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Holocene Evolution of the South-Western Baltic Coast – Geological, Archaeological and Palaeo-environmental Aspects

Field meeting of INQUA Subcommission V
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Editor
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Contents

Preface

From September 23 – 27, 2002 the INQUA Sub-commission V "Western European Shore-lines" conducted a field meeting entitled "Holocene Evolution of the South-Western Baltic Coast – Geological, Archaeological and Palaeo-environmental Aspects". Forty scientists from nine countries took part in the conference and the four subsequent excursions which were organized by the University of Greifswald, the Institute of Baltic Research, Warnemünde, the State Agency for Protection of Archaeological Heritage of Mecklenburg-Vorpommern, Lüb-storf, and the State Geological Survey of Mecklenburg-Vorpommern, Güstrow.

In 2000, when the idea of the field meeting was first discussed with Antony Long, President of the Subcommission V, one main reason existed for inviting those associated with the commission to Greifswald. The last time a comparable meeting was held in North-East Germany was in 1967, when the late Otto Kolp, Warnemünde, guided an INQUA commission and presented the state-of-the-art regarding the Holocene sea-level development and the related coastal evolution and morphodynamics. After that, scientific and personal exchange with colleagues from Western Europe was broken off due to the political circumstances and until 1990 only very few personal contacts were possible. However, throughout this period the few geoscientists working on coastal evolutionary problems in what is now Mecklenburg – West Pomerania gathered a lot of new data, ideas and hypotheses as well as discovering new problems. Some of those remain unresolved and are the subject of a variety of current geoscientific investigations. The rather small circle of colleagues who could be brought to-gether in a field meeting seemed us to be the best frame to present and discuss both the re-sults of these investigations and the problems still open.

A second reason for holding the field meeting arose in the last few months with the success-ful application to launch the interdisciplinary research unit "Sinking Coasts: Geosphere, Eco-sphere and Anthroposphere of the Holocene Southern Baltic Sea (SINCOS)" which will be supported by the Deutsche Forschungsgemeinschaft in the next few years. Along the entire coast of Mecklenburg – West Pomerania, geoscientists and archaeologists, together with geophysicists, experts in dating, and palaeo-botanists, will investigate the interplay between eustasy, neotectonics and material supply during the main Littorina transgression stage and the consequences of the transgression and fast landscape changes for the ancient human so-ciety living at the coast. The meeting provides the chance to present the project to a wider international audience and to encourage the scientific discussion.

Among the most important topics to be addressed during the meeting are:
- Facies architecture and morphological development of barrier spits and beach ridge plains and the problem of neotectonic movements
- Holocene sedimentation in the West Pomeranian coastal waters – the evolution from open sea bays to isolated lagoons
- The Late Holocene sea-level record in coastal peat sequences
- Drowned Mesolithic settlement sites off the coast of Mecklenburg - West Pomerania
- Recent morphodynamics and implications for future coastal management.

The volume of the Greifswalder Geographische Arbeiten presented herewith is the product of many of the SINCOS project members and their collaborators. It has been designed firstly as an excursion guide and provides the morphological, stratigraphical and archaeological background to the sites to be visited in the order of the excursions routes on Rügen, Usedom, Darss-Zingst and Poel. It is also a first compilation regarding the present state of our knowl-

edge about the sea-level evolution and the related formation of the coastal Holocene deposits in the south Baltic area, although not all sites of interest could be described and presented.

Finally, the editor wishes to express his gratitude to all the authors for their contributions, to the draughts(wo)men B. Lintzen and P. Wiese for careful drawing and final design, to the translators M. Pater and A. Zühr who took care of the proof reading and language revision and, last not least, to the management of the Institute of Geography for financial support.

Reinhard Lampe

Regional geology of the south-western Baltic coast

GÖSTA HOFFMANN

In a tectonic sense the Baltic Sea basin covers parts of the East European (EEP) and West European Platform (WEP). Different tectonic conditions allow a subdivision of the EEP into the Fennoscandian Shield, the Russian Plate and the Baltic Syneclise (Fig. 1).
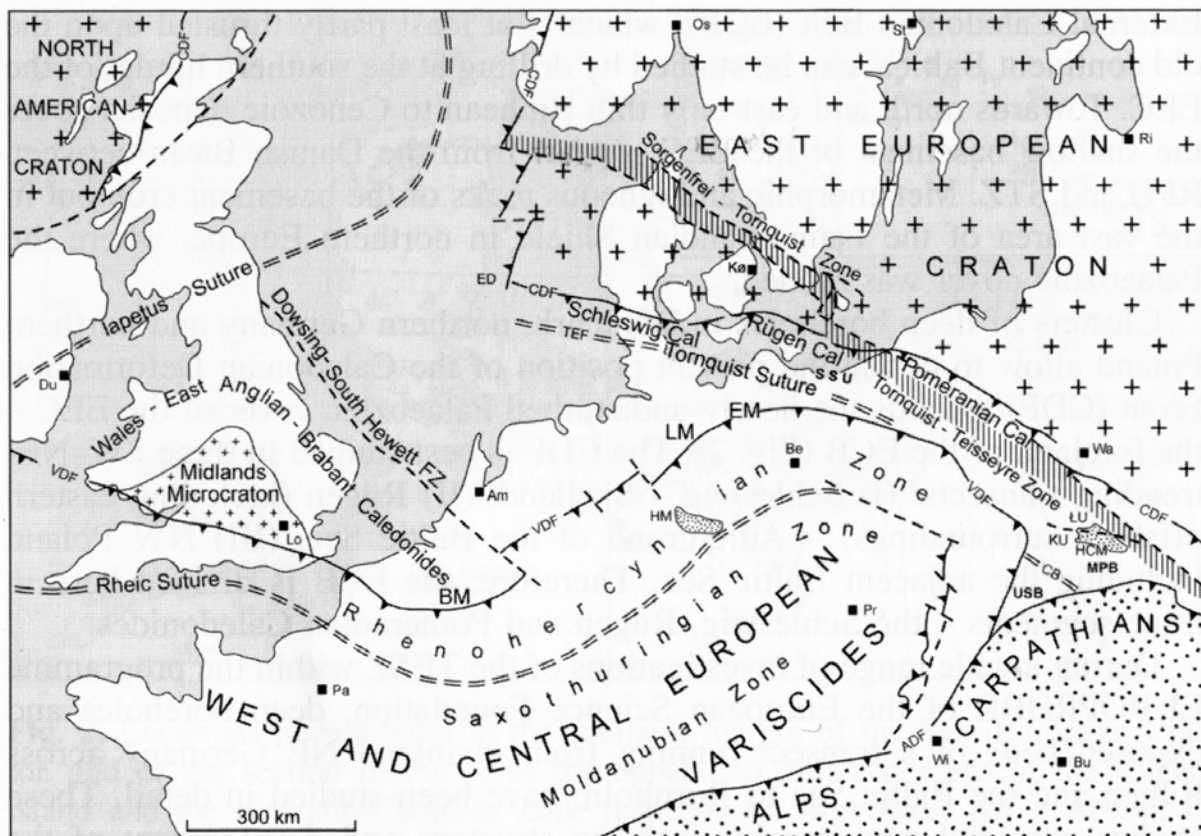
Fig. 1: Structural outline of the pre-Permian basement in Central Europe (KATZUNG 2001).
BM - Brabanter Massif; CB - Cracovian Belt; ED - Else duplex; EM - East Elbian Massif; HM - Harz Mts.; HCM - Holy Cross Mts.; KU - Kielce Unit; LM - Lüneburg Massif; LU - Lysogory Unit; MPB - Malopolska Block; SSU - Strelasund-Szcecinek Uplift; TEF - Trans European Fault; USB - Upper Silesian Block; ADF - Alpine Deformation Front; CDF - Caledonian Deformation Front; VDF - Variscan Deformation Front

The Fennoscandian Shield is dominated by Precambrian crystalline rocks; the Russian Plate is covered by Phanerozoic sediments. Palaeozoic sediments fill the Baltic Syneclise (HARFF et al. 2001). BERTHELSEN (1992) named the SW-border of the EEP Trans-European Fault (TEF). As a structural-geological element it extends in the subsurface of the coastal area of West Pomerania through the Strelasund, Greifswalder Bodden and Usedom. Strike direction is NW-SE to WNW-ESE. Further towards the east it is approaching the Tornquist-Teisseyre-Zone (TTZ) following it in SE direction. KATZUNG (2001) describes the Caledonian Deformation Front on the southern margin of the Eastern European Craton. Thus the TTZ represents

a complex zone, which was tectonically superimposed several times. The first tectonic stress is due to the Caledonian deformation followed by an extensional phase in Palaeozoic to Mesozoic, and finally an inversional phase in Late Mesozoic to Cenozoic. According to KATZUNG (2001) the TTZ stretches from NW Poland in SE direction parallel to the Caledonian Deformation Front. To the NW the TTZ and the Sorgenfrei-Tornquist Zone (STZ), which is dislocated dextral at the Rønne-Graben, extending in same direction across the East European Craton, whereas the Caledonian Deformation Front runs further to the south. As a result, the coastal area of West Pomerania is situated on the NE margin of the WEP which is upthrusted onto the EEP.

The subsurface of the southern Baltic Sea as well as the bordering areas are characterized by block faulting (KRAUSS, MÖBUS 1981). The structural character is dominated by an orthogonally (E-W, N-S) and a diagonally (NW-SE, NE-SW) direction system. Tectonic activities at deep reaching fractures influencing the geomorphologic evolution of the area are discussed by KRAUSS & MÖBUS (1981). According to these authors the course of ice marginal zones of the Brandenburg and Pomeranian stages of the Weichselian glaciation reflects NE-SW striking faults in the subsurface. According to MÖBUS (1996) the NE-SW orientated course of today's coastline from Rügen Island to Lübeck Bay as well as the NW-SE orientated course from Rügen Island to the Oder estuary reflect the subsurface fault system.

Because the coast in Mecklenburg-Vorpommern mostly consists of unconsolidated Pleistocene sediments it is difficult to identify the formation of faults (MÖBUS 1996). Normally it is not possible to determine whether faults are endogenous or a result of glacial tectonics. To verify recent crust movements, i.e. neotectonic processes, Holocene deposits have to be investigated. Most of these formations are not easily accessible, because they are situated below the present sea level. For this reason an attempt is made to reconstruct the Holocene sea level rise for different areas along the south-west Baltic coast. If significant differences appear, neotectonic processes have to be taken into account.

Most important for the recent geomorphologic setting of the coast of the south-western Baltic Sea as well as for the rest of Mecklenburg-Vorpommern are glacial dynamics during the Pleistocene (Fig. 2). During this period different glaciations affected the area. The positive landforms of Mecklenburg-Vorpommern forming the cliff sections, for instance, consist of deposits associated with the last, the Weichselian glaciation (DUPHORN, KLIEWE 1995). From the island of Rügen in the North to the south-western part of Mecklenburg-Vorpommern three major pleniglacial ice advances can be reconstructed. Due to missing biostratigraphical indicators subdivision within the glacial deposits is problematic (MÜLLER et al. 1995). Morphostratigraphical evidence combined with lithostratigraphical methods as described in the TGL standard of the GDR (TGL 25 232/01-06) are used to separate and link the different deposits within the area of former glaciations.

MÜLLER et al. (1995) subdivided the Weichselian glaciation into several phases (see Fig. 2). The lowest till sheet together with proglacial outwash deposits belong to the Brandenburg stage W_{1b}). The W_1 - end moraine is also the southernmost marginal zone. The later course of the Weichselian is characterized by ice decay and readvances. The Frankfurt marginal zone (W_{1F}) possibly represents the border of such an oscillation (MÜLLER et al. 1995). No ground moraine could be found for the W_{1F}–advance (RÜHBERG et al. 1995). The Pomeranian stage (W_2) is subdivided into two phases (W_{2u}, W_{2o} in Fig. 2) by RÜHBERG et al. (1995). Ice dynamics are described as strongly scouring. During this phase the thickest and most widely spread bed of ground moraine was deposited. Eskers are characteristic for the W_2 ground moraine. The W_3 till of the Mecklenburg stage covers the older units only sporadically. There is no

continuous end moraine. Only in some parts, as in the west of Stralsund and the southern part of Usedom Island (Velgast marginal zone, W_{3V} in Fig 2) the deposits demonstrate the character of an end moraine. It is believed that this marginal zone belongs to an ice advance (RÜHBERG et al. 1995).
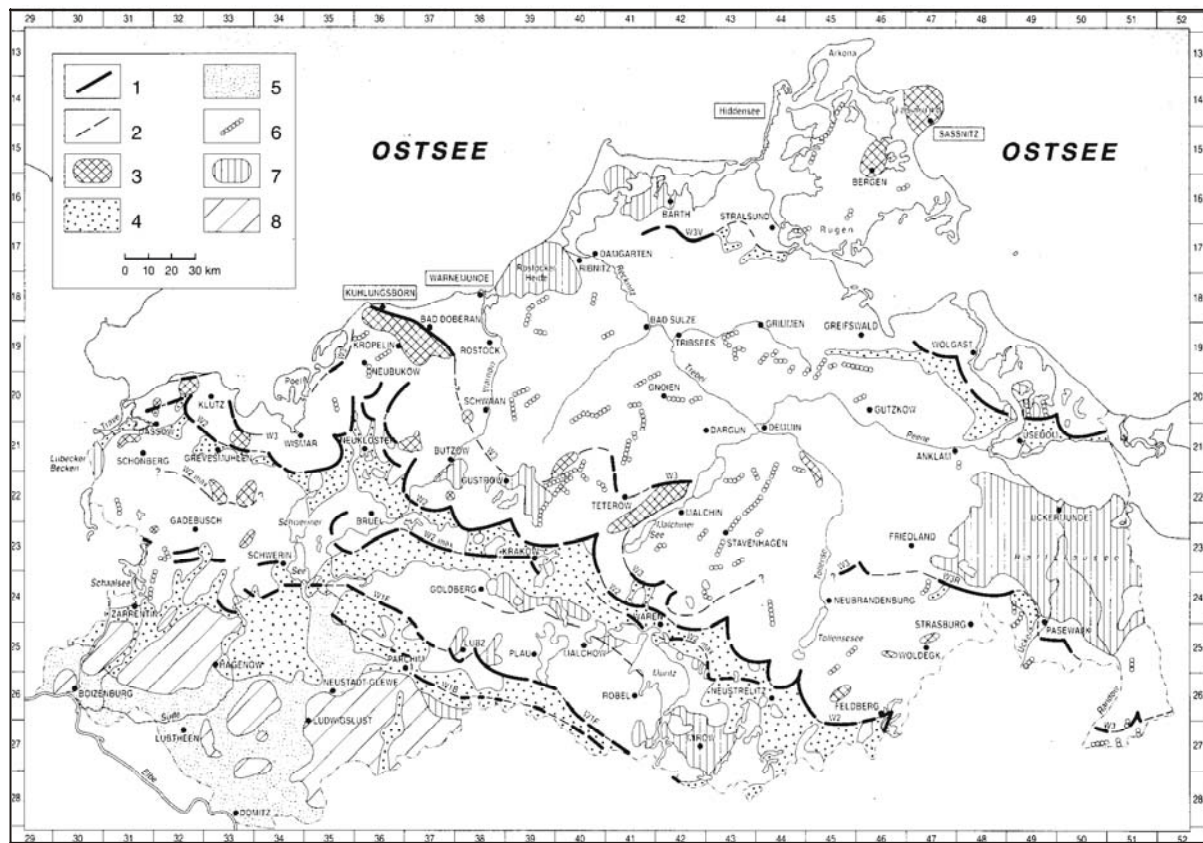
Fig. 2: Geological map of the Quaternary of Mecklenburg-Vorpommern (RÜHBERG et al. 1995).
1 - marginal zones, 2 - marginal zone, supposed, 3 - glacitectonic compression zone, 4 - outwash plain, 5 - ice-marginal valley, 6 - Esker, 7 - basin, 8 - Saalian flat upland area, W_3 - ground moraine of the Mecklenburg stage, subdivided by W_{3R}: Rosenthal marginal zone and W_{3V}: Velgast marginal zone; W_{2max} and W_2 - Pomeranian marginal zone and ground moraine; W_{1F}: Frankfurt stage; W_{1B}: Brandenburg stage;

Because of rapid ice decay, melt-out of dead-ice and the rapid dispersion of ground vegetation the shape of the young moraine area is well preserved. The hydrographical system is still fragmentary. Although there are stratigraphical problems, making it difficult to correlate the different Pleistocene deposits, the glacial processes provided the clastic material the coast consists of. Due to coastal dynamics their reworking and redeposition is still going on.

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Post-glacial water-level variability along the south Baltic coast – a short overview

REINHARD LAMPE

The water-level evolution which occurred in the area of the southern Baltic mainland after the retreat of the Weichsel-III ice sheet was characterized by some remarkable fluctuations. The reasons were the formation of the postglacial drainage system and – later – the arrival of the Holocene sea-level transgression in the area off the recent coast.

The oldest and simultaneously highest water level marks, located between 25 – 3 m above mean sea level (msl), are terraces, mostly of erosive but sometimes of accumulative nature too (JANKE 1978, cf. C-3 this volume), which are connected with the existence of a pre-Bölling meltwater lake ("Haffstausee") in the region of the Ueckermünder Heide, the Puzszcza Goleniowska as well as the Puszcza Wkrzanska, both located in westernmost Poland. The primary drainage occurred to the northwest through the Grenztal valley. The opening of additional drainage channels towards the northwest (Peene, Peenestrom-Ziese-Strelasund system) led to the first water table degradations. Associated with the ice retreat to the northern edge of today's Pomeranian Bight, the drainage direction changed more and more to a northerly direction and led to the accumulation of fluvio- and limno-glacial sediments in the inner bight, probably as a delta or braided river plain. With further degradation of the water table the delta area largely dried out. The Late glacial lacustrine sediments of the Oder Bight are located at depths of –12 m (KRAMARSKA 1998: 281), along the western shore they can be found at –14 m (SCHMIDT 1957/58: 270). The lowering of the base level was accompanied by an incision phase of the rivers. Among others, the lowermost river bed level of the lower Oder river at –45 to –65 m (BROSE 1972: 60, DOBRACKA 1982: 114) is believed to be due to this process. Because, according to recent knowledge, this very low level cannot be traced to the Oder Bight, additional processes have to be considered to explain how it was formed .

The earliest phases of the Baltic Ice Lake (BIL), which came into being about 13,000 BP (BJÖRK 1995a) , can be demonstrated by warve clays at Kriegers Flak in waters depths of about –25 m (LEMKE 1998: 137). In the Older Dryas the replenishment of the valleys started initially with periglacial flowsheets. Simultaneously, a water level rise is to be observed, which reached its maximum at the end of the Alleröd and in the Younger Dryas. Throughout the Alleröd there was widespread accumulation of muds and peats, the altitude of which spread over a wide range – depending on the elevation of the depressions. It is not clear if the peats located in the Szczecin Lagoon at –11 m (cf. C-4) or in the Oder Bight at –16 m (KRAMARSKA 1998: 282,) represent the maximum water table in the Lower Oder Valley or in the Baltic basin at that time because, at least until this period, inactive ice blocks were melting and causing shifts of the sediments formed at the same time. LEMKE (1998: 156) indicates that, during the Alleröd/Younger Dryas period, the water table of the Baltic Ice Lake east of the Darss sill rose from –40 m to –20 m (see also BENNIKE, JENSEN 1998, cf. curve A in Fig. 1). SCHWARZER et al. (2000: 72) even suspect the maximum height of the BIL reached –9 m according to the results of seismic investigations in the inner part of the Tromper Wiek/Rügen (cf. B-6); this is substantiated by a neotectonic uplift of about 6m according to SCHUMACHER & BAYERL (1999: 112, cf. B-5). If this elevation can be proved, we have to imagine at least the western part of the Oder Bight as a wide Late Pleistocene delta-like sedimentation area,

characterized by braided rivers and many small local waters. The accumulation of sandy and silty sediments would then have led to an extensive levelling of the former relief. The areas not drowned then would have been subjected to substantial deflation and the evolution of aeolian sand sheets and dunes (KAISER 2001: 154).
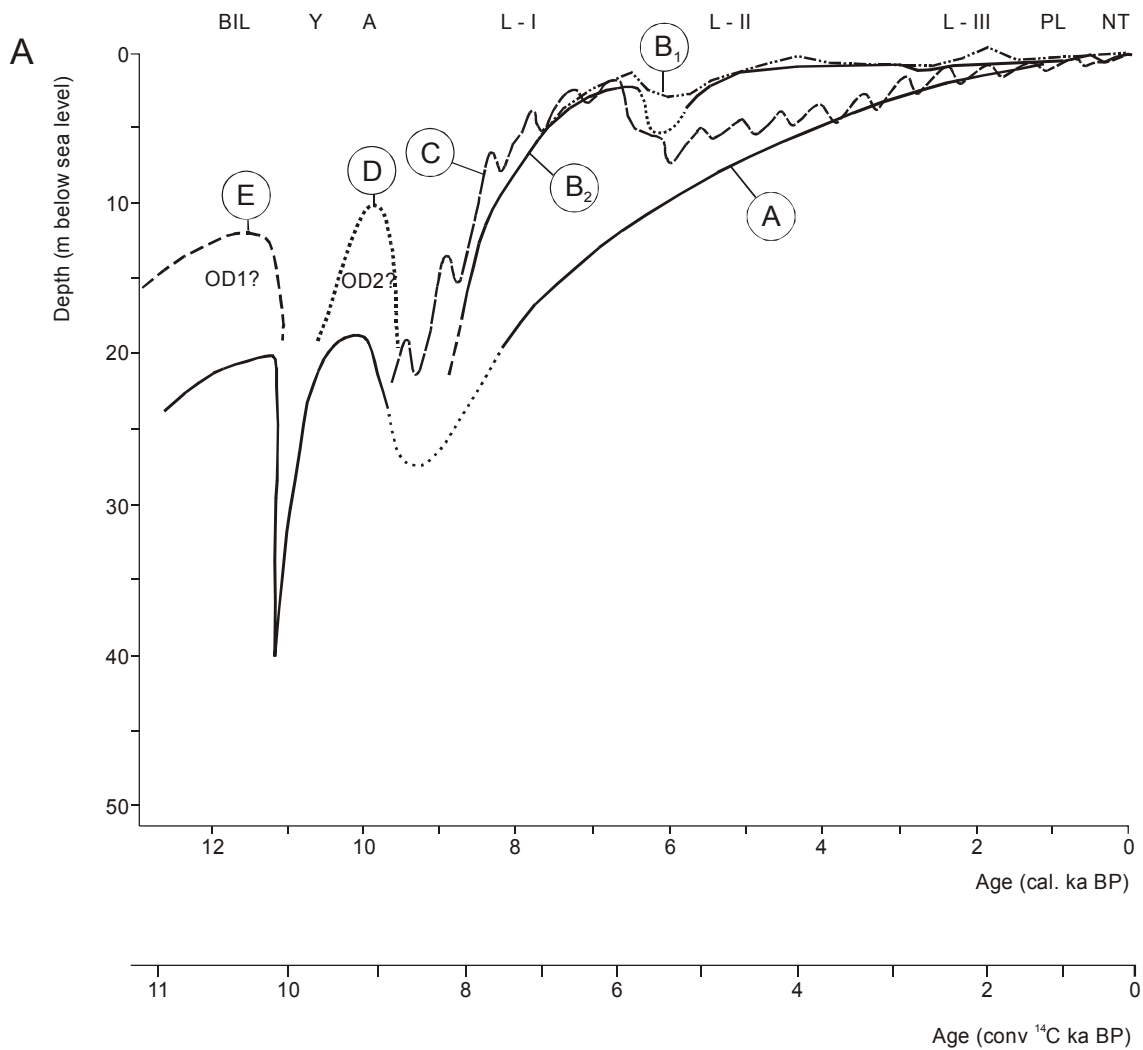
Fig. 1: The Postglacial water table variations in the south Baltic area

A - Relative shoreline displacement in the Arkona basin after BENNIKE & JENSEN (1998)

B_1 - relative shoreline displacement along the West Pomeranian coast after KLIEWE & JANKE (1982)

B_2 - relative sea-level variations along the West Pomeranian coast after JANKE & LAMPE (2000)

C - the shoreline displacement curve of Rügen Island according to SCHUMACHER (this volume, see B-5)

D – water level course as revealed from the distribution of carbonate-bearing sandy sediments in the vicinity of the Oder Bight, related to the Ancylus Lake by KLIEWE & REINHARD (1960)

E – water table of coastal rivers and inland waters after JANKE (1978, see C-3)

OD1, OD2 – two stages of water table rise according to the distribution of sandy sediments preliminary related to an ancient Oder delta, assumed due to current surveys

The transgression of the BIL ended with the retreat of the Scandinavian ice sheet from the southern Swedish mountains. The opening of the gap at Billingen in about 10,300 BP caused the final regression of the BIL (Björk 1995: 27) and the degradation of the water table to about –40 m. Hence, in the valleys the early Holocene incision phase started and in the basins further peat aggradation and desiccation took place, which comprised the Preboreal and Boreal period. However, the very low lying areas experienced a water level rise again. According to BJÖRK (1995), in the Baltic basin in 9,500 BP the Ancylus phase had already started as an freshwater body isolated from the ocean. The views regarding the maximum level of the Ancylus transgression differ widely in the scientific literature. KLIEWE (1960: 230, 1995: 183) and KLIEWE & REINHARD (1960: 166f) assumed an elevation of –8 m due to their findings of fine sandy freshwater sediments on Usedom (cf. C-10) and eastern Rügen (cf. B-8); KOLP (1975: 38) initially supposed a level not higher than –20 m. KLIEWE & JANKE (1982: 68f, curve B$_1$ in Fig. 1) again determined the maximum at –8 m and dated it to 8,800 – 8,700 BP. Finally KOLP (1986: 90) accepted this view and identified the Darss sill as a natural dam, the breaching of which caused the Ancylus regression and the origin of the Kadet Channel in about 8,800 BP. BJÖRK (1995b: 31) considers earlier estimations of –20 m possible and specifies the onset of the regression in 9,200 BP. Recent investigations in the Mecklenburg Bight and the Arkona Basin carried out by LEMKE (1998: 148ff) and LEMKE et al. (1999: 69) led them to state that the Darss sill could not have been a dam barrier and therefore east of the sill the Ancylus Lake could not have been higher than –18 m (cf. D-4). In fact, the freshwater sands found by KLIEWE and REINHARD and determined as Preboreal/Boreal accumulations seem to be restricted to the region between Jasmund/Rügen and Usedom.

The investigation of the Schaabe by SCHUMACHER & BAYERL (1997) was not able to verify the existence of corresponding accumulations, and the findings near Zingst, like those from the Bug/NW Rügen area, could also be interpreted as local lake deposits (KLIEWE, JANKE 1991: 6f; LEMKE 1998: 150; LEMKE et al. 1999: 69). BENNIKE & JENSEN (1998: 30) argue that all of these higher freshwater sediments, formerly related to the Ancylus Lake, are accumulations of smaller freshwater basins.

Summarizing everything stated above about the Ancylus Lake level, three competing hypotheses result, namely
   a) a large Preboreal/Boreal Ancylus Lake, stretching fjord-like in the south into the deep ice-excavated basins of Rügen and Usedom during its maximum height of –8 m,
   b) a freshwater body with a level of –8 m (the primary Oder Lagoon) covering at least the western part of the recent Oder Bight and a short steep outflow of the Oder down to the Ancylus Lake in the Arkona Basin with a level of –18 m (from the geomorphological point of view rather unlikely), or
   c) the reinterpretation of the above mentioned freshwater sands as accumulations of an end-Pleistocene/Early Holocene delta, intervening between the Oder river and the Baltic Ice Lake or the Ancylus Lake, with sustained desiccation and river incision during the base level fall and remediation during its rise (Fig. 1, curve sections OD1 and OD2). The fluvio-limnic depression filling occurred until the Boreal and even the earliest Atlantic. With the arrival of the Littorina transgression the area was finally flooded. This latter assumption results from current surveys not yet finished. Until these investigations are completed and new radiocarbon data are available, this enigma of the Ancylus Lake (HURTIG 1958) will remain unresolved.

All the water level data mentioned above are related to their current position in respect of the sea-level, without a consideration of any subsequent isostatic movement or compaction

that has caused an unknown relocation of sediment layers to another height than primarily deposited. This ignorance about such post-sedimentary movements finally makes the fluvio-limnic deposits "uncorrelatable" (KAISER 2001: 164).

The first precursors of the Littorina transgression are marine-brackish diatom assemblages found in deposits of the Mecklenburg Bight which are 8,500 to 8,000 radiocarbon years old (ERONEN et al. 1990). Over the depth interval of –30 to –20 m LEMKE (1998: 153) found indications of a rapid transition to marine conditions for the period between 7,500 and 7,000 BP. Closer to the coast the oldest limnic-telmatic sediments, which were overlaid by marine deposits, were found at about –15m and dated to c. 8,000 BP. The initial rise of the water table occurred rapidly and reached –2 m in about 6,000 BP (JANKE, LAMPE 2000: 587, cf. B-3, D-6,).

Recently an end-Mesolithic settlement site with three dug-out boats has been excavated in the city of Stralsund; they had been preserved in a former coastal area of the Littorina Sea now located at about - 2 m. Preliminary observations suggest a dating of c. 5,400 to c. 4,000 cal. BC (cf. B-4), which corresponds to c. 6,400 to c. 5,200 BP. This agrees with the previously stated level. However, for the Wismar Bight a noticeably lower sea-level has to be assumed, as demonstrated by findings from end-Mesolithic sites at depths of -7 m (6,200-6,300 BP) and -2.5 to - 3.5 m (5,500-5,300 BP, LÜBKE 2000: 31, cf. E-2); this correlates better with the sea-level curve for the southern Baltic described by KLUG (1980).

The following period until about 5,300 BP, which is believed to have been a retardation or regression phase (RL-I, KLIEWE, JANKE 1982: 70), became the subject of discussion due to the investigations of SCHUMACHER & BAYERL (1997, 1999) and JANKE & LAMPE (2000). The authors believe they found hints of a neotectonic uplift of some meters in that period (Fig. 1, curves B_2 and C, cf. B-5). They found peats and soils intercalated in marine sediments which have been dated by means of pollen analysis and radiocarbon measurements. Attempts to verify these findings at other sites have not yet been successful. However, the problem of neotectonic movements is not out of the discussion for this reason. Moreover, it remains the key to explain the cause of the West Pomeranian sea-level curve running higher than the curves for adjacent regions (Fig. 1). For instance, in comparison with contiguous areas, the 1st Littorina phase (L-I) reached the –2 m level about 1,500 years earlier (KLUG 1980: 242). Also, older sediments like the deposits of the BIL are located in exceptionally high positions in northern Rügen (SCHWARZER et al. 2000: 72, cf. B-6).

The continuation of the sea-level rise just after 5,000 BP may be traced mainly by investigations of the coastal peat lands as well as archaeological findings, because siliciclastic sediments of barrier spits and beach ridge plains contain very little datable material. After the RL-I, which attracts attention by a peat oxidation horizon and a hiatus in the peat profiles, the sea-level rose slowly to about –0.6 m msl until 3,000 BP. The period of the Urnfield Bronze Age, which is known from the inland as a dry period (JÄGER, LOZEK 1978: 217), is characterized by slight peat degradation in the coastal mires. Whether a (minor) sea-level fall occurred simultaneously is still under discussion. MÖRNER (1999: 81) argued such a relationship between drought und sea-level fall, in line with changes in regional air pressure and river runoff.

The transgression throughout the Roman Age (L-III) raised the water table only marginally to –0.5 m msl. The subsequent regression caused by the climate deterioration during the period of the German Tribes Migration might also have been only slight. Perhaps it constitutes a retardation or cessation of the transgression. In contrast, during or just after the medieval climate optimum, a remarkable sea-level rise to –0.25 m occurred about 1,000 to 600 BP.

LANGE et al. (1986: 14) used Slavonic findings from Ralswiek/Rügen even to reconstruct a water table of 0.25 – 1 m msl (cf. B-2). However, evidence for such a high water level cannot be found in the coastal peat lands and it must be argued that traces of a surge have been confused with evidence of a secular sea-level variation.

The striking subsequent regression, which is indicated by the widespread appearance of a prominent peat oxidation horizon in the coastal peat lands, has been related to the Little Ice Age between 450 to 150 BP. According to current knowledge, such sea-level variations over a range of about ± 20 cm coincide by all means with the average margin of error in respect of sea-level determinations and are therefore difficult to detect. As a result of the minor natural variations, the available data base for the period younger than 5,000 BP must be assessed as still uncertain.

It was stated above that at least in the past 5,000 years the sea-level raised on a rather smoothed course which was interrupted only by some few minor regression stages (Fig. 1, curves B_1, B_2). But in the light of other investigations it remains still open whether or not the sea-level has experienced more frequent oscillations of an order of about a meter. SCHUMACHER assumes that such oscillations, he detected in sediment sequences from the Schaabe barrier spit (SCHUMACHER, ENDTMANN 2000) and from Poel Island (SCHUMACHER 1990), are related to periodic climate fluctuations (Fig. 1, curve C, cf. B-5). He refers to similar findings described by TOOLEY (1974), MÖRNER (1978) and others.

Since the onset of regular gauge records in the middle of the 19th century, the sea-level along the southern Baltic (e.g. in Warnemünde) has risen on average by another 18 cm (DIETRICH, LIEBSCH 2000: 616). Here a notable spatial differentiation in the rate of the rise may be observed (Fig. 2), which can only be ascribed to non-eustatic, endogenic causes. The extent to which this spatial pattern is temporally stable will be the subject of future investigations (HARFF, SINCOS-project members 2002).
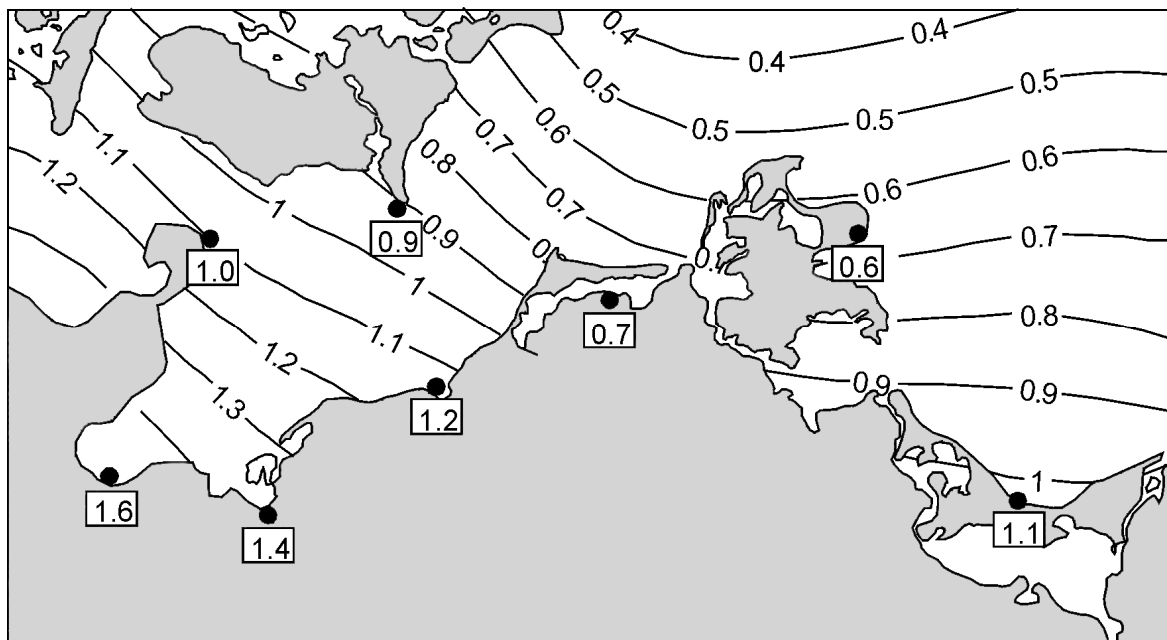

Fig. 2: Recent relative sea-level movements in the area of the south Baltic Sea, calculated from gauge records by DIETRICH & LIEBSCH (2000)

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Glacial and coastal geomorphology of eastern Rügen Island

WOLFGANG JANKE

From a genetical viewpoint, Rügen Island is an archipelago comprising more than a dozen larger and smaller Pleistocene isles, which were connected by barrier spits during the younger Holocene to form only one island. The largest among them is the central Rügen isle, c. 700 km² in size, which stretches between the Strelasund, Greifswalder Bodden, the North Rügen (Großer and Kleiner Jasmunder Bodden) and West Rügen (Kubitzer und Schaproder Bodden) Bodden waters and the Granitz hills. It consists of two sections. The westerly section – mainly west of the highway B96 – is characterized by flat or gently undulating ground moraines and coastal lowlands seawards of them. The easterly section possesses a wavy or hilly relief (around Bergen/Rugard, Granitz) with frequent alternations of wavy ground moraines, sand areals, kames, channels, basins and coastal lowlands. Most of the other isles of the former archipelago are located in front of the northern and eastern edge of the central island and are connected by barrier spits. In the North and the East these are the spits Bug, Schaabe and Schmale Heide and the Pleistocene corelands Wittow, Jasmund and Granitz. On SE Rügen, southwards of the Granitz and located between the Greifswalder Bodden and the Pomeranian Bight, the Baaber Heide and the Göhren coreland and, on the Mönchgut peninsula, the corelands Lobbe, Gager, Thiessow and Klein Zicker and their connecting barrier spits are located.

The Pleistocene corelands on Rügen are widely covered by the boulder clay of the Mecklenburg stage (Fig. 1). Sands appear frequently too, such as basin and valley sands which are located on top of the ground moraine or in incised depressions. Sands are also located in higher elevated areas with a stronger relief where the youngest ground moraine has already been removed.

About the Late Pleistocene, particular the Late Weichselian formation of the island, two opinions exist. According to KLIEWE (1975), the glacial relief and landform inventory are determined mainly by three glacial marginal zones. These are 1. the Velgast marginal zone located in the very South between Poseritz, Rothenkirchen and Altefähr, 2. the Central Rügen marginal zone stretching in a strip from the Zudar peninsula across Garz, Sehlen, Gingster Heide, Kluis, Ganschvitz to Ummanz Island and 3. the North Rügen (or Coastal) marginal zone which is divided into five sub-zones.

On the other hand RÜHBERG (1987) and RÜHBERG et al. (1995) are of the opinion that no end moraines exist on Rügen. This position is stated also in the Geological Map of Mecklenburg – West Pomerania (1994). The morphological high areas (Jasmund peninsula, Bergen/Rugard and Granitz) are characterized as "positive landforms (predominantly of glacitectonic origin); older protrusions". Unfortunately newer investigations about the structure and formation of the Granitz and the Bergen/Rugard area are missing. Due to many personal investigations in different areas of West Pomerania (JANKE 1987, 1992 u. 1995), the author of this contribution, who once advocated the opinion of KLIEWE (KLIEWE, JANKE 1972, 1978), now shares the view of RÜHBERG. The uppermost boulder clay, covering almost all areas of Rügen, is the till of the Mecklenburg stage. The Velgast marginal zone as defined by ELBERT

(1907) and RICHTER (1933) and the sub-stage II, which can be traced in the SW of Rügen (KLIEWE 1975), are basically ground moraines.
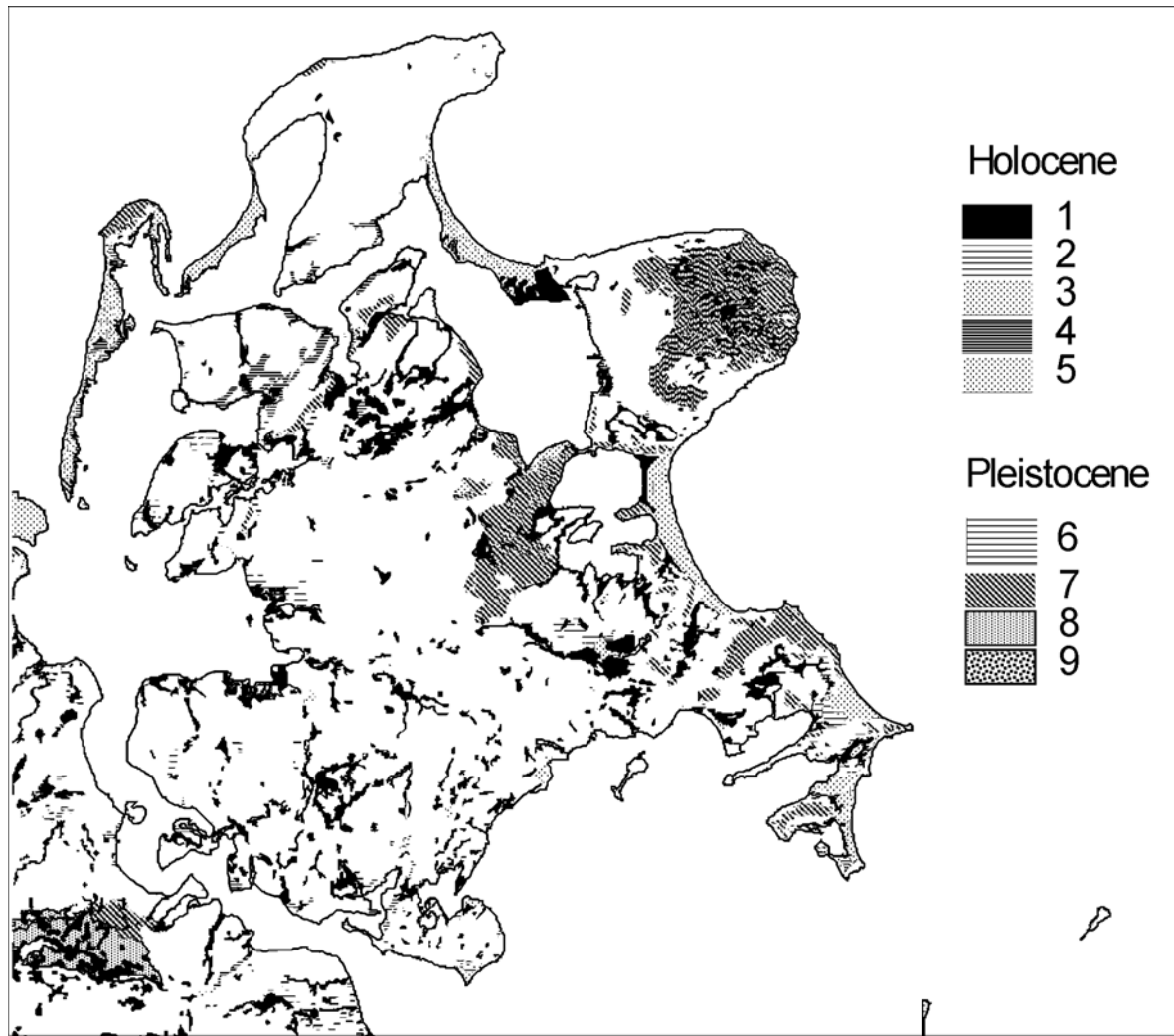
Fig. 1: Section from the Geological Map of Mecklenburg – West Pomerania, 1 : 500,000, simplified
1 – peatland, 2 – limnic deposits, 3 – sand and gravel, 4 – loam and clay, 5 – aeolian deposits, 6 – basin and valley deposits, 7 – positive landforms (predominantly of glacitectonic origin); older protrusions), 8 – outwash plain, 9 - esker

At the cliffs along the Rügen coast three to four ground moraines can be observed, mostly only fragmentarily, one Saalian and the moraines from the Brandenburg, Pomeranian and Mecklenburg stage of the Weichselian glaciation. The M3-till from SE Rügen – analogous to Usedom Island – covers thick fine sands, widely deposited in the period between the decay of the Pomeranian and the advance of the Mecklenburg ice sheet. In other areas the M3-till is located directly on top of the Pomeranian ground moraine or discordantly above glacitectonic destruction structures (cf. B-7, this volume). However, in many areas – particularly where there is a strong relief - the till has already been removed due to its limited thickness.

On the NW slopes of the peninsulas Jasmund and Wittow glacitectonic piling structures are exposed, discordantly covered by the M3 of the Mecklenburg stage. Their formation was probably caused by this youngest advance of the Weichselian glaciation. At the Jasmund east coast the hangingwall till has been completely reworked and redeposited as flow debris.

Below, interbedded strata of steep dipping glacial and Cretaceous clods crop out. Ideally, the first comprises a M1-I1-M2-I2-sequence. Here, the M1 is the Saalian while the M2 and M3 are the Weichselian tills (cf. B-7). The numeration differs spatially: on SE Rügen the tills of the Brandenburg and the Pomeranian stages are called M1 and M2 respectively (KRIENKE 2001).

On Rügen as in the entire area of West Pomerania the water-table development since the Pleniglacial is characterized by some high-level intervals interrupted by low-level stages. The high-levels correspond to the stages of the Baltic Ice Lake and the Ancylus Lake, which reached approximately the same level (cf. A-2) The low-level stages are linked to the melting of the inland ice sheet and the decay of the permafrost at the end of the Dryas I, to the Yoldia Sea stage and to the regression of the Ancylus Lake. The Littorina Sea reached the Rügen area about 7,200 BP. The initial phase was connected with an extremely fast sea-level rise, which changed the area into an archipelago. In place of the Bodden waters, bays and sounds of different depths existed at that period, to which fossil cliffs on the present day Bodden coast testify.

Temporarily, the pace of the rise amounted to more than 2.5 mm per year (cf. A-2). Since 6,000 BP, with the decreasing velocity of the transgression, the transition to a phase of coastal smoothing occurred. The first stage was characterized by a filling of the submarine basins, whereas in the second stage, which began at about 5,000 BP, the barrier spits grew above the mean water level. Due to the exposure of large, dry, sandy areas, the dune formation started where four generations can be differentiated (cf. B-8).

The first colonization of Rügen Island is related to the end-Mesolithic Ertebölle-Lietzow culture (c. 6,000 – 5,000 BP; cf. B-3, B-4). Sheltered coves and creek mouths were the favoured settlement sites of the fishermen, hunters and gatherers, e.g. near Augustenhof and at Buddelin near Lietzow. KRAMM (1968) reported findings of more than 30,000 flint artefacts from the Lietzow site alone (arrowheads, scrapers, blades, flakes and axes). For the area further inland no settlements sites are known from that period. The Lietzow culture layers are interlocked with marine sediments from the Littorina Sea and were covered later by beach sands (see GRAMSCH 1978, B-3). Therefore important hints about the sea-level history may be revealed by excavations of these sites.

From 5,000 – 4,500 BP agriculture is known on Rügen Island and from then onwards settlement – albeit very sparse - spread out over the entire island. The same is true for the Iron Age, Roman Age and the period of the German Tribes' Migration. The Neolithic Megalith tombs (5,000 – 3,800 BP), the Bronze Age tumulus tombs and the ring walls and tombs from the Slavonic Age are conspicuous in this landscape. During the latter period (700 – 1300 AD), a higher population density was reached for the first time, which in some places was even higher than during the German Colonization in the 13th century.

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The early medieval trading site of Ralswiek and the development of the depression

THOMAS TERBERGER

Sea trading sites are of special importance for the Slavonic period (7th -12th century AD). They are characterized by their protected position, their remarkable size and evidence for craftsmen production and trading activities. The sites generally consist of a settlement, at least one grave field and a harbour. Regular evidence of Scandinavian find material is a another typical feature. Without doubt Scandinavians had an important influence on the development of the trading sites and we have indications that these people stayed at Ralswiek and comparable sites for a longer time (see i. e. SCHOKNECHT 1977). At present some of these early city like trading sites with a distance of about one day sailing are known at the southern Baltic coast (i. e. JÖNS et al. 1997).
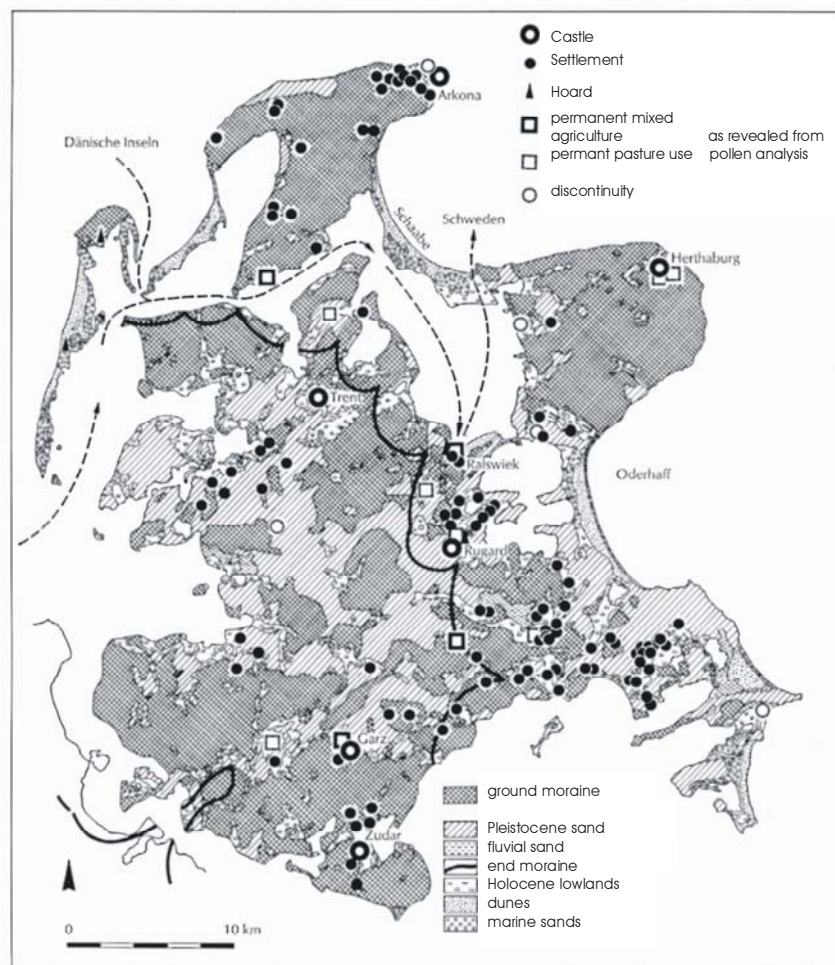
Fig. 1. Position of the early medieval sea trading site of Ralswiek, island of Rügen, on the geological map. The medieval connections to the sea are marked by interrupted lines (after HERRMANN 1997: 8 with modifications).
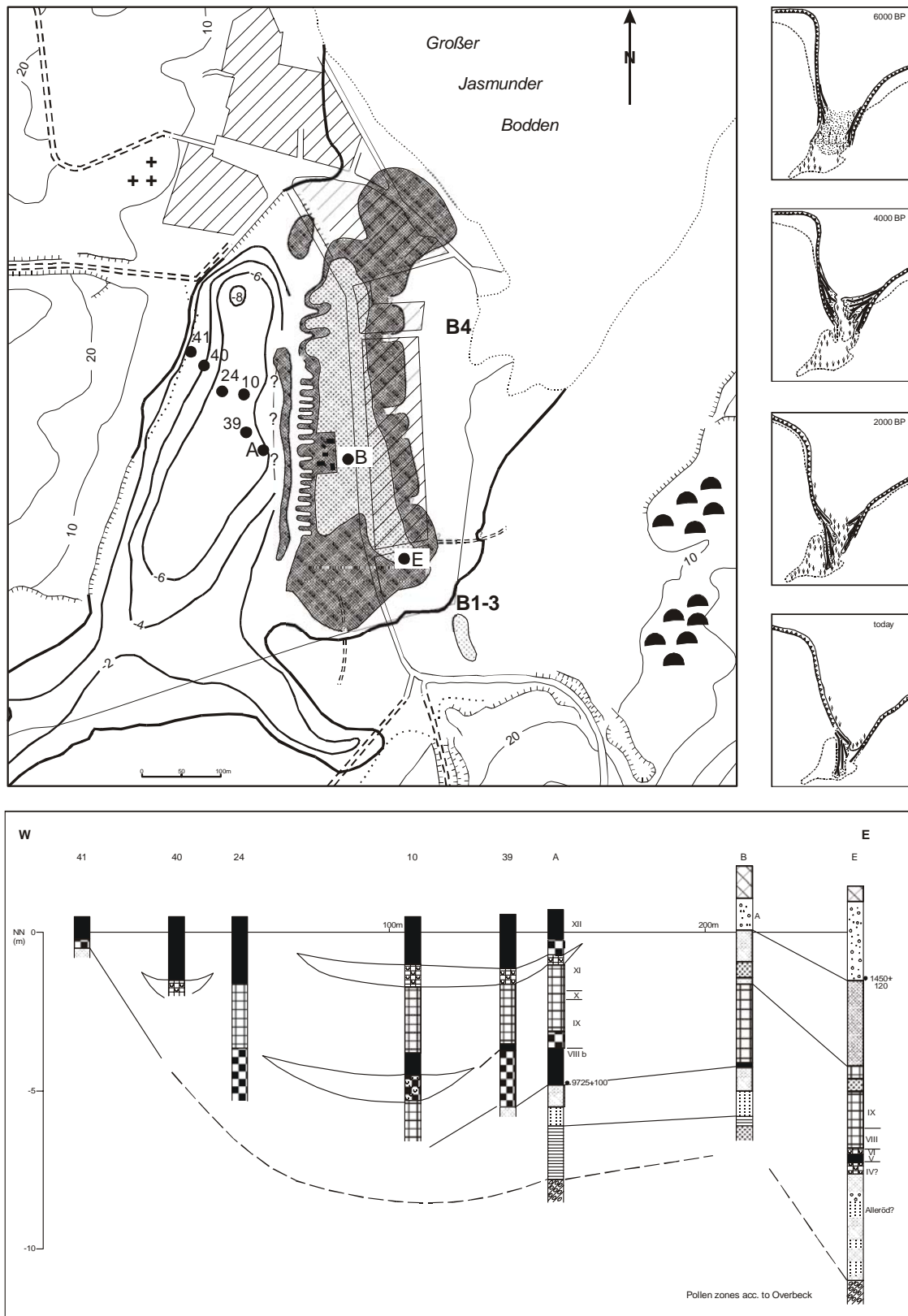
Fig. 2. The Holocene evolution of the Ralswiek lowland and the settlement complex with the settlement size in phase A/B (9th to 10th century). The entrance to the lake south of the settlement is uncertain (modified after HERRMANN 1980, 1998: 585, LAUSCHKE 1978, KLIEWE, LANGE 1976, GOMOLKA 1980, draft: LAMPE)

B – ship wrecks, + - graves, ⏵ – grave mounds

The trading site of Ralswiek was founded in the 2nd half of the 8th century. The site belongs to the more important sites of this type, although – in contrast to Haithabu, Wollin or Groß Strömkendorf („Reric") (see i.e. JÖNS 1999, E-4) – the site has never been mentioned in the written sources of that time. The site is situated on a c. 500 m long beach ridge at the SW-coast of the Großer Jasmunder Bodden (Fig. 1). Excavations headed by P. HERFERT and J. HERRMANN were conducted since the 1960es to 1989 and modern construction works at the village document that the site is still not exhausted. With the excavations of more than 5000 m² it was possible to investigate parts of the main settlement (with phases A-D) and the harbour. Of special interest was the documentation of four ship wrecks (fig. 2). The most spectacular find was a big silver hoard detected under a house floor. Excavations headed by D. WARNKE on the grave field east of the settlement with more than 400 grave mounds derives special interest (HERRMANN 1989, 588). The archaeological excavations were accompanied by a natural scientific program to investigate the landscape development on the island of Rügen (LANGE et al. 1986).

Topographic situation and geo-scientific evidence

In general the sea trading sites have a protected position and the Ralswiek site situated in the inner part of Rügen can be taken as a typical example. Northwest of the site sailing to the sea was possible through the Großer Jasmunder Bodden and the waters between Hiddensee and Rügen. Geological investigations suggest that there was a second connection to the sea in early medieval times at the Schaabe near Glowe. Ideas of HERRMANN (1997: 26) that a further sailing possibility existed from Ralswiek following the Kleiner Jasmunder Bodden and the Wostevitz Lakes to the Southeast of the island have to be rejected. Geo-scientific investigations by RUDNITZKI (1979) and pollen and diatomeen evidence of a profile analysed by W. JANKE suggest an early isolation of the Wostevitz Lakes by beach ridges of the 1st Littorina transgression (cf. B-8, Fig. 3). The connections to the sea did offer sailing possibilities to the Ralswiek site and at the same moment it was possible to pass the dangerous Arkona promontory. However, small depths of the Bodden waters limited navigation possibilities in the inner waters of Rügen. Because we can not expect larger water construction works to improve the conditions at that time, it seems plausible that ships with a maximum load of 5-10 t could reach Ralswiek harbour.

The natural development of the Ralswiek area was summarized by HERRMANN (1997: 24 ff.). The Großer Jasmunder Bodden is a result of shaping by the Weichselian ice sheet. Some meters South and West of the site the end moraines rise up to more than 30 m a.s.l.. Natural filling of the Ralswiek depression started with the sedimentation of sandy muds in the Postglacial (Fig. 2). In the Preboreal we can observe the beginning of turf development. The beach ridge that was used for settlement ground in the medieval period was formed in the Littorina transgression at a shallow position. The separation of the small depression behind the beach ridge favoured the process of sedimentation.

For the Subatlantic period the investigations suggest a wetter phase and layers of beach sediment were found above the shore sediments of the lake. At the same moment we can observe an elevation of the beach ridge. In early medieval times only a small lake survived, but small rivers coming down from the end moraines gave fresh water.

Indications for possible water level changes during the settlement phases at Ralswiek are of special interest here. It is suggested that at 800 AD the beach ridge lay about 1 – 2.5 m above the water level. The houses of settlement phase A-B were situated on sandy ground above

1.1 m a.s.l. Buildings of the younger settlement phase (C-D) were constructed on turf or waste layers lying above turf down to c. 0.8 m a.s.l. At the same time we can observe a growing of the settlement area. This find layer was covered by sandy sediments, that are interpreted as evidence for transgression during the settlement period (HERRMANN 1997: 27). But it is possible that the sand layers do only reflect flood events.
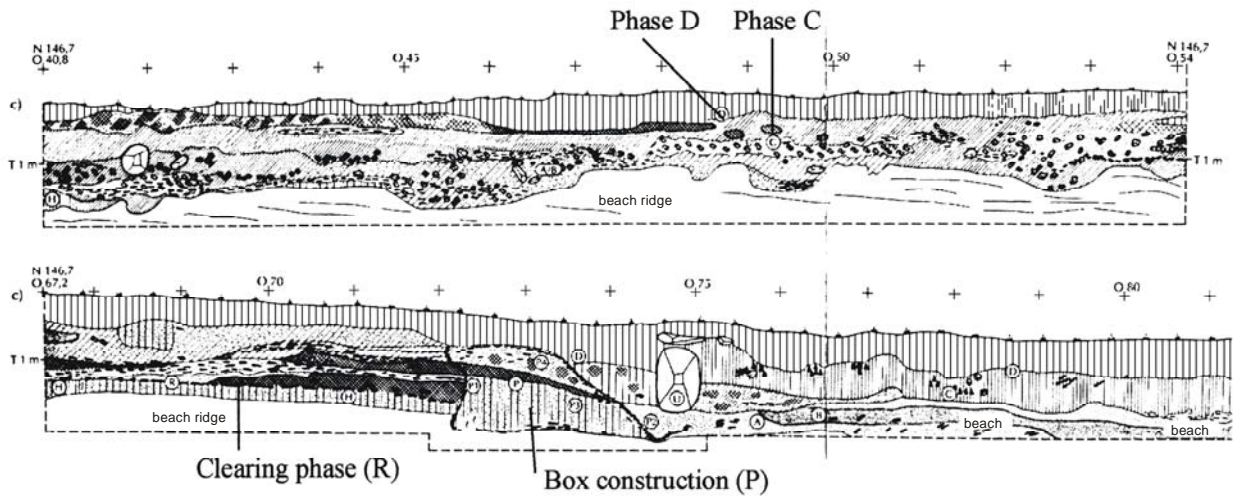

Fig. 3. Profile on the eastern part of the settlement with rests of a wooden construction to protect the beach (P).
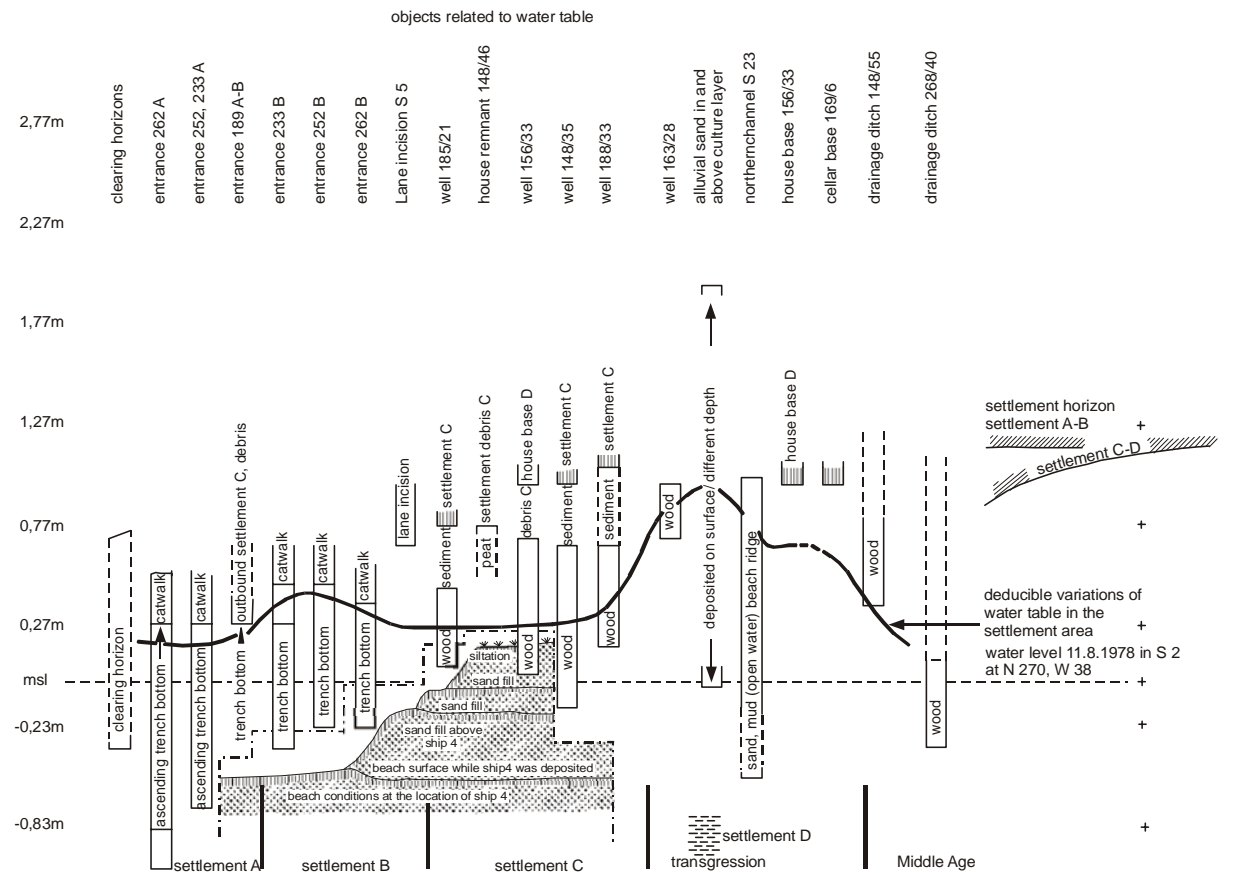

Fig. 4. Reconstruction of the water level at Ralswiek on the basis of archaeological evidence (after HERRMANN 1997: 30).

A typical profile is characterized by a basic layer of charcoal that is interpreted by HERRMANN as evidence of human forest clearance by burning. In phase A-B and D the settlement was partly protected against floods by wooden constructions filled with earth (Fig. 3). The profile at ship wreck 4 (Fig. 2) gives clear evidence of sandy sediments formed during phase B, that elevated the outer beach ridge 30 - 40 cm. Sandy layers (10 - 15 cm) on large parts of the settlement up to 2.17 m a.s.l. argue for heavy flooding during settlement phase D. This event lead to the closing of the northern entrance to the Bodden and can probably be dated to the end of the 12th/ beginning of the 13th century. The flooding is interpreted as the result of a supraregional water level rise. However, evidence of the younger settlement phase D proofs that soon after this high water level new houses on c. 1 m a.s.l. were erected. Observations like depth measurements at the ship landing places and the position of the small landing bridges form the basis for some general interpretations on the water level development (Fig. 4). In settlement phase B a water level of c. 0.6 to 0.3 m a.s.l. is suggested. The idea of falling water levels in settlement phase C partly relies on the construction of wells behind the houses at that time. On the basis of settlement phase D with evidence for high water levels and flooding of the settlement a tendency of rising water levels is concluded. Pollen analyses does roughly confirm this interpretation.

But it has to be emphazised that the interpretation of the sand layers of phase D as the result of a general transgressional period is only a possible explanation. These layers can also be interpreted as evidence for short heavy flood events. Therefore the conclusion of a general water level rising during the settlement has to be questioned.

Overview on the settlement structures

It is possible to divide the development of the settlement into three major periods: A/B, C/D and E (Fig. 5; HERRMANN 1997: 33 ff.).

The first settlement period (A/B) with an extension of c. 350 x 100 m was limited in the North by the water entrance into the lake. On the southern part of the beach ridge no houses were built at that time (Fig. 2). In phase A about 12 – 17 house sites were founded. The buildings with an extension of 25 m² to 90 m² were erected as timber post and rail constructions (Fig. 6). Cellars and pits for housing purposes were dug into the sandy ground. 15 ship landing places were connected with the house sites. Their purpose as ship landing places was indicated by clear traces of ship careens in the profiles. The earthern moles were fastened with wooden planks and interlacing. Natural scientific dates indicate the foundation of the settlement in the last third of the 8th century. Settlement A burnt down before the mid of the 9th century. New houses were built in settlement phase B while the use of the ship landing places continued. The silver hoard that represents one of the largest treasure hoards of the Baltic area was found in house 157/16. The youngest coin was produced in 844 AD and argues for the burning of the house around mid of the 9th century. It looks as if some houses have been destroyed at that time, but probably phase B lasted into the 10th century. It is possible that phase B ended with the raids of the Danes in the 2nd half of the 10th century.

The second major period (C/D) was characterized by a growing of the settlement to a maximum of c. 450 x 120 m (ca. 3.5 – 4 ha). In the northern part the settlement extended over the former water entrance and in the southern part the cult place was settled over. At the same time the ship landing places were given up. Parallel to the main settlement a small southern settlement was founded in phase C (Fig. 2). Although the settlement area was extended, the limited number of houses indicates that we are not dealing with a situation of population growth. Alternatively we have to consider possible changes in the spatial organization of the

settlement at that time (see HERRMANN 1997: 33). This interpretation is supported by evidence of pollen analyses where elements of farming activities are decreasing at that time. Phase C probably started in the 2nd half of the 10th century and continues to phase D without interruption. We get some idea on the dating of phase D by the sandy layer that was formed around 1100 AD. On the basis of late Slavonic ceramics (Teterow and Vipperow type) and first sherds of grey-blue German ceramics we can date the end of phase D to the period around 1200 AD.

main period	find layer	character and dating	number of objects
3rd main period	E	foundation of castle and houses	7 trenches
		construction of border trenches	
2nd main period	D2/3	Late Slavonic settlements	24 objects
		12th century	
silting up of ship entrances	Ds	sand layer, transgression at about 1100	
	D1	Late Slavonic settlement	15 objects
		11th century	
	C	Late Slavonic settlement	42 objects
1st main period	B	settlement(s) and ship entrances	39 objects
		since the 1st half of the 9th century	cult hall B
		hoard house destroyed at about 850	
		deposition of ship 4 and probably	
		of the ships 1-3	
	A	settlement and ship entrances	53 objects
		3rd quarter of the 8th until 1st half	cult hall A
		of the 9th century	cult site on beach
	R	forest clearing horizon	
		at about 775 preparations to found	
		the settlement	

Fig. 5. Overview on the settlement phases of Ralswiek (after HERRMANN 1997: 37).

The third period (E) is characterized by high and late medieval settlements, that led to some destructions of the earlier settlements in the ground. It seems likely that the castel of renaissance period that can be seen nowadays was founded on the basis of a medieval castle. In the high medieval time the site must still have had some importance because we know from written sources, that after the conquer of Rügen by the Danes in 1168 the represent of the Danish diocese Roskilde lived at Ralswiek.
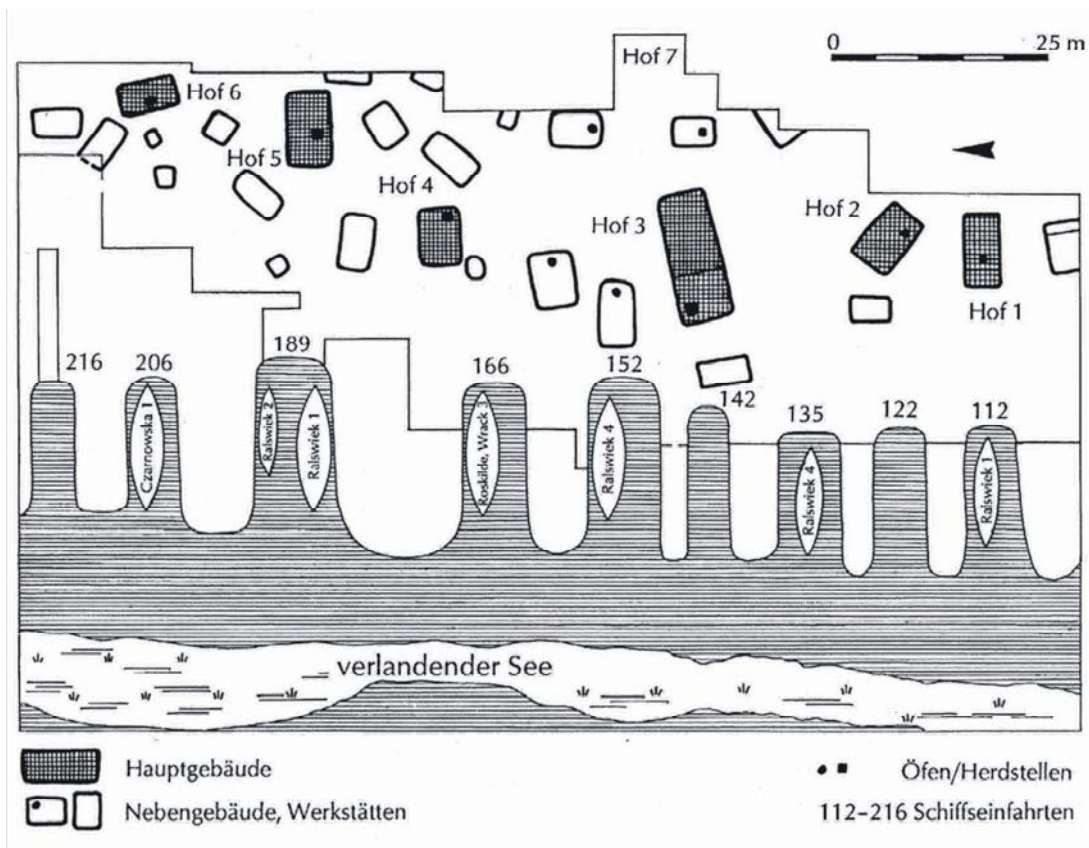
Fig. 6. Part of settlement phase A with houses and smaller buildings near the ship landing places in the habour (after HERRMANN 1997: 41).

Find material

It is only possible to give some general comments on the find material here. A large amount of finds consist of Slavonic pottery sherds and faunal remains. More important are finds indicating craftsmen production like metallic ingots of lead, copper and bronze. Melting pots give clear evidence for metal processing. Numerous antler waste material point to the systematic manufacturing of antler and comb production. On the other hand the widespread distribution of amber indicates home work processing of that raw material.

Some finds underline the character of Ralswiek as a trading site. Fragments of a Norwegian soapstone bowl can be mentioned here as well as a fibula from Gotland. The most important evidence for supraregional trading is represented by a silver hoard with a weight of c. 2750 g. (Fig. 7). Persian Drachmen and numerous Arabic Dirhems indicate strong connections to the orient and the Kalifat area of the 9th century (fig. 8). We can conclude that Arabic people played an important role in the trading activities. At the same moment grave goods and a burial of Nordic tradition with ship rivets clearly indicate the presence of Scandinavians for longer time periods. In summary besides normal people the elite of the Ralswiek society and sometimes foreign traders were buried on the grave field (WARNKE 1989). The four ship wrecks of Ralswiek belong to the few examples of direct navigation evidence at the southern Baltic coast. The ships were finally excavated in the 1990es and will give some new information on slavonic ship construction after their conservation (HERRMANN 1998: 109 ff.).
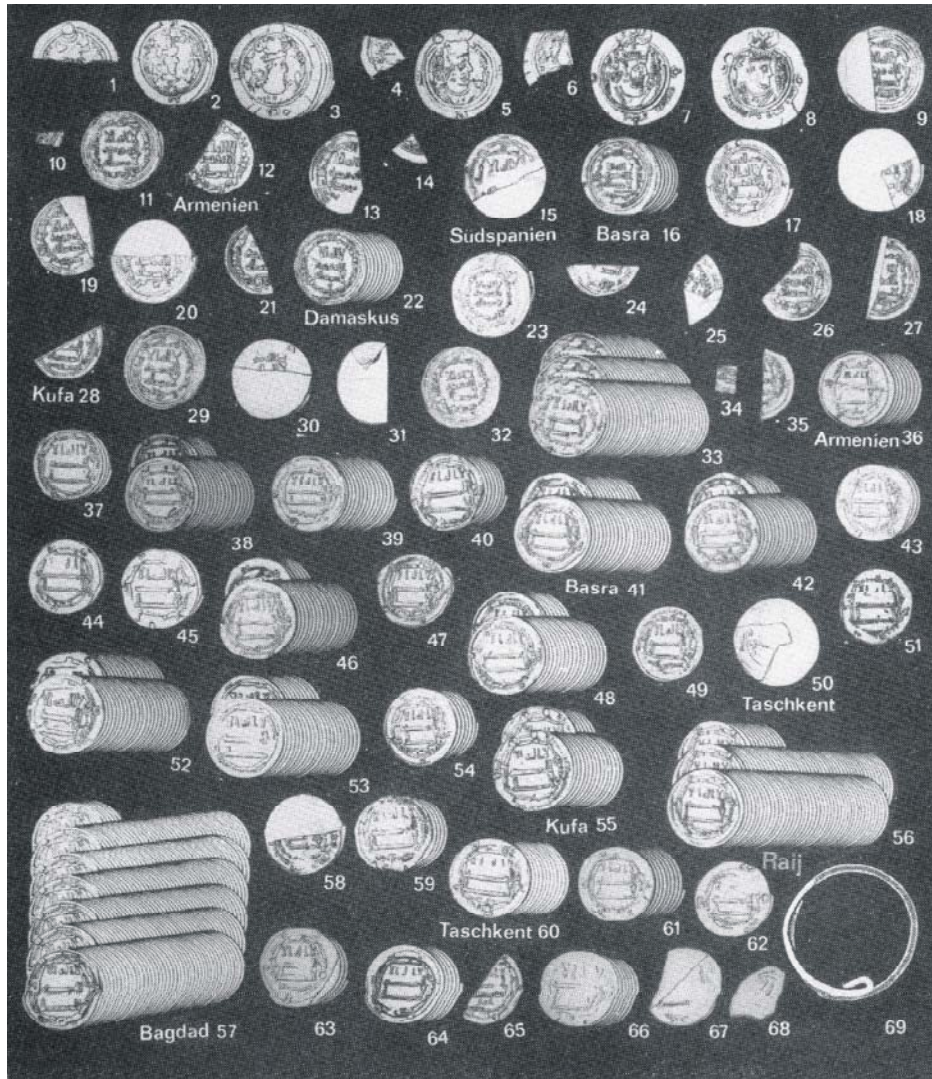
Fig. 7.
The silver hoard of Ralswiek (2750 g)
(after HERFERT o.J.).
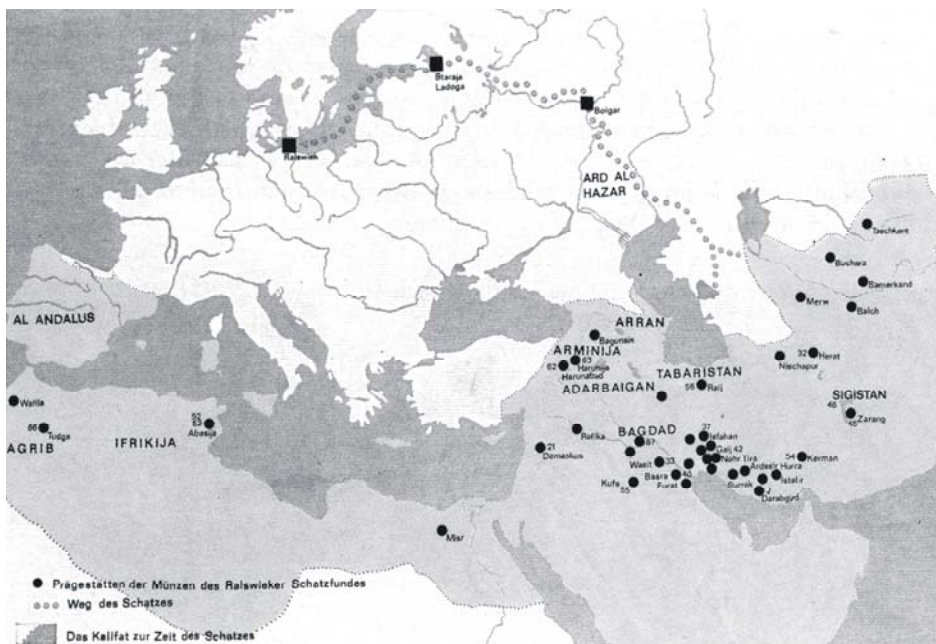
Fig. 8.
Production sites of the silver coins from the treasure hoard of Ralswiek (after HERFERT o.J.).

