DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2004/50

The Micropalaeontological Society Calcareous Plankton Spring meeting (Joint Nannofossil and Foraminifera Group Meeting) Geocenter Copenhagen

Abstracts and Field Guide

Emma Sheldon, Svend Stouge & Andy Henderson

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF THE ENVIRONMENT

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G E U S

The Micropalaeontological Society

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The Micropalaeontological Society

Calcareous Plankton Spring Meeting

(Joint Nannofossil and Foraminifera Group Meeting)

Geocenter, Copenhagen

Thursday 13th - Saturday 15th May 2004

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Foreword

The Micropalaeonotological Society (TMS) 'Nannofossil and Foraminifera Group' meeting at the Geocenter Copenhagen is only the second Spring meeting to be held outside of the UK. It would not have been possible without the generous support of our sponsors; Amerada Hess (Denmark) ApS, ChevronTexaco Energy Technology Company, RWE-Dea, Shell Exploration and Production Europe and TMS. We are grateful also to GEUS (The Geological Survey of Denmark and Greenland) and Copenhagen University Geological Institute for the use of facilities and for invaluable support.

Almost 50 delegates have registered for the meeting. During the one day of technical sessions much new information will be presented orally and through the posters. Over 40 persons will participate in the excursion to localities at Stevns Klint.

We would like to thank Jette Sejerslev and Hanne Sørensen (GEUS Stratigraphy Department secretaries) and all colleagues, the Geocenter technical staff and the Geological Institute students involved for their help, at all stages from the planning through to the meeting itself.

Thanks also are also due to Minik Rosing; Deputy Director of the Natural History Museum of Denmark, University of Copenhagen and Head of the Geological Museum who volunteered to open the meeting.

We wish you an enjoyable and rewarding stay in Copenhagen.

Emma Sheldon, Svend Stouge, Andy Henderson (Editors)
Copenhagen, May 2004

PROGRAMME

The aim of the meeting is to promote contact between workers in their respective groups in order to develop multi-disciplinary research topics.

Thursday 13th May

16.00 – 20.00 Registration and welcome reception
Rotunden, Geocenter, Øster Voldgade 10, DK 1350, København K

19.00 Informal welcome by Haydon Bailey, chairman of The Micropalaeontological Society.

Friday 14th May

ORAL PRESENTATIONS

Oral Presentations: Auditorium A, Geocenter, Øster Voldgade 10
Poster viewing: Rotunden, Geocenter

09.00 Meeting opens

09.05 – 09.15 Official welcome by Professor Minik Rosing; Deputy Director of the Natural History Museum of Denmark, University of Copenhagen and Head of the Geological Museum

Session 1 Presiding: Svend Stouge & Michal Kucera

09.15 – 09.40 **Hans Jørgen Hansen**: Keynote speech: Was there, or was there not a meteoritic impact at the K/T boundary 65 million years ago?

09.40 – 10.00 **Malcolm Hart, Sean Feist, Gregory Price & Melanie Leng**: New data on an expanded K/T boundary section, Stevns Klint, Denmark

10.00 – 10.20 **Norman Macleod, Mark O'Neill, & 'Stig' Arron Walsh**: A comparison between morphometric and unsupervised, artificial, neural-net approaches to automated species identification in foraminifera

10.20 – 10.40 **David J. Jutson, Mike Bidgood & Ben Johnson**: Microfaunal and nannofossil analyses of ditch cutting samples from two wells from within the Silverpit impact crater, British Sector, North Sea: evidence towards confirming the age and origin of the structure

10.40 – 11.00 Break: coffee, tea, soft drinks and biscuits / cakes will be served on the 3rd floor of the Rotunden

Session 2 Presiding: David J. Jutson & Andy Henderson

11.00 – 11.20 **Haydon W. Bailey & Matthew J. Hampton**: Development and application of an integrated biostratigraphical model for the South Arne field, offshore Denmark

11.20 – 11.40 **Bridget Wade & Paul Bown**: Calcareous nannofossils in extreme environments: the Messinian Salinity Crisis, Cyprus

11.40 – 12.00 **Claudia Schröder-Adams & Jim Craig**: Foraminifera and Nannofossils in the Western Interior Sea, Canada: reconstruction of Cretaceous sea-level History

12.00 – 12.20 **K.J. Sebastian Meier**: Stable isotopes in calcareous dinoflagellate cysts and their possible application in palaeoenvironmental reconstructions

12.20 – 13.20 Lunch in the Geocenter canteen

13.20 – 14.20 Posters in the Rotunden and group photo

Session 3 Presiding: Jörg Mutterlose & Eckart Håkansson

14.20 – 14.40 **Kurt Søren Svensson Nielsen & Holger Gebhardt**: *Orbulina pulchra*, a new species of the genus *Orbulina* from the Middle Miocene: its occurrence and phylogenetic relation to *O. universa*

14.40 – 15.00 **Michal Kucera & Kate F. Darling**: Morphological variation and taxonomy of modern high-latitude *Neogloboquadrina* (planktonic foraminifera)

15.00 – 15.20 **Jeremy R. Young, Markus Geisen, Ian Probert & Karen Henriksen**: Holococcolith biomineralisation

15.20 – 15.40 **Joachim Schoenfeld**: The Caribbean Salt Kitchen monitored *by Globigerinoides sacculifer* and *Globigerinoides ruber* during the last 50,000 years

15.40 – 16.00 **Blair A. Steel, Michal Kucera & Kate F. Darling**: Adaptation without differentiation: morphological homogeneity between 'pseudo-Cryptic' forms of *Globigerinoides ruber* d'Orbigny

16.00 –16.20 Break: coffee, tea, soft drinks and biscuits / cakes will be served on the 3rd floor of the Rotunden

Session 4 Presiding: Jeremy Young & Jan Audun Rasmussen

16.20 – 16.40 **Jörg Mutterlose & Sylvia Rückheim**: Calcareous nannofossils and planktonic foraminfera in the Cretaceous: an integrated approach for understanding palaeoecological changes in a Greenhouse world

16.40 – 17.00 **Jian Xu, Baoqi Huang, Pinxian Wang, Jun Tian, Chuanlian Liu & Zhimin Jian**: Comparison of Quaternary upper-ocean water changes between Southern and Northern South China Sea: a see-saw pattern

17.00 – 17.20 **Markus Geisen, Gerald Langer, Ulf Riebesell, Ian Probert & Jeremy Young**: The effects of rising pCO_2 on coccolithophore calcification

17.20 – 17.40 **Karen Henriksen, Susan L. S. Stipp, Jeremy Young & M.E. Marsh**: Coccolith Polysaccharides: influence on genesis and diagenesis

18.00 – 19.30: Refreshments and discussion around the posters in the Rotunden.

19.30 – 22.30: Meeting dinner in the Geocenter canteen, 1st floor

POSTERS

The following posters will be on show in the Rotunden from Thursday evening. A poster viewing session will take place after lunch on Friday.

1. **Erik Anthoniessen**: Calibrating the Neogene microfossil biostratigraphy of the North Sea region

2. **Nadia Al-Sabouni, Michal Kucera & Daniela Schmidt**: Removing assemblage-size bias from planktonic foraminifer biodiversity estimates

3. **André Bornemann & Jörg Mutterlose**: The Valanginian 'Weissert' Event in the western Atlantic (DSDP Sites 534A and 603B): results from calcareous nannofossils and carbon isotopes

4. **Kevin Brown**: Morphological variation in Recent *Globorotalia menardii*

5. **Daniela Crudeli, Hanno Kinkel, Jeremy R.Young, Silke Steph, & Ralph Tiedemann**: Extensive phenotypic and structural variability in very small and small Lower Pliocene reticulofenestrid coccoliths (South Caribbean Sea): evolutionary and palaeoecological implications

6. **Kate F. Darling & Christopher M. Wade**: Cryptic genetic diversity in the planktonic foraminfer *Neogloboquadrina pachyderma*

7. **Jodie K. Fisher, Gregory D. Price, Malcolm B. Hart & Melanie J. Leng:** Isotopic and foraminiferal analysis of the Cenomanian-Turonian Boundary event in the Indian Ocean

8. **Holger Gebhardt**: Biostratigraphy and palaeoecological interpretation of planktonic foraminifera from the Cenomanian to Coniacian Nkalagu Formation, south Nigeria

9. **Hans Jørgen Hansen**: 'Pele's Tears' and various misconcepts

10. **Malcolm B. Hart & Gregory D. Price:** New data on the Late Cenomanian Extinction Event

11. **Andrew S. Henderson, John, E, Whittaker & Clive Jones:** Henry Buckley: the unknown Planktonic Foraminiferal pioneer

12. **Mark D. Hylton, Malcolm B. Hart & Gregory D. Price:** The Foraminiferal Response to the Early Toarcian Extinction Event

13. **Eckart Håkansson, Claus Heinberg & Jan Audun Rasmussen**: Basal Danian Cerithium Limestone at Stevns Klint, Denmark – diachronous and unusual

14. **James Keegan, Graham Coles, Steve Starkie, Darrin Stead, Paul Swire & Bindra Thusu**: Integrated biozonation scheme for the Late Cretaceous to Tertiary of North Africa

15. **Michael Knappertsbusch**: Micro-evolution in planktonic foraminifera: a morphometric case study applied to the *Globorotalia menardii* plexus and *G. tumida* lineage

16. **Marcos A. Lamolda, Danuta Peryt & Jana Ion**: Planktonic foraminifera at the Coniacian – Santonian boundary at Olazagutía, Northern Spain

17. **Heiko Legge & Jörg Mutterlose**: Late Glacial and Holocene calcareous nannoplankton variations in the Northern Red Sea

18. **Kurt Søren Svensson Nielsen:** Palaeomagnetic and Planktonic foraminiferal biostratigraphy of a Plio-Pleistocene section, Rhodes (Greece)

19. **Jan A. Rasmussen & Emma Sheldon**: The Maastrichtian - Danian boundary of the TUBA-13 drill core, central Copenhagen, Denmark

20. **Sylvia Rückheim, André Bornemann & Jörg Mutterlose**: Calcareous plankton of the Cretaceous North Sea Basin: an integrated study of planktonic foraminifera and calcareous nannofossils

21. **Maria Antonieta Sánchez-Rios, Juan Rico-Pérez, Julio C. González-Lara, Lidia Aguirre-Meza, Mónica Ayala-Nieto, Guillermo Quintanilla, Patricia Padilla-Avila, Aarón del Valle-Reyes, Janett Sánchez-Durán, Daniel García-Urbano, Cristina Pérez-Castillo & Paula A. Fuentes- Franco:** High resolution biostratigraphy in Neogene sediments of two wells in the western Gulf of Mexico

22. **Claudia Schröder Adams & Ron Boyd**: Late Quaternary stratigraphy and foraminiferal response in the northern New South Wales continental shelf, Australia: a mixed siliciclastic-carbonate setting

23. **Jens Steffahn & Jörg Mutterlose**: An improved Upper Cretaceous foraminiferal biozonation and well log correlation for the Pompeckj block – preliminary results

Saturday 15th May

FIELD EXCURSION TO STEVNS KLINT

08.30 – 08.45:	Meet in the main Geocenter car park, Øster Voldgade 10.
09.00 sharp:	Leave the Geocenter by bus.
	Excursion leaders are Hans Jørgen Hansen and Eckart Håkansson (Copenhagen University), Svend Stouge (GEUS & The Geological Museum) and Tove Damholt (Østsjællands Museum)
10.30	Meet at Højerup Church car park
	The first stop is near Old Højerup Church. From the cliff top we will view the classic KT boundary section. Unfortunately, given the limited amount of time we have, and the distance down to the beach and along to the outcrop, we will not be able to get close up to the section. A short history of the church (and what happened early in the morning on Friday the 16th of March, 1928) and the area will be given by Tove Damholt and we'll have the opportunity for a quick visit to the Østsjællands local history Museum (there is also a small geology section).
	After lunch we will drive the short distance to Rødvig where we can clearly see the KT section (the fish clay is at head height). There will be chance to sample at this locality.
15.00	We will leave by bus at approximately at 15.00 to arrive back at the Geocenter at 16.00 – 16.30.
16.00 – 16.30	Bus return to the Geocenter, Øster Voldgade 10. Meeting formally ends.
16.30 – 17.00	For those who wish, we will have a farewell drink in the sunshine outside the Geocenter.

INFORMATION

Presentations

We have a very full day, it is therefore imperative that speakers adhere strictly to their 20 minutes, including questions. The meeting will be divided into 4 sessions (divided randomly, not based upon subject matter) and each session will have two chairmen. The chairmen will be responsible for making sure that each speaker does not run over time and will use his / her discretion as to whether there is time for questions. There will be ample time for discussion during lunch, the poster viewing session, in the evening and during the field trip.

Geocenter opening hours

The Geocenter is open to the public from 8.00 to 16.00. Outside of these times, it will not be possible to get back into the building once you are outside, unless you are with someone with a keycard. Outside opening hours please do not hold doors open for more than a few seconds as the Geocenter's alarm system will be activated. The main entrance to the Geocenter will be manned on the Thursday evening for the reception/registration until 22.00. On Friday, after the talks it will not be possible to leave the building and re-enter for the evening meal. There will be refreshments served in the Rotunden after the talks at 18.00 and the meal will begin at 19.30. The Geocenter will be closed on Saturday. Please do not try to enter the building before we leave for the field excursion.

Oral abstracts

Was there, or was there not a meteoritic impact at the K/T boundary 65 million years ago?

Hans Jørgen Hansen

It was a so-called mass extinction. Two larger mass-extinctions are recognised: one at the Permo-Triassic boundary 250 million years ago and one 65 million years ago. The earlier extinction marks the boundary between the Palaeozoic (old life) and the Mesozoic (middle life), and the second lies between the Mesozoic and the Cainozoic periods. The K/T boundary event caused the disappearance of around 70 % of all species, while the P/T boundary event caused the disappearance of around 90 % of known species. All other so-called mass extinctions are dubious but the P/T and K/T are not (though we may discuss the numbers).

The K/T boundary: Who disappeared? The planktonic foraminfera. Some coccoliths disappeared permanently, while others only disappeared temporarily (the so-called 'Lazarus effect'). The ammonites and the belemnites disappeared permanently. Some lamellibranchs and gastropods too, while others made it across the boundary.

Common to all that disappeared is the possession of a planktonic carbonate larval shell. The larger animals in the marine ecosystem (such as the marine lizards (Mosasaurs) disappeared when the food chain broke down, because the primary produces were hit. The dinoflagellates were un-hurt and the same applies to the diatoms (siliceous algae). These two groups are without carbonate and they do not seem to be effected. It looks as though marine animals and plants using carbonate, spending their lives in the uppermost part of the water column (the photic zone) were effected.

At the K/T boundary, one observes the presence of a negative carbon isotopic anomaly. This is a drop in ^{13}C relative to ^{12}C. There are three carbon isotopes in our system: ^{12}C, ^{13}C, and ^{14}C. The last one is radioactive, disappears after some 60,000 years, and is without interest in our discussion. The ratio between the two others is usually recorded as a ‰ deviation relative to a standard.

The $^{13}C/^{12}C$ can be measured in carbonate or in organic carbon such as soot, charcoal or sporo-pollenine. The negative ^{13}C anomaly at the K/T boundary has been linked to a meteoritic impact, which was supposed to have caused darkness on earth for an extended period of time (months to years) and thereby killed the marine plants such as coccoliths. The coccolithophoriids produce carbonate plates that fall to the seafloor. These plates are slightly enriched in the lighter carbon isotope (^{12}C). Therefore, if they were stopped in their activity, there would be more ^{12}C left in the system causing a depression in the relative amount of ^{13}C. This must take place right at the disappearance time of the algae or very shortly after they were hit.

