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On the age of the marine Eem in northwestern Germany

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Abstract: In the last interglacial, the North Sea transgressed over large parts of the Northwest European coastal area from Holland to Denmark, with a passage forming through northern Germany to the paleo-Baltic Sea. Two core holes were drilled in these interglacial deposits in Schleswig-Holstein, North Germany: the first from the regime of the paleo-North Sea, close to the town of Dagebuell, west coast, and the second near the settlement of Krummland, east of Eckernfoerde, from the regime of the paleo-Baltic Sea. Sedimentological, paleontological, and palynological studies, along with high resolution oxygen and carbon isotope stratigraphical work, and absolute dating applying the Thorium/Uranium (Th/U) and Electron Spin Resonance (ESR) methods allowed the reconstruction of the sedimentary facies associations and depositional history of this warm period in North Germany. The absence of large isostatic adjustments rendered it possible to link the local hydrographic and climatic evidence to the global development of this interglacial.

Th/U-datings of molluscan shells from the marine transgression at Dagebuell (Senescens Sand unit, 28.1 to 22.1 m b.s.l.) yielded an average of 132±1 ka (n = 4 of 5). The results from the younger units (Turritella Clay; Olander Beds; 12 measurements) and from outcrops of Eemian sediments (14 measurements from 7 localities) suffered from open-system-reactions and did not provide reliable ages. ESR-measurements gave collateral support and assigned a rough age to the upper part of the sequence at Dagebuell. Climatic classification and relative correlation of these units is based on pollen-stratigraphy.

In the Krummland core, Eemian beds (26.0 to 19.7 m b.s.l.) spanned the initial terrestrial/lacustrine depositional regime to the brackish/marine environment. Palynological evidence assigned the Eemian sediments to Zone 0 (subarctic) through Zone III (warm Eem) to Stage IVa (cooler Eem), following the pollen

zonation by Müller (1974). In Dagebuell, the Senescens Sand unit of Zone IIIc was followed by the Turritella Clay and Lower Olander Beds of Zone IVa/b, and ended with the Upper Olander Beds in Zone V.
With reference to the global event stratigraphy of the deep-sea oxygen isotope history and the sea level rise during the penultimate interglacial, the climate optimum of the Eem is found to precede the minimum stage of the global ice sheets and likely relates to δ^{18}O-Stage 5.5.3. The sedimentological and paleontological characteristics of the Dagebuell depositional sequence as well as the isotope evidence indicated that the sea level continued to rise beyond the Eemian hypsithermal up to a time when climate already grew colder, as is shown by the pollen assemblage, and probably culminated in δ^{18}O-Stage 5.5.1.

Key words: Eem, foraminifera, pollen, Th/U-dating, ESR, N. Germany.

Kurzfassung: Im letzten Interglazial transgredierte die Nordsee weite Teile der nordwest-europäischen Küstenregionen von Holland bis Dänemark. Eine Meeresstraße zur Ostsee hin öffnete sich in Schleswig-Holstein. Die Sedimente dieser Warmzeit wurden mit zwei Kernen erbohrt: im Einflußbereich der Paläo-Nordsee bei Dagebüll an der Westküste, und nahe der Siedlung Krummland östlich von Eckernförde im Einflußbereich der Paläo-Ostsee. Die sedimentologischen, paläontologischen und pollenfloristischen Befunde zusammen mit hoch auflösenden Untersuchungen der stabilen Kohlenstoff- und Sauerstoff-isotope sowie absoluten Datierungen nach der Thorium/Uran-Methode (Th/U) und dem Elektronen-Spin-Resonanz-Verfahren (ESR) ermöglichten es, die Faziesassoziationen im Sediment und die Ablagerungsgeschichte während dieser Warmperiode in Norddeutschland zu rekonstruieren. Da größere isostatische Bewegungen an den Bohrpunkten auszuschließen sind, kann die lokale hydrographische und klimatische Evidenz unter Berücksichtigung der möglichen Wassertiefen in die globale Entwicklung des Interglazials eingehängt werden.

Die Absolutalter basieren auf Th/U-Datierungen an Bivalvienschalen aus dem marinen Transgressionshorizont in Dagebüll (Senescens Sand, 28,1–22,1 m unter NN). Sie ergaben einen Mittelwert von 132±1 ka (n = 4 aus 5 Messungen). Proben aus den jüngeren Abschnitten (Turritella Ton; Olander Schichten; 12 Analysen) und von weiteren Aufschlüssen eemzeitlicher Sedimente (14 Analysen von 7 Fundstätten) sind nach ihrer Ablagerung durch Lösungstransport chemisch verändert worden und erbrachten keine verläßlichen Alter.

ESR-Datierungen stimmen im Rahmen ihrer Genauigkeiten gut mit den Th/U-Altern der Senescens Sande überein und lieferten eine Altersabschätzung auch für das obere Interglazial von Dagebüll. Klimatische Einstufung und relative Korrelation dieser Abschnitte werden durch die Pollenanalyse möglich.

Im Kern von Krummland umfassen die Eem-Ablagerungen das zunächst terrestrisch/limnisch geprägte bis schließlich brackisch-marine Ablagerungsmilieu. Die Pollenstratigraphie zeigt die Gliederung (nach Müller, 1974) in Pollenzone 0 (subarktisch) bis Zone III (Hoch-Eem) und Zone IVa (Nachwärmezeit). In Dagebüll fallen der Senescens Sand in Zone IIIc, im Hangenden der Turritellen Ton und die Unteren Olander Schichten in Zone IVa/b, die Oberen Olander Schichten in Zone V bis VI.

Bezogen auf die globale Entwicklung von Meeresspiegel und Klima im letzten Interglazial, wie sie sich an der marinen Sauerstoff-Isotopen-Stratigraphie der Tiefseesedimente und an den Daten der Eiskerne zeigt, ist das Klimaoptimum des Eem vor dem Tiefststand des globalen Eisvolumens erreicht und fällt wahrscheinlich auf das marine Sauerstoff-Isotopenstadium 5.5.3. Nach den sedimentologischen und paläontologischen wie auch den isotopischen Befunden von Dagebüll zeigt der Meeresspiegel ein weiteres Ansteigen in der schon kühleren Nachwärmezeit und erreicht seinen Hochstand wahrscheinlich im Stadium 5.5.1.