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Late Mesolithic settlement and sea level development at the Littorina coastal sites of Ralswiek-Augustenhof and Lietzow-Buddelin

BERNHARD GRAMSCH

From 1964 to 1967 archaeological excavations were conducted by the author in cooperation with H. KLIEWE (Greifswald University) on two Late Mesolithic settlement sites on Rügen Island - Ralswiek-Augustenhof and Lietzow-Buddelin (for site locations see Lübke, Terberger, this volume) - which were situated immediately on the Littorina coast of the Rügen archipelago in later Atlantic times (5th millenium cal BC). The following geomorphological and sedimentological descriptions and data, as well as the stratigraphical-chronological conclusions, are the results of the combined archaeological and geological treatment, evaluations and discussions in the field and afterwards between the author and KLIEWE and his working group.

The sites are representative of the Lietzow facies of the Ertebölle culture of the West Baltic region distributed along the coasts and fjords/firths of Denmark, Scania, Schleswig-Holstein, Mecklenburg and western Pomerania (BRÖNSTED 1961; GRAMSCH 1963; CLARK 1975; SCHWABEDISSEN 1994; ANDERSEN 2001). The Ertebölle populations were the last Stone Age hunters/-gatherers/-fishermen in the region. They maintained their existence very effectively and successfully by hunting red-deer, roe-deer, wild boar and sea-mammals and by fishing salt-water fish along the Danish coasts and fjords at the Skagerrak and the Kattegat and also by collecting huge amounts of sea molluscs such as oysters. Their mode of settlement was somewhat residential for longer times in places which were ecologically and economically favourable. They had sporadic contacts with contemporary early Neolithic farmer groups in the Lower Elbe and Oder regions through which they were probably incorporated later into the world of Neolithic farmers and herdsmen.

Ralswiek - Augustenhof

The site of Ralswiek-Augustenhof - discovered and first crudely excavated by the local forester WIESE before 1914 (later investigations by PERNICE, KLINGHARDT and PETZSCH in 1922/23 and by WERTH in 1928) - is situated on a low peninsula or island in a peat-bog area which formerly was a small bay of the Littorina sea (KLIEWE 1965; GRAMSCH 1971; KLIEWE, JANKE 1978). A fresh water brook runs down from an end moraine area in the hinterland and flows into the bay. In the subground the island is preformed by a low hill of glacial till, which later and also in the settlement time was covered by marine sands (Fig. 1) on which Mesolithic man settled. The site sediments were then covered by a beach ridge consisting of sands, gravels and stones (including water-rolled flint artefacts) produced by a high sea-level period in later Littorina times. A sandy 'Anmoor' layer with unrolled flint artefacts below the beach ridge sediments has been RC-dated to 3,150 +/- 100 uncal BP (Bln) = 1395 +/- 135 cal BC (information: J. GÖRSDORF of the Berlin Laboratory, 2002), but the dated material was roots of trees growing after the Stone Age and before the formation of the beach ridge. Since its formation the beach ridge has separated the bay finally from the seaside area.

The marine sands are divided into two layers (Fig. 1), each having a lower stratum of fine/medium sand and an upper stratum of fine/medium sand with humus representing

ranker horizons of former soil surfaces. The lower humus layer is clearly eroded by the upper sand complex. This stratigraphy has been interpreted as the result of two events of marine sand deposition with subsequent growth of vegetation connected with humus production. The marine sand accumulations of the pre-beach ridge time rise to about 1.6 m above the present sea-level.
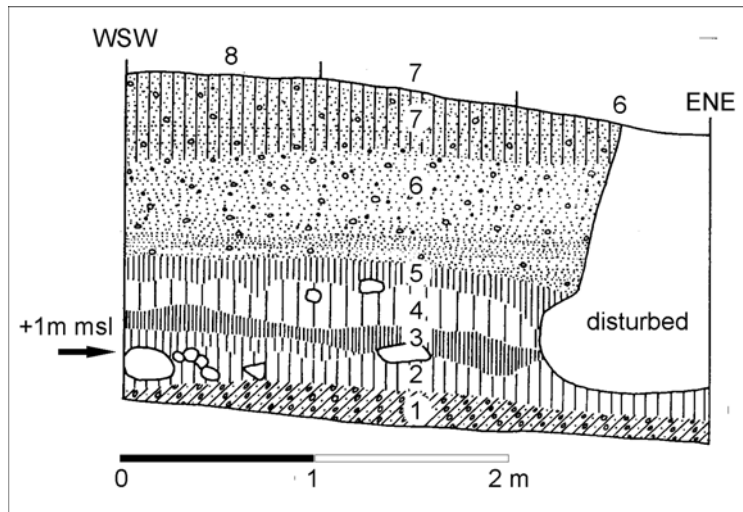
Fig. 1:
Ralswiek-Augustenhof:
Profile of trench I (meter 6 - 8).
1 - boulder clay,
2 - sand,
3 - sand with humus,
4 - sand,
5 - sand with humus,
6 - sand and gravel of beach ridge,
7 - humus soil on the beach ridge.
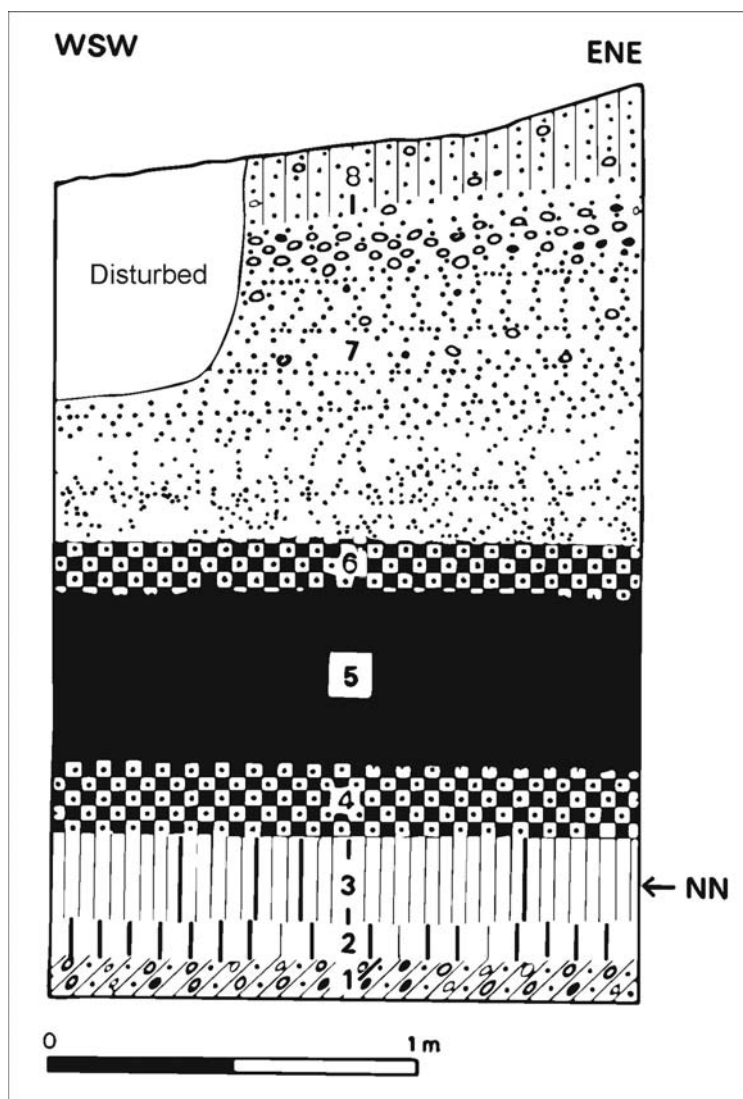
Fig. 2:
Ralswiek-Augustenhof:
Profile of trench III.
1 - boulder clay,
2 - sand,
3 - sand with humus,
4 - peaty sand ('Anmoor'),
5 - peat,
6 - peaty sand (Anmoor'),
7 - sand and gravel of beach ridge,
8 - humus soil on the beach ridge.

At Ralswiek-Augustenhof both layers of marine sands contain flint artefacts and tools of the Ertebölle culture in autochthonous position; this means that they were accumulated in the layers during the presence of Stone Age man. Around the settlement site on the hill or island a refuse area with flint waste and animal bone fragments of their prey/diet reaches into the sandy 'Anmoor' layer and organic mud of the subaquatic shore zone of the Littorina sea (Fig. 2), situated a few decimeters above the present sea level and about 1 m below the marine sands with the artefacts. The marine sand layers of the site and the surrounding 'Anmoor' and sandy organic mud also contained pieces of charcoal from the fire-places of the settlers, particularly in the humus layers, the 'Anmoor' and the sandy organic mud. The latter layer has been dated by pollen analysis (LANGE, JESCHKE, KNAPP 1986) to the later Atlantic period (pollen-zone VIIIb sensu OVERBECK) and by radiocarbon measurement (Bln-562) to 5,455 +/- 100 uncal PB = 4,328 +/- 110 cal BC (GRAMSCH 1978; information J. GÖRSDORF of the Berlin Laboratory, 2002). Recent radiocarbon measurements on bones from the subaquatic layer have confirmed the respective time span of the fifth millenium cal BC (kind information from the Archäologisches Landesmuseum Mecklenburg-Vorpommern 2002).
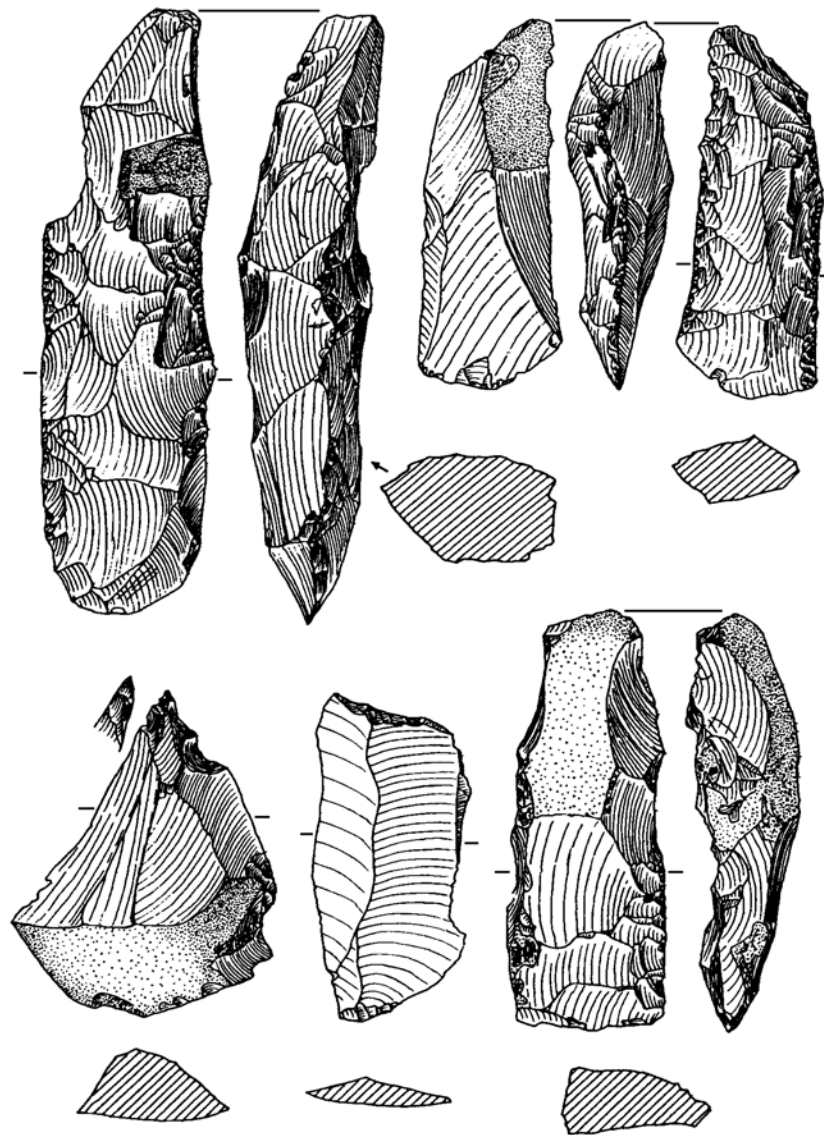
Fig. 3: Ralswiek-Augustenhof: Flint tools of the Lietzow-facies of Ertebölle-culture.
a, b, e core axes, c 'zinken', d knife with terminal retouche. 1 : 2.

It is not possible here to give detailed information about the archaeological finds from the excavations and cuttings. They can only be listed: many flint artefacts (cores, flakes, blades, debris, fragments) and tools (e.g. core axes, 'picks', flake axes, retouched blades and flakes, scrapers, borers, large backed knives, 'Grobzinken'. - Fig. 3; see also PETZSCH 1928; GRAMSCH 1971; WECHLER 1993); bone and red deer antler artefacts and tools (e. g. antler T-axes, antler tools with cutting ends, bone hooks, bone 'knives' and 'daggers' - see PETZSCH 1928; GRAMSCH 1973); few sherds of ceramic vessels; two 'imported' Neolithic objects (an ornamented bone plate and a fragment of a perforated stone axe from the Danubian cultures - TERBERGER 1999). The fauna list comprises domesticated dog, horse, aurochs, red deer, roe deer, wild boar, fox, otter, two genera of seal, swan (TEICHERT 1989).

It is of great interest to examine the position of the Ralswiek-Augustenhof settlement- site in relation to sea level changes in the younger Holocene and to the estimated sea level at the time of the Ertebölle settlement. The recent sea level would have been good for living near to the shore in our days, but at the time of the Ertebölle settlement on the site, around 6,300 sun-years before the present - according to KOLP (1979), KLIEWE, JANKE (1978), NIEDERMEYER, KLIEWE, JANKE (1987) and JANKE, LAMPE (2000), the absolute sea-level in the Baltic region of Rügen was about 2 m below the present level. But the sandy organic mud of the refuse area of the site could never have developed at -that time because of being situated c. 2 m above the sea level and ground water level of the Ertebölle times. A reasonable explanation is the assumption of an isostatic uprise of the earth crust in the Rügen region of about 2 m and more over the past 6,000 years, as is assumed by geophysicists (BANKWITZ 1965; see also KOLP 1979). This assumption is supported by similar results at the other Ertebölle site investigated on Rügen island, namely Lietzow-Buddelin. But in the Ertebölle settlement periods at Augustenhof the sea level must have been already somewhat below the highest level of the transgression causing the marine sand sedimentation. The humus horizons of the sands give proof of a retreat of the sea resulting in vegetation growth and humus accumulations in the soil. Therefore the Ertebölle-settlement took place during regression events after the transgressive phases of the Littorina period (Figs. 7 and 8).

Lietzow - Buddelin

The Ertebölle site Lietzow-Buddelin is situated at the mouth of a fresh water brook running into the Kleiner Jasmunder Bodden which at the time of settlement was part of the open Littorina sea. The site was discovered by an amateur archaeologist soon after 1900, but after having been forgotten it was rediscovered in 1930 by CARL UMBREIT, a teacher in Berlin and PhD archaeologist. Between 1936 and 1941 UMBREIT undertook systematic archaeological excavations on the site. The results of the excavations have been published in part (UMBREIT 1939, 1940); we have additional information from hand written records, plans/profiles and inventories which were found around 1960 in UMBREIT'S home. Our investigations in 1964 and 1965 were mainly undertaken in order to understand this documentation better.

The site of Lietzow-Buddelin is located on the shallow slope of the westernmost part of an end moraine ridge reaching from this area in the west to the Baltic Sea in the east. UMBREIT excavated parts of the site on the slope but not in the transition zone from the site to the sea shore and also not in the littoral zone. In his excavation areas not only were Mesolithic Ertebölle artefacts distributed but also archaeological remains of a Middle Neolithic settlement period of the second 4th millennium cal BC. Therefore UMBREIT mainly excavated layers with mixed objects of chronologically far distant periods, also because of the fact that in this slope area of the Buddelin hill colluvial processes took place in and since Stone Age times.

Our main excavation trench (GRAMSCH 1966) ran down from the afore-mentioned slope and reached 11 m into the adjacent meadow area where UMBREIT had already found a layer with artefacts below peat in a trial pit. The following stratigraphy was recorded (Fig. 4, the layer numbers of the following descriptions are related to this Figure). Below subrecent artificial sand deposition with humus above (layers 8, 9) sand with humus (layer 7) and peat (layer 6) were deposited, the age of which age was determined by pollen analysis (LANGE, JESCHKE, KNAPP 1986) as zone XI sensu OVERBECK, i. e. Subatlantic times. Down there a sand layer with pebbles follows including more than a few rolled Ertebölle flint artefacts (layer 5). This layer has not been dated but a few unrolled artefacts and ceramic sherds of the Upper Neolithic culture mentioned above point to an age of about the second half of 4th millennium cal BC. Further down a real cultural layer was found (layer 4) consisting of sandy peat with extremely many unrolled flint artefacts and tools of Ertebölle style plus a few animal bone fragments and pieces of charcoal; sometimes the impression was that a layer of artefacts was laden with sediment but not conversely. This (Lietzow culture upper) layer is RC-dated to 5,190 +/- 120 uncal BP (Bln-560) = 4,057 +/- 158 cal BC (information from J. GÖRSDORF, 2002, Berlin laboratory) and by pollen analysis to zone VIIIb sensu OVERBECK, i. e. Upper Atlantic time (LANGE, JESCHKE, KNAPP 1986); the same pollen determination was given to the underlying peat layer 3 containing some Ertebölle flint artefacts too. Below the peat layer marine sands - layer 2 = medium-coarse sand and layer 1 = coarse sand with pebbles - contained Ertebölle flint artefacts and tools as well as animal bone fragments and charcoal pieces (= Lietzow culture lower layer). Layer 1 is RC-dated to 5,815 +/- 100 uncal BP (Bln 561) = 4,658 +/- 119 cal BC (information from J. GÖRSDORF 2002, Berlin Laboratory) and pollen analysis resulted again in pollen zone VIIIb sensu OVERBECK (LANGE, JESCHKE, KNAPP 1986).
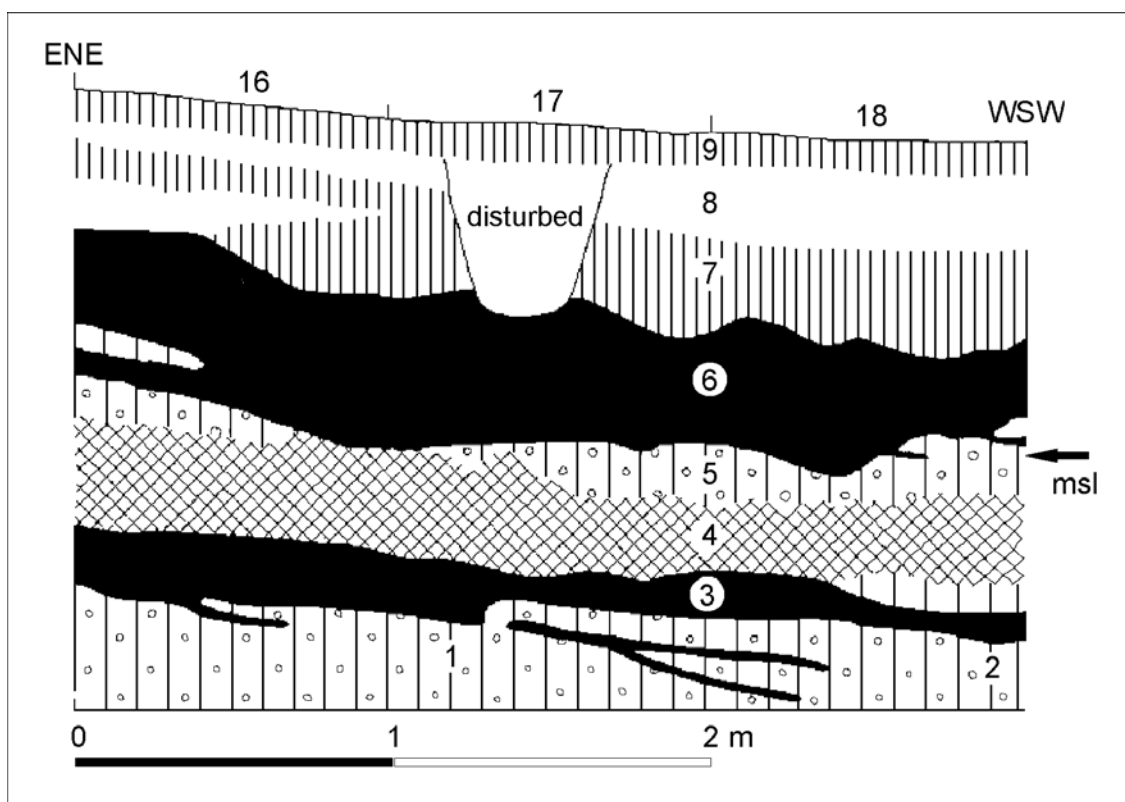
Fig. 4: Lietzow-Buddelin: Profile of the trench 1965 (meter 16 - 18).
1 - coarse sand with pebbles, 2 - middle sand, 3 peat, 4 - peaty cultural layer, 5 - fine sand with pebbles and rolled artefacts, 6 - peat, 7 - sand with humus, 8 -colluvial sand, 9 - sand with humus.

The basal marine sand (layers 1/2) lying at the most at about the present sea level represents a transgressive Littorina phase at about 4,600 cal BC, in which time Ertebölle settlement on the site first happened - as is seems - directly in the shore area, resulting in intrusions of man made objects and refuse materials in the marine sand. As at the Augustenhof site, the question again arises whether the Littorina sea level of that time really reached the recent sea level. Assuming an isostatic uplift of the earth´s crust of c. 2 m since the earlier Ertebölle settlement on the Buddelin site there seems to be good agreement with the picture of Littorina sea levels around Rügen island (KOLP 1979; KLIEWE, JANKE 1978), as given above for the Augustenhof site. The upper Ertebölle layer 4 at Lietzow-Buddelin with its organic contents reaching about 0.4 m above present sea level represents a regression phase (after another transgression later than the transgression connected with layers 1/2) associated with peat/mud formation in a coastal lake which possibly developed at the back of a (presumed but at the moment not provable) sand barrier in the subground resulting from a Littorina transgression event. In a discussion on the site, the late STEN FLORIN (Uppsala University) expressed the opinion that layer 4 resulted from beach meadows as usually found in some coastal areas of the Baltic with its very slight tidal lift; man could live directly on such meadows which would explain the high numbers of artefacts in the layer itself. - Layer 5 was deposited some time after the formation of layer 4 as the result of another transgression phase in the area. This layer amounts at its highest point to 0.6 m above the present sea level. The many rolled Ertebölle artefacts again provide evidence of strong abrasive impacts on the original younger Ertebölle layer 4.

New RC-datings for bones from the different layers of Buddelin correspond quite well to the above-mentioned datation for the lower horizon (layer 1/2), but the new datation results for bones from the upper horizon fall outside of the presumed limits and need to be explained (kind information from Archäologisches Landesmuseum Mecklenburg-Vorpommern 2002).
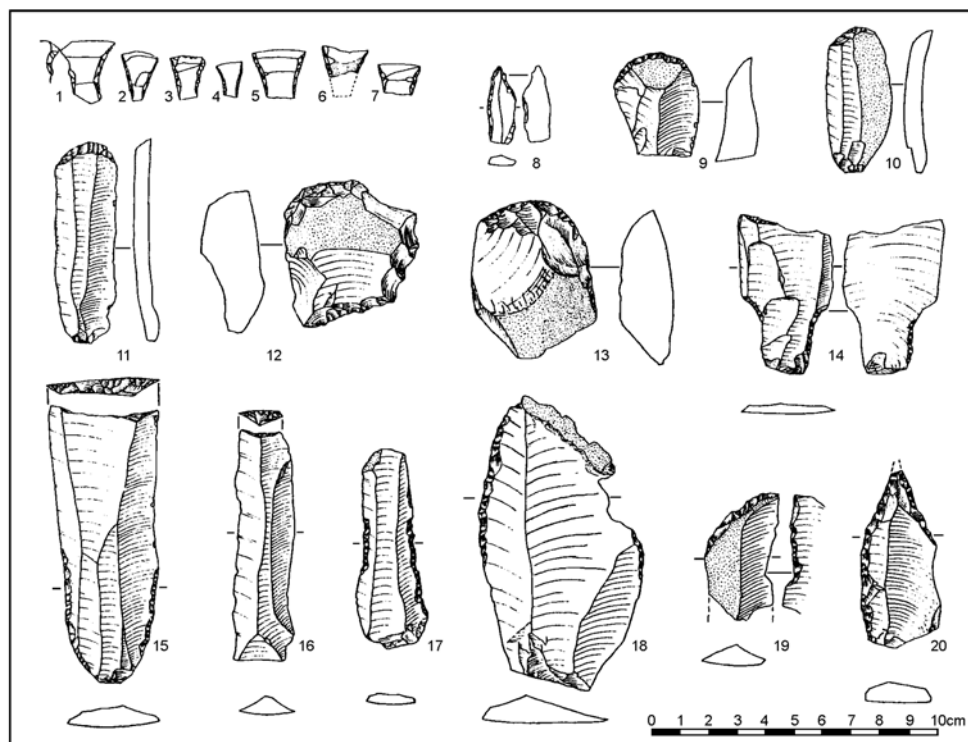
Fig. 5: Lietzow-Buddelin: Flint tools of the Lietzow-facies of Ertebölle-culture.
1 - 7 transverse arrowheads, 8 - borer, 9 - 13 scrapers, 14 - tanged knife with terminal retouche, 15 - 16 knifes with terminal retouche, 17 - 20 blades and flakes with lateral retouches. 1 : 2.

The archaeological contents of the lower Ertebölle layer (1/2) mainly comprises silex artefacts including core and flake axes, one stag antler fragment with shaft-hole, one worked piece of wood, as well as animal bone fragments representing the animal food of the settlers. The main cultural layer 4 contained many thousands of worked flints including many flint tools (Fig. 5) such as transverse arrowheads, scrapers on flakes and blades, blades with end-retouche, laterally retouched flakes and blades, many flake axes and extremely numerous core axes. A number of small bone points seem to have been arrowheads, a type which is usual in Ertebölle culture. One ceramic sherd derives from a vessel of the Ertebölle type.

The animal bones from the excavations of 1964/65 represent the following genera (TEICHERT 1989): Red deer, roe deer, wild boar and sea mammals and several genera of seal; these were the main animals hunted; then there are domesticated dog, sheep/goat, badger, otter, marten species and water fowl. The birds hunted were swan, several genera of duck and sea eagle, while the fishes caught were sturgeon, pike, roach, codfish, perch and perch-pike, namely sea and freshwater fishes.

General remarks

The sequence of transgressive and regressive Littorina phases in the 5th millennium cal BC seem to be clear at the Lietzow-Buddelin site, and there is good correspondence in this respect between Augustenhof and Lietzow. Fig. 6 shows the picture in the 1970s (KLIEWE, GRAMSCH) but it seems that since that time there is no new evidence for another, more modern picture.
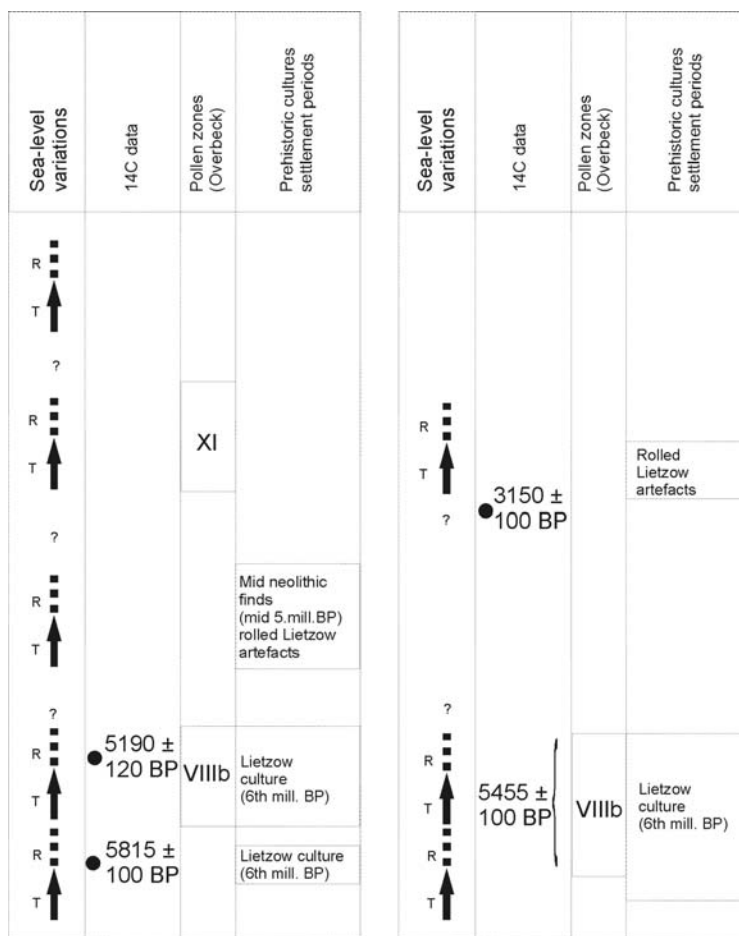
Fig. 6:
Comparative table of sea level oscillations, RC-dates and results of pollen analyses and archaeological horizons (after GRAMSCH, KLIEWE, and LANGE).

T - transgression phase   R - regression phase

The summarizing table of Lange, Jeschke, Knapp (1986, Fig. 7) may well represent the general picture as well as our view. It is important that sediments and layers connected with Stone Age Ertebölle sites on Rügen island are situated near to the present sea level. If there are geomorphological and hydrographical reasons for new or better knowledge about the development of the absolute sea level in the Baltic Sea since the middle Holocene, they could not change the picture given here based on sediments from the sites mentioned above. Only the absolute values in terms of plus/minus meters could change. The latter is not a problem for archaeology but merely for natural sciences engaged in these problems. If geological/hydrographical data and reasons demand new figures for the sea level development in later Atlantic times, it must always be considered that the Ertebölle inhabitants of the sites of Augustenhof and Buddelin had their camps more or less above the contemporary sea level – and did not live with their feet in the water, and that some sediments on and near to their camps are produced by marine transgression events or resulted from humus accumulation and peat formation in lakes/ponds. The origin of which was connected again with sea level changes at that time.

|							conv. ^{14}C-years
Ancylus	Mastogloia	Littorina		Limnaea			Baltic evolution stages acc. to Kolp 1979, Kliewe, Janke 1978
Ancylus-Transgression	initial Littorina-Transgression	1st Littorina Transgression	2nd Littorina Transgression		3rd Littorina Transgression	post-Littorina Transgression	relative sea-level curve on Rügen Island as derived from the archaeological and geological record
Ancylus Regression NN			Early Littorina Regression	Late Littorina Regression	Roman Age Stagnation	subrecent Stagnation	
		BF Augustenhof Lietzow		BF Lietzow	BF Schaabe III		
			TC Neuenkirchen	regression peat Lietzow	TC Lobber See	peat Neuenkirchen	
	TC Ralswiek 76						
	TC Lietzow		TC - transgression contact				
	TC Ralswiek E		BF - beach facies				
-Rügen belongs to the south Baltic mainland -alteration of the water balance -accelerated siltation of lakes (calcareous muds) -decreasing peat accumulation	-the Littorina Sea arrives Rügen (Tromper and Prorer Wiek) -inundation of the Strelasund, -Greifswalder Bodden remains as an inland water	-inundation of the Greifswalder Bodden Rügen becomes an island -formation of an archipelago, sub-marine phase of barrier spit formation -Lietzow men settle on beach ridges	-intensive coastal smoothing cutoff of coastal waters and lakes, brown dunes -introduction of agriculture (funnel beaker culture), forest clearing -Megalith tombs	-increasing settlement on Jasmund -tumulus tombs	-active coastal smoothing -yellow dunes -climate becomes cooler and wetter	-Slavonian colonization, clearings, rye cultivation -formation of the historic settlement structures -copious development of Fagus -formation of the recent landscape	main features of landscape evolution
moderate	wet-warm						Climate (Willerding 1977)
Maglemose culture		Lietzow culture	Early Middle Late (Neolithic)	Tumulus Urnfield (Bronce Age)	Latene Roman Age / Germ. Tribes Migr. (Iron Age)	Slavonic Age / Late Middle Ages / Modern times	Settlement periods
V Boreal	VI	VII Atlantic	VIII Subboreal		IX Early Subatlantic	Xa b Late Subatlantic	Pollen zones (Firbas)

Legend: dry-warm; wet-cool

Fig. 7: Table of the development of landscape on Rügen Island, in parts for development of the Baltic sea, for sea level changes and transgressive/regressive phases, settlement periods and pollen zones sensu Firbas (after Lange, Jeschke, Knapp 1986, simplified).

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New evidence on the Ertebølle Culture on Rügen and neighbouring areas

HARALD LÜBKE, THOMAS TERBERGER

Since the excavations of B. GRAMSCH and H. KLIEWE in the 1960es (see GRAMSCH this volume) no further systematic field work has been conducted on the Rügen Ertebølle sites. But new information was obtained by the accidentally detected coastal sites of Prohn and Parow situated at the Strelasund southwest of Rügen (Fig. 1) (LÜBKE et al. 2000). Together with some Ertebølle finds which were discovered in the 1930es by sand dredging near Drigge, these sites give evidence of the importance of the Strelasund and the Jasmunder Bodden area on Rügen for the final Mesolithic hunter-gatherer-fisher settlements. This view point was confirmed by rescue excavations of the Landesamt für Bodendenkmalpflege Mecklenburg-Vorpommern at Stralsund in spring 2002, where three final Mesolithic/early Neolithic dugouts were discovered at the southern Baltic coast for the first time. There are some less important sites in the Rügen area which have only been documented by surface finds (Fig. 1).
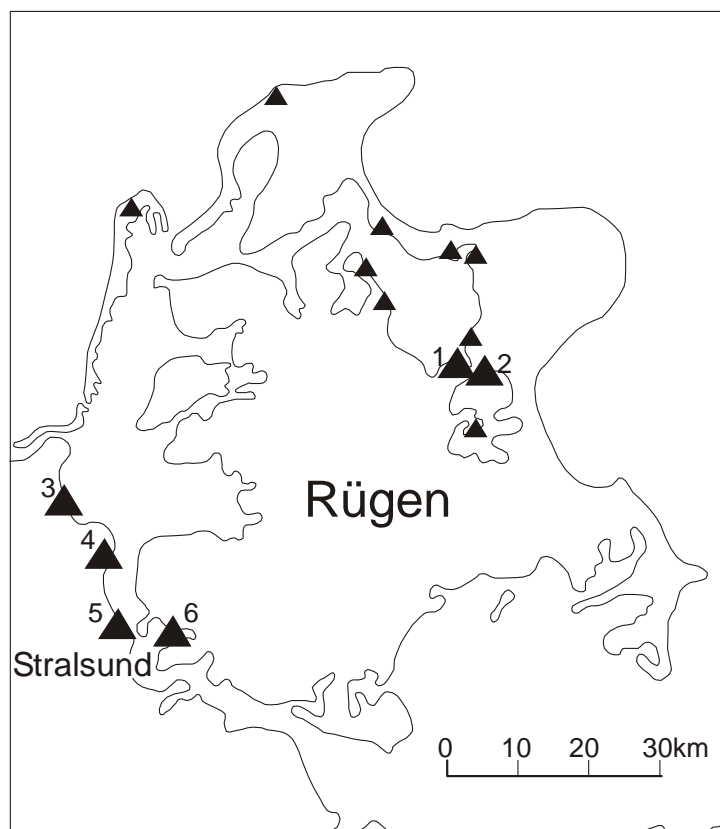
Fig. 1:
Location of final Mesolithic and early Neolithic sites in the Rügen area
1 – Augustenhof,
2 – Buddelin, 3 - Prohn ,
4 - Parow, 5 - Stralsund,
6 - Drigge

Besides the discovery of new sites helpful information was obtained by sample series for radiocarbon dating conducted by the Landesamt für Bodendenkmalpflege in the last years. In the following we will briefly present some of the new results, but we will not discuss evidence and development of the material culture and the character of the Lietzow Group here (see GRAMSCH 1978; HARTZ u.a. 2000; LÜBKE et al. 2000; TERBERGER 1998; 1999).

Absolute dating

The early radiocarbon dates of Ralswiek-Augustenhof and Lietzow-Buddelin were measured on charcoal and charred wood samples that were not necessarily linked to human activity. New samples were initiated by the authors on processed bone or antler material, some charred food remains from pottery and on human remains to get more reliable results. Animal species like seals and cattle were preferred for selection to gather information on the subsistence strategy. Samples taken from seal, human and dog can be influenced by the marine reservoir effect and their results can appear somewhat older than contemporaneous terrestrial samples (see i.e. BARRETT et al. 2000). It is not intended to discuss this topic here in detail. But it should be mentioned that under the human remains only the calvarium from Ralswiek-Augustenhof with a δ ¹³C-value of -17,1 ‰ seems to be somewhat influenced by this effect. This is more the case with five seal samples from Lietzow-Buddelin, Ralswiek-Augustenhof and Prohn with δ ¹³C-values from -14,0 ‰ to -17,3 ‰. It is interesting to notice that at Ralswiek-Augustenhof there is another seal sample with a much lower δ ¹³C-value of -19,3 ‰. The dates are presented on the calibrated time scale using the program Calpal by O. JÖRIS (Neuwied) and B. WENINGER (Köln) based on Intcal98 for correction (compare www.calpal.de).

2-D DISPERSION CALIBRATION

Gesamt

Statistical Limits — Span [a]

95 % Peak   5180 calBC – 1302 calAD   6482
68 % Peak   4666 calBC – 3193 calBC   1473
50 % Peak   4525 calBC – 3496 calBC   1029

DATE LIST

Lab.Number	Date Std [14C-BP]	Date 68 % [calBC/AD]
UtC-8112	5170± 60	3950± 95
UtC-8109	5158± 43	3934± 82
UtC-8110	5138± 43	3907± 76
UtC-8111	5088± 47	3876± 64
UtC-9611	621± 44	-1349± 40
Bln-562	5455± 100	4261± 129
UtC-7452	5471± 41	4305± 47
KIA-12053	5395± 42	4227± 82
KIA-12129	5269± 39	4101± 87
KIA-12055	5248± 33	4090± 92
KIA-12473	5196± 32	4006± 36
KIA-12130	4766± 37	3559± 56
KIA-12474	2123± 50	172± 96
UtC-9732	5753± 46	4604± 67
UtC-9730	4751± 45	3515± 96
UtC-8108	4720± 39	3503± 100
UtC-9612	4609± 47	3353± 132
UtC-9731	868± 40	-1147± 69
Bln-561	5815± 100	4662± 115
Bln-560	5190± 120	4007± 167
KIA-12048	5927± 35	4791± 51
KIA-12051	5767± 33	4618± 55
KIA-12050	5603± 33	4419± 45
KIA-12049	4441± 59	3134± 144
UZ-4093	6250± 80	5188± 106
UtC-6938	6070± 60	4967± 91

Calibration Data Base:
File c:\calpal\calcurve\intcal98.ext
Error Bars On Calibration Curve are:
U/Th+Marine+PS2644+SUIGETSU(+2ka Shift)

Fig. 2: Calibrated radiocarbon dates of the final Mesolithic and early Neolithic coastal sites. Calibration was conducted with the program Calpal by JÖRIS/ WENINGER; (www.calpal.de).

A summarizing calibration of the data demonstrates that the majority of the results fall into the period from 4,700 – 3,900 cal. B.C. (Fig. 2). Within the time range of the selected calibration curve we realize some plateaus especially in the periods from 4,350 to 4,050 cal. B.C. and after 3,350 cal. B.C. The latter one is not of relevance here but the older one is important for the dating of the Mesolithic/Neolithic transition in the southwestern Baltic.

The earliest evidence for the Ertebølle culture is connected with finds from Drigge (Fig. 1). Two dates place this site to the time around 5,200 – 4,950 cal. B.C. (Tab. 1; Fig. 3). They are comparable to datings for the early Ertebølle culture at the Jäckelberg site in Wismar Bay and in Schleswig-Holstein (cf. E-2 this volume; HARTZ et al. 2000). The Drigge finds were dredged out and so we have no further information on the find layer. But because the archaeological material is of quite homogenous character, we can expect a limited time range for the development of the find layer (TERBERGER 1998).

Tab. 1 List of radiocarbon dates of final Mesolithic and early Neolithic sites in the Rügen area.

Sample-No.	Age BP	Age calBC	δC13	Object
Drigge				
UZ-4093	6250±80	5188±106	-19,7	human skull
UtC-6938	6070±60	4967±91		antler, red deer
Lietzow-Buddelin				
Bln-560	5190±120	4007±167		Charcoal
Bln-561	5815±100	4662±115		charred wood
KIA-12048	5927±35	4791±51	-19,1	animal bone, dog, ob. Hor. B2
KIA-12049	4441±59	3134±144	-17,3	animal bone, seal, ob. Hor. B2
KIA-12050	5603±33	4419±45	-22,8	animal bone, red deer, unt. Hor. B1
KIA-12051	5767±33	4618±55	-15,3	animal bone, seal, unt. Hor. B1
Ralswiek-Augustenhof				
Bln-562	5455±100	4261±129		charcoal
UtC-7452	5471±41	4305±47	-17,1	human skull
KIA-12053	5395±42	4227±82	-18,1	animal bone, wild boar, ob. Hor. A2
KIA-12055	5248±33	4090±92	-15,7	animal bone, seal, unt. Hor. A1
KIA-12129	5269±39	4101±87	-19,9	animal bone, seal, Altgrabung
KIA-12130	4766±37	3559±56	-24,7	animal bone, cattle, Altgrabung
KIA-12473	5196±32	4006±36	-23,2	animal bone, wild boar, unt. Hor. A1
KIA-12474	2123±50	172±96	-32,2	animal bone, wild boar, ob. Hor. A2
Prohn				
UtC-8108	4720±39	3503±100	-21,1	human skull
UtC-9612	4609±47	3353±132	-15,0	animal bone, seal
UtC-9730	4751±45	3515±96	-14,0	animal bone, seal
UtC-9731	868±40	1147±69 AD	-23,4	animal bone, goat
UtC-9732	5753±46	4604±65	-23,8	animal bone, aurochs scapulae
Parow				
UtC-8109	5158±43	3934±82	-27,6	charred food crust, TRB-rimsherd
UtC-8110	5138±43	3907±76	-28,0	charred food crust, base sherd
UtC-8111	5088±47	3876±64	-25,9	charred food crust, body sherd
UtC-8112	5170±60	3950±95	-26,2	charred food crust, body sherd
UtC-9611	621±44	1349±40 AD	-19,9	human skull

On first sight the new results for Lietzow-Buddelin seem to confirm an early settlement phase that is indicated by the older date of the Berlin laboratory (Fig. 2). But because the new samples were taken from the upper find layer Lietzow-Buddelin B they can not be linked with the Berlin result for the lower find layer A. The new dates point to a settlement phase of the middle Ertebølle culture from around 4,800 to 4,400 cal. B.C. at the site. Due to reservoir effects minor corrections for this time range have to be expected (Tab. 1). A second much younger settlement phase of the middle Neolithic funnel beaker culture at Lietzow-Buddelin is suggested by another sample of the new series. This date can probably be connected with some stray finds identified in the excavation area (see GRAMSCH, Fig. 7). The new results do

not confirm a find layer of the earliest Neolithic (c. 4,000 cal. B.C.) as suggested by the earlier charcoal sample measured at the Berlin laboratory.
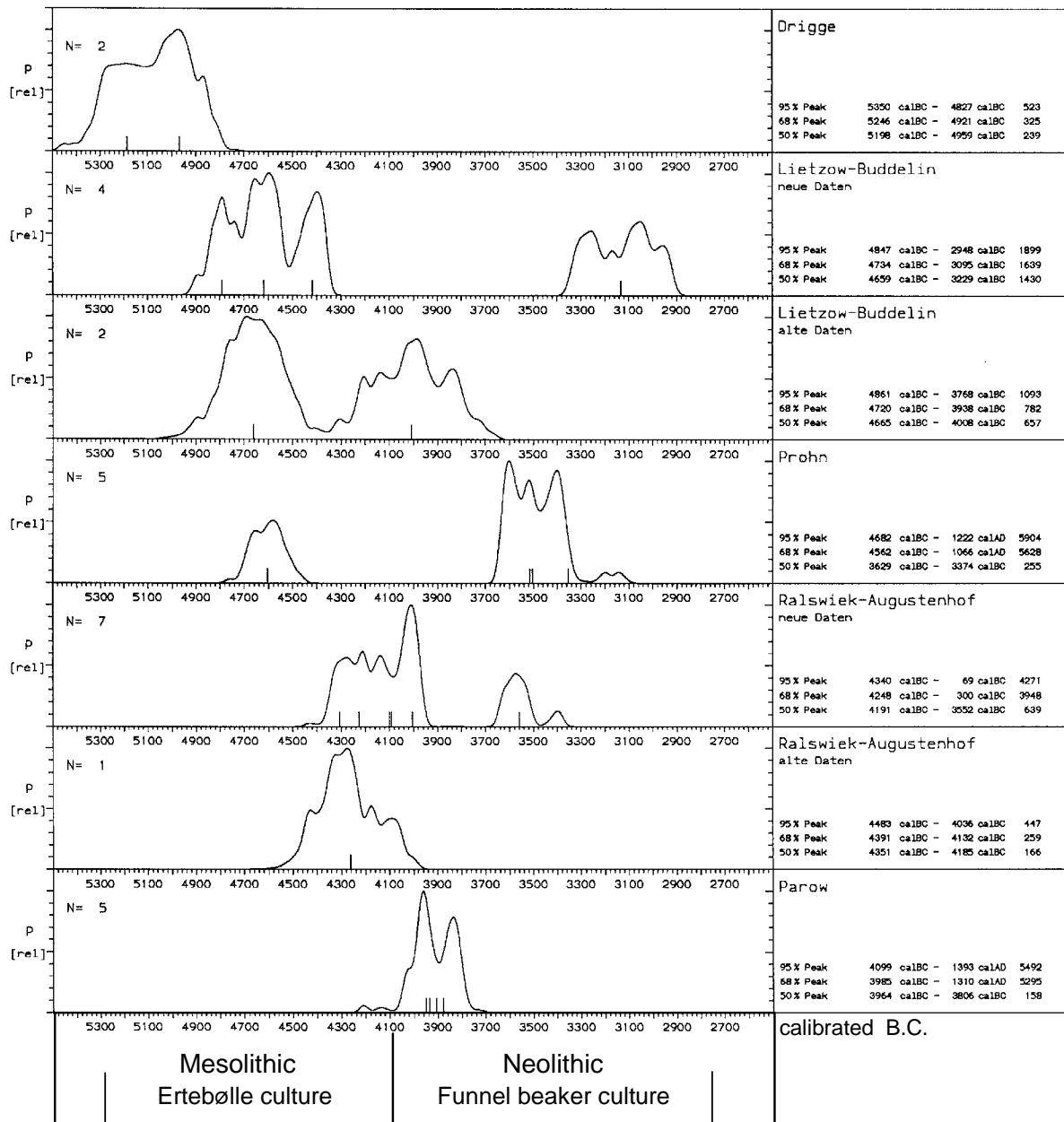

Fig. 3: Calibrated radiocarbon dates of the final Mesolithic and early Neolithic grouped by sites (see Fig. 2).

The new radiocarbon dates raise some doubt on the earlier dating evidence of Lietzow-Buddelin (see GRAMSCH this volume; 1978: 159). If we accept the new results as the more reliable information the following preliminary conclusions can be drawn. The lower find layer Buddelin A with some (partly redeposited) artefacts, faunal remains, charcoal fragments and used stone slabs (but with no ceramics) was separated from the upper find layer (Buddelin B) by a 0.1 – 0.15 m thick peat layer. So Buddelin A should be somewhat older than the upper find layer (> 4,800 cal. B.C.). Because B. GRAMSCH recognized some typical Ertebølle elements layer A can probably be linked to the early Ertebølle culture (c. 5,200 – 4,800 cal. B.C.). On the basis of the new radiocarbon datings the richer layer Buddelin B with

numerous stone artefacts, faunal remains, worked bone material and some Ertebølle pottery should correspond to a middle phase of the Ertebølle culture (c. 4,800 – 4,400 cal. B.C.). We can observe a marked change in the stratigraphy above find layer B. The overlying sandy layer is interpreted as a transgression sediment with some redeposited finds of Ertebølle and funnel beaker character. The younger Neolithic date for Lietzow-Buddelin can probably be connected with some reworked Neolithic material of this layer. The fact that the oldest and youngest date of Lietzow-Buddelin both belong to the upper part of layer B (B2) points to some mixture and contact to the overlying sediments. It should be mentioned that the correlation of the sandy layer with a transgression phase has to be taken with some caution, because this layer can possibly be interpreted as well as the result of a short flood event (pers. communication R. Lampe).

Prohn is another site with evidence for the middle phase of the Ertebølle culture where a date of c. 4,600 cal. B.C. was obtained on a worked scapula of an aurochs (Fig. 3). This result is in agreement with the typological evidence: The scapula with a cut out rectangular section finds its parallels in the Danish Ertebølle culture (LÜBKE et al. 2000). A possibly more important settlement phase of the younger early Neolithic (c. 3,550 – 3,350 cal. B.C.) at Prohn is indicated by three samples of a human calvarium and two seal bones (LEHMKUHL 1992). The Neolithic seal bones of Prohn and Lietzow-Buddelin illustrate that marine resources were still of some importance for the subsistence strategy in that period. Finally the Middle Age date for a goat bone from Prohn has to be mentioned (Tab. 1). This result underlines that we have to expect mixing of find material at the site.

For Ralswiek-Augustenhof the new radiocarbon dates are in good accordance with the result of the Berlin laboratory. They form a cluster of dates in the period from about 4,300 to 4,000 cal. B.C.; the oldest date refers to a human calvarium that may be slightly influenced by the reservoir effect and the settlement might start a bit later. So we have probably evidence for a younger Ertebølle to early Neolithic settlement, but the situation is somewhat influenced by the plateau effect at that time (Fig. 2). So future work has to demonstrate whether we can support an early Neolithic period with the find material. One date of the new sample series points to a second clearly younger Neolithic settlement phase (c. 3,500 cal. B.C.). The sample was taken from a cattle bone of the early excavations at Ralswiek-Augustenhof and so we have no clear information on the find circumstances. At the same moment speculations on early domesticated animals in the Ertebølle culture in the Rügen area have to be rejected. Although sites in Schleswig-Holstein like Grube-Rosenhof show isolated evidence for the use of cattle and possibly grain in the middle to younger phase of the Ertebølle culture (see HARTZ et al. 2000, 134 ff.) no finds of this character were detected until now in the eastern Ertebølle territory at the southern Baltic coast. Finally there is a much younger iron age date for a wild boar bone from Ralswiek-Augustenhof (Tab. 1). The sample KIA-12474 had a very low collagen value and the laboratory raised some doubt on the reliability of the sample (letter P. GROOTES 8.6.2001). Therefore the authors suggest to reject this date.

Four dates from Parow obtained on charred food remains from early Neolithic ceramics with a cluster of dates from about 4,000 to 3,900 cal. B.C. point to a beginning of the Neolithic period in the Rügen area before 4,000 cal. B.C. This is in accordance with results for Schleswig-Holstein, where at 4,100 cal. B.C. a change in the economy and material culture towards a Neolithic way of life can be observed. So Parow is the most important complex of the earliest Neolithic in West Pomerania. The radiocarbon date for a human skull points to some mixture with medieval material at Parow (Tab. 1).

For the new Stralsund site reliable dating information are not yet available. But some big trees that were found directly underneath the find layer will give the chance for dendrochronological dating of that period. Preliminary observations suggest a dating of the lower find layer with two dug-out boats to c. 5,400 to 5,000 cal. B.C and for the upper layer with another ca. 11 m long dug-out boat to c. 4,000 cal. B.C.

The new radiocarbon evidence is an important step to a more reliable chronological framework of the Ertebølle culture in the Rügen area. At the same time it becomes apparent that we have to expect mixture of different occupation phases at some sites. As a consequence a critical revision of the material basis for the definition of the Lietzow group seems necessary.

Evidence for sea level development

On the basis of the archaeological sites in the Rügen area we get some more or less reliable information on former sea levels which will be summarized in the following. The problem of eustatic and isostatic uplift will not be discussed here. According to the available information the find layer of the early Ertebølle culture at Drigge in the Strelasund (c. 5,200 – 5,000 cal. B.C.) was situated in c. -5m under sea level. Because the material has been found by sand dredging this evidence has to be treated with caution. The sandy layer of the early Ertebølle culture at Lietzow-Buddelin (layer 1/2 or Buddelin A) which is now dated to > 4,800 cal. B.C. was found at maximum at present sea level. The sandy peat layer 4 (Buddelin B; c. 4,800 – 4,400 cal. B.C.) was documented from c. –0.5 m under sea level to 0.4 m above sea level (see GRAMSCH this volume). At Ralswiek-Augustenhof the „anmoor" layer of the subaquatic shore zone with the archaeological material (c. 4,300 – 4,000 cal. B.C.) was documented a few decimetre above present sea level (cf. B-3). For Prohn and Parow there are only vague information. We can expect more reliable data for the Stralsund site. The lower refuse layer which is only preliminary dated to the end of the 6th millenium cal. B.C. so far, was situated c. –2 m under sea level (kindly personal communication by P. Kaute and R. Lampe, Greifswald).

In conclusion we realize a remarkable discrepancy of the find layer positions at the Jasmunder Bodden sites and the Strelasund sites. We hope that in near future investigations of the research unit "SINCOS" supported by the Deutsche Forschungsgemeinschaft at the sites in the Rügen area will help to better understand the reasons for these differences in a distance of c. 33 km.

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Coastal evolution of the Schaabe spit and the shoreline displacement curve for Rügen Island

WALTER SCHUMACHER

The eological, stratigraphical and palaeoecological evidence collected from the „Schaabe" spit in northeast Rügen include 167 cores and about 70 radiocarbon dates resulting in a local shoreline displacement curve (SCHUMACHER, BAYERL 1997,1999a, b). Most of the radiocarbon dated profiles are supported by pollen analysis. The stratigraphical base is the master profile "Herthamoor" with 34 absolute dates from the Alleröd to the present (SCHUMACHER, ENDTMANN 2000). The palaeoecological events of Northeast Germany and their age (Tab. 1) were derived from this profile in close vicinity to the Schaabe and Tromper Wiek. The important borings and their data are shown in Figs. 1, 2 and 3 as well as the reconstruction of the shoreline displacement curve since 8,300 conv. ^{14}C-years.

Fig.1: Selected transgression and regression contacts of the borings from NE Rügen, their dating and the shoreline displacement curve for the interval of 8,000-5,000 conv. ^{14}C-years (symbols see Fig. 2)

Fig 2: Selected transgression and regression contacts of the borings from NE Rügen, their dating and the shoreline displacement curve fo rthe interval of 5,800-2,000 conv. ¹⁴C-years
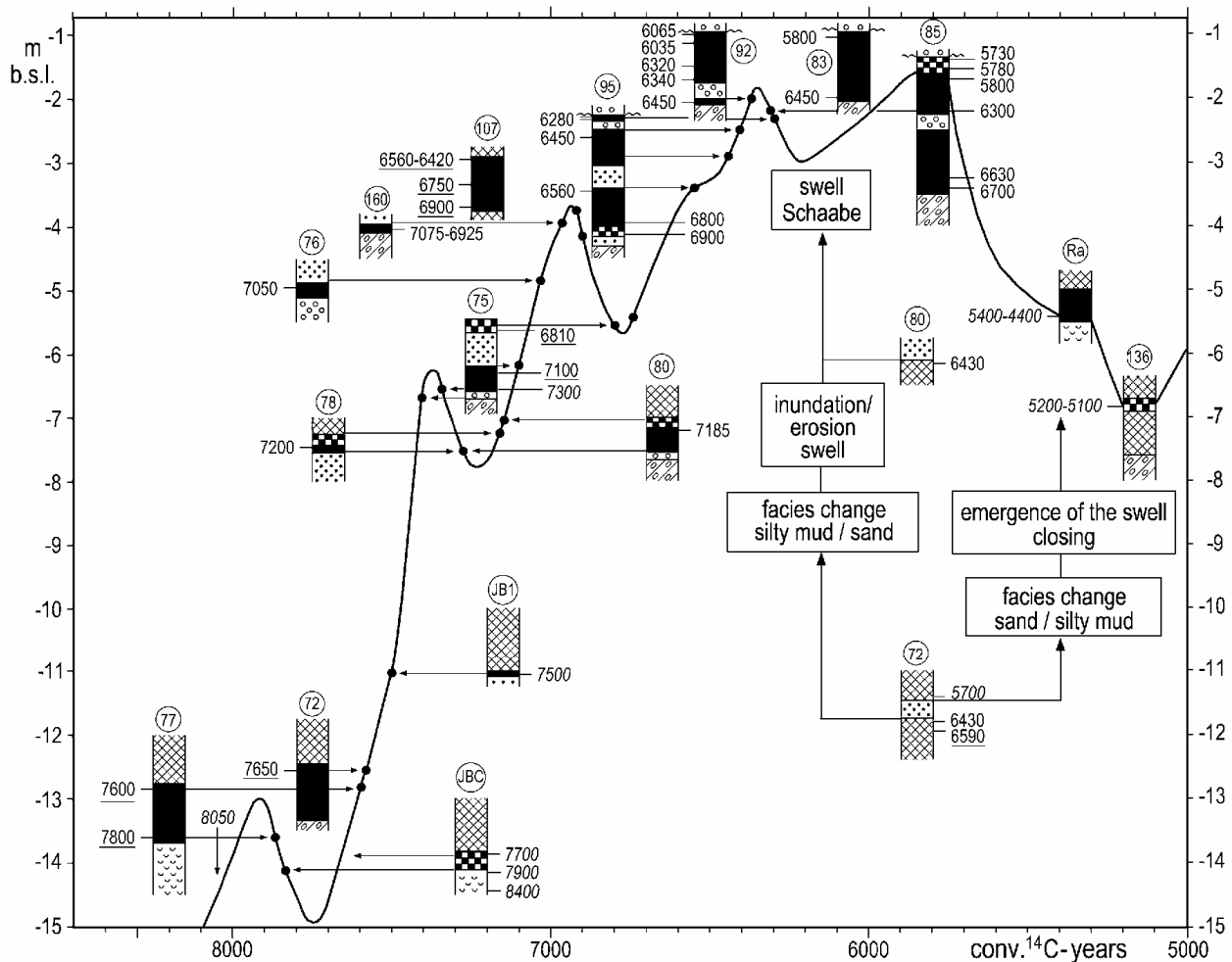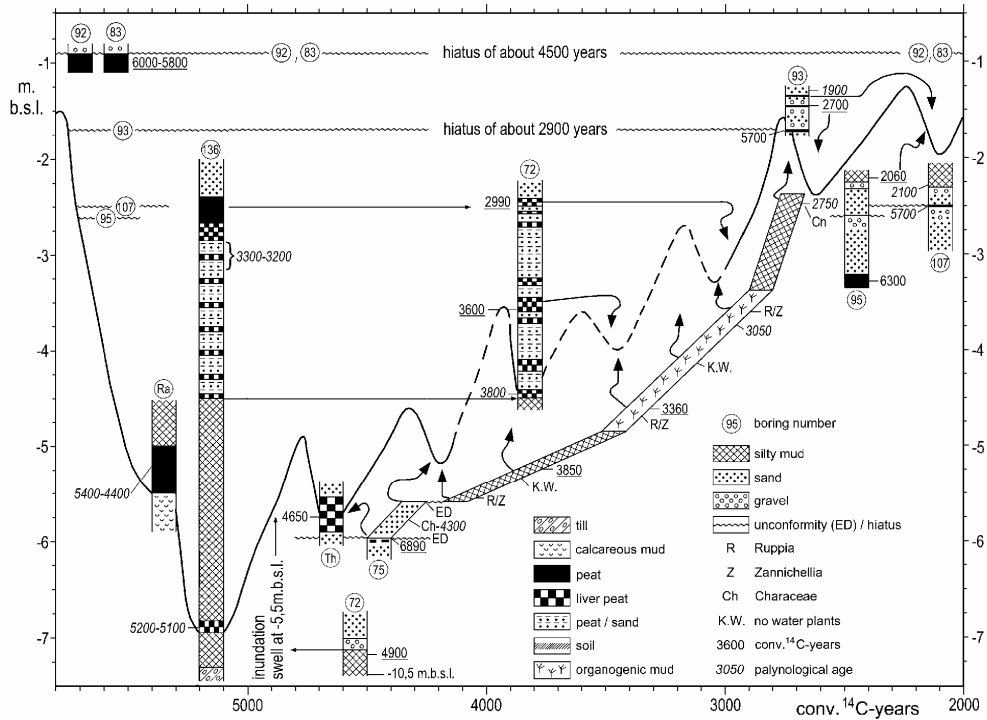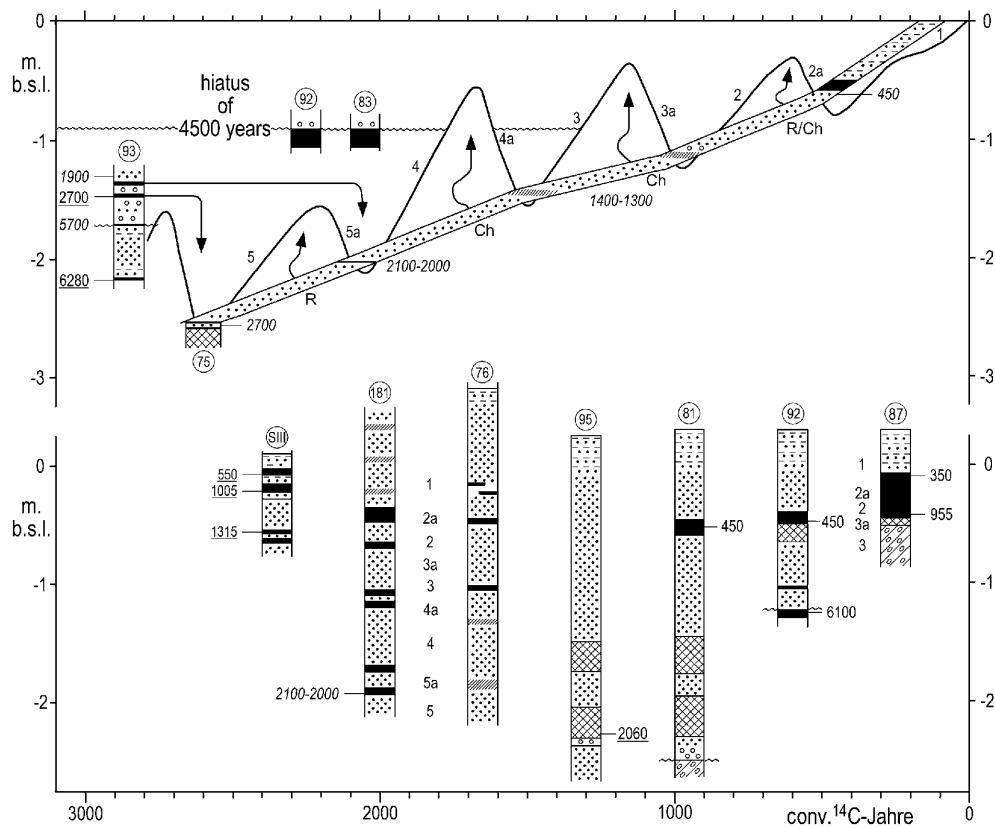

Fig. 3: Selected transgression and regression contacts of the borings from NE Rügen, their dating and the shoreline displacement curve for the interval of 3,000-0 conv. ¹⁴C-years
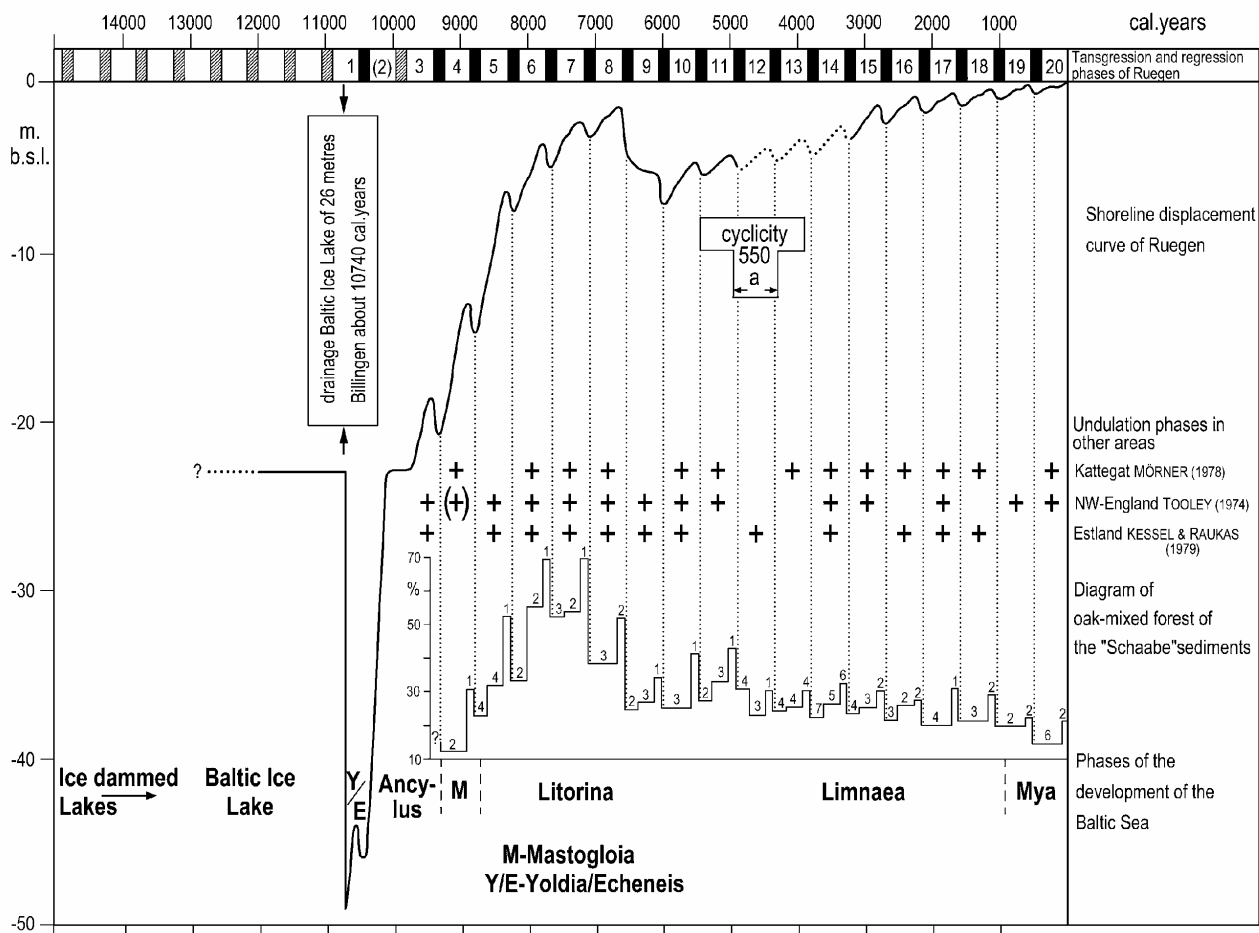
Tansgression and regression phases of Ruegen

1 (2) 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

0

m. b.s.l.

drainage Baltic Ice Lake of 26 metres Billingen about 10740 cal.years

-10

cyclicity 550 a

Shoreline displacement curve of Ruegen

-20

? ....

+ + + + + + + + + + + +
+ (+) + + + + + + + + + + + +
+ + + + + + + + + + + +

Undulation phases in other areas
Kattegat MÖRNER (1978)
NW-England TOOLEY (1974)
Estland KESSEL & RAUKAS (1979)

-30

70
%
50

30

10

Diagram of oak-mixed forest of the "Schaabe"sediments

-40

Ice dammed Lakes → Baltic Ice Lake Y/E Ancy-lus M Litorina Limnaea Mya

Phases of the development of the Baltic Sea

M-Mastogloia
Y/E-Yoldia/Echeneis

-50

Fig. 4: Shoreline displacement curve for Rügen during the last 13,000 calibrated years (cyclicity of the sea level changes over 550 years; similar changes in mixed oak forest trees derived from the littoral sediments of NE Rügen; general conformity to the phases in the Kattegat from MÖRNER (1978), in NW England from TOOLEY (1974) and in Estonia from KESSEL & RAUKAS (1979); phases of the development of the Baltic Sea)

Fig. 4 is a synthesis of all useful data concerning the shoreline displacement of Rügen in calibrated form (SCHUMACHER, ENDTMANN 2000). The older development of the Baltic Sea (in excess of 9,000 calendar years: Baltic Ice Lake, Yoldia/Echeneis, Ancylus and Mastogloia Phase) was derived from investigations in the Tromper Wiek, Arkona basin and the Pomeranian Bay (published data of LEMKE (1998), LEMKE et al. (1998), KOLP (1976,1983); GROMOLL (1994) and unpublished data of MOROS (1999) and SCHUMACHER, ENDTMANN (2000). The important results are:

1. Our date for the drainage of the Baltic Ice Lake (Mt. Billingen event) is in conformity with the Swedish varve age for this event - about 10,740 cal. years ago.
2. The marine influence of the Yoldia Phase on the coast of the southern Baltic Sea was very weak. It is difficult to identify.
3. The rise of the water level in the Ancylus Lake was about 6-7 metres per century and must be related to the uplift of the Närke Strait in central Sweden. The water level rise stopped at the level of the Darss- Sill. There is no significant evidence of an Ancylus high-level or an Ancylus regression.
4. Higher salt content can be dated in Northeast Rügen at about 8,500 cal. years. But the ocean level has controlled the level of the Baltic Sea for about 9,500 cal. years. Between 9,500 and 8,500 cal. years the change from fresh to brackish water (Mastogloia Phase?) occurred.

5. The shoreline displacement curve for Rügen is a strongly undulating curve with 17 regression and transgression phases since the connection occurred between the ocean and the Baltic Sea at about 9,500 cal. years. These phases are in general conformity with the phases in the Kattegat (MÖRNER 1978), in NW England (TOOLEY 1974) and in Estonia (KESSEL, RAUKAS 1979).

6. The span of these sea level fluctuations could be dated to about 500 to 600 years. The fluctuations must be related to world-wide climatic changes. Seventeen phases in 9,400 cal. years suggest a climatic cycle of 550 years. Cyclicity over such an interval of time is confirmed by investigations of the North Atlantic circulation pattern (CHAPMAN, SHACKLETON 2000).

7. The relation to climatic changes can be seen in the variations of mixed oak trees in the area studied. It seems that the climatic fluctuations influenced the behaviour of human beings too (Fig. 5).

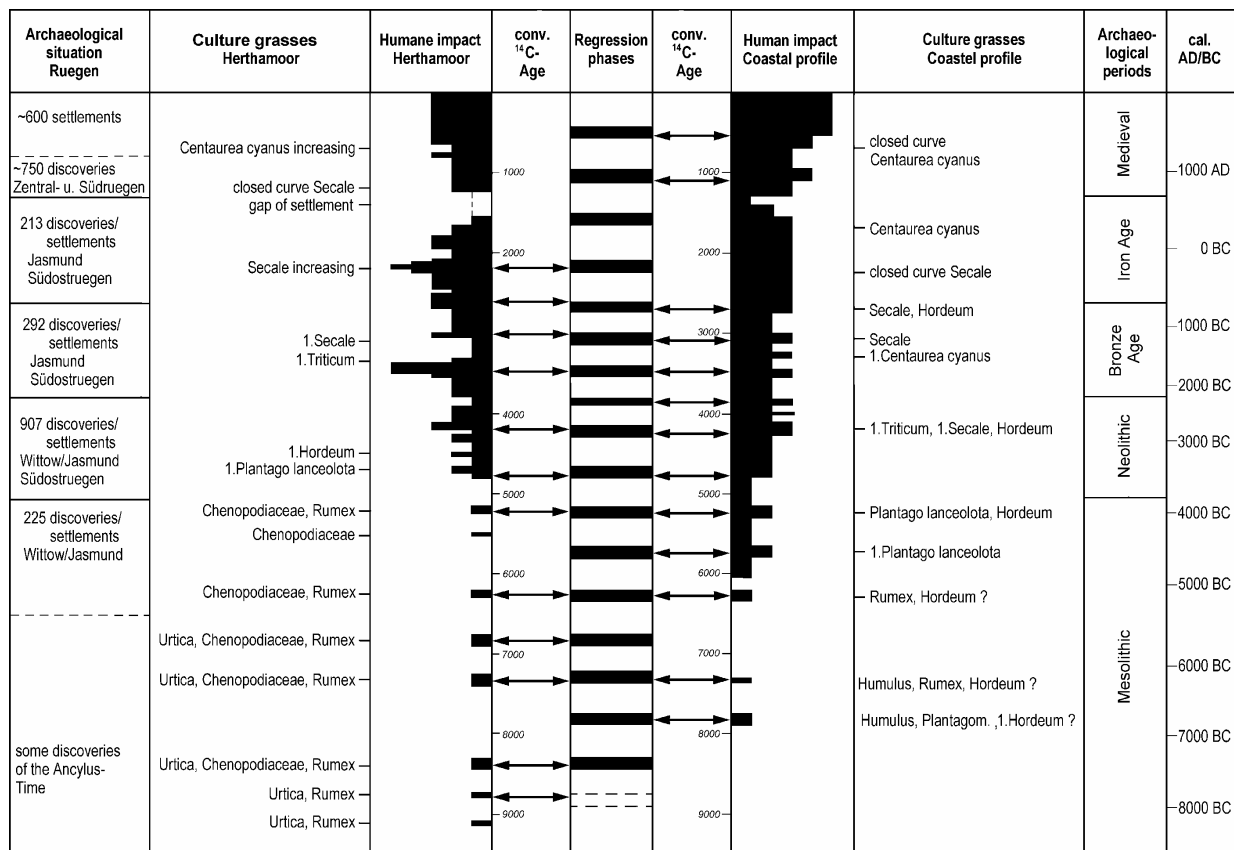| Archaeological situation Ruegen	Culture grasses Herthamoor	Humane impact Herthamoor	conv. 14C-Age	Regression phases	conv. 14C-Age	Human impact Coastal profile	Culture grasses Coastel profile	Archaeological periods	cal. AD/BC
~600 settlements	Centaurea cyanus increasing		1000		1000		closed curve Centaurea cyanus	Medieval	1000 AD
~750 discoveries Zentral- u. Südruegen	closed curve Secale								
213 discoveries/ settlements Jasmund Südostruegen	gap of settlement		2000		2000		Centaurea cyanus	Iron Age	0 BC
	Secale increasing						closed curve Secale		
292 discoveries/ settlements Jasmund Südostruegen	1.Secale 1.Triticum				3000		Secale, Hordeum	Bronze Age	1000 BC
							Secale 1.Centaurea cyanus		2000 BC
907 discoveries/ settlements Wittow/Jasmund Südostruegen	1.Hordeum 1.Plantago lanceolota		4000		4000		1.Triticum, 1.Secale, Hordeum	Neolithic	3000 BC
			5000		5000				4000 BC
225 discoveries/ settlements Wittow/Jasmund	Chenopodiaceae, Rumex Chenopodiaceae						Plantago lanceolota, Hordeum 1.Plantago lanceolota		
	Chenopodiaceae, Rumex		6000		6000		Rumex, Hordeum ?		5000 BC
	Urtica, Chenopodiaceae, Rumex		7000		7000			Mesolithic	6000 BC
	Urtica, Chenopodiaceae, Rumex						Humulus, Rumex, Hordeum ?		
			8000		8000		Humulus, Plantagom. ,1.Hordeum ?		7000 BC
some discoveries of the Ancylus-Time	Urtica, Chenopodiaceae, Rumex								
	Urtica, Rumex		9000		9000				8000 BC
	Urtica, Rumex								

Fig. 5: Relationships between regression phases and the intensity of the settlement of Rügen derived from pollen analysis of the coastal profiles and of the Herthamoor profile

The problem of this shoreline displacement curve is the strong regression from 6,800 up to 6,000 cal. years. That period is indeed known to have been a cooling phase (elm/lime decline) after the Holocene climatic optimum. But other shoreline displacement curves in the world do not show such strong regression. The comparison between the local shoreline displacement curves for Blekinge (Southeast Sweden, BERGLUND 1964) and Rügen shows the relative crustal behaviour of the two areas (Fig. 6). The behaviour is similar (2.4 metres per thousand years) from 8,000 to 6,800 and from 6,000 to 1,200 cal. years. A significant break exists between 6,800 and 6,000 cal. years. This break is interpreted as land upheaval on Rügen Island. The upheaval amounts to 8 metres. There are more indications of such an event along the whole coast of Mecklenburg - West Pomerania. However the reason, mecha-

nism and regional extension of this upheaval are not clear. It is necessary to plot new detailed local shoreline displacement curves.

Fig. 6:
Relative crustal behaviour between the coastal areas of Blekinge (Southeast Sweden) and Rügen. $S_{RÜ}$ - shoreline displacement curve for Rügen; S_{BLE} - shoreline displacement curve for Blekinge (BERGLUND 1964); I_r - relative crustal behaviour.

Fig. 7:
Holocene eustatic curve derived from the shore line displacement curve for Rügen by reduction of a tectonic uplift of 8.2 metres (solid line). Comparison with the eustatic curve from FAIRBANKS (1989, dashed line) and the sea level curve for the Netherlands from JELGERSMA (1966, dotted line).

