demonstrated in late-glacial lake deposits near Glüsing in western Holstein which MENKE (1968, cit. by MENKE in 1970) called the Meiendorf interval (according to ^{14}C-analyses their age is 13,000 - 13,600 years bp.) A worldwide improvement of the climate seems to have been involved. There after followed the Grömitz- or Fehmarn-advance (STEPHAN 1971, BRÜCKNER 1954); with this advance the ice reached the mainland of Schleswig-Holstein for the last time. It most probably corresponds to the Langeland-advance on the Danish islands and to the "Rosenthaler" zone in Mecklenburg.

The Grömitz oscillation was followed by the Bölling-interstadial. A bibliograph of the numerous pollen diagrams and the development of the younger section of the Weichsel late-glacial together with the Older tundra period, the Alleröd and the younger Tundra-period is to be found in the Plant Evolution History chapter of this volume.

3. Holocene

3.1. Continental facies range

During the last few decades, the deposits of the Holocene have received varying geoscientific attention. In the continental facies of the inland, chiefly the flood plain sediments and the moorland and the lacustrine deposits in the lakes were studied. The eolian strata, mainly the dunes which have partly very well developed intercalated podsols, and the overlying beds did not receive the necessary attention. The studies of the Holocene concentrated doubtlessly on the marine and perimarine deposits in the marshlands, in the tidal areas and on the islands of the North Sea. A bibliography on further Holocene research, such as general plant evolution history, reconstruction of fossil plant-associations, history of cultivated plants, way of life of the primeval man and his influence on vegetation, and development of the moorlands can be found in the Plant Evolution History chapter of this volume.

LÜTTIG discussed the division of the floodplain sediments (1960, cit. by LÜTTIG in 1964), after mapping along the Weser near Liebenau and along the Leine south of Hannover. Chiefly from petrographic differences and height above the river, he identified three Holocene phases, gave them local namens and tried to assign them to certain periods. However, mapping along the Innerste (VINKEN 1971) and still unpublished data from the upper Weser, the Leine and the Oker collected by the NLfB, indicate that the presently valid divisions have primarily local character as is also emphasized by LÜTTIG. For example, the interchange between erosion and accumulation, the time-stratigraphic interpretation of these processes and the alteration of the deposits by the development of soil (OELKERS 1970) along the rivers of Northwest Germany have not yet been dealt with systematically on the whole. Mainly geological and pedological mapping covering wide areas along the individual rivers, as well as a considerable number of pollen analyses and ^{14}C-analyses allowing a statistical evalution are still missing. Thus it is easy to understand that a correlation of the fluviatile depositions of the river systems with the perimarine (e.g. "river flood plain") and the marine strata is at present not satisfactorily possible. This is in contrast to the Netherlands, where much progress in these fields has been made.

Problems of the age of the lake sediments, of the development of the lakes and the influence of human settlement on this development up to present times are important when studying the Northwest German lakes. The results obtained during the investigation of the following lakes deserve mention: Dümmer (DAHMS 1972), Steinhuder Meer (H. MÜLLER 1970), Otterstedter See (H. MÜLLER 1970, P. ROHDE, in print), Zwischenahner Meer (H. O. GRAHLE & H. MÜLLER 1967), Seeburger See (STREIF 1970), Bederkesaer, Flögelner, Halemer and Dahlemer See (lakes at the margin of geest areas, MERKT, in print). In connection with these studies, GEYH, MERKT, and H. MÜLLER (1970) dealt with the dating of lacustrine sediments by ^{14}C-scale, and the adjustment of the ^{14}C-scale. As a further result, a suggestion for the division and definition of lacustrine sediments was published by MERKT, LÜTTIG and SCHNEEKLOTH (1971).

3.2. Marine facies range

In the following, studies concentrated on the Holocene marine facies are discussed in more detail, also because of their supraregional importance (cf. also to Chapter: Plant Evolution History, in this volume).

