DGU DANMARKS GEOLOGISKE UNDERSØGELSE · DGU SERIE B · NR. 15
MILJØMINISTERIET · Geological Survey of Denmark · DGU SERIES B · No. 15

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Key-words:
Quaternary, Stratigraphy, Foraminifera, Saalian, Eemian, Weichselian, Holocene.

Vignette:
The island of Anholt with the location of boring no. 51.12.

DGU · Serie B · Nr. 15
ISBN 87-88640-56-6
ISSN 0901-0289
Oplag: 1000
Tryk: AiO Tryk as, Odense
Tegning: Jette Gissel Nielsen
Foto: Ebbe Christensen (text-photos) and Hans Jørgen Hansen (plates)
Dato: 1.9.1990
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Labyrinten 17, DK-8220 Brabrand, Denmark
Redaktion: Leif Banke Rasmussen

I kommission hos: Geografforlaget Aps.
Ekspedition: Fruerhøjvej 43, 5464 Brenderup
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Preface

This paper deals with a 229 m deep boring completed on Anholt in 1943. Substantial parts of the internal reports on the boring drawn up by the Geological Survey of Denmark but never published are sited in this paper. A. Nørvang examined and described the foraminiferal content of selected samples and on the basis of this made a suggestion on the paleoecology of part of the Quaternary penetrated by the boring. The method of sample-preparation used by Nørvang caused an underrepresentation of small-sized Foraminifera. Therefore it was concidered worthwhile to carry out a complementary new investigation of the foraminiferal content of the samples and cores which has been kept in the bore-archives at the Geological Survey of Denmark. The results of this new analysis are presented and on the basis of this, a stratigraphical interpretation of the Quaternary sequence is established. Although this interpretation should be taken with some reservation owing to the relatively poor quality of the samples, the analysis does provide some new aspects to the Quaternary geology in the Vendsyssel-Kattegat region.

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Abstract

Material from a 229 m deep boring on the island of Anholt in the central part of the Kattegat has been stratigraphically analysed on the basis of its foraminiferal content. Due to the lack of casing in the main part of the bore hole, only very few core samples and some samples from the drilling bit were not contaminated. The results of the foraminiferal analyses have, therefore, to be treated with some reservation.

The boring did not penetrate the Quaternary. The bottom 143 m of the boring represents deposits of pre-Eemian, possibly Saalian age. This interval seems to contain three marine interstadials, Anholt 1, 2 and 3, of which the upper interstadial is the warmest. Tills and glaciofluvial sediments are found between the marine sequences. The Eemian is represented by 13 m of marine deposits, which can be correlated with Eemian deposits known from other localities in the Vendsyssel-Kattegat region. They correspond to the Lower *Turritella terebra* Zone of the Skærumhede Series. The Early Weichselian and the lower part of the Middle Weichselian are missing, while the upper part of the Middle Weichselian, 32 m in all, is represented by marine deposits corresponding to foraminiferal zones known from the Vennebjerg Stadial and the Sandnes Interstadial in the Vendsyssel-Kattegat region. These Middle Weichselian zones correspond to the upper part of the *Portlandia arctica* Zone of the Skærumhede Series. The non-marine sequence on top of these deposits is considered to be glacial, belonging to the main Weichselian glacial event. Holocene littoral sands and gravels terminate the Quaternary sequence at Anholt.

Introduction

In 1943 a 229 m deep boring was sunk on the island of Anholt in the Kattegat (figs. 1, 2, 3, 4, 5, 6 and 7) on the initiative of The Ministery of Public Works in Copenhagen. The management of the project was entrusted to the Geological Survey of Denmark.

The boring (Denm. Geol. Surv. file no. 51.12) and its geological results were described in internal reports (Gry et al. 1944; Hansen 1944). Helge Gry gave a general account of the geology of the boring (the discription of the sediments are shown in an appendix at p. 33). Axel Nørvang described the practical work in the field and he presented the results of the foraminiferal analyses. V. Nordmann examined the molluscs and Sigurd Hansen gave an account of the economy.

As the geological results of the Anholt boring have never been published it is summarized below.

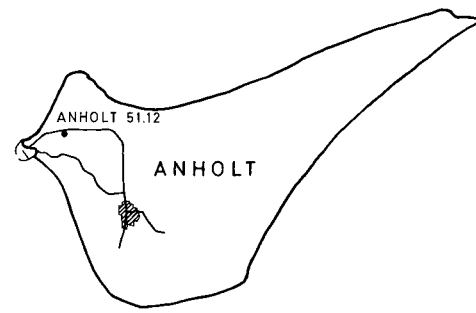

Fig. 2. The location of the Anholt boring no. 51.12. Anholt med placeringen af boring nr. 51.12.

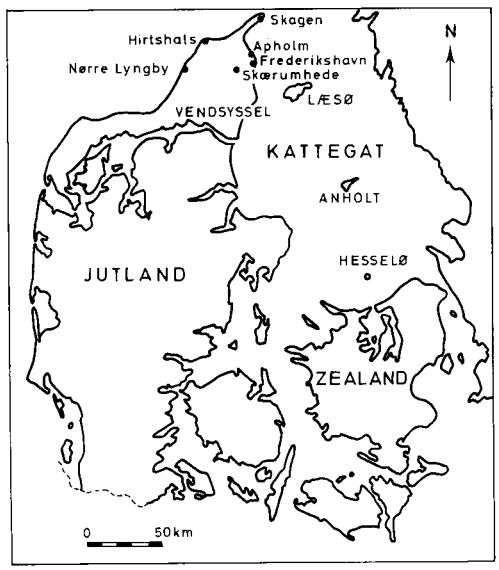

Fig. 1. Locality map. Lokalitetskort.

The purpose of the boring on Anholt was to investigate the potential for coal in the Kattegat region. The background for this was the well-known fact that considerable amounts of coal occasionally can be found washed up on the beaches of e. g. Anholt. It was not known whether this originated from Tertiary (Miocene) or from Rhaetian-Liassic deposits. It was considered a possibility that the Kullen Horst which contains coal bearing deposits of Jurassic age (e. g. Bergström et al. 1982), extended in a northwest direction towards Anholt.

The boring was undertaken by "Produktionsaktieselskabet Undergrunden, Aarhus" using a standard rotary technique. The aim was to obtain undisturbed cores of the whole section. The odds for recovering these cores were, however, soon much reduced because the casing jammed at a depth of 34.48 m. Only ten cores of variable

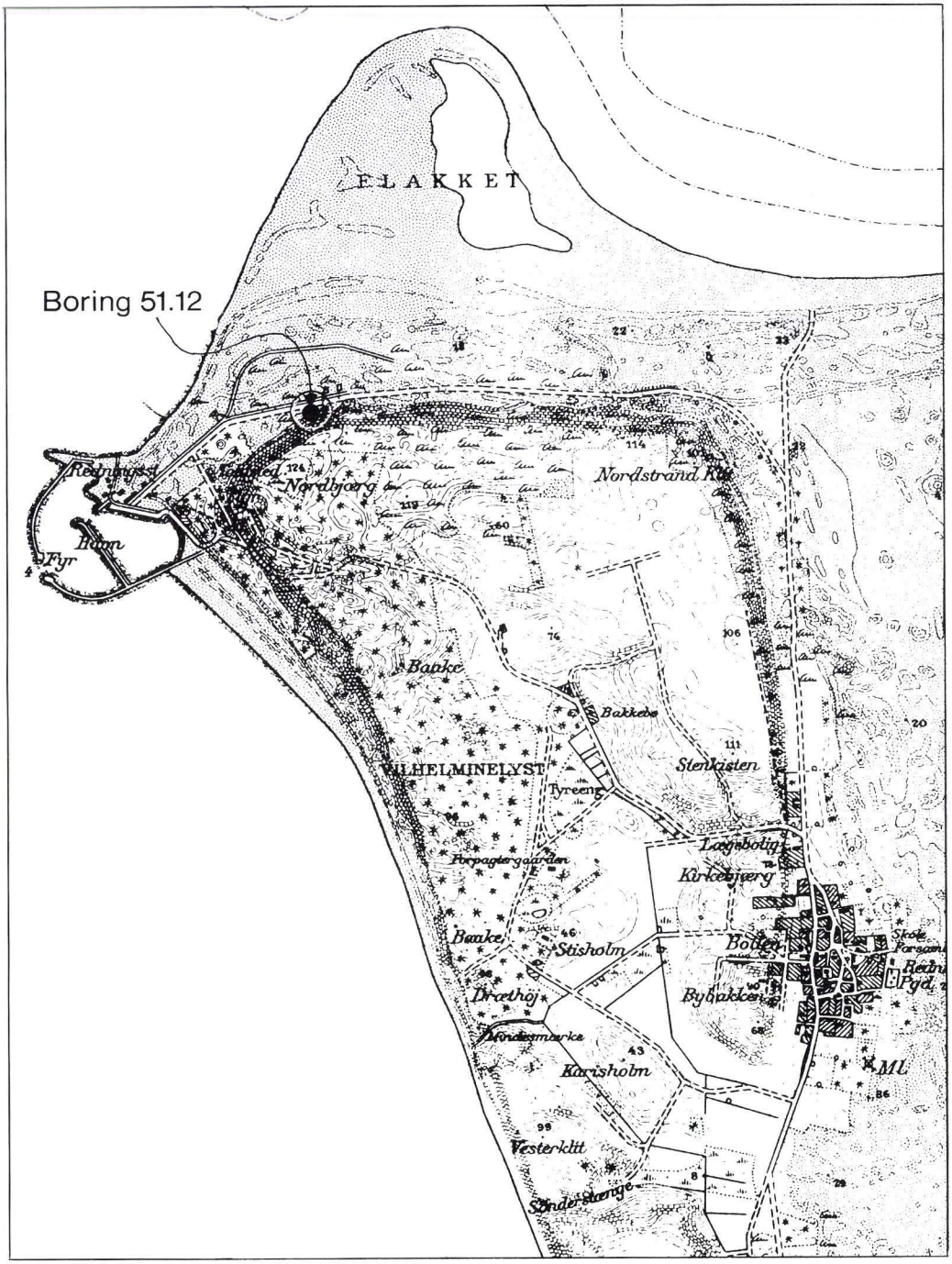

Fig. 3. Topographical map of the northwestern part of Anholt with the location of boring no. 51.12. From map sheet M 1623 (edit. 1935), scale: 1:20 000.
Topografisk kort over den nordvestlige del af Anholt med borestedet. Del af geodætisk Instituts blad M 1623 (udg. 1935) i 1:20 000 (Reproduceret med tilladelse A 83 fra Kort- og Matrikelstyrelsen).