Registration of the carbon-isotopes from dinocyst skeletons at the K/T boundary in Denmark demonstrates that there is a time difference in the appearance of the isotopic deviation between Stevns Klint in the south-eastern part to Nye Kløv in the north-western part of the country. This time difference can be estimated to be around 100,000 years. At Stevns Klint, the boundary between the Cretaceous and the Tertiary deposits takes place at the so-called Fish-Clay horizon where carbonate producers such as coccoliths and foraminifera disappear suddenly. At Nye Kløv, the plankton continues 15 cm higher than the negative isotopic excursion! Stevns Klint represents a much shallower depositional environment than the one at Nye Kløv. It follows that the carbonate deposition ended earlier in shallow water than in deeper water.

In the 1950's Worsley proposed a hypothesis which would explain the clay or marl-layer found everywhere in the marine deposits at the K/T boundary (at Stevns Klint, the Fish-Clay). Worsley claimed that there was disorder in the global carbonate cycle and that the clay/marl was a dissolution residue. He suggested a general rise in the CCD (carbonate compensation depth) as the cause. This can be directly discarded, since a slow rise in the CCD would lead to longer hiati in deeper waters than in shallow water. If the rise were fast, it would lead to hiati of equal duration. We do, however, see that the shallow locality has a longer hiatus than the deeper one, and this is impossible in Worsley's theory.

Dinoflagellate resting cysts are made of sporo-pollenine (as are spores and pollen) which is extremely resistant. They can be oxidised whereby they disappear. Investigation of the dinocysts of the Fish Clay at Stevns Klint shows that the flora is dominated by a dinocyst, which does not occur at all in the underlying chalk. If the Fish Clay should be a dissolution residue, its content should originate from the chalk. Thus, the Fish Clay is a sediment deposited in Fish Clay time, and it is not a dissolution residue.

This allows us to continue with the argument. We may now make statements as to the cause leading to a stop in carbonate production initially in shallow water and later in deeper water.

The uppermost part of the oceanic column's primary production occurs through planktonic algae (coccolithophosiids, diatoms and dinoflagellates) that need light for their production. This part of the ocean is up to a maximum of 100m deep (generally less). It is in this part of the ocean that the planktonic larvae of carbonate-shelled organisms lived (namely, where the high production is found).

We are looking for a mechanism, which will selectively strike the carbonate-shelled organisms living in the uppermost part of the oceanic water-column. The present atmosphere has a CO_2 content of around 370ppm. One may ask how much CO_2 is needed in the atmosphere in order to make the top of the ocean acidic! The ocean is a very sluggish system and any mechanism that involves diffusion is much too slow to give an effect. However, the ocean has a so-called mixed-layer, i.e. the layer being mixed through wave action causing mechanical stirring. It extends to about 50m depth, which is the deepest wave-base.

At an atmospheric CO_2 concentration of 5500ppm, the pH (acidity) of the seawater is 7.0 at 20°C. The normal acidity of seawater is alkaline (at around 8.2) and laboratory experiments show that coccoliths have serious problems producing carbonate scales at a pH of 7.5. Coccolithophores can survive pH down to 5.5 but they stop producing plates. When brought back to normal conditions they start producing again (the 'Lazarus effect' *op. cit*.).

Cretaceous coccolith species found above the K/T boundary in Israel were primarily interpreted as re-deposited fossils. However, carbon-isotopic measurements showed that their composition was different from that of the Cretaceous fossils and that they gave an Early Paleocene signal. Thus, they had survived and were not re-deposited.

Our present CO_2 content in the atmosphere is rather low. We are at present in an interglacial period. In order to obtain a mass-extinction in the ocean it is necessary to increase the present CO_2 content by around five times. We do not need a pH in the top ocean of 7,0 since the primary producers only need a collapse value of around 7,5. This corresponds to around 1750 ppm CO_2 relative to the present 370 ppm). Is such an addition realistic?

We know one mechanism that releases huge amounts of CO_2 to the atmosphere. These are the so-called plateau-basalts (or continental flood basalts) that occur now and then in the history of the earth. At the K/T boundary the Deccan Traps basalt province was active and caused extrusion of an estimated 1,5 million km^3.

The two main gases, which are released by basaltic eruptions, are CO_2 and SO_2. There is 2-3 times as much CO_2 as SO_2. The isotopic composition of the volcanic CO_2 is around -23, and therefore much more negative than our present atmospheric CO_2 which is around - 7. 100 years ago it was only -6 but has changed through our burning of fossil fuel! We have found that degassing from $2{,}8*10^5$ km^3 basalt is sufficient. Thus, we are able to create a mass extinction among calcareous marine organisms that live in the upper photic zone by intensive volcanism.

The immediate effect of the volcanism would appear to be a strong greenhouse effect. However, the greenhouse is delayed because of SO_2 (which is oxidised in the atmosphere to SO_3 and forms micro drops of sulphuric acid). As the droplets are smaller than the wavelength of light, photons that enter a drop will have the same chance of being returned to space as travelling to the earth. We thereby have a greenhouse that is initially cold. The effect of the cooling is the formation of glaciers on the more elevated areas (mountainous glaciation) and Antarctica. This leads to drop in the sea level, which can be seen in the presence of hard-grounds at Stevns Klint. The first hard-ground is found 700,000 years before the K/T boundary. The second is in the Fish Clay and the third and largest is straight after the deposition of the *Cerithium* Limestone at Stevns. In terms of time, the last hard-ground occurs only 40,000 years after that in the Fish Clay. The magnitude of the regressions (sea level drops) can be monitored in the incised river valleys in USA.

A small explanation is needed: The ice started melting after the last glaciation 11,500 years ago. 5,000 years ago the sea level was higher than today. Thus in 6,500 years the sea level rose by 100m! If one studies a seismic profile across the lower Mississippi River one can observe that the real riverbed is at 90m depth below surface. When sea level was lower during glacial times the river carved out its bed so that it corresponded to the existing sea level.

700,000 years before the K/T boundary incised river valleys with a cutting depth of 8.5 to 10.5m are observed everywhere in the terrestrial deposits in North America. The distance from the riverbeds to the ocean at that time was from 300 to 500km. The slope was small (1 foot per mile) since the sediments were very soft. The first drop in sea level was by around 20m; the second (during Fish Clay time) around 30m and the last one around 50m. In order to has some basis for comparison: Melting the Greenland inland ice would lead to an increase in sea level of around 12m. Where the main bulk of the ice was at that time is not hard to guess, since Antarctica was lying over the South Pole as it is today. The effects of mountain glaciation can be observed in the Alps, where we find melt water sediments in the valleys as the only sign of the presence of the glaciers.

Each of the repeated cooling events is followed by a CO_2 greenhouse, which rapidly melts the ice, fills up the ocean and stems the groundwater. The riverbeds are filled by sediments and are commonly covered by a coal layer. The system with incised valleys and super positioned coal layers continues into the Tertiary, but has not been studied in detail yet.

Plants with C3 photosynthesis were the only plants in existence prior to Miocene time around 30 million years ago. Thus, C4 plants (grass, maize etc.) had not evolved yet. Dinosaurs were not grass-eaters for very good reasons!

When C3 plants assimilate CO_2 from the atmosphere they fractionate the carbon through diffusion processes so that cellulose from a pine tree will have a delta ^{13}C ‰ of -27. This means that they fractionate the atmospheric carbon with -20 delta values. Therefore we have a means to determine the atmospheric CO_2 isotopic composition in former time. When changes occur in the atmospheric isotopic composition, C3 plants the world over will register this in their cellulose. Through the study of plant carbon isotopes from closely spaced samples across the mass extinction boundaries we find a variation pattern that can be used to correlate the different localities in time, since the atmospheric system rapidly mixes. We find that there are a series of negative anomalies both before and after the K/T and the P/T boundary.

They cannot all be caused by extinctions. How many times can one become extinct? We are looking for a repeated cause and the only one available seems to be volcanism. Volcanic activity is characterised by high activity phases followed by calm time intervals. At the K/T boundary we may therefore take the isotopic variation as an indication of the activity of the Deccan Traps volcanism which repeatedly extruded large amounts of negative carbon into the atmosphere and which the plants faithfully incorporate into their cellulose (because they just could not help it).

The Deccan Traps volcanism starts with an intensive phase 700,000 years before the extinction of marine organisms. It is registered on Stevns Klint by a hard-ground. The hard-ground separates the white chalk from the overlying grey chalk. The grey chalk owes its colour to a raised amount of elementary carbon. This carbon has an isotopic composition of -26 to -27 while charcoal from the Fish Clay has a value of -25.

It has been suggested that a meteoritic impact caused worldwide forest fires at the K/T boundary. If this should be the reason for the elementary carbon (soot) in the grey chalk, we face a problem, because the meteorite should have arrived 700,000 years before the boundary. Soot from wood fires consists of non-combusted material and should have the same isotopic composition as the wood (charcoal). Part of the carbon in the grey chalk may stem from marine plants but also from the Boudouard reaction, which is active at volcanic eruptions. It leads to the formation of elementary carbon of very negative isotopic composition. The reaction calls for the splitting of CO into CO_2 and elementary carbon. It takes place at one atmosphere and in the temperature interval between 600 and 1000°C. Since there are no differences in the organic content between the white chalk and the grey chalk the main part of the elementary carbon must stem from volcanism. The carbon particles consist of fluffy aggregates with a grain size of around 0.2 microns.

In 1979, a meeting was held in Copenhagen and was concerned with the subdivision of the Cretaceous time period. At this meeting, some Americans presented an investigation of the trace-element chemistry of the K/T boundary layer from Gubbio, Italy. This layer corresponds to the Fish Clay at Stevns Klint. It is an old suggestion that the extinction at the K/T boundary could have been caused by a nearby supernova explosion followed by a particle radiation reaching the earth. Heavy elements are created in supernova explosions and therefore they had looked for presence of plutonium. The plutonium half-life is long enough to ensure its presence in 65 million years. They found no plutonium, and therefore: exit supernova!

They also looked for the element iridium (which is from the group of noble metals). Iridium was used because it is relatively easy to analyse by instrumental neutron activation (INAA). This had earlier been used to estimate the input of material from space into the deep-sea sediments. Meteoritic dust has a rather high content of iridium relative to the earth's crustal rocks. The amount of iridium was therefore expected to yield an estimate of the time it had taken to deposit the boundary clay. They found surprisingly high values and when analysing the Fish Clay from Stevns Klint they found even more. This made them suggest that the iridium could stem from a meteoritic impact. By simple calculation, the size of the heavenly stone could be estimated to 10-15 km in diameter.

Well, it was not geologists who suggested this, because they would have smelled a rat. When a meteorite approaches the earth it does so with speeds of 20 to 30 km/second. The energy from an impact of a 10-15 km body corresponds to earthquakes measuring around 15 on the Richter Scale. The consequence would be that all loose, shallow water sediments would be mechanically disturbed and all these sediments outside river mouths would travel to the deep sea as turbidites. However, we see no disturbances in shallow water sediments and the K/T boundaries in the deep sea are very calm and undisturbed. In short: there was no meteoritic impact!

The iridium enrichment was, however, still unexplained, but in 1983, iridium enrichment was found on flying dust from the Kilauea volcano on Hawaii. Later, recent emanation of Ir from the Reunion Island volcano was reported. Russian geologists collected volcanic ash from Kamchatka and found that the smaller the grain size and the further away from the volcano they spread, the more Ir was present. Hawaii and Reunion are both 'hot spot' volcanoes, but Kamchatka is calc-alkaline so there are wide possibilities for Ir production by volcanoes. This was, however, not known in 1979.

The Deccan Traps volcanic field in India stems from the passage of the Indian plate over the hot spot volcano on Reunion Island. At that time India was positioned around 30 degrees south. Since we today find emanation from the volcano corresponding to a concentration in the magma of 7 ppb Ir, it would be logical to look for Ir-bearing basalt in Deccan. French and Indian scientists have looked, but have not found any. The problem has been that they have been looking randomly, because they have been unable to determine the K/T boundary position in the terrestrial Indian deposits. It has recently been shown that a basaltic flow very shortly before the K/T boundary is Ir bearing.

Now let us look at the Ir anomaly as a unique phenomenon. Is it unique and does it occur everywhere at the same time? This would be expected if it should stem from an impact. We have to separate terrestrial and marine deposits in this context. In the marine realm, many places have preserved Ir enrichment at the K/T boundary coincident with the extinction level. This is however, not the case in the Negev, Israel, where there is none at the extinction level but it occurs later at the P1b-P1c plankton boundary. Four Ir enrichments have been reported from marine deposits of Upper Paleocene age from Slovenia. At El Kef in Tunisia, two enrichment levels were reported long ago, one is at the extinction level and the other is younger.

In the terrestrial deposits in North America, from Alberta, Canada to New Mexico in southern USA, an Ir enrichment has been found. It occurs in a coal layer, which can be placed time wise 40,000 years later than the K/T boundary, which is marked by a change in spores and pollen. It is found in the close vicinity of a rhyolitic ash layer and is unrelated to the marine enrichment. It is related to the volcanic ash layer. The same is the case with three Ir-anomalies in a lake deposit in NW India (Gujarat Province). The age of the latter is several 100,000 years earlier than the K/T boundary and all three are associated with rhyolitic ash layers.

The find of an Ir-bearing basaltic flow in India suggests the possibility that the Ir from the basalt eruption can be the source of the Ir enrichment in the ocean. The basalt flow in India is a single and not a composite flow with a thickness of more than 30m covering a large area. If the basalt should yield enough iridium to cause a general enrichment of 4 ppb (nanogram/gram) corresponding to 50ng/cm^2 we need $2,5*10^8$ kg of iridium. If we assume a degassing of 7 ppb (like the present day value from Reunion) we end up with $2,8*10^4$ km^3 or 0,8% of the Deccan volume. This figure may be too high, since much of the iridium deposited on land eventually may end up in the ocean. No terrestrial K/T boundary has so far been found to show Ir enrichment (the American one happened too late).

A group of microbiologists wrote an article in which they pointed out, that by microbiological processes it would be possible to concentrate iridium into an anomaly provided that the iridium was available. The Ir anomaly is connected with the collapse-layer, which most often coincides with the extinction horizon. It is not the case in Israel where the extinction level occurs earlier than the collapse-layer (the latter is an organic-rich horizon).

The timing of the Ir-bearing basalt is very shortly before the K/T boundary. So there seems to be an explanation for the anomaly other than a meteoritic impact (which never took place!).

Now to some of the small side effects from the postulated meteoritic impact that time and again has called upon the sensational headlines:

1) Shocked quartz, which is ’only’ found in connection with meteoritic impacts

It is undoubtedly so, that when a meteorite impacts into quartz-containing rocks, quartz grains with micro-lamellae with characteristic directions are formed. The micro-lamellae consist of diaplectic (shocked) glass and are also found after larger subsurface TNT and atomic explosions. This has led to a larger literature regarding presumed meteor craters back in earth history. If one finds shocked quartz, then it is a meteoritic crater. This is, however, not so! A series of rhyolitic ash beds of different ages have been found to contain shocked quartz also. We now know seven examples of this.

Admittedly, not all rhyolitic ash beds contain shocked quartz, as it depends on the composition of the rocks overlying the explosion site. If a meteorite impacts rocks without quartz, you do not find shock quarts. The same goes for a rhyolitic volcano. We may talk of an ’upside down’ impact. Shocked quartz cannot be used as conclusive evidence for a meteoritic impact.

2) Tektites

When a meteorite impacts, smaller drops of melted rock are created. They are sprayed and may fall far from the impact site. The temperature of the material is very high and the surfaces of the drops, that may reach cm-size, often show a characteristic pitted surface. As the temperature is high and the oxygen content of the atmosphere is high, (21%) the material is being oxidised. If the glass contains carbon, it will be oxidised and one shall not expect to find a content of elementary carbon (graphite) in it.