The factors which affect coastal displacement, can be subdivided into two groups:

Controlling geophysical factors: To them belong the glacial-eustatic rise of the sea level — i.e. alterations of the macro-climate — and epirogenetic, isostatic and halokinetic movements of the land. Apart from these controlling factors, a series of modulating factors are important: settling of the sediments that show different degrees of compaction, natural and artifical alterations of the coastal features, influences of micro-climate and athmosphere. Here, emphasis is placed on the correlation of phases of the coastal development by various methods.

As old as the knowledge about the cyclic formation of the coastal Holocene are attempts to correlate the units that are locally observed in wells and exposures, and to get an idea of the paleogeographic development of the coast. Possibilities for a correlation are offered by the lithological facies of the individual complexes, their fossil content, the archaeological inventory and the ^{14}C-age determination method.

Lithostratigraphic correlation

In the older literature, two theories confront each other. One (HAARNAGEL 1950 and NILSSON 1948) assumes a stronger regression during the sub-boreal period, the other one denies that the sea level dropped at all (BENNEMA 1954, and DITTMER 1952). BAKKER (1954), SCHOTT (1950) and ZWILLENBERG (1954, as cit. by DECHEND in 1956) hesitate between these two opinions. DECHEND (1954, cit. in 1954) was the first to distinguish "transgression-" and "regression-layers" and thus made the first attempt of a further subdivision of the coastal Holocene. From the vertical sequence and the areal distribution of "transgression-" and "filling-up layers", DECHEND (1956) suggests a unit of "sedimtary cover" that includes both kinds of layers. As an analog, MÜLLER (1962) applies the terms "transgression sequence" and/or "inundation sequence". The emphasis has shifted from areas of purely clastic sedimentation to those of lagoonal and perimarine facies, where clastic sedimentary units interfinger with peat layers; for such facies pollen-analyses and ^{14}C-determinations can be carried out. On the proposal of LÜTTIG (1964), lately the term "ingressivum" or the synonym "ingression sequence" is applied for the smallest litho-stratigraphic unit of the coastal Holocene. A summary of the results and a comparison of the subdivisions developed in the coastal areas of the Netherlands, Lower Saxony and Schleswig-Holstein are presented by BRAND, HAGEMAN, JELGERSMA and SINDOWSKI (1965).

The attempt of SINDOWSKI (1968, cit. by STREIF in 1971) to apply by means of "sedimentary cycles" the classification system known from the interfingering zone of clastic sediments with peat layers to the purely sandy coastal Holocene must be regarded critically. He restricts his investigations to the "normal channel fillings" as distinguished from the "tidal sand series" on the one hand and from the "yong fillings of the island separating tidal channels" on the other hand. But also in the "normal channel fillings" independent sedimentary processes can be expected, during which "sedimentary cycles" may fail to be formed, may be incomplete or may occur additionally. Thus, a definite separation of the sedimentary cycles from each other is often problematic and a correlation of successions of cycles is very doubtful.

The objective to find a standard lithostratigraphic division of the coastal Holocene with a hierarchic system valid for the entire southern North Sea area, becomes particularly obvious in the paper of BRAND, HAGEMAN, JELGERSMA and SINDOWSKI (1965). Here, the "ingressivum" (the "ingression sequence") ranks as the smallest lithostratigraphic unit, a "bed". Six transgression sequences are distinguished B.C. which have local names from the coastal area of Schleswig-Holstein: Barlt-, Eesch-, Fiel-, Husum-, Meldorf- and Schwabstedt-Beds. The two transgression sequences that were formed A. D., were named Tönning-Bed (before diking) and Wyk-Bed (after diking). As the next higher lithostratigraphic unit "members" include two transgression sequences each and have local names from Lower Saxony. The sediments deposited in the period B.C. are divided into three "members": Baltrum-, Dornum- and Midlum-Members. The Pewsum-Member includes the deposits from the period A. D. The "formation" ranks above the "members". In accordance with Dutch usage, the Calais-Subformation (Baltrum- and Dornum-Members) and the Dünkirchen-Subformation (Midlum- and Pewsum-Members) were introduced. For the uppermost lithostratigraphic unit the name "Holocene North Sea Formation" is recommended. DE JONG (1971) points out that this term has a chronostratigraphic indication which is in contradiction to the rules of lithostratigraphic nomenclature, and suggests the term "North Sea Formation".