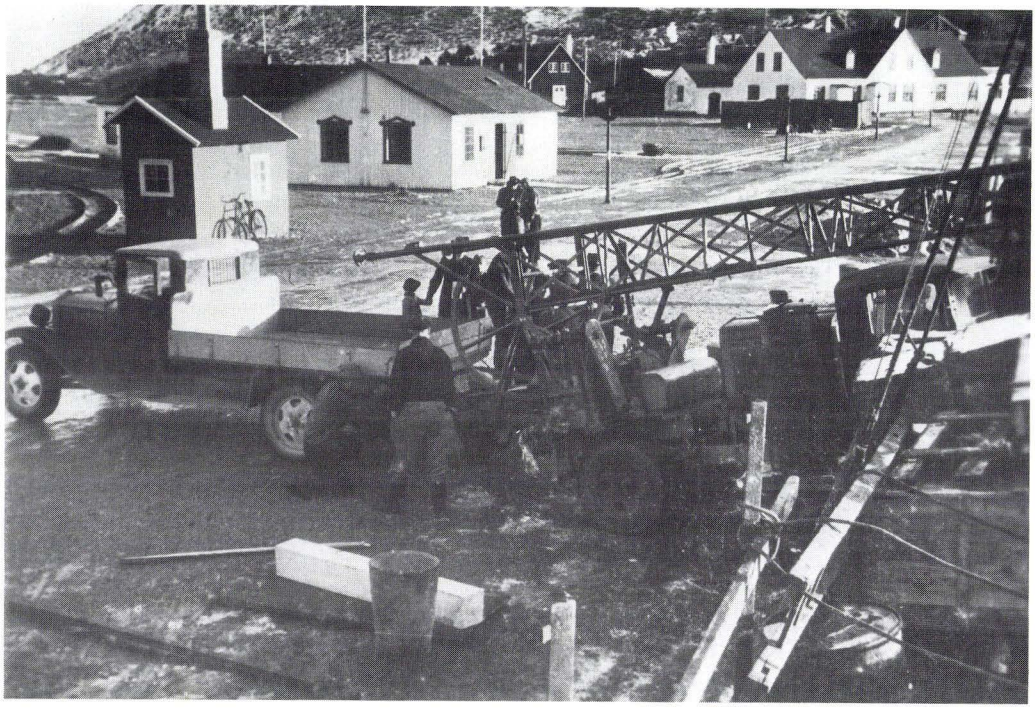

Fig. 4. Unloading of the bore rig in Anholt Harbour. Note the gas generator behind the drivers cabin on the lorry to the right.
Boretårnets ilandsætning i Anholt Havn fra skibet. Bemærk lastbilen med generatorgas-anlæg.

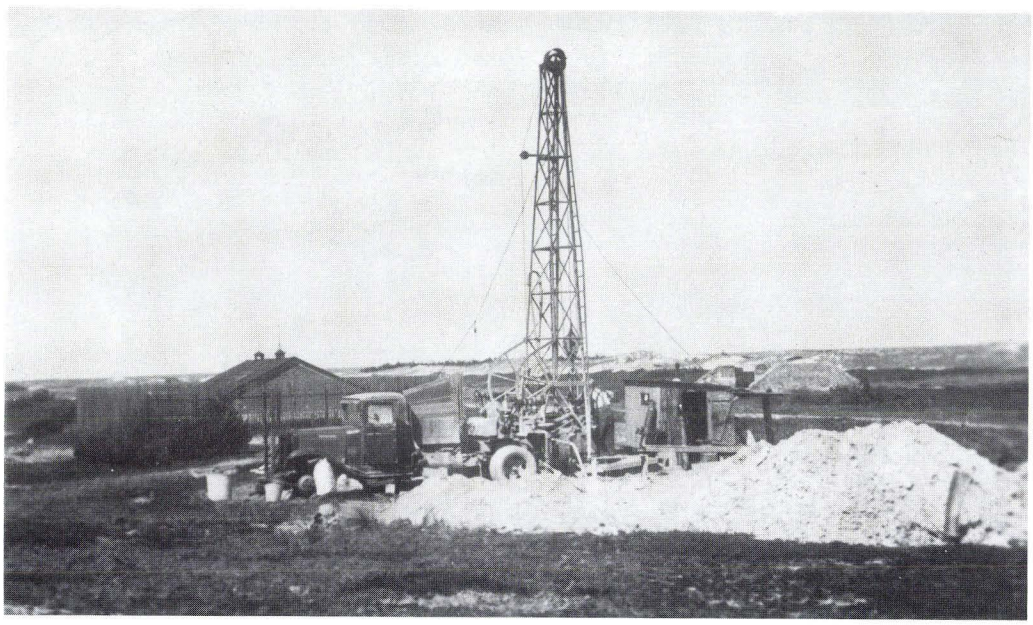

Fig. 5. The assembled rig in action. The northwestern part of Anholt. Flakket can be seen in the background.
Boreriggen opstillet og igang, med udsigt ud over Flakket.

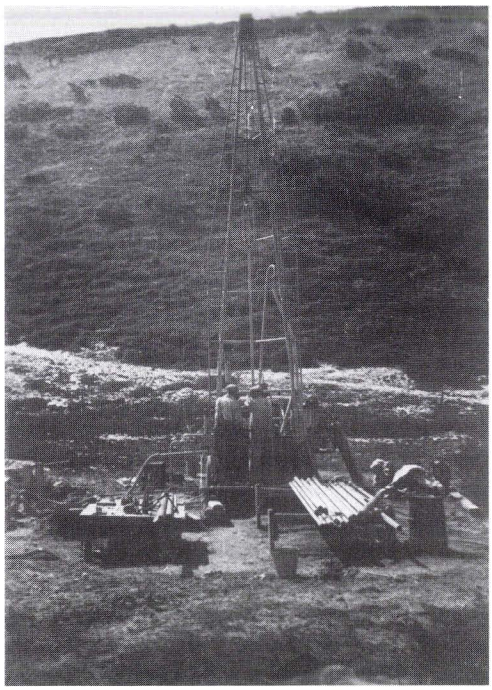

Fig. 6. A view of the bore rig, showing the equipment used. Nordbjerg's northern slope can be seen in the background.
Boretårnet set ind mod Nordbjergs nordskråning. Borerør og remedier ses i forgrunden.

length, normally less than 2 to 3 metres, exist. Of these the upper core was useless owing to the fact that the core sampler here exclusively contained reworked material. Twenty-four samples were also taken from the drilling bit and a total of two hundred and nineteen samples were extracted from the drilling mud at an interval of about 1 m, but due to the very short casing many of these samples may have been contaminated. The bore hole did not reach the base of the Pleistocene. After a series of accidents the drill stem broke at a depth of 228.81 m.

Nordmann examined twenty-two samples from a depth of 62.7 m to bottom. He con-

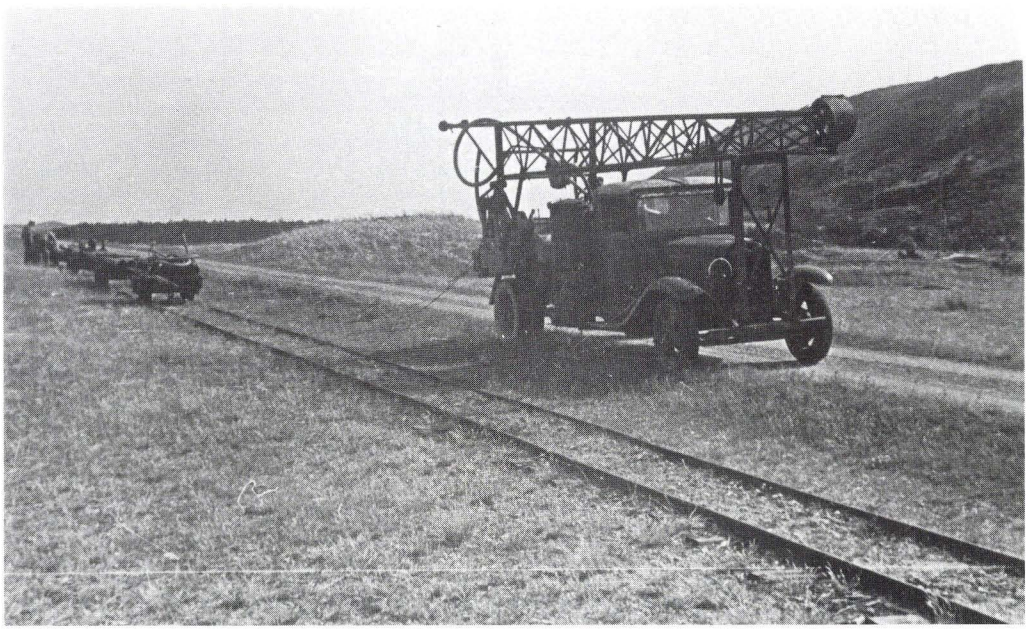

Fig. 7. Transportation of the bore rig from the drilling site to the harbour on the gas-driven lorry. The narrow-gauge railway dates from the time the harbour was built. This was also used to transport bore equipment and the collected material. The slope in the background is Nordbjerg.
Borttransportering af boreriggen på den gamle lastbil med generatorgas-anlæg. Sporanlægget, som stammer fra havnebyggeriets tid, blev også anvendt til transport af remedierne. Nordbjergs skrænter hæver sig i baggrunden.

cluded that the sediments between 62.7 and 70.7 m were marine in origin and suggested that the intervals from 73.7 – 76 m and 103 – 105 m depth may also be marine (fig. 8). Nordmann characterized the molluscs in these intervals as boreal with a southern affinity. He pointed out that the assemblages were not correlatable with any of the known interglacial faunas, neither the lusitanien Eemian fauna known from the southern part of Denmark nor the faunas of the Skærumhede Series, though they did, nevertheless, resemble the faunas of the *Turritella terebra* Zone of the Skærumhede Series (Jessen et al. 1910).

Nørvang analysed the foraminiferal faunas of twenty-eight samples including seventeen from the drilling bit. He subdivided part of the sequence into five foraminiferal fauna zones, viz. series I-V (fig. 8).

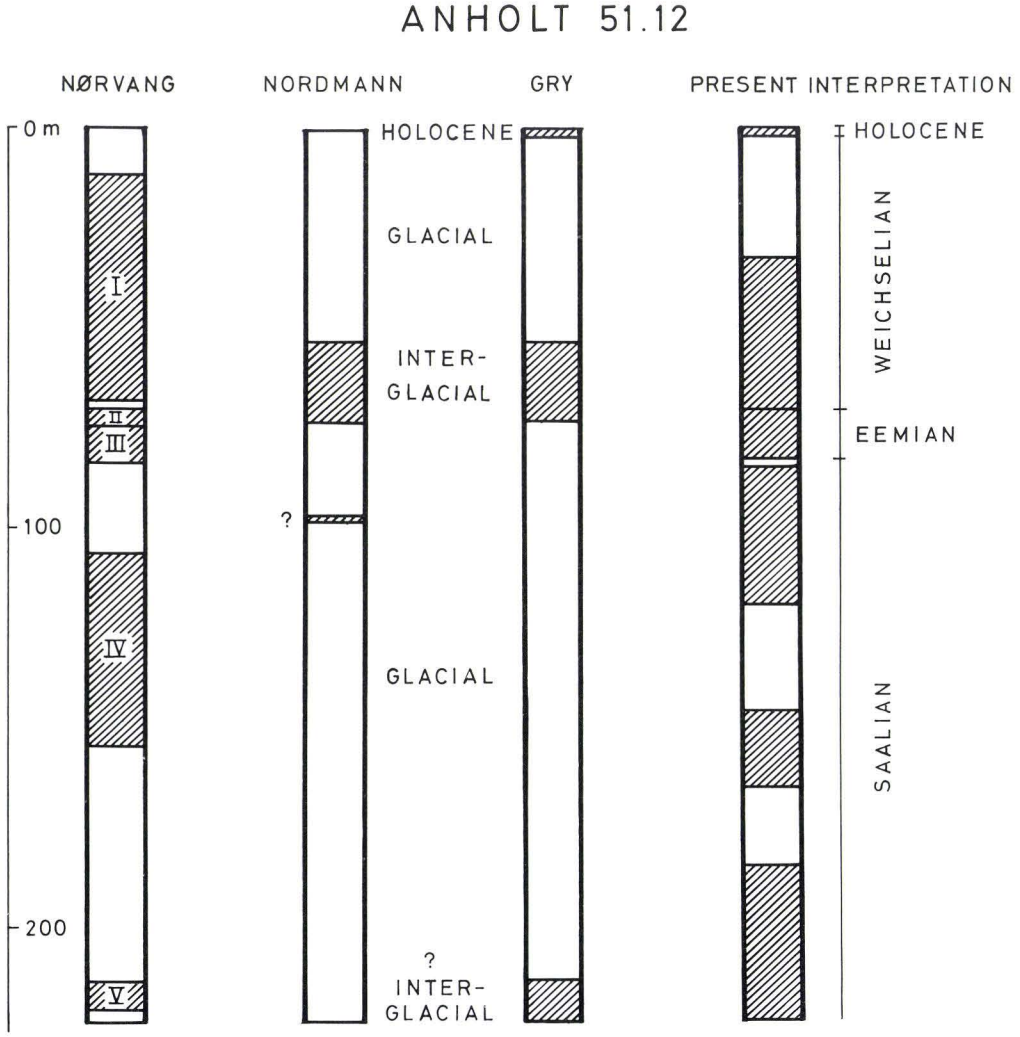

Fig. 8. An outline of the results of the investigations of Anholt boring no. 51.12. Hatching represents marine intervals. Nørvangs series I-V is explained in the text.
Oversigt over resultaterne af undersøgelserne af boring nr. 51.12, Anholt. De skraverede områder repræsenterer marine intervaller. Nørvangs serie I-V er forklaret i teksten.