Scientists supporting the impact hypothesis have interpreted spherules found at the marine K/T boundaries as being diagenetically altered micro-tektites. However, closer examination demonstrates that the so-called microtektites are sitting inside spherical algal skeletons. They are actually diagenetically infilled algal skeletons belonging to a group that have been called ’disaster species’. They occur in enormous amounts when their enemies are in trouble. They are also present at the other large mass-extinction at the Permo-Triassic boundary, where the same phenomenon occurs. Depending upon the local chemistry on the seafloor the skeletons may be filled by different minerals.

In the Mexican Gulf, beds containing spherules have been found. They have been declared altered micro-tektites. If such spherules are sectioned (some are mm size) one observes that they are full of vesicles. They have nothing to do with tektites. They contain small, hollow graphite spheres. If one dissolves basaltic volcanic glass one will end up with a residue of up to 15-micron hollow graphite spheres. They are sitting as a coating inside gas vesicles and would appear to have formed by the splitting of CO into CO_2 and elementary carbon (the Boudouard reaction). Free carbon does not exist in tektites. The spherules from the Caribbean are volcanic bead (Pele’s Tears). They are filled with gas-vesicles and many can float on seawater (some even on fresh water). Thus, they are volcanic products, and unrelated to meteorites.

3) Ni-rich spinels

Inside the spherules that have formed inside the ’disaster algae’ at the marine boundaries, one sometimes finds small branching crystallites. They consist of iron-nickel compounds with spinel structure. Such crystallites can be created by heating an iron-meteorite in an oven. Their presence in the spherules has been taken as an indication of an impact. However, they have a different chemical composition from place to place, and since they are sitting inside the filled algae it is evident that they formed where they are sitting today. The chemical difference from place to place also means that one has to suppose that each place had its own meteorite, in order to explain the difference.

4) Extra-terrestrial amino acids

At Stevns Klint, so-called extra-terrestrial amino acids have been found above and below the Fish Clay, but not in the Fish Clay proper. Such amino acids are common during fire-processes and their relevance for the K/T boundary is rather hazy.

As the dream about the ’bomb’ as the killing agent is incorrect, we have to look into other mechanisms, and so far, I have avoided the dinosaurs because that needs lengthy explanations.

In the terrestrial deposits before the K/T boundary, a change in the composition of the dinosaur fauna in France takes place. This happens at the level of incised valleys 700,000 years before the K/T. Southern France has the same incised valleys as in North America and it is here that the famous bone-beds that are being excavated in the Aude Valley are found. At this level a change takes place from a fauna with many titanosauriid forms (4-legged forms with long tails and long necks) to hadrosauriid forms (duckbilled dinosaurs). The French deposits are ’red-beds’. In these, the dinosaurs laid their eggs, which are found rather commonly. The sediments are red to reddish brown. There are occasional horizons with yellow or blue-green vertical traces after plant roots. Plant roots breathe and consume oxygen; they do not produce it. Therefore, around the root traces are reduced iron and therefore the other colours. There was occasional vegetation but the find of microscopic desert roses shows that is was a desert like environment.

When dinosaur eggshells are collected level by level from older to younger sediments there is, around 350,000 years before the K/T, an increase in the frequency of black eggshells. When collected further down, the frequency of black eggshells is around 1%, while it increases to between 10 and 15%, and the very last level contains black eggs only. The black colour is not confined to the surface of the eggshells, but stains the whole shell as seen in broken pieces. Bird's eggs with colours are not coloured throughout the shell, but only on the surface.

Black dinosaur eggshells have been found in China, India and France. Chemical analysis of the black eggshells shows that they contain silver (silver sulphide). The amount is on the ppm level, which is 1000 to 10,000 times the background silver value in the surrounding sediment. The find of silver-bearing eggshells in different regions and in different species tells us, that it is independent of species and must be caused by later processes. In spite of the goose known from fairy tales, the dinosaurs did not lay silvery eggs!

The hatching mechanism must be looked into. Dinosaur eggs (and alligator, crocodile, turtle etc.) eggs are all highly porous. Even when the shells are several mm thick, they still have very high water vapour conductivity. A fresh alligator egg and a bird's egg put together in a heating cupboard at 40° C show a water-loss of the alligator-egg that is 10-15 times that of the bird's egg. The Florida alligators solve the problem by laying their eggs in moist compost, which they scrape together in the swampy areas where they live. The high water vapour conductivity prescribes that the eggs must be hatched under moist conditions without exposure. The Everglade crocodiles are also able to use wet sand along rivers for their hatching. In the Indonesian region is a crocodile, which can knock down vegetation in the back mangroves. It waits until the primary fermentation is over because that leads to temperatures in the early 60's. When the temperature drops and cellulose fermentation takes over, temperatures drop to the early 30's. It then lays the eggs and starts waiting for the outcome.

The dinosaurs did not deposit their eggs exposed. They used wet sand or compost. It is, however, not easy to get compost in a desert-like environment, where we find their nests today. If you look at an elephant from behind, you will observe a big belly full of pre-fermented compost. Therefore, it is an obvious possibility, that plant-eating dinosaurs used their dung as compost material. The meat-eating dinosaurs were confined to parasiting on other's composts or to use wet sand. The parasite behaviour was just found in Portugal, where meat-eaters parasited upon crocodile-compost nests.

What is the origin of the silver? If an egg is no good and for one or another reason will not develop and hatch, it will start rotting. This leads to production of H_2S. Along with the fermentation of the compost all trace elements from the compost will be brought into contact with the rotting egg and all elements that can form sulphides will be precipitated in the shell. Silver sulfide is difficult to bring into dissolution. Think of a silver fork, which has been in contact with a fried egg. The silver sulfide has to be polished off or you have to use chemical means to clean it.

Thus - a black egg is one that never hatched. That all the eggs from the last level in France are black means that they never hatched. During the period of increased non-hatching of eggs, there were still eggs that were hatched. Among humans and animals it is so, that all chemical loads such as arsenic etc. show up in the hair and nails. We are de-poisoning ourselves. We therefore looked for eventual elements in the white eggshells in the period where the black eggshells were increasing in numbers. We found a surprisingly high content of the element selenium.

Selenium is an element, which is essential to humans and other animals. Experiments with hens, however, demonstrated that increased concentration of selenium strongly reduced the hatching of the eggs, through increased non-development of the foetuses. Those who looked into this made investigations of blood, brain, kidney, albumen and yoke. The only thing they did not investigate was the eggshell. Who cares? Therefore, we had to run our own experiments with hens suffering selenium load. From the literature, it appeared that 20-ppm selenium had a poisonous effect, and therefore the hens got 15-10-5 ppm and as a control chicken-fodder from the local Coop. The results were perfectly clear: irrespectable of the load, they invariably showed 1:2 in concentration of selenium between eggshell and yoke. We cannot make experiments with living dinosaurs, but their nearest relatives (the birds) did not become extinct; they just put on feathers and climbed into the trees.

The next question is of course where did the selenium come from? The analysis of the extrusion products from Kilauea, Hawaii in 1983 showed that the element that was most strongly enriched relative to Hawaiian basalt, was selenium. In the volcanic flying dust, the concentration relative to the basalt was raised by a factor of 10^7. How much did a plant-consuming dinosaur eat per day?

The Zoological Garden in Copenhagen has told us that a 4 ton African elephant eats 200-400kg plant material per day. If you want, you can scale it to a 20 ton dinosaur! This again you may convert into plant leaf area, which a plant-eating dinosaur would consume every day. If the leaves were carrying Se-bearing volcanic flying dust, one may assume a reduced hatching. One may argue, that there will always be someone who can survive this! However, one has to consider, that a Se-load is not constant but arrives in pulses. Thus, the 'normals' that just made it will get a renewed knock on the head, since it is not a constant pressure on the populations. A drop in hatching of 10% corresponds to the reduction in the crop of African elephants when the poaching for ivory was at its highest. In few years, the elephant was declared an animal facing extinction. The reduction in crop lead to the disappearance of the French dinosaurs 350,000 years before the K/T boundary. Interestingly enough the dinosaurs in India vanished at the same time. The dinosaurs in North America stayed on and the same goes for the Chinese ones. The very last American dinosaur (probably a Triceratops) lies 2.25 m beneath the K/T boundary while the three last nests with black eggs are 90,000 years below the K/T boundary in South China. We do not know of any younger dinosaurs. When talking about dinosaurs, we do not recognise loose bones and teeth. They are easily re-deposited. We recognise only: eggs in nests, footprints and articulated skeletons.

Thus, the dinosaurs disappeared at different time in different areas, and we are forced to suppose that they were unable to tolerate very rapid climatic changes coupled with the rapid drops in sea level. Their living space was strongly reduced following the sea level drops. It leads to other drainage patterns of the land areas, whereby the available feeding areas were reduced drastically. The observation, that each of the different families only had a single representative left at the end of the Cretaceous is in good agreement with this. We therefore conclude that the disappearance of the dinosaurs is linked to reduced hatching and limitation of living space.

This explanation is not as 'sexy' as the Heavenly Stone (or the 'bomb') but it fits well with the observations. And that, in a way, is very nice!

New data on an expanded K/T boundary section, Stevns Klint, Denmark

Malcolm Hart, Sean Feist, Gregory Price & Melanie Leng

The Cretaceous/Tertiary boundary sections of Stevns Klint (Denmark) famously record the transition from the white coccolith chalks of the Maastrichtian through to the bryozoan-rich mounds of the Lower Danian. Located at the boundary is the thin, organic-rich clay known as the Fish Clay. This clay contains, in its lowermost levels, the iridium concentration that is now accepted as the signature of the K/T "event" in successions from around the globe. The majority of workers have concentrated their efforts on one succession, immediately below the old church at Højerup, which is located in the middle of the 12 Km long cliff section. At this location the Fish Clay varies from 0 – 7 cm. in thickness, being preserved in a number of small troughs formed by a series of mounds in the uppermost Maastrichtian chalks. We have, over a period of 27 years, visited all parts of the succession from Rødvig (in the south) to Bøgeskov (in the north) and sampled the boundary extensively at three locations: Højerup, Rødvig and Kulstirenden. At the latter location, an expanded Fish Clay succession attains a maximum development of almost 40 cm. and has been sampled at ~1 cm. intervals. As part of our work we have studied the sedimentology, benthonic and planktonic foraminifera and the stable isotopes (δ^{13}C and δ^{18}). The benthonic foraminifera are only marginally affected by the extinction "event" at the K/T boundary, although there are subtle changes in the distribution/dominance of key taxa. The isotopic analysis (based on bulk carbonate and selected genera of benthonic foraminifera) shows the typical Maastrichtian pattern, followed by the pronounced negative δ^{13}C excursion within the lowest part of the Fish Clay. Within the expanded Fish Clay succession at Kulstirenden there are some significant variations in the δ^{13}C record and a number of 'cycles' are recorded within the organic-rich part of the succession. In other comparable K/T boundary successions, including those in other parts of Stevns Klint, only one pronounced negative excursion is recorded within the reduced thickness of the Fish Clay. The precise stratigraphy of the expanded Fish Clay is being investigated using the planktonic foraminifera, although most taxa in the more organic-rich part of the clay have suffered varying degrees of dissolution. Only the more robust benthonic taxa are preserved in this part of the succession and, again, this is almost certainly the result of dissolution either on the substrate or within the upper part of the sediment column. Using our microfaunal and sedimentological evidence a sequence stratigraphical model for the K/T boundary is proposed for the boundary interval which attempts to explain the "mounds" in the uppermost Maastrichtian and the variations within the Fish Clay.

A comparison between morphometric and unsupervised, artificial, neural-net approaches to automated species identification in foraminifera

Norman MacLeod, Mark O'Neill & 'Stig' Arron Walsh

One way of addressing long-standing concerns associated with low reproducibility of foraminiferal taxonomic results, and coping with the looming taxonomic impediment, is through development of automated species-identification systems. Two generalised approaches are considered relevant in this context, morphometric systems based on some form of linear discriminant analysis (LDA), and artificial neural networks (ANN). In this investigation, digital images of 202 specimens representing seven modern planktonic foraminiferal species were used to compare and contrast these approaches in terms of system accuracy, generality, speed, and scalability. Results demonstrate that both approaches are capable of yielding systems whose models of morphological variation are over ninety per cent accurate for small datasets. Performance of distance and landmark-based LDA systems was enhanced substantially through application of least-squares superposition methods that normalise such data for variations in size and 2D orientation. The LDA approach was, however, found to be limited practically to the detailed analysis of small numbers of species by a variety of factors (e.g., the complexity of basis morphologies, speed of data acquisition, feature-space sample dependencies). An ANN variant based on the concept of a plastic self-organising map, combined with an *n*-tuple classifier, was found to be marginally less accurate than landmark-based LDA, but far more flexible, much faster, and robust to feature-space sample dependencies. Both approaches are considered valid within their own analytic domains, and both can benefit from various sorts of technology transfers. Taken as a whole, though, results indicate that fast and efficient, automated species-recognition systems can be constructed using available hardware and software technology and would be sufficiently accurate to be of great practical value in a very wide range of micropalaeontological contexts.

Microfossil and nannofossil analyses of ditch cutting samples from two wells from within the Silverpit Crater, British Sector, North Sea: evidence towards confirming the age and origin of the structure

David J. Jutson, Mike Bidgood & Ben Johnson

The Silverpit structure, which lies in the Anglo Dutch Basin in the British Sector of the North Sea, was identified during 3D seismic studies for hydrocarbon exploration by Stewart and Allen in 2002.

The 20 kilometre diameter ring structure was interpreted by the authors as a meteorite impact, and although other possible methods of its formation have been proposed, the impact theory has been accepted for this presentation.

From their data, Stewart and Allen suggested that the age of the impact was probably around the K/T boundary which would make it especially interesting in the light of the recent controversy over the status of the Chicxulub Crater, and with the suggestion that the end-Cretaceous extinctions were partially caused by multiple impacts.

Both microfaunal and nannofossil analyses of the ditch cutting samples from two wells (43/24-3 and 43/25-1, both within the structure) have been used to attempt to define the exact age of the impact and to find any evidence that might support any of the proposed theories for its origin.

The results obtained so far partially answer both problems.

Development and application of an integrated biostratigraphical model for the South Arne field, offshore Denmark

Haydon W. Bailey & Matthew J. Hampton

Prior to initiating the horizontal development well programme on the South Arne field, offshore Denmark, the operators Amerada Hess A.S. undertook a review of the existing micropalaeontological and nannoplankton database on the original discovery and exploration wells. Since 1998, as each additional well has been drilled the biostratigraphic data generated has been integrated into the existing model used on the rig by on site biostratigraphers.

The model for the main Tor Formation reservoir was tested, evaluated and updated with each new well into a different sector of the field. In addition to this, the biostratigraphic zonation of the Ekofisk Formation has been completely reviewed during a series of major studies through this formation. These have resulted in the recognition of additional foraminiferid and radiolarian marker events which have been carefully calibrated with the controlling nannoplankton zonation. The current stratigraphic model for the south Arne field is presented.

The microfaunal content has proved to be of primary value in the monitoring of wells within the Tor Formation, given the recognition that the reservoir section comprises a series of biofacies units within an allochthonous chalk, capped by a thin succession of autochthonous hemipelagic chalks. The whole of this succession is constrained within a single nannofossil zone. Conversely, the nannoplankton zonation through the overlying Ekofisk Formation is extremely refined, allowing accurate monitoring of wellpaths for casing picks and also for the development of potential reservoir units within the Ekofisk itself. The increased refinement of the biostratigraphic model during development drilling on the crest of the field has assisted in the interpretation of the hydrocarbon bearing chalk succession encountered on the flanks of the structure.