Introduction

With the rise of the global sea level at the termination of the Saale Glaciation, the paleo-North Sea transgressed over large parts of the NW European coastal areas of Holland to Denmark, roughly following the present day coastlines. The Nordmann Channel with depths below 40 m formed in the west (Madsen *et al.* 1908; Dittmer 1941; Kosack & Lange 1985 among others), opening a passage through northern Germany to the paleo-Baltic Basin with a deep strait extending eastwards to beyond Ruegen Island. Over 20 m of Eemian sediments were deposited as the sea level kept on rising and inundated the NW German coastal area. Temmler (1995) reviewed the existing data from the west coast of Schleswig-Holstein, incorporating unpublished material from official archives in his paleogeographical map. In order to address in greater detail the environmental settings of the Eemian, Winn & Erlenkeuser (1995) began to study isotopic proxies on foraminiferal shells from the Eemian sediments.

The global response to the climatic optimum of the penultimate interglacial, such as recorded in the deep-sea sediments and in the ice cores, is frequently compared to and correlated with the Eemian pollen record (e.g. Field *et al.* 1994). From the sea level curve shown by Zagwijn (1983, 1996) for this period, it became apparent that the highest level of 4 to 7 m above the present, as was modelled for the Marine Oxygen Isotope Stage 5e (Lambeck & Nakada 1992), was not reached during the warmest Eem but significantly later.

The object of the present study was to reconstruct the geological history of the Eemian deposits in North Germany by applying relative dating tools such as the development of macro- and micropaleontological assemblages, and palynological associations in combination with absolute dating by means of the Th/U- and ESR-methods. Here we present some sedimentological and paleontological aspects evidencing the marine processes, show the palynological results correlating the sedimentological findings to the climatic development, and present the absolute dating of the Eemian Transgression.

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Methods

In order to obtain continuous sequences of the Eemian deposits, two wells were drilled at Dagebuell (8°45'E, 54°42'N, 1.9 m a. s. l.) and at Krummland (9°59'E, 54°27'N, 10.5 m a.s.l.), in the state of Schleswig-Holstein, Northern Germany. The Eem sediments were encountered in the cores between 9.4 and 30 m at Dagebuell (Winn & Erlenkeuser 1995) and 30.2 to 36.5 m at Krummland. They provided a composite sequence from their fluviatile/lacustrine begin-

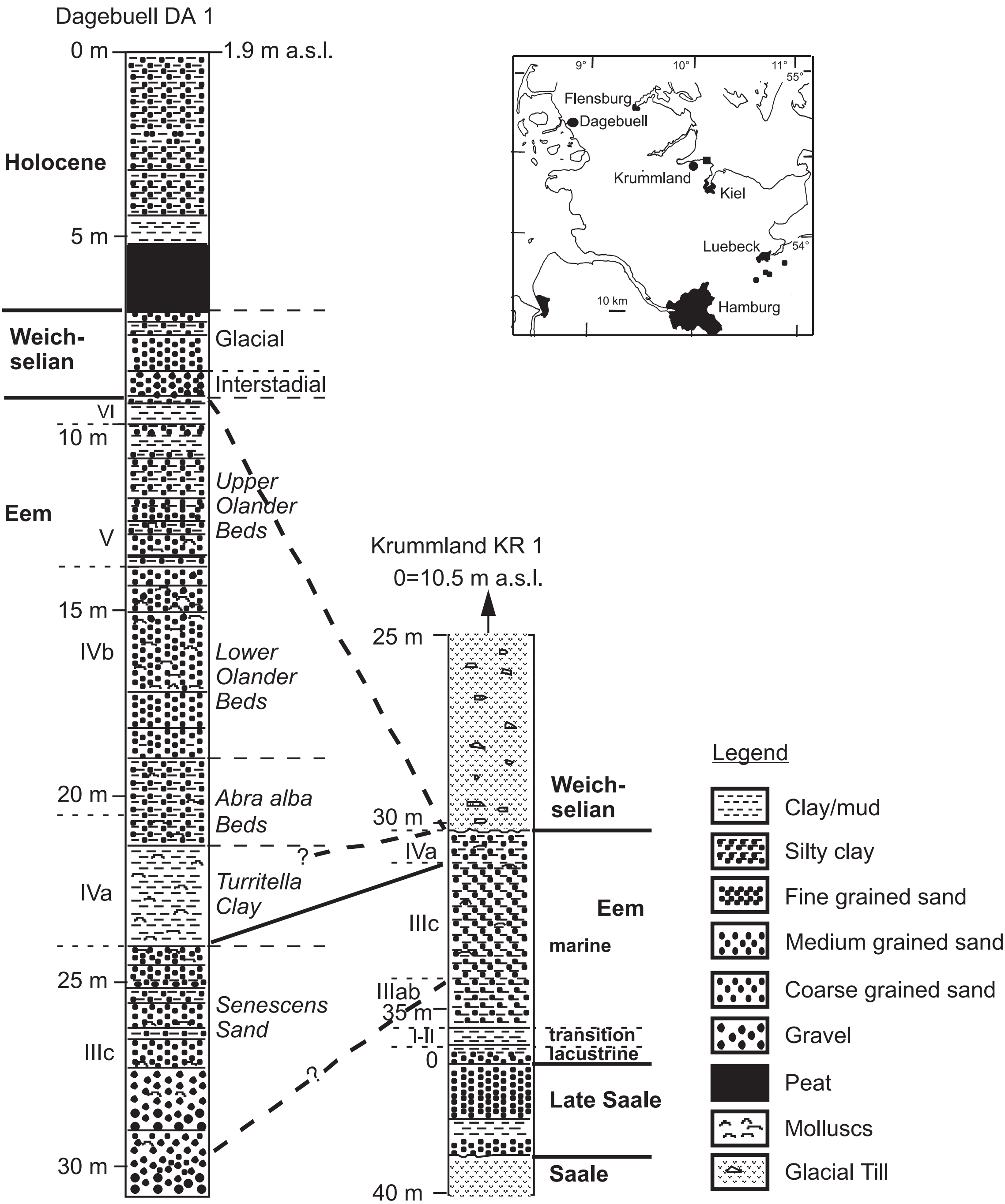

Fig. 1. Location and lithostratigraphy of cores Krummland KR 1 and Dagebuell DA 1. Roman numerals show the pollen zonation after Müller (1974).

ning through the marine incursion and the later regressive phase, amounting to a total of over 5 m of Eemian deposits (Fig. 1).