The reduction of this uplift produces the solid curve of Fig. 7. This curve correlates very well to the eustatic curve of FAIRBANKS (1989, dashed line) and to the sea level curve of the Netherlands (JELGERSMA 1966, dotted line). In addition, the solid curve should be corrected to take account of a modern uplift in Northeast Rügen of 0.24 mm/yr (SCHUMACHER 2001).

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Quaternary development of Tromper Wiek, Rügen Island

Wolfram Lemke, Klaus Schwarzer, M. Diesing

The Tromper Wiek is a semi-enclosed headland bay situated in the north-eastern part of Rügen Island. It is exposed to the Baltic Sea towards east to north-east and extends in a south-westerly direction between the morphologically high Pleistocene areas of Jasmund and Wittow, which are connected by the Holocene spit "Schaabe" (see Fig. 1). The Tromper Wiek forms a transitional area between the onshore outcrops at Wittow, Jasmund and Schaabe and the recent mud accumulation area of the Arkona Basin. Both Jasmund and Wittow are characterised by a complicated pattern of glaciotectonically deformed Cretaceous and Pleistocene deposits (cf. B-1, B-7 this volume).
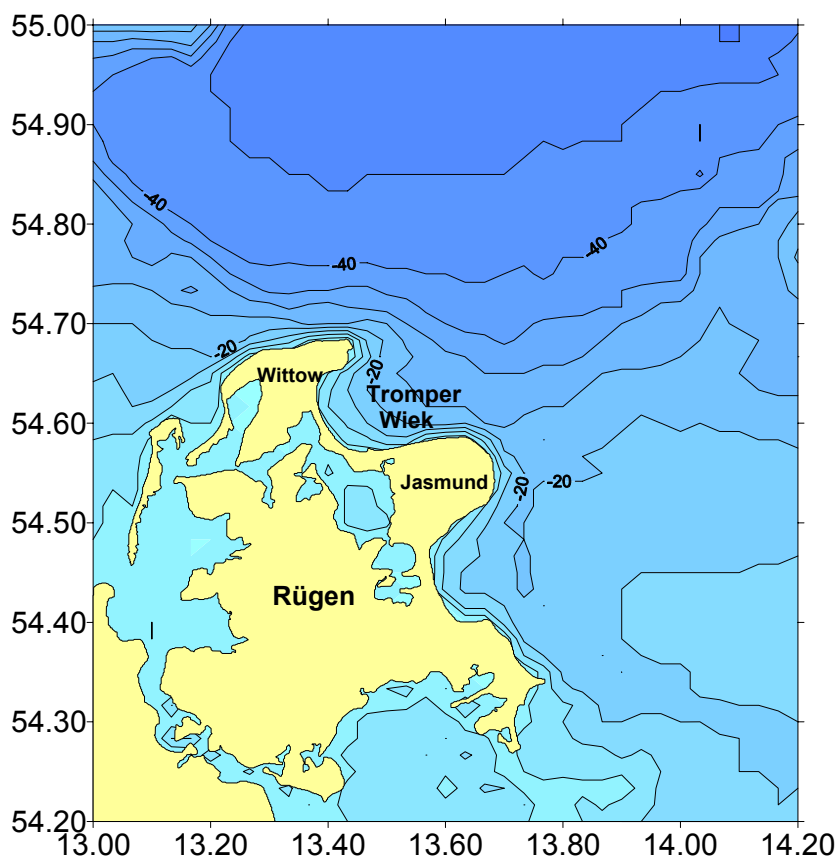
Fig. 1:
Regional setting; bathymetry according to SEIFERT & KAYSER (1995)

Between Jasmund and Wittow, which are both characterized by coastal erosion, the Holocene spit of Schaabe developed after the Littorina Transgression. Up to the early middle ages there was a navigable connection between the Tromper Wiek and the Jasmunder Bodden south of Glowe. This inlet started to close in the 12th century (DUPHORN et al. 1995). The water depth in the central part of the Tromper Wiek is in the range of 20 m below present sea level (b.s.l.). North of Jasmund there is a steep bathymetric gradient, while off the Schaabe spit the gradient is much more gentle. In the north-western part of the Tromper Wiek a steeper bathymetric gradient is found where the water depth increases from 12 m to 18 m b.s.l. over a horizontal distance of 400 m (STEPHAN et al. 1989).

PLEWE (1940) was the first to report on surficial sediment types from the Tromper Wiek. The latest results of sediment distribution patterns based on sidescan sonar data were published by SCHWARZER et al. (2000) and are shown in Fig. 2. In front of the Wittow and Jasmund cliff coasts the seafloor is covered with heterogeneous sediment comprising grain sizes from coarse sand to boulders. Small-scale patches of rippled sand are observed in these areas. This sediment type is interpreted as lag deposits caused by the selective marine abrasion of the glacial till underlying the lag deposit areas. Adjacent to these lag deposits the seafloor is covered with gravel at water depths between 8-14 m b.s.l. Prominent morphological ridges occur within the gravel fields. Observations by scuba divers revealed that the ridges are composed of well-rounded pebbles and cobbles up to 25 cm in diameter. The gravel deposits form the submarine cliff reported above. In front of the Schaabe spit fine sands are located in water depths down to 10 m b.s.l. and in excess of 14 m b.s.l. in the central part of the bay. Towards the deeper water the fine sands grade into muddy fine sands and finally (sandy) muds which form the seafloor of the Arkona Basin. They are the product of the brackish-marine environment which has prevailed in the area since the Littorina transgression.
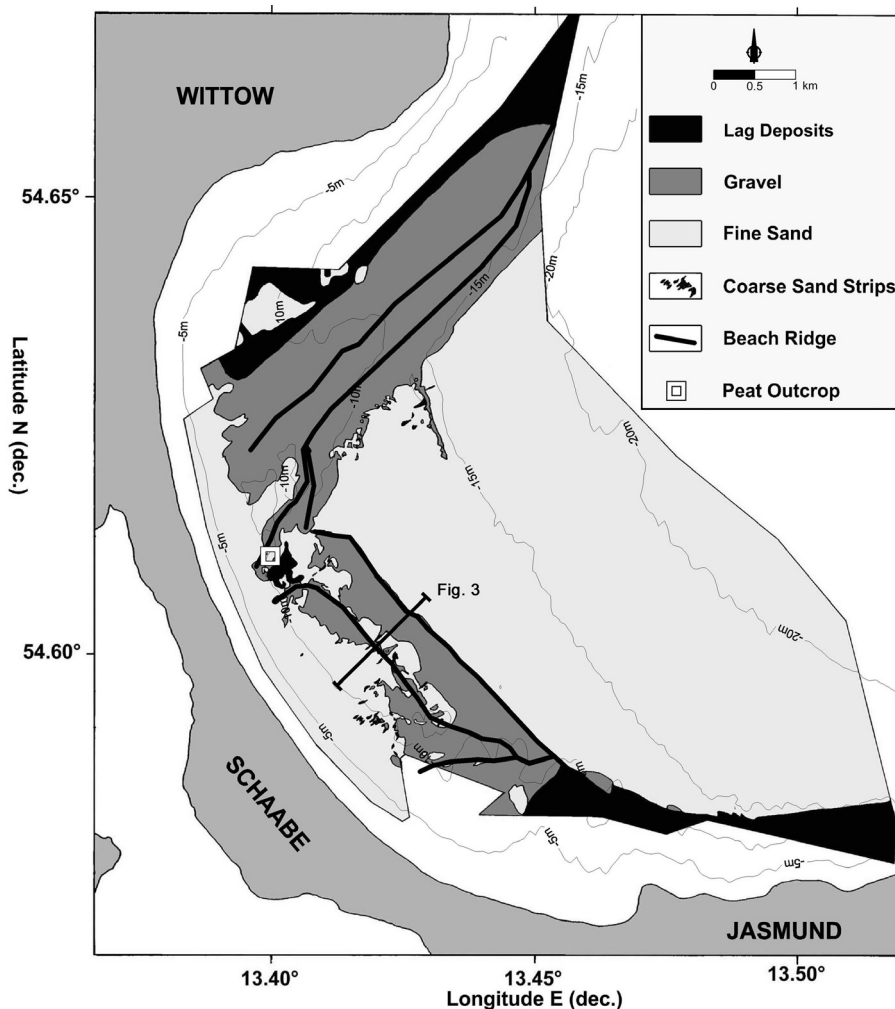
Fig. 2:
Sediment distribution patterns and location of the drowned beach ridges within the Tromper Wiek (SCHWARZER et al. 2000).

Based on the interpretation of shallow seismic sections, five seismo-stratigraphic units have been identified (Fig. 3, 4). Following JENSEN (1992), JENSEN & STECHER (1992) and JENSEN et al. (1997, 1999) they are called E1 to E5. For further details see LEMKE et al. (1998).
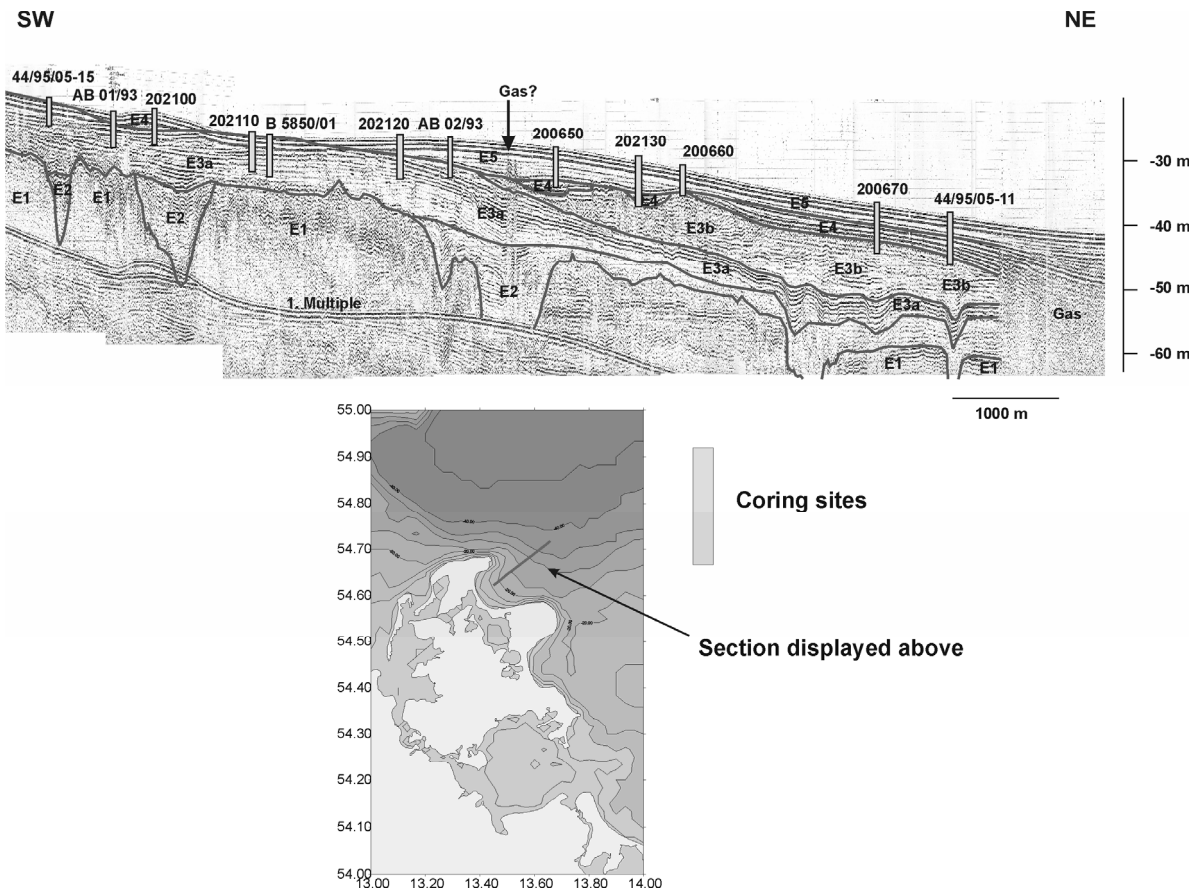
Fig. 3: Interpreted boomer section with seismo-stratigraphic units according to JENSEN (1992) (LEMKE, 1998)
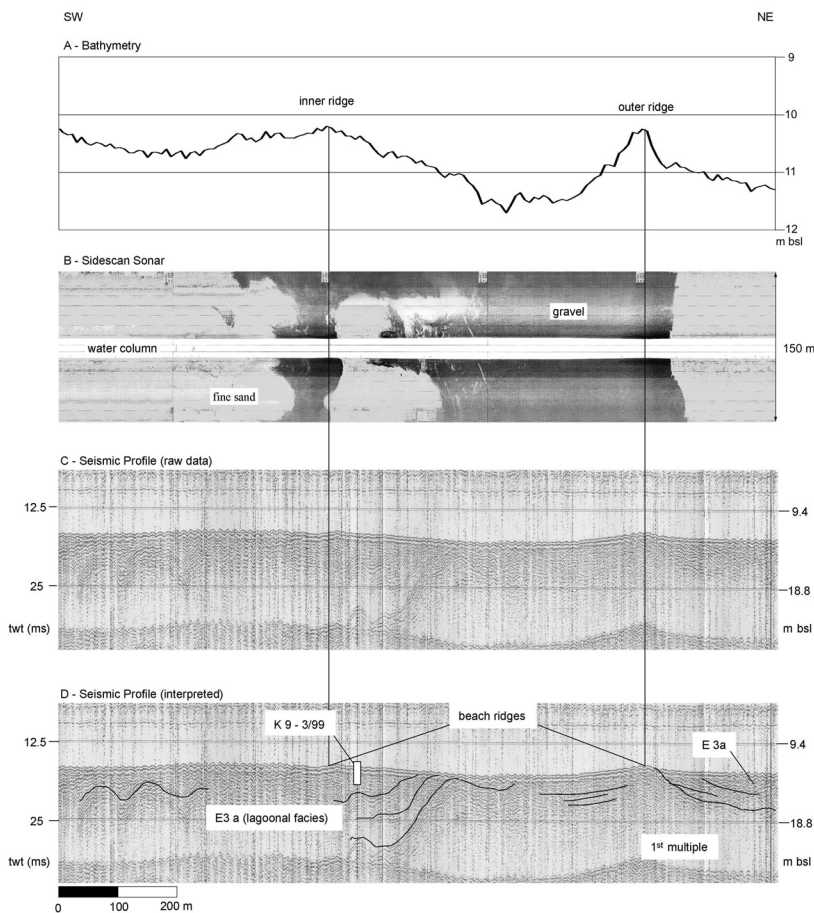

Fig. 4:
Seismic profile TW5-3/97 (for locations see Fig. 2)
A: In the morphological pro-file two ridges are visible
B: The sidescan sonar image shows that the morpho-logical ridges are built up by gravel deposits
C: Boomer profile without interpretation
D: Interpreted seismic profile: The outer beach ridge and an associated lagoon are clearly visible. The inner beach ridge is located on top of lagoonal deposits. Sediments of sequence E3a terminate onlap on the beach ridge.
(SCHWARZER et al. 2000)

Unit E1

The till is defined as unit E1 regardless of its stratigraphic position. Generally it is grey, partly clayey with numerous chalk fragments. It crops out in many places near the coast line and is usually overlain by thin lag deposits as described above. Towards the central part of the Tromper Wiek its surface dips steeply, reaching a level of more than 40 m b.s.l.

Unit E2

In the nearshore area the till surface exhibits irregular morphology with deeply incised channels. The fillings of these channels show parallel to wavy reflections in the seismic record. These fillings grade upwards into a widespread complex which has a distinct boundary with the overlying Unit E3. The thickness of the E2 deposits varies between 0 and 15 m. Their seismic facies suggests that they may consist of silty to sandy material. However, because of their depth below the sea bottom no coring of these deposits was possible.

Unit E3

The boundary between units E2 and E3 is marked by a major inconformity. Unit E3 is bipartite in the Tromper Wiek. The older of the two sub-units (unit E3a) consists of up to 12 m thick silt. The upper unit comprises olive grey, fine laminated silts with a high carbonate content usually containing small plant remains as well as remains of freshwater fauna. Ostracods like *Limnocythere sp.* and *Cytherissa lacustris* point to a larger freshwater lake. In their upper part AMS ^{14}C-ages of 10,100 ± 120 and 10,570 ± 150 years BP were obtained on reworked rootlets of terrestrial plants (lab. no. AAR 1921 and AAR 1920). In the seismic records the sub-unit shows distinct parallel internal reflections. Both the upper and lower boundaries of the sub-unit are discordant. Locally, the sediments of sub-unit E3a form the present-day sea floor. Sub-unit E3b is superposed on sub-unit E3a in the deeper part of the Tromper Wiek discordantly, wedging out at a depth of 35 m b.s.l. This unit is up to 10 m thick, shows subparallel to irregular internal seismic reflections and a discordant upper boundary. Lithologically, sub-unit E3b, which is accessible at least in the upper regions by vibrocoring, consists of silty fine sands. The transition from the marginal to the basinal facies of units E2 and E3 could not be observed in the seismic records due to gas enrichment in the overlying sediments.

Unit E4

Unit E4 is not present everywhere in the Tromper Wiek. In the inner part of the bay it occurs in isolated localities with a thickness up to 4 m. Further north-east extensive E4 deposits with similar thickness are found. Here, they turn into the well known grey silts and clays of the Arkona Basin (NEUMANN 1981). Below 32 m b.s.l. unit E4 is represented mainly by grey silts with admixtures of humous material. In some of the cores, which encountered unit E4 at this depth, brown peat gyttjas are found. The marginal facies of unit E4 was discovered in an isolated occurrence in the central part of the Tromper Wiek. Here, on top of the silty sub-unit E3 a peat was dated by conventional ^{14}C to 9,590 ± 140 years BP (lab. no. K 6339). This sedge peat contains numerous rootlets, seeds of *Menyanthes trifoliata* and fruits of *Carex*. Directly on top of the peat layer fragments of *Phragmites* are found. The peat is overlain by well-sorted fine sand which contains numerous chitinuous shells and head shields of *Cladoceras* and some cocoons of *Piscicola geometra* in its lower part. The upper part of the sand is barren with no indication of any marine influence.

Unit E5

Below 25 m b.s.l. deposits of unit E5 are widespread. They consist of olive grey sandy muds and muddy units with thin silty intercalations and some remains of marine shells. The thickness of unit E5 increases to more than 5 m in a clearly distinguishable SE-NW striking structure at the northeastern margin of the Tromper Wiek. Towards the Arkona Basin the thick-

ness of E5 is more than 10 m. In accordance with increasing water depth and thickness, the E5-muds contain an increasing amount of gas. This is evident by audible degassing of sediment cores. Furthermore, the high gas content results in a substantial attenuation of the seismo-acoustic signals with no reflections back from the subsurface. An example of this can be seen in the north-eastern part of the seismic section in Fig. 3. Another mud occurrence with a thickness of up to 3 m is found directly north of Jasmund.

Using these new dates, the sequence-stratigraphic units described above may be assigned to specific evolutionary stages of the Baltic Sea. The results are not completely satisfactory, however, for units E1 and E2. The stratigraphic position of the uppermost till referred to as E1 is not known for reasons described above. According to STEINICH (1992) it might be stated that it is a deposit of the last Weichselian glaciation.

Unit E2 is outside the range of the available sampling devices. According to its position in the stratigraphic succession, and its morphological and seismo-acoustical features, it might be correlated with unit 2 in the Faxe Bay north of Møn island (JENSEN 1992). Unit E2 is interpreted as a glacio-lacustrine sequence formed immediately after the final deglaciation of the area investigated. The deposits of sub-unit E3a clearly dip towards the Arkona Basin. Considering their depth from the transition area to the basin, they are expected to correspond to the late glacial clays of the Arkona Basin described by NEUMANN (1981). Thus, they are regarded as the products of sedimentation processes in the Baltic Ice Lake. The dates reported above indicate a Younger Dryas age, i.e. at least the upper part of unit E3 was formed in the Late Baltic Ice Lake. According to JENSEN (1992), LEMKE et al. (1997) and JENSEN et al. (1997), the final phase of the Baltic Ice Lake was characterised by a transgression in its southern part. JENSEN (1992) reported a water level of the Baltic Ice Lake in the Faxe Bay in the range of 13-15 m b.s.l. before its final drainage. Results of SCHWARZER et al. (2000) show that unit E3a extends up to a water depth of 9 m b.s.l. (see Figs. 2 and 4) where an associated beach ridge - lagoon system was detected. This level is considerably higher than that reported before by LEMKE et al. (1998). SCHWARZER et al. (2000) interpret this difference in connection with the results of SCHUMACHER & BAYERL (1999), who found indications of an additional uplift in the range of 6 m between 7,000 and 5,000 years BP for Rügen Island. Taking this into account, the maximum water level of the Baltic Ice Lake during its final transgression was around 13-14 m b.s.l. which corresponds to the level of Faxe Bay as reported by JENSEN (1992). In turn this would mean that no differential isostatic rebound between these two areas existed from the early Holocene onwards.

The facies of this sub-unit is distinctly different from the distal clays of the Arkona Basin and sandy deposits of the same age further to the west. The reasons for these differences are a more proximal position of the Tromper Wiek compared to the basin and a larger distance from the main sediment source areas in relation to the Darss Sill area.

Sub-unit E3b is interpreted to be either of fluvial or coastal origin because of its facies characteristics. It was deposited near the early Holocene Oder valley mouth at a time when the sea level in the Arkona Basin was extremely deep. Such a deep base level was only possible immediately after the final drainage of the Baltic Ice Lake. BJÖRCK (1995) showed that the water level drop after this drainage was about 25 m. This order of magnitude agrees with the data presented here. A highlevel of the Baltic Ice Lake at about 15 m b.s.l. corresponds to a water level of 45 m b.s.l. after its drainage. The base of sub-unit E3b is in the range of 50 m b.s.l. and corresponds to the surface of the late glacial clays in the Arkona Basin. If the water level in the Arkona Basin had been lower than 50 m b.s.l. for a substantial time span, erosional features in the clays would be expected, especially in the area between Cape Arkona and Born-

holmsgat. Their absence points to an early Holocene water level between 45 and 50 m b.s.l. in the Arkona Basin.

On account of their facies and fossil content, the sediments of unit E4 are regarded as freshwater lake deposits. Their position in the stratigraphic succession and the available data relate them to the development of the Ancylus Lake. The isolated sands in the central part of the Tromper Wiek are interpreted as representing nearshore deposits accumulated during the maximum height of the Ancylus Lake. Therefore, the height of the level is assumed to have been about 18 - 20 m b.s.l. This is in good agreement with the data of JENSEN et al. (1999), LEMKE et al. (1997) and LEMKE (1998) which indicate a similar level of the Ancylus Lake for the Mecklenburg Bay. The subsequent regressive phase of the Ancylus Lake is reflected by the incomplete record of E4-deposits down to a level of 32 m b.s.l. E4-sediments are widely distributed only below this level. This is possibly an indication of the Ancylus lake level in the area east of the Darss Sill after its maximum height. Preserved peat gyttja deposits at 30.5 m b.s.l. in a submarine valley northwest of Hiddensee island, which have been dated to 9,150 ± 135 years BP (lab. no. K 6342), support this assumption. KOLP (1986) also concludes a water level of 32 m b.s.l. at that time. NIELSEN et al. (subm.) provided evidence for a lowstand sand wedge that developed south-east of the Rønne Bank – Adler Ground shoal, corresponding to the low level after the Ancylus Lake's regression. According to KOLP (1986), this level was controlled by the Dana river draining the Ancylus Lake via the area between the Mecklenburg Bay and the Arkona Basin, the Fehmarn Belt and the Great Belt to the Kattegat. This concept would require a channel incised in the sand area between the Mecklenburg Bay and the Arkona Basin at a level of at least 32 m b.s.l. However, as reported by LEMKE et al. (1999) and JENSEN et al. (1999), such a channel does not exist in the predicted area east of the Darss Sill. Considering that there was no further major pre-Littorina transgression, it has to be concluded that another connection between the Ancylus Lake and the Kattegat is likely to have existed elsewhere.

The partly sandy muds of unit E5 are typical deposits of the post-Littorina brackish marine Baltic Sea. Their coarser grain sizes in comparison to the muds of the Arkona Basin are due to their more proximal position. The remarkable increase in thickness at the northeastern edge of the Tromper Wiek might be a result of (sub-)recent hydrodynamic processes. The increased mud thickness north of Jasmund is correlated with the palaeo-connection between the Tromper Wiek and the Großer Jasmunder Bodden (see DUPHORN et al. 1995). The E-W-striking zone of increased mud thickness might be regarded as a continuation of the ancient inlet at the southeastern end of the Schaabe spit.

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The Jasmund cliff section

HILMAR H. SCHNICK

The impressive and famous Rügen chalk cliff is located along the eastern coast of the Jasmund peninsula. The approximately 12 km long cliff section is the longest and with 118 m on top of the Königsstuhl the highest in Mecklenburg-Vorpommern, as well as the largest geological exposure of north Germany. Not only the Cretaceous chalk, its palaeontology and sedimentology, but also the Pleistocene sediments and the deformation have been the subject of scientific investigations for about two hundred years. Today, the Rügen chalk coast and the 500 m broad strip of the shallow water zone belong to the Jasmund National Park serving the general purpose to protect natural processes from human impacts. This offers the possibility to study the natural development of an extremely exposed Baltic coast including abrasion processes, sedimentary dynamics, and biological responses. A short excursion can not cover all aspects of the Jasmund geology but it will focus on (1.) The Rügen Chalk; (2.) The Quarternary Sediments; and (3.) Some aspects of the coastal dynamics. The southern chalk coast cliff, 2.5 km between Sassnitz and the prospect "Ernst-Moritz-Arndt-Sicht", was selected for the excursion to introduce into the genesis of the Jasmund peninsula.

The Rügen Chalk

Rügen is an important type locality of the European Lower Maastrichtian (Upper Cretaceous, Fig. 1) in pelagic sedimentary facies. Approximately 1.400 fossil plant and animal species are known from the chalk sequence (NESTLER 2002, REICH & FRENZEL 2002).
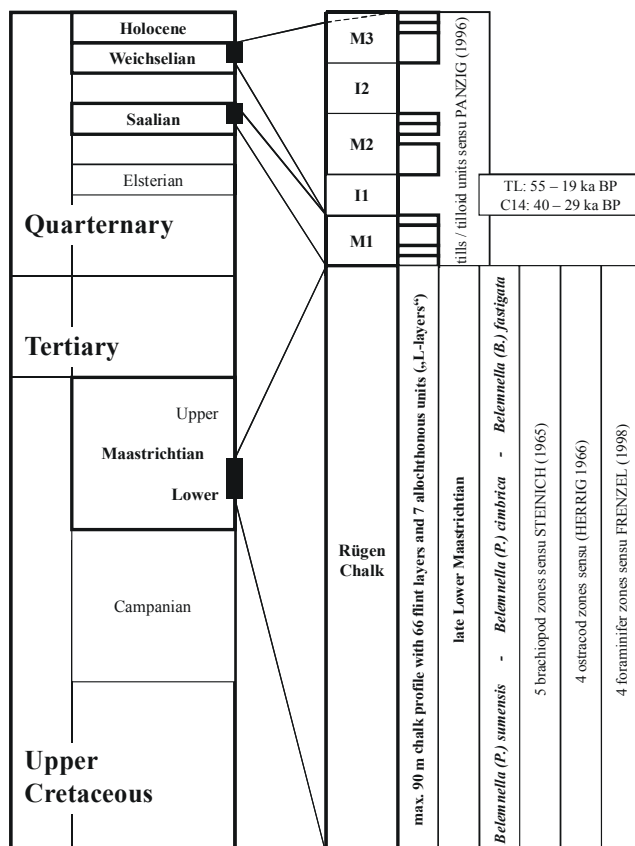

Fig. 1:
Stratigraphic correlation of the Jasmund sediments after PANZIG (1996) and REICH & FRENZEL (2002)

The Rügen chalk is a soft, weakly cemented biomicritic mudstone to wakestone and occasionally a floatstone (according to DUNHAMS extended classification by EMBRY & KLOVAN 1971). The major fraction of the chalk consists of microscopic, low-Mg-calcite skeletons of pelagic coccolithophorids (coccoliths). In addition there are varying amounts of other carbonate skeletons and skeletal debris. Planctonic foraminifers and calcispheres are other particles of pelagic origin. The total amount of benthic fossils is relatively low, important fossil groups are bryozoans, benthic foraminifers, echinoderms, brachiopods and molluscs. Representatives of the fossil nekton are belemnites, ammonites and nautilids as well as fishes and rare reptiles. The preservation of fossils mainly depends on its original mineral composition (calcitic, aragonitic, composite calcitic/aragonitic, siliceous, organic, Ca-phosphatic) and on the rather high compaction rate. Because of the diagenetic overprint only the calcitic components, i.e. echinoderms, foraminifers, ostracodes etc., are preserved in an excellent state, i.e. only with a low degree of calcitic cementation. Most of the aragonitic and siliceous skeletons or skeletal parts had been dissolved diagenetically or substituted by other minerals. The amount of non-carbonate minerals in the chalk varies between 2 and 5 % (MÜNZBERGER 1997, cit. in REICH, FRENZEL 2002).

Black flint concretions are very common in the chalk consisting of micro- to kryptocrystalline quartz. Several types of predominant early diagenetic flint have to be distinguished:
(1.) Flint nodules of the horizontal flint layers sometimes representing silicified decapodan burrow systems (trace fossil genus *Thalassinoides*). The degree of silification in such layers varies from isolated single-nodules to networks and massive plates of flint.
(2.) Flint as internal silification of bigger fossils (echinoids, bivalves, sponges) outside the flint layers.
(3.) Cylindrical paramoudra flints (local term: "Sassnitz flowerpot"): The vertically orientated trace fossil *Bathichnus paramudrae* typically occurs in unsilicified chalk but is encircled by the ring-like paramoudra flint concretion.
(4.) Flint fillings of non-horizontal fissures.

The Rügen Chalk was deposited as pelagic shelf sediment under moderately warm but non-tropical conditions in the intracratonic Danish Polish Basin. That was situated in the central part of a sea way between Britain and south-east Europe. The sediment composition reflects the high productivity of the calcareous plankton and the reduced terrigenous influx caused by the extreme high sea-level stands during the Maastrichtian stage. Sedimentation took place below storm wave base and below the photic zone at a bathymetrical position deeper than 100 m.

The Rügen chalk profile comprises authochthonous as well as allochthonous units recognized by STEINICH (1972). Ichnofabrics of some layers document intervals of non-sedimentation (omission). Truly pelagic autochtonous chalk contains a complex, tiered ichnofabric that is undisturbed by transport processes. The Rügen chalk ichnocoenoses are dominated by the ichnogenera *Thallasinoides*, *Zoophycos*, *Chondrites*, *Planolithes* and *Thaenidium*.

During the deposition of the Rügen chalk superficial sheets of bioturbated, pelagic ooze had been mobilized prior to final lithification and redeposited as allochthonous units. Several of such "avalanche-like" redeposited layers of up to several metres thickness exist in the profile. Most of them can be traced in the same stratigraphical level over a distance of several kilometres. The final textures and fabrics depending upon the thickness of the layer (destructive overprint by bioturbation), the degree of firmness (dewatering) of the initial sediment,

its fluidization (rewatering) under transport, and removal of fines, which is largely controlled by the distance and speed of travel (BROMLEY, EKDALE 1987). Generally chalk clasts as well as concentrations of bigger fossil skeletons characterize the proximal parts of these units. Its basal contact is sharp and erosive. Underneath the distal parts there is a non-erosive contact and an impregnation of the basal chalk by fine disperse pyrite. Another type of allochthonous units are slumps indicated by plastic deformation of flint layers and trace fossils.

The Quarternary Sediments
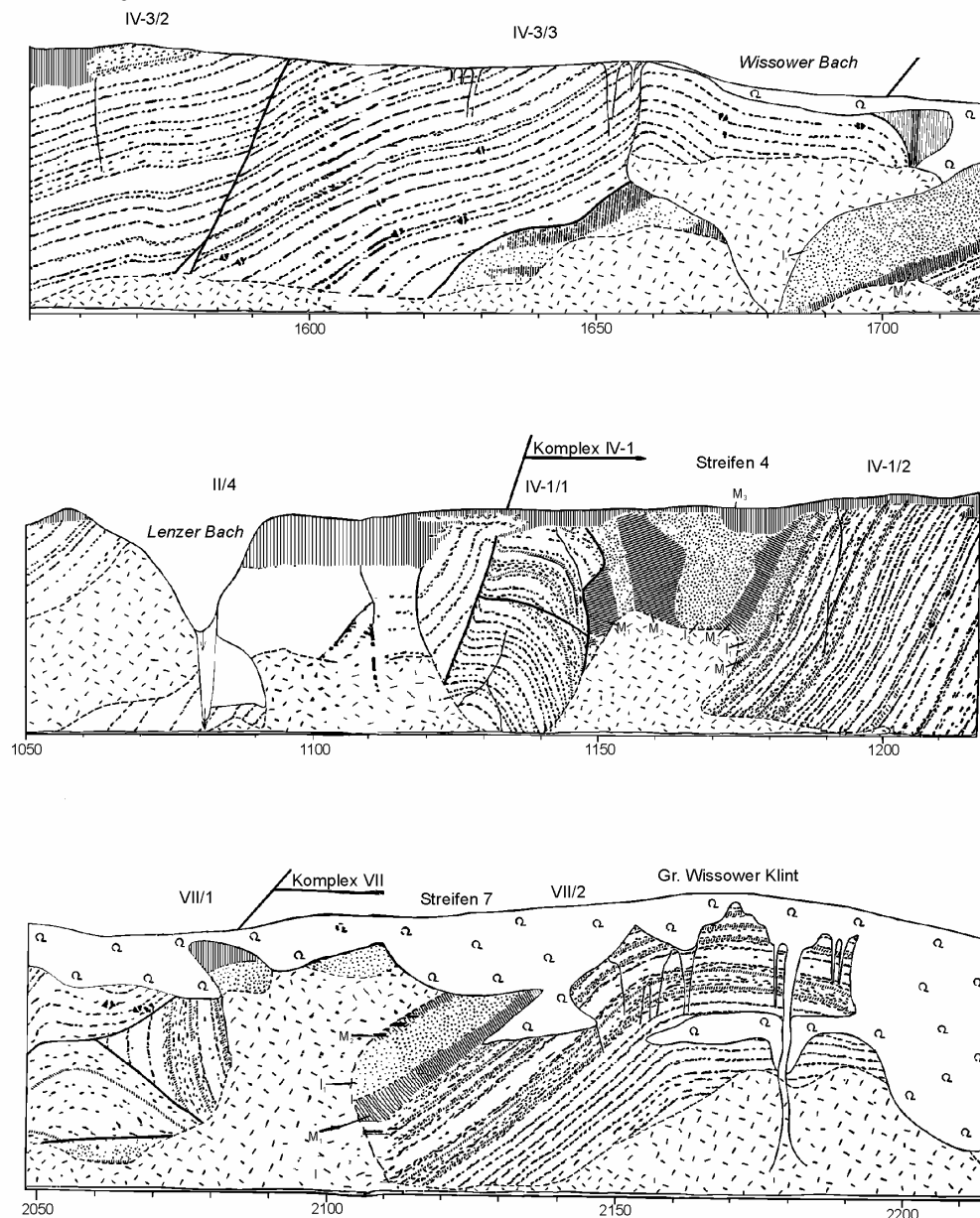
Fig. 2: Tectonically preformed units of Maastrichtian chalk carrying a sequence of quasi-concordant Saalian M1 sediments and Weichselian I1, M2 and I2 sediments had been deformed glaciotectonically. Now, these units represent inclined synclines with overthrusted upper limbs. M1- to I2-sediments are preserved only in the cores of the synclines. The Weichselian M3-sequence is absent locally due to soliflucction (after STEINICH 1972, simplified).

The Rügen-typical chalk coast is developed in the excursion area north of Sassnitz: steep chalk cliffs alternating with more shallow inclined slopes that are covered with vegetation. This superficial pattern is produced by the alternating of Maastrichtian chalk ("chalk complexes") and Pleistocene sediments ("Pleistocene strips"). KEILHACK (1912) first counted and numbered these units starting from Sassnitz to enable the discussion of the complicated geology. Detailed mapping, sedimentological and stratigraphical investigations especially of LUDWIG (1954/55), STEINICH (1972, cf. Fig. 2, 1992) and PANZIG (1995) had been necessary to interpret the cliff sections. These display the internal structure of the two basic units: the lower glaciotectonic complex and above a discordance the upper covering sediments. The lower glaciotectonic complex consists of more or less intensive deformed and displaced thrust sheets. Generally these comprise Maastrichtian chalk in the stratigraphically lower part and a succession of older Pleistocene sediments on top of the chalk, i.e. the "classical" till-sequences "M1" (Saalian) and "M2" (Weichselian), and the inter-till-sediments "I1" and "I2" (Weichselian) containing sands, gravel, silt and clay. Tertiary sediments do not occur in between. As second unit the upper diamicton sheet "M3" (Weichselian) covers the lower glaciotectonic complex. Because of intensive solifluction it is not present in steep top areas. More than 100, down to 20 m deep depressions on top of the East Jasmund plateau are filled with organic sediments representing nearly the whole postglacial development (LANGE et al. 1986, STRAHL 1999, ENDTMANN 2002). Holocene travertine is formed in springs of the cliff area having a maximum thickness of 2 m.

Some aspects of the coastal dynamics

The 5 km broad sea floor between the eastern Jasmund cliff and the erosional valley produced by the Oder (Odra) river during Latest Pleistocene / Early Holocene is a shallow inclined ramp. It was formed by marine abrasion processes since the *Littorina*-transgression (7,500 – 5,000 years BP). The Recent sediment dynamics is controlled by the exposed position of Jasmund in the Baltic Sea.

The abrasion rate of the cliff varies significantly between a few centimetres and several meters per year depending on the sediment composition, the degree of glaciotectonic deformation, the steepness of the cliff and the local water supply. For example, the shape of the Königsstuhl has not changed significantly compared with the 200 years old, excellent drawings of Caspar David Friedrich. On the other hand, occasionally, landslide events produce abrasion of several dekametres. In this case giant amounts of water saturated sediments breaking down to the beach and flowing up to 100 m into the sea where the material is reworked in turbulent shallow water by storm weaves, storm-induced currents and pack ice. A pavement of flint nodules and erratic boulders forms a residual layer that is the substrate of a epifaunal hard- and shellground assemblage dominated by the epi-byssate bivalve *Mytilus edulis* and different algae. The amount of gravel and sand increases with the water depth. In deeper regions these sediments cover the boulder pavement forming shoals and large ripples up to several decimetres height above the sea floor. Sedimentary structures as well as erosional channels cutting down into the chalk basement document events of storm-generated erosion and sediment transport down to water depths of at least 18 m.

In the mid 19th century the chalk was quarried and shipped directly at the cliff by the famous Pomeranian naturalist Friedrich von HAGENOW for the production of whiting. In 1929 quarrying was forbidden there and goes now in the hinterland of Sassnitz.

The construction of the Sassnitz port began in 1889. It became necessary to get a starting point for the regular ship and train-ferry-traffic to the Swedish Trelleborg that was established in 1897 and in 1909 respectively, and to serve as a storm protection for the local fishing boats. In 1912 the mole was finished having a length of 1.450 meters. According to the great demand for rock material Jasmund fishermen supplied boulders from the beaches and the shallow waters around Sassnitz. Very soon vessels from the whole Pomeranian coast and even from Danzig came to Sassnitz to participate in the lucrative business. They used special cranes and pincer facilities to obtain boulders from deeper sites off the coast. In this time it became obvious that the boulders had been very important in the coastal balance as natural wave breakers. Within a very short time the abrasion increased dramatically. At some places a broad beach had been lost completely. Therefore, in a first reaction the government prohibited the removal of boulders from the sea floor shallower than two meters. Furthermore artificial mole-like wave breakers were built north of Sassnitz parallel to the coast line (KOCH 1934).

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The Late glacial/Holocene evolution of a barrier spit and related lagoonary waters – Schmale Heide, Kleiner Jasmunder Bodden and Schmachter See

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HINRICH MEYER, GÖSTA HOFFMANN

The Kleiner Jasmunder and the Schmachter See, in the Late glacial and Early Holocene both single fresh waters became open marine bays in the course of the Littorina transgression and were cut-off from the Baltic by the barrier spit Schmale Heide (Figs. 1, 2, 3) due to longshore transport processes. The study of their sedimentary sequences by means of drillings, palaeoecological investigations and GPR - measurements reveals new insights concerning the stratigraphy, facies architecture and coastal process rates. Altogether eight new boreholes have been drilled, which – together with older data – enables us to reconstruct the evolution of the barrier more detailed.
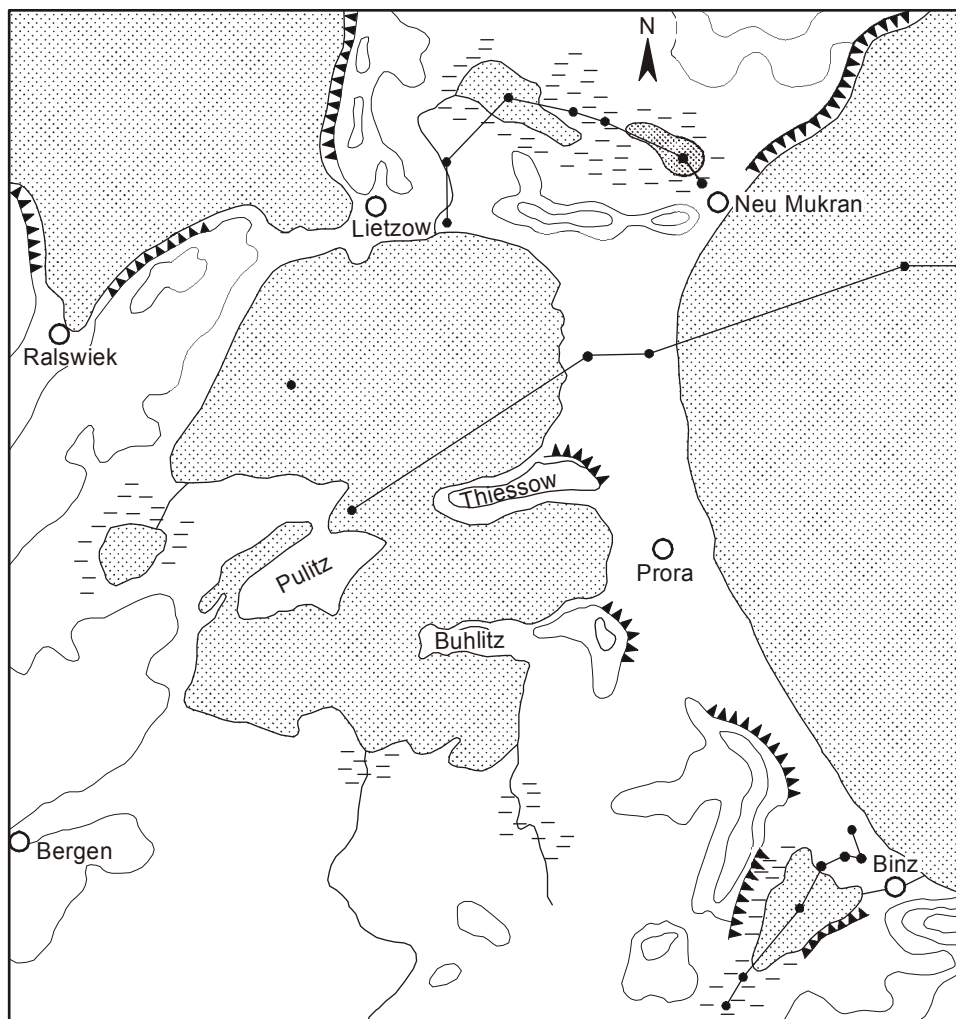
Fig. 1: Geographic setting and location of profile lines
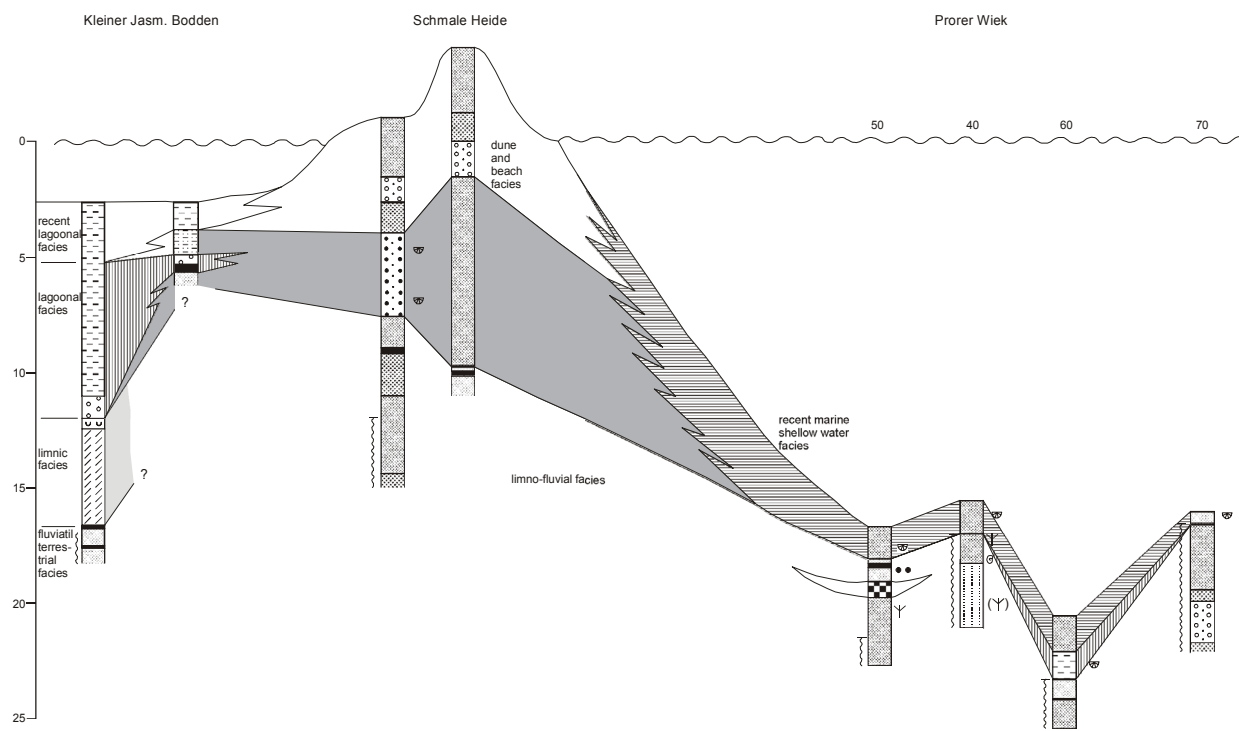
Fig. 2: Geological cross section from the Kleiner Jasmunder Bodden to the Prora Bight
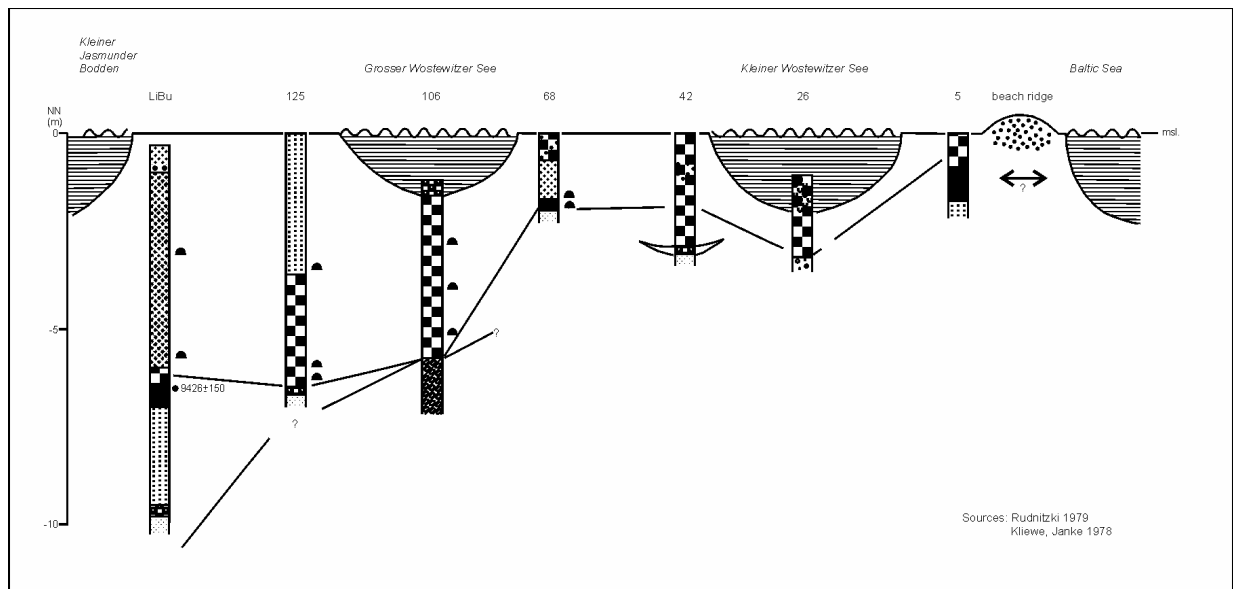
Fig. 3: Geological cross section from the Kleiner Jasmunder Bodden to the Wostewitz Lakes

Pollen and diatom analyses of two sediment cores from the Kleiner Jasmunder Bodden

The pollen and diatom diagrams of the boreholes KJB2a and KJB3 (Figs 4, 5) differ due to different location in the water and varying length of the profiles. Whereas KJB3 depicts the entire period from the Late Glacial *Hippophae* phase (Meiendorf Interstadial) to modern times, the spectrum of KJB2a comprises only the period from the Early Atlantic until the early Subboreal. The muddy sediments of these periods comprise only 97cm. Sediments from the later Subboreal and Subatlantic were not deposited.

In the profile KJB3, the upper boundary of the basin clay at 968cm corresponds to the Late Glacial/Holocene transition. At the end of a hiatus, a calcareous mud follows (968-930 cm), which was deposited in the period from the Younger Boreal until the Early Atlantic. After a water-level fall, the lake marl was replaced by an organic mud (930-875 cm) which corresponds palynologically to the very Early Atlantic (alder forest, rich in *Polypodiaceae*, high *Pinus* values). Between 875 and 865 cm the transition from a limnic to a marine evolution occurred at about 7,000 BP, characterized mainly by a strongly decreasing complete-*Pinus* curve, a slight decrease of the AP-percentage and the onset of permanent *Artemisia* and *Chenopodiaceae* curves.

The mud sediment, 875 cm thick, can be divided into three sections. At about 560 cm the transition between Atlantic/Subboreal (5,000 BP) is located, palynologically characterized by the onset of permanent *Fagus* and *Carpinus* curves as well as by the *Ulmus* decline. Particularly striking is the transition IXb/Ixc at a depth of 195 cm (about 1250 AD), which coincides with the onset of the German Colonization. This transition also demonstrates the time, when the Kleiner Jasmunder Bodden was cut off from the open Baltic, and the environmental changes which were the results of this process. Among the most important parameters emphasizing these changes are the decrease of *Operculodinium centrocarpum* and a rapid increase in *Pediastrum* and *Botryococcus* and the re-advance of the complete-*Pinus* curve at the same time.

From the point of view of diatom analysis, the marine section of the core depicts 8 stages, whereby one has to consider that the content of brackish water diatoms in the calcareous mud and in the organomud must be explained by infiltration and re-deposition. Furthermore, it must be emphasized that only the most robust species, which have resisted Si-solution and mechanical stress, have been preserved.

0 - 80 cm	predominance of small *Fragilaria* species due to freshening and eutrophication, typical accompanying species are *Epithemia adnata* and *Mastogloia braunii*. highest content of oligohalobic species, sponge needles scarce
80–165 cm	predominance of *Campylodiscus clypeus* and *Diploneis smithii* and increasing number of *Fragilaria*: further decreasing salinity
165-188 cm	predominance of *Campylodiscus clypeus* and *Diploneis smithii-Diploneis didyma* with *Grammatophora oceanica*: phase of strong coastal smoothing and beginning of freshening
188-240 cm	predominance of *Campylodiscus echeneis* and *Paralia sulcata*, high percentage of sponge needles, youngest salinity maximum

240-595 cm	predominance of epiphytic species, such as *Synedra crystallina*, *Cocconeis scutellum*, *Epithemia turgida*, small *Fragilaria* species and others; high quantity of sponge needles, *Campylodiscus* species appear only subordinately; the individual numbers of mesohalobic and oligohalobic species are equal, polyhalobic species are less frequent. The section reveals a lower salinity than in the hangingwall and footwall layers, maybe the water exchange with the Baltic was reduced. A rich underwater vegetation existed.
595-785 cm	lower salinity maximum with *Paralia sulcata* predominance, accompanied by *Synedra crystallina*, *Diploneis didyma*, *Campylodiscus clypeus*, *Actinocyclus octonarius* and others; sponges are rare.
785-865 cm	increasing salinity and formation of a bay, the individual numbers of oligo-, meso- and polyhalobic species are similar, main species are oligohalobic epiphytic species, such as *Paralia sulcata*, *Synedra crystallina*, *Campylodiscus clypeus* and *Diploneis didyma*.
865-963cm	*Campylodiscus clypeus-Epithemia turgida* flora with high sponge share, predominance of oligohalobic-halophilic species, ± similar individual number of oligo- and mesohalobic species, polyhalobic species appear subordinately, additional appearance of freshwater species such as *Ellerbeckia arenaria*, *Cymbella cf. silesiaca*, *Cocconeis placentula* and *Amphora ovalis*

The profile KJB2a can be divided into four lithological sections (from the footwall to the hanging-wall: fine sand, organomud, fine sand, mud) and into seven palynological and diatomological sections. The two lowermost pollen sections are located in the lower fine sand and are related to the pine rich part of the Early Atlantic. The basal part reveals a remarkably high share of NAP and re-deposited pollen grains and also the first *Campylodiscus clypeus* maximum. The second section shows particularly high AP pollen density connected with decreasing salinity. The following organomud (270-241 cm) is characterized by high pollen/spores density and a second *Campylodiscus clypeus* peak and shows characteristics of a black layer (see Lampe this volume). The layer depicts a higher share of wetness indicators, NAP and alder to the expense of *Pinus, Quercus* and *Corylus*. The hangingwall molluscs-bearing fine sand (241-97 cm) was probably deposited in the same period as the molluscs-bearing fine sands of the barrier spit Schmale Heide which were deposited directly below the flint pebble beach ridges of the Feuersteinfelder. The complete-*Pinus* number remains high and the salinity is still low as revealed by the small percentage of polyhalobic diatom species.

The hangingwall mud body (97 – 0 cm) consists of two sections. From the point of view of pollen analysis, the mud comprises parts of the Younger Atlantic and the Early Subboreal. The elm decline (c. 5,000 BP) is located at a depth of 58cm. The entire deposit is characterized by low complete-*Pinus* numbers and by a higher salinity than before. The latter roughly corresponds to the salinity demonstrated by the borehole KJB3 and is particularly proved by *Paralia sulcata*, *Rhabdonema* sp. and *Diploneis didyma*.

Fig. 6 shows the distribution of main and rare elements in the core KJB3. The single evolution stages are clearly traceable by the parameter variations. The clastic input caused by forest clearing at the onset of the PZ IXc and the subsequently starting eutrophication process as evident from increasing phosphorus and organic carbon content are particularly striking.
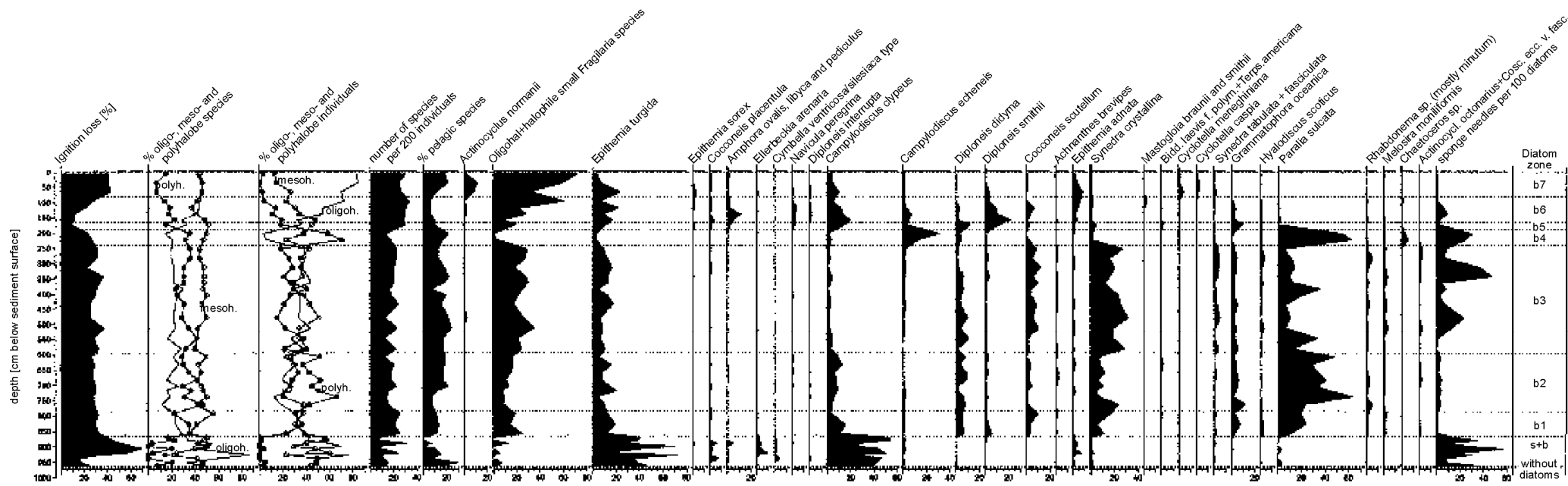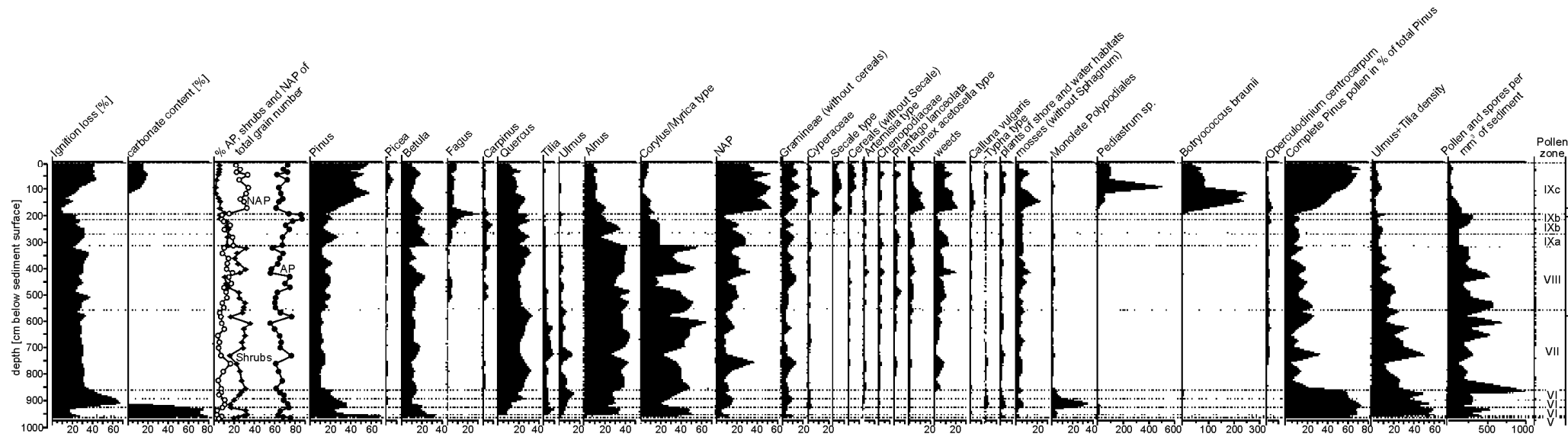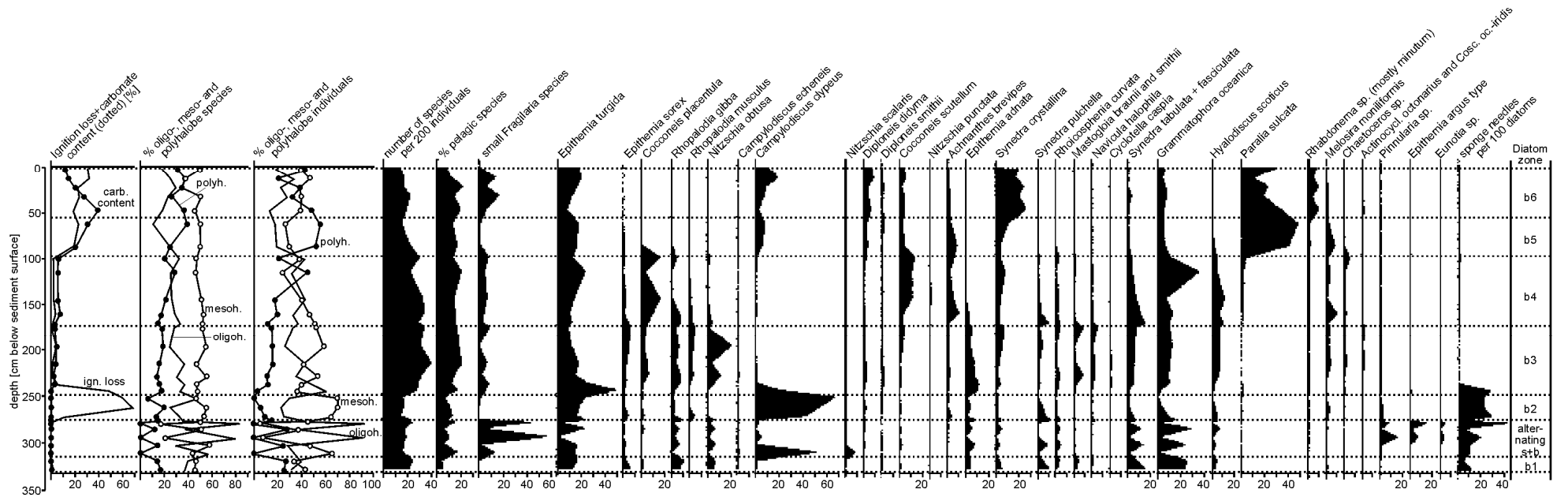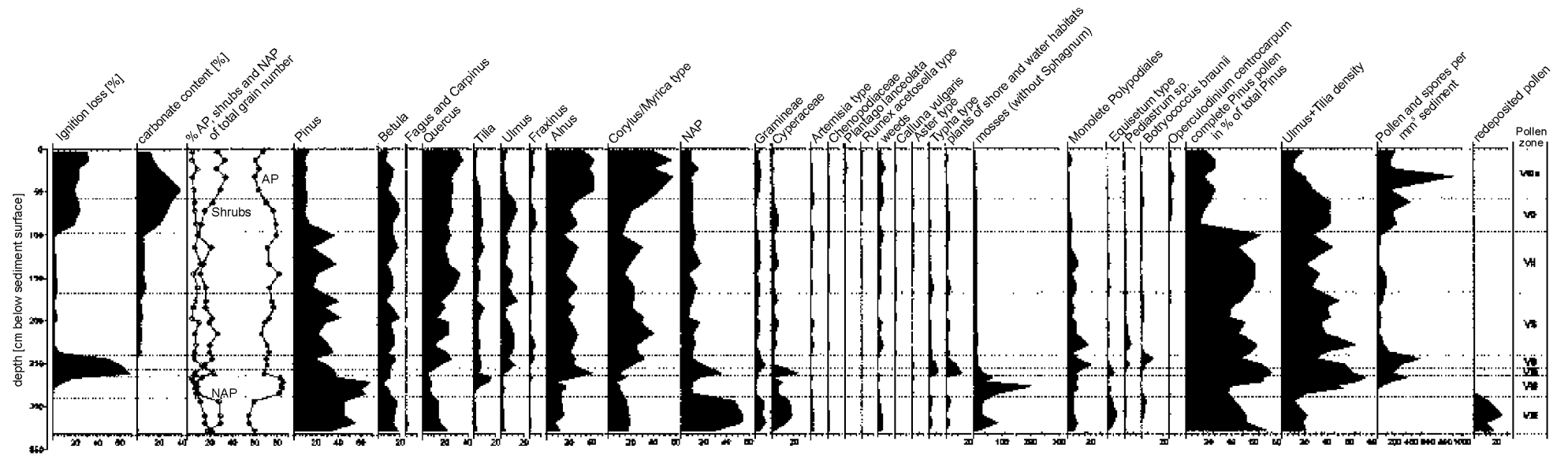
Fig. 4: Pollen and diatom diagram, core KJB 3
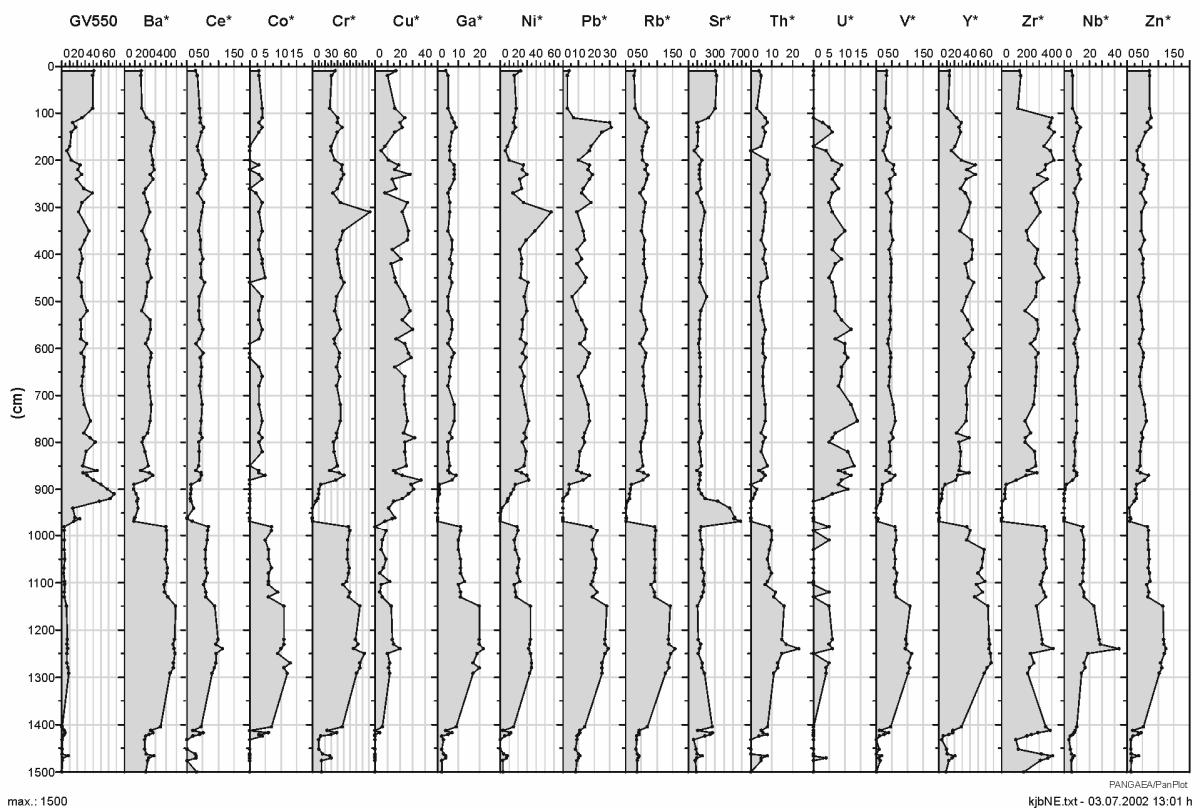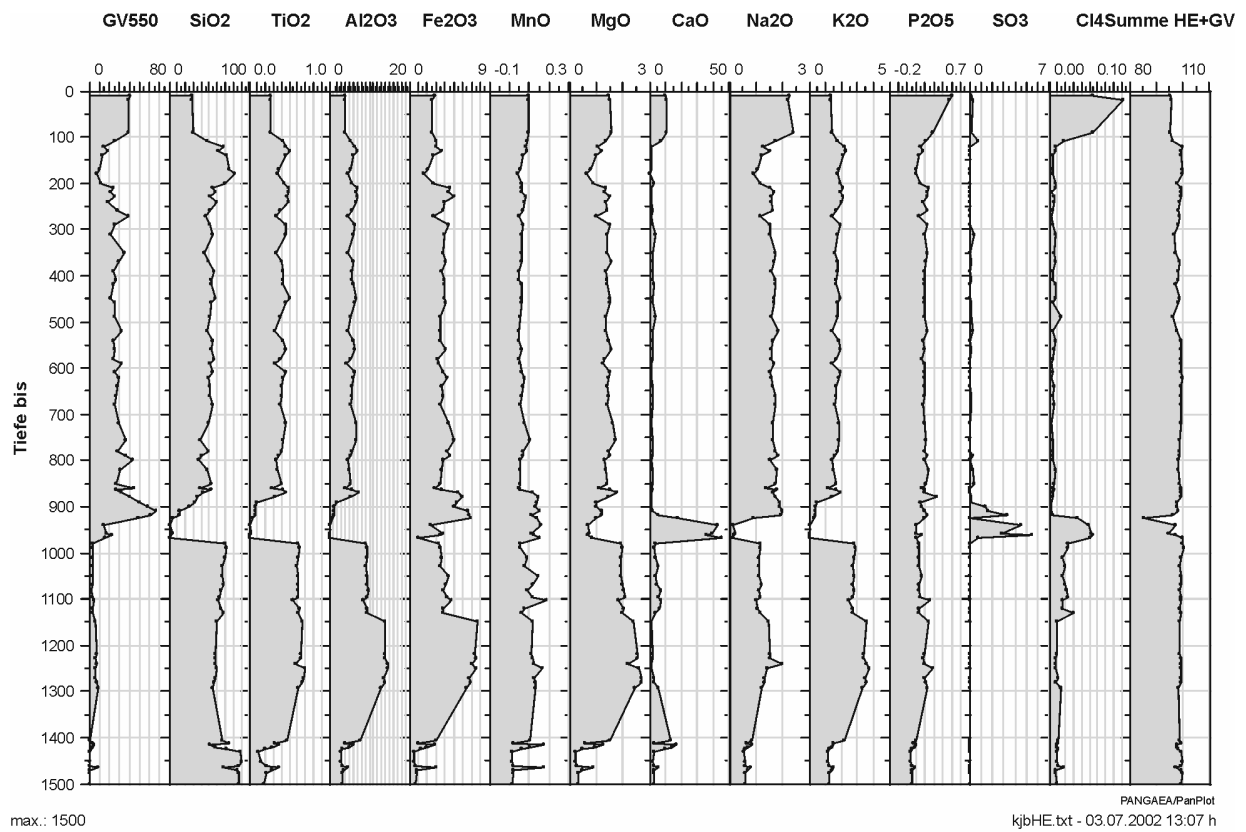
Fig. 5: Pollen and diatom diagram, core KJB 2a

Fig. 6: Distribution of geochemical parameters, core KJB 3

The barrier spit Schmale Heide

The Schmale Heide is a flat, forest-covered sandy barrier spit, stretching from the Pleistocene headland near Neu-Mukran (Bakenberg 35m) in the north to the Granitz hills near Binz in the south. In the west it borders some further Pleistocene hills, which steeply rise from the spit: Thiessow (Schifferberg 58m) in the central part, Buhlitz (Schanzenberg 60m) and Dollahner Berge (Moorberg 50m) in the south. The spit is 0.8 to 1.5 km wide and approximately 9.5 km long.

Until now only some drillings, which have been investigated stratigraphically, exist from that area. The first attempt was made by SCHMIDT (1957/58), who reached a depth of -25 m msl, KLIEWE & REINHARD (1960) drilled near Prora down to -18m msl. In the Binz area and in and around the Schmachter See some drillings were done by KLIEWE &, JANKE (1982) and JANKE &, LAMPE (1982). Some short mire profiles were published by LANGE et al. (1986) and JANKE (1995). Further drillings exist from lakes in the vicinity: Wostevitzer Seen (RUDNITZKI 1979), Großer Jasmunder Bodden (WASMUND 1939, MÜLLER 1998) and from the Kleiner Jasmunder Bodden and the Baltic bay Prorer Wiek (see below) as well.

The largest (eastern) part of the Schmale Heide consists of a forested dune belt with a wide beach at the Prorer Wiek. In the central part, flint-pebble beach ridges with varying vegetation are found. Their northernmost third forms a landscape feature, unique in the whole of Germany, which is called "Feuersteinfelder" ("fields of flints"). They have been protected as a nature reserve since 1935 , and, with a length of approximately 2 km and a width of 200 m, they cover an area of about 40 ha. The average thickness is 4 m according to GPR measurements. The material consists to 90 % of well rounded, fist-large flint and to 10% of mainly crystalline pebbles.

From the morphological viewpoint, the Feuersteinfelder are a system of beach ridges. In the northern part the ridges are higher, narrower and more numerous (approx. 18 ridges, up to 3.5 m) than in the south, where they are wider and gentler (5-6 ridges). The ridges located in the east are higher than those in the west. The size of the pebbles decreases from north to south. The eastern ridges are more or less covered by dunes (brown dunes, grey dunes, white dunes). According to previous opinions, the brown dunes (named after the colour of the eluvial horizon of their soils) were formed during the Littorina-II-transgression (4,500 – 2,800 BP). But an earlier formation could be possible, as remains to be shown. The grey dunes (named after the colour of the uppermost humus horizon) came into being around 1250 (onset of the Medieval clearings) to 1820 (begin of the reforestation). The western part consists of shallow coastal peat land covering marine sand. According to pollen analysis, the peat land started to grow in the younger Subatlantic (JANKE 1995). Particularly in the 19th century larger amounts of flints were gathered for use within ball mills in the ceramic industry (1882 - 1884 c. 1000 m³).

A first comprehensive explanation of the formation was given by SCHÜTZE (1931)
- The Littorina-submergence (at that time rather a submergence than a sea-level rise was presumed) led to a detachment of the Jasmund and Granitz hill areas and the formation of a bay
- A beach ridge system grew from north to south due to the predominant direction of the longshore sediment transport and cut off the bay (formation of the Kleiner Jasmunder Bodden, the Schmachter See and the Schmale Heide)
- The source of the flint pebbles was related to abrasion of cretaceous chalk outcrops north of the Schmale Heide (Truper Tannen)

- The beach ridges came into being in the aftermath of the Littorina transgression.

The Kranichbruch drilling (SCHMIDT 1957/58) provided further insights:

- the boulder clay appears unusually deep (c. 26 m)
- on top of the boulder clay are carbonate bearing silts, clay and sands, which have been interpreted as Late glacial deposits, covered by a peat at a depth of 13.5 m
- the following layer consists of marine sands with marine molluscs (*Cerastoderma, Mytilus, Macoma*)
- the upper three metres are rich in flints; on the surface of the ridges silex artefacts were found, possibly from the Ertebölle culture
- a beach ridge formation until 300 – 1,000 AD is considered possible.

The drillings in the area of Prora and Binz – which demonstrated a similar sequence – have been interpreted differently by the investigators:

- the carbonate-bearing sands overlying the boulder clay contain freshwater molluscs (*Valvata sp., Pisidium sp. Ancylus fluviatilis*) and are interpreted as sediments of the Ancylus Lake
- the following lake marls/calcareous muds and peats are indicators of the Ancylus regression and have been covered partly by transgression peats of the Littorina sea
- the sandy marine sequence is evidence for the fast formation of the Schmale Heide until c. 5,800 BP (KLIEWE, REINHARD 1960).

In a subsequent interpretation KLIEWE (1965, 1995 in DUPHORN et al.) determined the formation of the Feuersteinfelder as connected to the 2nd Littorina phase, "the water level of which, about four thousand years ago, was somewhat higher than the recent one". Temporally they are related to the generation of the older brown dunes of other barrier spits.

A new drilling west of the Feuersteinfelder generally confirms the sequence described by SCHMIDT. The profile starts with fine and medium sands (16 – 10.2 m). The carbonate-bearing sands below 12 m contain no diatoms. The 12..10.2m section bear freshwater diatoms (mainly *Ellerbeckia arenaria, Diploneis domblittensis*). The age can only be determined as pre-Atlantic. The peat lying above (10.2 – 9.95 m) is an Early Atlantic regression deposit, covered by c. 2 m thick freshwater sand. According to GPR - measurements (see below), the bedding dips towards the west. (Fig. 7). The diatom assemblage of the sands and the peat between 12 – 8 m is similar to the *Melosira* flora, typical for the Ancylus Lake. Characteristic cold-water species are missing. Up until 4-5 m horizontally bedded fine and medium sands with marine molluscs are situated. They are covered by sands containing numerous flint pebbles revealing a beach facies (4.5 – 2 m). Their beds dip towards the east. Above follow finer beach and dune sands with a thin soil cover (2 – 0 m). The sediment complex between 3.5 and 0.6 m is coloured brown or black-brown due to iron-humus compounds. This is believed to point to a gley oxidation horizon which grew parallel to a rising sea level.