Calcareous nannofossils in extreme environments: The Messinian Salinity Crisis, Cyprus

Bridget Wade & Paul Bown

The rapidly changing and extreme environmental conditions of the early Messinian Salinity Crisis are reflected in abrupt variations in nannofossil assemblages within the Messinian units (Kalavasos Formation) from the Polemi Basin, Cyprus. During the Messinian, the Polemi Basin was a semi-enclosed, neritic to littoral environment, subject to repeated influxes of marine and freshwater. Nannofossil diversity (3 to 11 species) is greatly reduced in comparison to the open ocean and assemblages are highly uneven with high dominance. One of five nannoplankton species were observed to dominate any of the assemblages, these were *Reticulofenestra minuta*, *Dictyococcites antarcticus*, *Helicosphaera carteri*, *Umbilicosphaera jafari* and *Sphenolithus abies*. The associated diatom and sedimentological evidence from the Polemi Basin are used to indicate the palaeoecology of key nannofossil taxa. *D. antarcticus* predominated in normal salinity, mesotrophic, shallow water environments; *H. carteri* in shallow, hyper-eutrophic environments with enhanced salinity; *U. jafari* hypersaline conditions; *R. minuta* in hyper-eutrophic conditions with an abnormal salinity from brackish to hypersaline; *S. abies* in mesotrophic, deeper and normal salinity environments. These species are indicated to be opportunistic taxa, adapted to unstable environments. Fluctuations in nutrient levels and salinity are interpreted as the primary factors controlling the overall nature of the nannoplankton assemblages and the species which dominate at any one level.

Foraminifera and nannofossils in the Western Interior Sea, Canada: reconstruction of Cretaceous sea-level history

Claudia Schröder-Adams & Jim Craig

The Canadian Western Sedimentary Basin documents a complex paleoenvironmental Mesozoic history linked to tectonism and global and relative sea-level changes. Cretaceous strata record the history of the Western Interior Sea, a marine basin under variable palaeoceanographic restriction. In unravelling its depositional history a multidisciplinary approach (in which foraminiferal and nannofossil studies play integral parts) has been proven as most successful.

Cretaceous sea-level history in the Western Interior Sea is recognised in ten global transgressive/regressive cycles. Highest sea levels are recorded during the Albian to Santonian, when the shale dominated Colorado Group was deposited in the Western Canada Sedimentary Basin. A seaway developed during times of highest sea levels connecting the Tethyan and Boreal seas and creating a complex watermass stratification pattern. Several anoxic to dysoxic events are documented that have influenced different basin areas with varying intensity.

When the basin was connected to the northern Boreal Sea, but enclosed to the south, agglutinated foraminifera dominated benthic environments. Salinities were reduced and at times sediment input into the basin was high. During phases of sea-level highstand normal marine conditions prevailed and southerly derived planktic foraminifera and nannofossils become important biostratigraphic markers. At the same time anoxic bottom-water conditions resulted in finely-laminated, organic-rich black shale sequences, barren of benthic foraminifera.

It is difficult to divide large mudstone and shale-dominated sequences, indicating deposition in distal basin settings, based purely on lithology. Faunal assemblages, however, respond to subtle basin processes and their changes can be correlated with regional log markers. Disconformities, hidden within shale sequences without pebble beds or bioclastic conglomerates, can only be detected by missing faunal and floral zones. Therefore micro- and nannofossils are a vital part of sequence stratigraphic analyses. They distinguish flooding surfaces from maximum flooding surfaces and determine unconformities.

Tracefossils have also become a reliable component of sequence stratigraphic analysis. In the Cretaceous Canadian Basin, in once soft, muddy offshore sediments with little lithological contrasts to enhance ichnofossils, the additional use of foraminifera supports paleoecological interpretations. In shallow marine settings, lagoonal sediments can resemble finer-grained, low-energy, fully marine shoreface settings in lithology and log signature. In these complex environments micropaleontology has been successful in paleoenvironmental analysis by showing distinct biofacies.

Stable isotopes in calcareous dinoflagellate cysts and their possible application in palaeoenvironmental reconstructions

K.J. Sebastian Meier

The ideal organism for stable oxygen and carbon isotopic palaeoclimatic studies should have a widespread geographic distribution, reach a sufficient abundance, be easily detectable and collectable, be resistant to dissolution, have no symbionts, live at a stable and restricted position in the water column, and continually produce calcareous tests throughout the year and in a relatively short time. Dinoflagellates producing calcareous cysts can fulfil most of these requirements, therefore they have recently been subject to preliminary stable isotopic studies.

Comparison of calcareous dinoflagellate and foraminifera stable oxygen isotopic data has been used to determine the relative depth habitat of Upper Cretaceous calcareous dinoflagellates, suggesting that calcareous dinoflagellates can probably be used in sea surface water temperature reconstructions.

More detailed investigations are possible on modern calcareous dinoflagellates. In a pilot study, it was suggested that *Thoracosphaera heimii*, the single most common species worldwide, can be used in temperature reconstructions. This species can be found in highest abundance in the upper part of the thermocline, and their $\delta^{18}O$ values seem to reflect the mean annual thermocline temperatures. However, the calculations are based on the assumption that *T. heimii* has no vital effect, i.e. that the stable oxygen ratio in its tests reflects the ratio in the surrounding sea water. In fact, T. heimii has a relatively strong vital effect in respect of $\delta^{18}O$ of about –2.5‰ (Dudley et al., 1980). Therefore, the temperatures calculated by Zonneveld (2004) are more than 10°C too high, and the general applicability of *T. heimii* for thermocline temperature reconstruction is strongly called into question.

However, by taking into account culturing experiments and field observations it can be shown that factors such as growth rates, size of the calcareous tests and seasonality in production might give an explanation for the discrepancy between the observed depth habitat and the stable oxygen signal of *T. heimii*.

A new species of the genus *Orbulina* (Foraminifera) from the Serravalian (Middle Miocene): its occurrence and phylogenetic relation to *O. universa* (d´Orbigny 1839)

Kurt Søren Svensson Nielsen & Holger Gebhardt

The genus *Orbulina universa* was introduced by d´Orbigny in 1839. Since then this species has been given much attention regarding its origin and evolution and at present no consensus regarding the evolution and the number of species, which should be classified as *Orbulina* exist. Many workers accept that the modern species of *Orbulina* evolved from *Globigerinoides triloba*. However, the presence of triangular spines and molecular data suggest that the modern species of Orbulina are closer related to the genera *Hastigerina* or *Globigerinella*.

The general consensus today is that Orbulina comprises three living species *O. bilobata*, *O. suturalis* and *O. universa*. However, laboratory studies of *O. universa* indicate that a smaller proportion of the population when subjected to changing environmental parameters, develop into morphologically similar forms as *O. suturalis* or *O. bilobata*, indicating that only one species of *Orbulina* exists today. Contrary to this, studies of rDNA sequences from cells of *O. universa* shows that the modern Atlantic population can be separated into three different cryptic species *of O. universa.*

In this study, we have investigated more than 1100 modern and fossil samples containing large numbers of *Orbulinas*, in regard to the morphology of the adult test. All modern specimens of *O. universa* investigated show little variation in test morphology. The occurrence of *O. bilobata* and *O. suturalis* is extremely rare in the modern samples, suggesting that these species are typical of only extreme marine settings. The large morphological variation that was observed in the adult test of Plio/Pleistocene specimens of *O. universa* indicates that a revision of the genus *Orbulina* may needed.

During an investigation of material from Middle Miocene (Serravallian) material from southern Spain (Alicante Province) a large number of unknown specimens of *Orbulina* was observed. The typical test surface of these specimens requires the description of at least one new species of *Orbulina*.

Morphological variation and taxonomy of modern high-latitude *Neogloboquadrina* (planktonic foraminifera)

Michal Kucera & Kate F. Darling

Until recently, polar and subpolar surface waters of the modern oceans were assumed to be inhabited by low-diversity assemblages of planktonic foraminifera, dominated by a single morphospecies, *Neogloboquadrina pachyderma*. Whilst it was acknowledged in practice that this morphospecies includes two distinct types, differentiated on the basis of their opposite coiling directions, this distinction has never been satisfactorily formalised. Recent genetic data have shown that there are indeed two distinct types of the high-latitude neogloboquadrinids and that these broadly correspond to the two coiling types. However, coiling direction is not an absolute discriminator between these types, making the traditional sinistral *versus* dextral informal nomenclature unsustainable. We have examined type material of a number of species and subspecies attributable to high-latitude neogloboquadrininds and we conclude that in the North Atlantic, *N. pachyderma* (Ehrenberg) appears to be the most appropriate name for the polar, mostly left-coiling type, whereas *N. incompta* (Cifelli) appears to be the appropriate name for the sub-polar mostly right-coiling type found in both hemispheres. The situation is more complicated in the Southern Hemisphere, where there are several genetically distinct left-coiling types, all of which are different from those found in the North Atlantic. We have examined their geographical distribution, shell morphology and microstructure, including logarithmic spire characteristics extracted from X-ray images, in an effort to find morphological traits specific to individual genetic types. Based on these analyses, we will present several alternative suggestions on how to treat the Southern Hemisphere group.

Holococcolith biomineralisation

Jeremy R. Young, Markus Geisen, Ian Probert & Karen Henriksen

Recent work from the CODENET research network (Coccolithophorid evolutionary biodiversity and ecology network) project has proven the hypothesis that the typical coccolithophore life-cycle is haplo-diploid with very different calcification modes in the haploid and diploid phases. Available evidence suggests that calcification evolved in the diploid phase and that diploid phase calcification results in formation of heterococcoliths. Calcification appears to have been adopted secondarily in the haploid phase several times resulting in different biomineralisation modes, including at least holococcoliths, ceratolith nannolith and "Polycrater" nannoliths. Of these holococcoliths are much the most widespread so critical reassessment of the nature of holococcolith biomineralisation is timely. A satisfying model of holococcolith biomineralisation cannot yet be produced, but the salient features of holococcolith formation which such a model needs to address can be outlined.

The Caribbean Salt Kitchen monitored by *Globigerinoides sacculifer* and *Globigerinoides ruber* during the last 50,000 years

Joachim Schoenfeld

The Caribbean is a marginal sea of the subtropical Atlantic Ocean. Driven by trade winds, Atlantic surface water masses enter the Caribbean through the Antilles Island Arc. The surface waters pass the Yucatan channel, flow through the Gulf of Mexico and are funnelled in the Florida Straits. This Florida Stream constitutes the central core of the Gulf Stream that flows further northwards into the western Atlantic. The Gulf Stream transports salt and heat to the northern hemisphere and controls to a large extent the recent climate in Europe. The strength of North Atlantic Deep-Water formation also depends on the supply of warm, salty water. After losing heat to the atmosphere, the former tropical surface water produces the dense water masses that sink to great depths. For palaeoclimatic studies, it is therefore crucial to understand the pre-conditioning of surface waters in the Caribbean Sea. Today, the surface mixed layer of Caribbean Water (50 to 80 m) is relatively low in salinity (<35.5) due to the Amazon and Orinoco River outflow and enhanced summer precipitation in the southern Caribbean. The mixed layer is underlain by highly saline (>36.5) Subtropical Underwater (80 to 200 m) that is formed in the central tropical Atlantic. Between 200 and 400 m, the Sargasso Sea Water prevails followed by the underlying Tropical Atlantic Central Water and the Antarctic Intermediate Water with a marked salinity minimum of ~35.0 between 600 and 1000 m. The salinity of the surface mixed layer increases and the vertical structure assimilates on the way from the southern Caribbean to the Gulf of Mexico and Florida Straits.

The magnesium content and oxygen isotopic composition of calcite precipitated by planktonic organisms record temperature and salinity of ambient seawater. *Globigerinoides ruber* dominates the living planktonic foraminiferal assemblage in near-surface waters. This species prevails with high standing stocks in lenses of low-salinity water (~34.0) with enhanced nutrient content due to freshwater input from the Orinoco River during the Autumn. *Globigerinoides sacculifer* is also frequent. It is not well adapted to large seasonal salinity changes and turbid surface waters, and hence is considered to rather reflect the conditions throughout the year.

Paired Mg/Ca and oxygen isotope measurements of *G. sacculifer* and *G. ruber* from 20 surface sediment samples were compared with surface water salinities and sea water oxygen isotope measurements from the World Ocean Atlas 1994 and Global Seawater Oxygen-18 Database. The measured oxygen isotope values of *G. ruber* did not correlate with equilibrium calcite, but those of *G. sacculifer.* The best correlation was achieved for annual average temperatures and salinities from 30 to 50 m water depth which corresponds to the average living depth (40 m) of this species. Surface water salinities can be estimated with an accuracy of ±0.5 from Mg/Ca and oxygen isotope measurements of *G. sacculifer* from recent sediments by using the modern Caribbean O-18 surface water - salinity relationship, a 0.5 permil offset to account for secondary, gammatogenetic calcite overgrowth, and the empirical O-18 - temperature relation for *G. sacculifer* from plankton catchments. The seasonal variability may also induce an uncertainty of ±0.5, in particular at low salinities.

Palaeo- salinities were calculated from three sediment cores from the western equatorial Atlantic, central Caribbean, and Florida Straits depicting the Caribbean surface water throughflow over the last 50,000 years. In the Caribbean and Florida Straits, the salinities were higher by one unit during Marine Oxygen Isotope Stage (MIS) 3 and two units during MIS2 beyond the influence of ice volume. This pattern may be attributed to stronger trade winds and higher evaporation during the last Glacial. The equatorial Atlantic, situated close to the Orinoco River debouchment stayed at the present, low-salinity level. A pronounced double maximum is recognized during the last deglaciation with salinity peaks during the Heinrich-Event H1 and Younger Dryas in all cores. These salinity maxima correspond to periods of low precipitation in the southern Caribbean region and Amazon Orinoco catchment areas. A return to wetter conditions during the intermittent Bølling/Allerød period is only visible in the Atlantic core reflecting a short-term re-initiation of river discharge from the southern American hinterland as it has been previously suggested for the Cariaco and western Caribbean Colombian basins.

A comparison of the Caribbean records with a core from the eastern subtropical Atlantic reveals a marked similarity in surface water salinity during the Holocene, Allerød, and Interstadial 2. The Caribbean salinity was higher by 1 to 2 units than in the eastern Atlantic during the cold and dry periods, however. This warm, salt-rich water flushed to the northern Atlantic and promoted the reinvigoration of thermohaline circulation in the subsequent warm climatic intervals.

Adaptation without differentiation: Morphological homogeneity between 'pseudo-Cryptic' forms of *Globigerinoides ruber* d'Orbigny

Blair A. Steel, Michal Kucera & Kate F. Darling

Globigerinoides ruber is a widespread and often dominant component of sub-tropical and tropical assemblages of planktic foraminifera, and consequently is often used as a vector for geochemical palaeoproxies.

Unusually for planktic foraminifera, the traditional morphospecies concept is habitually divided into two informally recognised sub-types (*Gs. ruber* 'pink' and 'white') based on test pigmentation. These two types are genetically dissimilar and have differing biogeographic and stratigraphic distributions, indicating that they are almost certainly reproductively isolated populations with different environmental preferences. Previous workers have also identified morphological features that could be used to distinguish the two types. If this is the case, then the variants can be separated independently of test colour- a potentially important finding, since there is circumstantial evidence that diagenesis may be altering the unstable pink pigment and artificially truncating the range of *Gs. ruber* 'pink' (currently thought to have first occurred at ~ 0.7 Ma). Extending the time of divergence between 'pink' and 'white' would also accord more closely with some molecular clock estimates, which seem to suggest a time of divergence that is considerably discordant with the stratigraphic record.

We have conducted a multivariate morphometric analysis based on material from ODP Site 926A (Ceara Rise), measuring 13 continuous metric characters based on two views of oriented, mature shells of *Gs. ruber*. Preliminary analysis suggests that the two types are indeed morphometrically indistinguishable. Unfortunately, this implies that morphology cannot provide an independent appraisal of the evolutionary history of *Gs. ruber*, and hence that the molecular clock hypothesis cannot be tested using morphometrics. This is a result of more than academic interest; if the deep divergence model suggested by the molecular clock is correct, then geochemical analyses based on tests harvested from material older than 0.7 Ma are effectively pooling two species, and may therefore be inducing significant noise. We are currently exploring the potential for other characteristics (such as test ultrastructure) and microscopy techniques (such as illumination with UV light) to accurately delineate the two types, but it is likely that *Gs. ruber* represents a true case of long-term morphological stasis- 'cryptic' speciation in its truest sense.