The cores were sampled at 2 cm intervals for lithostratigraphical, sedimentological, and micropaleontological investigations, and also for isotopic analyses. Larger intervals were sampled for palynological work. Samples, taken with a defined volume, were weighed, freeze-dried, re-weighed, and wet-sieved through 63 µm mesh size. Palynological samples were additionally treated with hydrofluoric acid.

The frequency of three selected foraminiferal species, i.e. *Nonion germanicum*/sp., *Ammonia batavus/beccarii* and *Bucella frigida* was statistically analysed. Prior to isotopic analyses with the mass spectrometer, the foraminiferal specimens were cracked, placed in Ethanol, and cleaned in a sonic bath.

Modern analogs to these measurements were provided by analyses of modern foraminifera (Winn *et al*. 1998) and the ecological significance of the echinoidal, ostracodal and partial foraminiferal assemblage was investigated (Peter Frenzel, Greifswald). In the Krummland core KR 1, the beds were thinly laminated with lighter summer layers and darker winter deposits. Physical counting these yearly “varves” provided a floating chronology for parts of the sediment sequence.

Pollen associations were calculated as percentage of the total tree pollen. The interpretation of the pollenfloristic development (Figs. 1, 3, 6) follows the classification of Müller (1974).

Th/U (Lomitschka *et al*. 1997) and ESR (Hoffmann *et al*. 1999) measurements including the chemical pretreatment were carried out in Heidelberg, on molluscan shells picked from sediment layers of core DA1 as well as from the flowline at Dagebuell. The shell samples were powdered with a mortar and extracted with Vitamin C (ascorbic acid) and Na_2EDTA (Ethylene-diamine-tetraacetate). Vitamin C dissolves erratic metallic oxides on the sample surface including detrital ^{230}Th and ^{232}Th. EDTA transfers the metal ions into a stable chelate complex, preventing them from re-accumulating on the sample surface. The sample is then centrifuged and dried.

Replicate datings were made (Laukenmann 1997) to check the significance of the dating results. Apart from an isolated occurrence of *Nassaria* sp. and small fragments of molluscs, carbonate material for absolute dating could not be found in Krummland core KR 1.

Results

Krummland

In KR 1, the complete marine transgression over the Saale deposits is cored (Fig. 1). The Saale glacial tills are unconformably overlain by lacustrine fine sands, silts and muds between 36.00 and 35.52 m, which were deposited at gradually increasing water depth, and finally turned into a clay facies. The boundary to the initially brackish silts and clays of the early Eemian is gradational. The uppermost marine beds have been eroded by the overiding Weichselian glaciers, leaving 5.33 m of dominantly marine Eemian deposits between 35.52 and 30.19 m.

The marine Eem deposits are dominantly olive grey, laminated (< 1 mm in thickness), lighter silts and darker clays. Apart from small-scale subaquatic synsedimentary structures, large disturbances caused by ice tectonics are not observed though a general uplift by ice movement and pressure cannot be excluded (see below). The laminations are thicker in the lower part of the succession (5–7 cycles/cm) and thinner above (10 cycles/cm). Laminations are not preserved in the uppermost beds due to bioturbation. The varve counting of the 4.46 m thick laminated sequence from 31.00–35.46 m yielded a total of approximately 3800 years with an average sedimentation rate of 1.17 mm/year.

Elphidium dominates the microfaunal assemblage in KR 1, with *E. excavatum* as the most common species followed by *E. albiumbilicatum, E. incertum* and *E. articulatum.* Foraminiferal masks indicating dissolution and probable falsification of the preserved assemblage are observed in deposits of the initial stage of the transgression below 35 m, and above 32 m. In spite of the low frequency of *Nonion*, *Bucella* and *Ammonia*, significant trends are noticeable. In sediment layers with high occurrences *of B. frigida*, a cold water form, the number of *A. batavus/beccarii* decreases significantly (Fig. 2). The *Bucella* curve likely indicates numerous temporal cold water inflows, a feature similarly known from the long and narrow straits in the present day Belt seas.

Pollen analyses (Fig. 3) of the lacustrine section below 36 m shows a dominance of *Betula* with frequent *Pinus*, Gramineae and herbs indicating a cold arctic climate with affinities to Zone 1-IIb (Selle 1962; Müller 1974) preceding the Eemian. The transitional phase from lacustrine to marine Eem reveals abundant *Pinus* and *Quercus* with frequent *Ulmus* and *Betula*, low *Alnus* and occasional *Corylus* – i.e. a hazel-poor mixed oak forest signalising the commencement of a warmer period. Hystrichosphaerideae indicate the beginning of the brackish to marine influence in the region.

The basal marine beds around 35 m show the pollen assemblage of a warmer climate with abundant *Corylus*, frequent *Quercus* and *Alnus* and less *Ulmus*, *Tilia*, *Pinus* and *Picea*. This lower section has been assigned to Zone IIIb of Müller (1974).