The admirable attempt made by BRAND, HAGEMAN, JELGERSMA and SINDOWSKI (1965) to set up a detailed, regionally valid classification (division) has however some faults. A valid correlation of lithological units extending large distances along the coast requires the assumption of a dominant factor controlling the development of the coast. The rise of the sea level caused by eustatic movements, is such a factor. The above-mentioned multiplicity of overlapping, controlling and modulating factors gives rise to doubts whether a strict simultaneity in the starting and ending of the transgression at different places necessarily must be assumed. PRANGE (1967 a and b, cit. by MENKE in 1969) points to the strong influence of local factors on the transgression process. It is indisputable that he is right in his opinion, "The succession of beds in the individual areas was consequently determined not only by the rise of the sea level but to a considerable extent also by local factors". A graphic comparison of the transgression sequences in the coastal areas of the Netherlands and of Lower Saxony shows a distinctly differing local development. DE JONG's (1971) correlation of lithostratigraphic units based on HAGEMAN's (1969, cit.

by STREIF in 1971) studies in the tidal areas, indicates, in comparison to BRAND et al., more transgression sequences. Also STREIF (1971) points out the problems of a lithostratigraphic correlation of local data with the supraregional system. According to this latest work, the transgression sequences are not geochronologically identical and also their simultaneity in the lithostratigraphic sense, which LÜTTIG (1967) assumed, has to be reconsidered.

Moreover, the proposal submitted by BRAND et al. (1965) to abolish the older numerical (sub)division of the coastal Holocene and to give local names ("from possible type localities") to the lithological units, is only of advantage if type localities are defined and also a clear-cut definition of the lithological unit is given, as is required by the regulations of stratigraphic nomenclature. As concerns the individual "bed" this requirement has not been fulfilled yet for one single case. Only for the Baltrum-Member have more detailed investigations in form of pollenanalyses been carried out on the material of well 6/54 drilled in tidal land (sheet Baltrum, scale 1 : 25,000) by GROHNE (1957, cit. by BEHRE in 1970). There are differences between the profile described by BRAND et al. (1965) and the representation and profile description by GROHNE. For the rest of the "members" as well as for the "formations" no type localities have been defined so far.

From this situation it is apparent that the classification system suggested by BRAND et al. (1965) has to be substantiated in detail by additional investigations. It will possibly turn out that a detailed, purely lithostratigraphic correlation of the Holocene sedimentary sequences is possible only in limited areas and then often only after careful observation. A regional correlation is so far only possible with the help of age determinations by pollenanalyses and ^{14}C-measurements.

Palynological correlation

The systematic application of pollen-analysis in the field of coastal research was introduced by ERDTMAN (1928) and OVERBECK & SCHMITZ (1931, both cit. by NILSSON in 1948). Palynological correlations of lithological units were made by WILDVANG (1933 a and b, cit. by NILSSON in 1948). A comprehensive interpretation of these and other studies is given by NILSSON (1948). A modern correlation for the coastal region of Ostfriesland was carried out by GROHNE (1957, cit. by BEHRE in 1970). The basis of these studies is a detailed pollen-floral interpretation of the undisturbed highmoor profile of Tannenhausen that was not affected by marine transgressions. Here, characteristic breaks in the vegetation history are marked by so-called developmental lines which allow a correlation of partly incomplete profiles and of peat series broken by clastic transgression sediments with the standard profile. According to the investigations of GROHNE, the peat developed in a completely different way in the areas which are now tidal- and marshlands. In the present tidal lands around the island of Juist and in the Hilgenried Bay, highmoor bogs were developed. Here, the deeper areas were affected by the transgression of the sea already during the first part of the Atlantic period. In the areas of higher ground this happened only some decades B. C. In contrast, the profiles studied in the tidal lands around Krummhörn and around Baltrum show two peat beds separated by clastic sediments. A synchronous development of the upper peat beds cannot be proved. GROHNE reached the opinion that the occurrence of the peats is mostly dependent on the facies and that the peat beds are only of minor value as stratigraphic marker horizons.