Calcareous nannofossils and planktic foraminifera in the Cretaceous: an integrated approach for understanding palaeoecological changes in a Greenhouse world

Jörg Mutterlose & Sylvia Rückheim

The Early Cretaceous of the Boreal Realm is characterised by different distribution and evolution patterns of calcareous nannofossils and planktic foraminifera. Calcareous nannofossils are present throughout all periods represented by marine sediments, covering the Berriasian – Albian. Planktic foraminifera, common in the Late Jurassic and Early Cretaceous of the Tethys, are, however, absent in the earliest Cretaceous of the Boreal Realm. They have their first occurrence in the late Barremian,, becoming a common component of the plankton assemblages in the Aptian. The calcareous plankton thus allows a two fold separation of the Early Cretaceous: 1. The Berriasian - Barremian interval without or with rare planktic forams, and 2. the mid Cretaceous (Aptian – younger) period with common planktic forams.

The calcareous nannofossils of the Berriasian – Barremian interval show in the Boreal Realm high rates of endemism, clearly reflecting geographic isolation of the Boreal Realm. The common occurrence of cosmopolitan taxa, and during certain intervals of Tethyan elements on the other hand indicates the presence of sea-ways throughout this period. Further parameters controlling nannofossil distribution are temperature and nutrients**.**

The Aptian (and younger intervals) are marked by a homogenisation of calcareous nannofossil floras showing more cosmopolitan affinities. Endemic taxa are rare or absent. The Aptian onset of planktic forams in the Boreal Realm shows taxa of Tethyan affinities settling in the North Sea and adjoining areas. There are no foram taxa endemic to the North Sea. This spread and homogenisation of marine floras and faunas is obviously linked to a major sea-level rise, establishment of new sea-ways (via the Proto-Channel) and a general change of the palaeoceanographic situation (increased MORB production). The different migration pathways for calcareous nannofossils and planktic foraminifera still need explanation by a) different nutrient/temperature affinities, b) different methods of the metabolistic test calcification, or c) palaeoceanographic reasons (e.g. barriers).

Comparison of Quaternary upper-ocean water changes between the Southern and Northern South China Sea: A Seesaw Pattern

Jian Xu, Baoqi Huang, Pinxian Wang, Jun Tian, Chuanlian Liu & Zhimin Jian

Palaeoceanographic multi-proxies on sea surface temperature (SST), depth of thermocline (DOT) and palaeoproductivity from ODP Site 1143 (9°21.72'N, 113°17.11'E, water depth 2,772 m) were analysed to study the response of upper-ocean water changes to glacial cycles in the southern South China Sea (SCS) during the past 2,100 kyr, with ~2 ka resolution, and were further compared with those from the northern SCS.

At ODP Site 1143, warm water species (*Globigerinoides ruber*, *Globigerinoides sacculifer*, *Globorotalia menardii* and *Pulleniatina obliquiloculata*) and results from transfer functions (FP-12E and SIMMAX-28) based on census data both show that SST has no clear glacial-interglacial cycles in the southern SCS over the whole time interval. DOT inferred from surface-water species (*G. ruber*, *G. sacculifer* and *Globigerinita glutinata*), thermocline species (*Neogloboquadrina* group and *G. menardii*), $\delta^{18}O_{(P.\ obliquiloculata\text{-}G.\ ruber)}$ and results derived from the faunal transfer function, however, displays faithful variations according to oxygen isotope cyclicities; deeper during glacials and shallower during interglacials. Amongst various palaeoproductivity indices, opal percent and opal accumulation rate indicate high productivity during interglacials since 1,600 ka (Wang and Li, 2003), whereas other indices such as percentages of *Neogloboquadrina dutertrei*, *Globigerina bulloides* and *G. glutinata*, percentage of nannoplankton *Florisphaera profunda*, and the $\delta^{13}C$ difference between *P. obliquiloculata* and *G. ruber* show vague variations against glacial cycles.

Comparing these results with records from ODP Site 1146 (19°27.40'N, 116°16.37'E, water depth 2,091 m, ~10 ka resolution) from the northern SCS, SST and DOT indices and predominant species all indicate that upper-ocean waters between the southern and northern SCS underwent profound divergence around 1,000 ka. SST in the northern SCS have decreased dramatically since 1,000 ka; high in interglacials and low in glacials, compared with those in the southern part. DOT gradient between the south and the north, represented by $DOT_{(1143\text{-}1146)}$, have increased conspicuously during glacial intervals in the past 1,000 kyr. In addition, it has been documented that paleoproductivity indicated by opal percent and opal accumulation rate from ODP Site 1144 (20°3.18'N, 117°25.14'E, water depth 2,037 m), close to ODP Site 1146 in the northern SCS, is high in glacials and low in interglacials since 1,050 ka, the reverse of results from ODP Site 1143.

It is suggested that the strong SST gradient between the south and north and the geographical enclosure of the basin to south during glacials in the past 1,000 kyr should be responsible for the development of the seesaw-like pattern of upper-ocean water changes within SCS. Strengthening of the winter monsoon during glacials in the north, and summer monsoon during interglacials in the south may play a direct role.

The effects of rising pCO2 on coccolithophore calcification

Markus Geisen, Gerald Langer, Ulf Riebesell, Ian Probert & Jeremy Young

The growth of coccolithophores and their subsequent sinking to depth contribute to two different processes by which carbon is transported to the deep sea: the organic carbon pump transports photosynthetically fixed carbon (POC) and the carbonate pump transports particulate inorganic carbon (PIC) - biomineralised calcite in the coccoliths. While photosynthesis removes CO_2 from the surface water thus forming a sink in ocean-atmosphere CO_2 exchange, calcification causes a shift in the carbonate system towards higher p CO_2 thereby providing a potential source of CO_2. According to the IPCC (Intergovernmental Panel on Climate Change) report anthropogenic CO_2 emissions will double atmospheric p CO_2 over the next 100 years. Previous studies have shown that two closely related coccolithophore species, *Emiliania huxleyi* and *Gephyrocapsa oceanica*, decrease their PIC/POC ratio due to increasing p CO_2. In order to test whether this is a common phenomenon we have conducted similar experiments with two other important producers of coccolithophore calcite, *Calcidiscus leptoporus* and *Coccolithus pelagicus*. These two species are the dominant calcite producers in the northern part of the Atlantic Ocean and contain considerably more calcite than *E. huxleyi* (roughly 50 and 100 fold, respectively).

Coccolith polysaccharides: influence on genesis and diagenesis

Karen Henriksen, Susan L.S. Stipp, Jeremy R. Young and M.E. Marsh

Coccoliths are composed of tiny but intricate crystals, with morphologies far removed from those characterising calcite grown in inorganic systems. Their genesis is known to involve complex organic molecules called coccolith associated polysaccharides (CAPs), that are present during crystal growth and form an organic cover on complete coccoliths. Using atomic force microscopy (AFM), we have investigated the influence of CAP on dissolution and growth of calcite. Our results show that the CAP coating protects the coccolith crystal faces against dissolution, therefore impacting diagenetic behaviour. For the species *Emiliania huxleyi*, we have shown how CAP can regulate crystal morphology to enhance precipitation of specific faces; a crucial aspect of coccolith genesis. *E. huxleyi* CAP preferentially interacts with acute surface sites, blocking them during dissolution and growth. Therefore, CAP makes the energetically most stable calcite face, $\{10\bar{1}4\}$, extend preferentially on the obtuse edges, promoting development of faces with lower angles to the **c**-axis, such as the $\{21\bar{3}4\}$ scalenohedral and $\{1\bar{2}10\}$ prismatic faces. AFM images of *E. huxleyi* at micrometer- and atomic scale established that these are precisely the type of faces that define the morphology of the coccolith crystals. Therefore, we interpret that crystal shape regulation by CAP is a fundamental aspect of coccolith biomineralisation.

Changes in foraminiferal associations during southern Baltic Sea history

Peter Frenzel & Jan Bartholdy

The Holocene history of foraminiferal faunas during the evolution of the Baltic Sea is practically unknown compared to the adjacent areas of the Kattegat and the Skagerrak. We now have data on foraminiferal assemblages from the southern Baltic Sea coast from the last 8000 years. The studied sites lie in the coastal zone of north-eastern Germany and within the deeper basins offshore. They represent archaeological excavations and geological coring sites connected mostly to the SINCOS (Sinking Coasts - Geosphere, Ecosphere and Anthroposphere of the Holocene Southern Baltic Sea) program. We studied four shallow water localities at the coast on the Isle of Usedom, in the towns of Greifswald and Stralsund in Pomerania and close to Oldenburg in Holstein as well as twelve sediment cores from Mecklenburg and Pomeranian Bay.

The marine/brackish history of the Baltic Sea starts about 7900 years BP with the 1st Litorina transgression. Since then, the sea level has risen gradually with a slowing down tendency and salinity has fluctuated within the brackish water range.

Mecklenburg Bay: The foraminifer *Eggerella scabra* indicates cool water and slightly higher salinity then today. *E. scabra* disappeared during the Main Litorina regression when the salinity dropped. Then, foraminifers are replaced mainly by characean oospores and plant detritus. Probably during the Second Litorina transgression, the salinity rose again – *Ammonia batavus* and *A. beccarii* appear as well as *E. scabra* and *Rheophax* spp. later. We found an *E. scabra* peak in most cores some centimetres below the sediment surface. This phenomenon is documented from further to the inner Baltic Sea in the Arkona basin too, pointing towards a main salt water input from the North Sea during historical times. Today, *E. scabra* is not so common and only patchy distributed in this part of the Mecklenburg Bay.

Pomeranian Bay: Very high numbers of elphidiids indicate the First Litorina transgression within the Pomeranian Bay. Later, they are only scarcely found. Today, *Miliammina fusca* dominates here, although with low abundance. We can conclude a major drop in salinity, which is documented from the coastal site on the Isle of Usedom too.

Coastal sites: The coastal site samples show high numbers and high diversity of foraminifers during First Litorina transgression. The main species are *A. batavus* and *Haynesina germanica*. Foraminiferal numbers and diversity drop markedly in relation to salinity later on. Nevertheless *A. batavus* stays the main element of the foraminiferal assemblages and is replaced only by trochamminids and *Cribroelphidium williamsoni* in very shallow water sites within the phytal zone. Also, trochamminids (*Jadammina macrescens, Balticammina pseudomacrescens* and *Haplophragmoides* spp.) and *C. williamsoni* are the main taxa to withstand anthropogenic eutrophication as seen in the studied archaeological excavation sites. In contrast to modern day distribution *Miliammina fusca* is rarely found in our subfossil samples. We suppose this is a taphonomical effect as well as due to the dissolution of calcareous tests in many samples.

Despite common taphonomical problems by destruction of tests, we can obtain data on changes of foraminiferal association in the history of the southern Baltic Sea by studying sediment cores and outcrops. All species found in Holocene sediments still occur in the Baltic Sea today, however many species are restricted to more westerly situated areas or to water below the halocline where the salinity is higher. Salinity is the main driving factor for changes in foraminiferal associations. The foraminifers give us information on salinity, temperature, water stratification and habitat structure and are therefore valuable tools for palaeoenvironmental reconstructions in the Holocene of the southern Baltic Sea.

Poster abstracts

Calibrating the Neogene microfossil biostratigraphy of the North Sea region

Erik Anthonissen

The search for a viable means of disposal has led many countries in the circum-North Sea region to investigate the potential for gas disposal in saline aquifers of Neogene age. Until recently the petroleum industry has had little need for a high-resolution Neogene stratigraphy due to the lack of natural hydrocarbon accumulations in Neogene strata.

Previous biostratigraphic studies of the Neogene of the North Sea have resulted in often poorly calibrated and isolated assemblage sequences providing weakly constrained ages. While the Ocean Drilling Project has produced well calibrated Neogene zonations for the northern North Atlantic and for the Vøring Basin, the existing North Sea zonations have been calibrated most often by second and third order correlations. Until now the general zonations of King (1989) and Gradstein & Bäckström (1996) have proved useful in routine petroleum exploration where only ditch-cuttings are present, however, there is great potential for a much higher resolution and much better constrained zonal ages.

This study will have as its main aim the creation of a calibrated Neogene zonation scheme for the North Sea, incorporating a diverse range of microfossil data. Quantitative statistical treatment of a large Norwegian dataset will be used to determine the reliability of existing marker events. Robust events will then, through combined analysis of onshore and offshore well-cores and supplemented by outcrop observations, be calibrated to the new standard geological time scale of Gradstein *et al.* (in press). Limited first-order chronostratigraphic dating may be achieved using selected planktonic forminifers and dinoflagellate cysts. Calibration will also be achieved through radiometric strontium (Sr) isotope dating of principally benthic foraminiferal tests, supplemented partially by magnetostratigraphic control. Key biohorizons will be tied to the regional seismic and sequence stratigraphic framework.

Industrial implications are the creation of a high-resolution tool for Neogene stratigraphy in the North Sea and circum-North Sea region. It will be applicable in various depositional environments due to the integration of a broad fossil dataset, and incorporation into the regional stratigraphic framework. Secondary aims include assessing the reliability of *Bolboforma* (Chrysophyta) microfossils as North Sea Miocene markers, evaluating the usefulness of Sr-isotope stratigraphy for the last 15 ma, where Sr-dating precision is theoretically highest for the Neogene, and to produce a palaeobathymetric model of the depth evolution of the region based on fossil findings. Ultimately, this study will create a much needed chronostratigraphic link between the classical Neogene biostratigraphy of the Mediterranean, and the poorly calibrated Neogene biostratigraphy of the North Sea region.

Removing assemblage-size bias from planktonic foraminifer biodiversity estimates

Nadia Al-Sabouni, Michal Kucera & Daniela Schmidt

The excellent fossil record of planktonic foraminifera provides a unique opportunity to study past and present diversity patterns of this important group of oceanic zooplankton. Spatial and temporal analysis of species diversity of entire planktonic foraminiferal assemblages has the potential to provide insight into long-term biodiversity processes and their relationship with environmental change. However, for various methodological reasons, representative and consistent records of planktonic foraminifer biodiversity are lacking.

In the modern ocean, planktonic foraminifer size distribution is largely attributed to temperature and nutrient effects. On geological timescales, planktonic foraminifera have undergone several periods of diversification, each of which is thought to have involved a general increase in test size. In addition, recent quantitative analyses have identified large changes in the size of assemblages of planktonic foraminifera throughout the Cenozoic that can be attributed to long-term changes in vertical stratification of the surface ocean. Despite these large changes in size, analysis of planktonic foraminiferal assemblages is typically carried out using a uniform mesh size. This constitutes a major problem for consistent estimates of diversity of planktonic foraminifera.

To overcome this methodological problem, we have attempted to devise a technique that will produce a quantitative biodiversity estimate, independent of assemblage size distribution in the analysed sample. To achieve this, multiple splits of a single modern assemblage was first carried out, and the number of species counted and recorded. Data was then processed using PAST (PAlaeontological STatistics) v1.20, and a minimum number of specimens required to be counted, in order to obtain a representative species diversity estimate of the entire assemblage was established. We then analysed diversity in different sieve size fractions in several modern core-top samples and compared these diversity estimates with size distribution of foraminifera in these samples.

The Valanginian "Weissert" Event in the western Atlantic (DSDP Sites 534A and 603B): results from calcareous nannofossils and carbon isotopes

André Bornemann & Jörg Mutterlose

The mid Valanginian "Weissert Event" is characterised by a positive carbon isotope excursion (CIE), which has been observed on a supraregional scale. The CIE coincides with a sea level rise and increased volcanic activity (Paraná-Etendeka volcanism), which may have caused elevated atmospheric pCO_2 levels. A greenhouse climate and accelerated hydrologic cycling are thought to have intensified the weathering processes. This may have caused an elevated nutrient transfer from the continents into the oceans.