The main marine sediments represent the Eem warm optimum (Zone IIIc). *Corylus* continued to dominate the forest with frequent *Quercus*, *Tilia* and *Alnus* and sporadic *Carpinus* and *Picea.* The uppermost marine beds above 31 m indicate the end of the Eem warm optimum and the beginning of a temperate climate. *Carpinus*, *Quercus*, *Tilia*, *Alnus* and *Corylus* occurred frequently along with some *Ulmus* and occasional *Pinus* and *Picea.*

Dagebuell

Core DA 1 comprises more than 20 m of marine Eem sediments between 30.37 and 9.4 m. The basal Eem begins as medium to coarse grained sands and gravels/cobbles typical of beach ridge systems, and is followed up to 24 m by fine grained shallow nearshore marine sands (Senescens Sand; Fig. 1). Pyrite occurs frequently, either as disseminated small crystals or as fillings in foraminifera. The dark grey Turritella Clay directly overlies the Senescens Sand, and with increasing silt to very fine sand content passes into the layers with *Abra alba* that persist up to 19 m core depth. The Olander Beds could be subdivided into a lower fine grained sandy shallow coastal facies and an upper predominantly silty to muddy tidal flat facies, with increasing subaerial influence in the

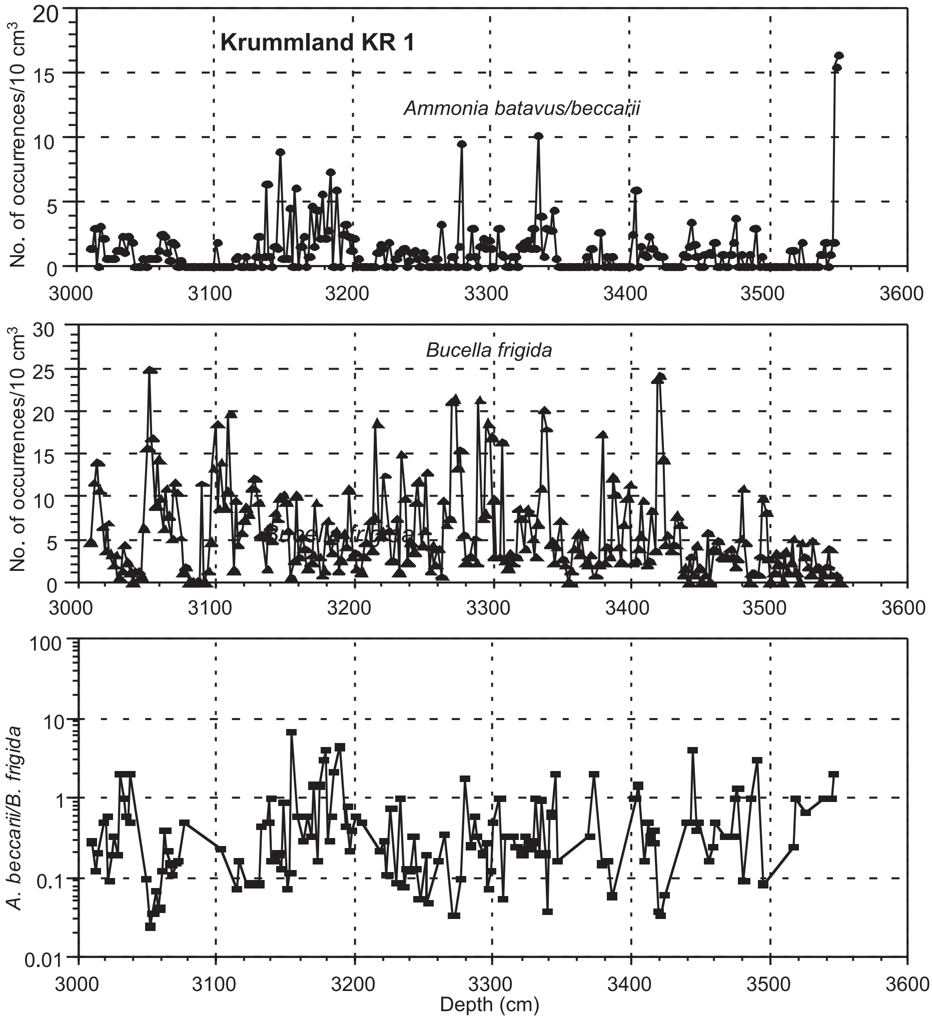

Fig. 2. Frequencies of *A. beccarii* and *B. frigida* in KR 1 and their ratio.

Table 1. Th/U-dates from mollusc shells below 25m depth in core DA1 (Lomitschka *et al.* 1997). Weighed average age t_w and its error s_w are calculated from the individual ages t_i and their errors s_i as t_w = sum(t_i s_i^{-2}) /sum(s_I^{-2}) and s_w = 1/sqrt(sum(s_i^{-2})). Age of sample 208 was rejected.

Lab. Nr	Sample	Depth, m	Age, ka	± err., ka
171	D28-29	28.5	129.67	2.87
202	D25-26	25.5	131.18	2.55
206	D25$^{06\text{-}15}$	25.1	135.75	6.54
208	D28$^{0\text{-}10}$I	28.05	(113.74)	5.44
209	D28$^{0\text{-}10}$II	28.05	132.07	1.24
	Weighed average		132.07	1.03

topmost 1.5 m of the sequence. The basal beds of the succeeding Weichselian deposits have reworked foraminifera.

Since the microfaunal assemblage of the west coast region is known (Lafrenz 1963; Knudsen 1985), we have concentrated on the foraminifers *Nonion*, *Bucella* and *Ammonia*, and their frequencies. These species occur in larger numbers here than at Krummland. Although *Ammonia* tolerates a broad range of conditions from brackish to marine to salt marsh environments, we have interpreted its abundance here as indicative of the brackish influence. *Bucella* showed its maximal development above the Turritella Clay from 21 m to 15 m (Fig. 4).

Th/U and and ESR measurements were carried out at Heidelberg University (Lomitschka *et al.* 1997; Laukenmann 1997; Hoffmann *et al.* 1999) on mollusc shells from 11 sediment horizons and 4 flowline samples between 14.3 m and 29.0 m. Samples from below the Turritella Clay (Lomitschka *et al.* 1997; Laukenmann 1997) yielded a (weighed) average Th/U-age of 132±1 ka (Table 1; Fig. 5) when the stray age of sample 208 (28.0–28.1 m) is not taken into account.

Samples above the Turritella Clay yield Th/U-ages which in general are too young. Apparently, the shells have been affected by percolating ground waters, poorly protected due to lack of an impervious sediment cover (see sediment succession, Fig. 1). The ESR-dating gave more reasonable ages, and date the deposition of the upper Eem sediments at around 127±15 ka (weighed average; from Hoffmann *et al.* 1999), i. e. in the Marine Oxygen Isotope Stage 5.5.