GROHNE's observation that, during the Holocene, a transgression began with a brackish water environment followed by a later marine environment is important for an understanding of the paleogeographic development at the coast. These findings are interpreted as evidence of a continually rising sea level. In areas not easily accessible to the sea, lagoonal more or less muddy lowmoor bogs and non-flooding highmoor bogs were formed.

Only after a considerable rise of the sea level are such areas directly affected by marine sedimentation following the removal and destructions of protecting barriers. As examples of these protecting barriers GROHNE (1957, cit. by BEHRE in 1970) discussed "landbarriers" and "sphagnum highmoors" which, considering the processes in the outer dike moor of Sehestedt, can float on stormflood high tides.

MENKE (1968, cit. in 1969), in dealing with plant associations at the western coast of Schleswig-Holstein, made very important contribution to the palynological correlation of transgression sequences. Apart from comprehensive palynological age determinations these papers also give methods that allow a delimitation of transgressive sequences on the basis of plant associations; by means of their pollen spectren, "allogenic series" are distinguished from "± autogenic series". The "allogenic series" are mainly characterized by a brackish environment definitely caused by outside influences. The "± autogenic series" are chiefly characterized by decreasing wetness, freshening and often by oligotrophy and dystrophy. On the basis of these paleosociologic facts, a better, geneticaly well-founded definition of the beginning and the end of a transgressive sequence can be given than possible merely on macropetrographic evidence. The beginning of an "allogenic series" is regarded by MENKE (1969) as start of a transgressive sequence, whereas the end of it is accordingly regarded as the beginning of an "± autogenic series". Since a "sedimentary cover" in the sense of DECHEND (1956) and a "transgressive sequence" in the sense of BRAND et al. (1965) are made up of an "overflooding sequence" as well as an accompanying "filling-up sequence", the beginning of a "± autogenic series" in the sense of MENKE will probably mark the end of the transgression, but not of the transgressive sequence as a whole. The end of the transgressive sequence is determined by the beginning of a newly starting "allogenic series".

The very high use of palynological and geobotanical methods in archeological research work on marshland and mounds induces the authors to give a brief outline of marshland archeology here. An outline of the geobotanical studies employed in the study of primeval and early settlement history in the marshlands of the southern North Sea coast is given by KÖRBER-GROHNE (1965). Detailed studies on plant evolution for the area at the mouth of the river Ems, and a correlation with the Holocene of the Netherlands has been made by BEHRE (1970) (see also Chapter A 2 in this volume). Moreover, the character of the vegetation around the pre-historic settlement of Boomborg/Hatzum has been reconstructed from the wood remains, fruits and seeds found in the excavation. Detailed geobotanical studies in the area of the Feddersen-Wierde mound at the mouth of the river Weser were published by KÖRBER-GROHNE (1967, cit. by BEHRE in 1970). BANTELMANN (1960, cit. in 1970, and in 1970) presented results of archaeological investigations on marshlands at the western coast of Schleswig-Holstein. PRANGE (1968/69) noted the importance of verbal information for studies in the field of geology and settlement history in the marshlands.

Chronostratigraphic correlation

The first radiocarbon age determinations from the German North Sea coast were published by GROHNE (1957, cit. by BEHRE in 1970); they were carried out by DE VRIES (University of Groningen). The importance of radiocarbon age determination for stratigraphic correlation is steadily increasing as the discussion of recent determination results by SCHNEEKLOTH & WENDT (1962) shows. A chronostratigraphic, numerical system is suggested that differs from the original lithostratigraphic division of the Holocene. The review papers published by MÜLLER (1962) and BRAND, HAGEMAN, JELGERSMA & SINDOWSKI (1965) are also based on a chronostratigraphic "skeleton" of ^{14}C-data.