The series I (13.9–70.7 m) faunas were characterized by species from arctic environments. The faunas were, however, rather sparse and he found it, therefore, difficult to decide whether these deposits were marine or fluvial.

Series II (73.7–79.7 m) consisted of a marine sequence with southern boreal foraminiferal faunas. This series showed a gradual upwards fall in temperature. High density, species-rich assemblages were present in all samples.

Series III (79.7–85.7 m) only included two samples from the drilling mud. Nørvang found faunas which consisted of both boreal and arctic species in these samples. He discussed the origin of this series and concluded that it might be either a local till composed of different marine clays or a marine arctic stony clay with arctic foraminiferal faunas, but contaminated by the overlying boreal faunas. He stressed in any case the presence of arctic Foraminifera under series II deposits.

The samples examined by Nørvang from series IV (109.7–157.7 m) were characterized by their sparsity of Foraminifera. It was not possible to determinate whether the sediments were of marine or fluvial origin.

The foraminiferal faunas of series V (215.8 – 224.7 m) were mainly arctic in character with an element of boreal species. Nørvang called these mixed faunas. He did not comment on the possible origin of this series.

In the geological part of the internal report Gry concluded that the Quaternary deposits of the Anholt boring could be subdivided as follows (see also fig. 8):

0– 3,0 m marine Holocene sand and gravel

3,0– 56.5 m mainly glaciofluvial deposits and tills (maybe with marine arctic clays from 43.7 to 45.2 m)

56.5– 77.2 m marine boreal interglacial (compared with the *Turritella terebra* Zone of the Skærumhede Series)

77.2–228.81 m mainly glaciofluvial deposits and till possibly with interglacial (marine) layers near the bottom

Though the boring did not penetrate the Quaternary deposits it gave valuable information about the pre-Quaternary, namely that Anholt is not situated in a horst region and that the possibility of finding Rhaetian-Liassic coal bearing sediments is thereby excluded.

Gry explained the deep position of the pre-Quaternary surface as either a result of glacial erosion or of tectonic movement along faults. He considered it most likely that the northwest-southeast trending valley known from Skåne as the Alnarp-Valley, which extends across Northeast Sjælland, continues as far as Anholt and that this basin had played a role in the transgression of the Skærumhede Sea.

Mörner (1969) interpreted the stratigraphy of the boring at Anholt in the following way:

A: To 72.7 m an upper drift series = the Upper Pleniglacial (of the Netherlands).

B: To 77.2 m marine clay = part of the *Portlandia arctica* Zone (57.4–74.4 m) of the Skærumhede I boring and the Interpleniglacial of the Netherlands.

C: To 228.8 m a lower drift series = the ice marginal deposits of the Lower Pleniglacial (of the Netherlands).

The "lower drift series" was considered to comprise deposits accumulated in front of the Weichselian "Old Baltic Ice" (about 50, 000 B.P.), which according to Mörner occupied at its maximum the eastern and southern part of Kattegat, extending to a line from Djursland to a point east of Anholt and further north to a point east of the island of Læsø.

"The Anholt Stadial" was proposed as a local name for this ice advance.

The purpose of the present investigation is to establish as detailed a foraminiferal zonation of the Quaternary deposits in the Anholt boring as possible and to place this within the regional chronology for the Kattegat region (Lykke-Andersen 1987). The knowledge obtained could furthermore further our knowledge about basin development in this part of Kattegat.

Material and methods

Most of the samples from the Anholt boring are as mentioned above of rather poor quality. This is primarily due to the lack of casing in the main part of the bore hole, which increases the risk for contamination, particularly in the ditch samples. Secondly, the use of Holocene marine clays as drilling mud in the lowermost part of the bore hole (210–228.81 m) has reduced the value of the samples in this interval. Fortunately, a sample of the drilling mud had been stored, and the degree of contamination caused by its use as a drilling mud could be estimated.

The majority of samples used in this investigation are, therefore, cores and samples from the drilling bit. The ditch samples were also examined, but they have only been used in the intervals where other samples were missing or where they support the other types of samples.

The samples were processed using standard techniques (Feyling-Hanssen et al. 1971; Meldgaard & Knudsen 1979) with one minor alteration. Each sample were washed through sieves with mesh diameters of 63 μ and 1 mm. The use of 63 μ instead of 0.1 mm, as is normally used, was due to the fact that very many small species of Foraminifera was found in some of the samples. The frequency distribution of selected species is illustrated in fig. 9 together with other parameters, including the faunal diversity (Walton 1964) and boreal content (Knudsen 1984).

Zonation, correlation and age

The Anholt boring penetrated a Quaternary sequence which has been subdivided into eleven zones, (A-K: fig. 9). This zonation is very broad due to the poor condition of the samples.

Holocene

Zone A

The uppermost part of the sequence consists of shelly sands and gravels (0–3 m), belonging to the Holocene (Gry et al. 1944). Though these sediments are marine, they only contain a few Foraminifera, possibly due to dissolution. The Foraminifera which have been preserved are often filled with pyrite. These are not included in the diagram (fig. 9). This part of the boring is here called zone A.

Weichselian

Zone B

The sediments of zone B (3–34 m) are composed of different layers of sand, clay and sandy clay occasionally with stones (fig. 9).

Most of the samples from zone B contain Foraminifera. The high pre-Quaternary foraminiferal content indicates, however, that the faunas are presumably redeposited. In addition it is noteworthy that the faunas are the same as these present in the underlying marine zone (zone C).

The units composed of stony and sandy clays are therefore considered to be tills (20.1–21.7 m, 22.3–23.3 m and 25–26.55 m) and the intervening layers as glaciofluvial sediments, all belonging to the Late Weichselian. For the Middle Weichselian-Late Weichselian boundary an age of 25,000 B.P. (Mangerud & Berglund 1978) has been used.

No marine Late Weichselian sediments were identified. This does not mean that marine deposits are lacking, but may be due to the aforementioned problems encountered during boring.

Zone C

Compact clays with stones and shells were found in zone C (34–43 m). *Elphidium excavatum* and *Cassidulina reniforme* account for 34–47% and 15–28% of the foraminiferal faunas, respectively. Other important species include *Bulimina marginata, Elphidium albiumbilicatum* and *Buccella frigida* together with *Nonion labradoricum, N. orbiculare* and *Islandiella norcrossi.* The faunal diversity and the boreal content are both rather high, as is the pre-Quaternary foraminiferal content (fig. 9).

As an example of the foraminiferal assemblage of zone C, the analysis of sample no. 51 is presented below. The count represents about 15% of the sample (100 g):

Species	Frequency	Percentage
Elphidium excavatum	124	34
Cassidulina reniforme	95	26
Bulimina marginata	37	10
Elphidium albiumbilicatum	24	7
Buccella frigida	15	4
Epistominella vitrea	7	2
Pullenia osloensis	6	2
Angulogerina fluens	5	1
Epistominella takayanagii	5	1
Nonion labradoricum	5	1
Cassidulina laevigata	4	1
Nonion orbiculare	4	1
Nonionella iridea	4	1
Buliminella elegantissima	3	1
Bolivina cf. *robusta*	3	1
Nonion depressulum	3	1
Lagena sulcata laevicostata	2	1
Islandiella helenae	2	1
Islandiella norcrossi	2	1
Hyalinea balthica	2	1
Astrononion gallowayi	2	1
Pyrgo williamsoni	1	<0.5
Miliolinella subrotunda	1	<0.5
Fissurina danica	1	<0.5
Fissurina laevigata	1	<0.5
Parafissurina himatiostoma	1	<0.5
Parafissurina lateralis f.*carinata*	1	<0.5
Globobulimina auriculata arctica	1	<0.5
Stainforthia fusiformis	1	<0.5
Uvigerina peregrina	1	<0.5
Cibicides lobatulus	1	<0.5
Elphidium groenlandicum	1	<0.5
Total	365	

The zone C faunas are arctic with a boreal element indicating moderate water depths with a minimum depth of about 20 m. This fauna is referred to foraminiferal assemblage zone I, the *Nonion labradoricum-Islandiella norcrossi* Zone of the Vendsyssel-Kattegat region (Lykke-Andersen 1971, 1987; Konradi & Knudsen 1974; Knudsen 1986), which has been correlated with the Middle Weichselian Sandnes Interstadial in Southwest Norway (Feyling-Hanssen 1971).

Zone D

Zone D (43–72.7 m) is composed of the same stony and shelly, compact clays as zone C down to 67 m depth and thereafter of sand with shell-fragments. The faunas of this zone contain very few boreal specimens (fig. 9). *Elphidium excavatum* (43–66%) and *Cassidulina reniforme* (25–39%) dominate the faunas even more than in zone C. The faunal diversity is consequently lower, as is the number of species. The most important accessory species are *Elphidium asklundi, Nonion orbiculare, Buccella frigida, Islandiella norcrossi* and *Nonion labradoricum.*

Sample no. 67c (100 g) of which about 18% was counted, contains an assemblage as shown below:

Species	Frequency	Percentage
Elphidium excavatum	303	60
Cassidulina reniforme	170	34
Islandiella norcrossi	8	2
Elphidium asklundi	6	1
Nonion labradoricum	5	1
Stainforthia loeblichi	4	1
Nonion orbiculare	4	1
Pyrgo williamsoni	1	<0.5
Guttulina lactea	1	<0.5
Parafissurina sp.	1	<0.5
Buccella frigida	1	<0.5
Buccella tenerrima	1	<0.5
Astrononion gallowayi	1	<0.5
Elphidium albiumbilicatum	1	<0.5
Total	507	

The assemblages of zone D are arctic from rather shallow water environments. These faunas are identical with those found in foraminiferal assemblage zone II, the *Elphidium asklundi-Nonion orbiculare* Zone of the Vendsyssel-Kattegat region (Lykke-Andersen 1971, 1987; Konradi & Knudsen 1974; Knudsen 1986). This zone has been placed in the Middle Weichselian Vennebjerg Stadial (Lykke-Andersen & Knudsen 1990).