The Senescens Sand of the lowermost sequence is assigned to Pollen Zone IIIc – the *Tilia-Taxus-Corylus*-phase (Fig. 6). It is dominant in *Tilia* and *Taxus*, which however, exhibit distinctly lower occurrences than in comparable other diagrams from the region. In addition, the percentages of *Carpinus*, *Picea* and *Abies* are comparatively high for this zone. These pecularities may be due to the very low pollen content in these sands and by the number of reworked, corroded unidentified pollen grains which is significantly higher than in the following zones. The lithological and faunistical characteristics indicate that the Senescens Sands underwent frequent episodes of deposition and erosion mainly in the littoral (partly subaerial) to very shallow nearshore marine facies.

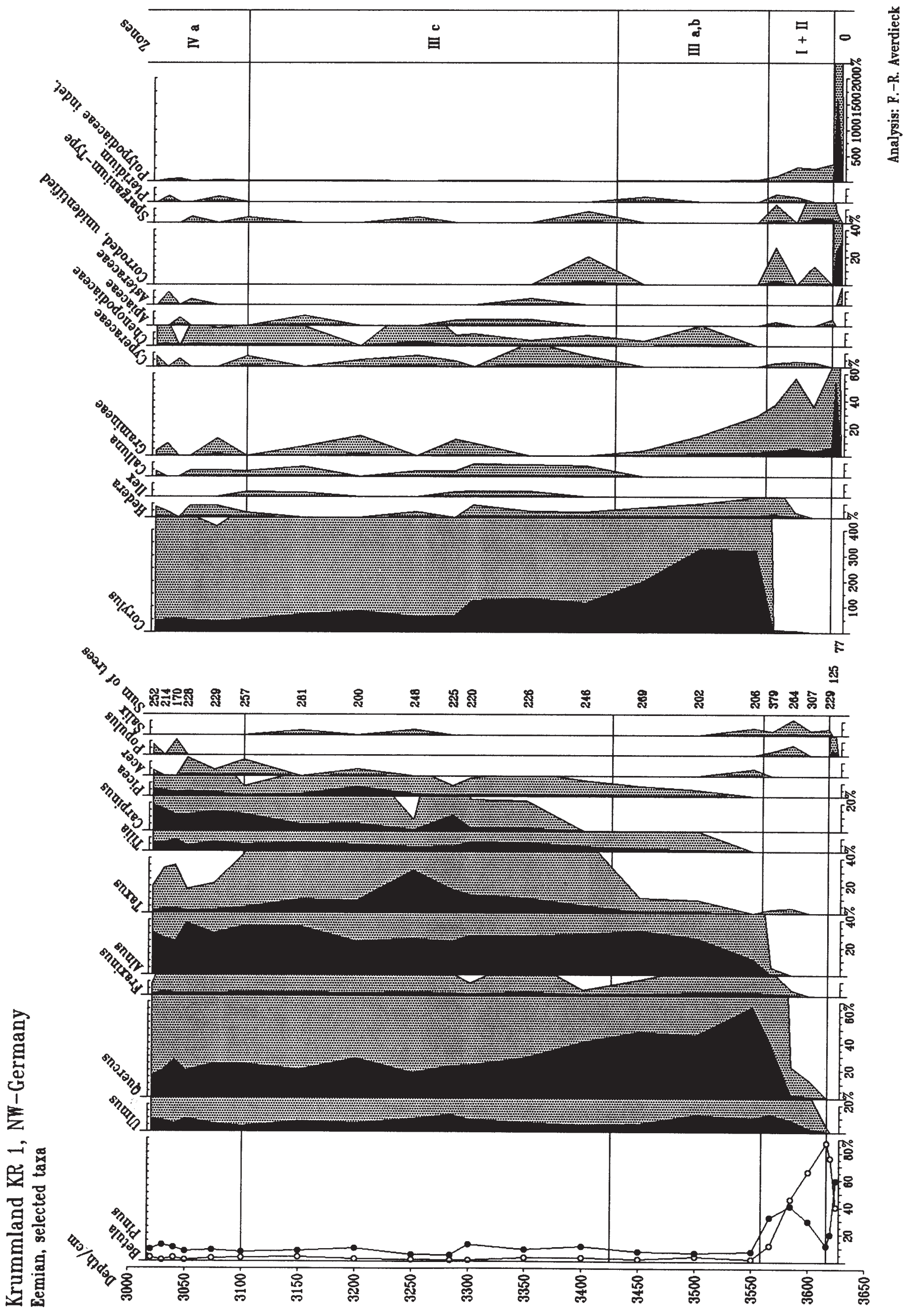

Fig. 3. Pollendiagram of Krummland KR 1 (values in percentage of total tree pollen).