In the western Atlantic Ocean (DSDP Sites 534A and 603B) enhanced surface-water fertility is indicated by an increase in abundance of nannofossil species which are believed to indicate more eutrophic conditions. This increase coincides with the turning point of the carbon isotope record at the magnetostratigraphic M15/M14 boundary and therefore predates the CIE. Enhanced surface-water productivity is also presumably reflected by an increase in bulk-rock Sr/Ca-ratios reported from the same sites, and by the occurrence of TOC-rich marlstones. We assume that enhanced surface water productivity may have contributed to the shift in the carbon isotopic composition of the carbonates.

In the western Tethys the mid Valanginian is also marked by a sharp decrease in the abundance of rockforming nannoconids ('the nannoconid crisis'). This event is much less pronounced in the western Atlantic (this study) and the Pacific due to a general scarcity of these nannoliths in open oceanic settings, but nevertheless a decline in the carbonate accumulation and a dominance of less calcified nannofossil species were observed. We assume that the interval of the so-called 'nannoconid crisis' was characterised by generally lower rates of carbonate accumulation reflecting a crisis in the biogenic carbonate production.

The decrease in the biogenic carbonate production may have been caused by enhanced surface-water nutrification, by a pH drop of seawater due to enhanced volcanic CO_2 outgassing and/or by the release of trace elements, which limit or inhibit calcification, during volcanism.

Morphological variation in Recent *Globorotalia menardii*

Kevin Brown

Globorotalia menardii is a prominent Neogene sub-tropical to tropical planktonic foraminiferal species. It has a distinctive lenticular keeled morphology. However there is a range of morphotypes, from more robust, heavily keeled types to the more delicately walled finer keeled forms. This work attempts to geographically map out the various Recent morphotypes, identify end members and determine if this morphological variation can be linked to environmental conditions, and or geographical areas.

The initial findings indicate a geographic variation in the spiral height of the '*menardii* form' globorotalids; the highest spired specimens being found in samples form the higher latitudes, and lowest values of spiral height are found in lower latitude samples. There is an apparent trend towards flatter, plate-like tests in '*menardii* form' globorotalids found in the northern subtropical Atlantic and Caribbean regions. It is possible that the distinctive morphotypes identified represent end members of more than one sub-group, but overlap in the geographical areas hides the trend of decreasing spiral height, making visual recognition of the trend difficult.

Extensive phenotypic and structural variability in very small and small Lower Pliocene reticulofenestrid coccoliths (South Caribbean Sea): evolutionary and paleoecological implications

Daniela Crudeli, Hanno Kinkel, Jeremy R. Young, Silke Steph & Ralph Tiedemann

Modern reticulofenestrid coccolithophores (*Emiliania huxleyi*, *Gephyrocapsa, Reticulofenestra*) show a very wide range of morphological variability and many species and varieties have been described. By contrast, the fossil record of reticulofenestrids is conventionally represented by a limited set of species that evolve geologically instantaneously and remain morphologically stable over millions of years. In particular, there is minimal documentation of morphological differentiation within the very small and small (<3µm and 3-5µm) reticulofenestrid groups, even though these frequently dominate assemblages. Due to their small size these are usually assigned to broad size-defined groups.

Exceptionally preserved sediments from the South Caribbean basin (ODP Site 1000A Leg 165, Lower Pliocene) have offered a unique opportunity to carry out detailed scanning electron microscope observations on morphological variability of the small reticulofenestrid populations and analyse the primary composition of these assemblages. A range of peculiar morphotypes have been observed. Morphological variability mainly consists of differential development of distally directed extensions of the inner tube elements, with variable contribution of the outer tube elements. These morphotypes have been quantified in terms of absolute abundance and relative abundance and compared with morphological variation patterns seen in extant small *Gephyrocapsa* coccoliths.

Phenotypic characters that allowed separation of a set of very small morphotypes appear to be fairly stable morphologies and, in conjunction with the presence of intermediate forms, suggests that these represent in fact (eco)phenotypes of small *Gephyrocapsa* rather then separate species.

By comparison, morphological variation displayed amongst a second set of very small reticulofenestrids (*R. minuta* s.l.), which consists of the development of tube elements at the coccolith's side, is also thought to be ecologically driven. A “malformed” coccolith with slitted distal shield elements very similar to those of *Emiliania huxleyi*, but clearly separable from this species and from the *Pseudoemiliania* group, possibly represents a precursor response to similar ecological pressures which subsequently resulted in stable adoption of this morphology. A distinct coccolith, *Reticulofenestra calicis* n. sp., appears in the fossil record shortly after the first common occurrence of small *Gephyrocapsa,* when the previously discussed morphotypes become much less common. The affinity of this coccolith, present for a relatively short interval, is still unclear. The opposite absolute abundance (n. /g dry sediment) pattern of *R. calicis* with respect to small *Gephyrocapsa* coccoliths suggests different ecology. A similarly opposite abundance trend (with respect to small *Gephyrocapsa* population) is showed by forms of the *R. minuta* s.l. group. This possibly suggests that *R. calicis* evolved from this group of coccoliths to fill up slightly different ecological niches.It possibly represents the final evolution of the “malformed” coccoliths group.

The evolutionary dynamics of the population is currently under investigation, but it is clear from our results to date that the small reticulofenestrid coccoliths are much more morphologically variable than previously thought. It is possible that at this Caribbean site peculiar ecological conditions occurred resulting in the previously unreported diversity, alternatively the diversity may be universal but as yet has not been reported due to an absence of detailed studies of co-eval assemblages; this requires testing.

Cryptic genetic diversity in the planktonic foraminifer *Neogloboquadrina pachyderma*

Kate F. Darling & Christopher Wade

Morphological distinction provides the main basis for foraminiferal counts and derived palaeoceanographic reconstructions. *Neogloboquadrina pachyderma* is the dominant morphospecies today in the high latitudes and has played a pivotal role in the reconstruction of past climate in these regions. Although known to exhibit a degree of morphological plasticity, coiling direction is currently the sole criterion used in its application as a palaeoceanographic proxy. Molecular analyses of living *Neogloboquadrina pachyderma* assemblages have now revealed a previously unrecognised high degree of genetic diversity which is particularly manifest in the left coiling morphotype. Several genetic variants are associated with different regions of the global ocean and some exhibit specific adaptations. Coiling direction is not a sufficient guide to genetic type or their adaptation and in some cases can be positively misleading. It has now become imperative to rationalise nomenclature and investigate the morphologies of the different genetic types of *Neogloboquadrina pachyderma* to provide guidance for their use as paleoproxies.

Isotopic and foraminiferal analysis of the Cenomanian-Turonian Boundary event in the Indian Ocean

Jodie K. Fisher, Gregory D. Price, Malcolm B. Hart & Melanie J. Leng

The Cenomanian/Turonian boundary event occurred some 93 million years ago and is one of the most distinctive events in mid-Cretaceous stratigraphy. It can be detected as a faunal, chemical, isotope and sedimentological event on all continents and is, genuinely, a global event. Samples from ODP sites on the Exmouth Plateau (Indian Ocean) have been analysed for both foraminiferal stratigraphy and stable isotopes. The data from these successions are part of a wider study of Cenomanian/Turonian boundary successions in various parts of the world, including Australia, Europe, Crimea and South America. In the successions from the Indian Ocean and the Crimea there is a degree of diagenetic overprinting that makes comparisons to other successions slightly more difficult than might otherwise be the case. Recognition of these diagenetic overprints is very important.

Biostratigraphy and palaeoecological interpretation of planktonic foraminifera from the Cenomanian to Coniacian Nkalagu Formation, southern Nigeria

Holger Gebhardt

Planktonic foraminifera form the base of many marine biostratigraphic zonations in the Cretaceous and Tertiary intervals. However, long ranging shallow water associations dominate in most marine Cretaceous deposits of the Benue Trough and keeled deep-water forms are restricted to the Nigerian coastal basins. Only the Turonian to Coniacian of the Lower Benue Trough (Nkalagu Fm) yielded forms which are important for biostratigraphy and worldwide correlation of strata. Due to their relatively rare occurrence in Nigeria, a biostratigraphic zonation based on planktonic foraminifera for the Late Cretaceous was never attempted. Due to the higher concentration of foraminiferal tests from keeled species with the dry sieving of the studied samples, it was possible to gain sufficient material for a zonation of the ?middle Turonian to Coniacian strata of the Lower Benue Trough. In addition to the biostratigraphic study, the planktonic foraminiferal associations were analysed statistically and interpreted palaeoecologically. The three investigated sections are situated on the north-western flank of the Abakaliki Anticline, a major tectonic structure in the Lower Benue Trough.

Four biostratigraphic zones are proposed for the (?)middle Turonian to Coniacian interval in southern Nigeria: (1) *Praeglobotruncana* cf. *stephani* Zone (middle? Turonian); (2) *Marginotruncana sigali* Zone (late Turonian); (3) *Dicarinella primitiva* Zone (latest Turonian); and (4) *Dicarinella concavata* Zone (Coniacian). Based on planktonic/benthonic foraminiferal ratios and environmental index forms, a general deepening of depositional environments is indicated from late Cenomanian to Turonian and Coniacian ages. Upper Cenomanian sediments were deposited in an inner shelf environment (0-70 m, 0-20% planktonic foraminifera; only one *Heterohelix* species occurs). During the (?)middle to early late Turonian, an upper bathyal environment of about 600 m water-depth is indicated (46-94 % planktonic foraminifera, with heterohelicids dominating and a relatively large number of keeled specimens). The middle late to latest Turonian interval is characterized by 20-71 % planktonic foraminifera with heterohelicids dominating and very rare keeled specimens, pointing to an upper bathyal depositional environment (c. 250 m water-depth). A (deeper) upper bathyal environment (c. 600 m water-depth), dominated by heterohelicids but with up to 30% hedbergellids during the Coniacian, is indicated by 63-93% planktonic foraminifera with a relatively large number of keeled specimens. In general, an open marine deep-water environment (upper bathyal) is indicated by the (?)middle Turonian to Coniacian planktonic foraminiferal faunas, further influenced by periods of eutrophication or (weak) salinity fluctuations. The (?)middle Turonian and latest late Turonian were time intervals of highest surface productivity in southern Nigeria.

Pele's Tears and various misconcepts

Hans Jørgen Hansen

Pele's Tears are quenched droplets from basaltic magma fountains found i.e. on Hawaii, USA. They are mainly composed of gas bubbles separated by thin, glassy walls. They are characterised by their low density, and they can float on seawater. This explains their wide marine distribution.

When the magma erupts, it passes the temperature interval of 1000 to 600°C and here the Boudouard reaction takes place. At 1000 degrees C and a pressure of 1 atmosphere the carbon gas is CO only. The Boudouard reaction prescribes, that the CO splits into free carbon and CO_2 (i.e. 2CO = C and CO_2). This leads to the formation of graphite spheres in the vesicles forming a coating of the vesicle walls. Thus it results in formation of hollow, graphite spheres. By dissolution of basaltic glass, one observes in the residue, hollow graphite spheres in the size range of sub-micron to 15 microns in diameter.

A side effect of a meteoritic impact is the formation of tektites. They consist of melted drops of the impacted rock. A tektite is a drop of melted rock, which passes through the atmosphere where the oxygen content is high, and thereby, the material becomes well oxidised. Thus, one is not expected to find graphite in tektites. Dissolution of specimens of tektites present in the collection of the Geological Museum in Copenhagen showed no residual carbon at all. (The dissolved tektites are called: Ivory Coast, Australites, Moldavites and Indochinites). They are all made of massive, glassy, non-vesicular material with pitted surfaces.

It has for years been claimed by "meteorists", that the presence of spherules (so-called "altered micro-tektites") at marine K/T boundaries is related to an impact. However, these spheres all seem to have formed inside the skeletons of prasinophyte algae. How each of the impact drops managed to strike an algal skeleton and slip inside remains unexplained.

At Caravaca and Gubbio the filled algae are sometimes overgrown by later-formed sanidine. Sanidine is a high-temperature K-feldspar. However, sanidine is known also to form in submarine tuffs. Sanidine dated by Ar/Ar resulted in 49,4 Ma ± 0,98 for Caravaca and 59,3 Ma ± 1,18 for Gubbio .

At the terrestrial K/T boundaries, no such spherules are found. The spheres claimed to be of K/T age, have turned out to occur too late, and besides, they are known in various volcanic ash layers of different ages. They are composed of minerals such as kaolinite or of minerals of the Crandallite group (phosphates such as Goyazite etc.).

Real tektites are massive glassy droplets of melt-rock from the impact site. They do not contain graphite. Therefore, the spherules from Haiti and other localities around the Mexican Gulf may safely be characterized as Pele's Tears due to their content of graphite and bubbly inner structure. The Haiti spherules are variously diagenetised ranging from specimens with a content of unaltered volcanic glass to pure smectite spheres. Their colour ranges from white to almost black depending on the degree of leaching. They are unrelated to impacts.

The Lower Eocene spherules from the Danish North Sea show spherical cavities (like the gas bubbles from true Pele's Tears) and definitely have nothing to do with tektites. Other North Sea spherules even contain fossils!

New data on the Late Cenomanian Extinction Event

Malcolm B. Hart & Gregory D. Price

The Late Cenomanian extinction event is one of those initially identified by Raup & Sepkoski in 1982. The 'event' has long been recognised as one of the major features of the Cretaceous succession on all continents and, in many localities, is associated with dark/black mudstones. The Bonarelli Event, as it is known in some parts of Europe (or CTBE in other areas) records a moderate turnover of both macrofauna and microfauna/flora. Associated with these extinctions and biodiversification events are a number of geochemical signals, including REEs and the presence of iridium. The sedimentary, isotopic, chemical, floral and faunal changes can be matched across continents and a detailed event stratigraphy generated. The mechanisms controlling this event are still debated and range from impacts to sea level rise (or fall) and productivity changes.

Henry Buckley: an unknown planktonic foraminiferal pioneer

Andrew S. Henderson, John, E, Whittaker & Clive Jones

Henry Buckley (who died in 2001) was a curator at The Natural History Museum, London, in the Mineralogy Department. He spent most of his career working with ocean-bottom sediments and managed the vast collections at the NHM. He was first directed to the study of modern planktonic foraminifera through working with Dr J. Wiseman, the oceanographer and his manager at the time, and this became a passion for the rest of his life. Due to his sitation, however, and being in a non-Palaeontological department, the Museum subsequently officially discouraged Henry from this work. As a result, he was to publish little on the planktonic foraminifera (a notable exeption was a paper in *Nature* in 1973) and in consequence is almost unknown within the foraminiferal community. This is a great pity because Henry Buckley was one of the first scientists to use the SEM (in the late 1960's) to examine wall texture and to appreciate it had an important bearing on the systematics of planktonic foraminifera. Henry had hoped to prepare an Atlas of Planktonic Foraminifera, using state-of-the-art SEM's, but he was never allowed to proceed with its publication.

Recently, a transfer has been arranged between the Mineralogy and Palaeontology departments at The Natural History Museum which has enabled us to acquire the entire collection of Henry Buckley, including over 2,500 foraminiferal slides and 10,000 SEM micrographs. The collection represents an extremely important resource for the study of Recent planktonic foraminifera as it encompasses material from ocean bottom sediments from all over the globe. The collection is currently being databased with an aim to promote its contents and the research of Henry Buckley to the foraminiferal community. It is fitting that this collection should now, at last, receive the attention that it deserves - the legacy of Henry Buckley, an almost unknown pioneer of planktonic foraminifera.