Geyh in 1969 (cit. in 1971) and in more extensive work in 1971 tried to overcome the faults of such individual analyses of ^{14}C-data by means of statistical evaluation. Proceeding from the concept that transgression of any origin cause a retardation of the peat development at the coast, while regressions favour it, Geyh set up frequency diagrams, in which the frequency of ^{14}C-data is plotted against time. In such histograms, transgression phases, i. e. phases of retarted peat growth, have to be represented as minima, whereas stagnation and regression phases, i.e. phases of full peat growth, appear as maxima of sample frequency. The peats developed at the bottom of the Holocene sedimentary succession are an exception. These peats partly developed with full independence from the sea level as "basal peats", partly as "basis peats" in the sense of Lange & Menke (1967, cit. by Streif 1971) which developed under the direct influence of the rise of the sea and/or the river level. These peats cannot be considered in the statistic interpretation because they cause nonrealistic deformations of the histograms.

The histograms caculated by Geyh (1969, cit. in 1971) for the Netherlands, Lower Saxony and Schleswig-Holstein, as well as the regional histogram of the North Sea coast indicate a distinct cyclic return of the transgressions which can be traced over wide distances. This is interpreted as evidence of regionally simultaneous transgressions (Geyh 1971). Some caution is necessary, however, for the tentative assignment of the maxima and minima in the histograms to the different lithostratigraphic division schemes cannot be applied for the individual coastal sections, since the defined meanings of the lithostratigraphic terms would partly require reinterpretation. The value of the independent chronostratigraphic system would, however, not be diminished.

If individual histograms are combined to a total histogram, one must realize that the common tendencies may be accentuated by the cumulation, but that significant differences in the details of the coastal development and important trends of local development may be neglected. When calculating histograms, it should always be clear for which purpose, regional or local, they are set up.

The main problems of the chronostratigraphic correlation are the procuring and selection of suitable samples. The problem of a perfect routine drilling of undisturbed sedimentary cores of the coastal deposits has also been solved technically in Germany since Merkt & Streif (1970, cit. by Streif in 1971) developed a special coring device. The material thus obtained allows one in general to determine if the peat layers found are autochthonous or allochthonous, that means it is possible to distinguish stationary from drifted material.

Nevertheless some preliminary investigation of the material to be dated is necessary in order to check the homogeneity of the sample. Already Menke (1969) points out that there are contaminations in the samples that can only be seen under the microscope. The investigated material often has a considerable content of clay, halob diatoms, hystrichopheres, foraminifera as well as pollen and spores of taxae which contradict the plant association and which originate from reworked older material and thus cause the ^{14}C-age of the total sample to be too high. Menke therefore recommends a selection of samples according to macroscopic and microscopic examination. The microscopic studies have the additional advantage that exact, reproducible genetic niveaus within the sedimentary sequences can be recognized and the beginning and end of a sequence of transgressions can be determined more exactly.

As Streif (1971) demonstrated, ^{14}C-ages which are too low because of the great number of roots in the samples must be as frequent as falsification of ^{14}C-data by reworked older material. Streif examines the manually sorted root- and stigmaria-fraction of lowmoor peats and the residual substance separately. Except for a few cases when the ^{14}C-data of both fractions were identical, the root- and stigmaria-fraction turned out to be generally younger, in the maximum even about 845 ± 210 years. As would be expected, the relation between the degree of contamination and the sedimentation rate is clearly recognizable. On this evidence, the separation of the stigmaria- and the rootsubstance is regarded as necessary in order to exclude any possible contaminations by root material not belonging to the sample.

Results of other systematic studies on the reliability of the ^{14}C-age determinations on fossil A_h-horizons of soils, the so-called Dwog-horizons, are presented by GEYH (1970, cit. by GEYH et al. 1971) and GEYH, BENZLER & ROESCHMANN (1971). On the basis of the comparison of the statistic interpretation of representative ^{14}C-data of dwogs and peat samples of the same area, these authors concluded that Dwog-material yields such unreliable data that neither the individual dates nor the statistic interpretation of many ^{14}C-analyses produce results of any use. The reason is that humic acids of different age are mixed and the samples contain a great number of roots; in general this results in ages which are too low. Falsifications as a consequence of a contamination by older material that might have been reworked during short-term flooding cannot be excluded, but are generally unimportant because they are not very frequent.