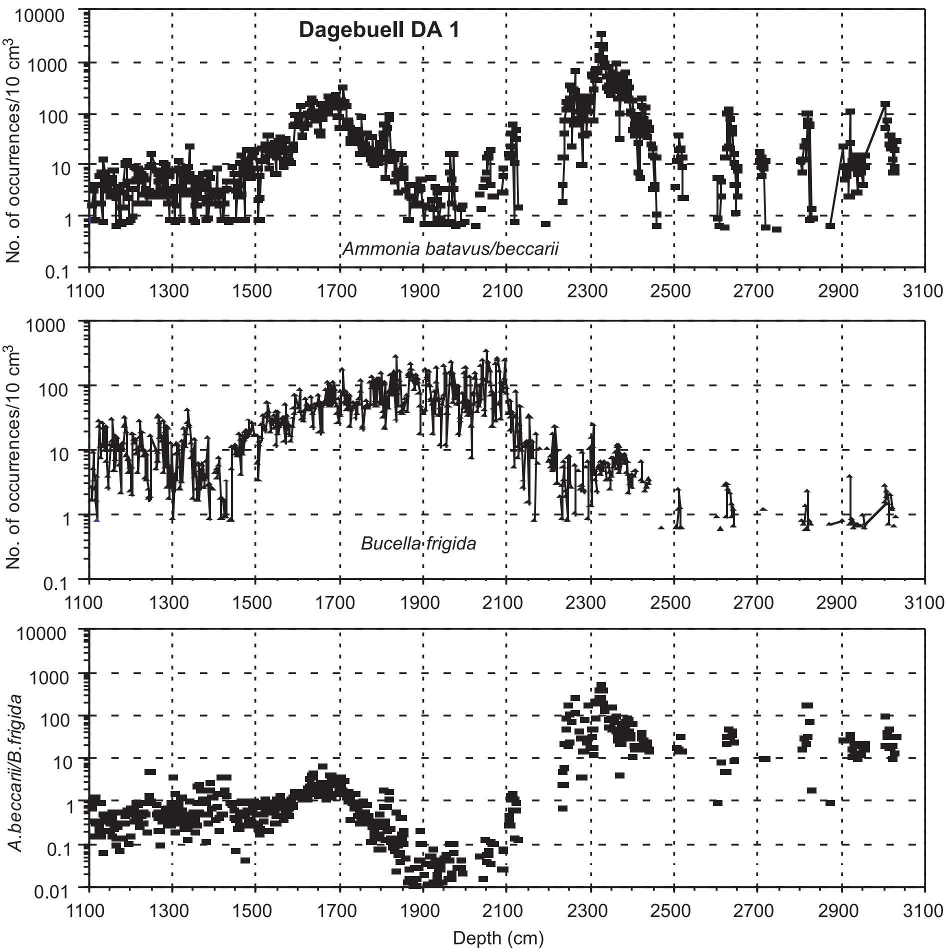

Fig. 4. Frequencies of *A. beccarii* and *B. frigida* in DA 1 and their ratio.

The following Pollen Zone IV, the *Carpinus*-*Picea*-phase, is well reflected in the diagram. Lithostratigraphically, it encompasses the Turritella Clay, the layers with *Abra alba* and the lower Olander Beds (24 to 14 m). Characteristic for the early section is the decreasing values of *Alnus*, *Corylus*, *Taxus* and members of *Quercetum mixtum*. On the other hand, the percentages of *Carpinus* and *Picea* rise steeply and dominate the rest of the zone. A differentiation between the subzones IVa and IVb based on the frequencies of *Picea* as in neighbouring localities in the region (e.g. Averdieck *et al.* 1976) is not possible at Dagebuell. The low occurrences of reworked and corroded pollen grains are in harmony with the continuous sedimentation in a deeper marine facies indicated by the macro- and microfaunal assemblages. The succeeding *Pinus*-*Carpinus*-*Picea*-stage (Pollen Zone V, 14 to 9.85 m) shows a rise of *Pinus* which prevailed, and a simultaneous decrease in percentage of *Corylus* and all other trees. *Carpinus* reaches values between 5% and 10%, *Calluna* has higher occurrences and *Em*-

petrum is present throughout. Because of the larger sampling interval, the maximum of *Abies* in the upper part of the zone, a typical feature in comparable pollen diagrams of NW-Germany, is not apparent at Dagebuell. In the uppermost section, *Pinus* is dominant. The number of unidentifiable pollen grains is similar to the preceding zone.

Zone VI comprises the very short core segment between 9.85 and 9.4 m. *Pinus* remains very high with sporadic thermophilic tree species. Heath and bog indicators increase as do light demanding shrubs and herbs. Very high values of Gramineae and Cyperaceae (200%, not shown in Fig. 6) in the uppermost beds reflect very extreme local conditions.

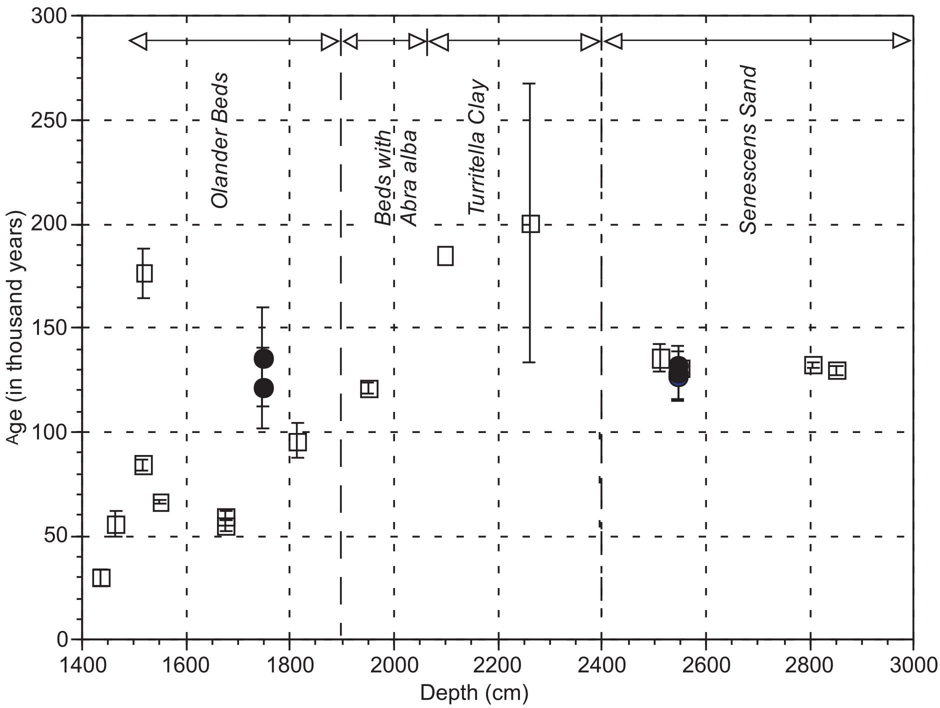

Fig. 5. Th/U-ages (open squares) and ESR-ages (solid circles), in 1000 years, in DA 1.

Surface Outcrops

14 Th/U-measurements were also carried out on bivalves from surface exposures of Eem sediments at Stohl, Kluetz Hoved, Schwaan, Grimmen, Hiddensee, Klucknow and Kluesser Nische in North Germany. Unfortunately, all samples indicated an excess of secondary (detrital) Thorium in the shells, thus hindering the calculation of reliable ages.