The facies architecture of the Feuersteinfelder has been investigated by means of ground penetrating radar (ZIEKUR 2000). Fig. 7 shows two 500m-GPR records. The upper plot runs perpendicularly across the pebble ridges and depicts - from the top to the footwall beds - aeolian sand sheets (more or less parallel bedded), eastwards dipping beach ridges (2-4,5m, the ridge facies ceases out at about 600m), horizontally bedded shallow water sands (4,5-8m). Between 400m and 700m westwards dipping strata can be identified between 8 to 10m. The peat layer of about 20cm known from the borehole at 675m (see above) cannot be detected in

the GPR record. Below westwards dipping strata are demonstrated again. The GPR record running parallel to the pebble ridges (lower figure) depicts their base at about 4,5..5m, some steep dipping structures at 350m which cannot be interpreted and a strata boundary rising from S (>11m) to N (c. 8m). Because no borehole could be drilled in that area until now the interpretation is rather vague. It is believed that the rising boundary corresponds likely to the transition between Holocene and Late glacial sands.
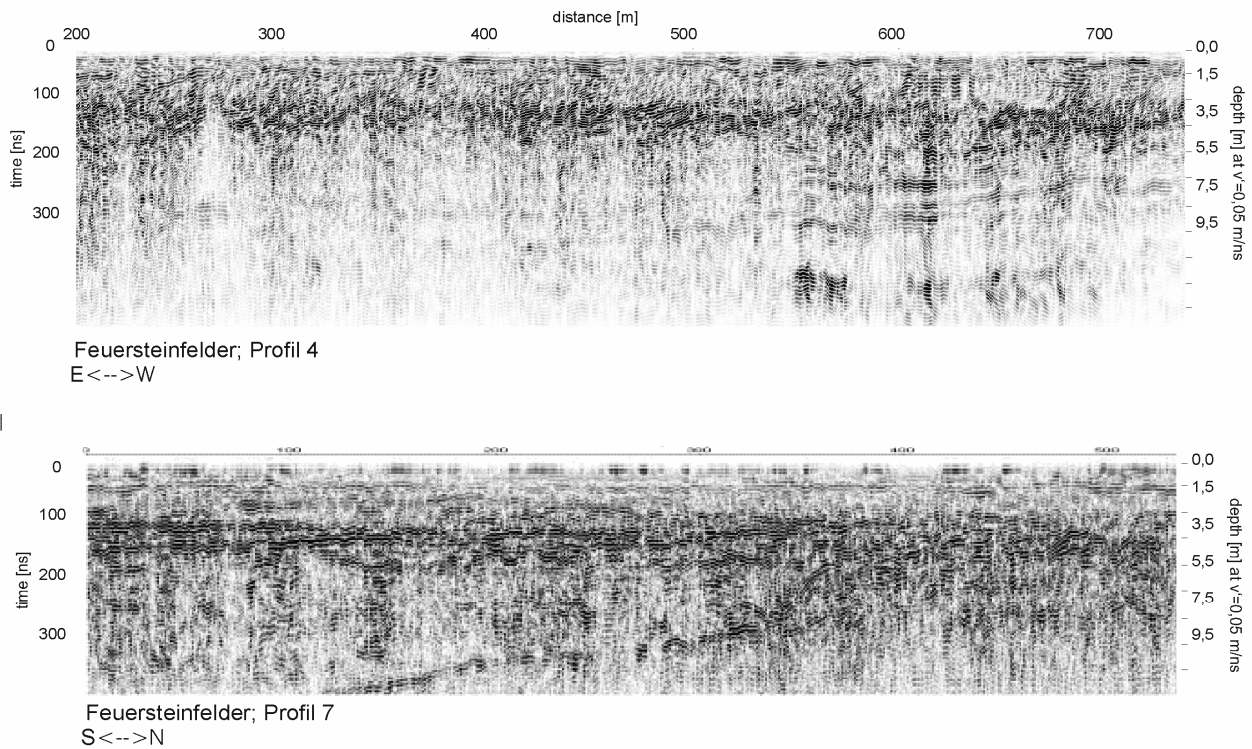

Fig. 7: Facies architecture of the southern part of the Schmale Heide, as revealed from drilling and GPR - measurements

The pollen diagram 1b from the Heidemoor, located northwest of the Feuersteinfelder, reveals that in the period of pollen zone VIII a marine shallow water existed, characterized by the typical *Campylodiscus clypeus/echeneis* flora. After a regressive stage the development of a coastal mire started above the sand. The pollen spectrum additionally contains a large number of *Chenopodiaceae*, which points to shoreline vicinity. The peat deposit is interrupted by a sandy tempestit, but altogether demonstrates a moderate sea-level rise, with which the peat accumulation kept pace (PZ IXa + b). A black layer is situated between 40-57 cm below ground surface. According to the pollen diagram, the layer was formed before the onset of the German Colonization. Therefore it can hardly be related to the Little Ice Age.

The age and the formation mechanism of the Feuersteinfelder are not yet satisfyingly determined. Abrasion of nearby chalk clods (STEINICH 1977) cannot explain the amount of pebbles contained in the ridges. More probable is the assumption, that pre-accumulated fluvioglacial gravel located in the vicinity was the source (HERRIG 1995: 110). This gravel must have been the only source over a long time, because no hint for a remarkable sand deposition in the beach-ridge fan has been identified. The dislocated artefacts (MALMKOPF 1939), found on its surface point to a "terminus post quem" but are so heavily rolled that they cannot be related to the Lietzow-culture without any doubts (p.c. TERBERGER). Therefore, the formation period can be determined only vaguely as the interval from 5,800 to 3,000 BP.

Schmachter See

The Schmachter See is located in the southern part of the Schmale Heide behind the barrier spit. The investigation of the sediments involved not only the spit, the constituents of which are similar to those of the Feuersteinfelder though including less flint, but also the lake and the surrounding lowlands (Fig. 8). Radiocarbon datings, pollen, diatom and chemical analyses led to a detailed description of the pre-Atlantic evolution, the onset of the Littorina transgression, the cutting-off of the cove and the development into a coastal lake, the freshening rate, and the sedimentation rates (JANKE, LAMPE 1982).
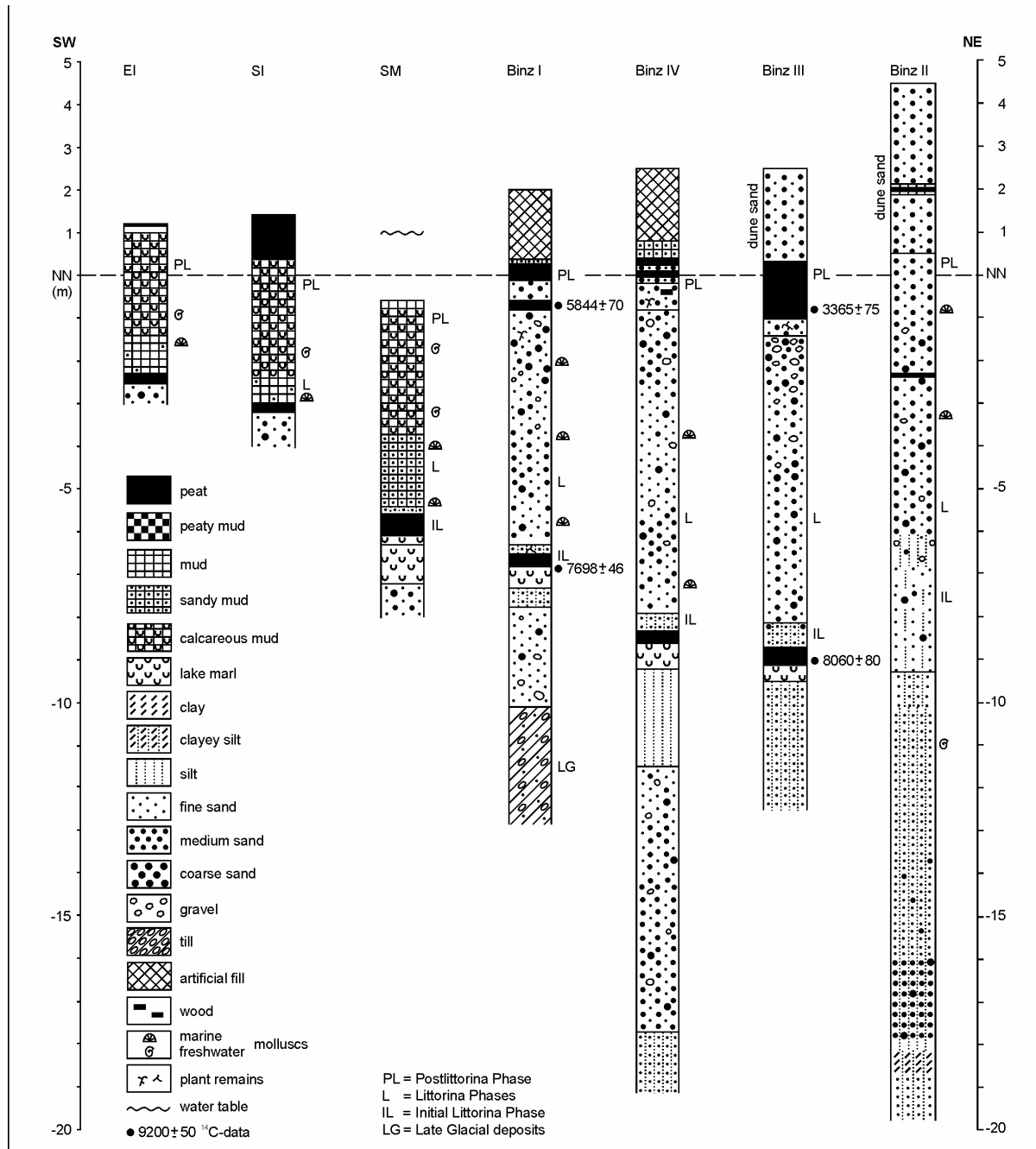

Fig. 8: Sediment cores drilled in the vicinity of the Schmachter See (after JANKE, LAMPE 1982)

In the area of the Prorer Wiek/Schmachter See the transgression started – depending on the topography - between 7,800 and 6,000 BP. About 3,600 – 3,200 years ago, the barrier spit was completely formed, and the separate evolution of the coastal lake started. The process of freshening was finished in the course of only some centuries. For almost 2,000 years the lake possessed mesotrophic state with *Bithynia tentaculata* and a diatom assemblage with *Campylodiscus hibernicus, Cymbella ehrenbergii,* and *Navicula scutelloides.* Since the early Middle Ages, the underwater vegetation and the share of epiphytic diatoms have increased because the lake has become shallower. In the past decades the water quality deteriorated due to wastewater inflow and intensified agriculture. The lake sediment changed from a carbonate bearing to a calcareous and finally to a sandy detritus mud. The sedimentation rate increased markedly. The average sediment accretion of the Schmachter See amounted to 0.1 cm/yr but rose to 0.8 cm/yr in the uppermost 50 cm. The single evolution stages are particularly well demonstrated by the chemical parameters which were examined (Figs. 9, 10). The following stages can be clearly distinguished due to differences in the distribution of the chemical parameters: calcareous mud of the Boreal, basal peat of the Early Atlantic, deposits of the Littorina transgression, and the increasing sand-bearing detritus mud, which has been deposited since the medieval clearings.
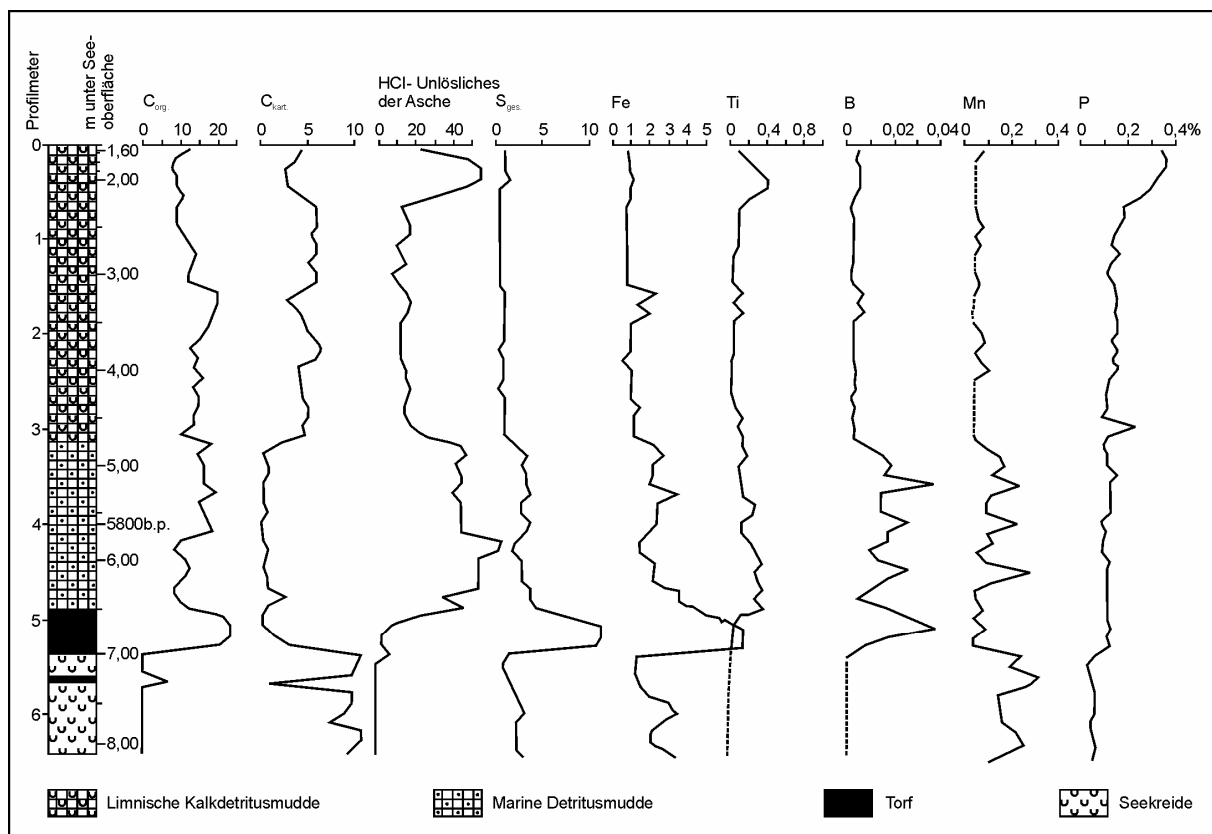

Fig. 9: Distribution of chemical parameters in a sediment core from the Schmachter See (after JANKE, LAMPE 1982)
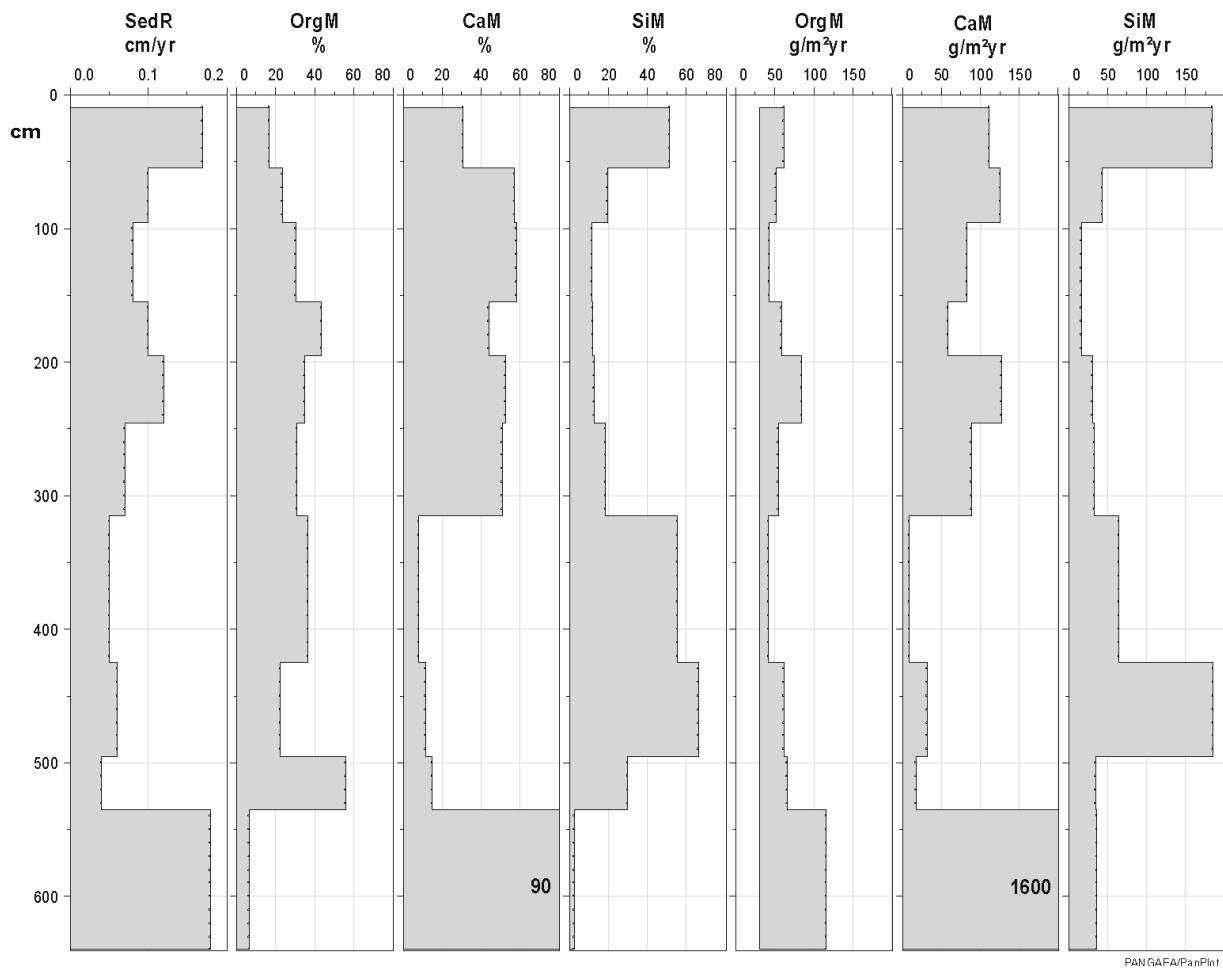
Fig. 10: Matter accumulation rates throughout different periods as revealed from Schmachter See sediments (after JANKE, LAMPE 1982)
SedR – sedimentation rate, OrgM, CaM, SiM – organic matter, carbonate matter and silici-clastic matter; the concentrations in % and the accumulation rates in g/m²year are depicted.

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The geological evolution of Usedom Island

GÖSTA HOFFMANN

Usedom covers an area of approximately 406 km² and is the second largest island along the German Baltic coast. To the west it is separated from the mainland by the Peenestrom. To the south and south-west it borders lagoonary basins of the Oderhaff, the Achterwasser and the Krumminer Wiek. The north-eastern boundary is made up of an arched to straight lined stretch of the coast line, 42 km long. To the east, the Swine-river (pol. Šwina) separates Usedom and Wolin.

A description of the morphological relief displays the dependency of genesis and form. Narrow hills like the Gnitz peninsula (cf. C-9), the Streckelsberg near Koserow (cf. C-8) as well as the wide scattered hills in the south-eastern part of the island consist of glacial and late-glacial sediments (KLIEWE 1960). Three large adjoining lowlands, the Peenemünde-Zinnowitz, the Pudagla and the Swine lowland are build up of Holocene deposits. Bedded into the moraine-landscape and the Holocene lowlands lies the so called Westusedom-lagoon-system comprising the Achterwasser, Krumminer Wiek the Peenestrom and the Oderhaff. Numerous lakes, in most cases without outflows, belong to the geomorphologic inventory (cf. C-7).

The base of the Quaternary sediments of Usedom Island are Cretaceous deposits, which can be found in depths of 50 to 100 meters (GEOLOGICAL MAP OF MV). There is no evidence for autochthonous Tertiary sediments. WERNICKE (1931) points out that the surface of pre-quaternary deposits is supposed to be even with no connections to the present relief.

The cliffs of the island provide insight in the succession of glacial sediments (Fig. 1). From bottom to top glaciofluvial and glaciolacustrine melt water deposits follow on top of an underlying till. The overlying upper sediment layer is interpreted as a till as well (SCHUMACHER 1995). This diamicton unit is present only sporadically. In some cases the uppermost sediments on the cliff are fine to medium sands of aeolian deposition (dunes), sometimes underlain by an organic horizon (MALMBERG-PERSSON 1999).

The lower till which crops out only on a few places at the base of the cliffs is strongly folded. It is a blue-grey, clay rich and massive diamicton. The grain-size distribution as well as the petrographic composition varies. The main part of the coastal cliff sections is formed by melt water deposits (fine to medium sand). They reach a thickness of up to 50 m. MALMBERG-PERSSON (1999) recognised cross lamination, planar parallel lamination and planar cross lamination. According to SCHUMACHER (1995) the lower section of the unit demonstrates large-scale cross bedding partly replaced by ripple and horizontal bedding. In the upper section large-scale cross bedding dominates again. Flow channel structures are common in the whole unit. Silt and diamicton occur in layers. Typical for the upper diamicton is a brown-grey colour and a sandy composition. The thickness varies between 0 and 4 m. According to MALMBERG-PERSSON (1999) this bed is thick where the cliffs are low. On topographically high areas it is missing.
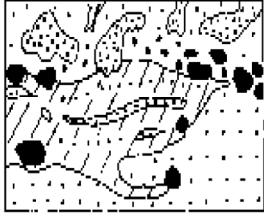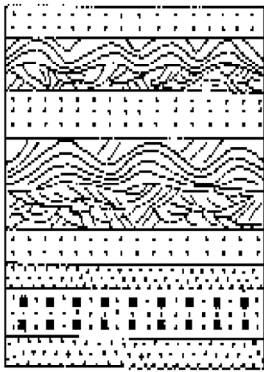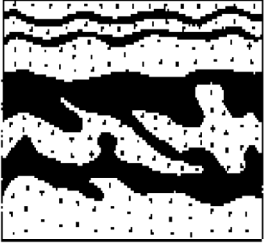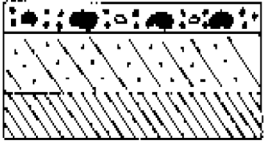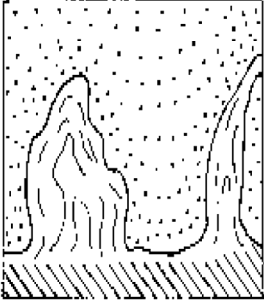
Profil	Sediment-characterization/bedding	Stratigraphy
	Cliff dune Cross laminated fine sands Locally podzolization, limonite-incrustation	Holocene
	Upper till, lightbrown, marly sand, at the top in parts with brodel texture Discordant bedding	W IV Nordrügen-stage
	Melt water sands, predominantly cross laminated, planar parallel laminated and planar cross laminated fine sands. Sometimes silt and clay- banded or with ripple bedding	W III/IV Meiendorf interstadial
	Enriched in layers are brown coals (Miocene) and amber	
	In parts massive clay/silt-beds show deformations-structures	
	Lower till, grey, clay rich marl, upper 2 m brown-grey, sandy, weathered, boulder bed on top	W III Mecklen-burg-stage
	Till and overlying sands are deformed Large sand-basins and narrow till-upfolds	

Fig. 1: Overview of the Pleistocene sediments of Usedom Island (cliff sections), SCHUMACHER 1995

Because no organic material can be found within the glacial deposits the stratigraphy is not completely understood. MÜLLER et al. (1995) correlate the lower till to the Saalian stage. Correlation to the deposits on Rügen Island where at least five Weichselian deposits have been recognised (PANZIG 1995) seems to be difficult. KRIENKE (2001) correlates the two diamictons of Usedom to tills found on Rügen but he emphazise that the older diamicton of Usedom possibly represents some tills of different stratigraphic ages. According to KRIENKE (2001) the upper diamicton is a deposit of the last readvance of Weichselian glaciers (W3 – Mecklenburg stage; >14 ^{14}C ka BP). MALMBERG-PERSSON (1999) points to connections between the Usedom and Wolin deposits.

Due to the stratigraphical problems the reconstruction of glacial dynamics is difficult. KLIEWE (1960, 1987) described the morphology of the landforms as a result of a Late Weichselian ice re-advance. He reconstructed a push end moraine running from northern Rügen to eastern Usedom. RUCHHOLZ (1979) interpreted the deformations within the glacial deposits as a result of gravitational and loading processes caused by density-inversion (till kinematics). RÜHBERG (1987) considers a combination of glacial-tectonics due to a readvance of the glacier and melt out processes of older ice. MALMBERG-PERSSON (1999) provides the latest reconstruction of the environmental development during the late phases of Weichselian glaciations in the southern Baltic area. The underlying till was possibly deposited as a push moraine. Melt- out and flow processes are responsible for the accumulation of the thick bed of fine to medium sand. It is interpreted as a proglacial outwash, deposited on a braided plain. For some parts ice-dammed lakes were considered as well. The dislocation within these beds is due to collapse when buried ice melted. The upper, sandy diamicton was deposited by debris flow (flow till). There is no explicit difference in the petrographical composition of the two diamictons, so that it is believed that both units have been deposited during the same glacial event.

During the deglaciation stage, several melt water lakes developed. In the central part of the Baltic depression the Baltic Ice Lake came into existence. BJÖRCK (1995) dates this first stage of the evolution of the Baltic Sea from 12.6 to 10.3 ka BP. The relationship between local meltwater lakes and the Baltic Ice Lake is not completely determined (KAISER 2001).

KAISER (2001) describes the evolution of the so called „Haffstausee", a freshwater reservoir which developed south of today's Usedom in the "Ueckermünder Heide" probably during the Older Dryas (12,900-12,400 BP).The water level reached + 30 m. Fine to medium sand was deposited during the existence of the lake in glaciofluvial to glaciolacustrine facies. The deposits are homogenous and the sedimentation is supposed to have been uninterrupted. The sedimentary basin was flown through by several rivers like Odra, Randow, Uecker and Ina. The northern boundary of the lake is uncertain. A barrier of glacial ice in the Pomeranian Bight is discussed by KAISER (2001). Following this hypothesis similar deposits should be found on and around Usedom which have not yet been described.

The Odra mouth as an important place of freshwater and sediment input moved southward during the Holocene. There is a close connection between the different evolutionary stages of the river valley and the Baltic Sea. KOLP (1983) recognised terraces in different depths of the Baltic Sea basin. He connected them to the Odra river and describes the stepwise shifting of the river mouth (Fig. 2). The reconstruction of the river's course reveals the changing level of the sea.

In postglacial, early Holocene time, Usedom and adjoining areas were mostly onshore. In Pleistocene depressions minor lakes existed. If these lakes were connected with the

precursors of the Baltic Sea (Baltic Ice Lake, Yoldia Sea, Ancylus Lake) is still unknown (SCHUMACHER 1995).
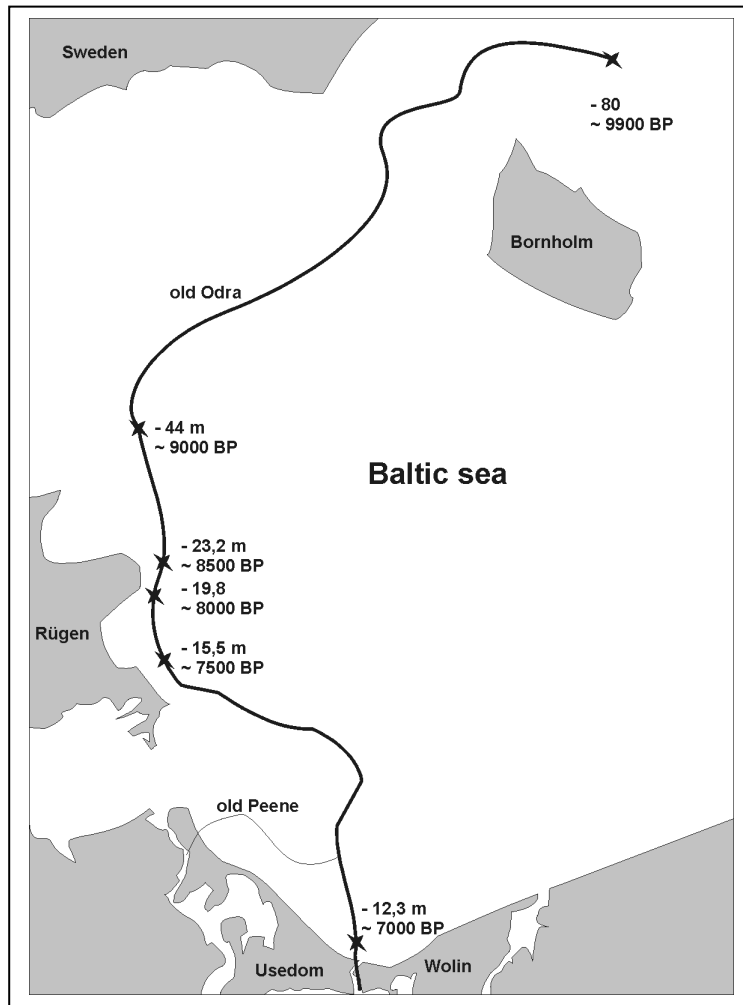

Fig. 2:
Stepwise shifting of the Odra river mouth in the Baltic Sea (according to KOLP 1983, simplified).

Recent mappings of the sedimentary structure of the Holocene lowlands (barrier spits) revealed limnic phases during the Preboreal/Boreal (HOFFMANN, LAMPE 2002, HOFFMANN 2000, cf. C-10). These deposits, which are up to several meters thick, mostly consist of fine sand. Molluscs are very rare, some species of *Valvate cristata, Valvata piscinalis, Sphaerium cornium* and *Pisidium* spp. could be found. Unidentified plant remains were found only sporadically.

With the beginning of the Littorina transgression sedimentation in the lowlands continued under marine/marine-brackish conditions. The normal sequence starts with peat: initiated by a rising ground-water table, due to rising sea level, accumulation of plant material took place. In the area of the Zinnowitz sand flat the marine sequence starts at around –10 m (HOFFMANN 2000). In the Pudagla lowland similar depths were determined. Sedimentation continues with detritus-rich, organic and fine clastic material (mud). Different species of molluscs such as *Mytilus edulis, Scrobicularia plana, Macoma balthica, Theodoxus fluviatilis, Hydrobia* spp. *Littorina littorea* occur. *Cerastoderma* spp. is the dominating species.

These deposits are interpreted as deep-water or slack-water sediments. In the beginning of the Littorina-Transgression (8,000-6,000 conv. [14]C years) the water level was rising fast with

velocities of more than 0.25 m/100 years (SCHUMACHER, BAYERL 1997, 1999, JANKE, LAMPE 2000). Due to this rapid rise the landscape "drowned". Although there are still uncertainties about the following development of the sea level, it is believed that there were only minor oscillations leading to present sea-level. The sediment cores from Usedom (about 150) reveal no significant fall of the water level. In most cases the mud is overlain by fine sand containing the same assemblage of molluscs. There are different sub-facies types within this unit such as beach-ridge facies, "Windwatt" facies (shallow water areas, which becomes sometimes dry due to wind-generated water-level fluctuations) etc. The main geomorphologic effect of the rising sea-level is the formation of cliffs, transport of eroded material along the coast and redeposition as sand bars and beach ridges. Along the shoreline dunes can be found on top of the barrier spits (cf. C-6). The ages of the dunes vary. According to PRUS-INKIEWICZ & NORYSKIEWICZ (1966) the oldest dunes in the Swine lowland are 4,810+/- 300 years (conv. ^{14}C) old.

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Peatlands in ice marginal valleys and their relation to sea level changes

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Mecklenburg – West Pomerania, the north-eastern part of the Federal Republic of Germany, is characterised by an extensive system of former ice marginal valleys (Urstromtäler), that are largely filled by peatlands (Fig. 1). These peatlands are largely fed by spring water, coming from the valley sides, and showed a typical pattern of spring mires at the valley margins, percolation mires in the valley extent, and fluvial transgression mires near the central river (SUCCOW, LANGE 1984, SUCCOW, JOOSTEN 2001) (fig. 2). Characteristic for these valleys are the percolation mires. Percolation mires were the dominant mire type of the temperate forest zone, but currently belong to the most threatened mire types of the World. In the whole of Europe (incl. European Russia), large parts of North America, and the eastern part of Eurasia (notably Japan), these mires have largely been destroyed by drainage because of their suitability for agriculture.
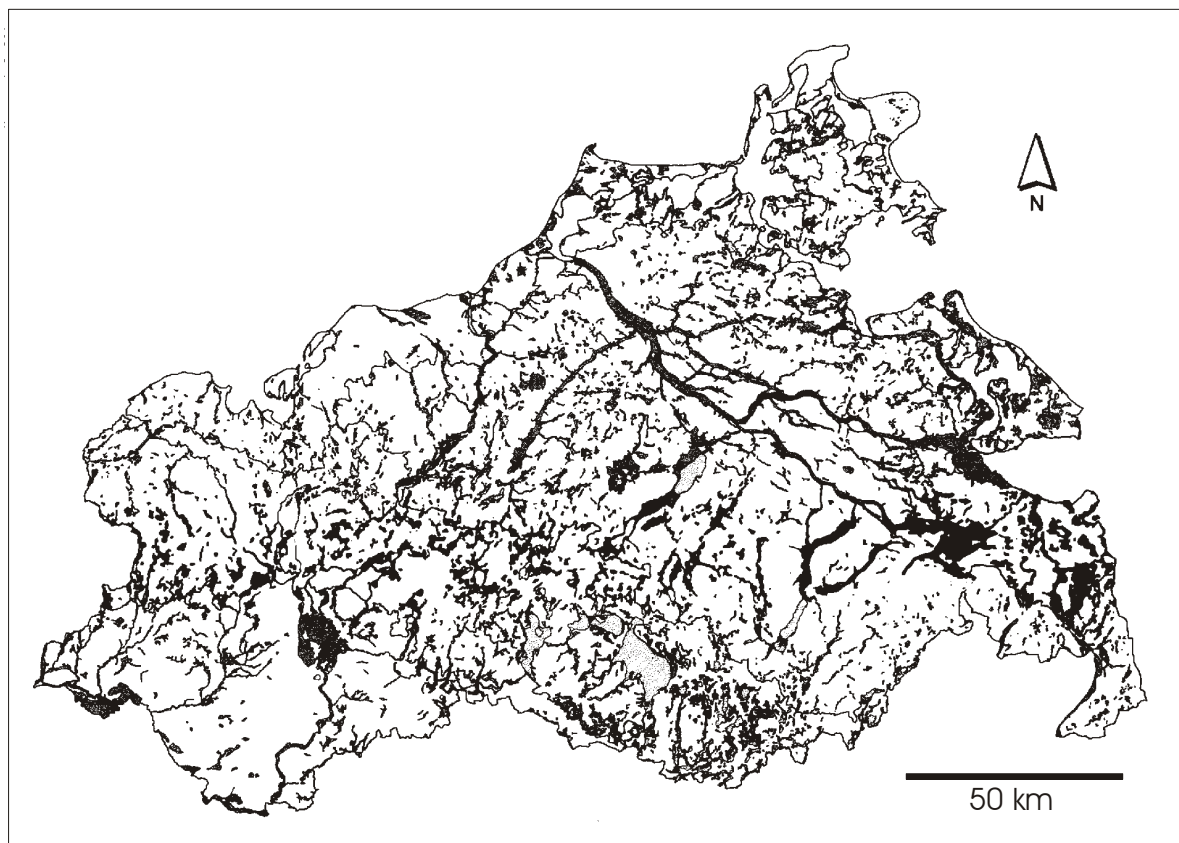

Fig. 1: Distribution of peatlands in Mecklenburg – West Pomerania (after SUCCOW, JOOSTEN 2001, simplified).
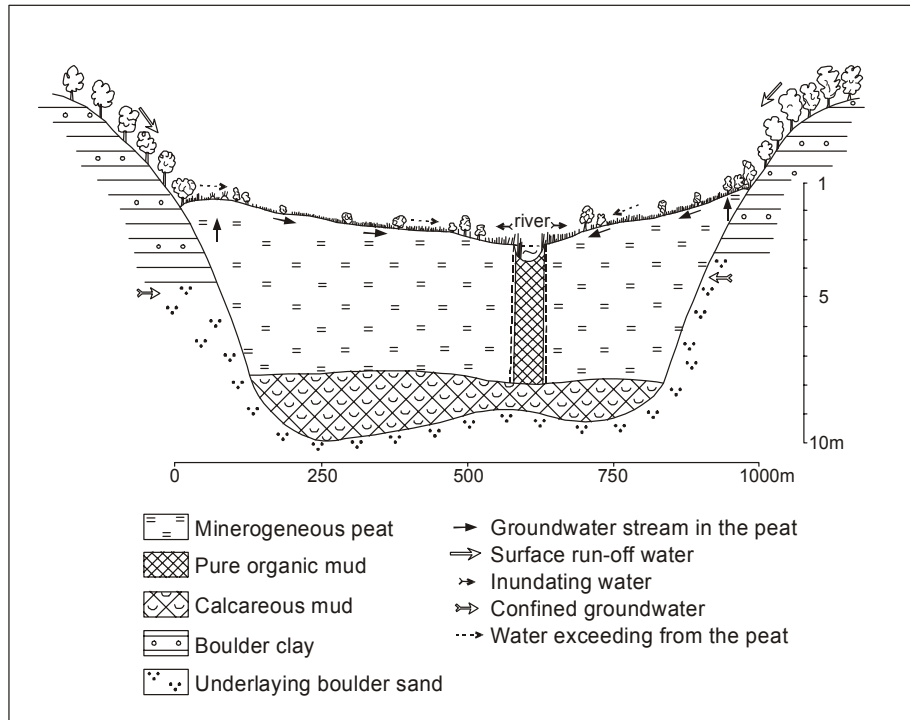
Fig. 2: Idealized transect through a valley mire in Northeast Germany (after SUCCOW, LANGE 1984, simplified).

Percolation mires ("Durchströmungsmoore") are found in landscapes where water supply is large and very evenly distributed over the year. As a result, the water level in the mire hardly ever drops. The dead plant material soon reaches the permanently waterlogged zone, is therefore only subjected to fast aerobic decay for a short time, and the peat remains weakly decomposed and elastic ("schwammsumpfig"). Because of the large pores and the related high hydraulic conductivity, a substantial water flow occurs through the whole peat body. The peat's capability to oscillate makes conditions for peat formation at the surface more and more stable. Whereas at the start percolation mires are susceptible to water level fluctuations, with growing peat thickness any fluctuations in water supply are more and more compensated by mire oscillation ("Mooratmung").

Mire development in the wide and deeply incised ice marginal valleys has always been decisively influenced by Holocene Baltic Sea water levels changes, as is apparent from the increase of indicators of brackish and open water conditions, changes in peat types, and alterations between peats and lake sediments. The peats and gyttjas reflect long-term minimum water levels.

An often overlooked complication when reconstructing former sea levels from peat deposits is, that various mire types (incl. percolation mires) raise their water level and that of their surroundings autogenously (JOOSTEN. SUCCOW 2001). The development of percolation mires in ice marginal valleys, for example, may lead to a relocation of seepage mires and sloping fens to progressively higher positions on the valley margin slope (MICHAELIS 2002). Such rising water levels result in the gradual paludification of hitherto dry upland depressions (COUWENBERG et al. 2001) and may even reverse water flow from groundwater recharge to groundwater discharge conditions (BARTHELMES 2000, MICHAELIS 2000).

Furthermore some mire types (including percolation mires) become in the course of their development increasingly more resilient and may obtain a virtual independence from climatic and hydrologic changes (COUWENBERG, JOOSTEN 1999, COUWENBERG et al. 2001). They only change their character (and their resulting stratigraphy) when certain hydrological thresholds are crossed, the exact magnitude of these thresholds being dependent on the stage of mire development

A correct discrimination between external forcing (sea level rise, climate change, upland forest composition and evapotranspiration change, deforestation, beaver activity) and autonomous water level changes therefore requires the identification of hydrologically effective changes in upland vegetation, climate, and land use and the reconstruction of the hydrogenetic mire types involved (cf. SUCCOW, JOOSTEN 2001).

These aspects are clearly shown in the development of the Recknitz valley peatlands. Detailed palynological and macrofossil analysis– with adequate time control – enabled the reconstruction of their peat-forming vegetation, hydrology, micro topography, nutrient availability, pH, and salinity. It was possible to identify deposits of terrestrialization mires, paludification mires, spring mires, marine and fluvial transgression mires, surface flow mires, percolation mires, and raised bogs (MICHAELIS 2002), illustrating the complex development of the valley mires. Fig. 3 shows the development in a cross-section through the Recknitz valley near Bad Sülze.
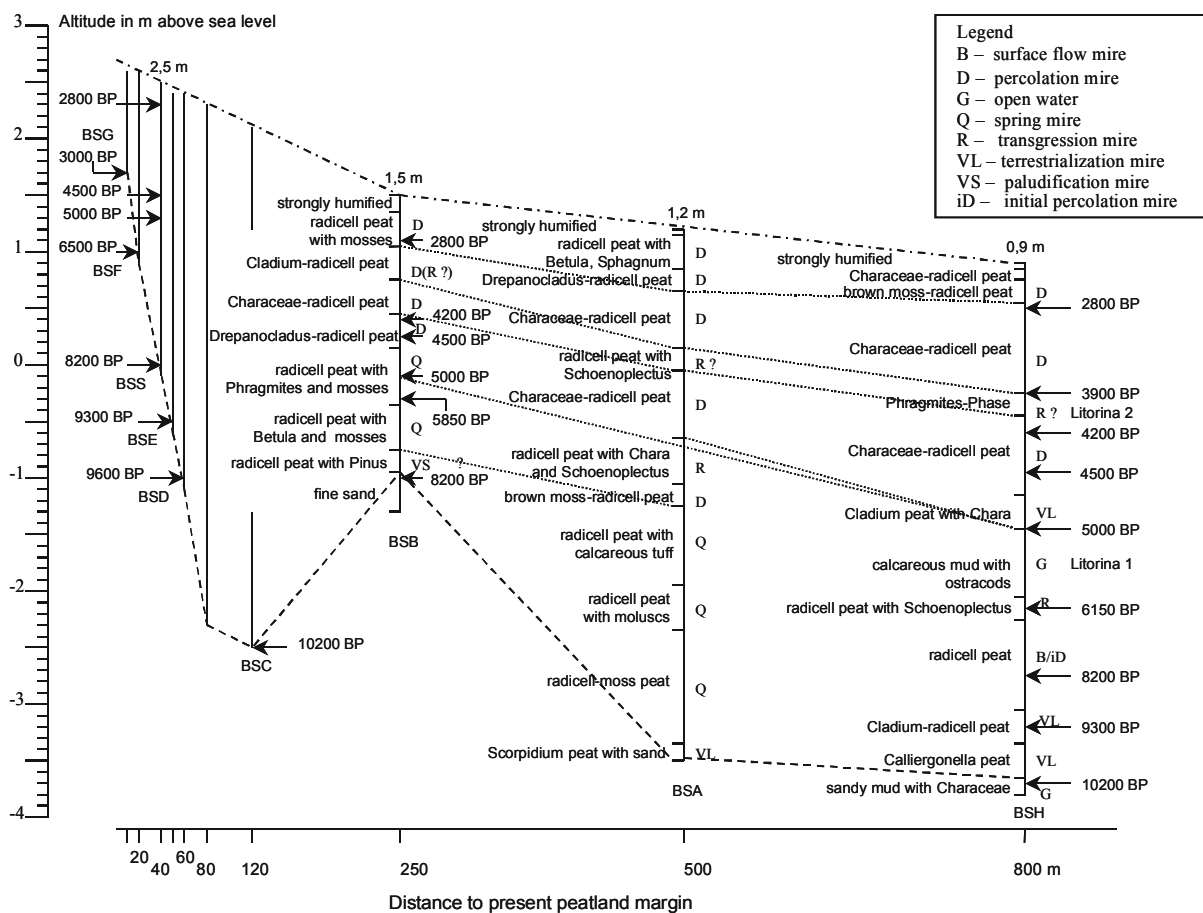

Fig. 3: Cross-section through the Recknitz valley near Bad Sülze (after MICHAELIS 2002).

Mire development at BSH and BSA started as open water, that terrestrialized by the sedimentation of sand gyttjas during the Late Glacial and by brownmoss peats at the beginning of the Holocene. Subsequently at BSA calcareous peats with both hummock (*Homalothecium*) and wet hollow (*Calliergon*) moss species were deposited, that must be interpreted as resulting from a spring mire. The growing spring mire provided a continuous water supply to the mire down slope at BSH, that is an initial percolation mire, that at first must have had the characteristics of a surface flow mire. *Carex rostrata* and *C. limosa* expanded at the end of this initial phase. This filling up of the lower valley parts with peat caused a decreased groundwater recharge (infiltration) at the mineral ridge of BSB, with a consequent paludification by acid radicell peats with *Pinus* and *Calluna*. Somewhat later, BSB changed into spring mire with calcareous peats that are more strongly decomposed but similar to the BSA spring peats. Probably, spring mire development at BSB was caused by the increasing peat thickness in the lower parts of the valley, forcing groundwater to pass through the higher but more permeable mineral ridge. Simple hydrological modelling with FLOWNET supports this hypothesis.

The interpretation of brown moss-radicell peats as peats originating from percolation mires follows from the presence of low competitive species like *Carex limosa* and *Meesia triquetra*. They require loose, water saturated, rather nutrient poor substrates, which are nowadays largely restricted to floating mats (Schwingmoor). While the spring mire at BSA was growing upwards rather rapidly, the accumulation and expansion capacity of peat in the initial percolation mire at BSH could not keep pace with the rising water level around 7,000 BP, when the first Littorina transgression (and consequent damming up) flooded the Recknitz valley with slightly brackish water (as indicated by the presence of the diatom *Campylodiscus clypeus*). Calcareous gyttjas with ostracods and seeds of *Najas marina* clearly illustrate this development. No gyttja sedimentation following the Littorina transgression was observed at BSA, but a phase with *Schoenoplectus* and *Chara* was interpreted as a wetting phase. Its top part can be related to the final terrestrialization of the water at BSH during a regression phase of the Baltic Sea. The first Littorina transgression did not leave any traces at BSB.

After the phasing out of the first Littorina trangression, sedge reeds with *Carex rostrata* and *C. limosa* expanded over large areas. At BSB, these contained more brown mosses, while at BSA and BSH Characeae were abundant. This phase can be interpreted as a percolation mire. The spring mire at BSB apparently had also changed into a percolation mire, possibly fed by newly originated spring mires higher up the valley margin.

All cores show a peat layer that may result from a wetting phase, indicated at BSH by a *Phragmites* phase, at BSA by the presence of *Schoenoplectus*, and at BSB by the expansion of *Chara*. This phase is interpreted as an effect of the second Litorina transgression around 4,000 BP, who's effect was the weakest at the highest situated site BSB. An inundation of the sites probably did not occur.

Subsequently, sedge reeds with *Carex rostrata* and *C. limosa* expanded. The *Cladium*-radicell peat at BSB possibly reflects the formation of a deep hollow, independent of the transgression events. The brown moss rich peats overlaying the *Chara-Carex* peats indicate a somewhat drier percolation mire. Around 2,000 BP, the palaeo-record stops as a result of recent drainage and agricultural use, leading to rapidly progressing peat oxidation.

The effects of the Littorina transgressions in the Recknitz valley can be observed up to a distance of 18 km inland the present Baltic Sea coast. They show as depositions of brackish *Phragmites*-peats, partly brackish calcareous muds, and *Cladium*-peats, with the saltwater

influence decreasing with increasing distance to the sea. Whether a concrete mire site was flooded depended on its altitude a.s.l. and on the relation between the rate of sea level rise and the rate of peat accumulation at that site.

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The development of the river valleys from the Uecker to the Warnow

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The first valleys came into being during the destruction phase of the inland ice in the partly criss-crossing fissures of the melting ice bodies. These small valleys were used by flowing water only in this short evolution phase, although they are still a characteristic landscape element particularly of the flat ground moraines. Already during this melting phase, before the river-mouth area of the Oder became ice free in the NE, a large melt-water lake (called Haffstausee) was formed, discharging in northwest direction to what is today the Recknitz mouth. This process had no effects on the Warnow valley. Immediately after the coastal area became ice free, the runoff direction was changed to north to the Oder Bight, intermittently accompanied by valley incision. Further destruction of the permafrost, melting of the dead-ice and increasing temperature led to a rising ground-water and surface-water tabel.

After completion of this valley evolution phase, at the end of the Weichselian pleniglacial, the main configuration of the coastal river valleys of Mecklenburg – West Pomerania was already finished. The younger, particularly the Holocene evolution only modified the relief, and also the development of the periglacial slope slacks was completed no later than in the Younger Dryas. All larger rivers of the coastal lowland possess wide valleys, but they were not able to form those under the hydrological circumstances of the younger Late glacial (since the end of the Dryas I) or the Holocene. They are the result of subglacial and subaerial drainage processes during the period of the final destruction of the inland ice sheet.

Further, due to their additional dependence on the sea level, the Holocene evolution of the lowland rivers, and of the lakes they flowed through (perimarine waters sensu HAGEMAN & KLIEWE 1969, mainly located below 10m msl) was temporarily different from the development of the inland waters, which depend only on the groundwater level and the evaporation/precipitation relationship. The data about the Holocene inland water-level variations are still contradictory, as shown by KAISER (1996) who compared water-level curves of lakes from different authors.

Altogether ten Late and Postglacial stages of the valley evolution – among them two incision phases are to be discussed. They draw on investigations from JANKE (1978) and show many similarities with the evolution phases of the surface relief and the drainage net provided by KAISER (2000).

The Late glacial and Holocene river valley evolution stages

1. stage: First meltwater channels with NW directed sediment bodies came into being (ice sheet decay of the Pomeranian stage?). The corresponding sediments in the area of the West Pomeranian channels are sand deposits located directly below the boulder clay of the Mecklenburgian stage e.g. near Sandhagen, east of Ramelow and Brook in the Grenztal, near Unnode in the Kuckucksgraben and near Jarmen and Pensin in the Peene valley as well (partly depicted in Fig. 1, see also JANKE, REINHARD 1968).
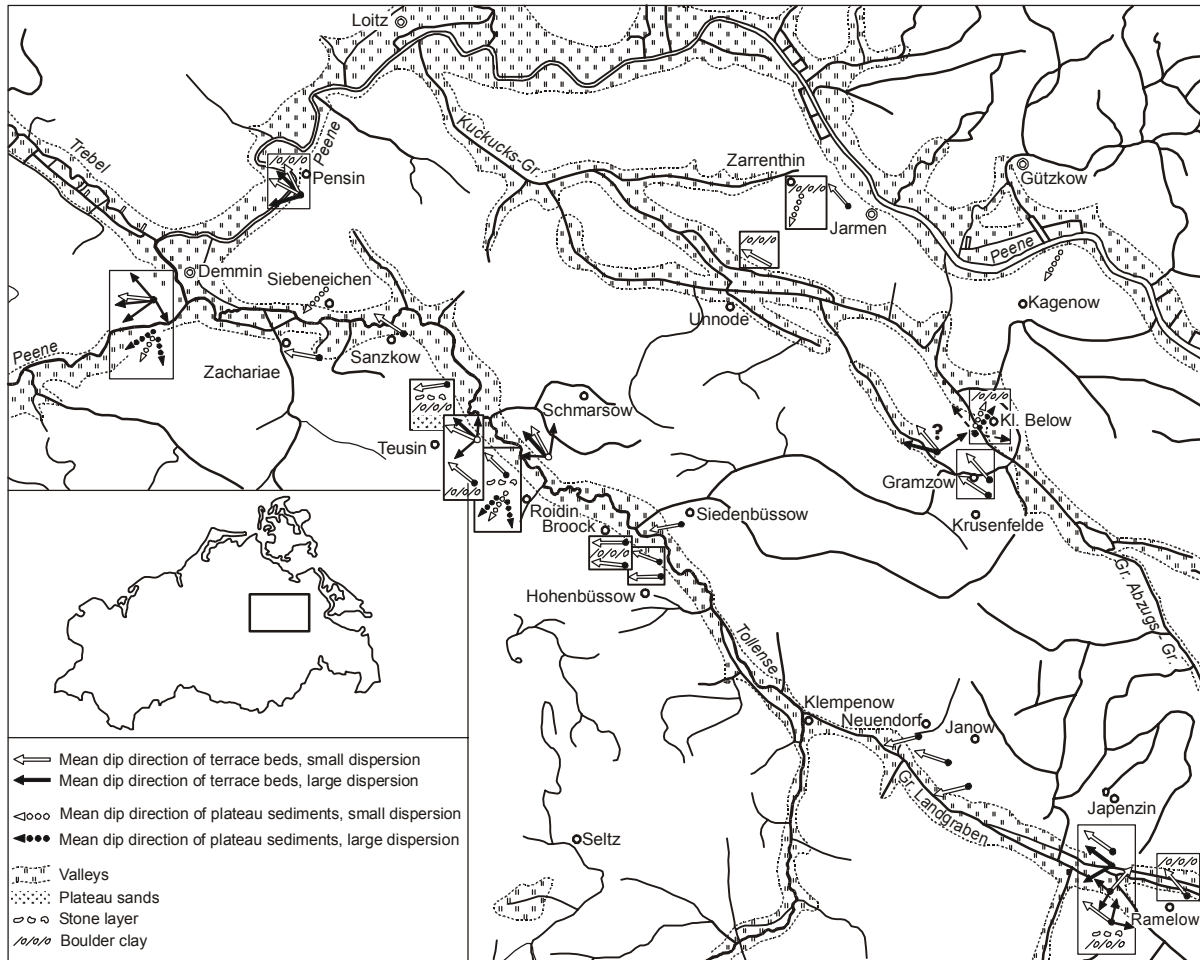
Fig. 1: Mean dip directions in terrace and plateau sediments which border outlet channels of the Haffstausee (after Janke, Reinhard 1968, modified)

2. stage: The area was covered again by an advancing ice sheet (Mecklenburg stage). In the basins and valleys to the south melt-water lakes emerged: Bützow and Güstrow basin, upper Tollense valley (Rühberg 1998).

3. stage: decay of the Mecklenburg inland ice sheet and formation of melt-water channels of all sizes and, in some places, of melt-water lakes. The main spillways discharged to the Mecklenburg Bay. Already before the final ice decay in the Oder mouth area, this way was also used by the waters draining the Haffstausee, particularly through the Grenztal (Fig. 1). In valley bends and extensions erosion terraces came into existence (particularly the 20 m-terrace) often characterised by complete reworking and redeposition of the Mecklenburg ground moraine. Accumulation occurred only in larger basins and connected tributary valleys. It was the stage, were braided rivers were developed, mostly on permafrost. The Warnow valley did not belong to the Haffstausee outflows. At the close of this stage, the formation of the valleys, far too wide for the Late glacial and Holocene rivers, was finished.

4. stage: The Late Glacial incision phase occurred during the younger period of the Oldest Dryas. Until now, the stage has been investigated only in the V-shaped valley sections of the Grenztal near Klempenow and the lower Peene valley near Görke, where basin sediments exist intercalated with Alleröd deposits. This early incision stage appears plausible due to the increasing melt-water masses, the thinning-out of the permafrost, particularly in the

channels, and finally by the very low-lying base level in what is today the Baltic basin. The pollen diagram Görke 1 (Fig. 2) from the lower Peene valley west of Anklam depicts in its basal part (Pollen zones II and III) the upper section of such a younger basin fill, consisting of clay and fine sand. The lower sections – not shown in the diagram – contained almost only re-deposited pollen grains from warmer periods.
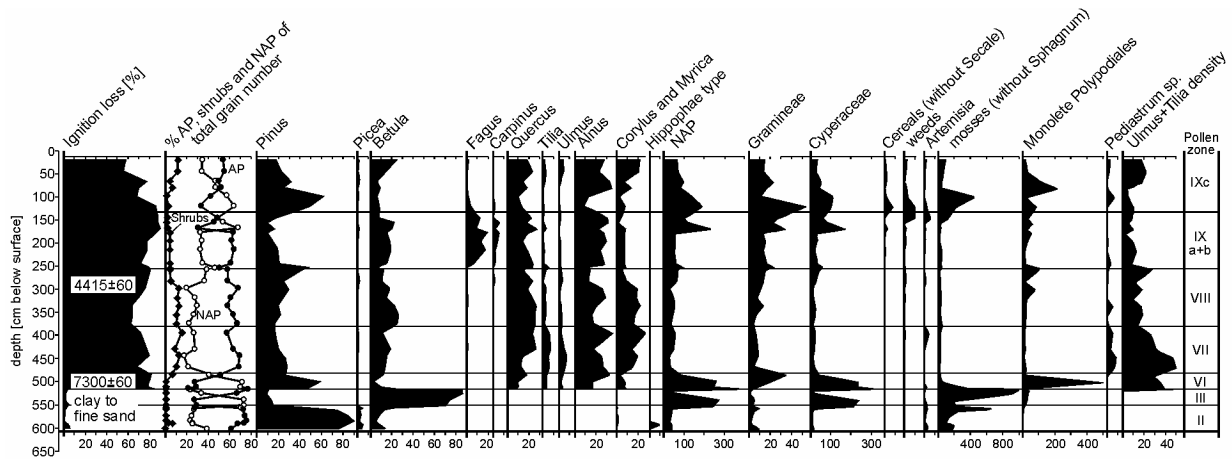

Fig. 2: Pollen diagram Görke 1, abridged version (the results of arboreal pollen are given in per cent; the others relate to 100 arboreal pollen in each case). The drilling point is situated in the lower Peene valley, approximately 50 m southwards of the river and northwards of the village Görke

5. stage: During the Meiendorf interstadial (Hippophae stage) until the Younger Dryas the water level rose again due to the final melting of the permafrost and the decay of dead-ice. The landscape´s surface was changed, lakes came into being and the drainage network was reorganized. With the growth of the melt-water basins retrograde erosion was intensified and many basins were taped by river channels. In the course of the Younger Dryas the run-off was probably reduced and slowed down (due to long lasting frost or permafrost) and widespread calm water sediments (silt, fine sand) were deposited, partly above Alleröd.

6. stage: In the period of the closure of the Younger Dryas until the Younger Boreal, a second time a strong river incision occurred (Early Holocene incision stage). V-shaped profiles came into being in all valleys, smaller flowing waters dried out. During the Boreal the valleys were almost free of mires and therefore, in the pollen diagram Görke 1 (Fig. 2), the pollen zones IV and V are missing. In the areas of what are today the river mouths, the valley bottoms were located 6 – 13m below the current sea level.

7. stage: This is the climate optimum stage, characterized by a fast rising ground and surface-water table due to a strong climate change at the transition Boreal/Atlantic and, sometimes later, in the coastal areas due to the rising sea level (Littorina-I transgression). In the initial stage, the relief of the valley bottoms was very uneven, and in numerous places shallow lakes came into existence, depositing calcareous and organic mud. Parallel to the rising sea level the gradient of the rivers decreased. At the same time, the run-off and the river width increased, and meander and oxbow-lake evolution occurred. A spacious mire development took place in the valleys, and the shallow waters silted up very fast. The further away from the coast, the later the valley-mire development started; south of the Pomeranian Terminal Moraine partly as late as during the Subatlantic.

The less steep valley bottoms of the main Baltic tributaries got a more or less closed peat cover already at the end of the Atlantic. The forests persisted near valley slopes. Due to decreasing nutrition supply from the mineral subsoil, the swampy forest peat and the regression peat of the shallow waters, deposited in the lower parts of the sediment sequence, were displaced by transgression peats. At least rudimentarily, the genetic/hydrologic mire types (SUCCOW, JESCHKE 1986) such as spring mire, percolation mire and transgression mire came into being. In 6,500 to 5,000 BP, the sea penetrated the funnel-shaped estuaries of the rivers Warnow, Ryck, Ziese, Peene and Uecker, which is evident from mollusc- or diatom-bearing sediments above –5m msl (Warnow, Ryck, Ziese, see GEINITZ 1902, V. BÜLOW 1933, Peenetal near Görke and Anklam, Uecker valley near Ueckermünde, see JANKE 1983 and BRAMER 1978). According to BRINKMANN (1958) the sea ingressed into the Warnow valley at least 15 km landward.

8. stage: Due to reduced or interrupted sea-level rise and climate changes between 5,300-5,000 and 3,000-2,700 BP the growth of the peat has been reduced or – near the valley slopes - even stopped. Generally, the organic deposits in the valleys, formed during 5,300 and 2,500 BP (Late Atlantic and Subboreal with the Urnfield Bronce Age) are less thick than those formed in the main periods of the Atlantic and Subatlantic. At the West Pomeranian coast the sea level had reached approximately –1m msl between 5,600 and 5,000 BP (KLIEWE, JANKE 1978, JANKE, LAMPE 2000) and was therefore much higher located than in the Kiel Bay and the North Sea. A glacio-isostatic effect is assumed. How far inland the phenomenon had effects is still unknown. The low-lying river-mouth areas were still under strong marine influence during the first half of the Subboreal (Littorina-II transgression). In the lower Peene valley this is evident from a *Campylodiscus-clypeus* diatom assemblage found in sediments near Görke.

9. stage: Permanent, at times stronger peat growth took place in this stage, particularly in the Roman Age and throughout the younger Subatlantic transgression. The water budget of the valley mires was anthropogenically influenced only locally. In the higher located peripheral parts of the valleys, the peat evolution only started in the Slavonic period. In the main valleys percolation mires predominated. The thicker the mires and the larger the distance to the valley slopes, the more the percolation mires suffered from lacking nutrition. Therefore, in the central places of some mires, raised bogs started to grow. The Subatlantic peat growth (stages 9 and 10) amounts to 1.5 – 2.5 m in some larger valleys (see profile Görke 1, Fig. 2)

10a stage: The stage is characterized by further increasing anthropogenic influence, such as different land use (meadows and pastures), peat digging and the first construction of drainage ditches, particularly since the medieval German Colonisation. Until now, the "black layer", a dark peat degradation horizon occurring mainly 30-60 cm below the ground surface, is known only from coastal mires (JANKE, LAMPE 2000). The mineralization had affect not only the peat of the Subatlantic transgression, but also parts of lower-lying, older deposits. The formation of the black layer is connected with the changed climate conditions in the Little Ice Age (long, cool winters and short, hot summers)

10b stage: Since the 18th century the valleys are influenced by intensive land use, such as drainage and river regulation. Many bifurcations – for instance in the valleys of Recknitz-Augraben, Ibitzgraben, Großer Kuckuckusgraben and Ziese – are probably man-made. In coastal mires, not influenced by dikes and drainage, the latest transgression stage, occurring since about 1850 is traceable by a 8-15cm peat column (JANKE, LAMPE 2000).

The perimarine valley sections which build the transition between the marine and terrestrial Holocene facies are only poorly investigated. They are characterized by an indirect interaction of the sea level, the ground water table and the sediment accumulation. The perimarine sections reach a height of up to 10m msl and comprise all coastal valleys with a very small gradient, e.g. the Peene valley up the Malchin Lake. REINHARD (1963) and RICHTER (1968) argued that the alternating sequence of peat and calcareous mud found in the Grenztal, the Kummerow Lake, the Teterow Lake and the Dahmer Moor was caused by 3 - 4 regression and transgression phases. The latter have been related to the Atlantic, the transitions between the Atlantic/Subboreal and Subboreal/Subatlantic and to the Subatlantic and connected to transgression phases in the Baltic. The origin of the two younger limnic intercalations is doubtful and needs further investigations, because they appear only locally and in different depths and do not cover the entire width of the valley or basin. In the Grenztal, for instance, the formation of the calcareous mud could also have happened as an accumulation in oxbow lakes.

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Palaeogeography and palaeoecology of Szczecin Lagoon

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Abstract

The studies revealed that during the Late Glacial and Holocene this area developed in several stages. In the Late Glacial the whole area studied constituted a low alluvial plain. At the transition from Younger Dryas to Holocene the alluvial plain was divided by the Odra river at the level of 10-11 m below sea level (b.s.l.). Along with the first phases of the Holocene marine transgression along the southern Baltic Sea coasts, the accumulation of the limnic-swampy deposits characteristic of anastomosing rivers began in this part of the Odra valley. At c. 6-6.5 ka BP, transgressive Littorina Sea waters flooded the area. At that time the Szczecin Lagoon constituted a marine bay in which a series of sands partly rich in malacofauna was deposited. The development of the Swina barrier resulted in the isolation of the embayment from the direct inflow of Baltic Sea water. The barrier is composed of two parts which developed from the sides of Wolin and Usedom Islands respectively. The process of this barrier development was rather fast.

Introduction

The present paper is based on the results of a large versatile project, supported by the State Committee for Scientific Research (6PO4E 00216), which was preceded by a geophysical survey of the Great Lagoon (Grosses Haff). In the first phase the research was focused on the possible recognition of the whole depositional sequence of the area studied during the time span from Late Glacial to today. This served as a basis to typify several key profiles in which almost all the series of the Szczecin Lagoon sedimentary infill are represented. Lithostratigraphic investigations of sediment cores taken from the bottom of the Szczecin Lagoon allowed the reconstruction of the main stages of the Baltic Sea's coastal sedimentary basin development from the end of the Late Glacial until recent times.

Methods

Seismo-acoustic recognition of the Szczecin Lagoon bottom was conducted by means of the sub-bottom profiler "Seabed Oretech 3010-S" (5 kHz) on board the R/V „Doktor Lubecki". Altogether 18 seismo-acoustic profiles, 200 km in length, were produced. Based on the results of the seismo-acoustic profiling, 27 sites were chosen for vibrocoring (Fig. 1). Particular cores of 3-4 meters in length were cut into 1 m segments and stored at a temperature of 3-4 °C. Under laboratory conditions, all the cores were documented photographically and their lithology was described macroscopically. Sub-sampling for the following analyses was done: granulometric, diatomological, palynological, malacological, geochemical and for ^{14}C dating.
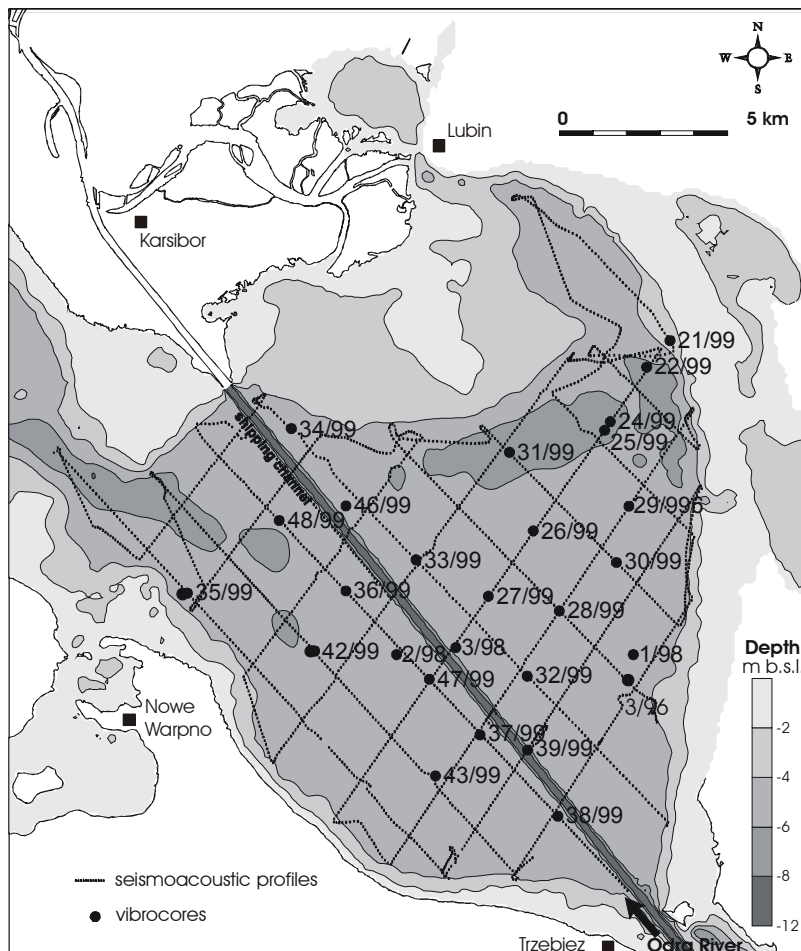
Fig. 1.
Position of vibrocores and seismoacoustic profiles in the eastern part of Szczecin Lagon (Grosses Haff)
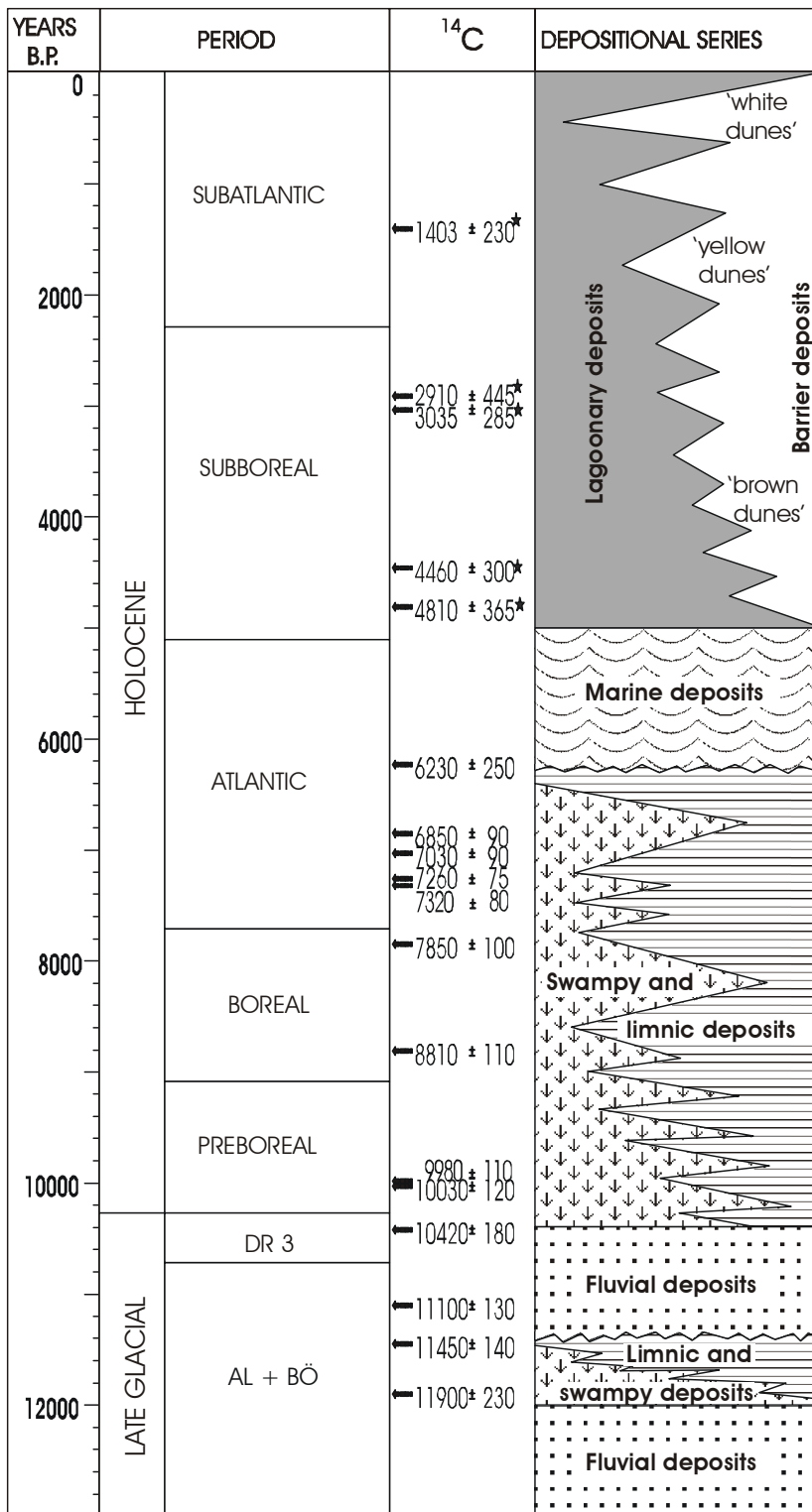
Late Glacial and Holocene stages of the Szczecin Lagoon development

The analysis of stratigraphical and spatial variability of the Great Lagoon sedimentary infilling made it possible to distinguish several stages of the development of this depositional basin (Fig. 2). Their preliminary chronostratigraphic position was based on numerous radiocarbon datings of limnic-swampy deposits (BORÓWKA et al. 2001).

The pre-Alleröd stage is represented by a series of fluvial sediments, the origin of which is related to the development of the lower Odra River valley from the end of last glaciation to the distinct climate amelioration during Alleröd. Within this period a complex of six terrace levels in the area of the recent Odra River valley and the Szczecin Lagoon was formed. The highest of them reaches c. 20 m a.s.l., whereas the lowest lies at c. 10 m b.s.l. (KARCZEWSKI 1968; DUDA 1999). The age of particular terraces has not yet been determined. However, it has already been documented that at a height of c. 8 m b.s.l., within fluvial deposits, thin intercalations of limnic-swampy deposits appear, which have been dated to Alleröd. It cannot be excluded that we are dealing with sediments deposited on the surface of the flood terrace of the contemporary Odra River.
Nowadays, it is hard to reconstruct the contemporary bottom of the Odra River Valley and the spread of the river bed itself. Based on the palaeohydrological studies (KOZARSKI & ROTNICKI 1977; KOZARSKI 1983; ROTNICKI 1983, 1991) conducted for the Odra River's catchment area and some of its tributaries, it is known that during the Late Glacial, at the bottom of some contemporary valleys, large meandering channels were formed. Compared with the Early and Middle Holocene period, they discharged several-fold higher magnitudes of water

(ROTNICKI 1983, 1991). However, it cannot be excluded that at the same time the lower Odra was a braided river, similar to the other rivers draining the northern slope of Pomerania (FLOREK 1991). This problem remains unsolved and its resolution will only be possible after detailed studies of all the fluvial sediments deposited during that period.

YEARS B.P.	PERIOD		^{14}C	DEPOSITIONAL SERIES

Fig. 2.
Late Glacial and Holo-cene stages the Szczecin Lagon development

★ after Prusinkiewicz & Noryskiewicz (1966)

The *Alleröd stage* is still poorly documented. It is already known that during this period some parts of the Szczecin Lagoon were filled in with shallow water bodies and covered by bogs and swamps. At that time, in the surroundings of the Szczecin Lagoon pine birch and pine forests developed. Patches of heliophilous vegetation were rather common and included tundra elements. This is evidenced not only by the results of palaeobotanical analyses (LATAŁOWA 1989, 1999; LATAŁOWA, ŚWIĘTA 2001), but also by well developed and widely distributed covers of fossil soils on Wolin Island (BORÓWKA et al. 1982, 1986).

The *Younger Dryas stage* is marked in the area of the Great Lagoon by a distinct acceleration of fluvial processes, and particularly by the aggradation of sandy deposits at earlier developed covers of Alleröd limnic-swampy deposits. In cores 36/99 and 37/99 the post-Alleröd fluvial deposits attain thicknesses exceeding 1.5 m. This situation was probably related to a deterioration of climatic conditions in the Younger Dryas. At that time, open-land vegetation spread at the cost of forest communities, soil erosion processes accelerated (LATAŁOWA 1999) and periglacial and aeolian processes also became more intensified (BORÓWKA et al. 1999a, b). Probably during that period the quantity of sediment load transported in traction and in suspension by Odra River showed a distinct increase. At the present stage of research it is not known how these processes affected the middle part of the Great Lagoon, where the Late Glacial fluvial deposits are recognised to a very limited extent.

The *Early and Middle Holocene stage* encompasses the time span from the beginning of the Preboreal to the second half of the Atlantic period (~10,250 – 6,200 yr BP). The Great Lagoon area was predominantly filled in with limnic-swampy deposits (Fig. 3). In large areas swamps with *Thelypteris palustris* and *Cladium mariscus* developed. Patches of water plants with nympheides as the dominant component commonly occured (LATAŁOWA, ŚWIĘTA 2001). It is very likely that during that time the Pre-Odra was an anastomosing river which flowed through swamps and reedy areas, similar to the recent lower Odra near Szczecin. In such cases one can observe a distinct stability of river beds and the limnic-swampy deposits are accumulated on the swampy flood terrace (GRADZIŃSKI et al. 2000).