The advantages of a chronostratigraphic division of the Holocene using ^{14}C-data are quite obvious. Also palynologically little significant parts of the Holocene may be further subdivided by ^{14}C-analyses. Thus the possibility arises to set up a detailed system that can also be applied to other regions and do not depend on facies, to study and classify local developments as well as to balance the importance of regional and local development factors against each other.

Extent and course of the sea level rise

SCHÜTTE (1933, in more detail: 1939, cit. by MENKE in 1969) made the first proposals about the process of relative coastal displacements in the form of a wavy schematic curve representing the elevation of the coast with reference to time. On the basis of palynological studies on the "marsh-horizons and submersion peat-occurrences of the southern North Sea coast", NILSSON (1948) set up a hypothetical curve of the post-glacial coastal displacement relative to the mean high tide level. He also discusses the differing opinions of previous workers and the special findings obtained in individual study areas. As a result of his interpretations, NILSSON published a curve with a very characteristic and considerable rise of the sea level from — 50 m to approx. today's level during the period between approx. 7 500 and 2 000 B.C. From 2 000 B.C. to about 1 000 B.C. the mean high tide level dropped to approx. — 1 to — 1,5 m followed by a rise to the approx. + 1,5 m at present.

HAARNAGEL (1950) pointed out the differences between the results obtained in the Weser-Ems area and the NILSSON curve, and particularly to the problem of dating very early sea levels. In agreement with NILSSON, also HAARNAGEL assumes that an atlantic and a subatlantic transgression and a subboreal regression took place. JELGERSMA (1961, cit. by BRAND et al.) published a steady curve of the sea level rise at the Dutch North Sea coast; the interpretation method does not allow regression phases to be represented in this curve.

With the help of 57 radiocarbon age determinations carried out on samples from the German Dutch coastal areas, MÜLLER (1962) developed an undulating curve representing the transgression course during the last 7 500 years:

5 600 — 4 300 B.C.	transgression phase, average sea level rise: 73 cm/century
4 300 — 3 800 B.C.	distinct deceleration of transgression, peat development over wide areas
3 800 — 3 400 B.C.	transgression phase, average sea level rise: 70 cm/century
3 400 — 2 900 B.C.	strong deceleration of the transgression, possibly complete halt, if not even short regressic⁻

2 900 — 2 500 B.C.	transgression phase, average sea level rise: 45 cm/century
2 500 — 1 700 B.C.	pause; MÜLLER regards it to be possible that certain regression movements took place during this period
1 700 — 1 350 B.C.	transgression phase, average rise of the sea level: 36 cm/century
1 350 — 1 100 B.C.	pause with peat development over wide areas
1 100 — approx. 800 B.C.	transgression phase, average rise of the sea level: 27 cm/century
800 — shortly A.D.	distinct dropping of the sea level is most probable
100 — 250 A.D.	new flooding of wide areas
250 — 650 A.D.	pause

This pause is followed by the flood of the Ottonian and Carolingian times. The younger known high-tide catastrophes of the Late Middle Ages do not tell anything about a sea-level rise, since because of man-made structures (dikes, channel passages etc.) natural high-tide marks practically do not exist. W. MÜLLER (1962) compared the results he obtained in the southern North Sea area with the findings and the sea-level-rise curves of NILSSON (1948), SEIFERT (1955), GRAUL (1959) and FAIRBRIDGE & NEWMAN (1960/61). This outline should be completed by a comparison with the curve of MOERNER (1969, cit. by STREIF in 1971).