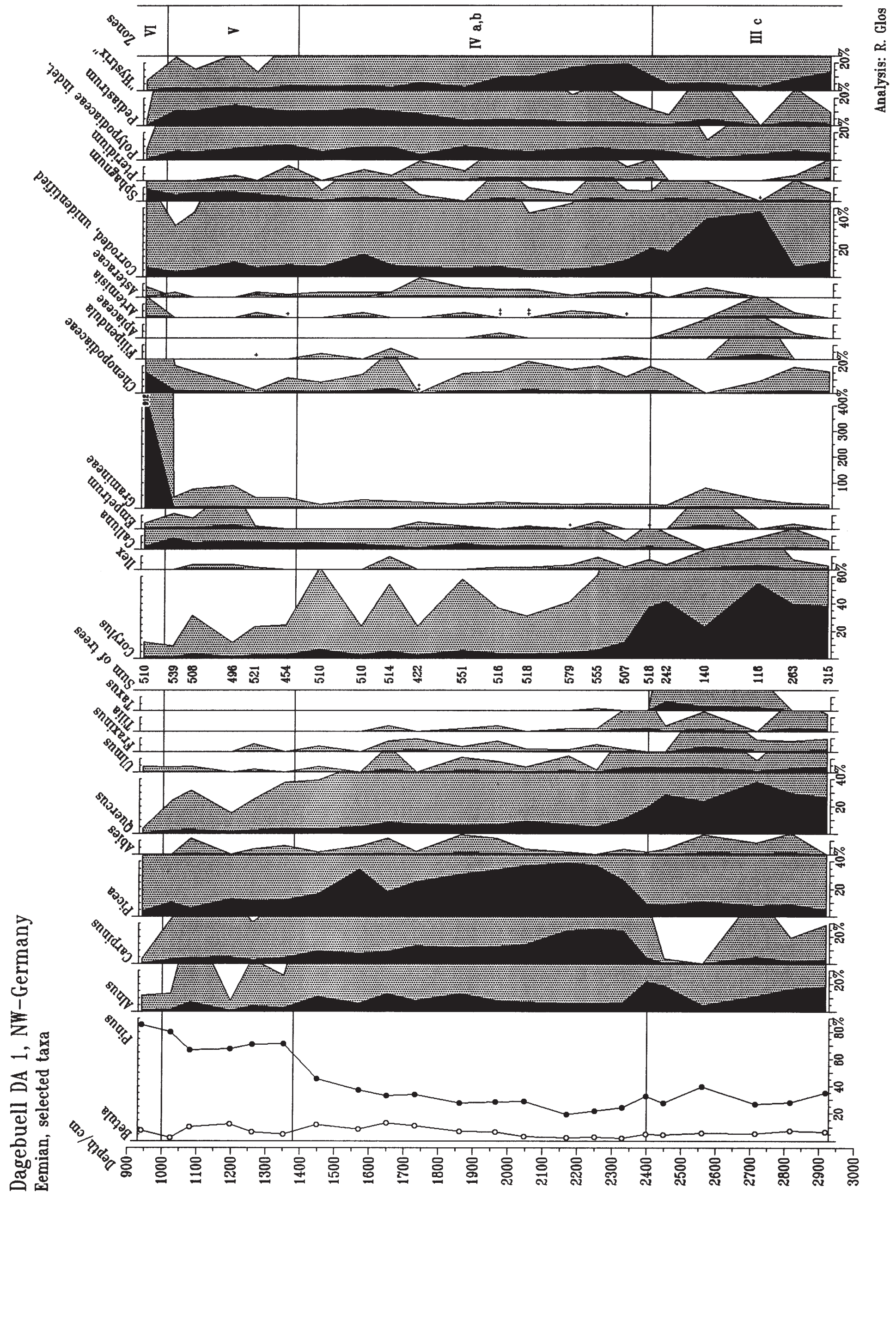

Fig. 6. Pollendiagram of Dagebuell DA 1 (values in percentage of total tree pollen).

Geological and hydrological development of the Eem Sea

Through the combination of absolute dating (Th/U and ESR) with sequential and environmental studies (lithostratigraphical characteristics, micropaleontological and palynological assemblages), the depositional history of the Eemian sediments could be reconstructed for northern Germany. With the retreat of the ice at the termination of the Saale Glaciation, fluviatile to lacustrine sediments were laid down. The consequential global rise of the sea level led to a breakthrough to the Paleo-Baltic Sea through the Nordmann Channel (Temmler 1995). The deposits at Krummland located at the northern flank of this channel indicated that the initial marine incursions resulted in a transitional brackish phase. No absolute datings exist for the duration of this period. The following marine sediments were deposited in rapidly fluctuating warm and cold waters indicating the existence of a strong thermohaline layering of the water column analogous to the situation in the postglacial Belt Sea (Winn *et al.* 1998). Palynological associations showed that around this time, the sea also broke through north of Dagebuell and resulted in the deposition of the nearshore marine Senescens Sand, frequently under anaerobic conditions especially during the initial period. The absolute Th/U-age of 132±1 ka of these sands would mean that the marine influence at Krummland began at about 136 ka, taking into account the “varve” estimate of about 3800 years at Krummland.

During the deposition of the Turritella Clay and the *Abra alba* Beds which took place below the wave base, sea level rise continued. The isotopic record supports a warming of the bottom water mass along with a stronger salinity signal in the upper surface section (Winn & Erlenkeuser 1995). In the lower part of the Olander Sand, both our micropaleontological work and the study of the Ostracod assemblage (Peter Frenzel, pers. comm.) manifests the commencement of the regressive phase of the sea. From the palynological data (Fig. 6), indications of a colder climate became already evident at the base of the Turritella Clay. Comparing the Specmap ages of the marine oxygen isotope curve (Bassinot *et al.* 1994) with the Th/U-and ESR-dates, this event could well be correlated with δ^{18}O-event 5e (5.5.1). The pollen associations in the upper Olander Beds indicate that the cooling had further progressed and sediment and faunal characteristics corroborate the lowering of the sea level in the area (Fig. 7).

A rough estimate of the sea level history of the Eemian can be drawn from the present results on the following reasoning.