Radiocarbon dates from the corresponding zone at Hirtshals have yielded ages of at least 34,000 B.P. (Lykke-Andersen 1982). New radiocarbon dates using the accelerator mass spectrometry facility at Aarhus University (molluscs and Foraminifera) gave ages of 31,500 ±2100 and 32,700 ±2400 B. P. (Thomsen 1990).

The present study shows that the deposits between 3 and 72.7 m depth belong to the Late and Middle Weichselian (fig 9). The Middle Weichselian marine sequence can also be correlated with part of the *Portlandia arctica* Zone of the Skærumhede I boring (Jessen et al. 1910).

Series I of Nørvang (Gry et al. 1944) includes the greatest part of zones B, C and D. Nørvang found it difficult to decide whether this sequence was marine or fluvial (see above).

Nordmann examined three samples from zone D and found that they were all marine due to their content of very well preserved mollusc fragments. Actually this was the only sequence Nordmann with certainty identified as marine (see above).

Gry concluded that only the lowermost part of zone D was definitely of marine origin, though he did not reject the possibility that the upper part of zone D was also marine. He, unfortunately, combined this part of the boring with the subjacent interglacial sequence (zone E of this investigation).

Eemian

Zone E

An abrupt change in both sediment type and faunal composition occur at 72.7 m (fig. 9). Zone E (72.7–83.7 m) consists of about five metres of sticky, shell-rich clays underlain by alternating layers of shelly sand and clay. Boreal and boreal-lusitanian deeper water Foraminifera are important faunal elements in this zone. *Bulimina marginata* dominates, accounting for 30 to 73% of the faunas. Other frequent species are *Hyalinea balthica, Cassidulina laevigata, Pullenia osloensis* and *Elphidium excavatum. Epistominella vitrea* is also important. Boreal-lusitanian species such as *Planulina ariminensis, Textularia sagittula, Bolivina subspinescens, Globobulimina turgida, Nonion barleeanum, Angulogerina angulosa* and the lusitanian *Quinqueloculina padana* are characteristic elements of the fauna. The number of specimens is very high, as is the number of species, the faunal diversity and the boreal content.

The assemblage of sample no. 112d is shown below. The foraminiferal content of about 2% of the sample (100 g) was counted:

Species	Frequency	Percentage
Bulimina marginata	724	65
Hyalinea balthica	110	10
Elphidium excavatum	79	7
Epistominella vitrea	38	3
Cassidulina laevigata	34	3
Stainforthia fusiformis	28	3
Pullenia osloensis	23	2
Nonionella iridea	11	1
Fissurina danica	9	1
Textularia sagittula	5	<0.5
Amphicoryna scalaris	5	<0.5
Bolivina subspinescens	5	<0.5
Quinqueloculina seminulum	4	<0.5
Cassidulina reniforme	3	<0.5
Nonionella turgida	3	<0.5
Lagena striata	2	<0.5
Uvigerina peregrina	2	<0.5
Cibicides lobatulus	2	<0.5
Nonion barleeanum	2	<0.5
Ammonia batava	2	<0.5
Spiroloculina rotunda	1	<0.5
Pyrgo williamsoni	1	<0.5
Sigmoilopsis schlumbergeri	1	<0.5
Dentalina sp.	1	<0.5
Lenticulina sp.	1	<0.5
Lagena distoma	1	<0.5
Lagena sulcata laevicostata	1	<0.5
Fissurina lucida	1	<0.5
Parafissurina later. f. *carin.*	1	<0.5
Stainforthia loeblichi	1	<0.5
Angulogerina angulosa	1	<0.5
Bolivina cf. *robusta*	1	<0.5
Buccella frigida	1	<0.5
Anomalina globulosa	1	<0.5

Species	Frequency	Percentage
Planulina ariminensis	1	<0.5
Nonion depressulum	1	<0.5
Elphidium macellum	1	<0.5
Elphidium williamsoni	1	<0.5
Total	1109	

This fauna indicates climatic conditions at least as warm as today and water depths of about 50 to 100 m. The very high number of specimens indicates low sedimentation rates during the warmest period in the Eemian. The faunas in the uppermost part of the zone suggest shallower conditions and perhaps also a drop in temperature. The lowermost part of the section, from which only ditch samples were available, include species from colder and shallower waters.

The majority of the faunas in zone E are identical to faunas known from the Lower *Turritella terebra* Zone of the Skærumhede Series. In the Vendsyssel-Kattegat region this foraminiferal assemblage zone is called zone X, the *Bulimina marginata-Quinqueloculina padana* Zone (Lykke-Andersen 1987), and has been placed in the Eemian Interglacial (Feyling-Hanssen et al. 1971; Knudsen & Lykke-Andersen 1982; Knudsen 1984, 1985; Lykke-Andersen 1987; Lykke-Andersen & Knudsen 1990).

Amino acid measurements on *Bulimina marginata* from sample no. 112d gave an aIle/Ile ratio of 0.083 (BAL 443). This corresponds to values known from the Eemian in the North Sea region (Knudsen & Sejrup 1988), and thus complements the conclusions based on the foraminiferal faunas.

Nørvang (Gry et al. 1944) called this section of the Anholt boring series II and III (see above). He considered both series to be marine. He interpreted the faunas of series II as southern boreal. Species preferring colder climates were only present at the top of this series. He characterized the foraminiferal faunas of series III as a mixed fauna, and he pointed out the presence of an arctic faunal element in layers older than the boreal faunas of series II.

Nordmann examined two samples from this section and concluded that one of them could be marine (see above).

Gry concluded that this part of the boring represented a marine boreal interglacial. These interglacial deposits (56.5–77.2 m) were correlated with the *Turritella terebra* Zone of the Skærumhede Series (Jessen et al. 1910) but they were not referred to any known interglacial period (fig. 8).

Mörner (1969) referred this interval to part of the *Portlandia arctica* Zone (57.4–74.4 m) of the Skærumhede Series (Jessen et al. 1910), which belongs to the Middle Weichselian Sandnes Interstadial and Vennebjerg Stadial (Lykke-Andersen & Knudsen 1990).

Pre-Eemian

Zone F

The interval between 85.7 and 87.9 m, zone F, comprises stony sands with considerable amounts of bryozoans. The character of the sediment, together with the fact that core samples from this unit contain thousands of pre-Quaternary Foraminifera and only a few Quaternary specimens per 100 g, suggests that it might be a till or a glaciofluvial deposit (fig. 9). This very characteristic zone must belong to a glacial period older than the Eemian, in all probability the Saalian (sensu lato).

It is noteworthy that the Skærumhede I boring also includes a section rich in bryozoans below the Eemian sequence, namely the uppermost part of the "lower glacial beds" (Jessen et al. 1910; Knudsen & Lykke-Andersen 1982).

Nørvang did not study samples from this zone and Nordmann only looked at one sample, which he did not comment on (Gry et al. 1944).

Zone G

Zone G (87.9–125 m) is composed of thin alternating layers of sand and clay with some shell-fragments. A 2.5 m thick sand unit occurs between 98 and 100.5 m depth (fig. 9). No core samples were obtained from these sediments. Only five samples from the drilling bit were available in addition to the ditch samples.

All samples from zone G contain between 500 and 1000 Quaternary Foraminifera per 100 g sediment. *Elphidium excavatum* and *Bulimina marginata* dominate. Other important species are *Cassidulina reniforme, C. laevigata* and *Hyalinea balthica. Buccella frigida, Nonion orbiculare, N. labradoricum, Islandiella helenae* and *I. norcrossi* are characteristic accessory species. The frequency of boreal forms, including *Bulimina marginata,* is very high in the ditch samples, while the arctic forms play a greater role in the samples from the drilling bit. This is in all probability a function of contamination from above, especially in the case of the ditch samples. Consequently only the samples taken from the drilling bit have been used in interpretating the faunas.

The foramiferal analysis of sample no. 171 (13 g) is shown as an example of the zone G faunas.

Species	Frequency	Percentage
Bulimina marginata	66	44
Elphidium excavatum	33	22
Cassidulina laevigata	9	6
Cassidulina reniforme	9	6
Hyalinea balthica	9	6
Epistominella vitrea	5	5
Textularia sagittula	2	1
Angulogerina angulosa	2	1
Buccella frigida	2	1
Nonion labradoricum	2	1
Pyrgo williamsoni	1	1
Stainforthia loeblichi	1	1
Angulogerina fluens	1	1
Islandiella helenae	1	1
Islandiella norcrossi	1	1
Nonion barleeanum	1	1
Nonion orbiculare	1	1
Nonionella iridea	1	1
Pullenia osloensis	1	1
Elphidium albiumbilicatum	1	1
Elphidium bartletti	1	1
Ammonia batava	1	1
Total	151	

The apparent foraminiferal content of these samples indicates that the sediments are marine. The faunas belong to boreal to boreal-arctic palaeoenvironments with moderate water depths.

Zone G may correspond to an interstadial period. It is here called Anholt 1 and is referred to the Saalian Glaciation. There is, however, no evidence of an age other than its location in the sequence in the boring. If zone G was not separated from the Eemian zone E by glacial deposits (zone F), it could as well belong to an early part of the Eemian Interglacial. It should be pointed out that the foraminiferal faunas of Anholt 1 also resemble faunas from the so-called Rügen Interglacial, which has been referred to the upper part of the Saalian Glacial period (Wiegank 1972). This interglacial is, however, controversial and perhaps identic with the Eemian Interglacial.

Zone G corresponds to part of series IV of Nørvang (Gry et al. 1944). Nørvang could not make out whether this zone was marine or fluvial.

Nordmann concluded from the presence of mollusc fragments that one of the nine examined samples from this interval might be marine.

Zone H

The sediments contain only very few Foraminifera between 125 and 151 m. This sequence is called zone H and it includes coarse grained quartz-sand with some stones, shell-fragments and pieces of coal.

In the lowermost part of the zone there are two intervals with sandy clay. Only ditch samples were available from this zone (fig. 9).

Elphidium excavatum, Bulimina marginata and *Hyalinea balthica* dominate these very sparse faunas. All the species found are also present in the overlying zone. Therefore it cannot be excluded that the Foraminifera in zone H were washed down during drilling.

On account of this, zone H is considered to include glacial deposits. The composition of the sediments suggests that these have been derived from erosion of the Jurassic sediments which are exposed in the region south-east of Anholt (Liboriussen et al. 1987). The zone may represent a stadial in the Saalian Glacial period.

Nørvang also included this part of the boring in his series IV (Gry et al. 1944).

Nordmann examined three samples from this zone, but he did not comment on the mollusc fragments found.

Species	Frequency	Percentage
Elphidium excavatum	141	46
Cassidulina reniforme	46	15
Bulimina marginata	25	8
Buccella frigida	15	5
Nonion labradoricum	14	5
Hyalinea balthica	11	4
Elphidium albiumbilicatum	11	4
Nonion orbiculare	9	3
Cassidulina laevigata	7	2
Islandiella norcrossi	5	2
Angulogerina fluens	4	1
Islandiella helenae	2	1
Nonion depressulum	2	1
Astrononion gallowayi	2	1
Elphidium bartletti	2	1
Textularia sagittula	1	<0.5
Quinqueloculina seminulum	1	<0.5
Buliminella elegantissima	1	<0.5
Stainforthia loeblichi	1	<0.5
Angulogerina angulosa	1	<0.5
Nonion niveum	1	<0.5
Elphidium groenlandicum	1	<0.5
Elphidium hallandense	1	<0.5
Ammonia batava	1	<0.5
Total	305	

Zone I

Zone I (151–170.7 m) consists of stony and clayey, coarse to medium sands with shell-fragments and small pieces of coal.