The in part highly varied results make it obvious that knowledge of the course and extent of the Holocene sea level rise is not yet satisfactory. In particular, it is still not known, if and to which extend the general transgression was interrupted by regressive phases. Recent results, which support the idea of a "real dropping of the local mean high tide", have been published by MENKE (1969). Moreover, MENKE sees in the alternation of transgressive and regressive phases a distinct 550 year periodicity which corresponds well with the results of BAKKER (1954) and BENNEMA (1954, both papers cit. by DECHEND in 1956) which indicate a periodicity of 500 and/or 525 years. MENKE (1969) claims mainly a climatic periodicity to be responsible for these processes. GEYH (1971) develops the idea of a clear, though simplifying causality between solar activity, ^{14}C-variations and alternations of the sea level. According to this idea, the electromagnetic field of the sun plasma, which is emitted during the periods of high solar activity, reduces the intensity of the cosmic rays reaching the earth by screening. Consequently the ^{14}C-production goes down. At the same time an intensified shortwave radiation causes a warmer climate on the earth and starts a melting process at the polar ice caps as well as rise of the sea level. The transgressing sea interrupts or reduces the peat growth at the coast. On the basis of such considerations, GEYH (1971) assumes a 200—400 years rhythm of the sea-level-rise phases.

Actuogeological and -paleontological working methods

In order to get a detailed litho- and biofacial analysis of the various stages of coastal development in the area of the southern North Sea, a wide range of actuo-geological and paleontological investigation methods may be applied. Since the material is very abundant and the investigations are often very specialized, only the most important studies can be referred to here.

A modern summary of actuo-geological and paleontological observations from the marine shallow-water and tidal areas of the southern North Sea is given by REINECK (1970, cit. by STREIF in 1971). It contains, apart from a great number of results obtained by the "Senckenberg am Meer" working team, a complete review of the older literature. A review of history, methodology and importance of the diatom analysis with particular reference to the whole scheme of coastal research is given by BENDA (in. STREIF 1971). ZIEGELMEIER (1957 and 1966, cit. by STREIF in 1971) published a compilation of the North Sea molluscan fauna and its environment. Studies of the foraminiferal assemblages of the tidal areas have been carried out by ROTTGARDT (1952), VAN VOORTHUYSEN (1960) and HAAKE (1962), whereas WAGNER (1960) dealt with ostracod-biocoenoses and thanatocoenoses (all papers cit. by STREIF in 1971).

The principle of actualism can be applied only to a limited extent to the coastal area since here an equilibrium has been achieved by natural and artifical changes that is not in the least typical for the total Holocene. Nowadays, only marine shallow water areas, tidal flats and estuaries are to be found in the coastal region. The whole palette of the lagoonal and partly lacustrine sediments, however, which are very important within the sequence of Holocene sediments, as well as areas with widely distributed lowmoor bogs are missing. Nevertheless the modern studies are of great importance as they allow a direct interpretation of the genesis of part of the fossil sediments and definition of different types of sediments.

Conclusions

Several conclusions can be drawn from the studies of the Holocene at the southern North Sea coast. The Holocene coastal development is characterized by a sea level rise which was primarily glacial-eustatically controlled and was caused by the melting in the North American and Greenland inland ice and polar ice caps. The sea level change was not regular and presumably also not always in the same direction. The rise, which in general took place with decreasing velocity, shows a cycle of retarding phases, pauses and partly regressive phases. A number of scientists assume a rhythmic division of the transgressions and think climatic factors to be responsible; they point to a partial causality between solar activity and sea level changes. The effect of the dominant controlling factors was modified by the superposition of numerous regional and local modulating factors.

It should be the objective of further studies of the coastal Holocene to try to distinguish local modulating factors as clearly as possible. Only this way will it be possible to get an idea of the extent and course of the supraregional transgressions. This attempt might only be reasonable on the basis of a chronostratigraphic division of the coastal Holocene.

As a further objective of the studies on the coastal Holocene a paleogeographic representation of the various phases of coastal development could be taken into consideration. A first step has already been done with the compilation of a base map of the Holocene in isoline representation on a scale of 1 : 50000 covering Lower Saxony (for Schleswig-Holstein it is being prepared in the Geological Survey). The computer-processed documentation and evalution of all drillings sunk at the coast is under preparation. On the basis of litho- and biofacial as well as cultural-geographical studies, an idea shall be formed on the different sedimentary environments and their alteration during certain periods of time. The purpose of this kind of investigations is to obtain very exact basic data for the future economic progress of the coastal region and possibly to predict potential trends in the expected coastal development.

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