The foraminiferal response to the Early Toarcian Extinction Event

Mark D. Hylton, Malcolm B. Hart & Gregory D. Price

In their initial investigation of periodic extinctions Raup & Sepkowski (1982) identified an important faunal turnover at, or about, the Pliensbachian/Toarcian boundary. Subsequent work on the palaeontology of the lower Jurassic successions in Europe, South America and Asia has shown that the most important faunal turnover was in the early Toarcian. By comparison to some other events (Permo-Triassic boundary, K/T boundary, etc.) the early Toarcian is clearly of less importance and appears to be both regional (?) and at the species (rather than genus or family) level. As part of our on-going research on Jurassic foraminiferal assemblages the early Toarcian extinction event has been studies at a number of locations in the UK, Germany and France. In N.W.Europe the main extinction ‘level’ appears to be coincident with a sharp negative $d^{13}C$ excursion (possibly caused by a major methane escape) at a time of sea level highstand.

Basal Danian Cerithium Limestone at Stevns Klint, Denmark – diachronous and unusual

Eckart Håkansson, Claus Heinberg & Jan Audun Rasmussen

The lenticular, discontinuous nature of the basal Danian Cerithium Limestone at Stevns Klint was first recognised by Rosenkrantz in 1924, but its true significance became apparent only when the Mesozoic-Cenozoic boundary was formally placed below the Danian. However, due to pervasive cementation biostratigraphic resolution within the Cerithium Limestone has so far been exceedingly poor.

Improved preparation techniques have provided thousands of specimens of planktic foraminiferids and have now remedied this situation, and as a result a detailed biostratigraphy has been established, revealing pronounced diachronism in the deposition of this crucial unit. Thus, in the southernmost part of the cliff most, or possibly all, of the Cerithium Limestone belongs to the *Parvularugoglobigerina eugubina* Zone (Pa), indicating that in this part of the cliff the Fish Clay – Cerithium Limestone transition is essentially continuous. Farther to the north the *P. eugubina* Zone gradually thins and is superseded by the *P. pseudobulloides* Subzone (P1a), while still farther north, at Holtug, only the *P. pseudobulloides* Subzone is found.

In contrast to the diachronous nature of the Cerithium Limestone at Stevns Klint, the lateral equivalents of this unit exhibit continuous and uninterrupted accumulation in the deeper part of the Danish Basin as exposed in e.g. Nye Kløv. Cross-basin correlation is supported by both micro- and nanno-fossils, but in detail it is based on parallel developments in the ratio between biserial and spirally coiled planktic foraminiferids, reflecting a common evolutionary signal of recovery, apparent in spite of pronounced differences in facies and accumulation patterns.

The recovery patterns of the mollusc fauna at Stevns Klint, revealed through exceptional preservation due to early cementation of the Cerithium Limestone lend further support to the diachroneity of this unit.

Integrated biozonation scheme for the Late Cretaceous to Tertiary of North Africa

James B Keegan, Graham Coles, Stephen Starkie, Darrin Stead, Paul Swire & Bindra Thusu

The application of sequence stratigraphic techniques for basinal modelling in oil exploration is playing an increasingly important role. Biostratigraphic input for definition of sedimentary sequences is crucial for the determination of precise tectonic and sedimentary histories of basins and their accurate modelling. The thick Late Cretaceous – Tertiary sequences preserved in North African basins have yielded abundant and diverse microfaunal and microfloral assemblages. An evaluation of the main biostratigraphic index fossils has been undertaken by reviewing published data across North Africa from Egypt to Morocco. Range charts of stratigraphically diagnostic dinoflagellate cysts, foraminifera, nannoplankton, ostracods and sporomorph species are presented. These range charts are based on, or modified from the currently available published data. The charts cover the Cenomanian to Pliocene intervals. Presentation of the various microfossil groups permits age-dating of both the carbonate and clastic sedimentary sequences. An integrated biozonation scheme is presented which is tied to the sea level curve of Haq *et al*. 1987. The proposed integrated scheme will permit for the first time, inter- and intra-basinal biostratigraphic correlation of the sedimentary sequences across North Africa.

Microevolution in planktonic foraminifera: a morphometric case study applied to the *Globorotalia menardii* plexus and *G. tumida* lineage

Michael Knappertsbusch

Never before has evolutionary research been so controversial than today: while the study of various groups of oceanic pelagic microfossils have provided the basis for morphology oriented taxonomy, results from molecular studies seem sometimes to question the findings of traditional micropaleontologists. A particular problem is the distinction between morphologically closely related species or subspecies, especially if their morphological expression has been influenced by present or past environmental regimes. There is evidence from stable isotope or genetic work, that morphological species do not always match with molecular taxonomy, indicating the occurrence of cryptic speciation. A detailed documentation of microevolutionary patterns through time and geography is therefore of great help to better understand fundamental processes of speciation, phylogenies, and finally to arrive at more stable species concepts.

In this context we investigate the morphological evolution of two Neogene planktonic foraminifers, which are thought to be phylogenetically connected, the *Globorotalia menardii* plexus and the group of *Globorotalia tumida* and its ancestors, across the ancient Central American Seaway, from 8 Ma (Upper Miocene) to Recent times. The Isthmus of Panama permanently disconnected the Atlantic from the Pacific Ocean about 3.2-2.5 Ma ago, and so provides an ideal natural laboratory for investigating speciation.

The coordinates of test outlines of these protists were acquired with digital imagery from isochroneous levels at DSDP Sites 502A (Caribbean Sea) and 503A (Eastern Equatorial Pacific). In a parallel, still ongoing PhD study we investigate the morphological variation of Holocene representatives of *G. menardii* and *G. tumida* across environmental gradients within the global 'menardine' biogeography, in order to recognise modern end-members.

Here, results of the morphological study through time at Sites 502 and 503 are presented: In *G. menardii* and *G. tumida* a distinct size increase during the past 8 million years was observed, while shape changes (flattening of tests) were mostly observed during the youngest interval of our study. During the upper Miocene to lower Pliocene small *G. menardii* increased gradually into larger morphotypes along a single regression line in the morphospace of test diameter versus test height. This trend can be seen at both sides of the Isthmus of Panama. In samples younger than 4 Ma, this trend diverged into two separate directions of larger specimens, eventually indicating a cladogenetic speciation event: one branch evolved into forms similar to *G. menardii menardii*, while the other into forms similar to *G. menardii cultrata*. An unresolved problem is the interpretation of juvenile specimens in our material: The juvenile portion of dissected adult menardines showed morphological similarities to small forms often recognised for example as *G. ungulata*. More ontogenetic studies are needed to clarify these relationships.

In the case of the *G. merotumida-plesiotumida-tumida tumida* lineage a different evolutionary pattern has appeared from the morphometric measurements: test size increased with a major transition between 5.5 and 4.5 Ma on both sides of the Isthmus, when *G. plesiotumida* evolved into *G. tumida tumida*. In contrast to *G. menardii*, however, no splitting event could be observed from test inflation, and the data show a continous time-progressive morphological trend. Size-based discrimination between *G. merotumida*, *G.*

plesiotumida and early *G. tumida tumida* is difficult because of the continuous transition; extra characters are needed for species recognition. Our measurements of *G. tumida* from DSDP Site 503A (Pacific) match very well with earlier morphometric observations at Southern Indian Ocean DSDP Site 214, which is very interesting when we consider the large distance between the two study areas.

Planktonic foraminifera at the Coniacian – Santonian boundary at Olazagutía, northern Spain

Marcos A. Lamolda, Danuta Peryt & Jana Ion

The Olazagutía section (Navarra province, northern Spain) was chosen during the second Symposium on Cretaceous Stage Boundaries in Brussels, 1995, as one of the three potential candidates for the Global Standard stratotype Section and Point (GSSP) for the Coniacian-Santonian boundary. In September 2002 during the meeting on the Coniacian/Santonian Boundary in Bilbao, organized by the Subcomission on Cretaceous Stratigraphy, the participants – members of the Santonian Working Group – agreed that the Olazagutía section should be chosen as the Coniacian-Santonian boundary stratotype.

The studied part of the section at Olazagutia represents a sequence across the Coniacian-Santonian boundary in a carbonate facies which is composed generally of two complexes: marlier (20m thick) in the lower part and more calcareous (25m thick) in the upper part.

More than thirty planktonic foraminiferal species were recorded. In the interval studied the following sequence of bioevents is recorded from bottom to top (a) FO of *Sigalia carpatica*; (b) FO of *Costellagerina pilula*; (c) FO of typical “pill-box” like morphotypes of *Globotruncana linneiana*. The planktonic foraminifera allow the subdivision of the studied section into two heterohelicid zones: *Pseudotextularia nuttalli* and *Sigalia carpatica* and the correlation of the zonal boundary with the inoceramid scheme. The Coniacian – Santonian boundary, as defined by the first occurrence of *Platyceramus undulatoplicatus* (Roemer), falls in the lower part of the *Sigalia carpatica* Zone. FOs of *Costellagerina pilula* and typical “pill-box” like morphotypes of *Globotruncana linneiana* are a good proxy for the stage boundary.

Late Glacial and Holocene calcareous nannoplankton variations in the Northern Red Sea

Heiko Legge & Jörg Mutterlose

We present a high-resolution calcareous nannoplankton record from the northern Red Sea (GeoB 5844-2). Absolute abundances and numerical variations between selected species were used to reconstruct the palaeoceanography during the last 22 ka and are compared with geochemical data. The present work was carried out in order to improve our understanding of short-term variations of the calcareous nannoplankton assemblages and their relation to the terrestrial climate history.

The Red Sea is a key area for studying climatic changes in the late Quaternary. The oceanographic conditions are controlled by the regional climate and the restricted exchange of water masses with the Indian Ocean via the shallow Strait of Bab el Mandeb. Due to this fact, the salinity is particularly sensitive to changes in the global sea level. Variations of the sea level driven exchange during glacial-interglacial cycles are well documented in an enhanced amplification of palaeoclimatic signals such as oxygen isotope ratios and microfossil compositions.

Extreme conditions with highest salinities during the late glacial result in the northern Red Sea in the total disappearance of planktic foraminifers („aplanktic zone"), caused by low abundances of the calcareous nannoplankton. However, it is proven that sea-surface salinity is not the controlling factor of variations within calcareous nannoplankton since the Heinrich event 1 (H1). Different assemblage compositions and absolute coccolith numbers throughout the H1 indicate fluctuations in productivity and surface water conditions. For example: the assemblages during the Bølling/Allerød warm period and especially the Red Sea humid period are dominated by *Emiliania huxleyi* suggesting more eutrophic and humid conditions. The period of the Younger Dryas is characterised by increased abundances of *Gephyrocapsa oceanica* indicating significant changes in the stratification and productivity. The palaeoceanographic implication of the calcareous nannoplankton composition is also documented by different geochemical proxies, providing the hypothesis of a strong coupling between the environmental changes in the northern Red Sea and the climate of the Northern Hemisphere high latitudes.

The Maastrichtian - Danian boundary of the TUBA-13 drill core, central Copenhagen, Denmark

Jan Audun Rasmussen & Emma Sheldon

The TUBA-13 drill core has been re-investigated with the aim of shedding new light on the biostratigraphic resolution around the Cretaceous - Palaeogene (K-P) boundary. Both the Maastrichtian chalk and the overlying Danian limestone contain rich and well-preserved microfaunas and nannofloras. The uppermost Maastrichtian strata contain e.g. the planktic foraminiferid species *Pseudotextularia elegans*, *Planoglobulina acervulinoides*, *Heterohelix globulosa*, *Guembelitria cretacea*, *Globigerinelloides multispina* and *Rugoglobigerina rugosa* together with the benthic *Brizalina incrassata* and *Stensioeina pommerana*. Characteristic nannofossil species of this level are *Cribrosphaerella daniae*, *Nephrolithus frequens*, and large (14µm) *Arkhangelskiella cymbiformis*. These biota demonstrate that the uppermost Maastrichtian strata correlate with the *P. elegans* foraminiferid Zone (FCS 23) and the UC20d nannofloral Zone.

The lowermost Danian samples contain e.g. the planktic foraminiferids *Globoconusa daubjergensis*, *Eoglobigerina eobulloides* and *Parasubbotina pseudobulloides*, while *Subbotina triloculinoides* and *Globanomalina compressa* appear further upward in the succession. The lowermost Danian sample contained only very rare, non-diagnostic nannofossils. The overlying sample contained *Coccolithus pelagicus*, *Placozygus sigmoides* and *Markalius inversus*, whereas *Prinsius dimorphosus* and *Cruciplacolithus asymmetricus* first appear in samples situated slightly higher up-section. Accordingly, the fossil assemblages indicate that the lowermost Danian strata correlate with the P1a foraminiferid Zone and the NNTp2C nannofossil Zone. In conclusion, it is suggested that the P0 and Pα foraminiferid zones and the NNTp1A-2B nannofossil subzones do not occur in the TUBA-13, central Copenhagen.

Palaeomagnetic and planktonic foraminiferal biostratigraphy of a Plio-Pleistocene section, Rhodes (Greece)

Kurt Søren Svensson Nielsen

The Island of Rhodes makes up the easternmost part of the Aegean Arch, located near the Turkish mainland, in the Eastern Mediterranean Sea.

The Tsambika profile is located on the road to Tsambika Beach, approximately 25 km from the centre of Rhodes City at the south-eastern coast of the Island. The basement in this area is composed of metamorphic limestone of Mesozoic age. The basement reaches an elevation of 300-400 m above sea level just beside the profile (Tsambika Mountain). The investigated section consists of 40m of marine sediment (limestone, silt/clay), that rests unconformably on the basement. The sections can be separated into two lithofacies. The first is a limestone facies occurring between 0-4 meters in the lower part of the section. The limestone is replaced by a silt/clay facies occurring throughout the rest of the section. The foraminiferal assemblage suggests that the limestone unit is not an in-situ sediment and has been deposited by several gravity flows during a transgression. During the transgression the carbonate environment was drowned and replaced by the silt/clay facies, representing a deep-sea environment (> 400 m). Both the foraminiferal and palaeomagnetic data suggest that the section is of Late Plio-Pleistocene age. The limestone facies is assigned to the Kolimbia limestone Formation, while the silt/clay facies is assigned to the Lindos Bay Clay Formation.

The marine deposits have a very diverse planktonic foraminifera fauna. A total of 6o species have been recorded. More than ten of those species have not been previously recorded in the Mediterranean Plio-Pleiostocene. Further, at least two unknown planktonic species has been observed.

The biostratigraphic correlation between the Tsambika section and the Plio-Pleistocene boundary stratotype at Vrica, Southern Italy, shows that most of the foraminiferal events are diachronous. The only possible exception is the FAD of *G. crassaformis*. Also the benthic foraminifera *Hyalina baltica* has been recorded but the FAD of this species predates the Plio-Pleistocene boundary in the Tsambika section as indicated by the paleomagnetic data. It is concluded that it is not possible to correlate between the Tsambika and the Vrica sections based on foraminiferal biostratigraphy.

Calcareous plankton of the Cretaceous North Sea Basin: an integrated study of planktonic foraminifera and calcareous nannofossils

Sylvia Rückheim, André Bornemann & Jörg Mutterlose

In order to establish an integrated stratigraphic scheme for the Barremian to Albian interval in the Boreal Realm as well as gaining palaeoceanographic information, the BGS Borehole 81/40, which is located in the western part of the Central North Sea Basin, has been studied. A stratigraphy based on ammonites and ostracods published by Lott et al. in 1985 shows a complete succession of middle Barremian to Albian sediments. Based on planktonic foraminifera, calcareous nannofossils and stable isotopes a revised stratigraphy was developed which reveals a hiatus covering the lower Aptian.

While the planktonic foraminiferal assemblage indicates a more isolated position for the North Sea Basin during Barremian times with low abundances and specimen numbers, the upper Aptian is characterised by high abundances and specimen numbers which suggest more open oceanic conditions. The assemblages are dominated by small trochospiral and opportunistic hedbergellids; the episodical occurrence of planispiral specimens of *Globigerinelloides*, *Leupoldina* and *Ticinella* let us assume that different phases of water mass exchange between the Tethys and Boreal Realm took place during the Barremian to Albian interval.