Foraminifera are present in rather large numbers in most of the samples. Only one sample was taken from the drilling bit and it contained more than 2000 specimens in 100 g sediment.

Elphidium excavatum dominates the faunas and *Cassidulina reniforme* is also important. In addition *Bulimina marginata, Buccella frigida, Nonion labradoricum, Elphidium albiumbilicatum, Hyalinea balthica, Nonion orbiculare* and *Cassidulina laevigata* are all common (fig. 9).

The faunal composition of sample no. 192 (15 g) is shown as an example.

There would appear an overrepresentation of *Bulimina marginata* and other boreal taxa in the ditch samples, possibly due to down-core contamination.

The foraminiferal fauna in the sample from the drilling bit indicates marine subarctic shallow water conditions with water depths of 20 to 50 m.

Zone I is referred to an interstadial period called Anholt 2 and it is placed in the Saalian Glacial period.

This zone was included in series IV by Nørvang (Gry et al. 1944).

Nordmann studied the molluscs in one sample from this zone, but he did not report what he found.

Zone J

Only very few Foraminifera are present in the interval between 170.7 and 192.25 m (fig. 9). The sediments here consist of compact stony clays with comminuted shell material and coal underlain by thin layers of sand, clay and sandy clay with stones.

The core samples from zone J did not contain any Foraminifera. *Bulimina marginata, Elphidium excavatum, Hyalinea balthica* and *Cassidulina laevigata* are the most common taxa in the ditch samples. All the species found also occur in the overlying layers, an indication of possible contamination during drilling. Due to the type of sediment and the sparsity of Foraminifera, this zone is regarded as a glacial till. It is not possible to date this glacial event, but on the basis of its location in the boring it is referred to a Saalian Stadial period (fig. 9).

Nørvang examined one sample from this interval but found no Foraminifera.

Zone K

The lowermost part of the boring (192.25–228.81 m) contains several sedimental facies. Stony, medium to coarse grained sands with shells occur in the upper 14 m. These sands are underlain by stony clays with two thin layers of sand. Near the bottom layers of sticky clay, sand, stony sand with shell-fragments and stony clays occur (fig. 9).

Core samples, samples extracted from the drilling bit and ditch samples are all available from this section of the boring and they all contain Foraminifera.

Elphidium excavatum dominates the faunas together with *Cassidulina reniforme* and *Bulimina marginata. Nonion labradoricum, N. orbiculare, Buccella frigida, Elphidium albiumbilicatum, Cassidulina laevigata, Hyalinea balthica, Epistominella vitrea* and *Islandiella helenae* are also common. As already mentioned there is a clear difference between the faunal composition of the different types of samples, as the content of *Bulimina marginata* and other boreal forms is overrepresented in the ditch samples. Therefore the interpretation of the foraminiferal assemblages is also here based only on the core samples and the samples from the drilling bit.

An example of the assemblage of zone K (sample no. 251b) is presented below; the foraminiferal content of half of the sample (100 g) was counted:

Species	Frequency	Percentage
Elphidium excavatum	123	39
Bulimina marginata	47	15
Cassidulina reniforme	41	13
Buccella frigida	14	5
Cassidulina laevigata	13	4
Nonion orbiculare	13	4
Hyalinea balthica	10	3
Elphidium albiumbilicatum	9	3
Nonion labradoricum	7	2
Elphidium bartletti	6	2
Epistominella vitrea	4	1
Fissurina danica	3	1
Stainforthia schreibersiana	3	1
Islandiella helenae	2	1
Islandiella islandica	2	1
Planulina ariminensis	2	1
Nonionella iridea	2	1
Ammonia batava	2	1
Dentalina sp.	1	<0.5
Lagena striata	1	<0.5
Guttulina austriaca	1	<0.5
Fissurina laevigata	1	<0.5
Stainforthia loeblichi	1	<0.5
Uvigerina peregrina	1	<0.5
Angulogerina fluens	1	<0.5
Islandiella norcrossi	1	<0.5
Cibicides lobatulus	1	<0.5
Elphidium asklundi	1	<0.5
Elphidium macellum	1	<0.5
Total	314	

The foraminiferal faunas of zone K indicate a marine boreal-arctic to arctic environment with moderate water depths, suggesting an interstadial period. This interstadial is here called Anholt 3, and it is placed in the Saalian Glaciation due to the lack of contrary evidence for placing it in an older glacial period.

The Hesselø boring (Geol. Surv. file no. 180.1) in the southern part of Kattegat contains 47 m of Quaternary deposits. Here the lowermost sample, which was extracted from stony clays containing shell-fragments, contains a foraminiferal assemblage which can be correlated with zone K on Anholt.

The Saalian zone 8c, the lower part of the *Epistominella vitrea-Nonion labradoricum* Zone, at the base of the Nørre Lyngby boring in Vendsyssel also contains this fauna (Lykke-Andersen 1987).

The whole sequence in the Anholt boring from 85.7 to 228.81 m has consequently been placed in the Saalian (sensu lato).

Nørvang looked at the foraminiferal faunas in part of zone K and found a mixed fauna, with the main emphasis being placed on arctic species. He called this part of the boring series V (fig. 8).

The molluscs from the same interval were not described.

Gry concluded that the main part of the sequence from 77.2 to 228.81 m consisted of glaciofluvial and till deposits but with possible interglacial layers near the bottom corresponding to series V of Nørvang (see above).

Conclusions

The 228.81 m deep boring at Anholt contains a Quaternary sequence representing in all probability the timespan from the Saalian to the Holocene. The main part of the deposits, from 228.81 to 85.7 m, are pre-Eemian, and they seem to belong to the Saalian (sensu lato). The very crude stratigraphic classification presented here, which is a function of the relatively bad condition of the samples, indicates the existence of at least three marine periods during the Saalian, interrupted by glacial periods (fig. 9). These are called Anholt 1, 2 and 3 and are interpreted as representing interstadials due to the composition of their foraminiferal faunas. Temperature and water depth seem to have been at a maximum during Anholt 1.

The non-marine interval between Anholt 3 and 2 contains an about 20 m thick clayey till with some glaciofluvial layers near the bottom. About 30 m of glaciofluvial sand with some clay occur between Anholt 2 and 1, and 2 metres of sandy till or glaciofluvial sandy gravel rich in bryozoans are found on top of Anholt 1.

Eemian Interglacial deposits occur between 85.7 and 72.7 m (fig. 9). The foraminiferal assemblages indicate increasing temperatures and water depths upwards, both decreasing again near the top of the interval.

The sequence from 72.7 to 3.0 m is referred to the Weichselian (fig. 9). The Early Weichselian and the lower part of Middle Weichselian are not present. The foraminiferal faunas found in these sediments indicate a marine arctic shallow water environment and they correspond to faunas belonging to the Middle Weichselian Vennebjerg Stadial (Lykke-Andersen & Knudsen 1990). These are succeeded by another marine unit containing an arctic fauna with a boreal element which can be correlated with faunas from the Middle Weichselian Sandnes Interstadial (Feyling-Hanssen et al. 1971). The Middle Weichselian marine deposits are covered by sediments which are presumed to be of glacial origin. These seem to include three tills and some glaciofluvial sediments, and they are referred to the Late Weichselian. No marine Late Weichselian layers have been recognized.

Holocene marine shallow water deposits form the top 3 m of the Quaternary sequence (fig. 9).

The Quaternary sequence present in the Anholt boring is comparable with sequences found in a number of borings in the Vendsyssel-Kattegat region (Jessen et al. 1910; Bahnson et al. 1974; Knudsen & Lykke-Andersen 1982; Knudsen 1984, 1985, 1986; Lykke-Andersen 1987; Lykke-Andersen & Knudsen 1990). The sequence in Anholt differs from most of the borings in the region primarily because of its thick pre-Eemian and thin Eemian interval. Another difference is the greater number of tills and glaciofluvial sediments in the Anholt boring. The thickness of the pre-Eemian deposits suggest a basin located in the southern part of the region prior to the Eemian Interglacial. The Eemian and the Weichselian deposits thicken to the northeast indicating that the depocentre has moved to the north during these periods. Comparable thick Saalian sequences are known in the buried valleys of Germany (e. g. Ehlers et al. 1984) and in the British sector of the North Sea (Cameron et al 1987).

Foraminiferal list

The species shown in the range chart (fig. 9) and mentioned in the text are arranged alphabetically in the following list. A total of at least 80 species were found, 17 of which are illustrated in Plates 1 and 2.

Ammonia batava (Hofker 1951)
Amphicoryna scalaris (Batsch 1791)
Angulogerina angulosa (Williamson 1858)
Angulogerina fluens Todd 1947
Anomalina globulosa Chapman & Parr 1937
Astrononion gallowayi Loeblich & Tappan 1953
Bolivina subspinescens Cushman 1922
Bolivina cf. *robusta* Brady
Buccella frigida (Cushman 1922)
Buccella tenerrima (Bandy 1950)
Bulimina marginata d 'Orbigny 1826
Buliminella elegantissima (d 'Orbigny 1839)
Cassidulina laevigata d 'Orbigny 1826
Cassidulina reniforme Nørvang 1945
Cibicides lobatulus (Walker & Jacob 1798)
Elphidium albiumbilicatum (Weiss 1954)
Elphidium asklundi Brotzen 1943
Elphidium bartletti Cushman 1933
Elphidium excavatum (Terquem 1876)
Elphidium groenlandicum Cushman 1933
Elphidium hallandense Brotzen 1943
Elphidium macellum (Fichtel & Moll 1798)
Elphidium williamsoni Haynes 1973
Epistominella takayanagii Iwasa 1955
Epistominella vitrea Parker 1953
Fissurina danica (Madsen 1895)
Fissurina laevigata Reuss 1850
Globobulimina auriculata arctica Höglund 1947
Globobulimina turgida (Bailey 1851)
Guttulina austriaca d 'Orbigny 1846
Guttulina lactea (Walker & Jacob 1798)
Hyalinea balthica (Schroeter 1783)
Islandiella helenae Feyling-Hanssen & Buzas 1976
Islandiella islandica (Nørvang 1945)
Islandiella norcrossi (Cushman 1933)
Lagena distoma Parker & Jones 1864
Lagena striata (d 'Orbigny 1839)
Lagena sulcata laevicostata Cushman & Gray 1946
Miliolinella subrotunda (Montagu 1784)
Nonion barleeanum (Williamson 1858)
Nonion depressulum (Walker & Jacob 1798)
Nonion labradoricum (Dawson 1960)
Nonion niveum Lafrenz 1963
Nonion orbiculare (Brady 1881)
Nonionella iridea Heron-Allen & Earland 1932
Nonionella turgida (Williamson 1858)
Parafissurina himatiostoma Loeblich & Tappan 1953
Parafissurina lateralis (Cushman), forma *carinata* (Buchner 1940)
Planulina ariminensis d 'Orbigny 1826
Pullenia osloensis Feyling-Hanssen 1954
Pyrgo williamsoni (Silvestri 1858)
Quinqueloculina padana Perconig 1954
Quinqueloculina seminulum (Linné 1758)
Sigmoilopsis schlumbergeri (Silvestri 1904)
Spiroloculina rotunda d'Orbigny 1826
Stainforthia fusiformis (Williamson 1858)
Stainforthia loeblichi (Feyling-Hanssen 1954)
Stainforthia schreibersiana (Czjzek 1848)
Textularia sagittula Defrance 1824
Uvigerina peregrina Cushman 1923

Acknowledgements

I am grateful to the Geological Survey of Denmark for placing material from the Anholt boring no. 51.12 at my disposal. In that connection I owe special thanks to Niels V. Jessen for unremitting help and interest in my work. My sincere thanks to Karen Luise Knudsen and Holger Lykke-Andersen for valuable discussions about the stratigraphy and to David N. Penney for improving the English text. I would also like to thank Jette Gissel Nielsen for making the drawings and Hans Jørgen Hansen for preparing the scanning electron micrographs.