The *Late Atlantic stage* marked the Great Lagoon area with a large marine transgression (the Littorina transgression). Almost the whole Great Lagoon at that time constituted an open marine bay extending southward into the lower Odra River valley up to where Szczecin is located (BORÓWKA, DUDA 2001). It also penetrated the mouth areas of small valleys reaching the Szczecin Lagoon - e.g. Uecker Valley in the area of Ueckermünde (BRAMER 1975). The contemporaneous water salinity was higher than in the recent Pomeranian Bay, as indicated by preserved shells of *Cerastoderma glaucum,* reaching a size characteristic of waters with salinity values higher than 6-7 ‰ (BORÓWKA et al. 2000). At the lagoon margins water plants with *Salvinia natans*, *Nymphea alba* and *Nuphar luteum* formed vegetation belts (LATA-ŁOWA, ŚWIĘTA 2001).
The duration and the rate of this transgression in the area of the Pomeranian Bay and the Szczecin Lagoon has not yet been satisfactorily identified. It cannot be excluded that it was a disastrous event as was suggested by ROSA (1963). It may have been that during extremely strong storms a sandy bar existing in the area of the Odra Bank and extending further eastward up to the region of Kołobrzeg was disrupted and destroyed (MOJSKI, ed. 1995; KRAMARSKA 1999). Radiocarbon datings of limnic-swampy deposits from the Pomeranian Bay (KRAMARSKA 1999) and from the Szczecin Lagoon (WYPYCH 1980; BORÓWKA et.al. 2001) show very similar ages for the deposits in both areas and indicate a relatively fast rate of transgression.
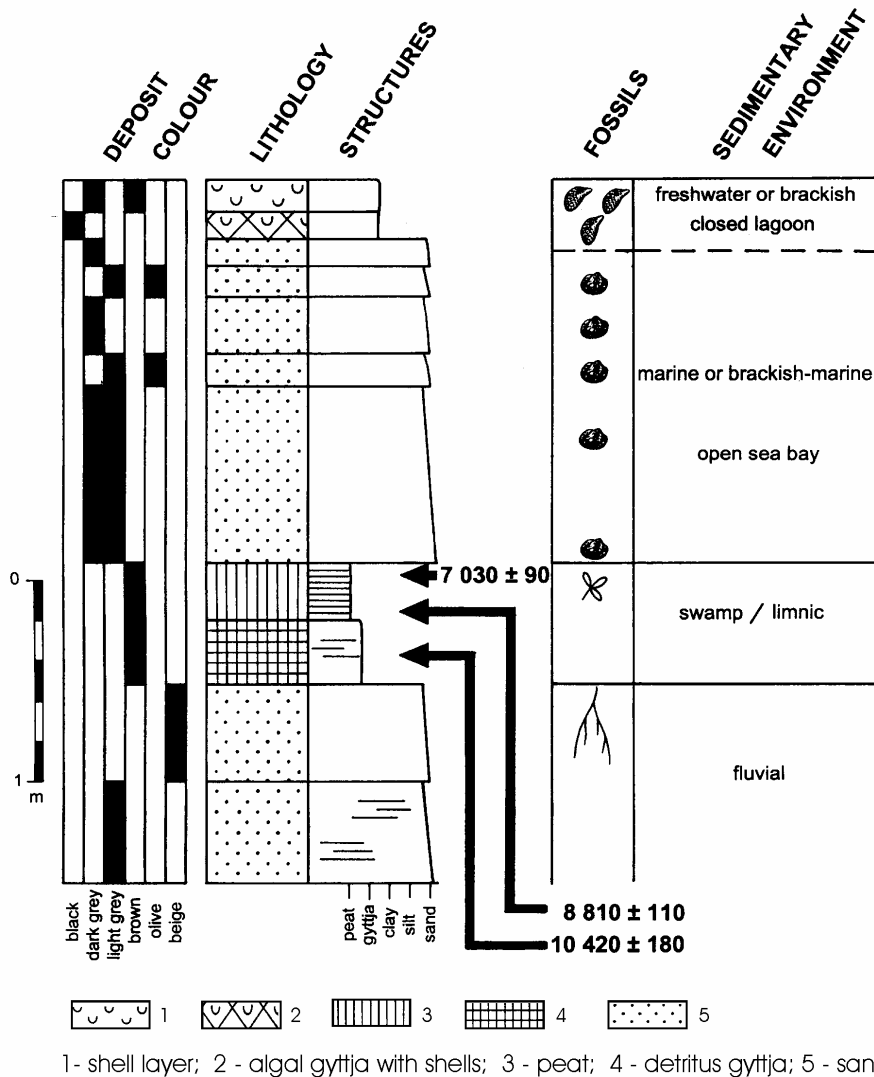
Fig. 3.
Core log 35/99

1- shell layer; 2 - algal gyttja with shells; 3 - peat; 4 - detritus gyttja; 5 - sand;

The *Late Holocene stage,* encompassing the Subboreal and Subatlantic periods, began to-
gether with the isolation of the Szczecin Lagoon from direct marine influences. Intensified
abrasion processes on the high morainic shores of the Uznam and Wolin Islands caused
rapid growth of spits and the development of a sand barrier in the area of the recent Świna
Barrier (KEILHACK 1911; PRUSINKIEWICZ, NORYŚKIEWICZ 1966). Simultaneously, the Świna
back-delta began to develop behind the barrier formation. Its submerged part (the Wyskok
Krzecki) extends far into the lagoon´s interior and dips with a relatively steep slope to the
depth of 6.5 - 7 meters.

The isolation of the Great Lagoon from direct marine influences resulted in a change in the
deposition processes. The content of organic matter rose, and marine molluscs were re-
placed by freshwater taxa (BORÓWKA et al. 2000). Lagoon series deposited during that time
also contain predominantly freshwater diatom flora and a large quantity of green and blue-
green algae remains (BORÓWKA et al. 1999, LATAŁOWA, ŚWIĘTA 2001). The accumulation of
this type of deposits has continued in the Great Lagoon until today. However, its sedimenta-
tion rate is highly variable and ranges from c. 20 cm during the last century in the Little La-
goon (LEIPE et al. 1995) to c. 50 cm in the eastern part of the Great Lagoon (BORÓWKA 2000).
MÜLLER et al. (1996) consider that the sedimentation rate of lagoon series can amount to 80-
110 cm per century in some parts of the lagoon. The lowest deposition rate, and perhaps
even its lack, is characteristic for the regions adjoining the western coast of the Great La-
goon, which are located on a distinct elevation of the fluvial series top.

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Pollen and diatom analyses from sediment cores
of the Szczecin Lagoon

WOLFGANG JANKE

The cores - mainly 4m long and taken between 1994 and 1999 from the Szczecin Lagoon - depict very distinct differences due to their location on a differentiated pre-Atlantic relief and to their relation to the Baltic and the Oder river. The oldest sediments which have been found are sands from the Late glacial Haffstausee. In higher located basin areas Alleröd peats were widespread deposited above them, in lower lying areas diatom bearing muds from the Alleröd and the Younger Dryas. These lake sediments are sometimes superimposed by peats from the Preboreal and the Boreal. In the boreholes 222100 (53° 43.025´N 14° 23.293´E) and 214220 (53° 48.94´N 14° 00.79´E) these peat show no visible transition to the overlying peats of the Early Atlantic. Due to a permanent rising water table a lake came into being covering almost the entire lagoon. The diatom bearing sands and calcareous muds deposited throughout this stage are located in an depth interval of –10,7 to –7,3 m.

The Atlantic carbonate bearing mud demonstrates a meso- to eutrophic diatom flora rich in species. In the borehole 18120 (53° 42.456´N, 14° 30.0´E, in the western part of the Großes Haff) a peat-like sediment was found (-8,1 to -7,9 m msl) showing copious development of *Thelypteris phegopteris* accompanied by *Lycopodium inundatum* and the epiphytic diatom *Epithemia turgida*. This layer corresponds already to the onset of the pollen zone VII.

In the middle and younger Atlantic the freshwater sediments are replaced by marine deposits, which are exclusively muds. Only some borings show thin sand bodies at the transgression contacts, which are located in the central part of the lagoon between 10-7m below sea level. Due to the diatom assemblage and the size and frequency of marine molluscs the salinity was at its maximum in the lowermost quarter or third of the marine sequence.

Due to the remarkable distance of the boreholes from the shoreline the pollen diagrams show less species and are less differentiated and resolvable than those from the mainland. In the following the diagram from the borehole 214220 (Kleines Haff, south of the Borkenhaken) are described (Fig. 1). The diatom diagram is the only one of all cores investigated which shows an uninterrupted distribution of brackish water diatoms up to the sediment surface and for the period before the closure of the barrier spit a permanent curve of *Operculodinium*. In all other cores Si-solution led to a more or less complete diatom disappearance and only the uppermost sediments representing the past 1,000 years at maximum contains a well preserved diatom assemblage, predominated by *Aulacoseira granulata*.

The interpretation of the pollen and diatom diagrams of sediment cores from the Kleines and Großes Haff reveal some discrepancies: while in the core 214220 the transgression contact is in about –8.65 m msl according to pollen analyses, the lower boundary from where brackish water diatoms appear is located at –9.25m msl in the Preboreal. As in the core KJB3 from the Kleiner Jasmunder Bodden we have to imagine, that at the onset of the transgression the diatom flora of the marine water was admixed to an older, hardly consolidated sediment in a very (?) short time, but without an corresponding admixture of pollen grains. Therefore these older sediments contain the diatoms brought by the Littorina Sea but not the pollen signal of the transgression period.
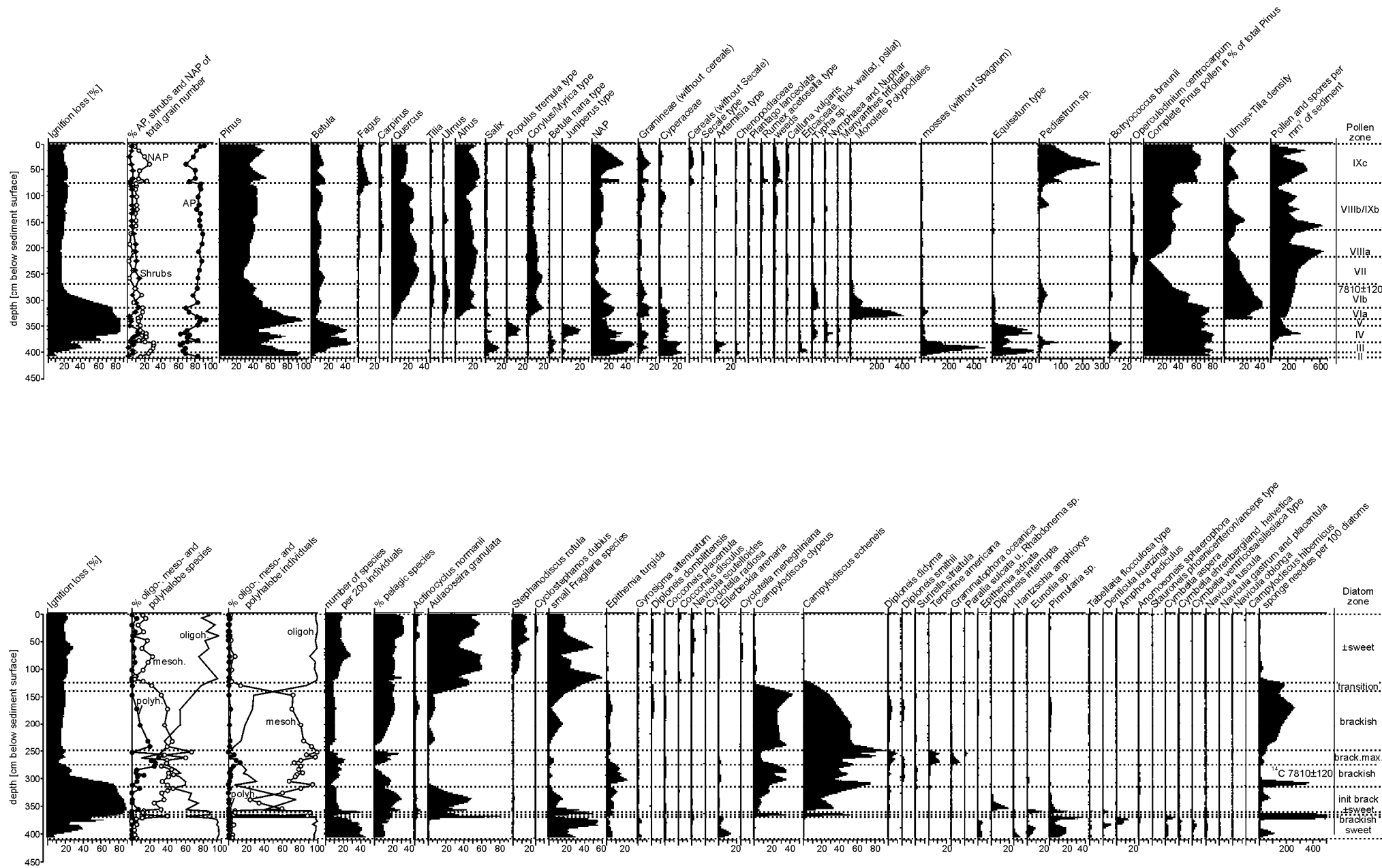
Fig. 1: Pollen and diatom diagram from the site 214220, Kleines Haff, Szczecin Lagoon (water depth 5,55 m)

From the investigator the complete-*Pinus* curve (complete *Pinus* = total *Pinus* – (incomplete *Pinus*/2)) has been introduced as an indicator for the hydrodynamic of the waters, in which the pollen grains were deposited. The value demonstrates the percentage of complete pollen grains – having two windsleeves – on the total number of the counted windsleeves. In the core sections, most strongly influenced by the Littorina Sea throughout the period while the barrier spits were still not closed, the complete-*Pinus* value is particularly low. The decrease in the middle and younger Atlantic and the subsequent increase between c. 2,000 and 800 BP are clearly shown by all diagrams. The complete-*Pinus* curve shows also relatively high values in the entire Late Glacial – even in the Younger Dryas – and in the younger Subatlantic. Parallel to the youngest increase of the complete-*Pinus* curve in the Subatlantic (not later than the onset of the German Colonization) an increase of *Pediastrum* is evident. Increasing eutrophication reveals also from the appearance of *Stephanodiscus rotula, Cyclostephanos dubius* and certain small *Fragilaria* species in the diatom flora.

Evolution of the Świna barrier spit

KRYSTYNA OSADCZUK

The Świna barrier spit is situated in the Odra river mouth. It is a barrier between the two Pleistocene push moraines of Usedom (Uznam in Polish) and Wolin (Wollin in German) islands. This barrier separates the waters of the Szczecin Lagoon from the Baltic Sea and consists of two sandy spits adjoining the morainic cores of those islands. The barrier origins are related to processes accompanying the Littorina transgression. It is a classical example of the gradual growth of sand spits in a lateral and longitudinal direction by the successive accretion of beach ridges or dune chains, thereby filling in an open bay between two opposed marginal basement cores.

The Świna barrier spit is composed of marine, fluvial and aeolian sand as well as swamp peat similar to the other spits. The spit marine basement is covered by a system of dune ridges which form the most characteristic relief of the barrier (Fig. 1). A detailed analysis of a computer-processed topographic map has revealed the existence of four morphologically distinct dune complexes. Apart from the three complexes distinguished by KEILHACK (1912, 1914), of so-called "brown", "yellow" and "white" dunes, an additional generation was distinguished within the last group which was termed "white dunes I". These four dune complexes differ in size, orientation, morphological axes and extent of soil cover (Figs. 2, 3).

The oldest dunes, called "brown" due to their brown illuvial horizon, form long and narrow ridges from 1 to 8 m in height and of a generally meridional orientation. They are straight and free-ending on the Uznam spit and curved on the Wolin spit. The brown dunes represent a succession of parallel beach ridges transformed into coastal foredunes. Peat-filled hollows separate particular ridges of the brown dunes. The radiocarbon dates on bottom peat deposits as well as palynological data indicated that the brown dunes were formed during the Subboreal and the earlier part of the Subatlantic period, at about 5,000 to 1,800 years BP (PRUSINKIEWICZ, NORYŚKIEWICZ 1966).

The second generation of dunes, called "yellow", reflects the next stage of the Świna barrier spit development. The "yellow dunes" are formed as parallel ridges, too, but they discordantly abut on the brown dunes. The parallel-oriented yellow dunes from 3 to 10 m in height are covered by weakly developed podzols with a yellow illuvial horizon.

The third type of dunes is represented by a formation of transgressive dunes (called "white I") invading the "yellow dunes". They are the highest dunes, up to 22 m high. As opposed to previously described generally straight ridges, they are sinuous in shape. These dunes are only about 300 years old. KEILHACK (1912, 1914) determined their age by studying of Swedish maps of 1694. The youngest coastal dunes ("white II") reflect the most recent and contemporary stage of the Świna barrier spit development. The relative height of these forms is about 7 m.

A detailed geomorphologic analysis as well as sedimentologic analyses of deposits building the dunes that have developed on the Świna barrier made it possible to reconstruct the conditions under which the spits were formed. The geological development of the Świna barrier

spit had four stages, probably closely connected with the successive stages of marine transgression and regression (Fig. 4).
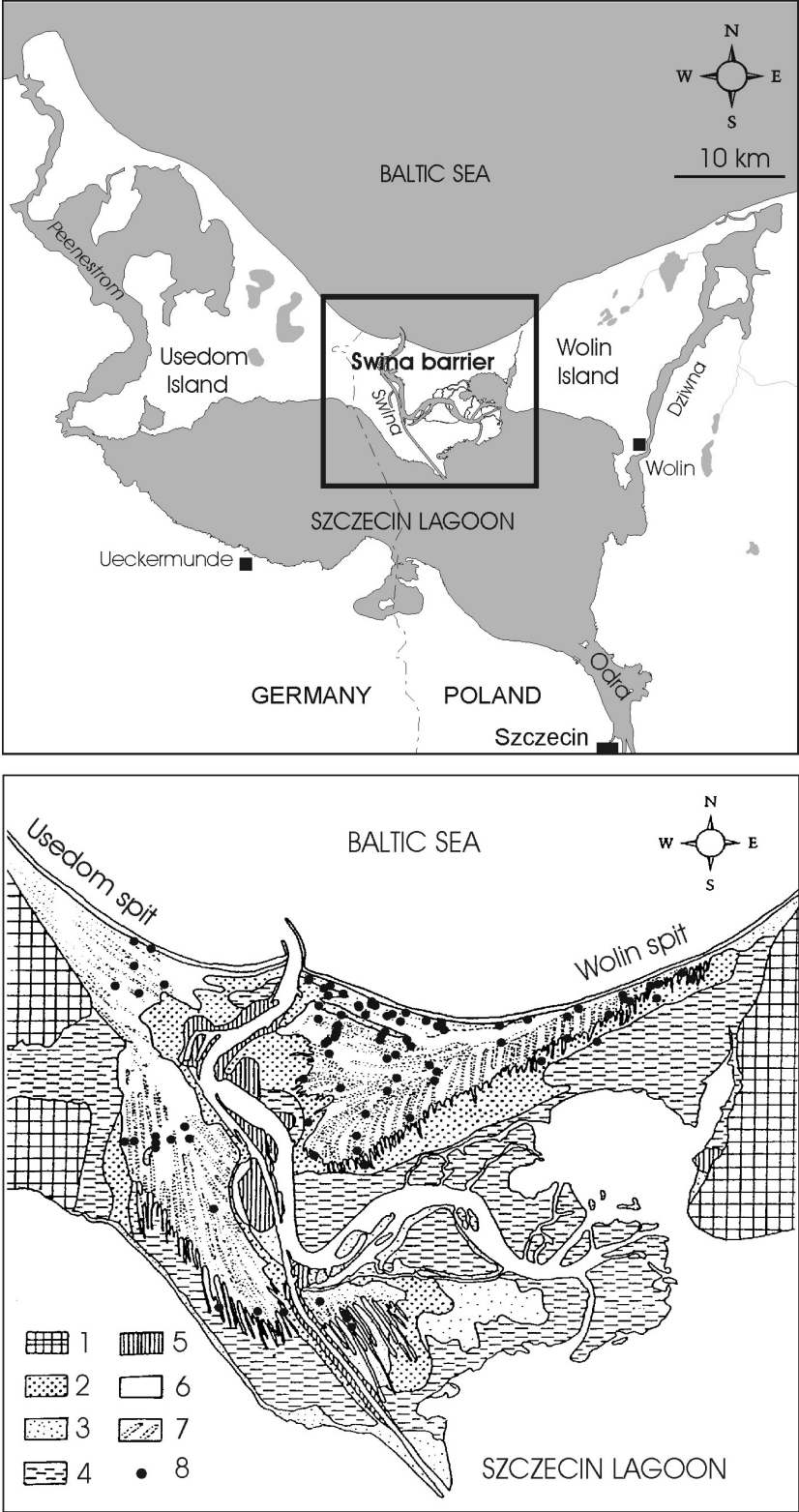
Fig. 1: Geomorphological map of the Swina Barrier with sampling stations
1 – Pleistocene morainic plateau, 2 – barrier sands, 3 – back delta sands,
4 – marshes, 5 – anthropogenic deposits, 6 – sandy beach, 7 – dunes,
8 – sampling stations
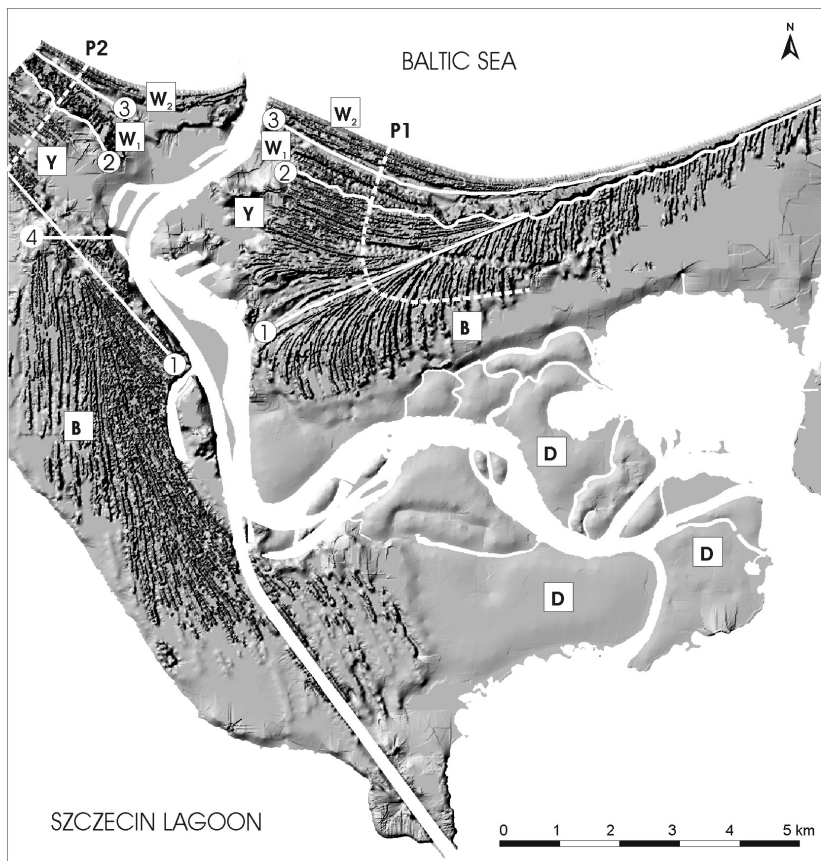
Fig. 2:
Shaded relief map of the Swina Barrier
B – brown dunes,
Y – yellow dunes,
W1 – white dunes I,
W2 – white dunes II,
D – back delta,
1 – border between brown and yellow dunes,
2 – border between yellow and white dunes I,
3 – border between white dunes I and white dunes II,
4 – old border between brown and yellow dunes (according to KEILHACK, 1912), P1 and P2 – morphological profiles
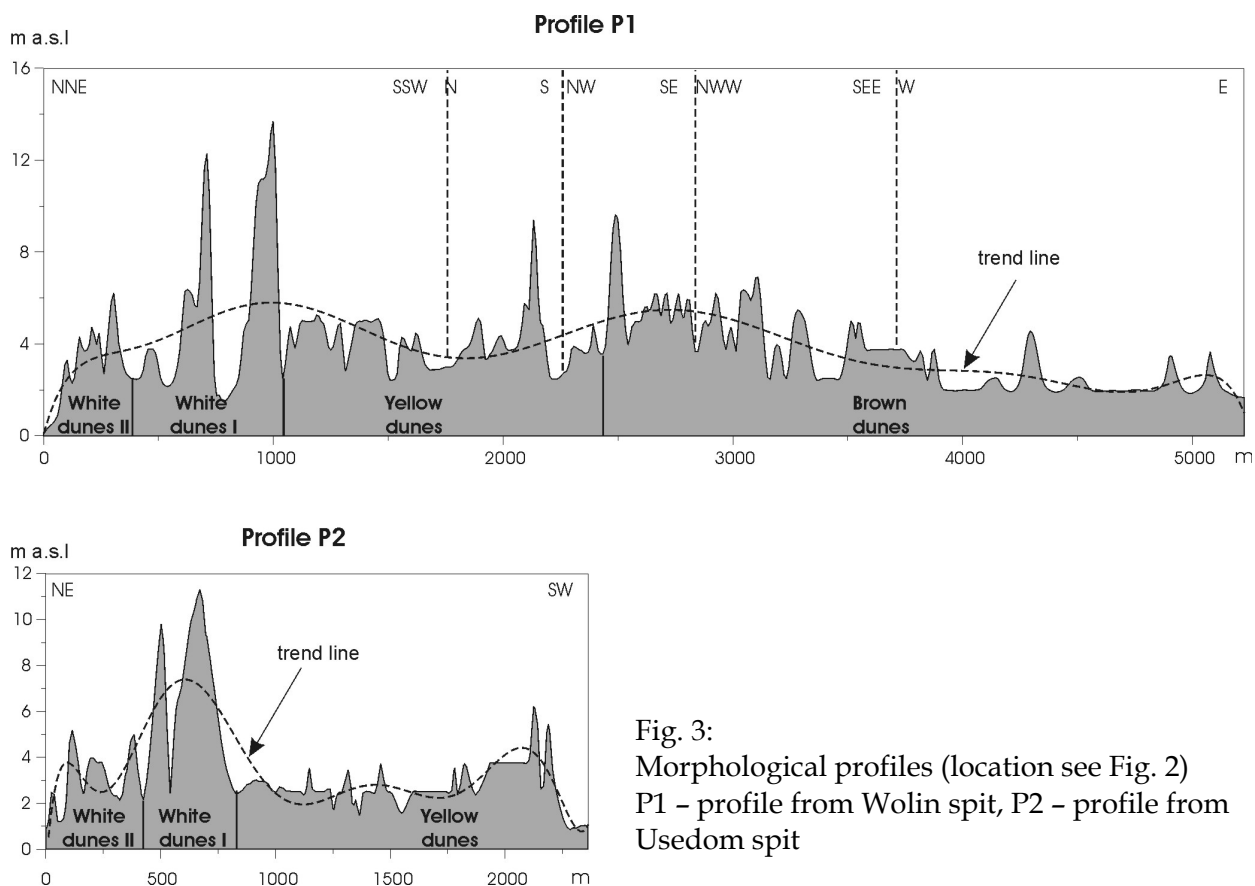
Fig. 3:
Morphological profiles (location see Fig. 2)
P1 – profile from Wolin spit, P2 – profile from Usedom spit

Stage Ia
1 - Littorina transgression (ca. 6200 yrs BP)
2 - initial phase of the Usedom spit development
(first 'brown dunes')
3-8 - next phases of the Usedom and Wolin spit
development (next 'brown dune' ridges)

3760±140 BP

Stage Ib
1....3 - continuation of the spits development with next
dune ridges ('brown dunes') and simultaneous erosion
of the Usedom spit and cutting of the oldest dunes

Stage II
1 - stabilisation of the sea level (? 2000 yr. BP) - initial
phase of the 'yellow dunes' development
2....4 - marine regression and widening of the spits toward
the sea; next ridges of the 'yellow dunes' have formed

Stage III
1 - stabilisation of the sea level; beginning of the foredunes
blowing out
2 - sea-level rise and formation of the transgressive dunes
('white dunes I') as result of the foredunes migration which
invade the older dune ridges ('brown' and 'yellow')

210±50 BP

Stage IV
1 - formation of the youngest foredunes ('white II')
2 - Swina back delta development

Field of 'brown dunes'   Field of 'white dunes I'

Field of 'yellow dunes'   Marshes

Field of 'white dunes II'   Morainic plateau

Fig. 4:
Evolution of the Swina barrier spit

Stage 1

As a result of the advancing Littorina transgression, about 6,200 years ago, the sand barrier between the Oder Bank and the eastern coast of the Pomeranian Bay becomes disrupted. The sea inundates the low-lying area between the uplands of Wolin and Usedom. An extensive bay formed which soon started to be cut off from the open sea: with the steadily rising sea-level and accelerated coastal abrasion, two spits started to be accreted to the abraded morainic plateaus of Wolin and Usedom islands. With the growth of those forms, ridges of foredunes parallel to the coastline developed on their surface, reflecting the successive p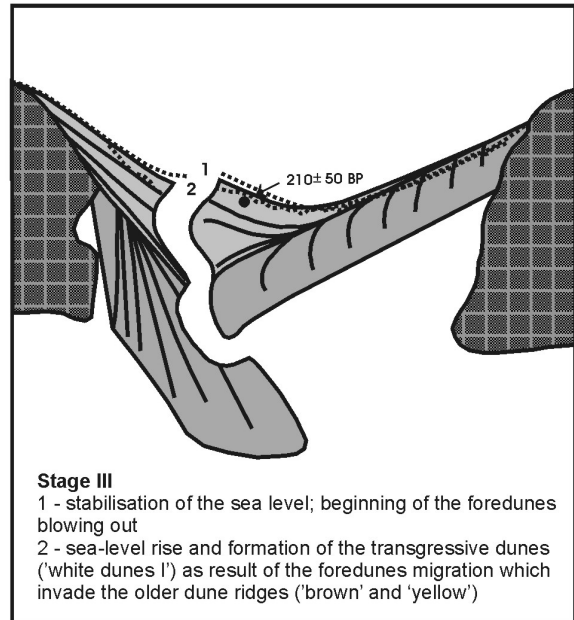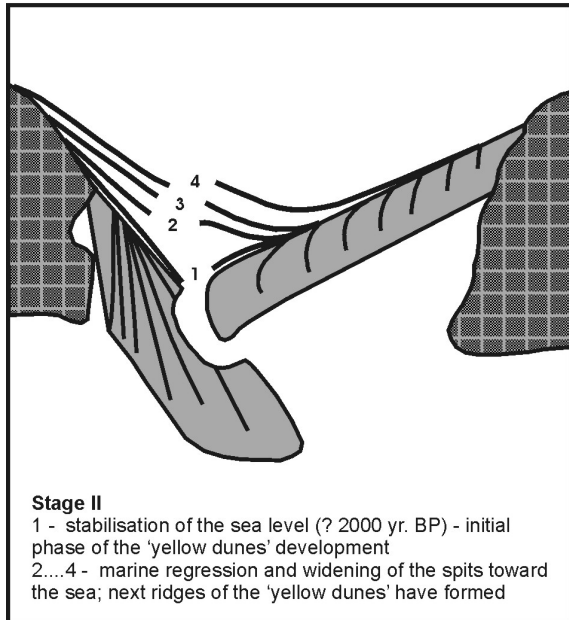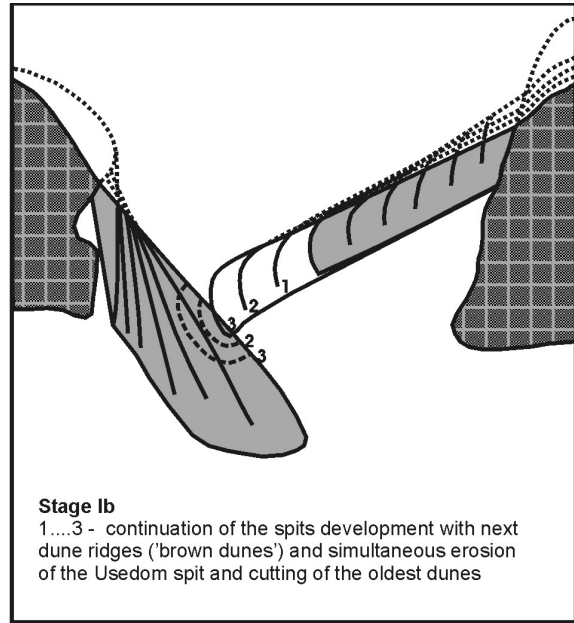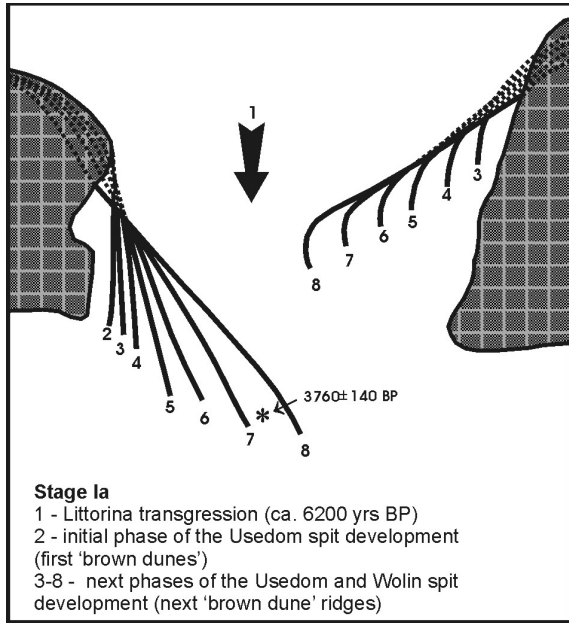hases of spit accumulation. The predominance of winds from the west made the Usedom spit develop faster than the Wolin spit. The shape of the Usedom spit and its rectilinear, free-ending dune ridges are evidence that this feature developed in an open body of water. In turn, the bends in the ridges on the Wolin spit are probably the result of its accumulation having been blocked by the Usedom spit which had formed earlier. As the Wolin spit lengthened, its initial dune ridges were gradually undercut, with the resultant destruction of their cliff sections. The westward elongation of the Wolin spit and the formation of the youngest ridges of "brown dunes" forced the water from the lagoon being closed by the spits to follow a different flow route. The readily visible erosional undercutting of the Usedom spit that disrupts the continuity of the long ridges of "brown dunes" is probably the effect of this forced water circulation.

Stage 2

The next stage of the Świna Barrier development is likely to have started when the sea-level had stabilised after the transgression. It is another period of accretion, connected with the development of the next generation of dunes, called "yellow". However, there are no well-documented data on the basis of which an exact starting date for this stage in the Świna Barrier formation could be established. An altered orientation of this generation of dunes, as well as the fact that the lithology of the sands that compose them is clearly different from that of "brown dunes", are evidence that the processes that led to the development of those sets of dunes were somewhat different. The morphological and lithological characteristics of "yellow dunes" show them to have been forming under the conditions of a gradual marine regression. This stage of the development of the Świna barrier can probably be associated with a lowering of the sea level in the Subatlantic period: 2,000-1,100 BP (KLIEWE, JANKE 1982), 2,000 - ? BP (ROSA 1994), 2,390 - ? BP (WOJCIECHOWSKI 1990), ? – 1,000 BP (TOMCZAK, 1995) or 2,900 - 400 BP (ROTNICKI 1999).

Stage 3

The third stage of the development of the Świna Barrier involves its further widening northward and the accumulation of dune ridges parallel to the coastline. Its specific feature is the appearance of a completely new formation of transgressive dunes called in this article "white dunes I". They formed as a result of the remobilization of the first ridges of foredunes and took the shape of a very high ridge (up to 22 m) with an irregular morphological axis. This encroaches upon the area occupied by yellow dunes and, where they are abraded away, directly upon brown dunes. The internal structure of "white dunes I" confirms their transgressive nature. They usually display large-scale, tabular cross-stratification. Their sands contain a predominance of fine fractions (usually in excess of 70%) and are the best-sorted of all the dunes of the Świna Barrier. Their appearance can be associated with the stage of a rising sea-level, as argued by COOPER (1958), PYE & BOWMAN (1984), SHEPARD (1987), HESP & THOM

(1990) and others. If this conception is right, the third stage of the Świna Barrier formation might have been initiated by another marine transgression. Apart from this initiating factor, i.e. rising sea-level, a significant condition that intensified aeolian processes leading to the development of those landforms was a depletion or even total disappearance of vegetation. It might have been brought about by man. The ^{14}C age (210 BP) of a bough found at the foot of a "white dune I" corroborates KEILHACK'S (1912, 1914) earlier assumptions about the initial date of the formation of white dunes.

Stage 4

In the final stage of the development of the Świna Barrier, a series of foredune ridges parallel to the coastline have been formed. This stage embraces the present time and is represented by "white dunes II". A decisive role in the present-day accumulation of spit material is played by the longshore transport of sediment, as indicated by the gradual fining of sand grains forming the ridges from the base of both spits to their tips.

Remote-sensing studies carried out in the 1990s made it possible to compare present-day and archival photographs of the Świna barrier area (MUSIELAK et al. 1991). While Poland's western coast has been generally observed to retreat at a rate of 0.35 - 1.2 m per year, the only fragment that has demonstrated a constant dominance of accumulation over the years is the Świna River mouth region. The widening of the spit occurs at a rate of up to 2 m per year (MUSIELAK, OSADCZUK 1995; ZAWADZKA-KAHLAU 1999).

In the hinterland of the spit, on the Szczecin Lagoon side, there a back delta of the Świna has formed, indicating intensive surges of sea water through the inlet during violent storms. Its basic pattern developed in the 17th and 18th centuries. Its further development seems to have been halted by the construction of a ship channel in the late 19th century. This is confirmed by a comparative analysis of aerial photos from the 1930s and the present time.

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Late Quaternary evolution of coastal lakes on Usedom Island

ULRIKE KERSTAN, PETER VOSS, WOLFGANG JANKE, REINHARD LAMPE,

Sediment cores from different lakes (Fig. 1) have been analysed to reconstruct their Holocene evolution, particularly the marine influenced stages due to sea-level variations of the Baltic.
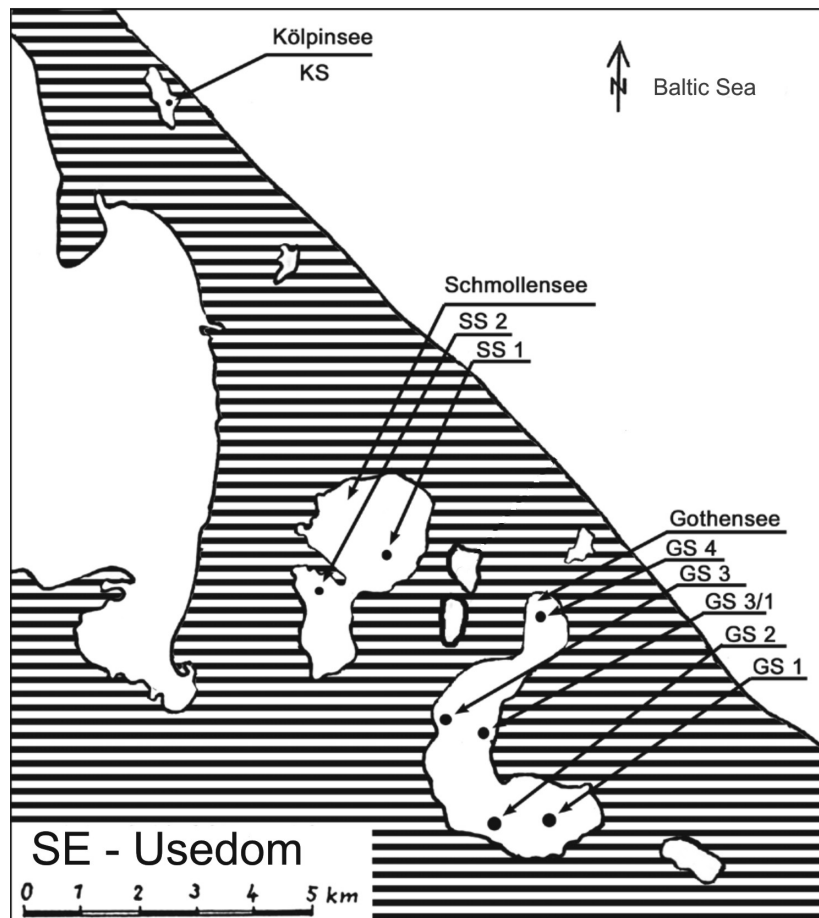
Fig. 1: The coastal lakes on Usedom Island and the positions of the drilling sites

Direct marine influences were only detected in the Lake Schmollensee where cores from both the southern and the northern basin were analysed (Fig. 2). The oldest sediment in the cores investigated was a peat deposited in the Boreal and the Early Atlantic. Later, in the southern basin a lake existed in which lake marl was deposited. The next evolution stage was mainly influenced by the Littorina Sea, which transformed the area into a sea cove. The silty muds, rich in organic carbon and shell remains (e.g. *Cerastoderma* sp.) were deposited in the period from the Late Atlantic (c. 7,000 – 5,000 BP) to the Subboreal and the Roman Age. The youngest sediment layer is a limnic fine detritus mud, which deposition started around the Slavonic Age (c. 1,300 – 800 BP). This corresponds roughly with the cutting-off of the cove from the Baltic and its transformation into a lagoon and, later, a lake.
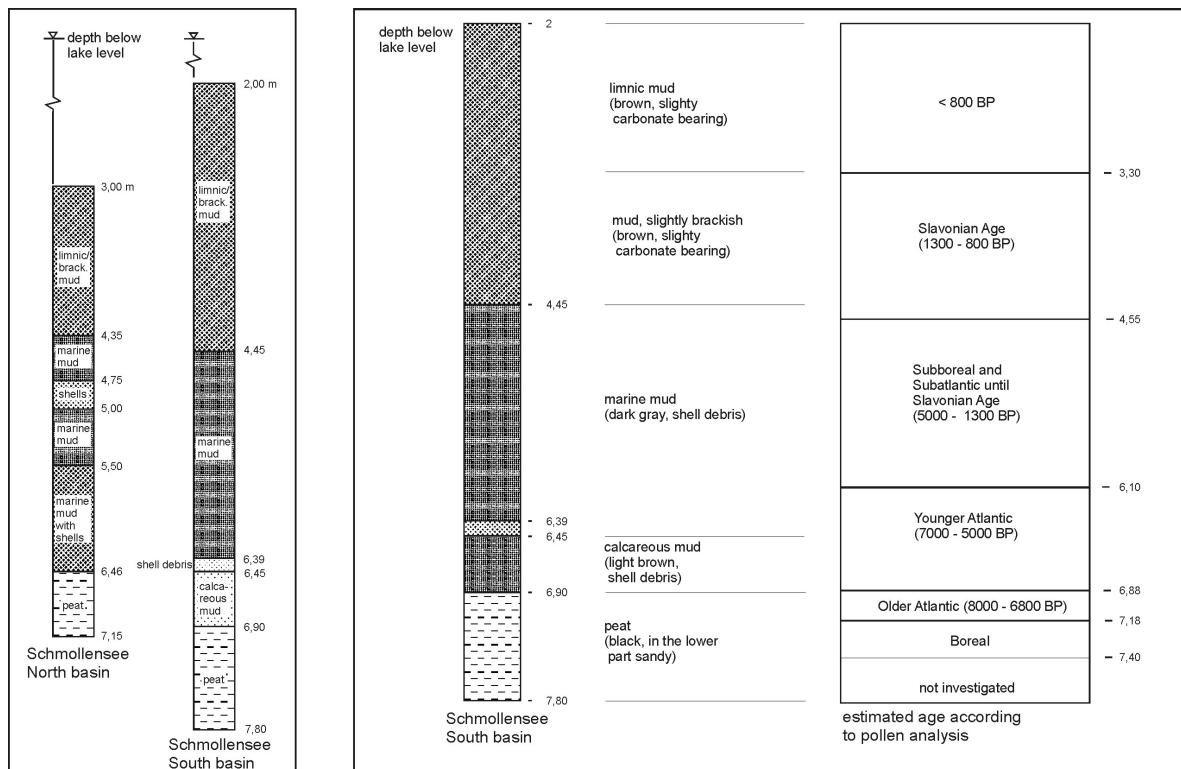
Fig. 2: : Stratigraphy of two sediment cores from the Schmollensee
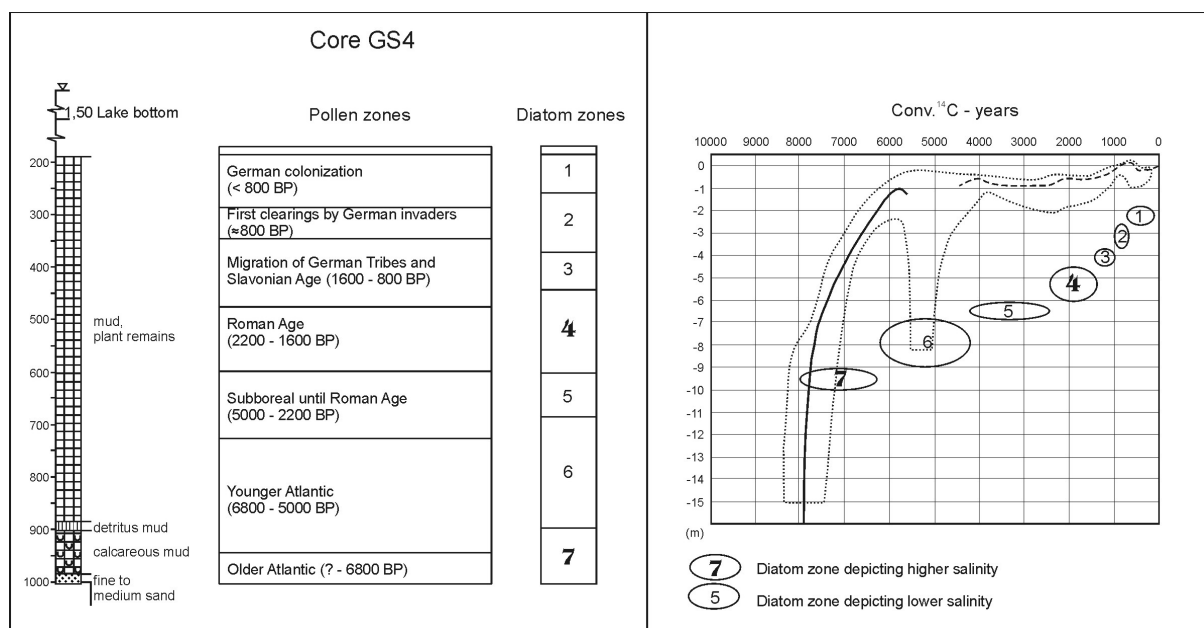
Fig. 3: Pollen and diatom zones as revealed from the core GS4/Gothensee and their relation to the sea-level curve according to JANKE, LAMPE 2000.

The sediments from the Gothensee comprise together the time interval from the Alleröd to the earlier Subatlantic, whereby the older sediments are contained in the core GS3 and the younger in the core GS4 (Fig. 3). Middle and Late Holocene evolution stages characterized by different salinities are particularly striking. A stage of higher salinity (diatom zone 7) corresponds to the Littorina-I stage in the Early and partly in the Late Atlantic. The stages 6 and

5 show a lower salinity and a wide freshening respectively. The prevailing diatom species are *Aulacoseira granulata, Cyclotella radiosa* and *Stephanodiscus rotula.* Again, a more brackish environment reveals from the diatom zone 4 in the Early Subatlantic, which could be related to the Littorina-III stage.

For the coastal lake Kölpinsee a continous limnic sedimentation could be proved interrupted by short marine influences, probably caused by flood events. Unfortunately, missing time markers prevent an unambiguous stratigraphic correlation.

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Coastal dynamics and coastal protection of the Island of Usedom

WALTER SCHUMACHER

The outer coast of Usedom is a simplified coast about 40 kilometres long. The whole middle part is characterized by abrasion (Fig. 1). The highest amounts of abrasion are found in the area of the Streckelsberg. This is shown by comparing the old Swedish map of 1695 with a map of 1986. The maximum coastal retreat amounts here to 300 metres. The Streckelsberg is a projection and the highest point (60 metres) on the outer shoreline of Usedom. Therefore its cliff has supplied most of the calculated sediment of Usedom in the past 300 years. A total amount of sediment of $40.7 \cdot 10^6$ m³ was eroded over this period (Fig. 1), which corresponds to a sediment supply of approximately $14 \cdot 10^4$ m³/year.
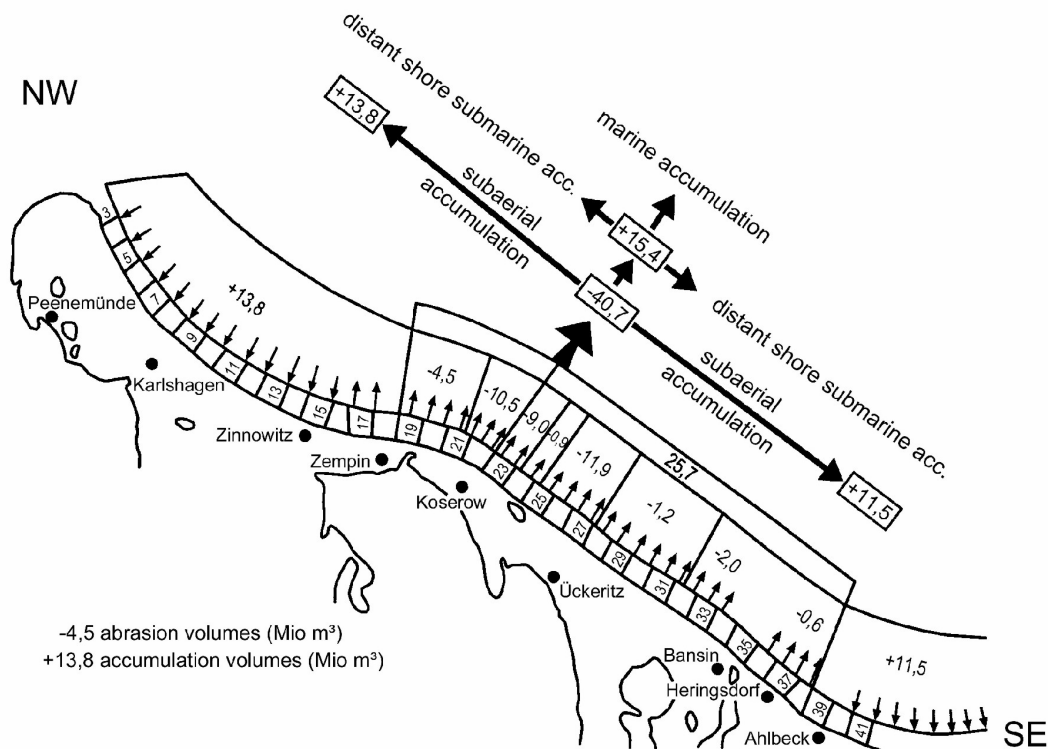
Fig. 1: Sediment movement along the open (outer) shoreline of Usedom Island over the past 300 years based on historical and modern maps.

Usedom Island reveals two main accumulation areas: the Peenemünde spit in the NW and the Swina gate in the SE reflecting an intense bi-directional longshore transport pattern. The calculated subaerial sediment accumulation amounts $11.5 \cdot 10^6$ m³ in the Swina gate and $13.8 \cdot 10^6$ m³ in the area of the Peenemünde spit for the past 300 years. Approximately $15.4 \cdot 10^6$ m³ sediment was available for submarine accumulation (SCHWARZER et al. in press).

The comparison between the older accumulation areas of Usedom shows the bi-directional longshore transport pattern too (Table 1). Computations for the area of brown, yellow and grey dunes show similar amounts (45-55 percent) to the north-west and to the south-east of the Streckelsberg. There is a slight trend towards an increase in the intensity of accumulation in the northwest from the past to the present. The recent energy flow is directed to the NW with 55-60 percent and to the SE with 40-45 percent.

Table 1: Comparision of tendencies to accumulation in NW and SE Usedom for different time spans (calculations of the dunes based on the works of WERNICKE 1929/30 and BOROWKA et al. 1986; calculation of the coastal accumulation 1700-1980 based on the work of ROMOND 1993; calculation of the distribution of wave energy based on the work of SCHÖNFELD 1993)

	accumulation in % NW-Usedom SE-Usedom		area of accumulation per millennium
brown dune phase 4700-1600 cal.BP	45	55	13,9 km^2
yellow dune phase 1600-700 cal.BP	48	52	13,9 km^2
grey dune phase 700- 0 cal.BP	49	51	13,9 km^2
coastal accumulation 1700-1980	54	46	-
distribution of wave energy: 1992/1993	55-60	40-45	-

This accumulation trend could suggest a change in exogenous agents. But this is not necessarily the case. The stronger retreat of the main source area „Streckelsberg" can lead to another angle between the coast line and the product of the exogenous agents (Fig. 2). The effect could be a stronger NW transport without a change in the result. Similar rates (13.9 km^2/millennium: Table 1) of dune development suggest similar exogenous conditions over the past 5000 years as well.

The development of the coast line of Usedom is directed to a concave graded shoreline with fundamental abrasion of the projecting point of the Streckelsberg (Fig. 2). A retrograding Streckelsberg endangers the southerly and northerly adjacent flat coastal areas to the south and north, especially their infrastructure. The old coastal engineers were always aware of this. Therefore they constructed a cliff rampart at the end of the 19th century. The protection of a navigation mark on the Streckelsberg and the diminution of sand silting in the harbour of Swinoujcie were further reasons. The cliff rampart was partly destroyed during the first major storm floods (1904 and 1913/14). It was not tended or repaired during or after the Second World War because there were many unfavourable circumstances like lee erosion and deepening of the shore platform (SCHWARZER et al. 1996). The old construction became a disturbance .
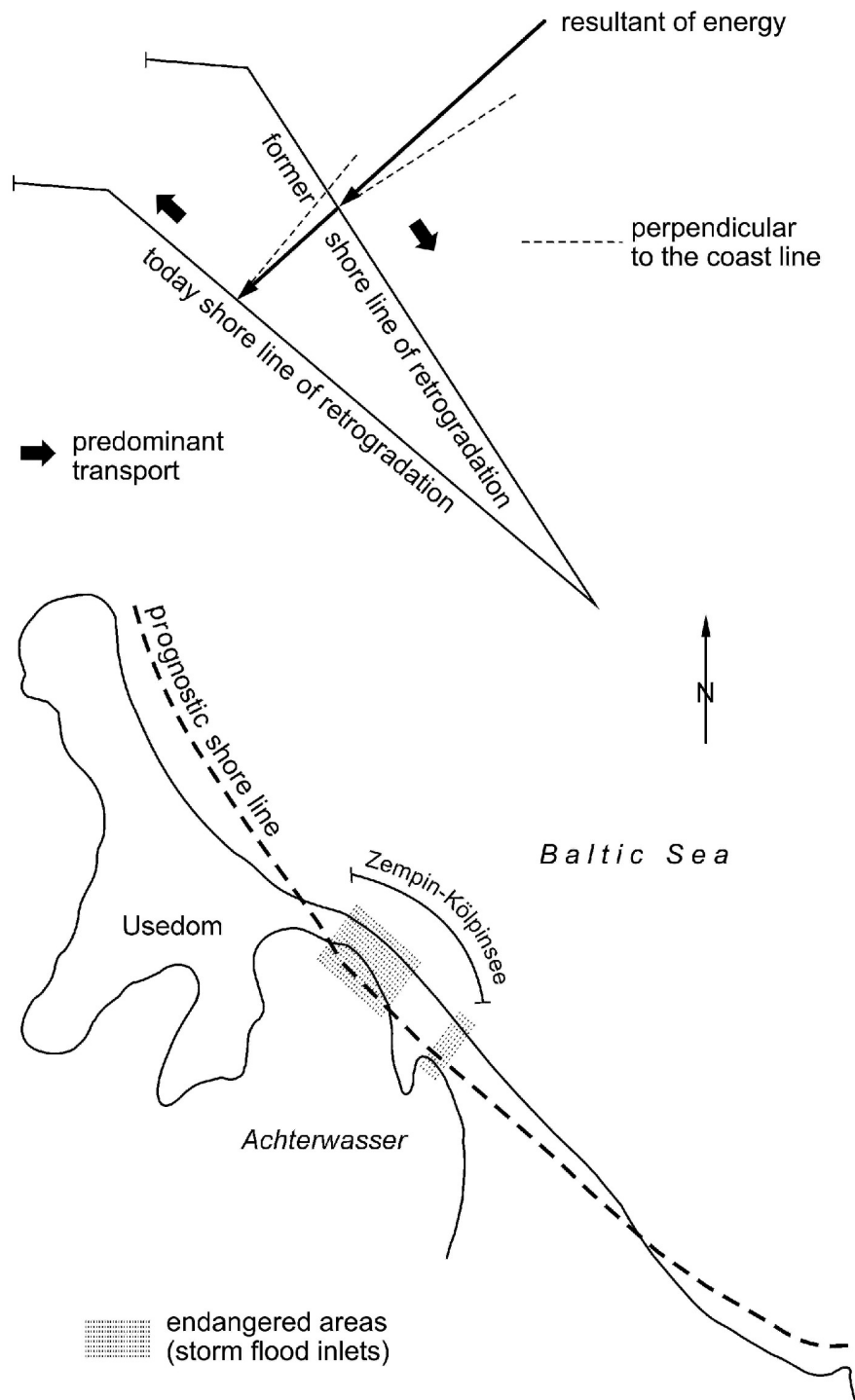
Fig. 2: The development of the coastal dynamics of Usedom Island in principle.

Therefore new measures of coastal protection were necessary. A complex system was constructed to provide a projecting point (Fig. 3B). The system is composed of three offshore water breakers, a beach nourishment and groins to the north and south of the Streckelsberg. The dangerous breach places along the flat coast also underwent new measures of coastal protection (Fig. 3A). From the sea to the land they comprise groins, beach nourishment, strengthening of dunes, coastal protection forest and elevation of the dykes.
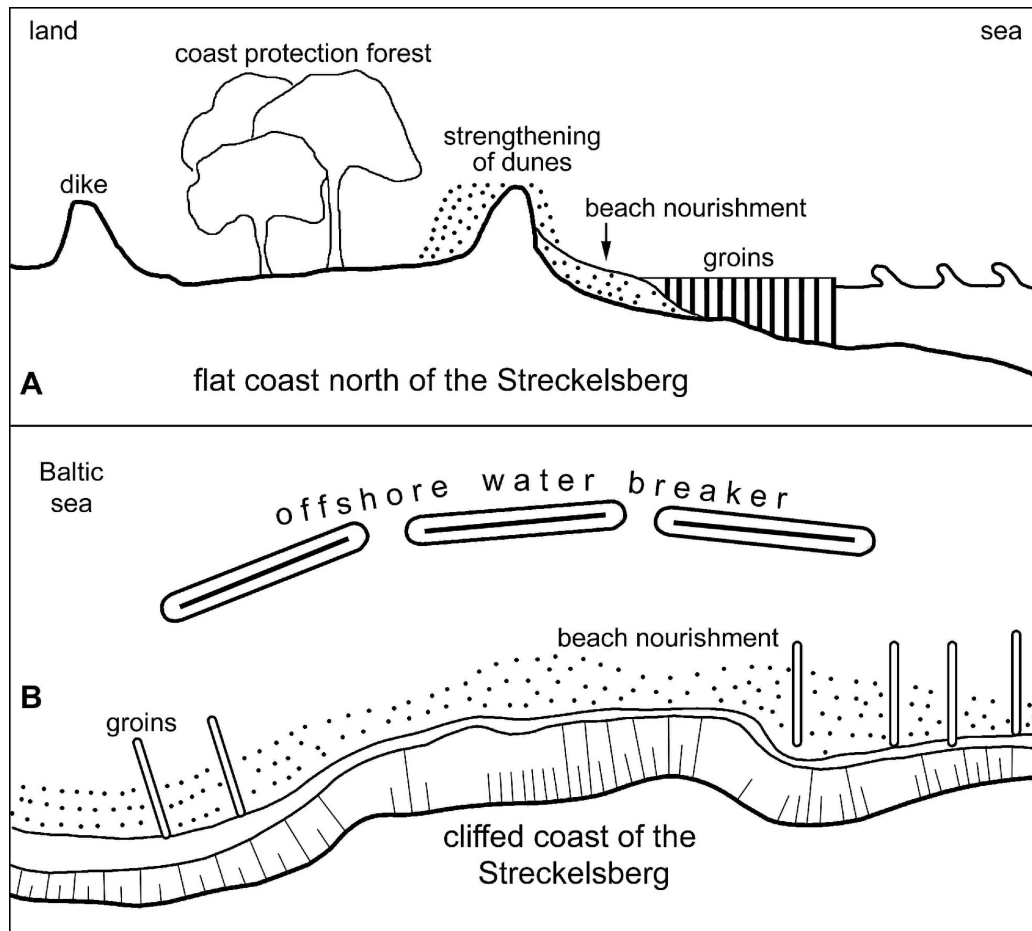
Fig. 3: Measures of coastal protection along the cliff coast (3B) and the flat coast (3A) of the Streckelsberg.

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Morphogenesis of the Gnitz peninsula

GÖSTA HOFFMANN

The Gnitz peninsula consists mostly of Pleistocene sediments. Strike direction of the sub-dued ridges is NNE-SSW. Cliffs, exposing the sedimentary sequence, developed at the coast which borders the Krumminer Wiek because westerly winds prevail. On the east coast of the peninsula the terrain is sloping gently towards the lagoonary basin of the Achterwasser. Holocene deposits cover the Pleistocene/Late-Pleistocene formations. The southerly tip ("Möwenort") is a small spit, formed by longshore transport processes during the Holocene. There are two different scenarios of Pleistocene evolution. KLIEWE (1960) and NIEDERMEYER (1995) interpret the glacial deposits as part of a boulder belt formed by a Late-Weichselian ice advance ("Velgaster Staffel" of the Mecklenburg stage). RÜHBERG (1995), MÜLLER et al. (1995) consider deposition of the sands in ice rifts and as fillings between vast dead-ice fields. In this case the deposits were not related to moving glacier ice. According to HAACK (1960) an ice-dammed lake developed in the Achterwasser. Due to melting (dead-) ice a centripetal drainage pattern generated. Terraces in elevations of 1-5 m in the surrounding of the lake led to the conclusion that the water level reached 5 meters. During this period erosion formed the first cliff sections which were partly reactivated during the Littorina-transgression.
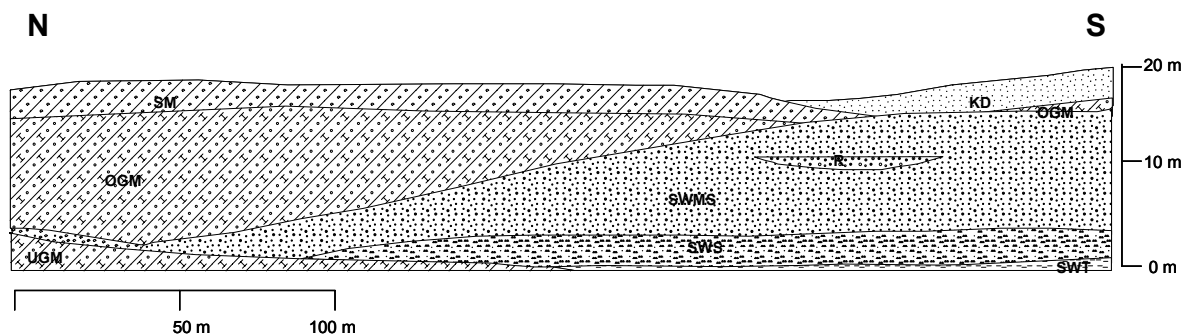
Fig. 1: Gnitz peninsula – schematic profile of the cliff section
Pleistocene sediments: UGM - till (diamicton), SWT - melt water deposits (clay), SWS - melt water deposits (silty fine sand), SWMS - melt water deposits (medium sand), R - channel cast (coarse sand), OGM - upper diamicton (till), SM - solifluction mass (diamicton), Holocene sediments: KD - cliff top dune (fine sand)

The Pleistocene sediments the peninsula consists of are exposed at the cliff facing the Krumminer Wiek. At the bottom (Fig. 1) the sequence starts with a grey-brown, jointed, solid, clay-rich till. In parts gravel and sand cover this unit, sometimes demonstrating a remarkable layer of erratic boulders. It is interpreted as an erosion surface. Macroscopic unfossiliferous, planar parallel laminated clay and silt interbeddings superpose the till locally. Obviously, the deposition took place in a calm, deep melt-water lake. The stratigraphy is not known. Towards the top an increase in grain size can be observed, which points to slowly intensified fluvial processes within the lake. Finally, the top of the sequence consists of medium to coarse sand. Gravel can be observed as channel-casts fillings. Allochthonous Tertiary remnants of brown coal and amber are enriched in layers. A second till is overlying the glacio-

lacustrine to glacio-fluvial unit. It is a diamicton as the older till but with less clay. It is not jointed, has a brown colour and is only sporadically present. Whether it is a till in the traditional sense, deposited by moving glacier ice or a proglacial solifluction mass deposited during periglacial conditions is not completely understood. Water escape structure can be observed in the underlying sand and gravel bed, piercing through the upper diamicton. Often the top of the cliff section is made up of cliff top dunes and solifluction masses.

The same sequence of Pleistocene to Late Pleistocene sediments can be observed on the east coast of the peninsula (Fig. 2). Here these formations are covered by Holocene deposits. Peat, fine sand and mud represent the filling-up process, due to Holocene sea-level rise. The bordering lagoonary basins Achterwasser and Krumminer Wiek are still linked to the Baltic Sea. HOFFMANN & MUSOLFF (2000) give a detailed overview of the Pleistocene and Holocene evolution of the east coast. The sediment sequence starts with a flat lying, solid, clay-rich till. The overlying fine to medium sands, more or less homogenous, carbonate bearing and unfossiliferous, reach a thickness of up to 13 meters. Locally this unit is lignite-bearing. Comparable to the cliff section, the upper diamicton is sandy, unconsolidated and only sporadically present.

Pleistocene sediments

UGM: lower diamicton, till

UPS: lower melt water sand

OGM: upper diamicton, till

OPS: upper melt water sand

Holocene sediments

HT: peat

HSm: fine sands, molluscs

HM: mud

HTv: peat

HKd: cliff dune
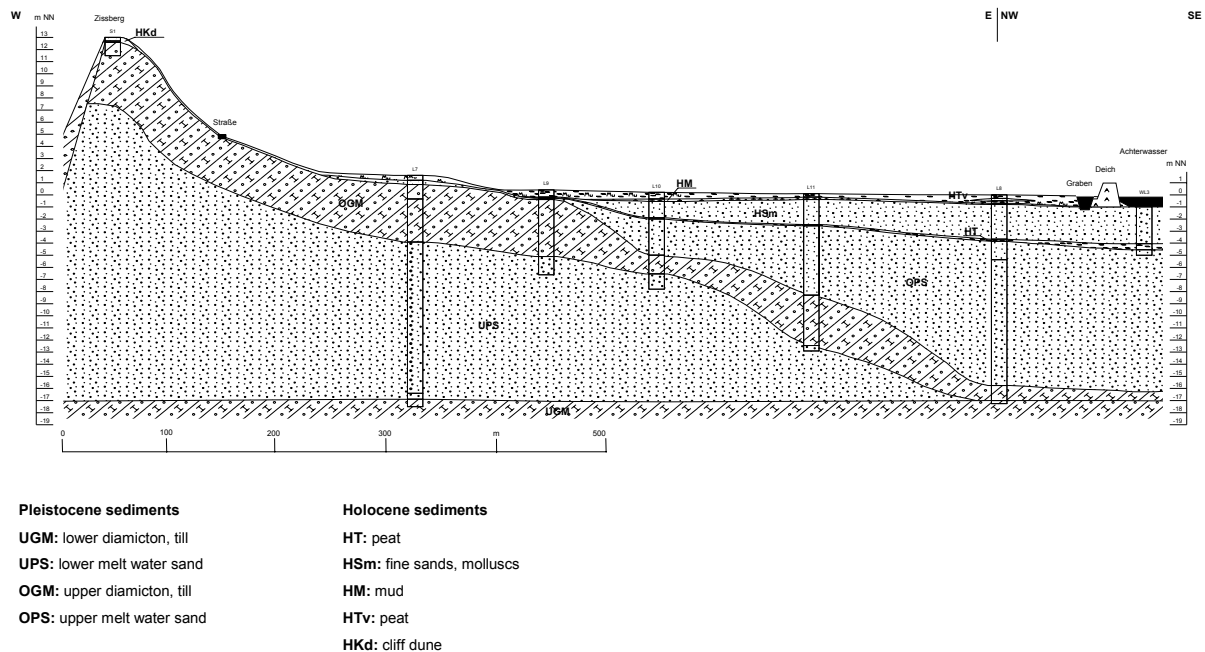
Fig. 2: Cross-section through Quaternary deposits on the east coast of the Gnitz peninsula

A unit of fine to medium sand up to 10 meter thick is bedded in between the upper diamicton and the marine deposits. Accessory constituents are silt, coarse sand and gravel. The colour varies between grey and grey-green. A slight calcium carbonate content can be realised. Plant remnants occur quite often, charcoal was noticed sporadically. The sedimentary conditions, described as late glacial melt-out accumulations by HOFFMANN & MUSOLFF (2000) which matched with the ice-dammed lake of HAACK (1960) are supplemented by the idea of a greater sedimentary basin with input from the Odra river. The marine deposits show a shifting of the shoreline facies in place and time. Analyses of the mollusc assemblage contained reveal a decreasing salt water influence. Peat is the most common deposit at the surface of the east coast sediments. Today, dikes prevent the area from flooding so that stock farming is possible.

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The Peenemünde-Zinnowitz area – the Holocene evolution
of a coastal lowland

GÖSTA HOFFMANN, REINHARD LAMPE, REGINE ZIEKUR, ROLF SCHURICHT

The Peenemünder-Zinnowitzer lowland covers the northeastern part of Usedom Island. It is one of the three large Holocene lowlands of the island (cf. C-1).

KLIEWE (1960) determined the size as 51,7 km². Characteristic is a plane relief with elevations of no more than 1 m, partly lying beneath the water level. An exception is a dune belt covering the lowland on the outer coast. Large parts of the lowland consists of meadow bog soil. There are two watercourses running from the lagoonary basin of Krumminer Wiek in northerly direction. The smaller Kleiner Strumminsee is drained nowadays. In order to enable agriculture the whole area is drained by ditches, the water is pumped into the Krumminer Wiek. The bedding conditions of the sediments deposited here during Late Pleistocene and Holocene reflect different phases of accumulation and erosion. Two channels, incised into early Holocene deposits have been detected (HOFFMANN 2000). A total of seven evolutionary stages could be reconstructed, controlled by different water levels during the palaeohydrological evolution.

The Late glacial and Holocene sequence starts at the bottom with a cohesive, calcareous grey till. According to LANGER & KRIENKE (1983) it is either the basal till of the Pomeranian or the Mecklenburg advance of the Weichselian glaciation. The surface of this unit is more or less even in depths of -18 m. Only to the west it is ascending and finally forming the terrain surface.
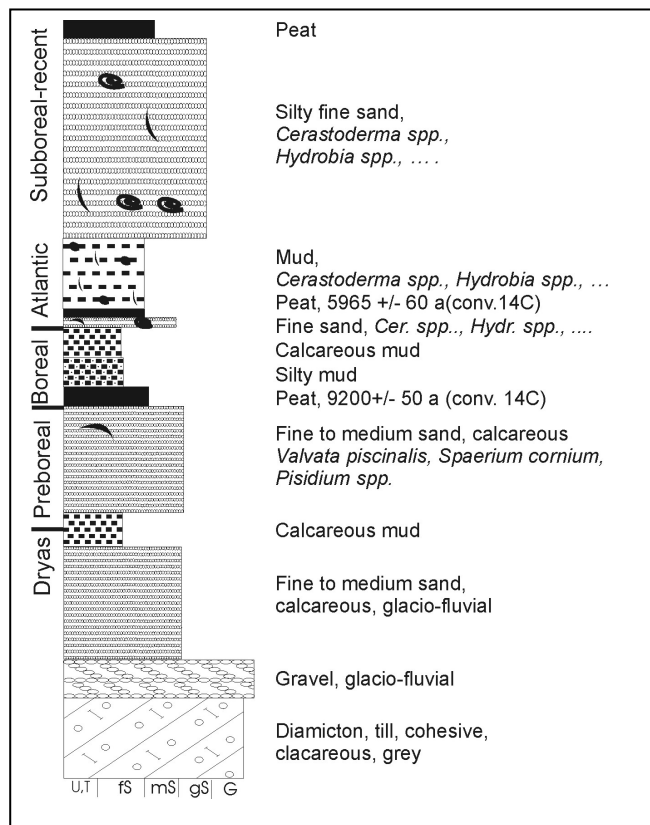
Fig. 1:
Columnar section of the
Peenemünde-Zinnowitz lowland

The till is overlain by coarse clastic deposits which pass into glacio-fluvial, unfossiliferous, slightly carbonate bearing fine to medium sands. Their thickness reaches up to 8 meters. Locally limnic calcareous mud has been found situated above the sands. Pollen analysis revealed sedimentation during Younger Dryas/Preboreal. Similar to the glacio-fluvial sands in respect to their lithological composition is the overlying bed of calcareous fine to medium sands (Fig. 1). Sporadically *Valvata piscinalis*, *Sphaerium corneum* and *Pisidium spp.* can be observed within this bed. According to LOŽEK (1964) they would tolerate a maximal salinity of 4 ‰. The habitat is described as calm to slow floating waters. Because of erosive processes this bed is preserved only locally. Missing lithological differences between the sand beds do not allow a definite classification of samples. The age of an overlying peat could be determined as 9,200 ± 50 years BP (conv. ^{14}C). Peat-growth points to a falling water level, therefore it is believed that the water-level reached – 5,50 m at this time and the depression was accumulated up to this height.
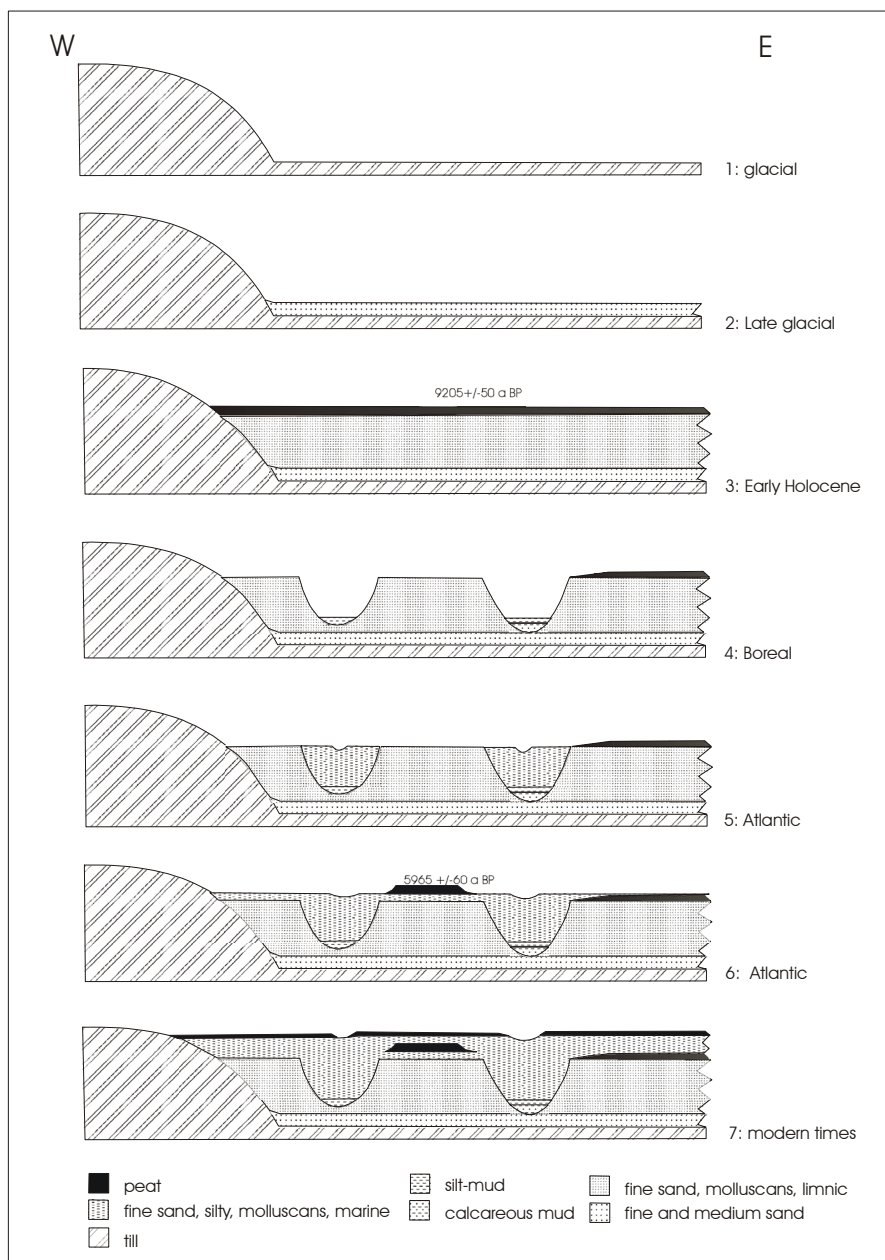
Fig. 2: Evolutionary stages of the Bannemin area

Afterwards the landscape was eroded. Two channels were incised into the late glacial and early Holocene deposits (Fig. 2). At the bottom of the channels deposition continued with fine clastic material. Outside the channels terrestrial conditions without sedimentation are to be noted. According to pollen analysis the oldest sediments at the base of the channels (calcareous and silty muds) were deposited during Boreal. The ostracod association revealed a limnic environment. Marine deposits (detritus- and mollusc-rich muds) follow. Dominating species of molluscs are: *Cerastoderma spp.* Subordinated *Mytilus edulis, Scrobicularia plana, Macoma balthica, Theodoxus fluviatilis* and *Hydrobia spp.* occur. Sporadically *Littorina littorea* was registered.

Layered organic beds, 10-40 cm thick, were found locally. Especially in depths of around – 5 m a wide distribution of this alluvial peat occurs. Radiocarbon dating points to deposition during early Atlantic 5,956 ± 60 years BP (conv. ^{14}C).