1. The Senescens Sand in core DA1 presents an interval of short duration (cf. Th/U-datings in Fig. 5) at an age of 132 ka, ending at 24 m (22.1 m b.s.l.). A water depth of about 0 to 5 m for these near-shore sands deposited in a sheltered inshore water sedimentary environment suggests a sea level around –17 m at 132 ka. Based on pollen chronostratigraphy, Zagwijn (1996) showed a sea level stand of –17 to –11 m for this period.

2. By the pollenanalytical results, the upper boundary at 31 m of the warm marine Eem (35 to 31 m) in core KR1 (10.5 m a.s.l.) is synchronous to 24 m in core DA1 (1.9 m a.s.l.). A water depth of at least 8 m for these silty to muddy sediments, which also were accumulated in a sheltered environment, yields a sea level of –13 m at 132 ka, much higher than the level at Dagebuell. The lower boundary (35 m) of the marine Eem in KR1, being about 3800 "varve"-years older, yields another sea level date of –17 m at about 136 ka. The lower part of the Senescens Sand (28 to 30 m in DA1) which was deposited in a beach ridge system sets the need to have the sea level drop further to –27 m with age (Fig. 7). The higher, though older level indicated in Krummland then had to be attributed to local uplift as a result of ice tectonics. Alternatively, the sea level could have stagnated or even have passed through a high stand as indicated in the deep sea δ^{18}O-record for this time interval (Termination IIa, Sarnthein & Tiedemann 1990).

3. In DA1, the faunal assemblages in the *Abra alba* Beds (Pollen Zone IVb, Fig. 1) manifest a transgressive facies, while in the basal part of the Lower Olander Beds at 18.5 m, the onset of a regression is indicated. This major event may well correlate with the Marine Oxygen Isotope Stage 5e, i.e. event 5.5.1. Sea level is adopted from literature as +6 m, at 122 ka according to the Specmap dating (Bassinot *et al.* 1994). Zagwijn (1996) showed his sea level curve culminating above –9 m in this pollen zone.

4. In the Lower Olander Beds, the peak occurrence of *Ammonia batavus/beccarii* between 16–17 m (Fig. 4) along with a dereasing abundance of *Bucella frigida* has been interpreted as a response of the fauna to a decline in sea level and a corresponding increase of bottom water temperature due to the weakening of the thermohaline layering. Faunistical und sedimentological evidence suggest a water depth of 13–16 m, i.e. 0 to 3 m below present sea level (Fig. 7).

5. With further cooling as evidenced by the pollen associations (Fig. 6), and decreasing warm fauna (Fig. 4), the sea level continued to fall and by the beginning of the Lower Olander Beds at 14 m, the water of the nearshore shallow marine area is assumed to be only a few meters deep.

6. Finally, a tidal flat environment as indicated in the upper interglacial deposits of core DA1 (around 10 m, Pollen Zone V/VI, Figs. 1, 6) along with

Table 2. Key ages and corresponding sea levels.

Age, ka	Sea level (m)	Sources
106	~ –10	Specmap, δ^{18}O-event 5d
~110/ ~111	~ –8	Tidal flat environment, 9–10 m in DA1, interpolated age
~115	~ –6	Nearshore coastal facies, 14 m in DA1, interpolated age
~118/ ~119	~ –1	Shallow marine facies, 16 m in DA1, interpolated age
122	+ 6	Specmap, δ^{18}O-event 5e, onset regression 18.5 m DA1
132±1	–22.1 to –27.1	Th/U-datings, 24 m to 28 m in DA1
132	–13	Pollen zones IVa/IIIc boundary DA1/KR1
136	–17	Palynological correlation DA1/KR1, varve counts

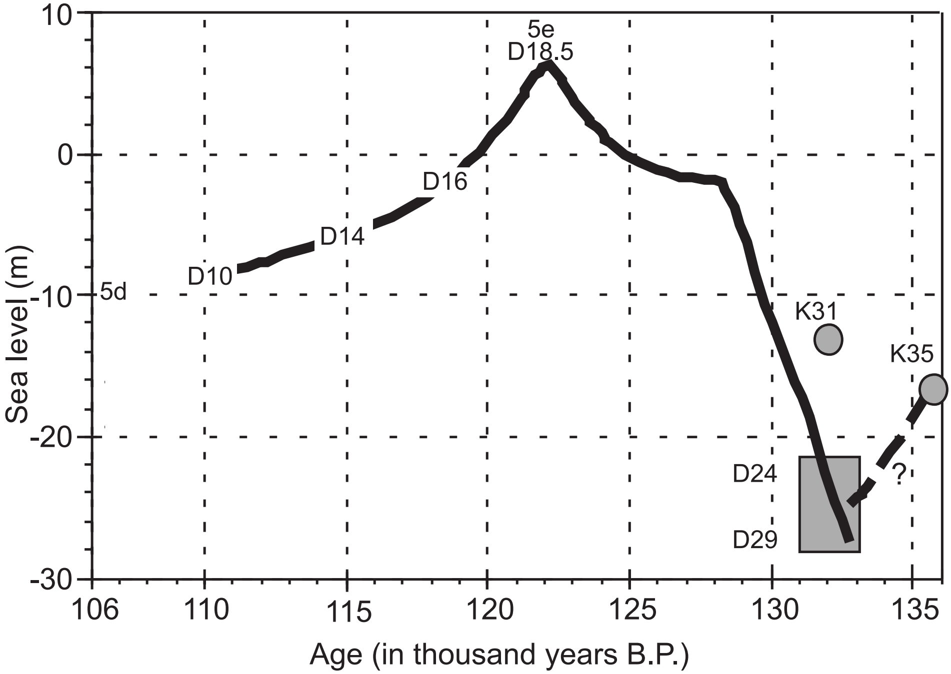

Fig. 7. Sea level curve for the Eemian, after U/Th & ESR-datings, Specmap-ages and sedimentological, paleontological, palynological, and isotopic data. D10 = DA1, 10 m; K31 = KR1, 31 m etc.

evidence of cooler conditions from the pollen assemblage showed that the climate is well on the way to Isotope Stage 5d (event 5.4), Specmap dated at 106 ka. Zagwijn (1996) showed his sea level curve regressing below –10 m in this pollen zone. The data base is summarized in Table 2 and a hand-drawn sea level curve is given in Fig. 7.

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