Dansk sammendrag

Foraminifer-stratigrafisk inddeling af kvartære aflejringer i boring nr. 51.12, Anholt

En 229 meter dyb boring (D.G.U. nr. 51.12) blev udført på Anholt i 1943 (fig. 1, 2, 3, 4, 5, 6 og 7). Borearbejdet blev udført af "Produktionsaktieselskabet Undergrunden, Aarhus". For Danmarks Geologiske Undersøgelse varetog Helge Gry den geologiske ledelse af boringen, og Axel Nørvang var geologisk tilsynsførende på borestedet. Boringen og dens geologiske resultater er beskrevet i Danmarks Geologiske Undersøgelses interne rapporter (Gry et al. 1944; Hansen 1944). Gry beskrev de geologiske forhold, Nordmann undersøgte molluskindholdet i nogle udvalgte prøver og Nørvang analyserede foraminifer-faunaerne. Nørvang beskrev desuden borearbejdets gang og Sigurd Hansen gjorde rede for de økonomiske forhold. Da de geologiske resultater af disse undersøgelser ikke er publiceret, gives her en ret udførlig gennemgang deraf.

Formålet med boringen var at undersøge de geologiske forhold med henblik på forekomster af anvendelige råstoffer specielt kul. Det havde længe været kendt, at der skyllede kul op på Anholts kyster, men man vidste ikke, om disse kul stammede fra tertiære lag fra havbunden i nærheden af Anholt, eller om det var Rhät-Lias kul af samme type, som i forekomsterne i Skåne og på Bornholm. Det ansås for sandsynligt, at Kullen-horsten med dens kulførende aflejringer fortsatte i nordvestlig retning til Anholt.

Boringen blev udført som Rotary-boring med henblik på at få kerneprøver gennem hele boreprofilet. De stenede aflejringer bevirkede, at borearbejdet flere gange gik i stå, enten fordi det var nødvendigt at foretage sprængninger, eller fordi grejet gik i stykker. Desværre satte forerørene sig fast i 34,48 meters dybde, hvilket bevirkede, at størsteparten af boringen blev udført uden foring. Dette besværliggjorde kernetagningen og forårsagede, at en stor del af prøverne, især de mange skylle- og sigteprøver, må formodes at være forurenede af materiale fra overliggende lag. Borehullet skred sammen flere gange under arbejdet, og skyllevandet forsvandt ud i nogle af de gennemborede lag. Under forsøg på at stoppe disse lækager slap det medbragte ler op. Der er derfor anvendt postglacialt ler fra Anholt som skyllemudder fra 210 m og nedefter. Da boringen havde nået en dybde af 228,81 m knækkede borestammen, og borearbejdet blev indstillet efter en række forgæves forsøg på at fiske borestammen op igen.

Der blev ialt taget 10 meget korte kerner, hvoraf den øverste (13,9–16,7 m) ikke kunne anvendes, idet kernetageren kun indeholdt nedfaldet materiale (Gry et al. 1944), 24 mejselprøver og 219 skylle- og sigteprøver.

Nordmann undersøgte molluskindholdet i 22 prøver fra en dybde af 62,7 m og nedefter. Ud fra skallernes bevaringstilstand mente han, at intervallet fra 62,7 til 70,7 m var marint, og at intervallerne 73,7–76 m og 103–105 m muligvis også var marine (fig. 8). Han kunne ikke konstatere, om de andre prøver var marine eller glacigene i deres oprindelse. Nordmann karakteriserede faunaen således: "... vi har at gøre med en boreal Fauna med et vist sydligt Præg, saa-

ledes at man ikke med Bestemthed kan henføre den til nogen af de kendte interglaciale faunaer, hverken til den lusitanske Eemfauna eller til Skærumhedefaunaen. Den synes nærmest at slutte sig til Skærumhede-Seriens nederste boreale, forholdsvis varme Zone (*Turritella terebra*-Zonen), men har dog paa Grund af Tilstedeværelsen af den lusitanske Form *Lucina divaricata* et endnu sydligere Præg".

Nordmann gjorde desuden opmærksom på, at der i de øvrige prøver ikke med sikkerhed kunne påvises højarktiske arter.

Nørvang analyserede foraminifer-faunaerne i 28 prøver, heraf 17 mejselprøver. Han inddelte lagserien i fem serier, I-V (fig. 8). Serie I (13,9–70,7 m) indeholdt en sparsom fauna, præget af arktiske arter. Nørvang fandt det vanskeligt at afgøre, om serien var af marin eller fluviatil oprindelse.

Serie II (73,7–79,7 m) var kendetegnet af et stort antal foraminiferer, som bestod af en række arter, som ikke lever under arktiske forhold. Han karakteriserede denne del af lagserien som marin med en fauna af en sydlig boreal karakter. Nørvang fandt dog i de øverste prøver i denne serie nogle former fra køligere områder.

Serie III (79,7–85,7 m) omfattede kun to sigteprøver. Foraminifer-faunaen karakteriseredes her af, at boreale arter går tilbage og erstattes af former, som lever i køligere områder. Nørvang opstillede tre mulige årsager til oprindelsen af denne fauna. 1: Faunaen i serie III svarede til faunaen i serie II, som under borearbejdet var blevet forurenet med faunaen i serie I. 2: Faunaen i serie III var en ren arktisk fauna, som under borearbejdet var blevet forurenet med faunaen fra serie II, 3: De arktiske eller de boreale foraminiferer eller begge var sekundære; serie III var fx en lokal till bestående af forskellige marine lag. De tre muligheder diskuteredes, og Nørvang hældede mest til den antagelse, at serie III indeholdt stenet ishavsler med en arktisk fauna, som var forurenet af materiale fra serie II eller, at serie II var en lokal till. Han påpegede tilstedeværelsen af et arktisk faunaelement ældre end lagene i den boreale serie II.

Serie IV (109,7–157,7 m) havde et ringe indhold af foraminiferer. Nørvang fandt det derfor vanskeligt at afgøre, om denne serie var marin.

Serie V (215,8–224,7 m) indeholdt igen en blandingsfauna med både arktiske og boreale arter. Nørvang påpegede, at de fleste arter var arktiske.

Nørvang forsøgte ikke at indplacere disse serier i de dengang kendte istider og mellemistider.

Gry opstillede som et foreløbigt resultat af undersøgelserne følgende lagserie (se også fig. 8):

0 – 3,0 m	marint, postglacialt sand og strandgrus
3,0 – 56,5 m	sandsynligvis overvejende fluvioglaciale dannelser og till (måske med marint arktisk ler fra 43,7 til 45,2 m)
56,5 – 77,2 m	marint, borealt interglacialt (sammenlignes med Skærumhede Seriens *Turritella terebra* Zone)
77,2 – 228,8 m	overvejende fluvioglaciale dannelser og moræne sandsynligvis med interglaciale lag forneden.

Selv om de kvartære aflejringer under Anholt ikke blev gennemboret, gav boringen en række værdifulde geologiske resultater. Gry konstaterede, at Anholt ikke lå i et horstområde, og at der derfor ikke fandtes kulførende Rhät-Lias dannelser i opnåelig dybde under øen. Prækvartæroverfladens dybe beliggenhed under Anholt blev forklaret enten som et resultat af iserosion eller af tektoniske bevægelser langs brudlinier. Gry fandt det sandsynligt, at den gravsænkning, som var fundet under Alnarp-Dalen i Skåne, fortsatte mod nordvest gennem Kattegat til Anholt, og at den havde spillet en rolle for Skærumhedehavets transgression.

Mörner (1969) tolkede aflejringerne i boringen på Anholt således:

A: Til 72,7 m en øvre glacigen serie ("drift series") = Øvre Pleniglacial (i Holland).
B: Til 77,2 m marint ler = en del af *Portlandia arctica* Zonen (57,4–74,4 m) i Skærumhede I boringen og Interpleniglacial i Holland.
C: Til 228,81 m en nedre glacigen serie ("drift series") = Nedre Pleniglacial (i Holland).

Den nedre glacigene serie blev anset for at indeholde sedimenter, som var akkumuleret foran isfronten under det "Gammelbaltiske isfremstød" i Weichsel (ca. 50.000 B.P.). Mörner antog, at isen i denne periode dækkede den østlige og sydlige del af Kattegat og at den, under dens maximale udbredelse, nåede til en linie fra Djursland til et område øst for Anholt og derfra videre mod nord til et område øst for Læsø. Som et lokalt navn for dette fremstød blev Anholt Stadial foreslået.

Formålet med den her foreliggende undersøgelse har været at foretage en foraminifer-stratigrafisk inddeling af de kvartære aflejringer i boringen. Lagserien, som indeholder både marine og ikke-marine glacigene sedimenter, er inddelt i elleve zoner, zone A til zone K (fig. 9). Disse zoner omfatter aflejringer fra Holocen til præ-Eem, rimeligvis Saale (sensu lato).

Holocen

Den øverste del af lagserien (0–3 m) består af marint sand og grus med skaller, zone A. Desværre er de fleste foraminiferer udvaskede eller fyldt med pyrit. De bestemmelige arter, sedimentets karakter og beliggenhed i lagserien peger på, at aflejringen er Holocen.

Weichsel

Zone B (3–34 m) omfatter sedimenter af forskellig karakter, som næsten alle indeholder foraminiferer. Et relativt stort indhold af prækvartære former i flere af prøverne tyder dog på, at materialet kan være omlejret. De stenede og sandede lersedimenter (20,1–21,7 m, 22,3–23,3 m og 25–26, 55 m) betragtes derfor som till-aflejringer, og lagene imellem disse som glaciofluviale. Der er ikke fundet senglaciale marine lag, hvilket sikkert skyldes en række boretekniske problemer netop under denne del af borearbejdet (se ovenfor). Zone B er henført til Sen Weichsel (fig. 9).

Zone C (34–43 m) består af lersedimenter med sten og skaller. Foraminifer-indholdet i disse lag tyder på, at aflejringen er marin. Faunaerne afspejler moderate vanddybder og arktiske til boreo-arktiske klimatiske betingelser. Tilsvarende faunaer er kendt fra Sandnes Interstadial (Feyling-Hanssen et al. 1971) i Vendsyssel-Kattegat området (Lykke-Andersen 1987).

Zone D (43–72,7 m) indeholder øverst de samme lersedimenter som zone C. Derunder findes sand med mange skalfragmenter. Disse lag indeholder en arktisk lavtvandsfauna, som kan korreleres med faunaer fundet i Vendsyssel-Kattegat området fra Vennebjerg Stadial perioden (Lykke-Andersen & Knudsen 1990).

Zonerne C og D er således henført til den øvre del af Mellem Weichsel (fig. 9).

Aflejringer fra den nedre del af Mellem Weichsel og Tidlig Weichsel er ikke antruffet her.