Within the marine deposits different sub-facies types can be defined. Most notable are variations in grain size and molluscs distribution. Most hydrodynamically influenced are the channels. As a result, coarse-grained sediments (medium to coarse sands), were deposited here. Wind-generated flats (Windwatt), as described by LEHFELDT & BARTHEL (1998), are believed to be the paleoenvironmental conditions under which most of the silty fine sands were deposited. The process of alluviation ends with peat in the hinterland of the Peenemünde-Zinnowitz lowland. Locally open waters still exist, such as the Kleiner and Großer Strumminsee. In historical times these have been reactivated as storm surge channels (BURKHARDT 1909). Fig. 3 depicts a cross section from the Krumminer Wiek to the Baltic.
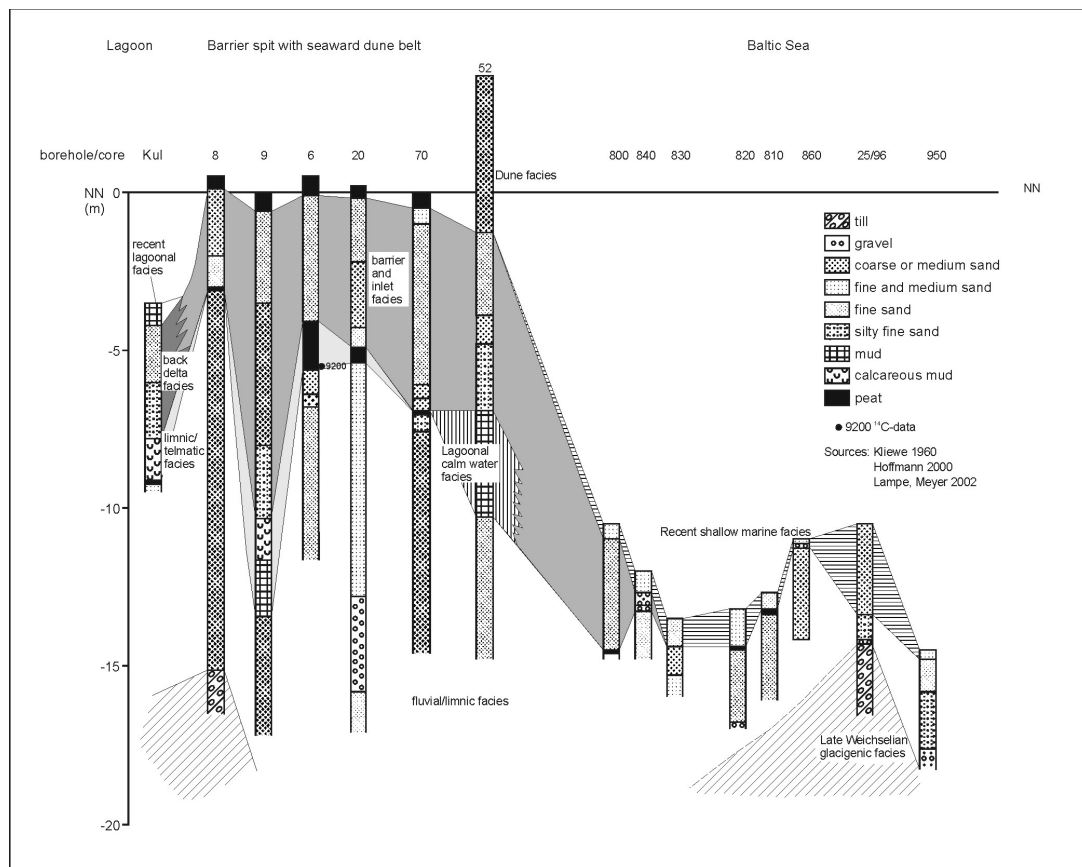
Fig. 3: Cross section through the Zinnowitz-Trassenheide lowland from the Krumminer Wiek to the Baltic

On the outer coast a system of dune belts is situated on top of the marine sediments. Apart from landward winds the preconditions of dune formation are the sufficient supply of fine to medium sands and a more or less constant sea level. According to the recent shoreline-displacement curve of JANKE & LAMPE (2000, cf. A-2), the latter condition existed since the Subboreal. The sufficient supply of fine to medium sands is regulated by erosion of Pleistocene material on the one hand and reworking of older marine deposited material on the other hand. The most important process of sand supply on the coast is longitudinal transport along the coast line. Storm surges are responsible for the forming of beach ridges whereby the material is deposited above the mean sea level.

Due to different age of their formation and therefore different stages of podzolization, three main stages of dune evolution can be differentiated: brown, yellow and white dunes (BILL-WITZ 1997). PRUSINKIEWICZ & NORYZKIEWICS (1966) determined the ages of the dunes in the Swine lowland by ^{14}C-analysis and concluded that the brown dunes developed from 4,800 - 1,600 years BC, the yellow dunes from 500 - 1,500 AD and the white dunes from 400 AD until today. As to be seen on maps, on aerial views and described by JANKE (1971) there is a shifting of the dunes´ course. The older ones are running in N-S direction, the younger ones parallel to the present coast line in NW-SE direction.
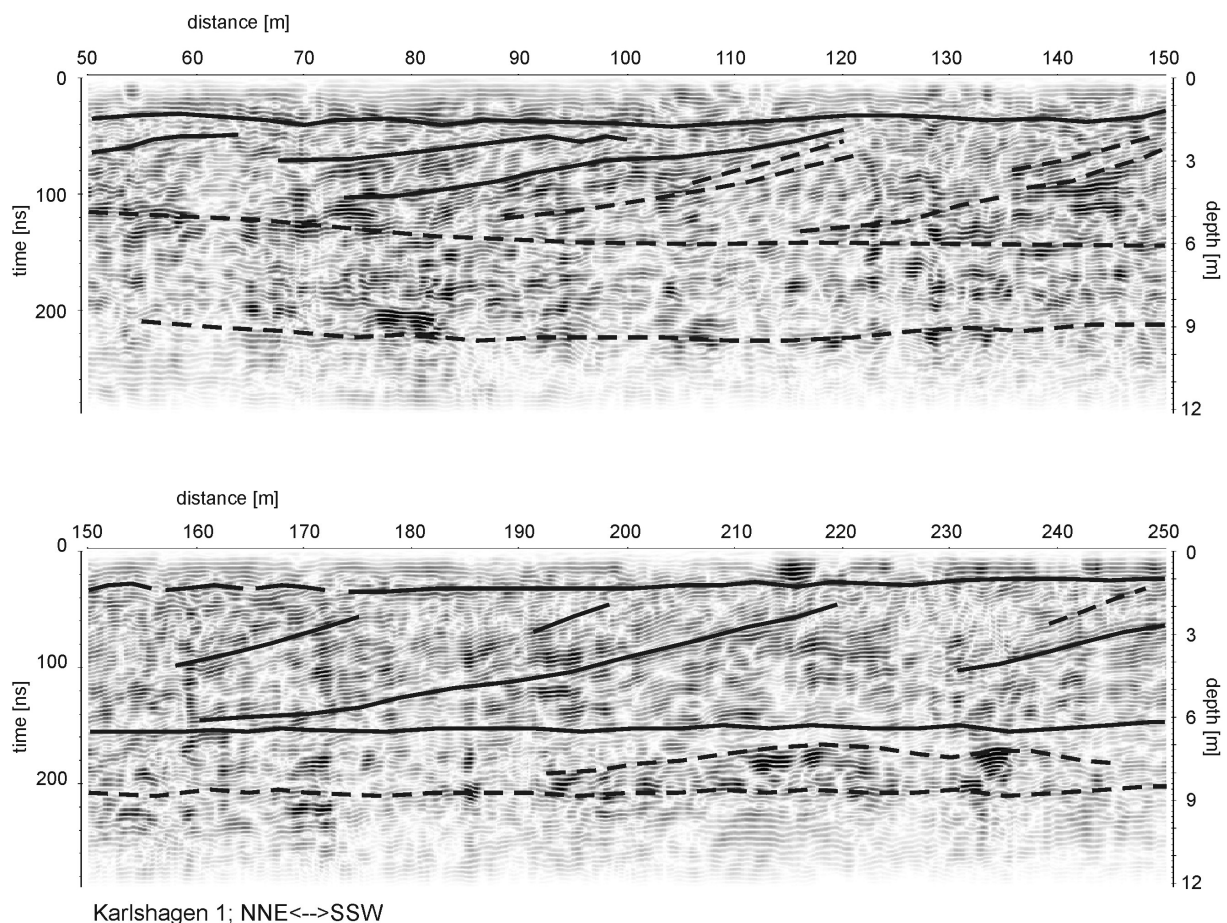
Fig. 4: Section from a GPR profile across the beach ridges between Karlshagen cemetery and Karlshagen camping site.

Recent ground penetrating radar (GPR) mappings revealed the internal structure of the dune system. Fig. 4 depicts a 250m section from a longer GPR record. Correlation of the GPR signals to different sedimentary units was done by comparison with results from drillings (Fig. 5). The GPR - profile runs perpendicularly across the beach ridges and depicts - from the top to the footwall beds - aeolian sand sheets (more or less parallel bedded), eastwards dipping beach ridge and shoreface layers and parallel bedded shallow water sands with a transition to silty fine sands in the lower part. At the boundary to silty muds in a depth of about 11m the GPR-signal vanishes probably due to higher conductivity. The boundary between the eastwards dipping sand layers and the underlying parallel bedded sand strata rises slightly from about 150 to 50 profile meter. The dip of the beach ridge strata decreases in the same way. This is interpreted as indices for increasing sand deposition in shallow water facies, gradual filling of the shallow bight off the shoreline and the onset of the formation of the Peenemünde shoal.

s,g/gl: sand, gravel/glacial

fs/l: fine sands/limnic

fs, u/m: fine sands, silty/marine

fs,ms/m: fine to medium sands/marine

fs/d: fine sands/dune
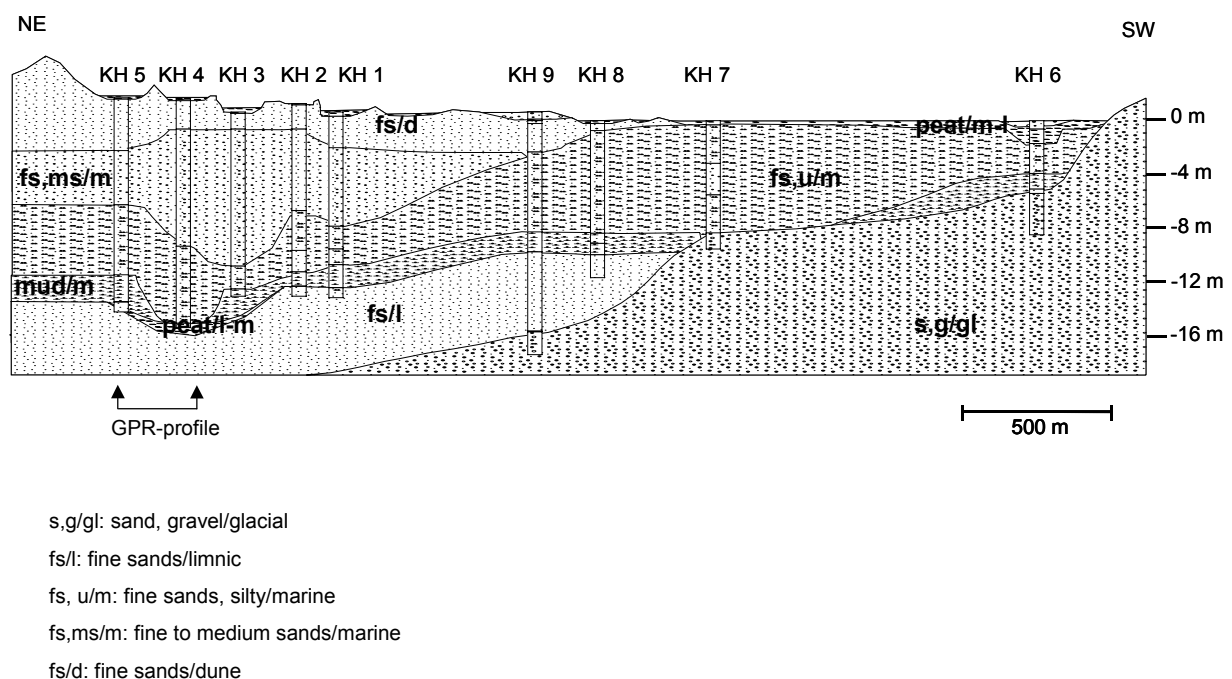
Fig. 5: Geological cross section across Usedom Island at Karlshagen

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Basin sands and inland dunes of the Lubminer Heide

Wolfgang Janke

The Lubminer Heide, covering 2.5 km², is a Late glacial basin area, which borders the southeast coast of the Greifswalder Bodden. It is approximately 3.5 km long and 400-900 m wide. The surface is covered with inland dunes which came into being during the period from 1250 to 1830 AD. Near the bluff, cliff top dunes and sand sheets exist, too. The current surface of the dune-covered area reaches heights between 2 and 13 m amsl. In the south and west the area borders the ground moraine of the Mecklenburg stadium. In the central part the basin sand has a thickness of more than 3 – 4 m. Near the seaside resort, the underlying boulder clay emerges above the sea level while the thickness of the overlying basin sands decreases to 1 – 2 m. The question, if the sands of the Lubminer Heide correspond in terms of origin and stratigraphy to similar sand areas of the Ueckermünder Heide, Barther Heide, Rostocker Heide and the Altdarss, is still unresolved and requires further investigations.

The grain size of the basin sands and the inland-dune sands differs only insignificantly. In both features very well-sorted fine sands predominate. The main fraction (0.1 – 0.2 mm) reaches an average of 50.2 % in the basin sands, in the inland dunes 57.9 %; the fraction 0.06 - 0.3 mm amounts to 82 – 98 %. The sands of the cliff top dunes are coarser (predominantly 0.3 – 0.7 mm) and less well sorted. The border between the basin sands and the inland dunes is formed by a soil which is visible at the cliff. The soil is predominantly a podzol, which, in the lower-lying eastern part, shows transitions to a gley with an iron-enriched oxidation horizon (meadow ore). The inland dunes are often partitioned by humus layers or regosols. The soils on their top are regosols and initial podzols.

During the surveys of the Swedish Matrikel Maps in 1694 and 1704 the Lubminer Heide consisted almost entirely of "sand hills and pits" and of Calluna - heathland. Investigations of the buried humus layers carried out by means of pollen analysis confirmed this description. For every 100 arboreal pollen grains there were – depending on location - 600 Calluna, 220 Cyperceae and up to 100 Graminaeae pollen grains (Janke 1971). The reforestation of the drifting dunes occurred in the period of 1804 to 1880.

In 1980, Alleröd sediments were found in the area of the former nuclear power plant (block 5). They were situated 1.5 to 1.9 m below the surface in 3.2 m thick fine sands. At the base the Alleröd sediments consisted of alternating moss-peat layers and fine sands with *Epithemia turgida*, in the upper part of sandy peat with pine stumps. The peat revealed an age between 11,850±150 and 11,200±150 conv. ^{14}C-years BP. The upper sand sequence was 1.5 m thick, probably of aeolian origin and could possibly correspond to the Younger Dryas. The base of the sand sequence consisted of boulder clay.

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Late Quaternary Sedimentation and Depositional History of the Greifswalder Bodden (southern Baltic Sea)

RALF-OTTO NIEDERMEYER, GUIDO VERSE, HAGEN BAUERHORST

The study area Greifswalder Bodden represents a shallow coastal basin which has the following bathymetric and hydrographic features (Fig. 1): east-west-extension 25 km, north-south-extension 24 km, surface 510.2 km^2, medium water depth 5.8 m, maximum water depth 13.5 m, volume of water 2,960 x 10^6 m^3, medium salt content 6.85 $\pm$ 1.03 PSU, medium oxygen content of the Bodden water 10.16 mg O$_2$/l. It can be seen that the depositional basin is subdivided into two parts: a flat ground moraine area in the west and a more reliefied area in the east. The latter shows some local deeps (in maximum 13.5 m bsl (below sea level), obviously being part of an ancient channel system of Late Pleistocene/Early Holocene times. On the other hand, there are morphological highs, some of which less than 2 m bsl, which are interpreted as ice-decay deposits, mainly due to dead ice and meltwater activities. Former assumed end moraine formations are no longer justified by the sedimentological results (cf. VERSE et al. 1998, VERSE 2001).
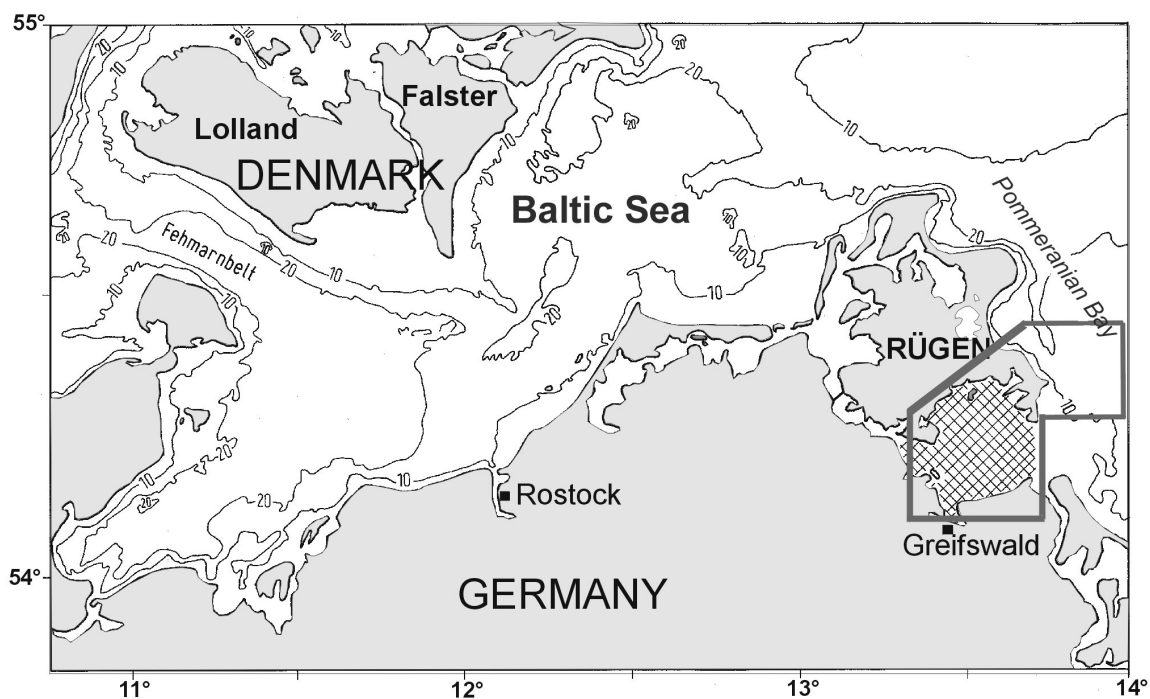
Fig. 1: Location of the study area Greifswalder Bodden (western Pomeranian Bight)

Fig. 2 shows the modern surface sediment distribution. The sedimentary patterns reflect the bathymetrical/morphological features: Muddy and organic rich deposits in the flat western subbasin and sands of different granulometrical compositions in the eastern subbasin, with the latter showing high-lying till complexes. Fig. 3 shows the mud thicknesses of the Greifswalder Bodden ranging in maximum up to 4 m. From both maps evidence can be obtained that there is an ancient channel system marked on the bottom which had linked the lagoonal bodden area with the open sea area of the Pomeranian Bight further east.
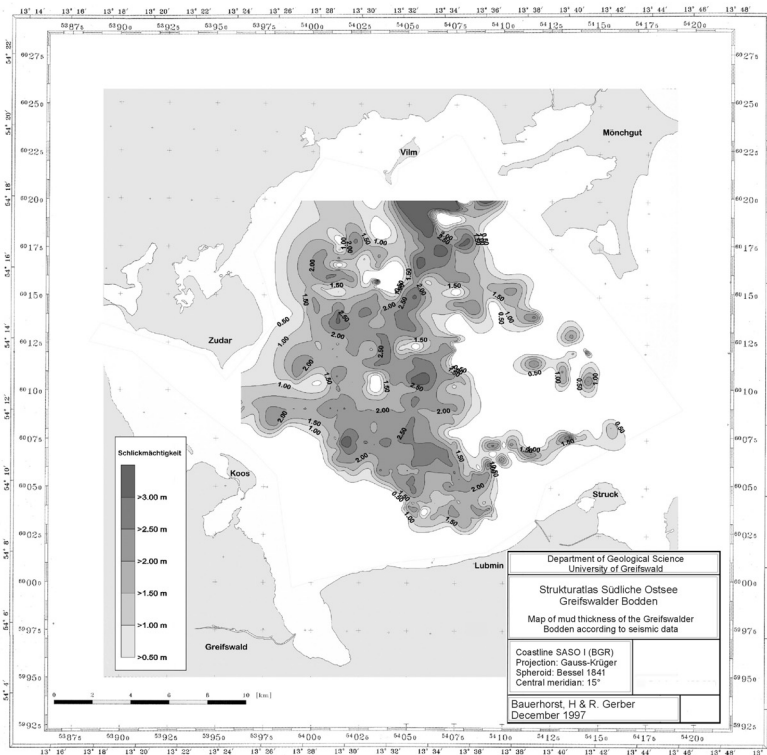
Fig. 2:
Map of mud thickness of the Greifswalder Bodden according to seismic data
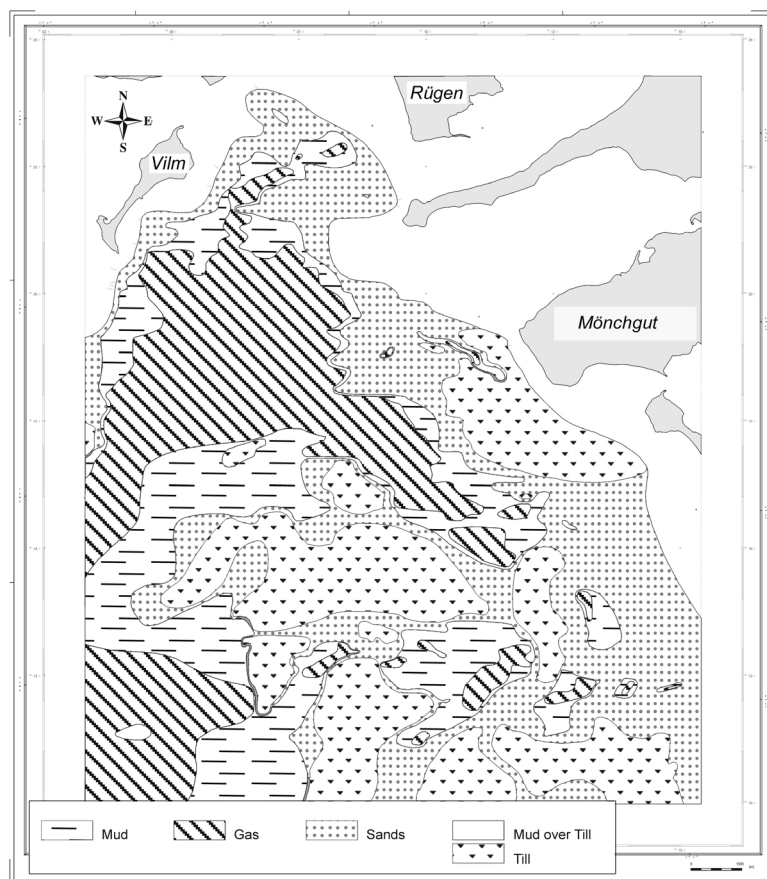
Fig. 3:
Map of surface sediment distribution of the Greifswalder Bodden

At first, results are presented of studies on seabed architecture and palaeo-relief of the Greifswalder Bodden during the Late Pleistocene/Holocene (Figs. 4, 5). On the basis of seismic and vibrocore data the depositional system was subdivided into four major lithofacies types:

Weichselian till, sand, mud, and gas-rich/organic sediments/peat. These sediments were characterized by seismostratigraphic units as follows (Fig. 5): SS1: Weichselian till of the Pomeranian/Mecklenburgian Stages (Weichselian 2 and 3); SS2: Glaciofluvial and glacio-limnic sand and gravel; SS3: Limnic-lacustrine silts, sands and organic sediments (peat) including marine-brackish mud and sand (SS4). On top the sequence is covered by marine-brackish mud and sand deposits (SS5). Stratigraphically, these lithotypes encompass the time period of the last 15 ka: SS1/SS2 are classified as High- to Late Weichselian (Pleistocene: 15 – 10 ka BP), and SS3/SS4/SS5 as Preboreal/Boreal to Subatlantic (Holocene: last 10 – 9 ka). In Figs. 4 and 5, selected profiles of the geological seabed architecture based on the seismic measurements and interpretations of vibrocores are shown. Seismostratigraphically, in Fig. 4 a basin- and channel-like seabed structure with gas-rich organic mud reveals part of the abovementioned ancient channel system. A core succession (GB-VC-37) has been studied in high sedimentological detail showing sedimentary units from the Holocene Ancylus Stage to the Littorina Stage. Obviously, a marine flooding surface (MaFS) could be detected representing from a sequence-stratigraphic point of view a "transgressional systems tract". The sedimentary structures, such as planar/bi-directional cross bedding including pebbles, suggest a sea level rise including high sediment mobilization (sediment supply). The westward dipping laminae in the seismic profile 21 (Fig. 4) are interpreted as a prograding sedimentary body which is controlled by sea level rise (i.e. transgression).

Moreover, in the seismic profile 22 (A; Fig. 5) a buried palaeo-relief is marked by incised channels which were evidently eroded into Weichselian tills and glaciofluvial deposits during both Late Pleistocene and Holocene times. The vibro-core succession (GB-VC-38) shows a similar sedimentological and stratigraphical composition as that of core succession GB-VC-37 with the exception that the former outcrops Late Weichselian meltwater sands below a strongly condensed Ancylus unit. Comparing both core succession it has to be stated that there are great facies changes close to each other.

The coastal evolution period of 15 ka can be classified into three stages (VERSE et al. 1998, 1999; BAUERHORST 1999; NIEDERMEYER et al. 1995, 1999; CRUSET 2000, VERSE 2001):

- High-Weichselian to Late Weichselian (Late Pleistocene)
- Preboreal/Boreal to Early Atlantic (Early Holocene)
- Early Atlantic to Subatlantic (Middle to Late Holocene).

Late Pleistocene:
The formation of the bodden basin was controlled by exarative and glacio-dynamical processes of the Pomeranian ice advance (W2-glacier/Pomeranian Stage). This was superimposed by the latest short ice advance of the Mecklenburgian Stage (W3-glacier). The melting of ice, mainly dead ice blocks, initiated the formation of meltwater channels and lakes. Such local ice lakes showed lake level differences of few meters (up to 4 m) which were controlled by damned morainic swells. This took place mainly during Alleröd times. Glacial lake deposits were found at following locations: Deeps around Vilm Island ("südliche Vilm-Gründe"), on top of swells ("großer Stubber"). Obviously, during the Younger Dryas a water level rise took place which flooded the high-lying areas and rhythmites overlay palaeosoils. From Younger Dryas to Early Preboreal the landscape was formed by periglacial processes which is reflected by solifluction, ice wedge casts and cryoturbational deformations ("Tropfenböden"). Moreover, periglacial-pedogenetic diamictites are widespread during that time.

Fig. 4. Seismic transect (profile 21) and core location (GB-VC-37) showing subbottom architecture and stratigraphy of the northeastern part of the Greifswalder Bodden

150

Seismic Profil (22) A
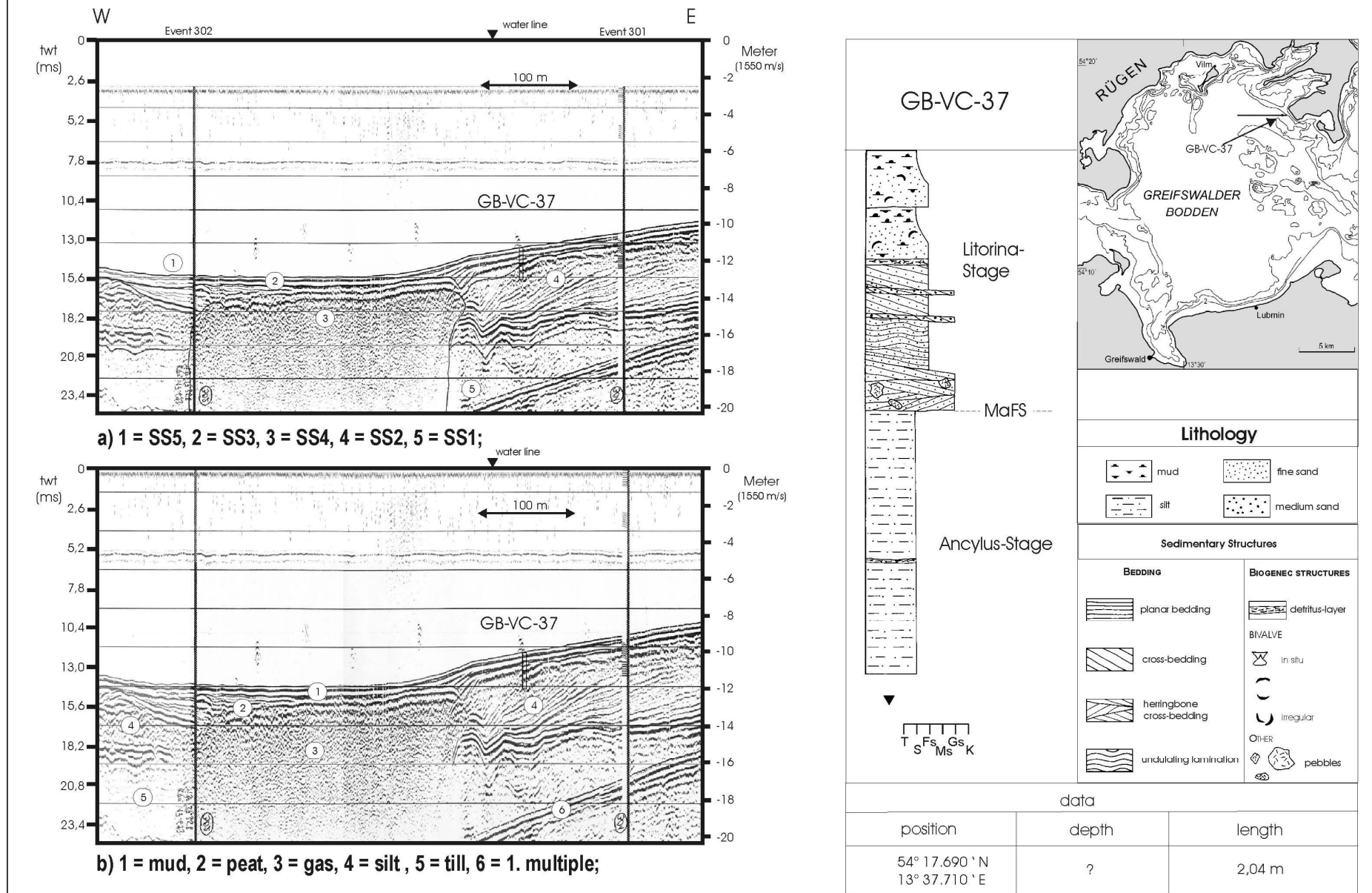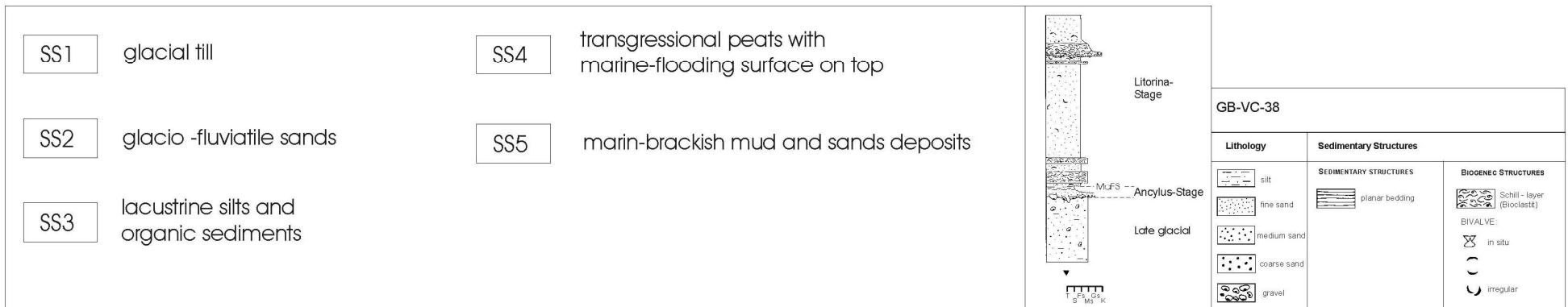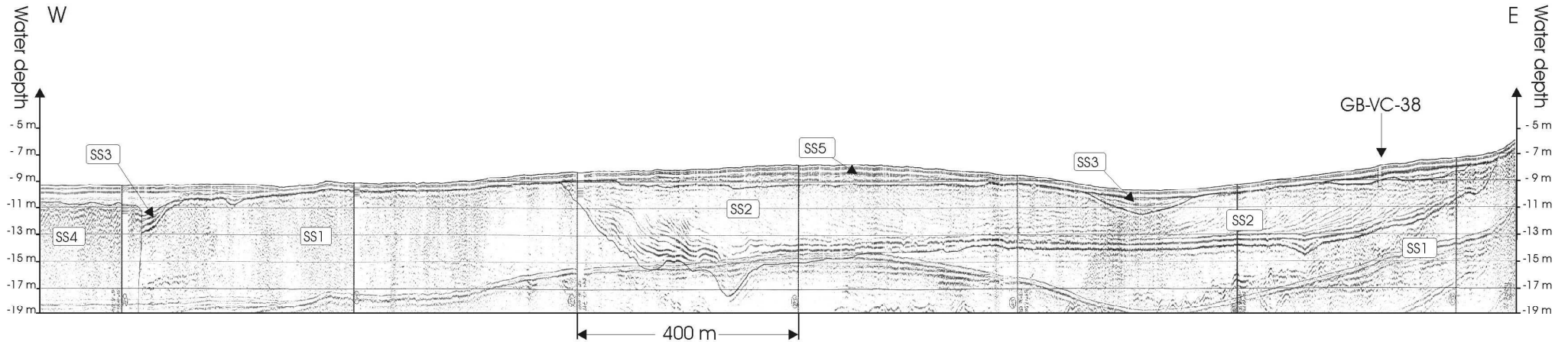

Fig. 5: Seismic transect (profile 22 A) and core location (GB-VC-38)showing subbottom architecture and stratigraphy of the northeastern part of the Greifswalder Bodden

151

Early Holocene:
Climatically controlled redepositional processes including the formation of colluvial deposits dominated in this phase. Permafrost was less important and fluvio-glacial processes were of widespread dimensions. For the Greifswalder Bodden these processes are shown in prograding meltwater sand deposits in the mouth areas of the Ryck and the Strelasund. Palaeogeographically, the landscape was characterized by an extended water net showing water level differences of few meters. The average water depth of lakes amounted to 4 – 7 m. Probably, dammed lakes were filled by delta-like sand deposits originating from breaking through moranic dams. At the lake shores fine sands of low thickness, sand muds, detritus layers and, locally, rhythmites form the proximal facies including *Equisetum-Cyperaceaen*-swamps. By sedimentological evidences a general lake lowstand at –12 to –14 m msl is assumed for this time (Ancylus-Stage).

Moreover, a channel system dewatered the Greifswalder Bodden in the vicinity of the present Ruden island into the Pomeranian Bight (open Baltic Sea). Evidence for that was abovementioned by the existence of an ancient channel system (Figs. 4, 5). Silt deposits in deeper bathymetrical (distal) positions give evidence for that (for example, Greifswalder Oie; channels). At that time the Mönchgut peninsula was separated by inlets linking Bodden and open sea area (Hagensche Wiek, Having).

Middle to Late Holocene:
According to SCHUMACHER & BAYERL (1999) the sea level rise of the southern Baltic coastal area (Littorina-transgression) took place between 8.0 and 5.8 ka BP with the sea level rising from –15 to –1.5 m msl. This transgression resulted in drastical environmental and depositional changes from a semiterrestrial/terrestrial to a marine-brackish landscape character. The transgression took place in different phases which, for the Greifswalder Bodden, is suggested to have started at levels of –13 to –10 m msl (initial phase). These deeper parts (channels, lakes) were successively flooded which can be shown by diatoms associations evidencing salinities around 8 – 10 PSU. During the transgessional highstand a maximum salinity of 19 – 21 PSU is suggested (SAMTLEBEN, NIEDERMEYER 1999). The initial ingressions should have taken place via a "flood gate" in the area beteween Ruden and Usedom. Bottom morphology and seismostratigraphy in the vicinity of Ruden/Usedom strongly suggest this assumption. First marine-brackish sand and mud deposition is assumed to have occurred at 7.5 ka BP. The salinity increses up to 17 PSU indicated by the diatom species *Paralia sulcata*, *Grammatophora oceanica* and *Rhabdonema minutum*. For the Littorina-maximum (about 5.8 ka BP) a sea level at –1 to –1.5 m msl is assumed (SCHUMACHER, BAYERL 1999). Additional ingression pathways were the Strelasund, Having and Hagensche Wiek (BAUERHORST 1999). The ancient Littorina shoreline of the Greifswalder Bodden is characterized by fossil cliffs (among other, northern Having, Moritzdorf, west of Göhren, southeast Having near Alt-Reddevitz, Groß Zicker east of Gager, east of Klein Zicker).

The post-Littorina phases of the Greifswalder Bodden (Lymnaea-, Mya-phases; Subboreal to Subatlantikum) quite often are marked by storm-controlled (tempestitic) beds within the mud deposits. In many sequences shell beds have been found which occurrences fit a 200 – 300 years periodicity/cyclicity of severe storms. Moreover, these tempestitic layers are not widespread but of local importance showing ancient storm-exposed shorelines.

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Holocene evolution and coastal dynamics
of the Fischland-Darss-Zingst peninsula

REINHARD LAMPE

The peninsula Fischland-Darss-Zingst, together with the Darss-Zingst Bodden chain, forms the westernmost part of the West Pomeranian Bodden coast (Figs. 1 and 2). It is composed of headlands built of Late Pleistocene sediments with Holocene lowlands in between and depicts an obtuse angled triangle with an opening of c. 120° to the Bodden waters. The western angle leg between Dierhagen and Darsser Ort is c. 25km long and the leg between Darsser Ort and Pramort c. 29km. The eastern sequel of the peninsula consists of some islands (Großer Werder, Kleine Werder, Bock), separated by inlets and is altogether c. 9km long. The latter island is separated from the southernmost tip of Hiddensee Island by the Gellenstrom, which must be often dredged (60 – 70.000 m³/yr) due to its location in the accumulation area between Zingst and Hiddensee. Along 39.75 km of the Baltic coast abrasion predominates, at 15.75km accumulation. The lagoon Bodden coast is widely characterised by spacious reed belts and stagnating shorelines.
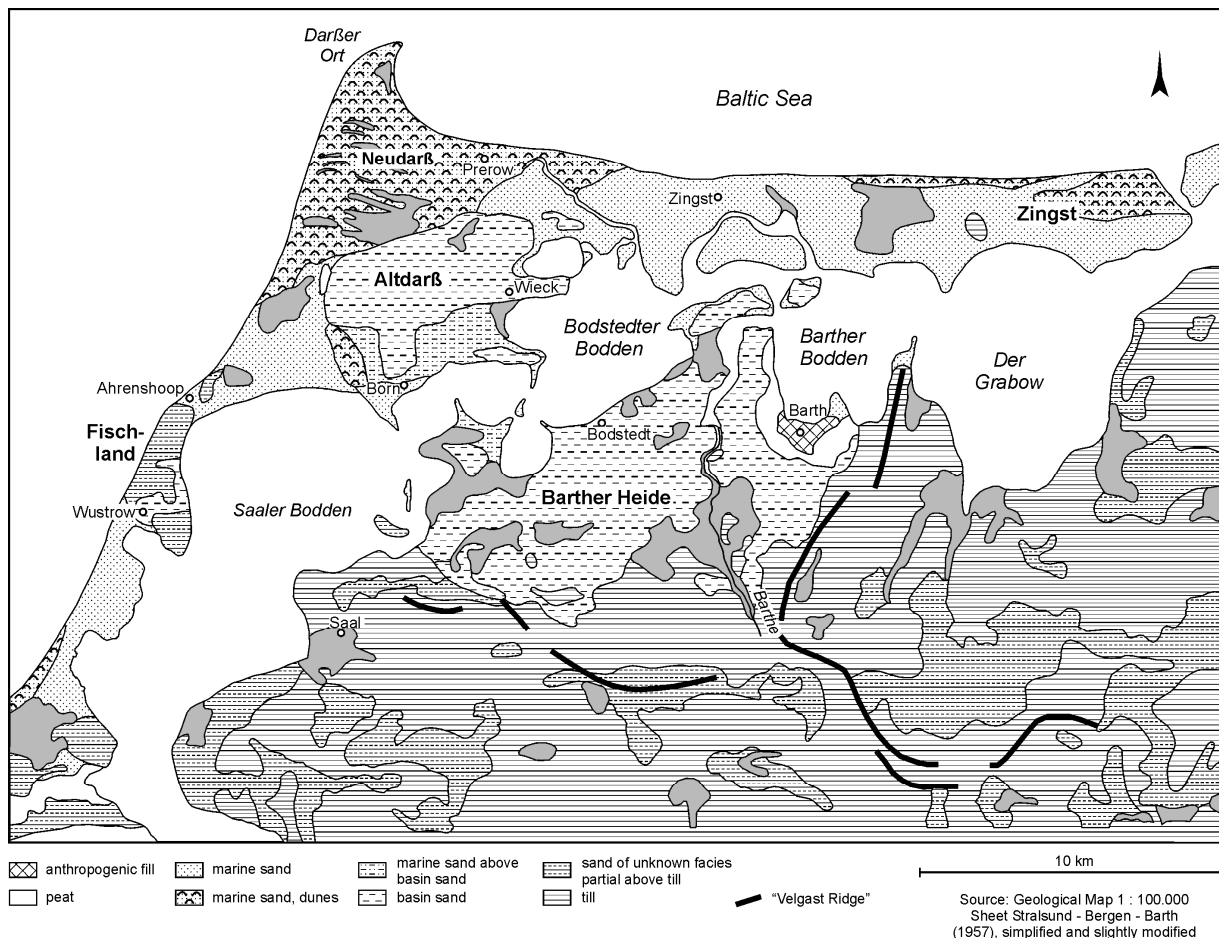
Fig. 1: Geological map of the Fischland – Darss – Zingst peninsula
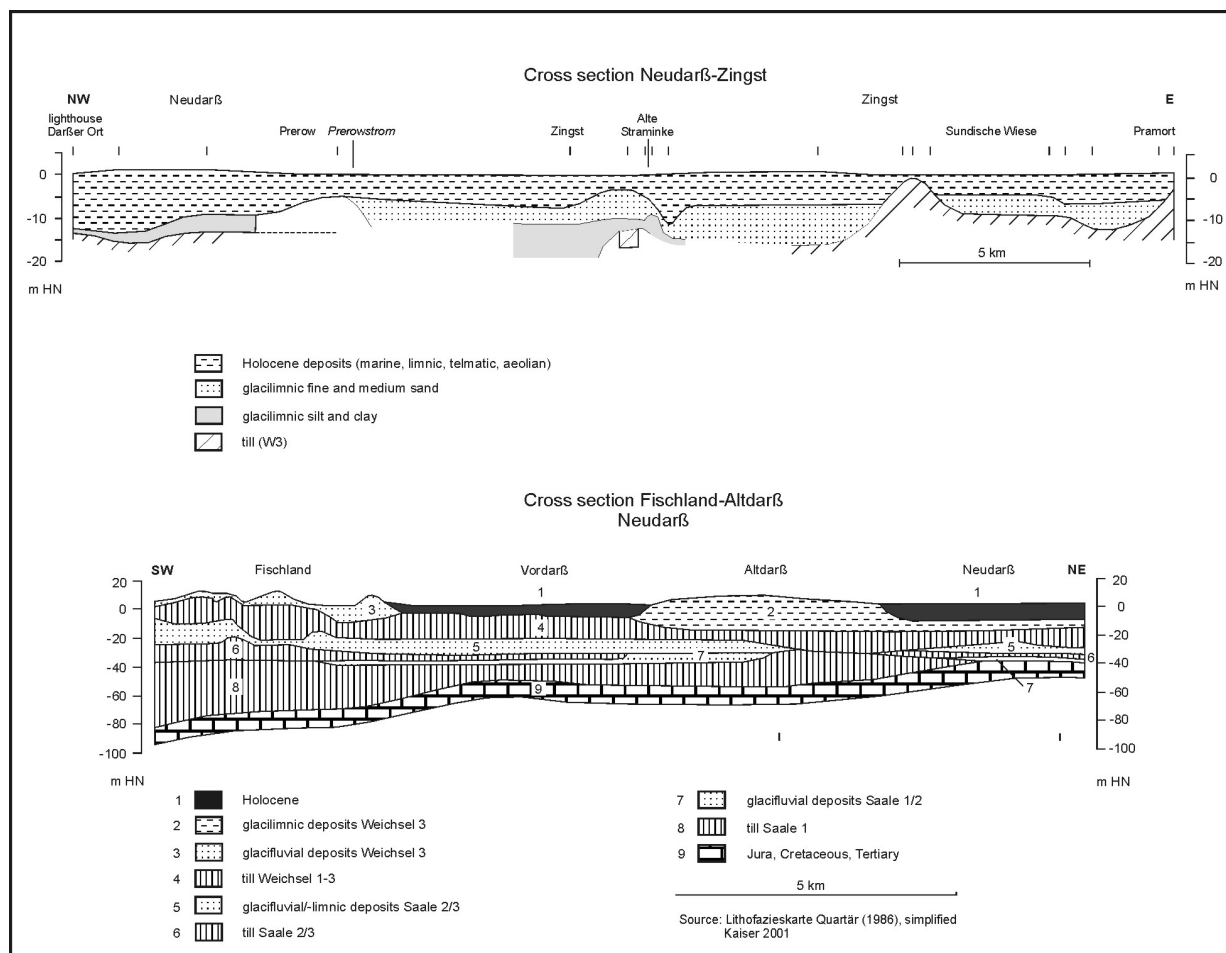
Fig. 2: Geological cross sections

The Holocene evolution of the entire peninsula was investigated by OTTO (1913), SCHÜTZE (1939), HURTIG 1954) and JANKE, LAMPE (1998), an analysis of the Late glacial/Early Holocene deposits was conducted by KAISER (2001). Contributions to the recent coastal dynamics and flooding endangerment were derived from KOLP (1955), TIEPOLT (1993), TIEPOLT, SCHUMACHER (1999), DETTE (2000) and SCHUMACHER (2000). Further important investigations dealt with the genesis of particular sections such as the Neudarss (GROBA 1954, 1957, FUKAREK 1961, KOLP 1978, 1982, KRBETSCHEK 1995, TIARKS 1999) and the Fischland (LUDWIG 1963, 1964, SCHULZ, PETERSS 1989, PIETSCH 1991, PÖSEL 1996, KAISER 2001). Descriptions of the coastal dynamics were provided by GEINITZ (1910), SCHUBERT (1955/56), BENTHIEN (1957), WEIß (1979) and GURWELL, WEIß (1989) which concentrated on the Fischland cliff. Numerical models concerning the coastal dynamics have been described by STEPHAN & SCHÖNFELDT (1999), WEILBEER & ZIELKE (1999); the submarine forefront has been investigated by KOLP (1956), LEMKE (1992, 1998) TAUBER & LEMKE (1995) and KRAUSE (1996). The historical development of the coastal protection in that area was depicted by REINHARD (1953), CORDSHAGEN (1964) und WEIß (in KRAMER, ROHDE 1992).

The forefront of the Fischland (also called Lower Fischland) between Dierhagen and Wustrow is a low lying peatland area (Ribnitzer Stadtwiesen) with a narrow dune belt in front on the sea side. Late glacial sands and gravels build the subground which is overlain with marine mud, peat and sand, deposited since the onset of the Littorina transgression (excursion point Körkwitz). HURTIG (1954) assumed the Late Pleistocene/Early Holocene mouth of the Recknitz river to have been in the area south of Wustrow and near Dierhagen. During the

Littorina transgression these areas were the inlets through which the sea penetrated into the depression of the recent Saaler Bodden. In the area of the Permin until the end of the 14th century a navigable channels existed, which was closed due to sinking of three ships. A durable protection of the section endangered by numerous breakthroughs was achieved in 1877 by endiking. Substantial coastal protection measures today defend the entire Lower Fischland from flooding and shoreline retreat.

Fig. 3: The cuspate foreland Darss, its landforms and cross sections through the beach ridge plain (after HURTIG 1954, modified)

The Fischland proper (also called Upper Fischland) consists of the Pleistocene headland of Wustrow-Ahrenshoop. The 3.2 km long western coast of this hilly area is called Hohes Ufer (= High Cliff). The active cliff reaches up to 8 - 12 m, then the surface dips gently to the Saaler Bodden in the east. At the cliff Weichselian tills and sandy sediments crop out and are covered partly by discordant fine sands, which have been called "Heidesand" (heath sand) by GEINITZ due to its similarity to sands in the Rostocker and Barther Heide. High loads by waves and currents in connection with a steep shore profile lead over the centennial average to an above average cliff retreat rate of 0.75 m/yr (JANKE, LAMPE 1998) and were the reason for protecting the northern and southern cliff ends and the transition to the neighbouring lowlands with wave breakers.

The continuation to the north is a Holocene lowland (Vordarss) which connects the Pleistocene headlands Fischland and Altdarss (Fig. 3). In its composition it corresponds to a large extent to the Lower Fischland, but the Holocene base is situated much deeper. Numerous channels, now silted-up, and flat sand fans point to frequent flooding and overwashes in the past. In the northernmost part the Rehberge form the transition to the Neudarss. They are the remnants of the oldest Holocene spit system, which (probably) started in the Upper Fischland and grew from there to the Altdarss in the northeast. The water exchange between the Littorina sea and the Bodden took place through the inlet in the area of the Josaarsbruch, which was divided into two forks by the Ibenhorst Island. On the lagoon side of the inlet a back delta was formed (area of the Werre), which is now diked and drained. Only after the closure of this inlet an accretionary beach ridges plain could develop which led to the formation of the Neudarss.

The Altdarss is the second large Late Pleistocene unit of the peninsula (Fig. 3). It consists mainly of basin sediments (KAISER 2001): above a basal W3-till follow thin glacilimnic clay and silt beds, then glacilimnic sands. The thickness of the late glacial basin deposits reaches up to 20-25 m. Compared with the basin deposits in the southern vicinity, the higher position points to a basin limitation by subaerial dead-ice. On the surface of the glacilimnic sands (whose transport direction is still unknown) there is frequent evidence of late glacial muds, peats and soils (arenic Regosols, sometimes with poorly developed spodic properties, and Gleysols in groundwater influenced areas). Above them aeolian sand sheets have been deposited during the Younger Dryas; another aeolian activity phase has been proven for the Younger Holocene (Middle Ages to modern times) andwas caused by forest deterioration. The northern edge of the Altdarss is formed by a prominent fossil cliff, stretching along the Mecklenburg Trail. It came into being with the arrival of the Littorina transgression at the Altdarss and was active probably only for a few hundred years.

The Holocene marine sequence of the Neudarss (see Fig. 3) consists of monotonous mollusc bearing, upward coarsing fine and medium sands. They are deposited above late glacial silts and clays (proved by pollen analysis) which crop out c. 10-12 m below sea level (TIARKS 1999). The deposition of the marine sequence started about 3,000 years BP (FUKAREK 1961) and was connected with the development of two coastal sediment transport systems. At first, the separation into a westerly (Rehberge) and an easterly (Prerow-Zingst) route of transport, which both showed a predominant eastward transport direction, was rather indistinct. Later, the western spit dislocated its deposition centre faster nordwards, due to the more extensive sediment supply and the backward advance of the western spit´s starting-point. Thus the northwards facing tip of the cuspate foreland developed. The central part in front of the Altdarss cliff occupied a certain lee position, into which material was poured in the case of northerly or easterly winds but could not be transported back under the influence of the prevailing westerly winds. Thereby the area in front of the cliff changed to an accumulation area

and pushed the abrasion centre more to the east. Contemporarily the foreland´s tip evolved into a dividing line between two coastal cells with convergent transport directions. The beach ridges heaped to the cuspate foreland from both east and west interlocked along a line which was shifted sometimes more westward and at other times more eastward (PÖSEL 1995). These deflections seem to have been caused by differences in the wind distribution and therefore in the sediment supply. Similarly, at times numerous, low, narrow-spaced beach ridges emerged, whereas in other periods less, higher and wide-spaced ridges were formed (Fig. 2); HURTIG had already linked this with sea level fluctuation (1954). However, because the available data concerning their chronostratigraphical position (FUKAREK 1961, reinterpretated by COUWENBERG et al. 1998, KRBETSCHEK 1995) are inconsistent, further investigations are needed.

The shoreline of the Prerow Bay perfectly fits the line of a zeta-bay, the same is true for the course of almost all the older beach ridges (Fig. 4). Their course can be approximated by curves of logarithmic spirals, whose pivot point is located in the vicinity of the Darsser Ort. The curves converge in the area of the former Prerowstrom mouth. The variation in the position of the pivot point demonstrates the same fluctuations as the beach ridge interlocking bend, i.e. the shoreline of the bay runs sometimes more lengthwise and at other times it is more contorted.
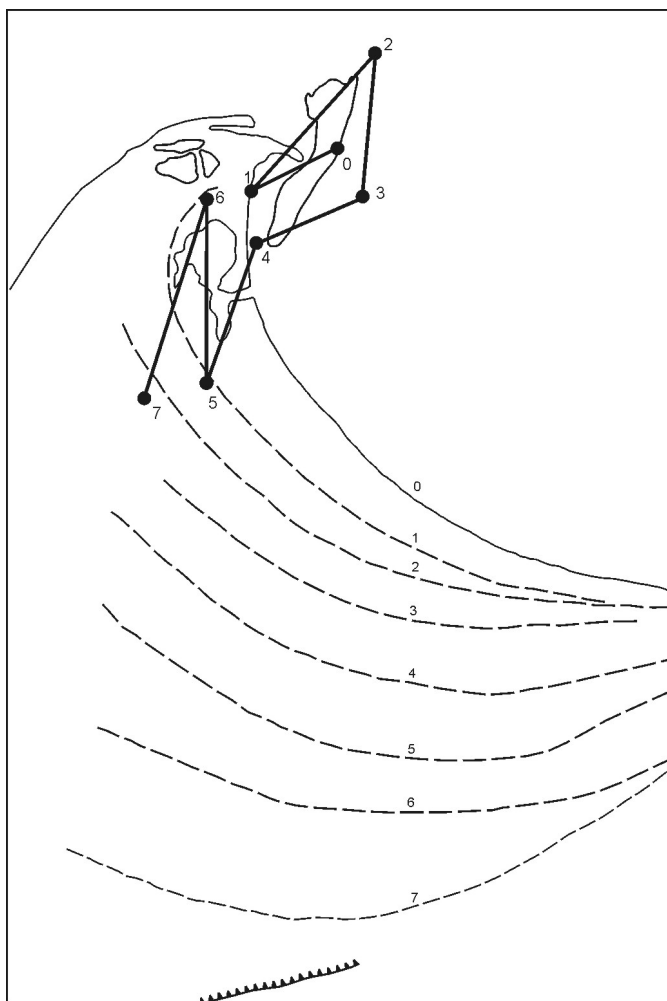

Fig. 4:
Approximation of the course of beach ridges and the shoreline by logarithmic spirals. The locations of the pivot-points are related to the accretion intensity and the prevailing wind direction.

The Prerowstrom forms the eastern border of the Darss. Until its artificial closure in 1884 this inlet formed the natural link between the Bodstedter Bodden and the Baltic. The relocation of

its mouth in a westward direction and the formation of the high dunes on its east bank reveal a sediment transport to the west. The dividing line between the coastal cell of the Prerow Bay and the subsequent Zingst coastal cell to the east is recently located at the sharp bend north of the Butterwiek. The area of maximal abrasion is located around Zingst, the associated accumulation area starts at about coast kilometre 218 and stretches until the Gellen channel.

The formation of the Zingst peninsula might be explained – in contrast to the Neudarss – not only by the longshore transport of sand and the formation of a beach ridge plain. The origin of a sand plain must be interpreted as the result not of seaward accretion but rather of landward overwash. The early phase – starting at about 4,000 BP – was still characterised by islands located seaward, from which spits grew southwards, perpendicular to the modern coastline. Their remnants are still preserved in the beach ridges of the Osterwald. Between them inlets and back-deltas existed, leading to a straighter stretching coastline on the Baltic side and spacious shallow water areas on the Bodden side. With the final abrasion of the islands and the old spits, the small-scale alternation between abrasion and accumulation areas vanished and – not later than 1,000 BP – a sand flat emerged with a more W-E oriented sediment transport at its northern edge. However, in case of surges sediment laden water was transported across the flat in a southward direction, leading to a gentle relief slighty dipping towards the south. Small circular isles similar to the recent Werder islands were built on the flat, probably around temporary beach ridge remains. Coming from the west a narrow dune belt has been poured in front of the isles, whereby the largest dunes have been built at the distal, eastern tip and their height decreased to the west. Due to the eastward displacement of the dune belt the inlets between the isles have successively been closed. In the belt´s shelter – and also driven by the slow transgression – the formation of a coastal peatland started. Finally, as the dune belt migrates far enough to the east (and under slighter contemporary shift to the south), the peatland borders directly on the sea and becomes the object of abrasion (Zingst coastal mire). The main course of the evolution of the entire peninsula is summarized in Fig. 5.
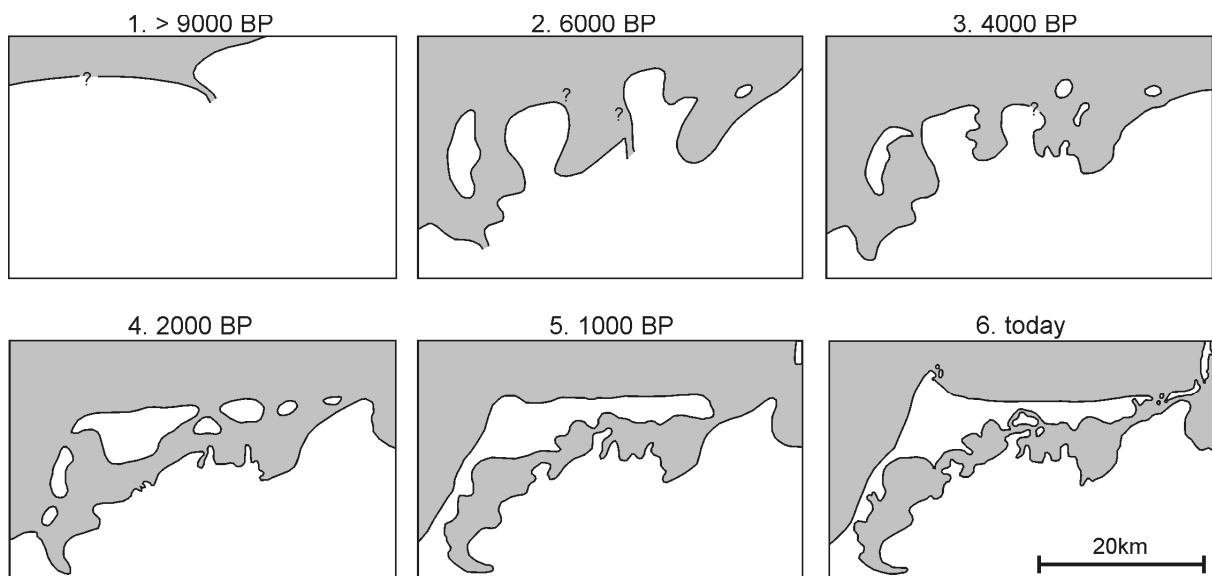
Fig. 5: The evolutionary stages of the Fischland-Darss-Zingst peninsula (after JANKE, LAMPE 1998, Kaiser 2001, modified)

Today the accumulation process around the Werder isles and the Bock island appears heavily accelerated due to voluminous beach nourishment off Zingst. According to map analyses in the area east of Pramort, about 6200 m³/km had been accumulated annually since 1835. This corresponds quite accurately to the amount which has accumulated off Zingst since 1965/66 in 5-year intervals on average. Therefore, in the past 40 years the amount of sediment which can be accumulated has doubled. An overview about the secular tendencies of abrasion and accumulation – calculated for the period 1835 to 1988/91 – is provided by Fig. 6.
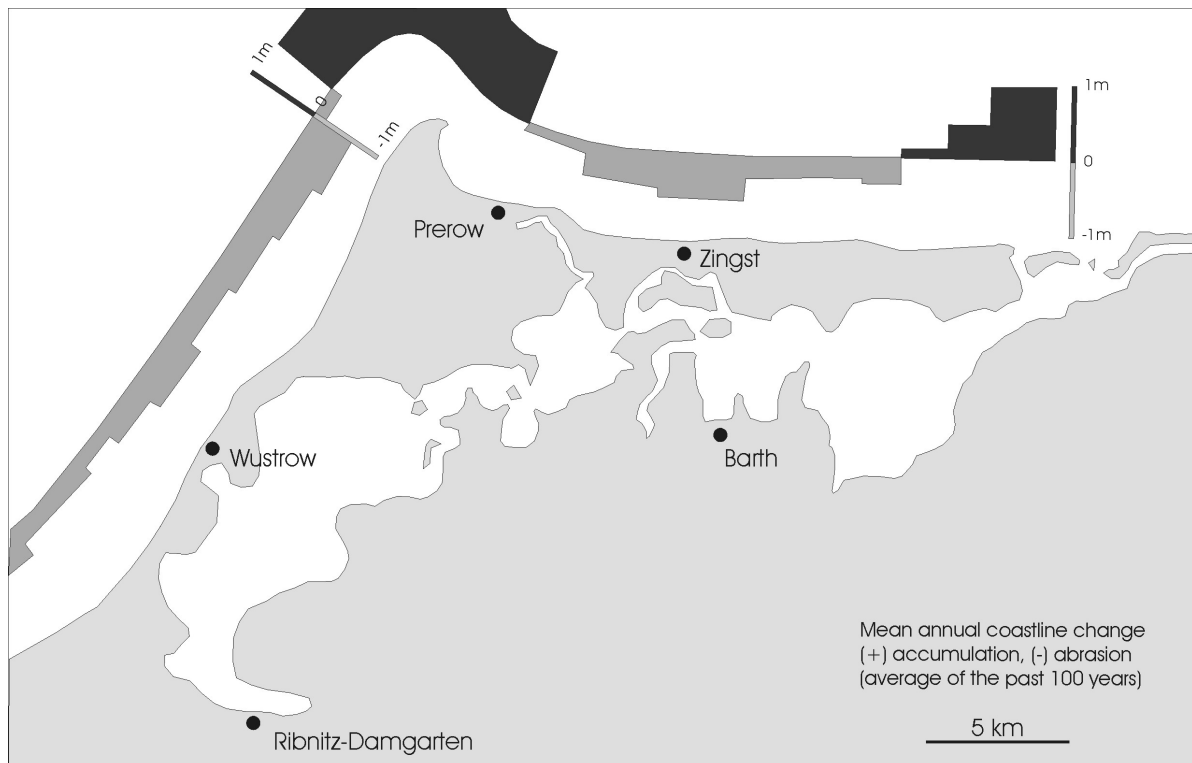
Fig. 6: Average accretion and abrasion rates along the coastline of the Fischland-Darss-Zingst peninsula, depicted as 100-year mean values (after JANKE, LAMPE 1998, simplified)

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Coastal evolution of the Darss Peninsula

WALTER SCHUMACHER

The strong water level rise of the Littorina period led to the flooding of the former mainland. It produced an archipelago. The bays and basins were nearly filled up with silty/sandy material from the eroded cliffs in the neighbourhood. The subsequent gradual shallowing of the basins and a decreasing water level rise was connected with the development of spits and barrier spits ("Haken" and "Nehrungen") between the Pleistocene islands. This process of straightening the coast line filled up the remaining parts of the old bays and isolated them from the open sea, forming Haken and Nehrungen with their systems of beach ridges and dunes at the front and peatlands at the back.
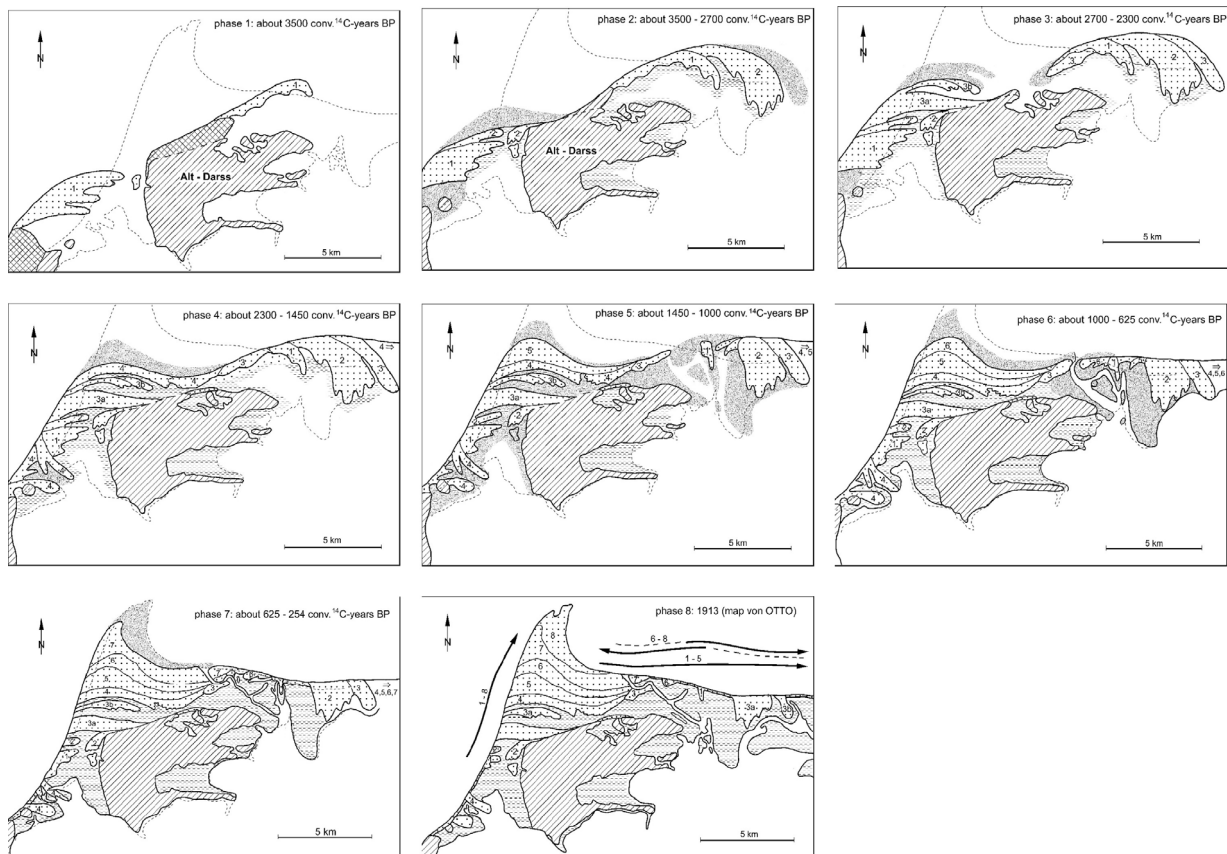
Figs. 1 - 8: Coastal development of the Darss Peninsula in 8 phases from 3,500 conv. ^{14}C-years up today (map by OTTO 1913). Diagonal hatching: Pleistocene island; crossed hatching: abraded Pleistocene island; thick dots: beach/dune ridge areas; thin dots: sands of the shore platform; scattered hatching: alluvium; hatched line: coast line from 1913; numbers: beach/dune ridges of the different phases; arrows: main direction of sediment transport at the different phases.

The palaeogeographical development of the Darss Peninsula is an excellent example of the evolution from a Pleistocene ingression coast to the Bodden equilibrium coast (Bodden-Ausgleichsküste). This development is illustrated in 8 stages (Fig. 1 - 8, SCHUMACHER 2000)

based on the former works of OTTO (1913), SCHÜTZE (1939), HURTIG (1954), FUKAREK (1961), KOLP (1982) and KRBETSCHEK (1995); the morphological analysis of the lines of the beach ridges and the new results for sea level variations (SCHUMACHER, ENDTMANN 2000).
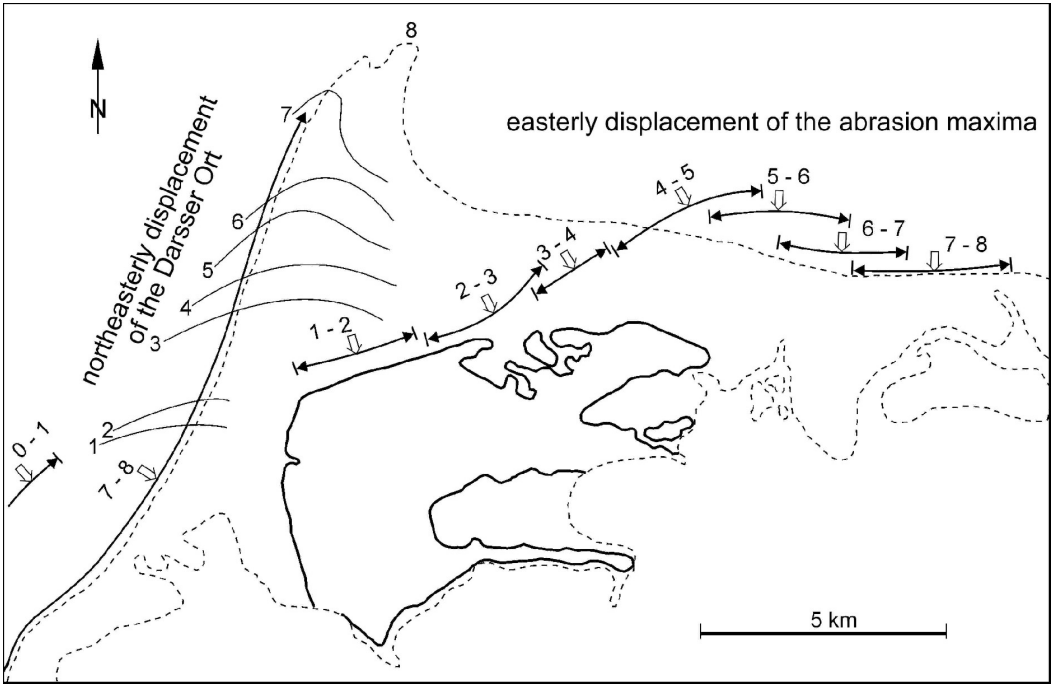
Fig. 9: Principle of the coastal dynamics of the Darss-Zingst Peninsula (numbers 7-8: situation of the spit of the Darsser Ort at the end of the relevant phase; numbers 7-2 to 7-8: abrasion maxima at the relevant phase).
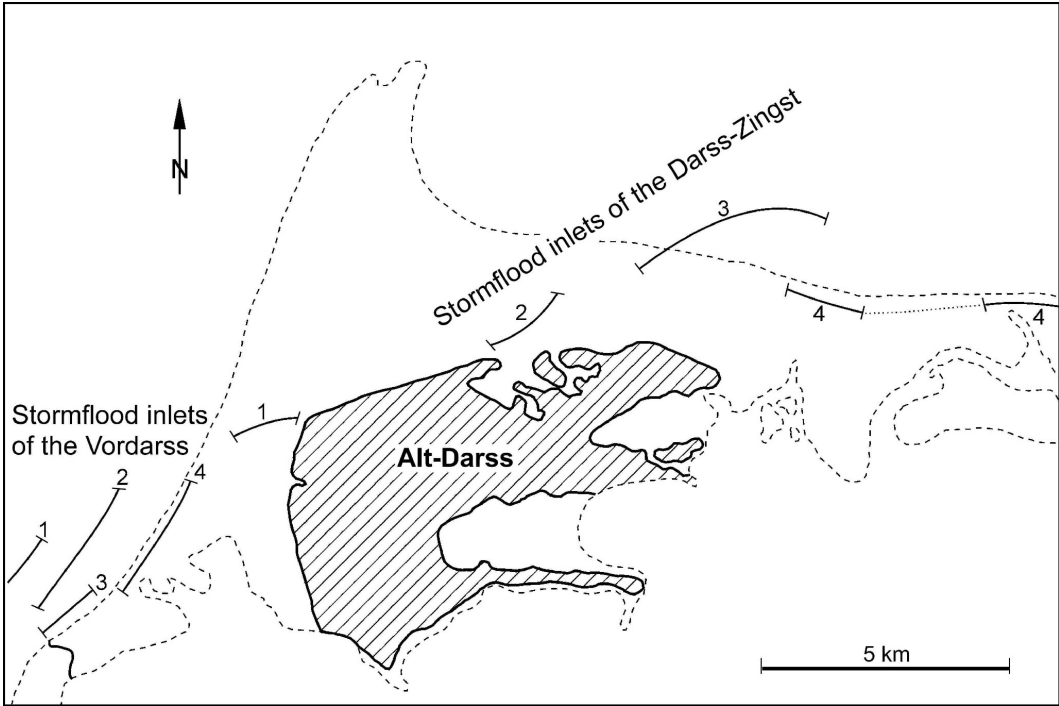
Fig. 10: Principle of the coastal dynamics of the Darss-Zingst Peninsula. Shifting of the different storm flood inlets on the westerly and northerly coast (see Figs. 1-8).

The basic principle of coastal dynamics is derived from this area. The westerly exposed coast of the Darss is characterized by strong abrasion of the cliff coast of the Fischland and of the flat coast of the Vordarss, as well as by a quick accumulation at the Darsser Ort in the northeast caused by the predominant westerly winds (Fig. 9). The development of stationary storm flood inlets is the consequence on the flat coast of the Vordarss (Fig. 10). The northerly exposed coast of the Darss is characterized by an easterly shift of the abrasion maxima and therefore of the storm flood inlets (Fig. 5 and 6). The evolution shows the predominance of westerly winds for the last 4000 years.

This basic principle of the coastal dynamics can be used to forecast the coastal configuration during the 21st century assuming a rising sea level and without human influence (Fig. 11). The coastal settlements of Ahrenshoop and Zingst would have to been abandoned.
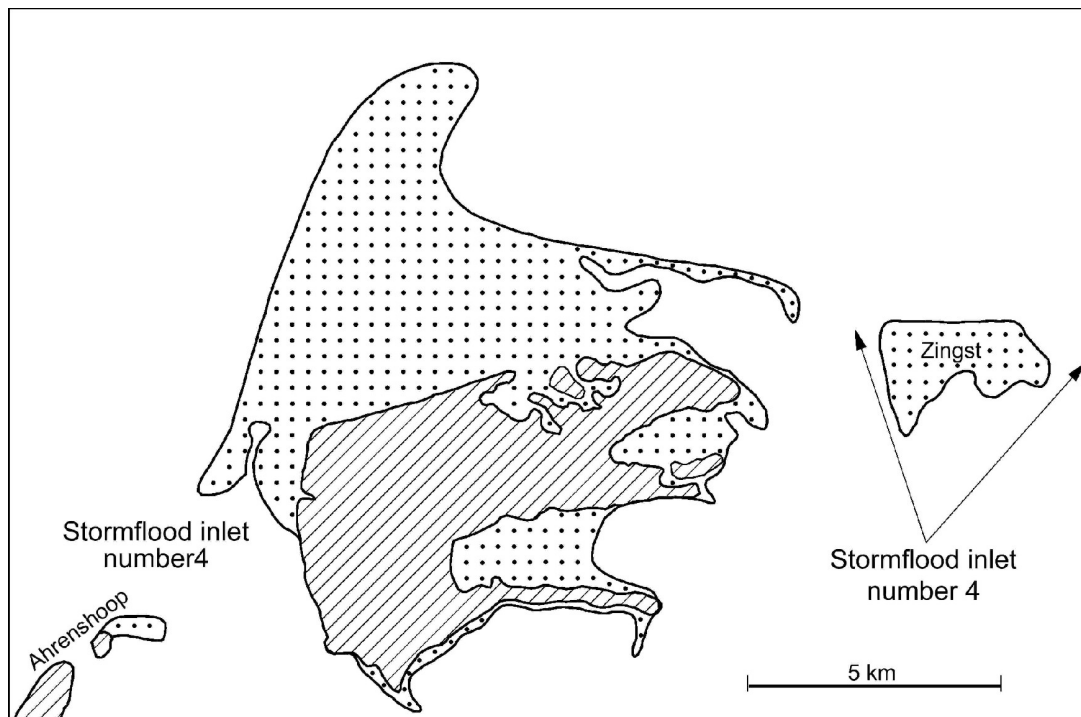
Fig. 11: Hypothetical coastal situation of the Darss-Zingst Peninsula at the end of the 21st century without measures of coastal protection and assuming a water level rise of 0.5 metre.