Eem

En tydelig ændring af både sedimenttype og foraminifer-faunaernes sammensætning markerer overgangen til zone E (72,7–83,7 m). Sedimentet består af grønligt, fedt ler, underlejret af skiftende lag af sand og ler. Alle lagene indeholder skaller af mollusker (fig. 9). Foraminifer-faunaerne i disse lag er

domineret af boreale arter og i en del af serien forekommer også boreo-lusitanske former. Hovedparten af faunaerne stammer fra havområder, hvor temperaturen har været lidt højere end i det nuværende Kattegat og vanddybden 50–100 m. I den allerøverste del af zone E tyder fauna-sammensætningen på, at både temperatur og vanddybde bliver lavere. De nederste prøver, som stammer fra de sandede sedimenter, indeholder en del arter fra arktiske lavtvandsområder. Disse prøver, som er skylleprøver, kan være forurenede af nedskyllet materiale.

Størstedelen af foraminifer-faunaerne i zone E udviser stor lighed med faunaer fra den nedre del af *Turritella terebra* Zonen i Skærumhede Serien (Jessen et al. 1910). Tilsvarende faunaer er kendt i dele af Vendsyssel-Kattegat området, og de er henført til Eem (Feyling-Hanssen et al. 1971; Knudsen & Lykke-Andersen 1982; Knudsen 1984, 1985; Lykke-Andersen 1987; Lykke-Andersen & Knudsen 1990). Aminosyre målinger på foraminiferer fra zone E i Anholt bekræfter denne antagelse (Knudsen & Sejrup 1988).

Præ-Eem

Zone F (85,7–87,9 m) består af stenholdigt sand med ret store mængder bryozoer. Kerneprøver fra denne aflejring indeholdt kun prækvartære foraminiferer. Det må derfor antages, at sedimentet er till-sand eller glaciofluvialt sand. Som følge af beliggenheden i lagserien er zone F placeret i Saale (fig. 9). Det skal bemærkes, at der findes et tilsvarende sediment under Eemet i Skærumhede I boringen (Jessen et al. 1910).

Vekslende tynde sand- og lerlag med skalfragmenter er indeholdt i zone G (87,9–125 m). Da alle prøver i denne zone indeholder foraminiferer, formodes den at være marin. Der er dog en tydelig nedvaskning af arter især fra Eemlagene, og det er derfor vanskeligt at vurdere, hvorledes den oprindelige fauna-sammensætning har været. Mejselprøverne indeholder faunaer fra boreale til boreo-arktiske marin-klimatiske miljøer, hvor havdybden har været moderat. Hvis disse faunaer er oprindelig hjemmehørende i sedimentet, må det stamme fra en interstadial periode. Zone G er i diagrammet (fig 9) kaldt Anholt 1 og henført til Saale.

En aflejring af grov- til mellemkornet kvartssand med et par sandede lerlag nær bunden underlejrer zone G. Sandet, som indeholder en del kulstykker og nogle få skalfragmenter, stammer rimeligvis fra erosion af jurassiske sedimenter, som er blottet på havbunden sydøst for Anholt (Liboriussen et al. 1987). Der er fundet ganske få kvartære foraminiferer i denne zone, som er kaldt H (125–151 m). Materialet i zone H er tolket som glaciofluvialt tilhørende en stadial periode i Saale (fig. 9).

Prøver fra zone I (151–170,7 m) indeholder igen foraminiferer, især i den øverste del af zonen er antallet stort. Der er dog desværre kun én mejselprøve fra dette interval. Faunaen i denne prøve afspejler et marint subarktisk lavtvandsområde. Dette støttes af foraminifer-indholdet i de omgivende skylle- og sigteprøver, selv om de tydeligvis er forurenede af materiale ovenfra. Zone I er henført til en interglacial periode i Saale, kaldet Anholt 2 (fig. 9).

Størstedelen af zone J (170,7–192,25 m) består af ret fedt stenet ler med kulstykker og små skalfragmenter. Nær bunden findes tynde lag af sand og ler. Kerneprøver herfra indeholder ikke foraminiferer og i de øvrige prøver, er der kun fundet få. Hovedparten af zone J kan være en till-aflejring. Det er ikke muligt at datere zonen, men den er ud fra placeringen i boringen henført til en Saale Stadial (fig. 9).

Den nederste del af lagserien, zone K (192,25–228,81 m), indeholder en række forskellige sedimenter. Stenholdige mellemtil grovkornede sandlag med molluskskaller overlejrer stenet ler med tynde sandlag. Derunder findes forskellige ler og sandlag igen med sten og skaller. Alle prøver fra dette interval indeholder foraminiferer, dog i varierende mængde (fig. 9). Det formodes,

at dele af denne lagserie er marine, og der kan være tale om flere marine perioder. Det prøvemateriale, som er til rådighed, tillader imidlertid ikke en opdeling. Zone K indeholder boreal-arktiske til arktiske foraminifer-faunaer fra moderate vanddybder. Sådanne faunaer må karakteriseres som interstadiale. Perioden er her kaldt Anholt 3 og placeret i Saale, da der ikke er arter i faunaen, som peger på en ældre glacial periode. Tilsvarende foraminifer-faunaer er fundet i den nederste del af den kvartære lagserie i en boring på Hesselø (DGU 180.1), og Nørre Lyngbyboringen (Lykke-Andersen 1987) indeholdt lignende faunaer i bunden af den kvartære serie.

Hele præ-Eem lagserien (85,7–228,81 m) er således placeret i Saale (sensu lato).

Den 229 m mægtige kvartære lagserie i boring nr. 51.12 på Anholt synes nederst at bestå af aflejringer fra Saale Istiden, som indeholder mindst tre marine interstadialer, kaldet Anholt 1, 2 og 3, hvoraf Anholt 1 er den varmeste. Glacigene materialer mellemlejrer de marine afsnit. Over Saale-forekomsterne findes marine lag fra Eem Mellemistiden, svarende til den nedre del af Skærumhede Seriens *Turritella terebra* Zone. Tidlig Weichsel og den nedre del af Mellem Weichsel mangler. Øvre Mellem Weichsel er repræsenteret af marine sedimenter fra Vennebjerg Stadial og Sandnes Interstadial, svarende til en del af *Portlandia arctica* Zonen i Skærumhede Serien. Derover forekommer lag, som tilsyneladende er glacigene og derfor henført til Sen Weichsel. Marine senglaciale aflejringer er ikke fundet, rimeligvis p.g.a. et mangelfuldt prøvemateriale fra denne del af boringen. Holocene marine dannelser afslutter lagserien.

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Appendix

The sediments described by H. Gry (1944)

0.0 –	1.4 m	Postglacial, cross-bedded marine sand
–	3.0	Marine gravel and stones
–	8.5	Coarse to fine sand with stones
–	9.9	Sandy clay with coal and a few grains of mica
–	12.45	Fine, grey, clayey sand with a little Jurassic coal and shell-fragments
–	14.3	Sandy clay
–	17.4	Rather fine, grey sand
–	19.7	Sandy clay with a few coals
–	20.1	Dark grey, clayey fine sand
–	21.7	Sandy clay with stones
–	22.3	Sand
–	23.3	Grey, sandy and stony clay
–	25.0	Alternating layers of sand and clay, 2–3 cm
–	26.55	Grey, sandy clay with stones
–	27.1	Grey, clayey sand with coal
–	28.55	Grey, sandy clay
–	29.3	Medium grained, grey sand
–	31.0	Sandy clay
–	31.9	Darker sticky clay
–	32.3	Medium grained, grey sand
–	33.9	Sandy clay with shell-fragments
–	34.0	Sand
–	56.5	Grey, stony clay with coal and shell-fragments
–	72.7	Greenish, marine sticky clay
–	77.88	Alternating layers of sand and clay
–	78.9	Stony, grey, sandy clay with shells
–	79.7	Stony sand
–	85.7	Grey, sandy clay with stones
–	87.9	Rather coarse, grey sand with great amounts of bryozoans (and stones)
–	98.0	Grey, sandy and stony clay. Probably alternating layers of sand and clay.
–	100.1	Stony sand
–	122.0	Grey, stony clay with alternating layers of sand and clay. Shells
–	144.4	Coarse, grey sand with stones and shells
–	146.9	Sandy clay
–	149.0	Coarse, grey sand with coal and shell-fragments
–	151.0	Sandy clay
–	170.7	Grey, rather coarse to medium, stony and clayey sand with coal and shell-fragments
–	188.1	Rather sticky, stony clay with coal and shell-fragments
–	188.7	Sand

– 188.8	Clay
– 189.6	Sand
– 192.25	Grey, stony, sandy clay
– 206.7	Stony, medium to rather coarse, gray sand with shells
– 208.8	Stony clay
– 209.0	Sand
– 215.75	Stony clay
– 216.0	Sand
– 217.3	Dark grey, rather sticky clay
– 218.6	Sand
– 219.3	Clay
– 219.9	Sand
– 220.1	Clay
– 224.7	Medium grained, grey, stony sand with shells
– 226.05	Dark grey, rather sticky, stony clay
– 227.0	Medium, grey sand
– 228.81	Clay

Plates 1–2

PLATE 1

Scale = 0.1 mm

Foraminifera from Eemian Interglacial at Anholt

Fig. 1. *Textularia sagittula* Defrance 1824. Sample no. 112d.
Fig. 2. *Quinqueloculina padana* Perconig 1954. Sample no. 112a.
Fig. 3. *Quinqueloculina padana* Perconig 1954. Apertural view. Sample no. 112a.
Fig. 4. *Bulimina marginata* d'Orbigny 1826. Sample no. 112d.
Fig. 5. *Globobulimina turgida* (Bailey 1851). Sample no. 112d.
Fig. 6. *Stainforthia fusiformis* (Williamson 1858). Sample no. 112d.
Fig. 7. *Uvigerina peregrina* Cushman 1923. Sample no. 112d.
Fig. 8. *Angulogerina angulosa* (Williamson 1858). Sample no. 112d.
Fig. 9. *Bolivina subspinescens* Cushman 1922. Sample no. 112d.
Fig. 10. *Bolivina subspinescens* Cushman 1922. Edge view. Sample no. 112d.
Fig. 11. *Cassidulina laevigata* d'Orbigny 1826. Side view. Sample no. 112d.
Fig. 12. *Cassidulina laevigata* d'Orbigny 1826. Edge view. Sample no. 112d.
Fig. 13. *Cassidulina reniforme* Nørvang 1945. Sample no. 112d.
Fig. 14. *Epistominella vitrea* Parker 1953. Umbilical view. Sample no. 112d.
Fig. 15. *Epistominella vitrea* Parker 1953. Spiral view. Sample no. 112d.