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The High Cliff of the Fischland

REINHARD LAMPE, WOLFGANG JANKE

The Cliff of Fischland – about 3.5km long and running nearly N-S – is one of the most interesting sections of the German Baltic coast in terms of geomorphology and geology as well. Both the composition of the cliff and the considerable land loss have stimulated detailed investigations. For the first time the cliff was geologically surveyed by GEINITZ (1910). He also determined the retreat rate and estimated the volume of the abraded mass. After further investigations by BENTHIEN (1957) and SCHULZ & AHRENS (1985) the cliff was mapped in detail again by SCHUBERT (1955/56), LEMBKE (1980) and PIETSCH (1991) creating the base for small-scale comparisons.
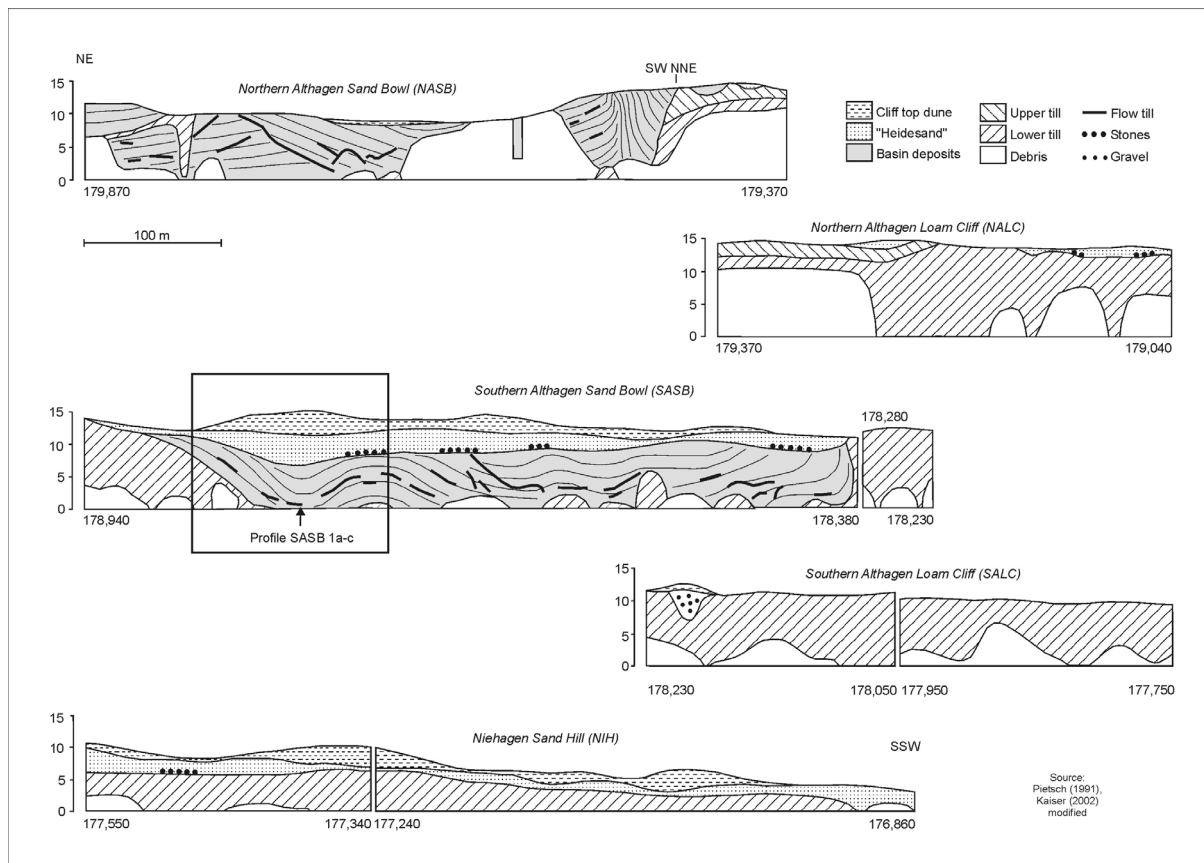
Fig. 1: Geological profile along the High Cliff of the Fischland (after KAISER 2001, modified)

Concordantly the cliff is dissected into several parts, well-defined in terms of their geology and morphology. According to GURWELL (1985) the following sections can be distinguished from N to S (Fig. 1)

1. Northern Althagen Sand Bowl (NASB)
2. Northern Althagen Loam Cliff (NALC)
3. Southern Althagen Sand Bowl (SASB)
4. Niehagen Sand Hill (NSH)

In the composition of the cliff five stratigraphic units of different thickness are involved

- dune sands   up to 6 m
- "Heidesand" at the top supporting an up to 0.6 m gleyic podzol   up to 5 m
- basin sands   up to 5 m
- Upper Till   up to 3,5 m
- Lower Till   up to 16 m

The tills can be distinguished statistically by higher numbers of Palaeozoic Chalks and Pa-laeozoic Shales in the Upper Till and very high numbers of Mesozoic Chalks in the Lower Till. PIETSCH associated the Upper Till with the W3 = Mecklenburg stage, and the Lower Till with the W2 = Pomeranian stage. The main strike of the joint system is more or less parallel to the coast (Fig. 2)
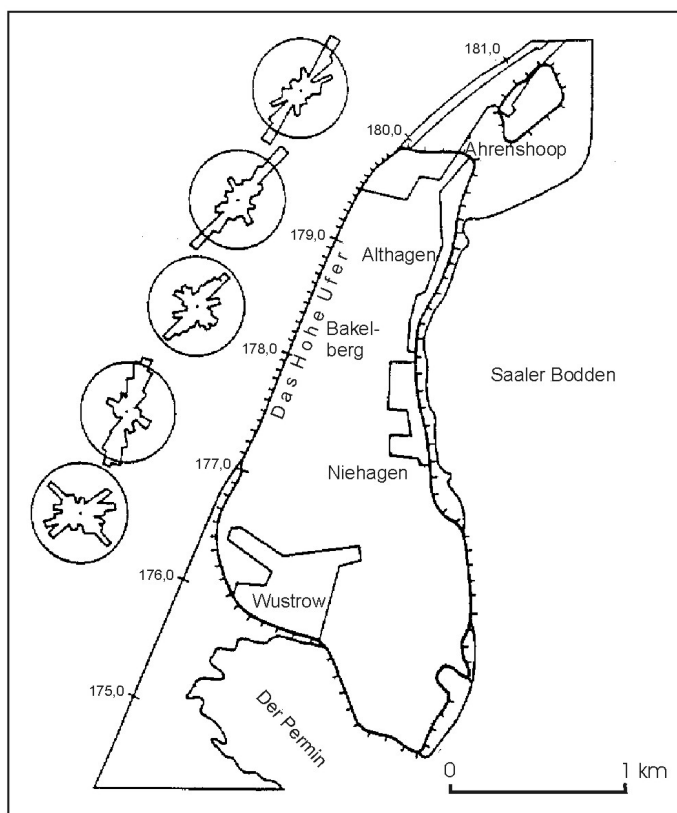
Fig. 2:
Distribution of fissure strike directions along the High Cliff (after PETERSS)

The basin sands appear in the areas of the SASB and NASB in bowl-like depressions immersed in the till surface (Fig. 3, 4). Numerous diamictic intercalations, bedding destructions as well as single stones and stone layers are present as solifluction debris and colluvial materials which filled dead-ice depressions. Partly with inconformity, an obliquely bedded and partly laminated mud from silty sand is attached, from which a number of plant and animal remains have been separated, at first by LUDWIG (1963) and later by other investigators too (Plants: *Potamogeton filiformis, P. perfoliatus, Selaginella selaginoides, Chara* sp., *Dryas octopetala, Nitella* sp., *Carex aquatilis*; Molluscs: *Radix peregra, Gyraulus laevis, Armiger crista, Galpa truncatula, Pisidium pulchellum, P. pseudosphaerium, P. subtruncatum*; Ostracods: *Ilyocypris gibba, Limnocythere inopinata, Candona candida, Herpetocypris reptans, Cyclocypris cf. ovum, Cypris pubera, Cypridopsis vidua*). They point to a small, limnic, cold, clear, stagnating or slowly running water under boreal or subarctic conditions. For the mud a pollen analysis proves Oldest Dryas to Allerød and a ^{14}C-date confirms that (11,543 ± 200, Bln-392, KAISER 2001).
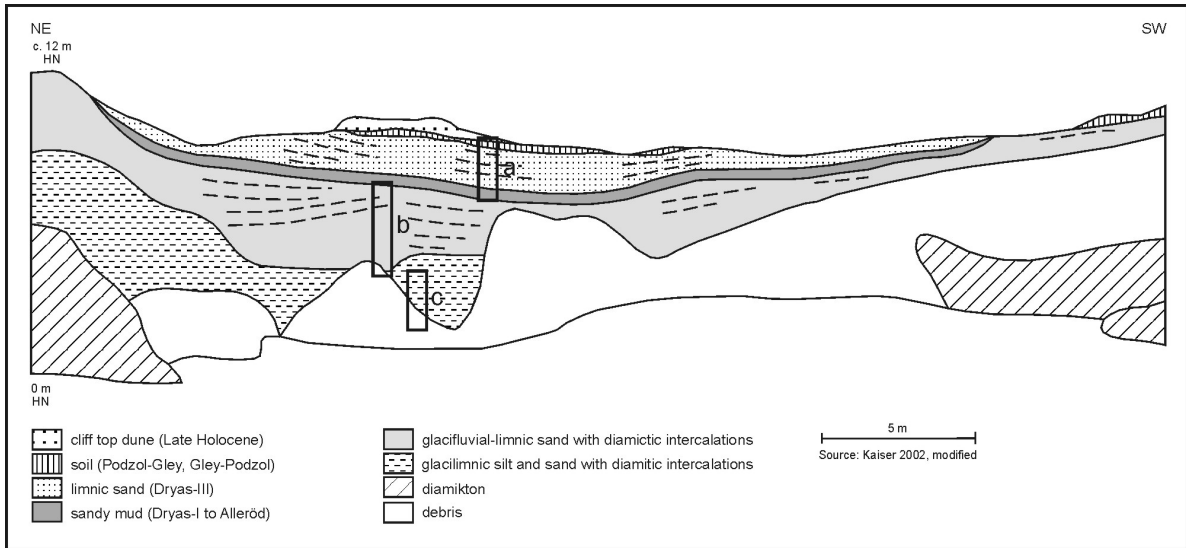
Fig. 3: Geological profile along the South Althagen Sand Bowl (after KAISER 2001, modified)
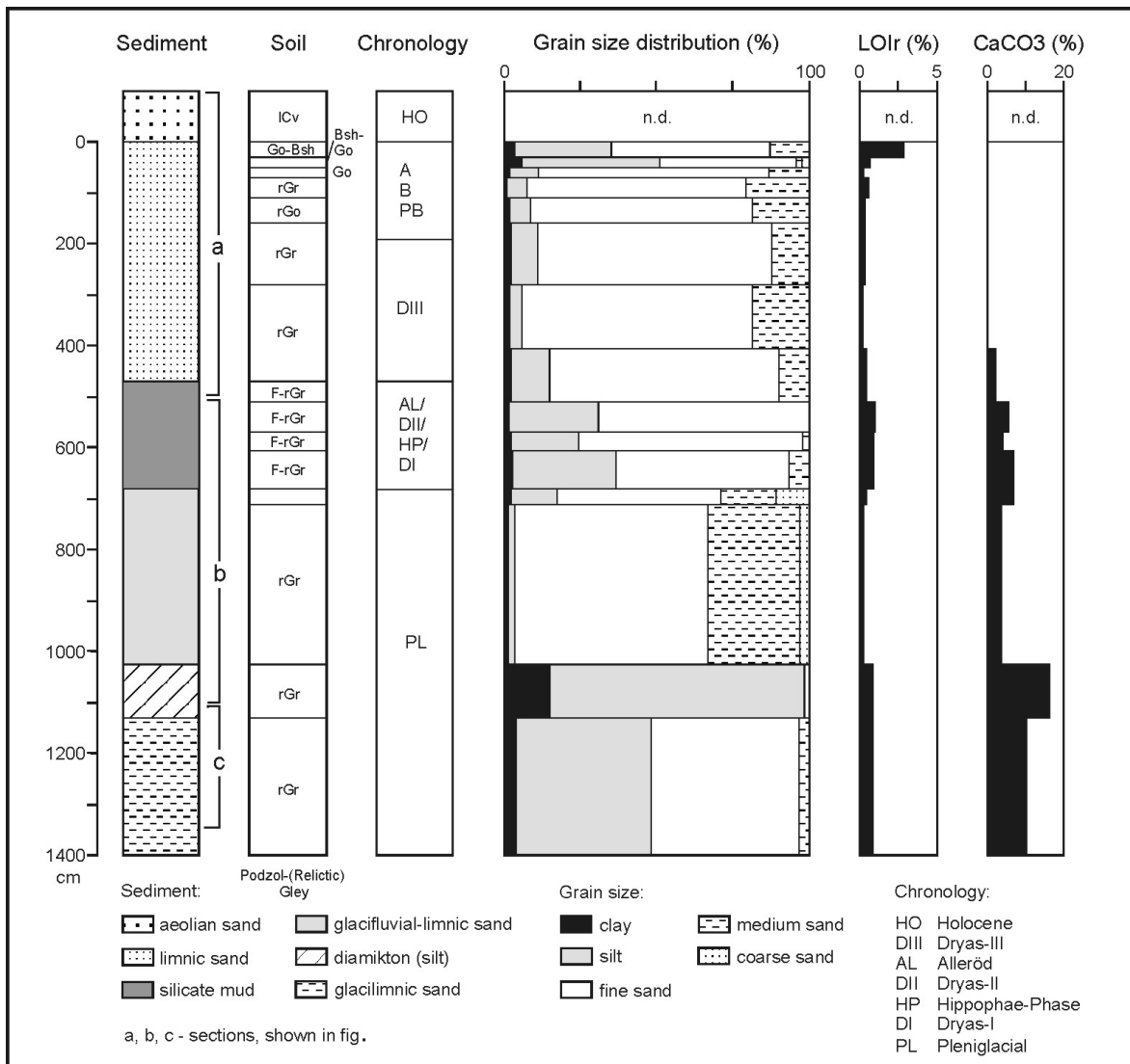
Fig. 4: Chrono-, biostratigraphy and characteristic parameters of the sediments of the South Althagen Sand Bowl (after KAISER 2001, modified)

Partly with inconformity, silty fine sands follow above, up to 5m thick. Primarily they have been called "Heidesand" (heath sand). Heidesands are sediments of a fluvial-limnic melt water basin, which once covered an area of more than 700 km² comprising the Rostocker Heide, Barther Heide, Altdarss, some parts of Fischland and Zingst and also areas now submarine. The very different altitude of the heidesand´s surface is attributed to its deposition above dead-ice, which melted later. The level of this pleniglacial melt water lake, located in distal position to the ice edge, must have been about 15 to 20m the today's sea level if no subsequent vertical movements of the earth´s crust are considered. The onset of the Heidesand´s accumulation dates – as far as is known – to the Oldest Dryas (KAISER 2001). During the Allerød peats and thin soils developed over a wide areaon the meanwhile desiccated sands and were covered by aeolian sand sheets and dunes in the succeeding Younger Dryas. The Heidesand accumulation during a fluvial-limnic phase (D-I to D-II) was followed by interstadial limnic and terrestrial deposits (A) and an aeolian redeposition and accumulation phase (D-III)

From structural and stratigraphic view points, the "Heidesands" from the Fischland cliff cannot be related to both the pleniglacial fluvial-limnic Heidesands in the surroundings and to the aeolian deposits of the Younger Dryas (KAISER (2001). In addition to parallel, oblique and ripple bedding, numerous load casts are traceable which indicate an aquatic environment. Microfossils, such as epiphytic diatoms, point to a limnic accumulation environment too. Late Palaeolithic and Mesolithic artefacts found in the range of the iron-humus pan of the podzol and the underlying mud lead to a temporal placement between Allerød and Younger Dryas. They came into being due to local deflation of vicinal older fine sands and their subsequent accumulation in a water basin. An additional sand supply from shoreline erosion seems to be possible due to a remarkable admixture of redeposited older pollen grains from former interstadials, interglacials and the Tertiary. However, the pollen diagram (Fig. 5) reveals that the accumulation in the basin has continued until the Early Atlantic without any interruption. E.g. the Boreal *Corylus* maximum was found 1.5 m below the hangingwall soil. The upper 65 cm of the sand sequence demonstrates a diatom assemblage typical for an oligotrophic water with some submerse plants.

At the top of these sands a buried gleyic podzol up to 0.6 m thick exists (according to FAO 1998). The upper horizons are truncated due to strong deflation but the iron-humus pan resisted the blow-out and forms a barn floor-like plane area. The cliff top dunes formed due to deflation of the sands outcropping at the cliff show a rugged relief and are heavily dissected in consequence of trampling.

All sections of the Fischland cliff are subject to strong shoreline retreat, which markedly exceeds the average value of all cliffs amounting to 0.34 m/yr. GEINITZ already gave a figure of 0.5 m/yr (1885-1903), which is equivalent to an annual abrasion of 24,000 m³. ZANDER (1934) estimated an average value of 0.65 m/yr, BENTHIEN (1957) of 0.62 m/yr and points to big spatial differences. SCHUBERT (1955/56) also proves big temporal distinctions. For instance, the maxima of the annual shoreline retreat scatter between 0.1 and 17.6 m (GURWELL 1985). A long-term average (1835-1988/91) of about 0.75 m/yr was provided by JANKE & LAMPE (1998). The strong deviations in the retreat rate indicate the importance of single events. As a predominant principle a cyclicity of the retreat can be stated, which is characterised by sudden slope failures, caused by snowmelts or surges, which are connected with the building of large debris heaps at the cliff´s toe. The rate of its reworking determines the time at which the next slope failure may occur. Due to the numerous factors on which the heap abrasion process depends, the period between two failure events varies considerably.
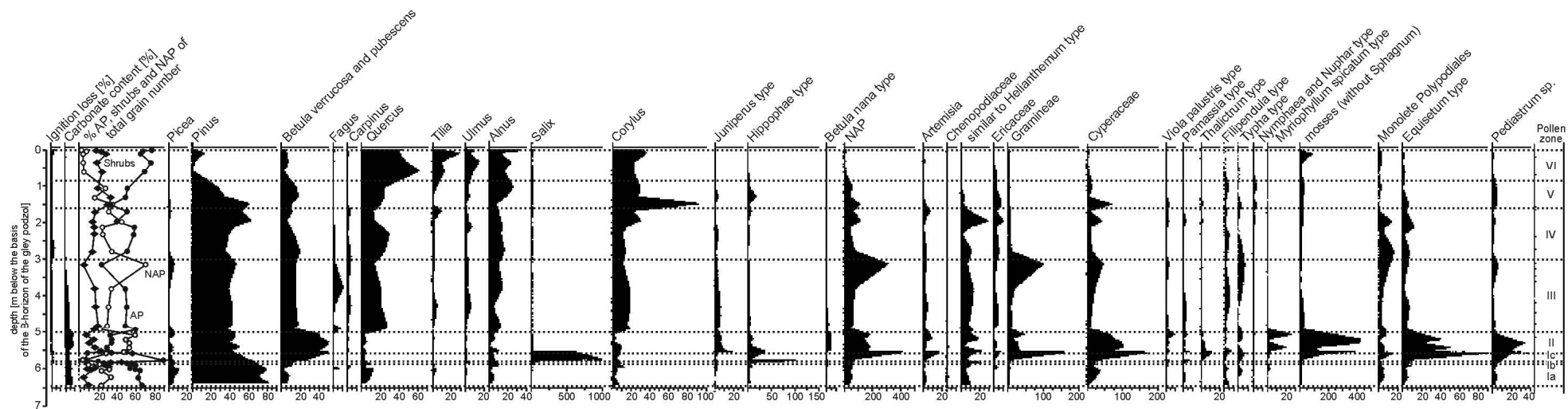
Fig. 5: Pollen diagram of the sandy sediments of the South Althagen Sand Bowl (investigator: W. Janke)

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The Darss Sill and the Ancylus Lake drainage

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Rudolf Endler, Andrzej Witkowski, Anton Kuijpers

The Late and post-glacial history of the Baltic Sea is characterised by a succession of isolation and inundation stages. During the Late Weichselian the Øresund functioned as the main outlet for Baltic Ice Lake freshwater discharge (Bergsten, Nordberg 1992). A short interruption occurred in the Late Allerød, when drainage shifted and took place via the Mt. Billingen area (Björck 1995). For the Late Weichselian, no evidence of any brackish water ingression into the Baltic basin can be found in the geological records.

Abrupt warming at the Pleistocene/Holocene boundary caused accelerated deglaciation in Scandinavia. When the ice margin receded from the Mt. Billingen area, the final drainage of the Baltic Ice Lake resulted in a 25 m water level drop. An open connection between the Kattegat and the Baltic was established through the south central Swedish lowlands. However, it took more than 200 years before brackish waters could enter the western Gotland Basin, and the duration of this brackish event is supposed to be in the order of 100-200 years (Strömberg 1989, Wastegård et al. 1995). Due to the rapid isostatic uplift of Scandinavia the straits to the Kattegat and Skagerrak were gradually closed, which resulted in a renewed decoupling from the open sea and a rising water level in the Baltic. This marks the beginning of the Ancylus Transgression at 9,500 ^{14}C years BP (Björck 1995). The higher isostatic uplift in the north caused a transgression in the southern part of the dammed up Baltic. Kliewe & Janke (1982, 1991) suggested a maximum Ancylus Lake level at 8 m below the present sea level (bsl) based on findings of *Ancylus fluviatilis* shells and freshwater diatoms in borings along the Northeast German coast. According to Kolp (1986) the maximum level was about 12 m bsl while Björck (1995) suppested this level lay in the range of 20 m bsl. Recent investigations indicate a maximum Ancylus Lake level in the southwestern Baltic of 19 m bsl (Jensen et al., 1999).

According to Kolp (1986) and Eronen (1988) the succeeding regression lowered the level of the Ancylus Lake by 20 m, while Svensson (1991) and Björck (1995) found indications of 8-10 m lowering in south-eastern Sweden. Kessel & Raukas (1979) reported an Ancylus Lake level lowering of 25 m in Estonia. A figure of 13-15 m was suggested by Alhonen (1979) for Finland and by Gudelis (1979) for Lithuania.

The crucial question in this context is the location of the final Ancylus Lake threshold.
A preliminary solution to this problem was provided by Kolp (1986) and Björck (1995), who proposed the Darss Sill as the threshold. They suggested a more or less catastrophic overflow of the sill between the German Darss peninsula and the Danish island of Falster. As a consequence of this overflow and associated gradual erosion of the sill, a river was formed which drained the Ancylus Lake via the Fehmarn Belt and Great Belt into the Kattegat for a period of about 1,000 years. Von Post (1929) named this hypothetical river Dana River. Deep channels in the western Baltic with a present water depth of 32 m (Kadet Channel) or more (Fehmarn Belt, Windsgrav Channel, Langeland Channel) were interpreted as having been parts of the Dana River.
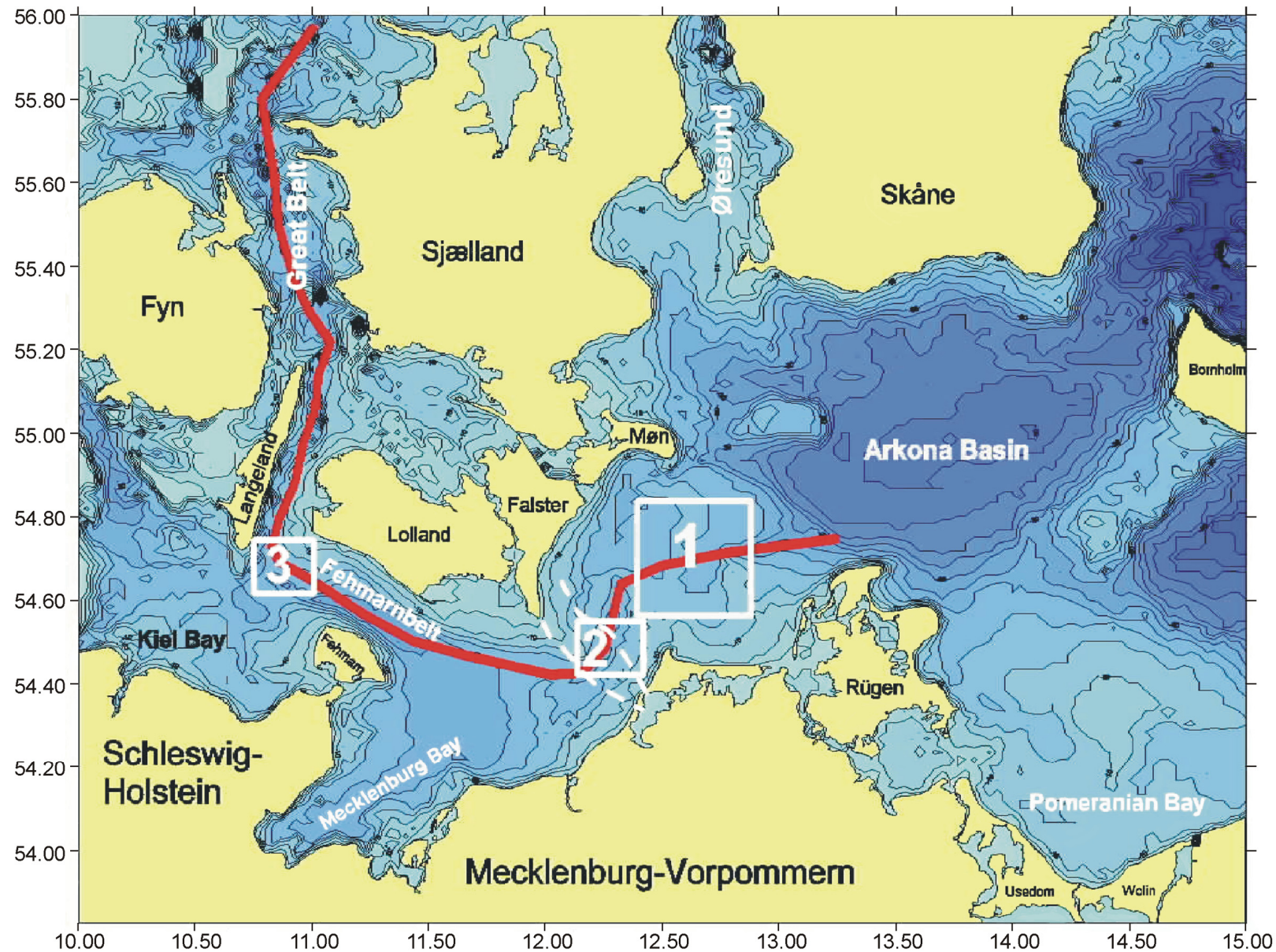
Fig. 1: Geographical setting, bathymetry according to SEIFERT & KAYSER (1995) The thick solid line marks the course of Dana River as proposed by KOLP (1986) and BJÖRCK (1995). Contour intervals are 4 m. The dashed lines outline the Darss Sill in geological terms as introduced by KOLP (1965) The white boxes mark critical thresholds referred to in the text: 1- Falster-Rügen sand plain, 2 - Central part of Kadet Channel, 3 - Triple junction of Langeland Channel, Vejsnaes Channel and Winds Grave Channel at the southern entrance of Langeland Belt

In this context not much attention was paid, however, to the present sills between the channels. So, KOLP (1986) assumed a buried north-eastward continuation of the Kadet Channel to the Arkona Basin, maintaining a drainage pathway for the Ancylus Lake at a level of 32 m bsl until the onset of the Littorina transgression. Joint Danish, Swedish, German and Polish investigations carried out recently in three of the critical threshold areas along the course of the hypothetical Dana River (Fig. 1) have produced new information about their Early Holocene palaeogeography.

In order to provide evidence that the suggested Dana River valley was to be found in the area between the Arkona Basin and Mecklenburg Bay, a grid of shallow seismic lines was run in the area of the Falster-Rügen sand plain. Instead of the expected valley structure, a shallow subbottom reflector was identified over nearly the entire area. Usually, this reflector is located some decimetres below the sea bottom. Locally, the overlying bed thins out completely so that the reflector forms the seabed surface. Vibrocoring confirmed that the seismic reflector marks the boundary between two different lithotypes.
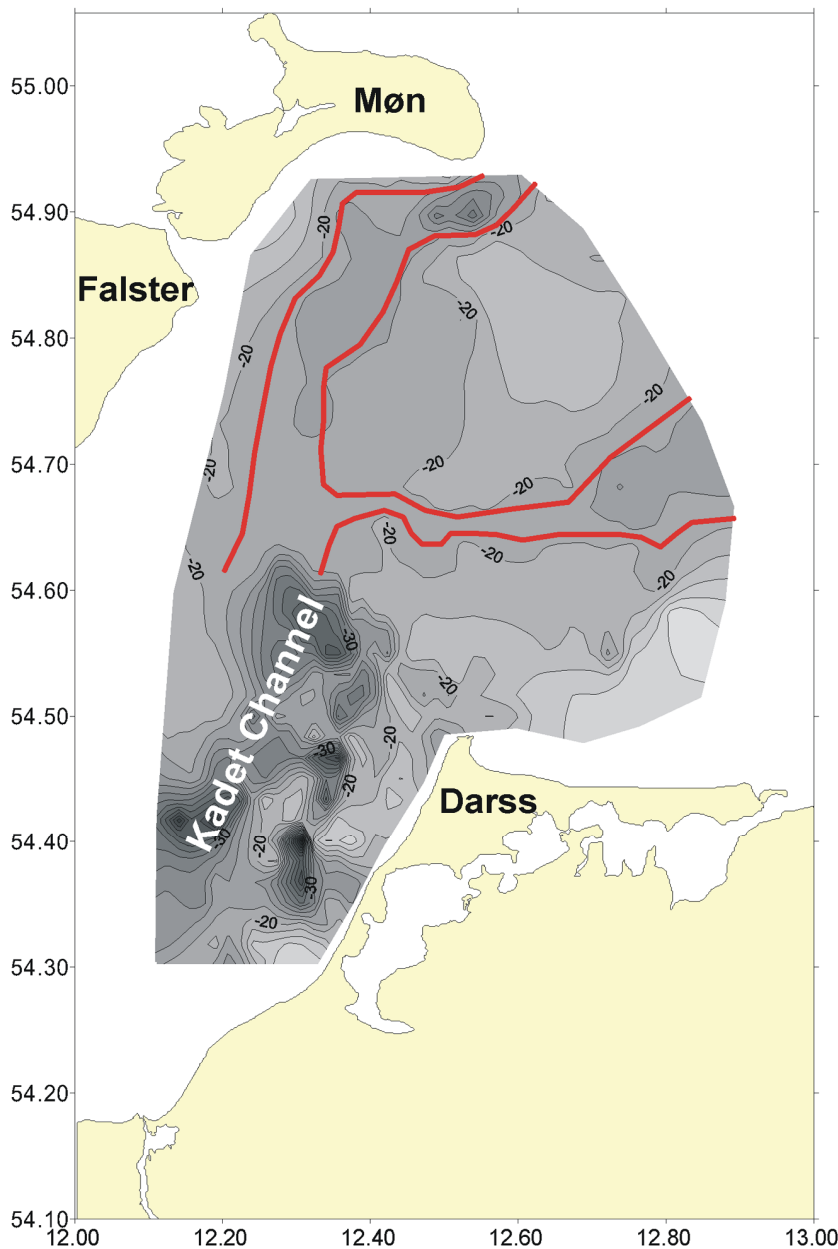
Fig. 2:
Surface of Pleistocene deposits at the Darss Sill in m below present sea level. Contour intervals are 2 m. Solid lines indicate the course of shallow channels

Lithologically, the upper bed consists of fine to medium sand with marine shells. Another fine sand below the boundary is rich in dispersed carbonate and does not contain any marine fossils. Fine humous particles are common. Shallow channels partly filled by organic detritus are incised in this lower sand body to a maximum depth of 23 m bsl.

The minimum age of the non-marine sand was determined by dating organic infillings within the shallow channels. A detritus gyttja was dated to 9,660 ± 145 years BP by conventional radiocarbon dating. Plant remains (*Menyanthes trifoliata*, *Scirpus lacustris*, *Pinus sylvestris*) within such a layer gave an age of 9,810 ± 75 years BP using the AMS technique. Within the fine sand itself, two dates for remains of *Betula nana* and *Salix polaris* yielded ages of 12,180 ± 100 years BP and 12,700 ± 110 years BP. Together with findings in the Arkona Basin and Mecklenburg Bay (JENSEN et al. 1997; JENSEN et al. 1999), these dates confirm a Late glacial age for the sand below the fragmentary thin marine sediment cover. It was possible to show that the sand belongs to a Late glacial deltaic outbuilding system, fed by meltwater from glacial valleys in the south west (JENSEN et al. 1997; LEMKE 1998; LEMKE et al. 1999).

A map of the upper boundary of the late glacial sand and till (Fig. 2) clearly shows a Pleistocene threshold instead of the expected 32 m deep river valley east of the Kadet Channel. As described above, the deepest incisions in the Pleistocene sand do not go beyond 23 m bsl. Actually, Boreal deposits were found in these channel structures. They consist, however, of calcareous gyttja reflecting a quiet lacustrine or paludal rather than a fluvial depositional environment. Similar Boreal deposits of local lake, mire or swamp origin are found at several places in the Darss Sill area and were dated by radiocarbon and pollen analysis (BENNIKE et al. 1998).

Kadet Channel

The Kadet Channel is incised into the Darss Sill and has a present maximum water depth of 32 m bsl. Considering the 20 m depth contour shown on nautical charts, it appears to be an elongated valley with a length of about 35 kilometres and a width of c. 5 kilometres. Based on available information, KOLP (1965) interpreted it as a large glacial valley ("Urstromtal").
A detailed re-examination of existing bathymetric data proved the existence of a sill within the Kadet Channel at a level of only 23-24 m bsl (box 2 in Fig.1, Fig. 3). Provided the Kadet Channel is a glacial valley with typical U-shaped morphology, the threshold within it must be younger than the final deglaciation. If the Kadet Channel was part of the Dana River, the threshold must have been formed even after the Ancylus Lake drainage, i.e. it should be younger than 9,200 ^{14}C years BP.

Boomer sections across the threshold indicate the uniform presence of well-consolidated deposits (Fig. 3). Core data and diver observations prove that they consist of till and associated lag deposits. Thus, a glacial origin of the threshold is very likely. This indicates that the Kadet Channel with its complicated bathymetric structure might be a succession of kettle holes rather than a large glacial valley. Moreover, we have to conclude that water exchange via the Kadet Channel at levels deeper than 24 m bsl has not occurred since the Late Weichselian.

The concept of a Dana River draining the Ancylus Lake via the Darss Sill, Fehmarn Belt and Great Belt at a level of 32 m bsl as proposed by KOLP (1986) is in obvious contradiction to the results presented here. As all the threshold areas are situated close to the isostatic zero-line (KOLP 1986, WINN 1974), it may be assumed that seabed fluctuations have been negligible here since the last deglaciation.
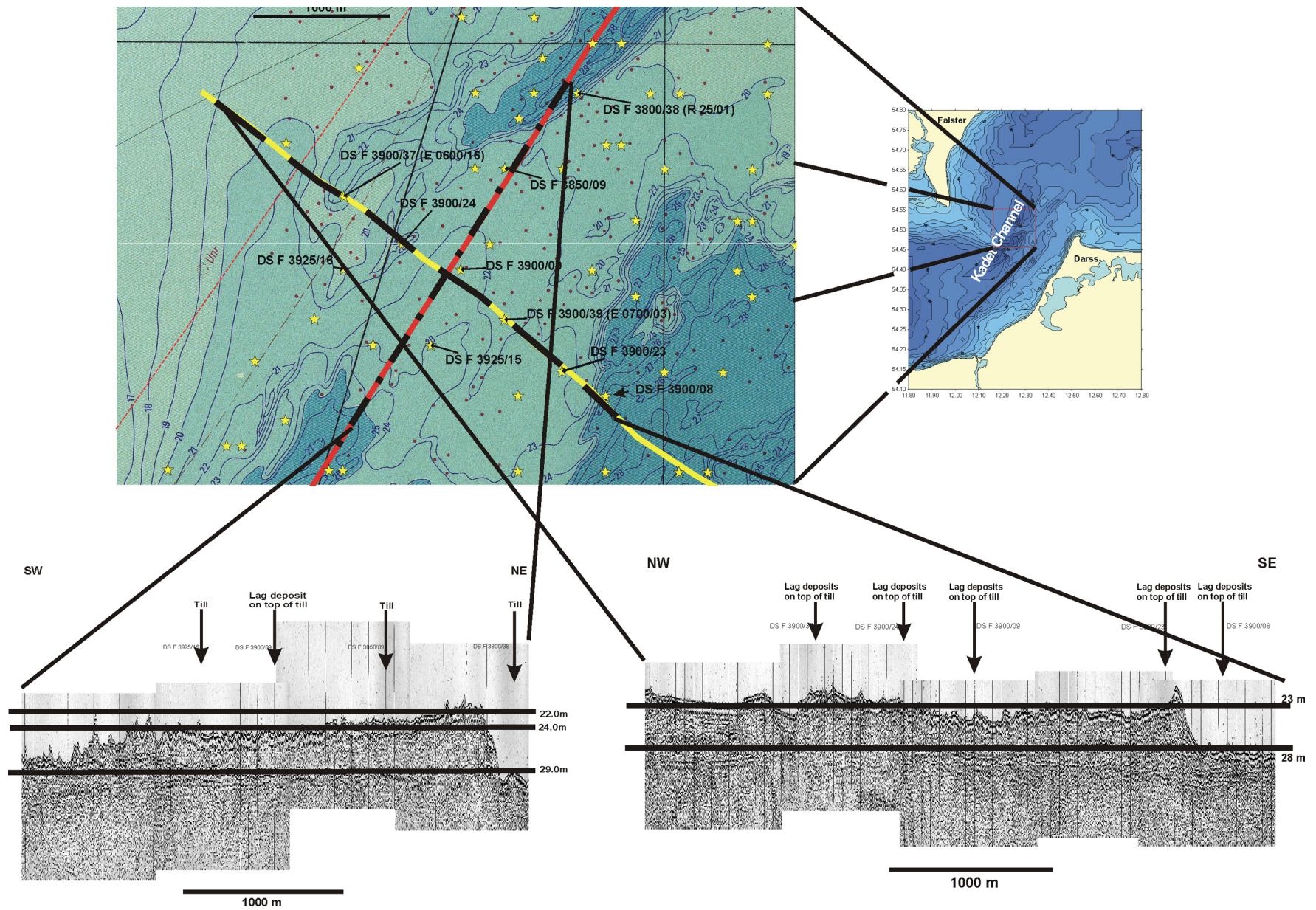
Fig. 3: Detail of the Kadet Channel bathymetry with boomer sections across the sill (23-24 m bsl) found within the Kadet Channel. Stars mark sites sampled by divers or box corer.

Since the beginning of the Holocene, at least two different thresholds have prevented water exchange at depths below 24 m bsl between the Arkona Basin and Mecklenburg Bay. The sedimentary infill of the shallow channels incised in the Pleistocene sands of the Falster-Rügen sand plain reflects a depositional environment characterised by local lakes, bogs and swamps after the regression of the Ancylus Lake at about 9,200 years BP (BENNIKE et al. 1998). According to BJÖRCK (1995), the Ancylus Lake became level with the sea after the regression. Present data from the Tromper Wiek, northeast of Rügen island, indicate a post-regressional level of the Ancylus Lake at about 32 m bsl (Lemke et al. 1998).

This necessarily implies a connection between the Kattegat and the Ancylus Lake. As the Pleistocene thresholds allow a maximum of 5 m drainage down to a level of 24 m bsl via the Darss Sill, the outlet must be sought in another place. Without such a connection in a different locality, a new transgression in the Darss Sill area would have occurred. However, there is no indication of this. Furthermore, if the Dana River had drained the Ancylus Lake via the Kadet Channel for a time span of several hundreds of years, a prograding (progressive?) system would have been likely to develop at the southwestern Kadet Channel exit. Interpretations of seismic data from this area show no indications of such a prograding (progressive?) system.

According to our data, the Mecklenburg Bay was separated from the Ancylus Lake east of the Darss Sill until the Littorina transgression which inundated the Darss Sill between 7,000 and 7,500 years BP (JENSEN et al. 1996; LEMKE et al. 1997). If the Darss Sill is ruled out as the drainage area for the Ancylus Lake, only the Øresund or the Lake Vänern area are left, though this would contradict most current publications by Scandinavian authors (e.g. BJÖRCK 1995). On the other hand, to assume an initial Littorina transgression via the Øresund at 8,200 years BP as proposed by Björck (1995) implies that at the end of the Boreal chronozone the sill depth must have been lower here than in the Darss Sill / Langeland areas. In this case, the Øresund has to be regarded as a possible drainage pathway for the Ancylus Lake.

However, then the present depth difference between 7 m bsl in the Øresund and 23 m bsl at the Darss Sill cannot be explained by differential glacio-isostatic uplift as measured today for these two areas. According to KOLP (1986) and Striggow & Till (1987), the difference in uplift rate between the Øresund and Darss Sill is about 1 mm per year. Using this as a constant for the Holocene back to 9,000 ^{14}C years BP (10,240 cal years BP according to STUIVER et al. 1998), the Darss Sill would still be 5-6 m below the elevation of the Øresund threshold.

Therefore, if the Øresund is regarded as a possible drainage pathway for the Ancylus Lake and a gateway for the initial Littorina transgression, we have to invoke additional uplift in the course of the Holocene. In this context, the finding of extraordinarily high Late glacial uplift rates on the Kullen Peninsula compared to the surrounding area (SANDGREN et al. 1999) gives rise to speculations about local or regional deviations from the general large scale glacio-isostatic pattern. Further investigations are needed to tackle this problem.

After the Ancylus Lake regression, the Mecklenburg Bay remained an isolated lake which probably drained via the Great Belt into the Kattegat. The dimensions of the channel system south of Langeland correspond well to such a regional drainage pattern.

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Coastal dynamics and coastal protection of the Fischland-Darss-Zingst peninsula

REINHARD LAMPE

The demand for coastal protection has been caused globally by the ongoing development in the past centuries. The importance of coastal protection increases with increasing population density and the expansion of development. The need for protection means for a sandy coast that more sand has been lost in the coastal section than has been gathered, i.e. the material budget is negative. By different methods, which range from compensating for losses by beach filling to the complete concreting of the coast, abrasion can be reduced or even pre-vented. With recently available technology the land can be protected without any problems, for instance by a resistant wall. The protection of a natural beach is much more difficult. The tasks of modern coastal management are

-   ensuring surge protection according to the flood design
-   stabilisation of the shoreline even including adjustment of the infrastructure
-   preservation of the natural scenery
-   maintenance of the beach as a factor of the tourist economy
-   minimisation of the costs
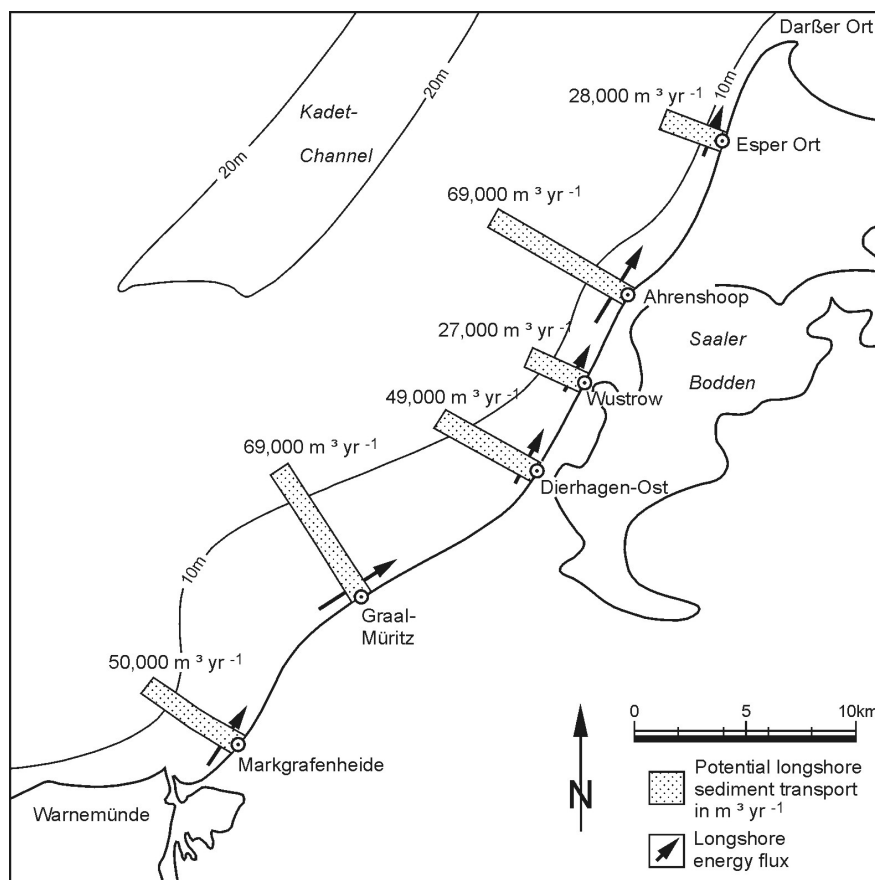
Fig. 1: Variability of the mean annual sediment transport potential along the Fischland coast (after DETTE 2000, redrawn)

The coast between the Warnow mouth and Darsser Ort constitutes a section which is composed of three flat bays (Fig. 1). The entire section is battered by prevailing waves from the westerly sector, which cause a net sediment transport directed to the northeast. Connected with changes of the coastal strike direction there are alterations of the hydrodynamic conditions and longshore energy flux. Of particular importance is the decrease in the mean annual transport potential of 69,000 m³/yr off Graal-Müritz to 27,000 m³/yr off Wustrow. For reasons of continuity, the difference of 40,000 m³/yr can only be dislocated in a seaward direction. Due to the steep shore slope (see the course of the 10m-isobath), a higher wave set-up develops off Wustrow, which amplifies the compensating undertow in the surf zone and initiates a seaward material transport. A comparison of the nautical maps of 1952 and 1979 thus demonstrates that the 5m-isobath has been shifted landward, while the 10m isobath was displaced seaward. Because the transport potential increases again off Ahrenshoop, an intensified erosion tendency exists in that area. Additionally, disturbances in the bar morphology in the transition area between the lowland and the cliff coast off Wustrow and off the Brake near Ahrenshoop (Fig. 2) lead to further wave and current energy concentrations. These difficult conditions regarding both hydro- and sediment dynamics have to be considered in coastal protection measures for the area of Dierhagen-Darss.
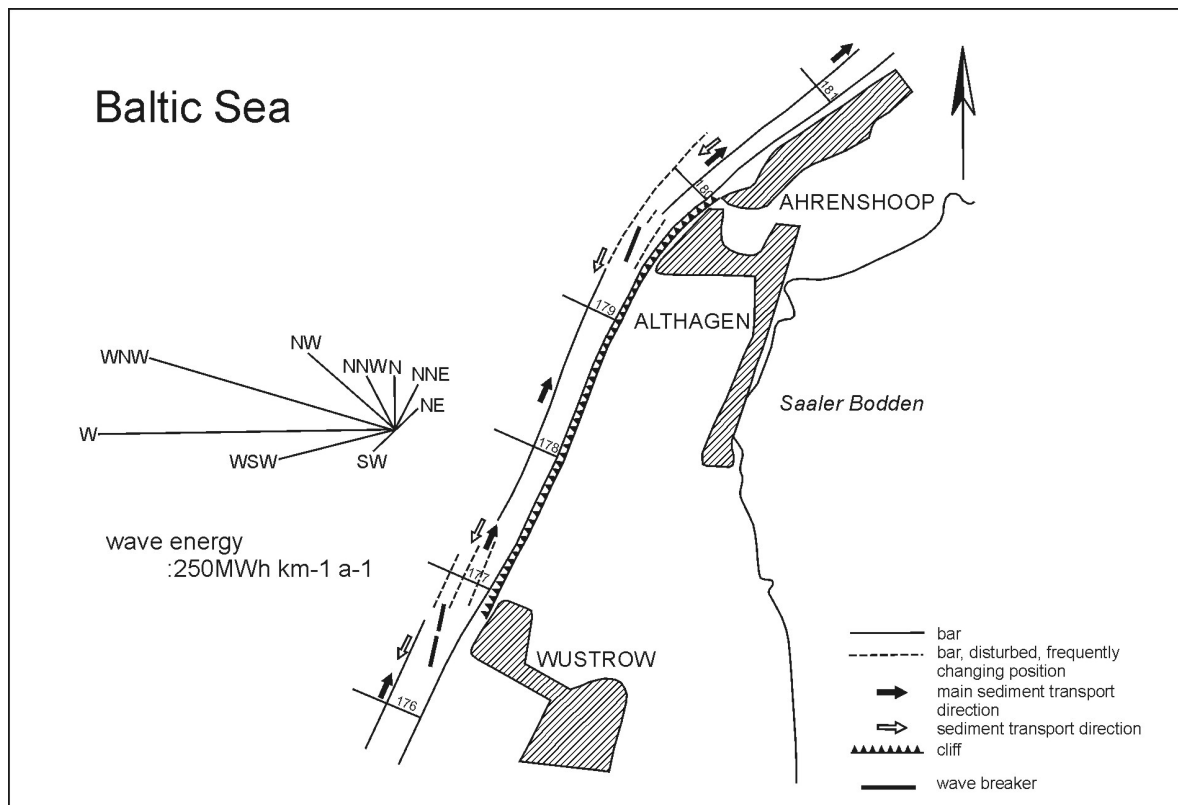
Fig. 2: Wave energy load, sediment transport directions, bar topography and breakwater positions off the Fischland (after WEISS 1986, redrawn)

Before 1872 the flat Lower Fischland stretching from Dierhagen to Wustrow was protected against surges only by dunes. During the heavy flood of 1872, a breakthrough and subsequent flooding demonstrated their insufficiency. Consequently, in 1875/78 a dike was erected between the sufficiently massive dunes near Dierhagen and the cliff near Wustrow. The dike´s foreland had widely disappeared by 1930, so 10 groynes made of wooden piles have been build to improve the sediment budget. The groyne construction proceeded in 1949

and by 1955 a system of more than 100 single-row groynes had been finished. However, around Wustrow the shoreline retreat proceeded in the faint zone at the transition from the lowland to the cliff (0,5m/yr). It was decided to move the dike backwards and this was done over a 1.1km section in 1967/70. At the southern end a reserve storage was built between the old and the new dike (230,000 m³) for the purpose of repairing destroyed dunes. In 1974/75 in the extension of the new line the dike was strengthened and in 1978/79 a beach nourishment (c. 148,000 m³) was carried out. However, the extremely difficult conditions in the section off the Fischland-Café could not be solved. Therefore in the area of the highest energy load two coast parallel wave breakers (150 m long each, 120 m from the shoreline, Fig. 2)) were constructed to attenuate the wave energy. Further in 1985/87 14 groynes with successively wider distances between the piles were built to control the sediment transport. In 1986 155,000m³ and again in 1990 135,000 m³ were added to the deficient sediment budget; in 1997 the dunes were strengthened with another 318,000 m³.

The efforts to prevent the retreat of the High Cliff go back to the 18th century. The operations were particularly intensive in the second half of the 19th century: beginning in 1865 9 groyne systems (two groynes each at 14m distance) with a clearance of 380m and altogether 16 smaller groynes in between have been built. Only the effects of the northern system were satisfactory. In 1876 the building started of a shore parallel measure of piles and hurdles which reached a length of c. 1900m in 1883. Ongoing retreat, scours and destructions led in about 1900 to a strategy change again back to groyne construction. Up until 1940 more than 100 groynes and 875m fascine revetment were built, which were not maintained during the war and were finally destroyed by the storm flood in 1954. The remains were removed in 1967/68. Since then no further protection measures have been introduced in the central part of the High Cliff.

In the northern part of the cliff a prominent sharp bend in the shoreline is located, the so called "Brake". Particularly high retreat rates since 1978 have also endangered this section, which is important for the stability of the cliff stretching from there to Ahrenshoop (Grenzweg). This section acts as the hanger for the Vordarss Lowland on which the dike is located, protecting Ahrenshoop against flooding. Because a dike withdrawal is not possible due to shortage of space, the shoreline must be kept in place ultimately. In 1986 a wavebreaker (180 m long, 120 m clearance from the shoreline, Fig. 2) was built to attenuate the waver power and to stabilise the Brake. The reduction of the natural sediment supply compulsorily connected with this measure was countered by the construction of 13 multi-row pile groynes and repeated beach fills and dune reinforcements (1987: 325,000 m³, 1991: 219,000 m³, 1997: 280,000m³). The cliff at the Grenzweg was additionally protected by a 100 m long rip rap revetment.

Already in 1887 seven groynes had been built north of the Brake. In 1932/33 this system was extended to the northern edge of Ahrenshoop. After that in 1937/38 24 sheet piling groynes were constructed, some more than 100 m long, which showed a good accumulation effect, but in the following 10 years caused strong coast retreat at their northern end near the Rehberge. Over a length of about 900 m the dune was completely destroyed. Therefore between 1949-53 a further 47 groynes were erected, whereby the retreat was reduced but it went on unhampered farther north. The sheet pilings were destroyed soon by the marine forces; in 1963-65 their remains were removed and replaced by single-row pile groynes. Already in 1956-59 a new dike was constructed between Ahrenshoop and the Rehberge to prevent a breakthrough from the Baltic to the Saaler Bodden.

On the c. 7 km long west coast of the Darss no flood protection measures are under construction or being maintained. In the core zone of the national park natural hydrography conditions and coastal dynamics are supposed to be sufficient. However, to protect Prerow, a dike is in preparation on the west side from the north coast to the higher bank of the Altdarss.

The north coast of the Darss is protected sufficiently by wide dunes. Only in the area of the High Dune east of Prerow the protection system begins, consisting of dune, protective forest and dike. The sea-dike Prerow-Zingst was reconstructed in 1965-74. Since the early sixties of the last century more than 100 pile groynes have been erected at this 11 km long section. To compensate for the increasing negative sediment budget to the east, sand was repeatedly filled into the groyne system. In the sixties 70,000 m³ were carried by trucks and 56,000 m³ were dredged at the Bodden side and hydraulically transported. Since 1976 6 voluminous nourishments have been carried out off Zingst, whereby 1.3 million m³ sand have been filled on 13 km coastline (1965/66: 56 Tm³, 1971: 202 Tm³, 1978/79: 602 Tm³, 1983: 156 Tm³, 1984: 152 Tm³, 1992: 123 Tm³). In the section Zingst/Stramminke a sea-dike was erected, which was equipped over 800m length with massive seaward protection (stony revetment on geotextile) due to the missing foreland.

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Salt meadow evolution and Holocene sea-level rise
- the examples Kooser Wiesen and Ribnitzer Wiesen

REINHARD LAMPE, WOLFGANG JANKE

Mires are archives of landscape development, because vegetation remnants are preserved in an anoxic environment for a long time and hardly removed or changed after sedimentation. Therefore highly resolved and selective stratigraphies can be obtained from peat profiles. Moreover, coastal grass peats depend in respect to their vertical growth totally on the sea level, are witnesses of its variations and, furthermore, preserve remnants of organisms which permit conclusions about the nutrient content and salinity of the flood water and thus of the surrounding sea.

Coastal peatlands develop if, on coastal sections with minor hydrodynamical stress (located widely on the inner lagoon coastal waters locally called "Bodden"), reeds come into being in place of a beach. Their extension in the landward direction depends on the increasing distance from the groundwater and, in the seaward direction, on the increasing mechanical power of waves, currents and drifting ice. As the dominant species, firstly *Phragmites australis* appears, and more seawards *Bolboschoenus maritimus*, too (SLOBODDA 1992). All coastal mires, which have a sufficient thickness possess such a reed/sedge peat base, the growth of which has been induced by the rising sea and whose development started in the middle Atlantic to the Subboreal depending on the elevation of the mineral subground.

A rising sea level causes a landward shift and a growing thickness of the, whereas a sea-level fall leads to superficial desiccation and mineralisation (development of black layers, see below) and, accordingly, a lowering of its surface. The dependence of the *Phragmites* peat surface on the vicinal sea level is quite marked and is restricted to an interval of about +20 to – 20 cm around the mean sea level (KRISCH 1978, SLOBODDA 1992). The peat of the coastal reeds is characterized by low to high losses on ignition (up to 90%) depending on the distance from the shoreline and small dry bulk densities (about 0.1 g/cm³). In the seaward direction, the peat is replaced successively by silicate muds and finally sand from the shallow water areas.

Typically, in their upper section the peat profiles of the salt grass meadows change into black muds, poorer in organic carbon (black layers), and finally into grass peats rich in mineral matter. The starting point of this alteration is a failure of the *Phragmites* reeds at about the closure of the pollen zone Xa due to a sea level regression (JESCHKE, LANGE 1992). The dried areas were then used by Slavonic and German settlers as cattle pasture without much effort. Connected with the continuation of the sea level rise during the pollen zone Xb, the development of the grass peat started. The strongly competing reed was repressed due to the grazing cattle, whereas halophilic grasses and herbs were encouraged. Resulting from 800 years of interplay between flooding with material supply from the lagoons, accumulation of organic matter (predominantly of grass roots) and zoogenic densification with prevention of oxygenation and mineralization, the coastal peatlands have the potential to grow to a higher elevation above sea level than any other peats (JESCHKE, LANGE 1992; KLIEWE, JANKE 1982; LANGE et al. 1983). Typical levels are between 20 to 50 cm above mean sea level (msl).

The black layers developed due to peat oxidation caused by a groundwater or sea level fall. Such a fall could have been triggered by eustatic sea level variations, by climate changes to warmer and drier vegetation periods with intensified evapotranspiration and, in the past some hundred years, by anthropogenic drainage measures. Apart from their more or less intensive colour, the black layers can be identified macroscopically by their amorphous-smeary structure and the lack of synchronously built plant remains. The latter have been more or less totally mineralised, but younger roots from the layers above may have penetrated into the deposit and been preserved.

At the margin to the layer above, a hiatus is usually found and can be proved only by means of pollen analysis or absolute dating. An important palynological criterion is the high pollen and spore density as a result of their relative enrichment during the degradation of the organic peat substance. Nonetheless, the ignition loss of the black layers amounts to about 40-65%, demonstrating that a strong peat accumulation must have preceded the subsequent degradation. In the upper section of the black layer a zone exists where *Pinnularia* diatoms are enriched. They point to an increase in subaerial conditions and a decreasing salinity during the turning period between the transgression and the following regression. Sedimentologically/geochemically the black layers are characterized by a density too high for the organic carbon content, by high degrees of humification and partly by enrichments of pedogenic iron.

Kooser Wiesen

The profile emanates from a coastal mire about 1m thick on the southwestern shore of the Greifswalder Bodden, which covers a flat, late glacial sand plain with only minor surface undulations. The investigation site is located directly on the southern bank of the Kooser See, a shallow bay which probably has been enlarged or even came into being due to heavy surges during the 14th century. With a ground surface of around 50 cm above msl, this site is located higher than any other coastal peatlands and therefore it was reached later by the transgression. In contrast to the Karrendorfer Wiesen site on the northern bank of the water, the Kooser Wiesen has never been diked and has been preserved as a nearly natural, undisturbed salt grassland. To the east it borders on the Greifswalder Bodden with its wide opening to the Oder Bight, and therefore the site is significantly exposed to surges which are mostly caused by northeasterly gales. Today the Greifswalder Bodden is a eutrophic water with a salinity of c. 7.5 PSU. The profile investigated has a length of 87cm and comprises the mire body and the underlying sand.

From the viewpoint of pollen analysis only the upper 83cm can be analysed (Fig. 1).

Section 1(87-83cm): the uppermost sample of the medium sand normally without pollen grains attracts attention with its extremely high *Ulmus* and *Tilia* and yet low *Polypodiales* pollen share. The number of *Chenopodiaceae* is also noticeable, as well as pollen of the *Aster* type.

Section 2 (81-72 cm): A mire comes into being, surrounded by alder together with oak mixed forests rich in limes and elms. The higher content of monolete *Polypodiales* and *Sphagnum* points to a fast rise of the groundwater level, and the high content of non-arboreal pollen (above all *Poaceae* and *Cyperaceae*) and the appearance of *Chenopodiaceae* and *Compositae* (*Aster* type) reveal an environment close to a shore. A ^{14}C-date gives an age of 5,155 ± 285 cal BP. The sediment still contains no diatoms.
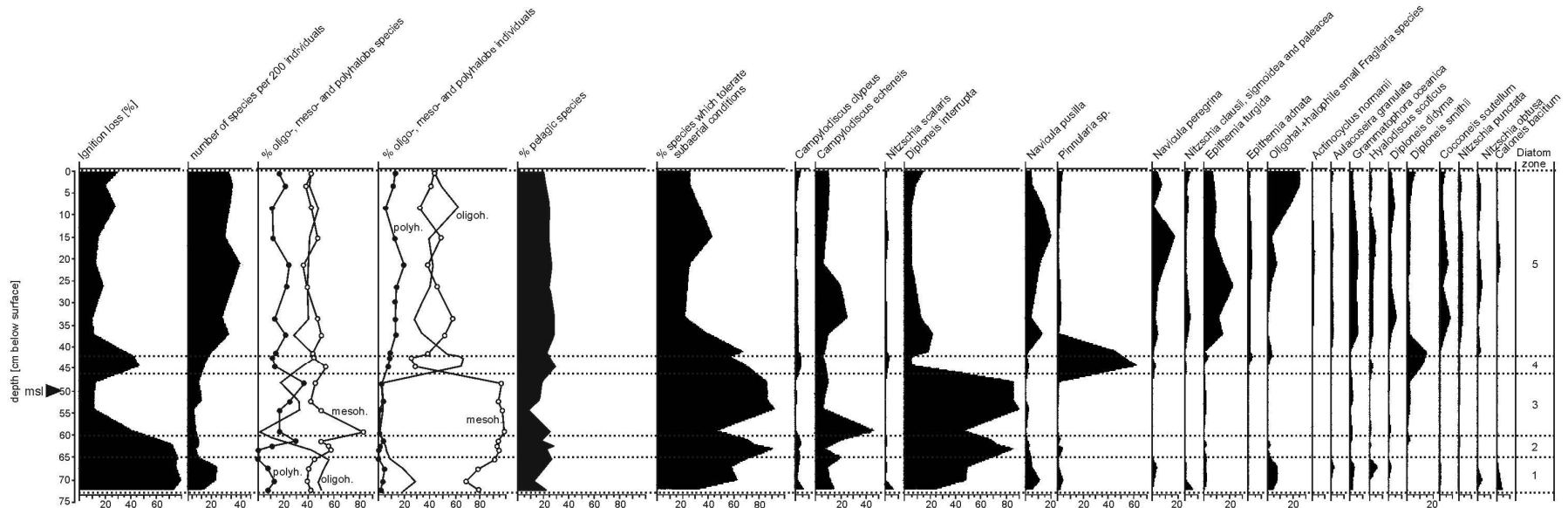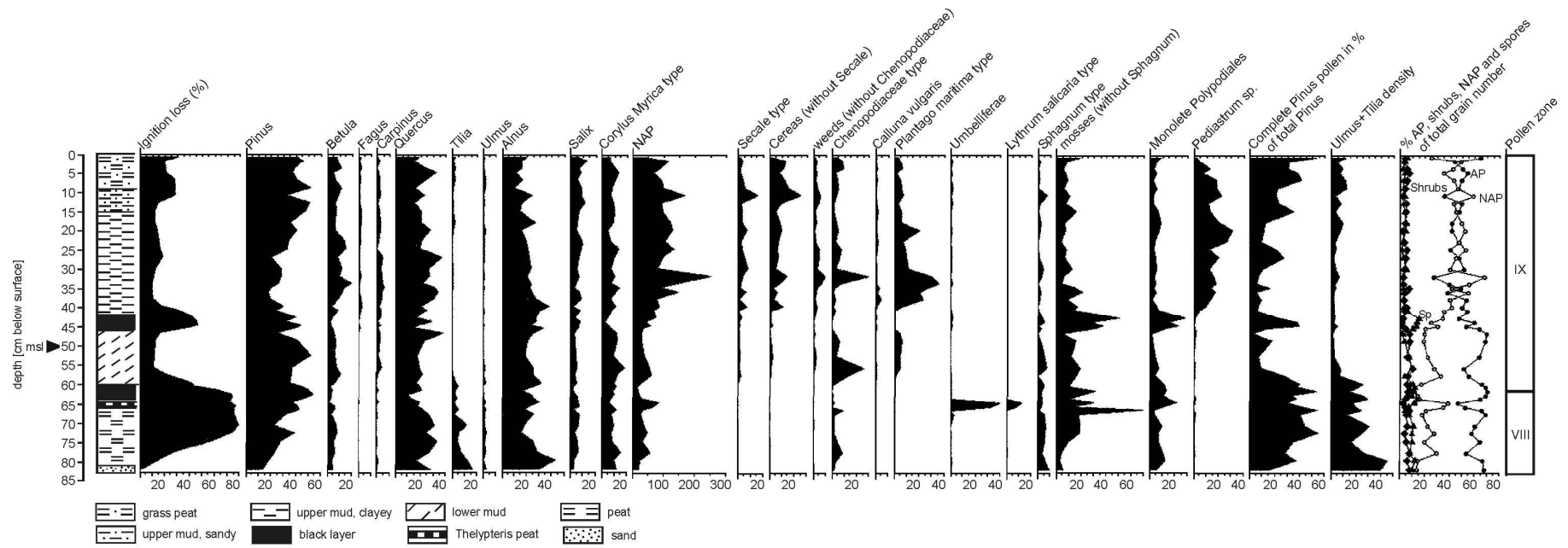
Fig 1.: Pollen and diatom diagram, profile Kooser Wiesen – Seeufer (KWS)

Section 3 (72-64cm): The mire, located close to the shore now develops into coastal peat land with oak mixed forests, rich in elms, limes and alders in the vicinity inland. In the final stage, a massive occurrence of *Thelypteris*, *Umbelliferae* and *Lythrum* is observable, accompanied by the appearance of *Hydrocotyle-*, *Menyanthes-*, *Valeriana dioica-*, *Lycopus-*, *Succisa-*, *Calystegia-* and *Filipendula*-type pollen grains. The existence of some brackish water diatoms demonstrates occasional flooding. A ^{14}C-date provides an age of 4,080 ± 140 cal BP.

Section 4 (64-60cm) is characterised by the lower black layer. The pollen distribution is still determined by quercetum mixtum with elm and lime and a high *Pinus* fraction. *Chenopodiaceae* appear only sporadically. Monolete *Polypodiales* increase which prefer an environment not influenced by brackish water. Pollen grains pointing to tillage and pastures are not yet observable.

Section 5 (60-46cm): In the basal part, mud of the L-III transgression with intercalated humous layers appears. The terrestrial vicinity was cover with forests; no cereal pollen has been observed. *Chenopodiaceae* increase again. Later continuous but minor cultivation of cereals; first continuous appearance of *Plantago maritima*; very high density of pollen grains and spores; remains of a *Campylodiscus echeneis* flora, poor species diversity due to post sedimentary opal solution, also species appear which tolerate subaeric conditions such as *Diploneis interrupta*. ^{14}C-AMS-dated charcoal points to 2,099±46 BP and 1,920±75 BP (terminus ante quem).

Section 6 (46-42): The upper black layer is the result of the mineralisation of a peat which developed during the Post-Littorina transgression. A ^{14}C-date shows 1,335 ± 55 cal BP. Probably the mineralisation occurred during the culmination of the Little Ice Age, characterised by a climate with hot, dry summers and long cold winters. The pollen diagram is characterised by a high *Pinus* fraction and strong increase in some NBP components (such as *Poaceae* and *Cyperaceae*) and of *Polypodiaceae*. Further, only minor agricultural land use, a strong decrease in *Chenopodiaceae* and *Plantago maritima*, as well as a low pollen/spore density were observed. The section reveals the strongest deviation from the normal diatom assemblage.

Section 7 (42-28cm) is characterised by very clayey mud, poor in humus. The pollen assemblage is indicated by the increasing usage of cereals and the first increase in *Botryococcus* and *Pediastrum*. A sharp decline in the curve depicting complete *Pinus* pollen grains points to increasing sediment transport and mixing. The increase in *Betula, Quercus* and *Carpinus* and the *Calluna* maximum between 38 and 33cm are probably related to the 30 years war. Above 33cm, the maxima of *Poaceae, Chenopodiaceae, Plantago lanceolata* and *Plantago maritima* have been observed and the agricultural use has been intensified.

Section 8 (28-12cm): In this section the youngest increase in the *Pinus* curve was caused by the introduction of forestry and reveals high values until today. The convergent shoreline causes a higher sand content in the sediment and a lower pollen density. The still ascending cereal curve indicates the intensification of agricultural land use.

Section 9 (12-0cm): is equivalent to the uppermost, more sandy and humus grass peat. It was probably accumulated only after the surge of 1872, which caused the prominent sand layer 14-15cm below the surface. The farther approaching shoreline led to the deposition of tempestites and an admixture of older and reworked sediments. Consequently the pollen assemblage can change so markedly that it no longer corresponds to the true pollen assemblage recently observed on salt meadows.

Körkwitz

The profile is located on the Ribnitzer Wiesen south of the village Dändorf. The mire is about 4-5m deep and consists predominantly of fenwood and *Phragmites* peat and peat muds. The assumption that the depression now filled by the mire, was built by the Recknitz before and during the Littorina period (Hurtig 1954) has not yet been proved conclusively. The vicinity is characterised by flat undulating sand plains, formerly used as arable land and recently covered with *Pinus* forests and pastures. The profile is located c. 200m away from the recent shoreline of the Saaler Bodden, from which resuspended sediment material can hardly reach the location due to the dense reed belt. Since the Middle Ages, the salinity of the Saaler Bodden has decreased explicitly due to the ongoing coastal change and amounts today to between 0.5 and 2 PSU. At the same time, the nutrient content increased to a polytrophic/hypertrophic degree, causing high mud sedimentation rates primarily in the southern part of the water. The section investigated chemically starts only at 108cm, the palynological/diatomological investigation starts at 410cm below the surface.

The basal sands between 410 and 390 cm below the ground surface (bgs) contain freshwater diatoms. Their age is difficult to determine due to only less preserved pollen grains, among them QM species and *Alnus*, but is likely Early Atlantic (pollen zone VI). They are covered by a Gleysol (390 – 350 cm bgs), which passes onwards into a peat. With the onset of the Littorina-I transgression the site becomes a wet meadow with *Diploneis interrupta* as the main species (350 – 344 cm bgs, Fig. b). The hangingwall section (344 – 325 cm) depicts a bi-peaky *Campylodiscus echeneis* maximum, accompanied by high sponge needle values. (From the Littorina-I period a similar diatom flora with *Campylodiscus echeneis* predominance is known from the salt meadow site Struck (southeasterly coast of the Greifswalder Bodden) – but there already at a depth of 140 – 145 cm bgs.) As the only section it contains *Operculodinium centrocarpum* and demonstrates low values of the complete-*Pinus* curve. Towards the end of the stage the contact to the open sea was gone lost.

The next section reveals a marsh-like area with shallow waters in the vicinity and drift lines around (*Chenopodiaceae*). Among the diatoms *Diploneis interrupta* predominates, whereas in the pollen diagram a high NAP share has to be stated, particularly from plants growing in underwater, beach and drift line habitats (*Typha*, *Potamogeton*-type, *Cyperaceae, Chenopodiaceae*). This and the next section up to 170 cm bgs consist of organic mud and peat with an ignition loss of c. 80% and came into being in the Late Atlantic. Upwards the clastic material increases slowly, above 170 cm faster to 40…70%.

A peat sample, taken at 137cm bgs reveals a conventional ^{14}C-age of 4,490 +/- 100 BP. In the section up to 80cm, the pollen diagram depicts a closed oak mixed forest, rich in *Corylus, Tilia* and *Ulmus* and some alder habitats. *Fagus/Carpinus* and cereals appear regularly. In the lower part some indicators for higher salinity have been proved (*Chenopodiaceae*, aster-type, fenestrate *Compositae*). The section is related to pollen zone VIIIa. The diatom flora – as far as preserved - consists only of *Diploneis interrupta* and *Campylodiscus echeneis.* The only slight increase in Na, Q4/6, C and C/N in the lowermost 10cm is related to a transgression (which can only be the L-II) and the subsequent stagnation of the sea level.

Ignition loss [%]

% AP, shrubs and NAP of total grain number

Pinus
Betula
Fagus
Carpinus
Quercus
Tilia
Ulmus
Alnus
Corylus/Myrica type
NAP
Cereals
Fagopyrum esculentum
Artemisia type
Centaurea cyanus
Chenopodiaceae
Plantago lanceolata and major
Rumex acetosella type
Sinapsis type
weeds
weeds (without Chenopodiaceae)
Gramineae (without cereals)
Cyperaceae
Plantago maritima

AP
NAP
Shrubs

depth [cm below surface]

20 40 60 80   20 40 60 80   20 40 60   20   20   20 40   20   20   20 40   20 40   200 400   20   20 40   200 400   20 40   20   200 400   20 40 60 80 100   50 100 150

Ericaceae
Asteraceae (without Artem.+Cent. Cyanus)
Fenestrate Compositae
Potentilla type. striat
Filipendula type
Succisa type
Valeriana sp.
Shrub plants of wet habitats
Typha sp.
Potamogeton Coleogeton/ Triglochin type
plants of wet habitats without Plant. Maritima+Cyperaceae
mosses (without Sphagnum)
Lycopodium inundatum
Monolete Polypodiales
Equisetum type
Botryococcus braunii
Pediastrum sp.
Operculodinum centrocarpum
Complete Pinus in % of total Pinus
Ulmus+Tilia density
Pollen and spores per mm sediment

Pollen zone   14C conv.

IXc   -415±85
       -595±65
       -710±80
IXa+b -2510±90
       -2555±70
VIII   -4490±100

VII

20 40   20 40 60 80 100   20 40   20   20 40   200 400 600   20 40   50 100 150   20   20 40 60 80   50 100 150   20 40 60 80   20 40 60   200 400 600

192

Fig. 2: Pollen and diatomeen diagram, profile Körkwitz

Pv   Pinnularia viridis
Ha   Hantzschia amphioxys
Npp   Navicula pusilla and peregrina

Fr   small Fragilaria species
Di   Diploneis interrupta
Nio   Nitzschia obtusa

Cc   Campylodiscus clypeus
Ce   Campylodiscus echeneis
An   Actinocyclus normanii

Ag   Aulacoseira granulata
Ps   Paralia sulcata,
        Rhabdonema sp., Achn. longipes

Cycist Cymbella cistula type
Schw   sponge needles
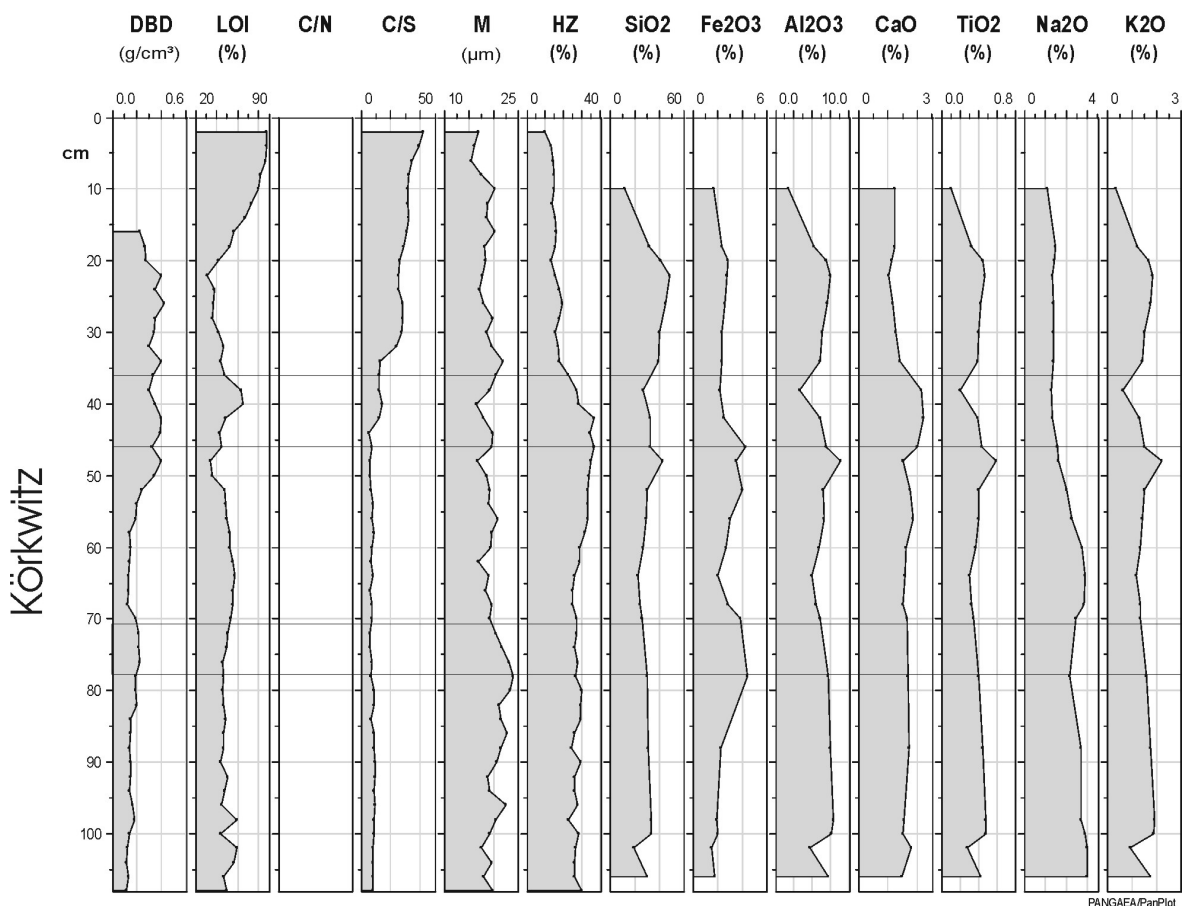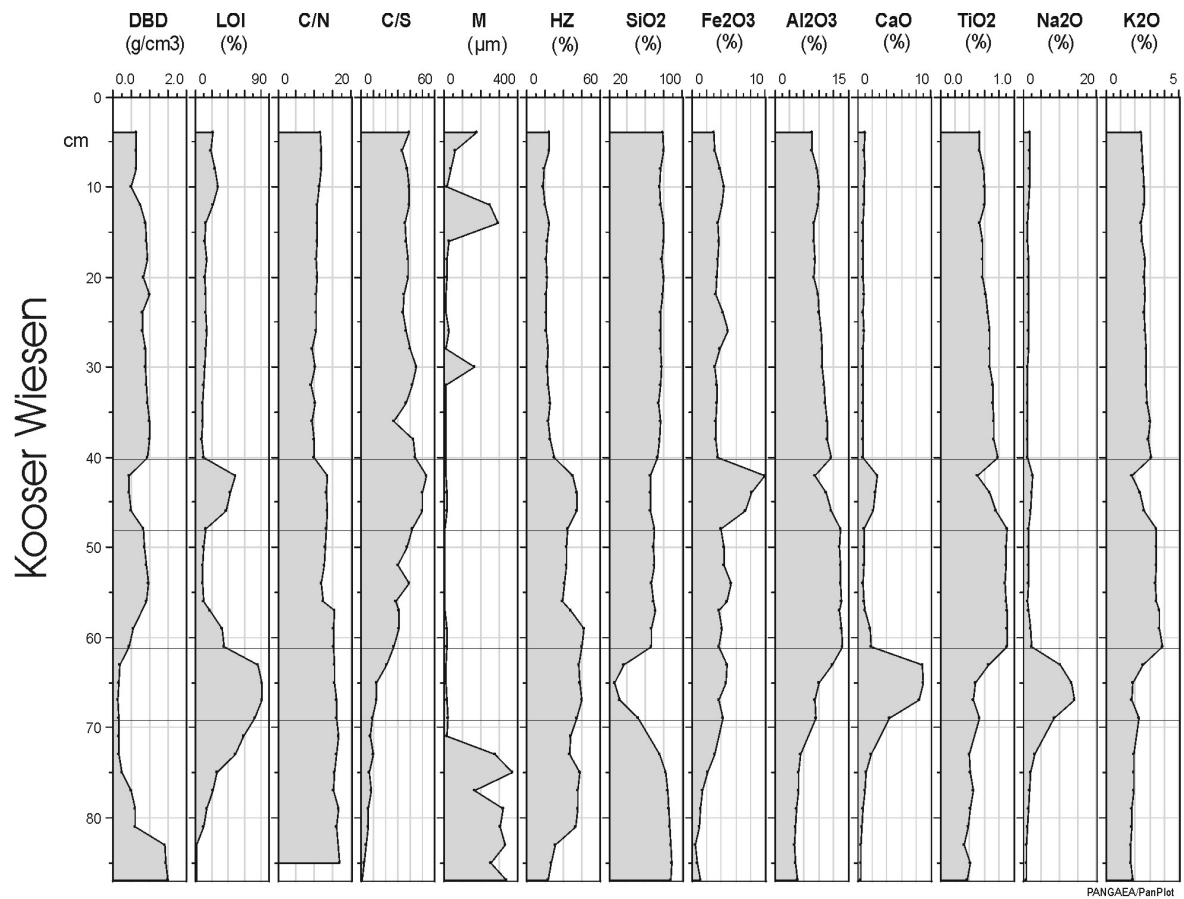
Fig. 3: Main element distribution in the profiles KWS and Körkwitz

In the succeeding layer up to 69cm the peat is black coloured. In this prominent layer Fe, Mn and P are enriched and the bulk density is increased. In the lower part between 75 and 80cm the organic substance seems to be more or less amorphous – except the later permeated roots. The pollen diagram shows an alder rich, oak mixed forest, salinity indicators are lacking, and the diatom assemblage is dominated by *Diploneis interrupta*. In the upper part *Pinus* increases and wetness indicators too. At the upper boundary an abrupt change in favour of NBP and *Cyperaceae* occurs. The layer is apparently bipartite, which is confirmed also by the distribution of Fe and Mn. The peat oxidation horizon which points to desiccation and mineralsation is at located about 75cm. The upper part is influenced by the peat reconstitution, whereby older material is admixed into the growing younger layer. At its upper boundary the pollen zone IXa starts, which is confirmed by a ^{14}C-date of 2,510 +/- 90.

Until 65cm in the pollen diagram the Littorina-III-transgression is recognisable due to the change to NBP and *Cyperaceae*, a slight increase of *Chenopodiaceae* and the occurrence of *Plantago maritima* and *Triglochin*. The diatom assemblage is dominated by the *Campylodiscus echeneis* flora. The chemical parameters depict an increase in Q4/6, C/N and Na as well as decreasing concentrations of Fe and Mn. However, the marine influence could be only of minor intensity because, at least from 65cm onwards, all parameters again show a tendency to forest closure (German Tribes´ Migration) and peat growths under freshwater conditions. About at 58cm the transition to pollen zone IXb occurs.

Until 48cm a successive change at the location happens. The accumulation of organic carbon decreases due to stronger clastic inputs (increase of Si, Fe, DBD), which point to the following mud sedimentation. In the vicinity grows an oak mixed forest rich in pines. Minor but regular cultivation of cereals can be proved. A phase of more frequent flooding is evident from a *Botryococcus* maximum, the first density maximum and a C-minimum at 48cm. The diatom assemblage remains unchanged.

Directly above, the upper black layer is located (36-46cm), for which a bipartite evolution can be demonstrated. The growth of the peat was initiated by a water level rise, as revealed by wetness indicators such as *Succisa, Valeriana, Malva althea, Lysimachia, Lycopus, Lythrum* and *Sphagnum*. The high BP-values point to a widely forest covered landscape initially, although continuous cereal cultivation is traceable. *Pinus* decreases strongly in favour of *Fagus/Carpinus*, and the NBP increase rapidly. At 40cm the pollen zone IXc is reached, and at 35cm the *Fagus/Carpinus* maximum of the Slavonic period. At 36cm NBP and cereals show particular high values and mark the onset of the German colonisation (a ^{14}C-date at 32-34cm provides 595 +/- 65 BP and is in good agreement). Salinity indicators are not yet found. In the diatom assemblages *Pinnularia* species dominate, *Diploneis interrupta, Cymbella aspera* and others are also detectable. The second phase comprises the surface lowering and mineralsation of these layers, changes their properties and produces a hiatus. The C/N-values decreases due to peat degradation and nitrogen release; pedogenic Fe and Ca are enriched secondarily. The pollen/spores density increases markedly .

During the following period characterized by a lower water level, which probably rises slowly, a very muddy grass peat starts to grow (above 36 cm). It is characterised by an extremely high NBP content caused by the medieval clear cuttings and a corresponding maximum of *Plantago maritima* , secondarily of *Chenopodiaceae* too. The salinity in the Bodden waters still seems to be high. But the curves for *Botryococcus* and *Pediastrum* ascend fast and indicate a first eutrophication episode caused by water isolation and desalinisation. The maximum coverage with forests during the second half of the 17th century due to the 30 years war and the contemporary low cereal cultivation was found at 23-29 cm. A ^{14}C-date

(355 +/- 85 BP) at 21-22 cm confirms this interpretation. The diatom flora is still dominated by Diploneis interrupta, supplemented by some robust brackish water diatom species

Above 18cm the sedimentation milieu changes. The high number of complete *Pinus* pollen grains demonstrates a sedation of the accumulation area; redepositions and inputs of resuspended material become less important. The mud deposition ceases and a grass peat very rich in organic carbon is accumulated. Contemporarily P increases as an eutrophication indicator and above 12 cm Zn as an industrialisation indicator. Due to the successive desalinisation of the vicinal water the C/S-relation depicts a limnic milieu. A durable fixation of sulphides does not occur. The sedimentation succeeds fast (low pollen density) and humus compounds achieve only minor degrees of polymerisation. In the pollen diagram the BP decreases in favour of grasses, and cereal pollen grains are also found in lesser number. In the diatom assemblage, generally poor in species, *Pinnularia* dominates, accompanied by species which tolerate subaerial conditions and low salinity.

It has to be stated that the diatom flora of the profile is poor in species. However, their distribution indicates salinity variations which have happened during the mire evolution in the Younger Holocene: The sections predominated by the *Diploneis interrupta* or the *Pinnularia* flora alternate with sections characterised by the predominance of *Campylodiscus echeneis* (173 – 140, 107 – 90 and 66 – 43 cm). It is assumed, that these variations correspond to alternating transgressive and regressive stages (e.g. the Subboreal L-II transgression between 173 and 140 cm). This assumption has to be corroborated by further investigations.

The radiocarbon data available from both profiles as well as from a similar coastal peat sequence located on Struck Island/Greifswalder Bodden and from tree stumps found in their vicinity are depicted in Fig. 4. The sea-level curve which can be determined form their distribution in the depth-time diagram reveals that periodical sea-level fluctuations of a range of 1m or more cannot be detected in the deposits. In fact, the rather indistinct black layers demonstrate, that throughout the past 5,000 to 6,000 years the sea level moved only in the range of some decimetre. Also, the placement of the particular transgression/regression stages could be determined with a higher accuracy than before and demonstrate a strong correlation to climate oscillations such as the Late Bronze Age dry period or the Little Ice Age climate deterioration. Uncertainties still remain in regard to the regression magnitudes and to the length of the hiatuses in the peat sequences. Due to the different response of the mires concerning the releasing sea-level fall the hiatus lengths determined will probably be of only local validity. A comparison of the height position of the black layers in respect to the recent sea level displays that different relative post-depositional movements occurred hardly during the past 3,000 years. But for the times before the curves diverges which lead to the assumption, that the pattern of movement behaviour of the Earth´s crust was another one than after 3,000 BP. However, no firm statements can be made without further investigations to decode the amount and the causes of the differences.

kyr BC/AD

No.	Site	Lab - No.	NN [m]	years BC/AD
1	Körkwitz	Hv 23976	0,03	1445 - 1650 AD
2	Körkwitz	Hv 23673	-0,09	1300 - 1415 AD
3	Körkwitz	Hv 23675	-0,13	1260 - 1385 AD
4	Körkwitz	Hv 23674	-0,13	1165 - 1280 AD
5	Barth	Hv 23979	-0,31	1070 - 1295 AD
6	Struck	Hv 23981	-0,02	1025 - 1210 AD
7	Koos, stump	Erl 2515	-0,45	620 - 660 AD
8	Kooser Wiesen	Gd 15292	0,07	560 - 670 AD
9	Barth	Hv 23978	-0,23	260 - 770 AD
10	Kooser Wiesen	Erl 2160	-0,04	-50 - 318 AD
11	Körkwitz	Hv 23977	-0,42	755 - 390 BC
12	Körkwitz	Hv 23676	-0,53	800 - 540 BC
13	Barth	Hv 23980	-0,47	1405 - 1005 BC
14	Kooser Wiesen	Gd 12355	-0,12	2270 - 1985 BC
15	Kooser Wiesen	Gd 15311	-0,30	2555 - 1685 BC
16	Struck	Hv 23982	-0,40	2560 - 2135 BC
17	Struck, stump 1	Gds 246	-0,25	2920 - 2790 BC
18	Körkwitz	Gd 15284	-1,13	3360 - 2935 BC
19	Kooser Wiesen	Gd 15308	-0,22	3490 - 2920 BC
20	Struck	Hv 23983	-0,52	3500 - 3035 BC
21	Recknitzmündung	Ki 3561	-0,50	3935 - 3665 BC
22	Karrendorf	Hv 23670	-0,55	3960 - 3700 BC
23	Struck, bel.stump 2	Gd 15309	-0,25	3965 - 3645 BC
24	Struck, stump 3	Gd 11350	-0,25	4040 - 3945 BC
25	Struck, stump 2	Gd 11350	-0,25	4450 - 4260 BC
26	Struck	Gd 12351	-0,90	4455 - 4335 BC
27	Fahrenkamp	Bln 2946	-1,10	4455 - 4255 BC
28	Struck	Gd 12354	-0,96	4690 - 4466 BC

¹⁴C-data from
▦ Kooser Wiesen
▢ Struck
▬ Körkwitz
─┴─ similar profiles in the vicinity
width corresponds to the 1 SD-interval
bold black frame = sample was taken from a black layer

¹⁴C-data from tree stumps

L-I, RL-I transgression/regression phases

──── estimated relative sea-level curve

- - - - sea-level curve, not well proved

·········· separate lake level

Fig. 4: Radiocarbon data from peat samples and tree stumps from the two profiles investigated, as well as from sites in their vicinities. Marine influenced peats and tree stumps trace the course of the rising sea level, whereas the position of black layers points to regression stages.

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The western cliff on Poel Island

WERNER SCHULZ

The western cliff on Poel Island extends from the port of Timmendorf (lighthouse) about 1.5 km to the south. Due to its exposal to the predominant westerly winds, the cliff retreat amounts to 0.3 to 0.5 m/year, somewhat more than the average for the Mecklenburg-West Pomeranian coast. The sedimentary sequence which built the cliff was mapped by N. RÜHBERG[1] (1969) in his diploma (Fig. 1). In a further diploma, M. LÜCKSTEDT (1987) described the orientation of boulders and joint systems in the 3 boulder clays of the cliff.

[1] RÜHBERG died on 20.2.2002 as a consequence of an accident after a long disease. He had particular merit in the foundation of the State Geological Survey of Mecklenburg-West Pomerania in 1991.

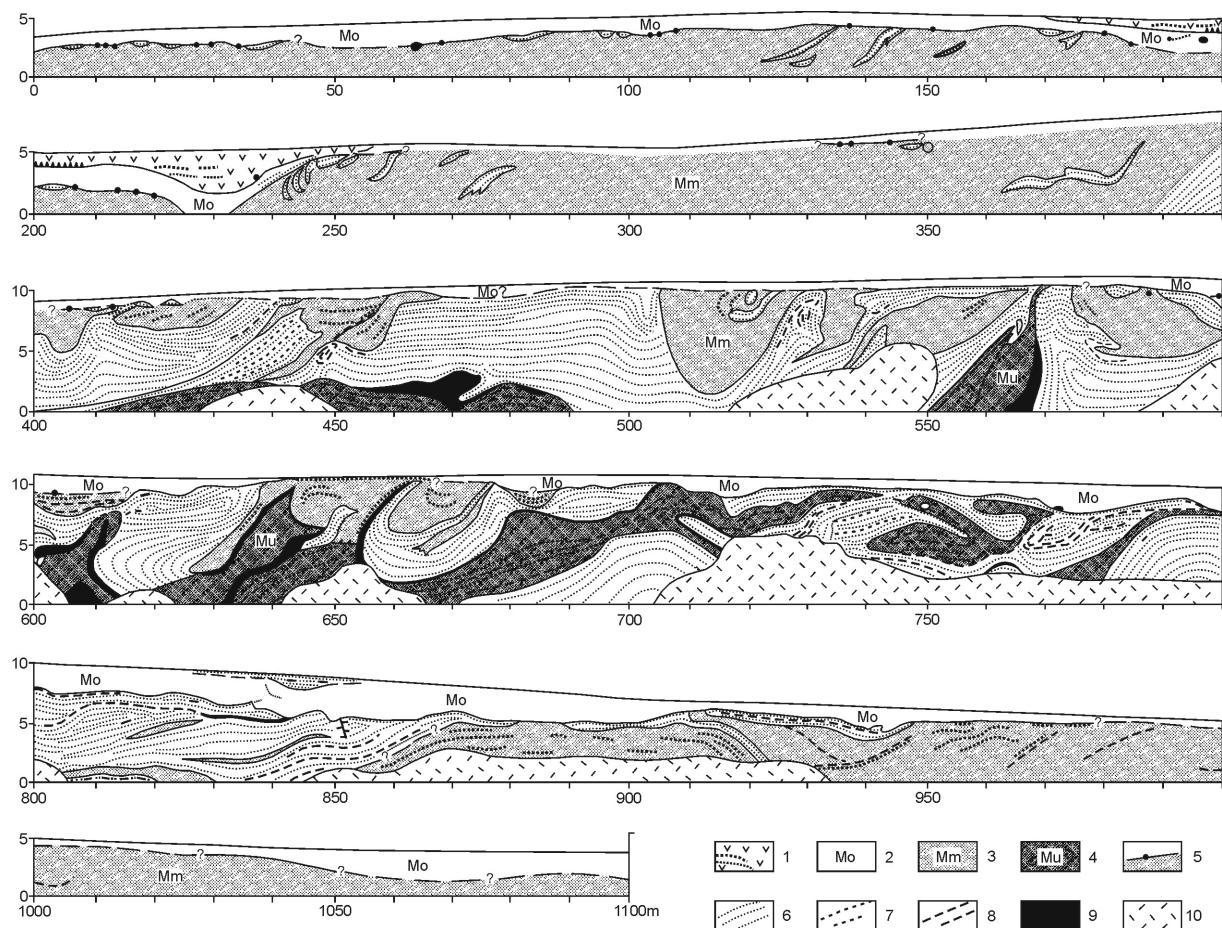The normal profile of the cliff consists of (see Fig. 1):

Fig. 1: Geological profile from the western cliff on Poel Island (vertical scale 2 : 1), acc. to RÜHBERG (1992).

1 – Kolluvium (humous sand), 2 – Mo, Upper Till, 3 – Mm, Middle Till, 4 – Mu, Lower Till, 5 – stone line between Mo and Mm, 6 – fine sand, 7 – silt, fine sandy, 8 – silt, clayey (6 – 8 are described in the normal profile as fine sand), 9 – red clay with *Lymnocythere baltica*, 10 – debris

Upper Till (Mo): 0 - 3m, nearly without textures, few boulders, more palaeozoic limestones than crystalline boulders, horizontal bedding; deposited during an ice advance which caused disturbances in the lower parts of the profile, orientation of boulders: NE-SW; belongs to the Mecklenburg Stage = Rosenthaler Staffel = Fehmarn Advance in Schleswig-Holstein

(indistinct hiatus, local sand lenses and several bigger boulders)

Middle Till (Mm): 3 - 10 m, distinct joint system: 120°/90° and 25°/90°, polyedric breaking; more crystalline boulders than palaeozoic limestones; in the northern area rich in cretaceous boulders, orientation of boulders: NE-SW to NNE-SSW, in the northern and southern area of the cliff horizontal and concordant bedding related to the Mo boulder clay; in the middle part of the cliff incorporated in the glacigenic disturbances, belongs to the Pomeranian Stage

Fine grained sands: Number 6 - 8 in Fig. 1; 8 m, in the central part of the cliff the sands rises up to + 11 m NN, ± very silty, folded

Red clay: Number 9 in Fig. 1; 0.5 - 1.0 m, red coloured due to redeposition of the red clay of Lower Eocene 3, silty, containing the ostracod species *Limnocythere baltica* DIEBEL 1965, which prefers cool water, indicating a melt water basin in front of the Pomeranian ice margin; the clay is easy to fold, therefore forms of disturbances from saddles to imbricate structures in W-E direction and verging to the south.

Lower Till (Mu): 3 - 5 m, very sandy and with sandy strips, orientation of boulders NNE to SSW, belongs to the Frankfurt-Brandenburg Stage, probably no true glacigenic boulder clay but a subaquatic pseudotill

Altogether the cliff shows the outcrop of a bending fold, reaching up to + 12 m NN, and in the plateau behind up to + 16 m NN. In its the northern part the easily folded red clay crops out in repeated saddles and imbricate structures, caused by the Mo - ice advance. On both sides of the clay deformations the fine sands and the Mm-boulder clay have been dragged. The orientation of the glacitectonic structures is W-E to WNW-ESE verging to the south.

The Mo - ice advance, which runs over the disturbed layers on Poel Island, reached nearly to the main marginal line of the Pomeranian Stage (W 3 in Fig. 2) according to the opinion of N. Rühberg. In the geological map of Mecklenburg-West Pomerania,
1 : 500,000, all of such isolated push moraine complexes behind the main line of the Pomeranian Stage have been connected and called "Mecklenburg Stage". That ground moraine should have a higher content of limestones from the outcropping Palaeozoic in the present depression of the Baltic Sea.
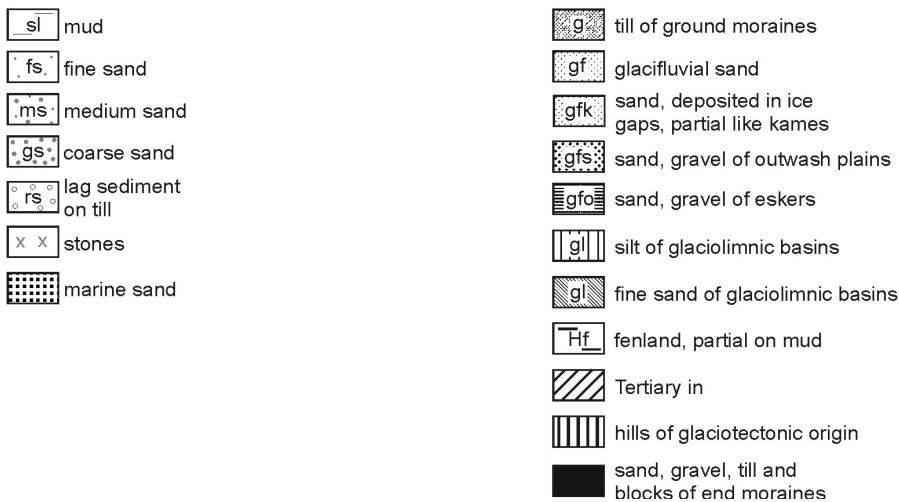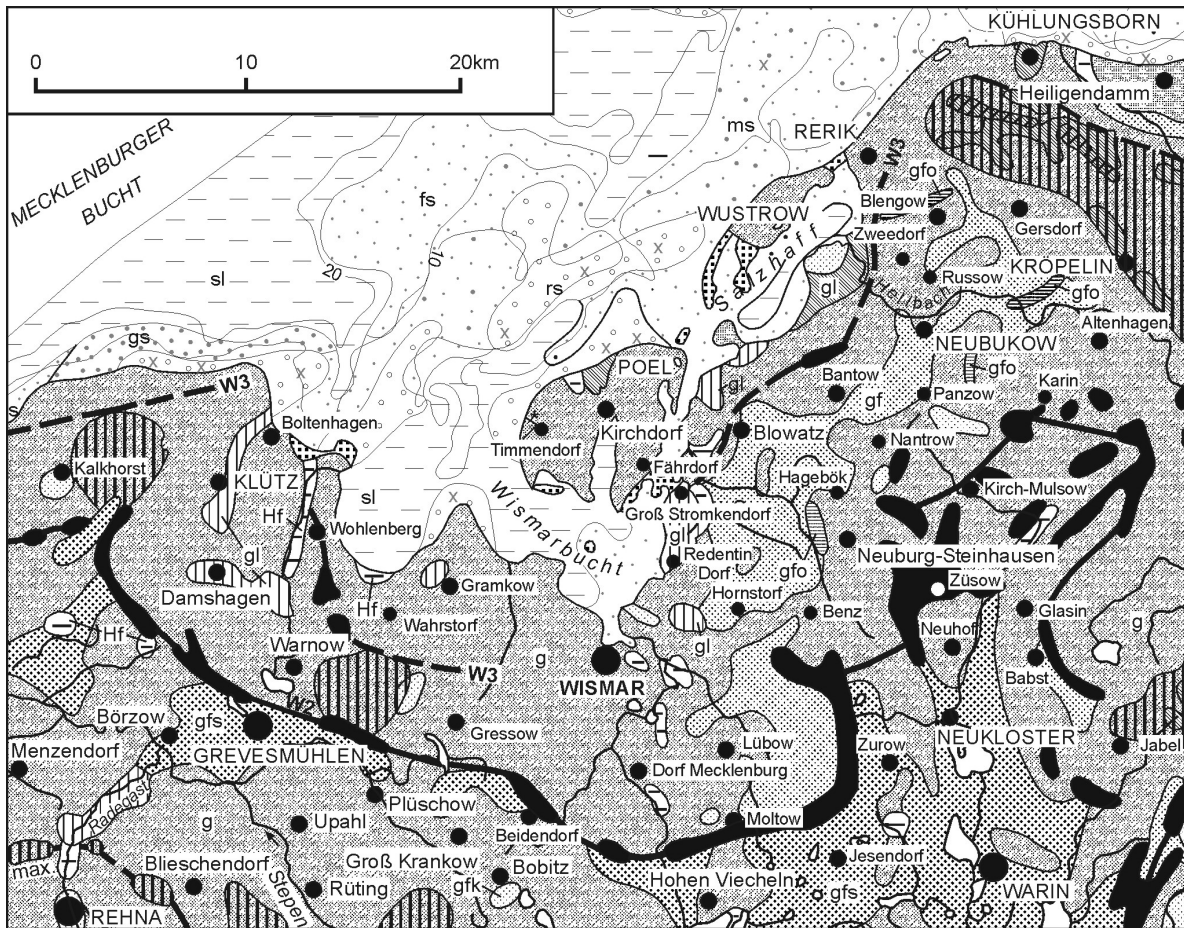
Fig. 2: The Wismar lobe of the Pomeranian Stage with the marginal zone W3 as proposed by RÜHBERG (1987), after MÜLLER et al. (1997).

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Submarine Stone Age settlements as indicators of sea-level changes and the coastal evolution of the Wismar Bay area.

HARALD LÜBKE

One of the main aspects of the underwater archaeological work in Mecklenburg-West Pomerania is the research on stone age settlements and cultures along the Baltic coast. Most of the coastal sites were flooded during the post-glacial sea level rise. Surveys of those settlements allow deeper insights into the strategies of subsistence and into the material culture of prehistoric societies. In addition they help to gather more reliable geological data about the Littorina transgression to reconstruct the development of the Baltic coast.

Special emphasis is put on investigations in the Wismar Bay in the western part of Mecklenburg - West Pomerania. Since 1998 the State Agency for Protection of Archaeological Heritage (LBD – Landesamt für Bodendenkmalpflege Mecklenburg-Vorpommern) has been conducting surveys of submerged Stone Age settlements in this area. A close cooperation between the State Agency and the Baltic Sea Research Center Warnemünde (IOW – Institut für Ostseeforschung Warnemünde) arose within the framework of the German Research Council (DFG – Deutsche Forschungsgemeinschaft) Project "Modellierung der Küstenentwicklung in der südwestlichen Ostsee", which has been carried out by the IOW in conjunction with the University of Greifswald since 1999 (HARFF et al. 1995; HARFF et al. 1999; HARFF et al. 2001; LEMKE 1998). The IOW and the LBD have been undertaking expeditions in the outer area of the Wismar Bay with the research vessel "Professor Albrecht Penck" since October 1999. During these investigations several submerged settlements dating back from the Late Mesolithic up to the Early Neolithic were discovered in the Wismar Bay (Fig. 1). In general, organic remains are in an excellent state of preservation (LÜBKE 2000; LÜBKE in press).

Since 2001 the investigations are part of the geo-archaeological research project „Ökologie und Ökonomie submariner Fundstellen aus der Zeit der Neolithisierung in der Wismarbucht" founded by the German Research Council (DFG). Three sites (Poel 16 – Jäckelberg-Nord; Poel 12 – Timmendorf-Nordmole; Poel 15 – Timmendorf-Tonnenhaken) with exceptional conditions for the preservation of cultural remains were investigated. The objectives were to examine the degree of preservation of spatial structures of the settlements and to gain sample material for further studies in archaeology and science, thereby exploring the potential for detailed interdisciplinary research in cultural ecology and economic archaeology.

Poel 16 –Jäckelberg-Nord

The oldest sites up to now are situated around 1.5 nm north of Poel (Fig. 1). Poel 16 ("Jäckelberg-Nord") was discovered during a survey with the research vessel "Prof. Albrecht Penck" in October 1999. Using a Side-Scan-Sonar and a Video-Sledge-System a peat sediment outcrop was located in 6.5 – 7.0 m deep water on the northern edge of the "Jäckelberg", a ground-moraine ridge off the Island of Poel. A high number of oak trunks are buried within the sediment. While the stratum below the trunks consists of limnic gyttja, the layer above is already a marine mud with numerous embedded shells. The coastal wood seems to have been flooded during the Littorina transgression.
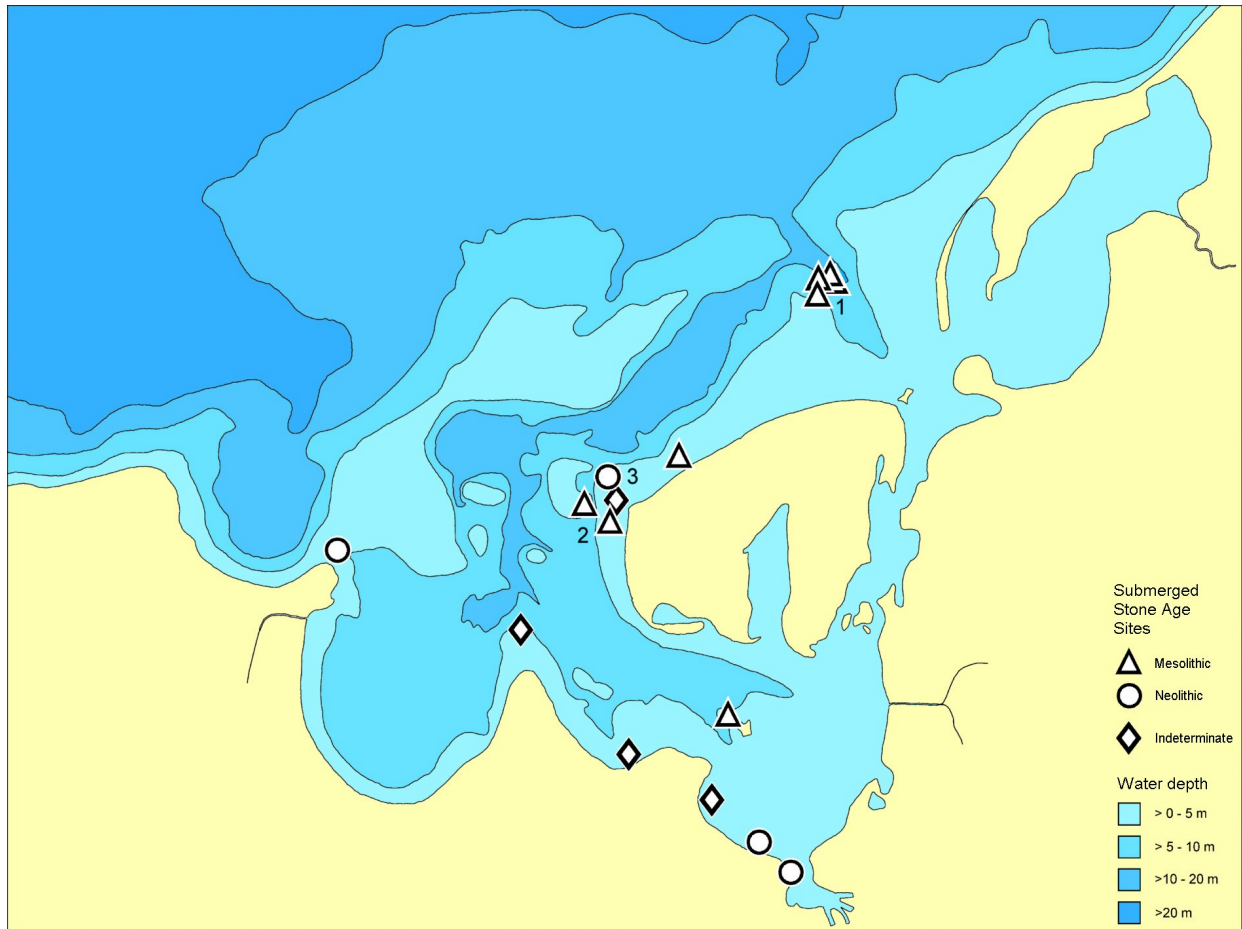
Fig. 1: The location of submarine Stone Age sites in Wismar Bay
1 – Jäckelberg - Nord, 2 – Timmendorf - Nordmole, 3 – Timmendorf - Tonnenhaken. No scale. H. LÜBKE del.

Remains of Stone Age settlements were discovered in the surroundings. According to today's knowledge parts of the former refuse zone, situated off the shore in shallow water are still preserved. The former settlement site and the immediate shore were destroyed by erosion. Up to one meter long wooden poles were discovered in the sediment. Taking into account Danish research work (PEDERSEN 1995), those poles may have been part of fishing fences. Among the bone and antler remains found are simple bone points and different antler tools. The stone artefacts include numerous blade implements. Nearly all of them show typical traces of a soft hammer production technique which is characteristic for the Late and Final Mesolithic. Implements found on the site include flake borers (Fig. 2; 4-5), different burins (Fig. 2; 10-12), truncated blades with oblique or straight distal retouches (Fig. 2; 6-8) and several partially retouched blades and flakes (Fig. 2; 9). Worth noticing are the burned fragment of a transverse arrowhead (Fig. 2; 3) and five core axes (Fig. 2; 1-2). No flake axes have been found up to now.

The zoo-archaeological material consists mainly of remains of land mammals like red deer, wild boar and roe deer. The existence of sea mammals on the site is not proven up to now. The few fish remains belong to fresh water species as well as to salt water species.
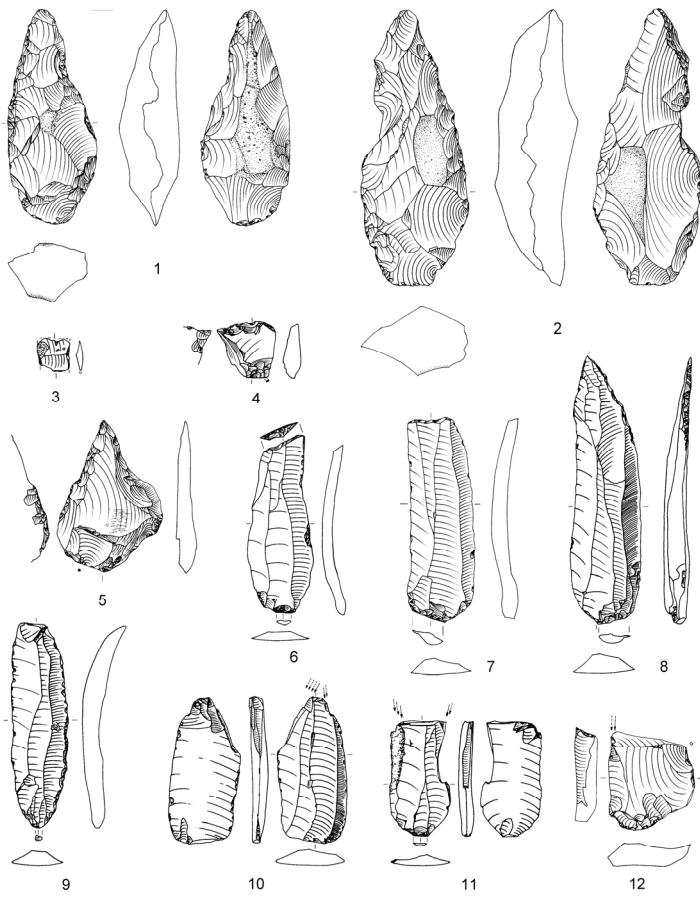
Fig. 2:
Jäckelberg - Nord
(Poel 16, Ostsee II).
Stone implements.
1-2 - Core axes,
3 - Transverse arrowhead,
4-5 – Borer,
6-8 - Truncated blades,
9 - Edge retouched blade,
10-12 - Burins.
Scale 1:2. J. FREIGANG del.

Fig. 3:
Timmendorf - Nordmole (Poel
12, Ostsee II). Stone imple-
ments.
1-2 - Flake axes,
3-4 - Flake borers,
5-6 - Flake scrapers,
7-12 - Transverse arrowheads,
13-14 - Edge retouched blades,
15 - Blade scraper,
16-17 - Blade burins,
18-21 - Truncated blades,
Scale 1:2. J. FREIGANG del.

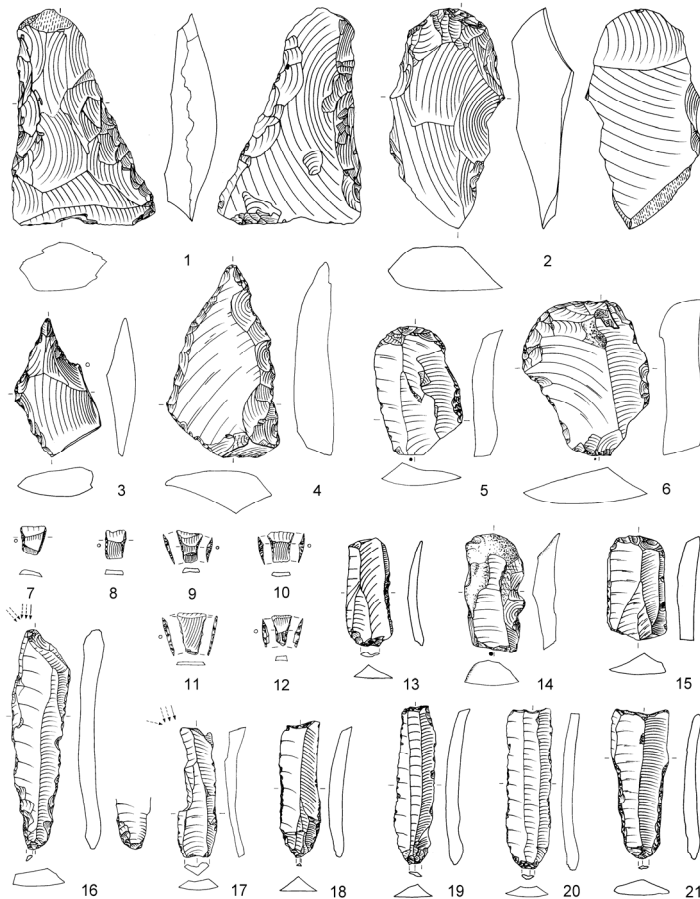According to the ¹⁴C dates (Fig. 4), Jäckelberg-Nord dates back to 5,100-5,600 cal BC, and can thus be assigned to the early Ertebølle period. Even the formal analysis of recovered finds confirms the dates, because they show similarities with the artefacts from contemporary sites in the interior of Schleswig-Holstein (HARTZ 1997).

Sample-No.	Age BP	Age calBC	δC13	Artefakt
Jäckelberg-Nord				
KIA-10401	6201±41	5115±62	-27,1	wooden post
KIA-10402	6325±35	5283±42	-20,0	animal bone, wild boar
KIA-11616	6253±39	5210±67	-22,6	animal bone, red deer
KIA-11617	6353±46	5326±61	-27,5	wooden post
KIA 16024	6494±33	5411±58	-27,7	wooden tool shaft
KIA 16025	6673±28	5539±28	-21,3	animal bone, wild boar
KIA 16026	6377±30	5340±56	-16,8	animal bone, wild boar
KIA 16027	6620±34	5525±40	-20,4	animal bone, indeterminate
Timmendorf-Nordmole				
KIA-8443	5604±29	4404±40	-13,8	animal bone, seal
KIA-8444	5621±29	4431±47	-11,0	animal bone, dog
KIA-8445	5362±39	4237±75	-24,3	charred food crust, body sherd
KIA-8446	5380±30	4268±58	-27,3	charred food crust, body herd
KIA-8447	5335±29	4156±65	-26,7	charred food crust, body sherd
KIA-9496	5420±42	4279±42	-23,5	charred food crust, pointed base
KIA-9497	5560±40	4389±41	-23,8	charred food crust, body sherd
KIA-9498	5323±35	4147±64	-31,7	leister prong
KIA-9499	5456±37	4287±41	-22,8	animal bone, red deer
KIA-9500	5791±39	4624±63	-19,8	charred food crust, lamp rim-sherd
KIA-9501	5536±32	4384±43	-27,0	charred food crust, body sherd
KIA-9825	5543±43	4387±44	-24,5	charred food crust, decorated rimsherd
KIA-11170	5580±35	4396±39	-17,3	animal bone, seal
KIA-11615	5692±35	4502±40	-24,5	wooden implement
KIA-11618	5343±34	4173±71	-26,2	leister prong
KIA-11619	5505±37	4379±56	-27,6	leister prong
KIA-11620	5327±39	4156±69	-28,2	log boat fragment
KIA-12475	5418±22	4282±38	-28,4	elm bow fragment
KIA-12476	5388±28	4270±51	-24,0	log boat fragment
KIA-16019	5443±36	4282±37	-28,9	wooden bowl
KIA-16020	5613±29	4419±43	-24,6	charred food crust, decorated rimsherd
Timmendorf-Tonnenhaken				
KIA-16021	4544±29	3174±86	-22,8	animal bone, indeterminate
KIA-16022	5076±36	3867±57	-21,9	animal bone, cattle
KIA-16023	4111±26	2631±78	-23,3	animal tooth, cattle

Fig. 4: List of radiocarbon dates of Jäckelberg - Nord (Poel 16, Ostsee II), Timmendorf - Nordmole (Poel 12, Ostsee II) and Timmendorf - Tonnenhaken (Poel 15, Ostsee II). Calibration after B. WENINGER, Cologne (calibrated age ± 1 stdv. B.C.).

In the neighbourhood of Jäckelberg-Nord three more sites (Poel 5; 40; 42, Ostsee II) were found during surveys with the research vessel "Prof. A. Penck" in autumn 2001 and spring 2002 (Fig. 1). They are situated on the little moraine hill Jäckelgrund, separated from the Jäckelberg by a small channel. During the period of settlement it must have been a small island in front of a peninsula and thus a typical location for Late Mesolithic settlements (SØRENSEN 1983, 111; FISCHER 1995, 374). Due to their depth of –7 up to – 8 m msl, they seemed to be slightly older than Jäckelberg-Nord, but no ^{14}C-results are available up to now.

Poel 12 – Timmendorf-Nordmole

The most important site discovered up to now is "Timmendorf-Nordmole" (Poel 12, Ostsee II) which is located off the west coast of the Island of Poel (Fig. 1). The large Final Mesolithic site is situated about 200 m from the small village of Timmendorf in 2.5 – 4 m deep water and has excellent conditions for the preservation of artefacts. Cultural layers in varying states of preservation were located. The area has a length of more than 250 m and is up to 100 m wide. To be able to work effectively, a grid with an extension of 210 x 80 m had to be established on the site. Iron measuring posts were put in every ten meters. Afterwards the conditions of the cultural layers in different parts of the settlement were analysed by sounding-trenches.

The survey showed that large parts of the former settlement surface in 2.5 m deep water were destroyed by erosion, as an abraded marl layer appeared directly below a 20 cm thick surface layer consisting of gravel with numerous eroded stone artefacts. But entrenched settlement features are preserved in this area, as e.g. a pit, which was excavated in summer 2001. It was 3.5 m long and 1.8 m wide at the surface with a remaining depth of 0.9 m. The basis had a pear-shaped outline with a narrow entry at one side and an extended utilization area at the other. Numerous tall logs and poles of a covering- or roof-construction have broken down into the pit. Thus it was not a simple waste pit, but a purposely entrenched construction. The precise function is still unclear. Due to the small size it seems improbable that the building was used as a hut. It might have been a storeroom. The pit contained a very heterogeneous sediment which consists of shares of clay, sand and organic material. In the sediment numerous important archaeological artefacts were found. The most remarkable artefact is a truncated blade with a preserved handle made of hazelwood and a binding of lime baste (LÜBKE 2001).

In deeper water the former border of the settlement and the organogenic shore zone are preserved. In some areas the occupation layer could be traced directly below a thin sand layer on the sea bottom. These layers contain unpatinated flint artefacts, large pottery fragments, bone or antler tools as well as wooden implements. A trench in the shore zone proved that the upper part of the stratum consists of gravely sand. Some thin layers of organic substratum are enclosed in the sand. They contain countless remains of plants, wooden particles, smaller vertebrate animals like fish, birds, etc. and numerous archaeological artefacts. The sandy layers are followed by a marine mud which contain reed and wood remains as well as many artefacts. Under the mud are a reed peat layer and finally the glacial moraine underground.

The wooden artefacts from Timmendorf-Nordmole are especially remarkable. Numerous side prongs and a shaft of a fishing leister, a broken elm bow, parts of log boats and countless pieces of sharpened sticks, maybe parts of fishing fences, were found. Hitherto a few bone and antler remains like small bone points, an elbow dagger, a harpoon fragment, antler strikers, an antler pendant and wild boar tusk knifes were recovered. The pottery consists

predominantly of thick-walled potsherds belonging to vessels with pointed bottoms and S-profiles. Some rim potsherds are decorated with simple stamps. Stone implements and their preparation waste form the largest group of artefacts. The amount of irregular blades, manufactured in the plain hard hammer blade technique is almost 50 percent, much higher than at Jäckelberg-Nord. Still the majority of the blade implements are slim pieces made in the soft hammer blade technique. Among those are truncated blades with straight or concave retouch (Fig. 3; 18-21), scrapers (Fig. 3;15), burins (Fig. 3; 16-17) and tools with edge retouch (Fig. 3; 13-14). Among the flake implements are scrapers (Fig. 3; 5-6) and various borers (Fig. 3; 3-4). The most frequently found flint artefacts are flake axes. At present more than 150 axes were found (Fig. 3; 1-2). Core axes are very rare on this site, but appear in irregular forms. Transverse arrowheads, usually very typical on Stone Age sites, were also discovered (Fig. 3; 7-12).

Numerous bones of small mammals and fish as well as floral remains were collected from the dredged material. The excellent state of preservation allows supplementary scientific studies. According to the preliminary results of the zoo-archaeological material seals and sea birds were hunted besides land mammals such as red deer and wild boar (HEINRICH 2001). Except for dogs the existence of domesticated animals could not be proven. The large amount of fish remains is remarkable. Most frequently represented is eel, followed by cod and other species. Taking into account the analysed artefacts, the inhabitants primarily subsisted on marine resources. Hunting played a secondary role.

At present twenty-one AMS dating results of different artefact groups confirm the archaeo-typological dating of Timmendorf-Nordmole (Fig. 4). The dates give proof of the existence of a younger phase of the Final Mesolithic Ertebølle Culture on the Northern German Baltic coast dating from 4,500 – 4,100 BC (LÜBKE 2000; HARTZ et al. 2000).

Poel 15 – Timmendorf-Tonnenhaken

The site "Timmendorf-Tonnenhaken" (Poel 15, Ostsee II) was discovered about 1,000 m to the north of Timmendorf-Nordmole 8, Fig. 1). It is situated on a former peninsula completely eroded by the sea today. An open peat layer in 2 m deep water contained a stone age occupation layer with preserved stone-, bone-, antler implements and potsherds, characteristic for the Early Neolithic Funnel Beaker Culture. Three small test-trenches were excavated in 2001. Only small parts of a cultural layer are preserved. This indicates a minor temporary occupation of the place. The few faunal remains are from domesticated animals like cattle or pig. In contrast to the Final Mesolithic site Timmendorf-Nordmole the Early Neolithic site Timmendorf-Tonnenhaken was not situated by the open sea, but by a small lagoon east of the former peninsula. Therefore both sites are completely different in settlement structure and economy despite of their neighbouring position.

The AMS dating results (Fig. 4) of the site are still incomparable to the archaeological results. The three samples taken from animal bones collected from the surface of the peat layer gave completely different dates. If the samples were not contaminated with younger carbon, the site was occupied more than one time. Further research has to prove this point.

Archaeological sites as indicators for sea level changes in Wismar Bay

The conducted research not only extended our knowledge of the archaeological settlement history, it was also important for the marine geological research concerning the Littorina

transgression in this region. The results changed the former transgression curve for Wismar Bay (SCHUMACHER 1991). This curve was based on sea level markers of a morphological and sedimentological analysis of the Rustwerder beach wall system in the south west of the Island of Poel. It was dated through a correlation with transgression dates from Schleswig-Holstein (KLUG 1980; KÖSTER 1967). For the time before 4,000 BC a sea level below –7 m msl was assumed. The –3 m msl level was supposed to have been reached around 2,000 BC. The new research showed that at the site Jäckelberg-Nord the –7 m msl level was already reached around 5,100 BC. The results from Timmendorf-Nordmole showed that between 4,400 and 4,100 BC the sea level must have been –3 m msl. Thus the sea level rise in Wismar Bay corresponds more closely to the situation in Eastern Holstein and Kieler Bay, than estimated earlier on (Fig. 5).
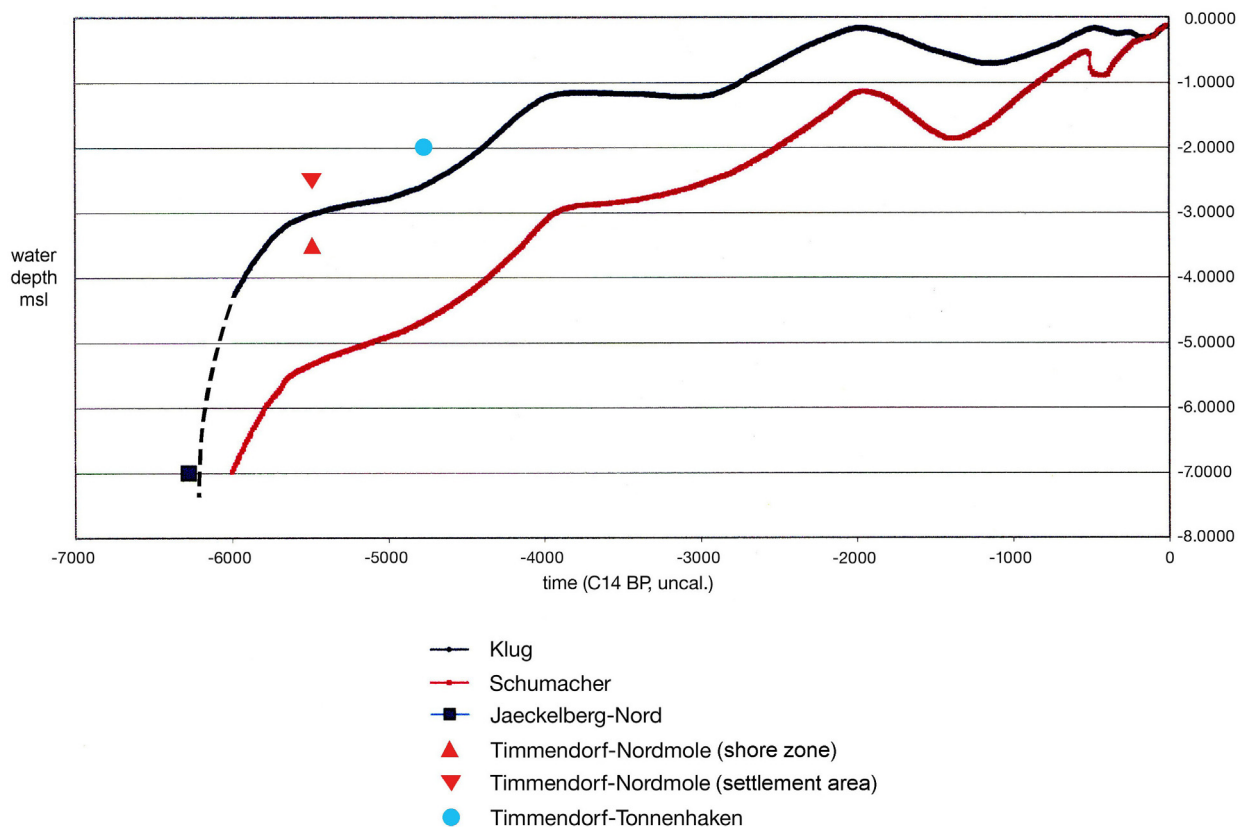

Fig. 5: Local RSL-curves of the Mecklenburg and Kieler Bay (after KLUG 1980; SCHUMACHER 1991). Dates and water depth (msl) of Stone Age sites in the Wismar Bay. M. WAGNER del.

Future research conducted by the interdisciplinary research unit "SINCOS" founded by the German Research Council (DFG) will hopefully extend our knowledge of the geological development and the settlement history of the south-western Baltic Coast.

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The Rustwerder spit - structural sediment features as water level marks

WALTER SCHUMACHER

The Rustwerder is a small spit to the southwest of the Island of Poel. This spit adjoins the Pleistocene cliff in the western part (source area) and its beach ridges separate the lagoonal system of the "Fauler See" from the Wismar Bay. The Rustwerder mainly consists of 5 stratigraphic complexes (Fig.1A, A-E). About 80 percent of the accumulated sediment is deposits of the shore platform (A) and of the beach (B). The aeolian deposits are mixed with washover sediments (E), whereas the separation of the lagoonal sediments (C) is clear. Peat (D) covers these deposits.
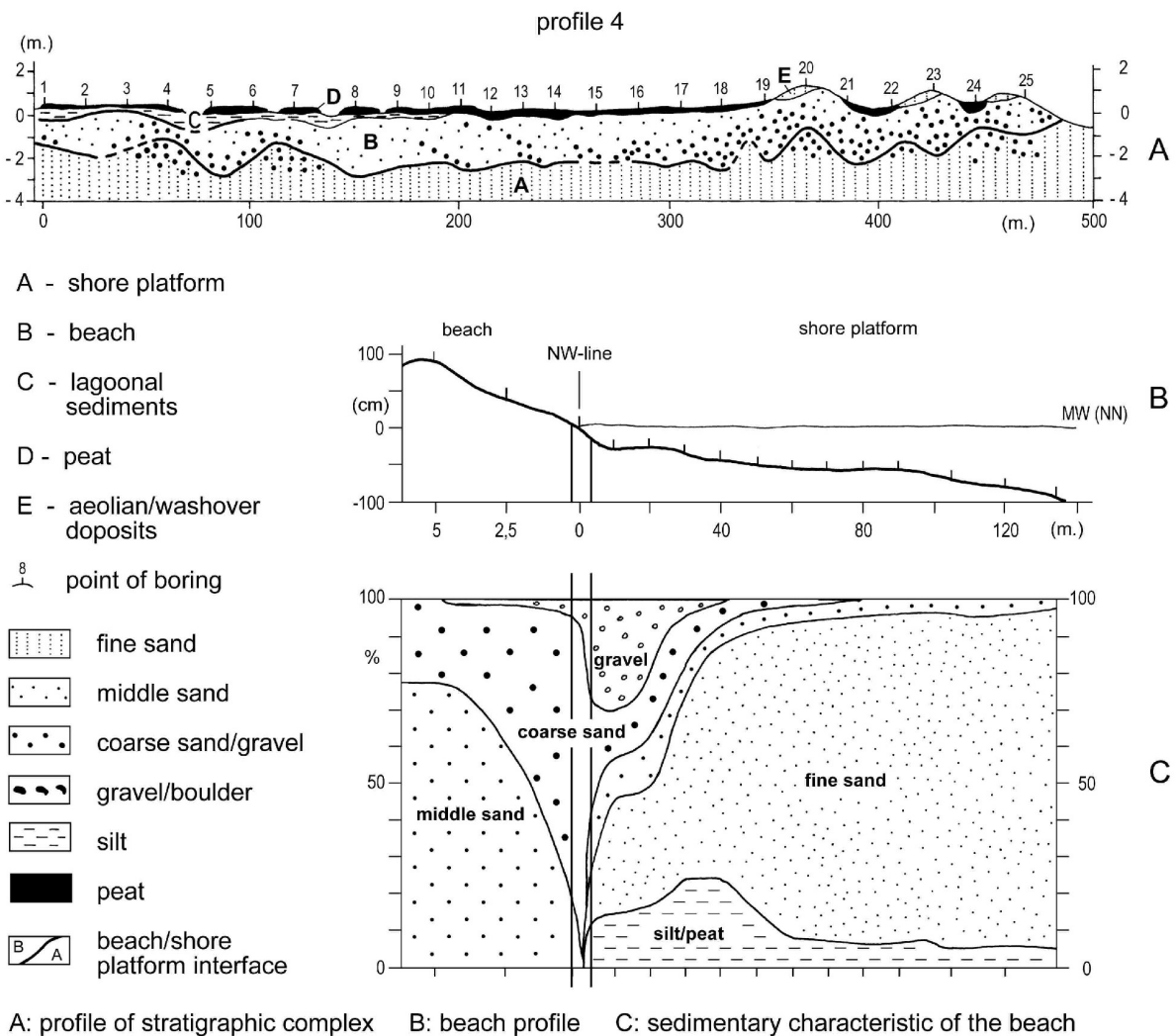

Fig. 1: Reconstruction of a beach/shore platform interface (1A) of the Rustwerder spit (Poel Island) based on the beach profile (1B) and the grain size distributions of the sediments sampled on the shore (1C).

The morphodynamic and sediment-dynamic results provide some correlation between the sedimentary complex and the topographic unit (Fig.1B and C). There is a strongly defined granulometrical differentiation between the beach (middle and coarse sand) and the shore platform (silty fine sand), separated by the small area of the plunge step (poorly sorted, unimodal sediment from gravel to silt). These sediment changes can be found vertically in the Rustwerder spit. Thus it is possible to reconstruct a beach/shore platform interface within the system of the beach ridges. The importance of this interface is related to the fact that it is possible to derive a relationship to the height of the mid-water sea level at the time of the formation of the beach ridges (SCHUMACHER 1985).

The derived heights of the mid-water sea level, from the oldest beach ridge to the youngest, are: 2.5; 1.2; 2.0; 0.7; 1.0 and 0.4 metres below sea level. In regard to the youngest part of the shoreline displacement curve of the Schaabe spit, this means a relative difference in the behaviour of the earth crust of approximately 0.8 mm/year. This amount agrees well with the relative difference in the gauging between Wismar and Sassnitz for the past one hundred years (DIETRICH, LIEBSCH 2000).

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The proto-historic sea-trading port at Groß Strömkendorf –
the "*emporium reric*" of the Royal Frankish Annals

HAUKE JÖNS

At the beginning of the 8th century AD, the area around the south western Baltic Sea became a contact zone between Scandinavian kingdoms, the Slavonic region/kingdoms of East Holstein and Mecklenburg/ West Pomerania, as well as the Frankish kingdom which was dominant in Central Europe at that time. This emerging heterogeneous area in terms of ethnicity, religion and economy offered seafaring merchants and specialised craftsmen excellent conditions to develop new markets for their products. Settlements, which were founded in the entire coastal area of the Baltic Sea from the early 8th century, mostly in sheltered bays or on river courses close to the coast, played a predominant role in the distribution of goods. They were economic centres which produced considerable profit, not only for the resident merchants and craftsmen but also for the ruling power (summary of CALLMER 1994). Up to now, archaeological investigations have been carried out in four of these central trading places along the coast of Mecklenburg - West Pomerania : at Rostock-Dirkow, Ralswiek, Menzlin and Groß Strömkendorf. Referring to written sources, archaeological finds as indicators and theoretical considerations, some additional sites can be assumed in the area of the Barther Bodden and on the island of Usedom.
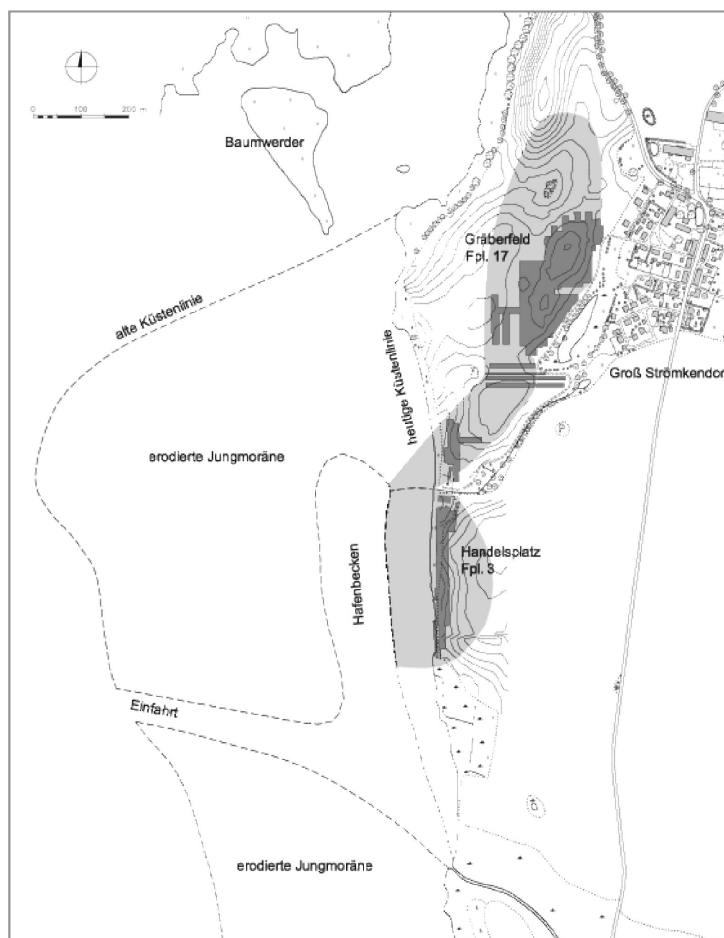

Fig. 1:
Geographic setting of the Groß Strömkendorf excavation site

The site of Groß Strömkendorf near Wismar became the centre of attention for research in the last few years (Fig. 1). At the beginning, numerous isolated finds were made a, so that limited investigations were carried out in the 1980's on some fields close to the Wismar Bay. They confirmed that a trading centre of national importance from the early Slavonic period once existed at this place. It was then discussed whether those were the remains of the "*emporium reric*" mentioned in the Royal Frankish Annals (WIETRZICHOWSKI 1993). The annals of the year 808 state that the Danish king, Godofrid, had destroyed the trading centre located at the seacoast. This happened before his retreat at the end of the campaign against the Obodrites. The trading centre was called Reric in Danish and Godofrid´s kingdom benefited a lot from it because of the tax income. It is said that Godofrid took the merchants away and sailed with them and his whole army to a harbour called Sliesthorp (ABEL 1940, 115). The same source names Reric in the following year 809, and says that Dražko, the duke of the Obodrites, was killed there by Godofrid's men in a crafty way (ABEL 1940, 118). After that, Reric was never mentioned again in any source; presumably, the once flourishing trade centre no longer existed.

Extensive excavations were carried out at Groß Strömkendorf in the years 1995 to 1999; they were the centre of an interdisciplinary research project launched by the German Research Council. On one side, it was necessary to first find out the extension and structure of the site, but the question was also to be answered, as far as possible, if *reric* could really be localised at Groß Strömkendorf.

The use of aerial photography in combination with archaeological and geophysical methods, as well as systematic surveys and small-scale investigations, made the delimitation of the area inhabited in the early Middle Ages possible. Extensive excavations were carried out in the area of the early medieval trading centre and at a cemetery which spread out over an area north of the settlement. The excavations were supplemented by large-scale geological, palaeo-botanical, archaeo-zoological and anthropological investigations (JÖNS 1998a; 1998b; 1999a, 1999b; 2000). The results obtained will be described here briefly.

The remains of numerous wells of the former settlement were detected, which delivered many samples for dendrochronological analysis. The results show, that the settlement was established during the first third of the 8th century and abandoned at the beginning of the 9th century already. During these approximately 100 years, the occupied area was more than 20 ha, which, as far as we know up to now, is much bigger than the size of early Haithabu (JANKUHN 1986) or Ribe on the western coast of Jutland (FEVEILE 1994).

The built-up area of Groß Strömkendorf consisted of single "Grubenhäuser" with store pits and wells until the middle of the 8th century. They were built without any apparent order in direct proximity to the coast as well as on the northern adjoining flat crest (TUMMUSCHEID 2002). Crafts and trade constituted the economic base of the settlement; this is shown by diverse production waste like remains of iron working, non-ferrous metal, bone, antler, amber and glass as well as typical commodities like grindstone-basalt, whetstone-slate, Frankish glass and pottery, tesserae etc. from the fillings of the features. Probably in the Sixties of the 8th century a reorganisation of the settlement area occurred. The area in direct proximity to the coast had "Grubenhäuser" and annexes built in a row, so that a structured "development plan" can be identified for this building phase. Production related to crafts and international exchange of goods continued to play a predominant role in the economic life of the settlement.

At the same time, the northern part of the settlement was given up and a cemetery was laid out on the flat crest. The burials which took place there then show a wide variation in rites. Women, children and men are buried there equally, so the presence of families can be deduced. Although a detailed analysis of grave forms is still underway , it can be said that the burial traditions of the entire northern Central Europe are discernible. It seems certain that the population residing at Groß Strömkendorf was of various origins. The use of boats in funeral customs, built in the Scandinavian tradition, is found mainly in Denmark and Sweden (MÜLLER-WILLE 1995). Therefore, an important Scandinavian share of the population can be deduced for Groß Strömkendorf (JÖNS 1998b). Besides, graves of dogs and horses were found, which suggest that people from Saxon and Frisian areas were also resident at Groß Strömkendorf (HORNIG 1993,84 pp.). The quality of the grave assemblages (e.g. Scandinavian disc brooches, Frisian textiles, millefiori beads) shows that there were quite prosperous persons at the site, who had far reaching connections especially to Scandinavia and the North Sea area.

Fig. 2: Aerial view of the harbour of Groß Strömkendorf

The position of the former harbour was reconstructed by evaluating satellite and aerial images (Fig. 2) as well as geophysical and geological-palynological investigations. The harbour was situated at a small bay orientated north-south approx. 80 m in front of the present-day coastline. This bay was formed by draining meltwater during the late glacial phase. It is separated from the deeper waters of the Wismar Bay by a ridge formerly some hundreds of metres wide. The bay offered excellent conditions for the construction of a harbour protected against the influences of the weather. Maybe the convenient location was the decisive factor in founding the trading centre at Groß Strömkendorf. Geological and palaeo-botanical investigations in the harbour basin led to calculations of the water level in the early Middle Ages (personal comment of W. DÖRFLER, Univ. Kiel). The peat exposed from –1.86 m NN almost

certainly lies in situ whereas the layers above consist of transferred material. The depth of the basin would have been approx. 1.09 m in the case of a postulated water level of approx. – 0.75 m NN in the 8th century AD (cf. HOFFMANN 1998). Theoretically, early medieval ships with a maximum draught of 1 m, as e.g. Skuldelev 3 or Ralswiek 2, could have berthed in the harbour of Groß Strömkendorf. Further geophysical investigations will have to show if remains of wooden piers, or maybe also of boats, have been preserved in the sediment.

Although the evaluation of the excavation results is not yet finished, it can be stated that the trading centre of Groß Strömkendorf has amazingly many characteristics associated with the destroyed *reric* on the basis of written sources. This concerns both the topographic situation and extension and the dating and the economic structure. Therefore, it must be assumed that *reric* and Groß Strömkendorf are identical, particularly because no other comparable site in the region of the Wismar Bay has come to light as yet.

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Storm floods of the southern Baltic Sea

WALTER SCHUMACHER

Storm floods are hydrological and geological events of short duration but of strong effect (Fig. 1). They can be identified in the coastal deposits over the whole time of the Baltic Sea. They are indicated by erosion discordances, gravel layers, storm flood channels and so on. The well-known flintstone beach ridges of Mukran (Feuersteinfelder, cf. B-8) as well the storm flood shells of the Greifswalder Bodden (cf. C-12) are impressive geological references to the storm flood history of the southern Baltic. The interpretation of the historical informa-tion of the past one thousand years and of the measured data of about the past one hundred years (SCHUMACHER 2001) shows following:

Fig. 1: The Ladies' bath of Heiligendamm, destroyed by the storm flood on 30.12.1913.

1. There are four factors influencing storm flood events inthe southern Baltic Sea - the abundance of water in the Baltic basin produced by an inflow of water from the North Sea (0.5 metres sea level rise); hydrodynamical oscillations (1.0-1.5 metres sea level rise); rising of the water level caused by the wind (1.5-2.0 metres sea level rise) and local effects, especially the effect of bays (0.5 metres sea level rise).

2. There are three main meteorological origins of storm floods (Fig. 2) - the Vb-type, the NW-type and the W-type. They are differentiated by the source area and the direction of the cy-clones, as well as by the behaviour of the winds.

wind conditions of the W-type

W-type

wind veers round counter-clockwise from SW/S to NW

wind conditions of the NW-type

NW-type

wind veers round clockwise from SW to N - NE

wind conditions of the Vb-type

Vb-type

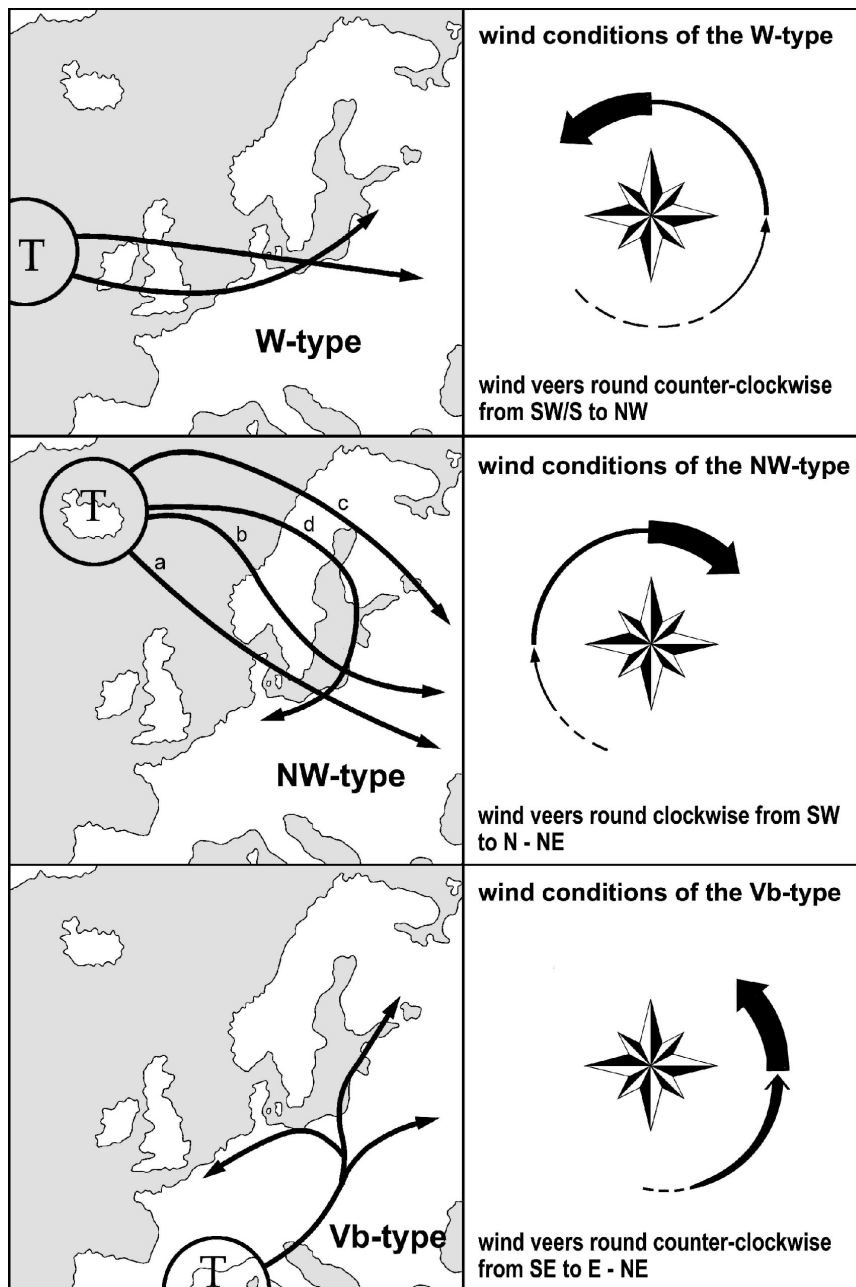wind veers round counter-clockwise from SE to E - NE

Fig. 2: Meteorological types of storm floods on the southern Baltic Sea and their wind behaviour.

3. The different behaviour of the wind leads to different variations inthe water level rise along the southern Baltic Sea (Fig. 3). The Vb-type causes the highest water level rise in Schleswig-Holstein, especially in Lübeck-Travemünde. The water level rise is successively decreasing from west to east. The NW-type shows a balanced water level rise from west to east. The highest amounts appear in Wismar and/or Greifswald (bay effect). The W-type gives the maximum figures in Wismar and on the Polish Baltic coast.

4. The strongest flood of the past one thousand years was the flood on 10.02.1625 (Fig. 4). About 3600 persons were drowned. This flood was of the NW-type. The abundance of water and a hydrodynamical oscillation led to a water level rise of approximately 1.5 metres without storm. The mean water level rise amounted to about 3.6 metres. The flood on 13.11.1872 was the strongest in the past 130 years and the flood on 03.11.1995 was the strongest in the past 45 years.
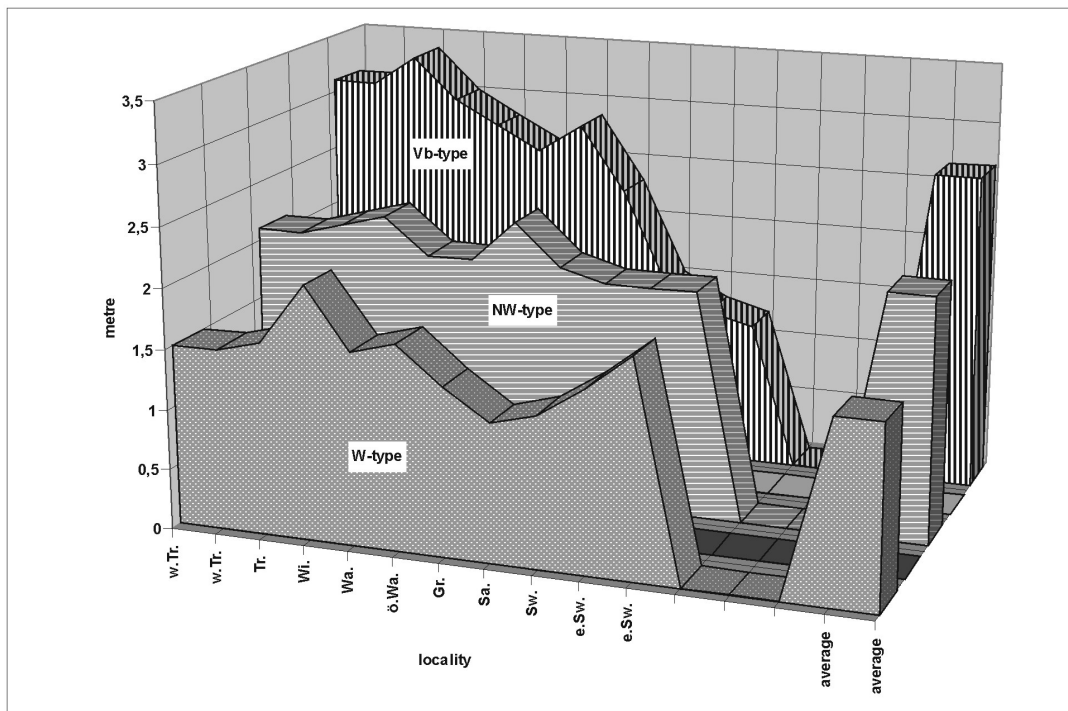
Fig. 3: Variations in the water level rise along the southern Baltic coast from the West to the East for different meteorological types (localities: w.Tr. – westwards of Travemünde, Tr. - Travemünde, Wi. - Wismar, Wa. - Warnemünde, e.Wa. –eastwards of Warnemünde, Gr. - Greifswald, Sa. - Saßnitz, Sw. - Swinoujscie, e.Sw. – eastwards of Swinoujscie; Vb-type: flood of the 13.11.1872, NW-type: floods of the 31.12.1904/30.12.1913, W-type: flood of the 07.11.1921).
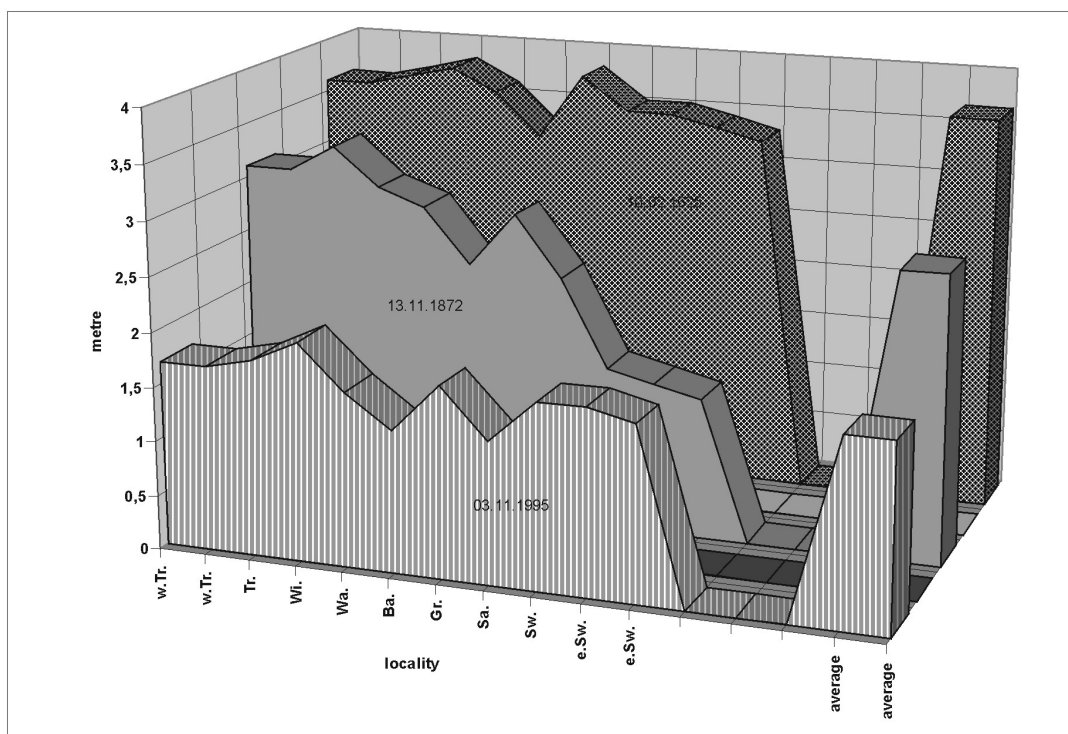

Fig. 4: Comparison of the heights of the storm floods of the 10.02.1625, 13.11.1872 and 03.11.1995 (localities see Fig. 3).

5. The average frequency amounts to strong storm floods (> 1.5 metres) every 14 years and to extreme floods (> 2.5 metres) every 138 years (Table 1). The frequency is different for different localities. The highest frequency is observed for the locality of Lübeck - Travemünde. The next extreme flood event can be expected in 2010 on the basis of statistical calculations.

Table 1: Average frequency of storm floods on the southern Baltic Sea and average frequency of an event > 2.5 m for different localities.

average height of the flood	>3,5m	>3,0m	>2,5m	>2,0m	>1,5m
average frequency	1000a	500a	138a	43a	14a
event > 2.5 m for the different localities					
locality	Travemünde	Wismar/ Greifswald	average/ Warnemünde	Saßnitz/ Swinoujscie	
last event	1872	1872	1872	1625	
average frequency	92a	110a	138a	276a	
next event	1964	1982	2010	1901	

6. There are some indications that the storm flood history of the southern Baltic Sea is cyclic too. The strongest floods of the Vb-type have an interval of about 550 years (1320 up to 1872 = 552 years; 1134 up to 1694 = 560 years). The strongest floods of the NW-type also occur about every 550 years (521 up to 1625 = 1104 years = 2 x 552 years; 1044 up to 1596 = 552 years; 906 up to 1449 = 543 years).

7. It is very interesting that the NW-floods (the source area of cyclones is located to the north of Iceland) dominated in the warming phases of the last climatic cycle (17th and 20th century). The W-floods (the source area of cyclones is located to the west of Ireland) seem to be more frequent in the main cold phase of the last cycle (Little Ice Age with the expansion of the North Atlantic ice drift in the $15^{th}/16^{th}$ century). The Vb-floods (source area of the cyclones over the Alps) seem to be more frequent at the moment (19th century) when the glaciers of the Alps had reached their maximum expansion after the last Ice Age.

8. If the cyclicity of the floods is true, than we can make the following prognosis: The next extreme flood of the NW-type can be expected in 2010 (906 + 1104 years). This is in good agreement with the statistical calculations. The strongest W-flood of the last 550 years could appear in 2049 (1497 + 552 years). The strongest NW- and Vb-floods could occur in 2148 (1044 + 1104 years) and in 2138 (1134 + 552 years).

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