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PLATE 2

Scale = 0.1 mm

Foraminifera from Eemian Interglacial at Anholt

Fig. 1. *Planulina ariminensis* d'Orbigny 1826. Side view. Sample no. 112d.
Fig. 2. *Planulina ariminensis* d'Orbigny 1826. Edge view. Sample no. 112d.
Fig. 3. *Hyalinea balthica* (Schroeter 1783). Edge view. Sample no. 112d.
Fig. 4. *Hyalinea balthica* (Schroeter 1783). Side view. Sample no. 112d.
Fig. 5. *Nonion barleeanum* (Williamson 1858). Edge view. Sample no. 112d.
Fig. 6. *Nonion barleeanum* (Williamson 1858). Side view. Sample no. 112d.
Fig. 7. *Nonionella iridea* Heron-Allen & Earland 1932. Side view. Sample no. 112d.
Fig. 8. *Nonionella iridea* Heron-Allen & Earland 1932. Edge view. Sample no. 112d.
Fig. 9. *Elphidium excavatum* (Terquem 1876). Side view. Sample no. 112d.
Fig. 10. *Elphidium excavatum* (Terquem 1876). Edge view. Sample no. 112d.
Fig. 11. *Ammonia batava* (Hofker 1951). Umbilical view. Sample no. 112d.
Fig. 12. *Ammonia batava* (Hofker 1951). Edge view. Sample no. 112d.
Fig. 13. *Ammonia batava* (Hofker 1951). Spiral view. Sample no. 112d

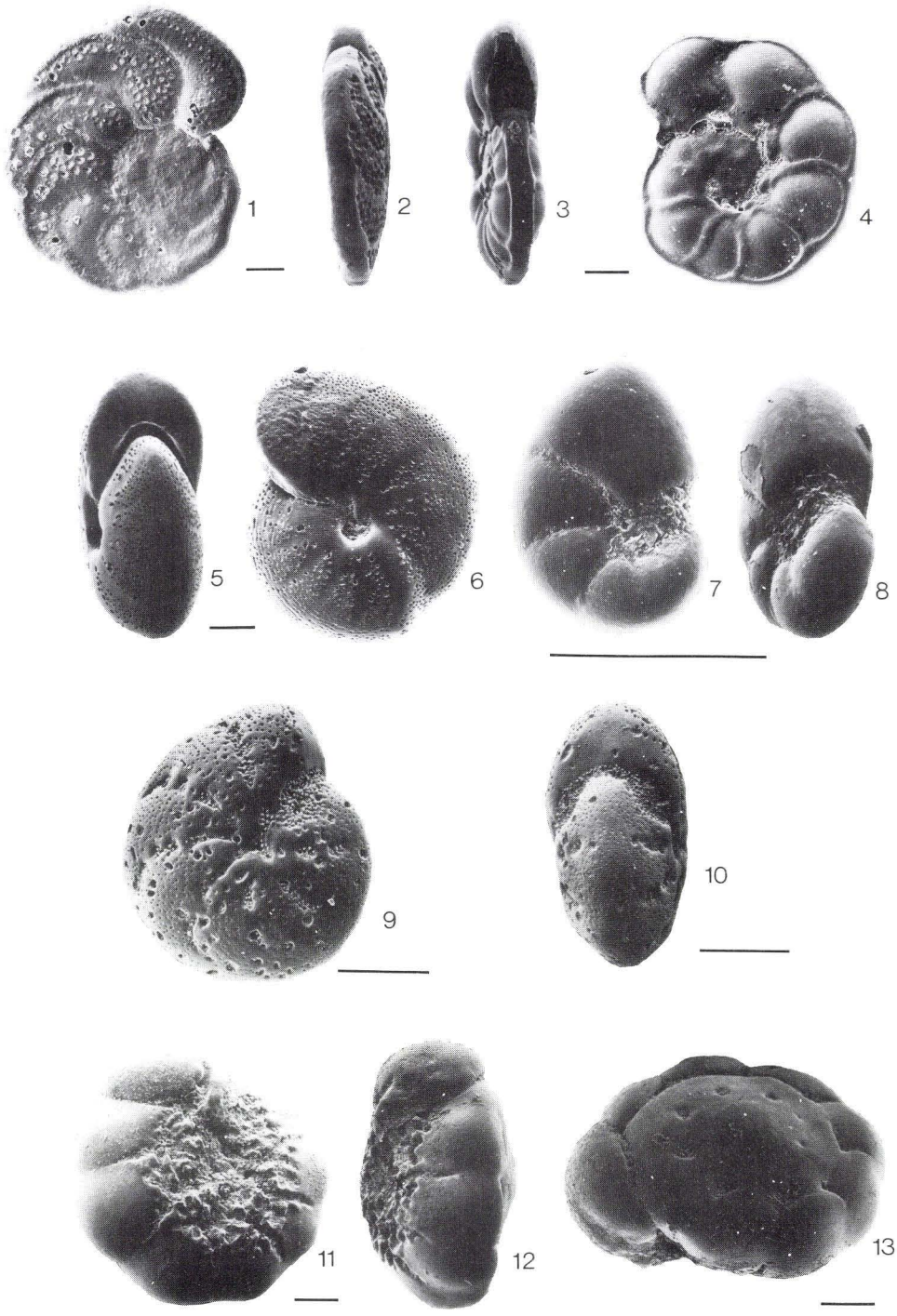
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Fig. 9. Range chart for the Anholt boring no. 51.12. The percentage distributions of selected foraminiferal species are shown. Legend fig. 10. The bore site is 2.5 m above sea-level.
Foraminiferdiagram over boring nr. 51.12, Anholt. Den procentuelle fordeling af udvalgte foraminiferarter er vist. Legende fig. 10. Borestedet er placeret i kote 2,5 m.

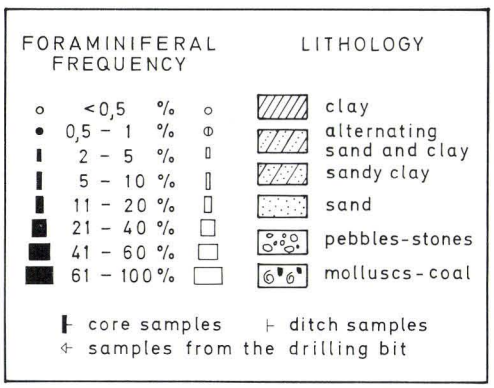
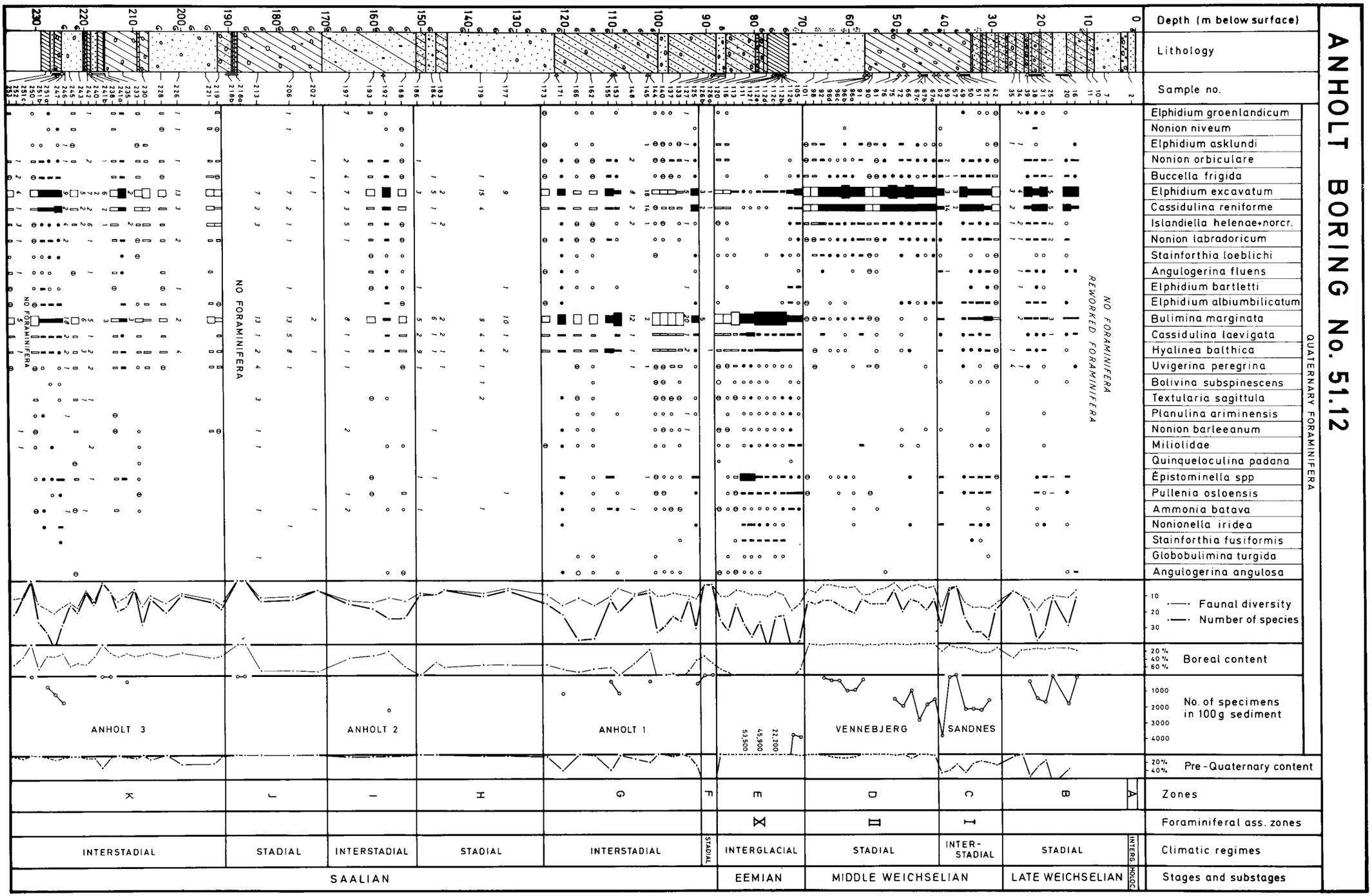


Fig. 10. Legend for fig. 9. The filled signatures and normal types are used for the core samples and the samples from the drilling bit. The open signatures and italics are used for the ditch samples.
Legende til fig. 9. De udfyldte signaturer og normal skrifttype er brugt til angivelse af kerne- og mejselprøver. Åbne signaturer og kursiv er benyttet til skylle- og sigteprøver.


ANHOLT BORING No. 51.12
Depth (m below surface)
Lithology
Sample no.
Elphidium groenlandicum
Nonion niveum
Elphidium asklundi
Nonion orbiculare
Buccella frigida
Elphidium excavatum
Cassidulina reniforme
Islandiella helenae+norcr.
Nonion labradoricum
Stainforthia loeblichi
Angulogerina fluens
Elphidium bartletti
Elphidium albiumbilicatum
Bulimina marginata
Cassidulina laevigata
Hyalinea balthica
Uvigerina peregrina
Bolivina subspinescens
Textularia sagittula
Planulina ariminensis
Nonion barleeanum
Miliolidae
Quinqueloculina padana
Epistominella spp
Pullenia osloensis
Ammonia batava
Nonionella iridea
Stainforthia fusiformis
Globobulimina turgida
Angulogerina angulosa
NO FORAMINIFERA
NO FORAMINIFERA
REWORKED FORAMINIFERA
QUATERNARY FORAMINIFERA
10
20
30
Faunal diversity
Number of species
20 %
40 %
60 %
Boreal content
1000
2000
3000
4000
No. of specimens in 100g sediment
ANHOLT 3
ANHOLT 2
ANHOLT 1
VENNEBJERG
SANDNES
53500
45900
22200
20 %
40 %
Pre-Quaternary content
K
J
I
H
G
F
E
D
C
B
A
Zones
IV
III
II
I
Foraminiferal ass. zones
INTERSTADIAL
STADIAL
INTERSTADIAL
STADIAL
INTERSTADIAL
STADIAL
INTERGLACIAL
STADIAL
INTER-STADIAL
STADIAL
INTERG.
Climatic regimes
SAALIAN
EEMIAN
MIDDLE WEICHSELIAN
LATE WEICHSELIAN
HOLOC.
Stages and substages

This paper describes and discuss the foraminiferal stratigraphy of a 229 m deep boring on the island of Anholt, situated between Denmark and Sweden, almost in the center of the Kattegat.

The author, furthermore, discuss the Quaternary stratigraphy of Anholt and resume the history of this almost 50 years old boring.

She, especially, demonstrates the exsistence of one Middle Weichselian Interstadial, Eemian Interglacial, and a thick pre-Eemian sequence of assumed Saalian age.

ISBN 87-88640-56-6
ISSN 0901-0289