A semi-quantitative analysis of calcareous nannofossils suggests warmer conditions during the middle Barremian which favoured high abundances of nannoconids. The representatives of the genus *Nannoconus* are mainly species restricted to the Boreal Realm such as *Nannoconus abundans*, *N. borealis* and *N. inornatus*. Whereas the upper Aptian is characterised by cooler conditions as indicated by high abundances of cool water taxa (*Repagulum parvidentatum*, *Crucibiscutum* spp.).

A semi-quantitative analysis of benthic foraminifera based on the agglutinated/calcareous-ratio suggests warmer bottom-water conditions during Barremian and lowermost upper Aptian times. For the upper Aptian a cooling trend which is indicated by a dominance of agglutinated specimens can be observed.

High resolution biostratigraphy in Neogene sediments of two wells in the western Gulf of Mexico

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High-resolution biostratigraphy was carried out using calcareous nannofossils, planktic and benthic foraminifera, and palynomorphs from two wells in the western Gulf of Mexico. The age of the sediments is early Pleistocene to middle Miocene.

The early Pleistocene is represented by nannoflora and microfauna of biozones NN19 and N22 (the *G. truncatulinoides truncatulinoides* Biozone) respectively, and by the dinocyst species: *S. delicates, S. membranaceous, M. quanta* and *H. rigaudiae*. These sediments were deposited in an inner neritic to middle neritic environment.

The Pliocene is characterised by biozones NN18, NN17, NN16, NN15, and NN14 to NN12, the *G. miocenica-G. tosaensis tosaensis* (N21-N20) biozones, the *Globorotalia margaritae* (N19-N18) biozones, and by the species of dinoflagellates *P. zoharyi, L. machaerophorum, M. choanophorum* and *O. crassum*. The palaeobathymetry corresponds to inner neritic to upper bathyal environments.

The late Miocene sediments comprise microfossils from the NN11, NN10, and NN9 biozones and the *G. humerosa* and *G. acostaensis* (N17 and N16) biozones. The dinocysts present in these sediments are: *S. mirabilis, D. pastielsii, S. hipidum*, and *Achomosphaera andalusiensis* among others. The palaeobathymetry of the sediments corresponds to an outer neritic to upper bathyal environment.

The middle Miocene strata are represented by the calcareous nannofossil biozones NN9, NN8, NN6 and NN5; the *G. mayeri*, *G. fohsi lobata* - *G. ruber* and *G. fohsi fohsi* (N14, N11-N13 and N10 biozones); and probably by part of the *G. fohsi peripheroronda* (N9) Biozone. These strata were deposited mainly in an outer neritic to upper bathyal environment.

The diversity and abundance of nannofossils presented notable variations throughout the two wells. In Well A, a strong predominance of calcareous nannofossils and marine palynomorphs from an outer neritic environment are observed, while planktic foraminifera from an upper bathyal environment increase in this well. In Well B an abundance of continental palynomorphs are noted from an inner neritic to middle neritic environment. One reduction is detected, indicating the outer neritic to upper bathyal.

Late Quaternary stratigraphy and foraminiferal response on the northern New South Wales continental shelf, Australia: a mixed siliclastic-carbonate setting

Claudia Schröder-Adams & Ron Boyd

The narrow continental shelf of northern New South Wales, Eastern Australia is covered by mixed siliclastic and temperate carbonate sediments. The strong, warm East Australian Current flows south sweeping mid and outer shelf biogenic sands and gravels. Inner and mid shelf clastic sediments are reworked by year-round, high- energy waves causing northward longshore currents or waning storm flows. This margin has low accommodation, and is dominated by wave and oceanic currents that have produced mixed siliclastic-carbonate facies. Ten cores are studied to establish benthic foraminiferal response to changes in lithofacies and Late Quaternary sea-level history. These cores cover two transects, from inner shelf to upper slope at Tweed Heads near the border to Queensland and from inner to outer shelf near the Clarence River at Yamba. Whereas the East Australian Current prevents fine-grained sediments from being deposited in less than 35m water depth on the shelf, coastal headlands and the relatively large sediment input of the Clarence River allows for some mud to settle near Yamba.

A total of five facies associations were identified in the cores including inner shelf siliclastic sands, mid shelf clastic sands, outer shelf and upper slope temperate carbonate sands and gravels, and estuarine sediments. Foraminifera clearly increase in abundance and diversity with greater distance from shore and decrease in siliclastic influence. Palaeoestuaries that developed during the last interglacial and subsequently filled during early transgression were recovered on the inner to mid shelf. Faunal content in various estuarine facies varies, resembling the faunal response to complex ecological conditions of modern estuaries in the same region. Estuarine fill on the modern shelf is thin suggesting only shallow incision into the continental shelf during lowstand and/or erosion of earlier estuarine deposits through wave ravinement. The inner shelf facies at Tweed Heads comprise fine to medium sands with a poorly preserved low diversity benthic fauna indicating some reworking. At Clarence River a higher mud portion is preserved in the inner to mid shelf facies, foraminiferal abundance and diversity increases and the spiny species *Parrellina imperatrix* becomes common. Quaternary carbonate outer shelf sediments form uniform and graded beds resulting from the East Australian Current and less frequent storm energy. Foraminiferal assemblages are rich in abundance and diversity including numerous taxa of large test size. Calcareous species widely dominate the outer shelf and upper slope assemblage with a slight increase in agglutinated species on the upper slope. These transgressive and highstand outer shelf and upper slope sediments comprise temperate water carbonates. This project is part of a larger multidisciplinary study of Quaternary coastal valley evolution in New South Wales, Australia.

An improved Upper Cretaceous foraminiferal biozonation and well log correlation for the Pompeckj Block: preliminary results

Jens Steffahn & Jörg Mutterlose

The objective of this study is to reconstruct - chronologically and spatially - the distribution patterns of the Upper Cretaceous sediments (Albian to Maastrichtian) and finally the inversion history of a part of the Northwest German Basin (NWGB), namely the Pompeckj Block (PB) on a high resolution scale. Therefore an improved stratigraphic zonation scheme is desirable.

The Cretaceous NWGB is likely defined as a structure which consists of three tectonic elements:

a. Münsterland Block (MB)
b. Lower Saxony Basin (LSB)
c. Pompeckj Block (PB)

Its structural and sedimentary development can be generalised as follows:

1) Large thicknesses of Upper Jurassic to Early Cretaceous sediments within the LSB. Deposits of this age are absent further south on the MB and in the north on the PB.
2) A quiet phase (Aptian to Cenomanian) is characterised by a widespread transgressive onlap of marine sediments.
3) The legitimate inversion took place most presumably from the Turonian to the Campanian, indicated by a spatial shift of the major depositional centre. The LSB was uplifted and eroded. Simultaneously sediments were accumulated on the subsiding MB and PB; the regions of former highs.
4) The inversion supposedly terminates with a stable phase (Upper Maastrichtian to Palaeogene).

Furthermore, it remains unclear where and at what time precisely, if repeated in multiple steps for instance, how intensely the MB and PB subsided during the phase of legitimate inversion. Thus the exact driving mechanism for this inversion within the varying stress conditions of the Central European Basin System (CEBS) is not known in detail.

Data sets and original material of relevant wells penetrating the Upper Cretaceous of the PB have been re-examined to refine the existing (bio-)zonation and to reassess calibration for SP well log correlation. To achieve an improved comprehensive biostratigraphic concept recent work dealing with distinct time slices of the Upper Cretaceous NWGB have been implemented. Additionally zonation schemes developed for the North Sea, Offshore Norway and the MB were estimated and checked for applicability.

The most complete and thick Upper Cretaceous sequence of the Offenseth 1 well (OFFS 1) serves as the reference section. Special attention is paid to first downhole appearances (FDA) of index foraminifera to minimise erroneous dating due to reworking and caving. Nevertheless taphonomical inquiry also allows the use of last downhole appearances (LDA) datum markers.

This improved zonation scheme based on benthic and planktic foraminifera allows biostratigraphic calibration of parts of the drilled Upper Cretaceous sequences with a resolution of less than 1Ma. It will be further refined and seconded in combination with well log peak stratigraphy and then used for correlation of wells penetrating the Late Cretaceous of the Pompeckj Block.

Excursion Guide, Stevns Klint, 2004

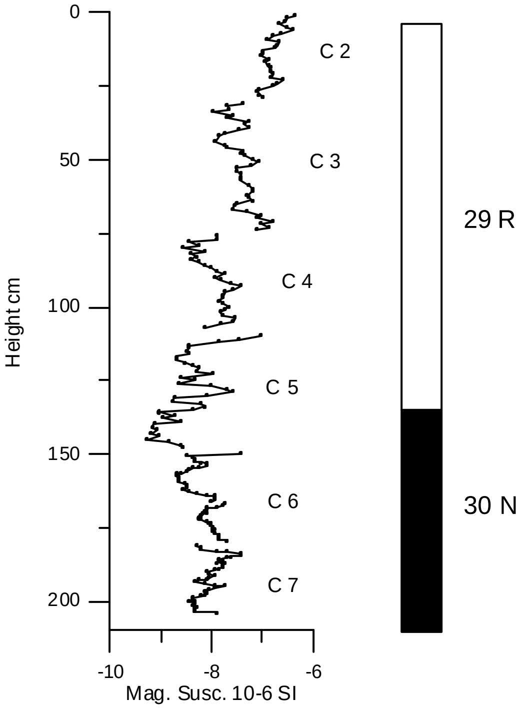
Hans Jørgen Hansen

The Stevns Klint section (along with Fakse Limestone Quarry) are the type Danian sections mentioned in the original definition of the Danian.

Since the classical locality below the church at Højerup is at present partly covered by scree, it was decided to visit the southern locality Rødvig for sampling in stead of the poor Højerup section.

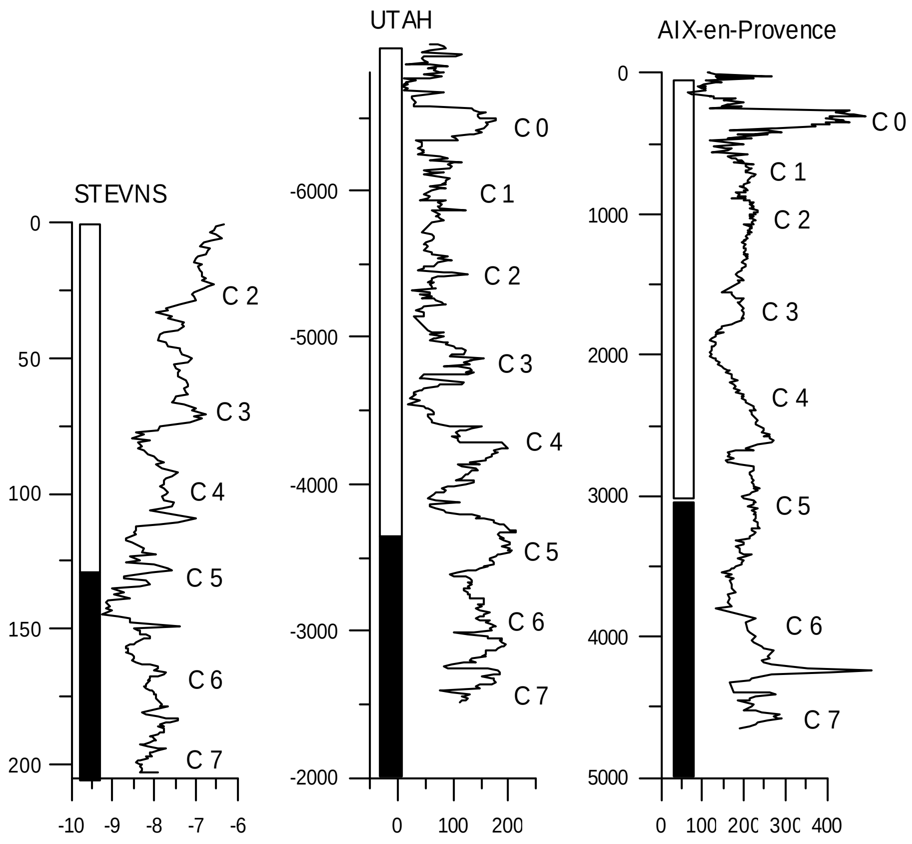
The Rødvig section is one of the few exposures not showing a N-S cross section, but rather an almost longitudinal section through a Fish Clay basin.

The section exposes (if water level permits) the boundary between the white "white chalk" and the grey "white chalk" (from hereon termed the "grey chalk"). The white chalk and the grey chalk are bedded with bed thicknesses of around 40 cm. Both are of Maastrichtian age. The overlying Fish Clay is Maastrichtian too, while the *Cerithium* Limestone is Danian.



The boundary between grey chalk and white chalk is situated in bed 6 below the Fish Clay. The boundary is a hardground with *Thalassinoides* burrows, that are observable in the underlying white chalk bed at low waterstand. The burrows are not silicified in contrast to those below the grey chalk boundary in the remaining part of Stevns Klint (12 km exposure).

The grey chalk owes its name to a raised amount of elementary carbon, which stains the otherwise white material slightly grey when compared with the "real" white chalk. This is particularly well seen on wet surfaces. The bedding of the grey and white chalk expresses Milankovic cycles with the bed boundaries marking the 100 ka elliptical situation. When sampled at a resolution of 5 mm, the precessional signal can be recorded by the magnetic susceptibility of the sediments (fig.). This indicates that the deposition of the grey chalk at Rødvig lasted for about 600 ka. The preservation of the precessional signal has interesting implications for the movements of sediments by burrowing organisms. The only burrow-type ruining the pattern, are the rather wide pipes of *Thalassinoides*. Apparently the other burrowing organisms are moving the sediment laterally and not vertically.



The grey chalk forms kind of elongate banks (almost bioherms) with an up-stream and a downstream side. They run in a NW-SE direction parallel with the Fenno-scandian Border-zone. The non-symmetry of the banks is reflected in the larger and more well developed bryozoa on the upstream side. The content of bryozoan skeletal remains may locally be considerable. The banks were formed below wave-base. The content of elementary carbon (with an isotopic value around delta -28 ‰ PDB) is unevenly distributed. In the upper beds, black bryozoa are found encrusting upon white ones and vice versa. The black bryozoa contain iridium while the white ones do not. The black colour of the bryozoa is caused by elementary carbon. The carbon fraction of the grey chalk (besides <1 micron beta-graphite particles) comprises small, hollow graphite spheres, 1-2 microns in diameter. These are otherwise only known from volcanic glasses.

The elementary carbon in the grey chalk occurs in higher concentration in the upper beds. Some of the bryozoa in the upper part of the grey chalk have micro-manganese nodules growing on their inside and on their surfaces. The manganese nodules contain unusually high amounts of cobalt.

The grey chalk terminates right below the bottom of the overlying Fish Clay in a series of thin dark stripes. These stripes are caused by carbon and not by clay. They have been variously interpreted as either incipient dissolution horizons (early stages of stylolites) or thin "coal seams".

The very bottom of the Fish Clay itself is made up of a ca. 3 mm pale grey clay layer. This layer contains bipyramidal low-quarts paramorphs after high-quarts with glass inclusions. They are clear evidence of rhyolitic volcanism. This layer also contains shock quartz grains.

Above this follows a 4 cm deep black clayey layer, which contains up to 800.000 dinoflagellate skeletons per gram dry sediment. It is the richest dinocyst concentration ever recorded. The black sediment may eventually be termed a "Dino-cystite". When washing the black Fish Clay, ordinary methods are of little use. One has to extract first the content of oil, otherwise the material is not washable (use e.g. petrol on the dry rock). In addition to dinocysts, the black material contains large amounts of cyanobacteria (blue-green algae) plus skeletons of the alga *Botryococcus* (which contain charotin-coloured oil drops as floating devices). The clay mineral of the Fish Clay (irrespectable of color) is smectite.

The black colour is due to elementary carbon and small, sharp, 20-30 micron pieces of charcoal. The charcoal has isotopic values around -25 ‰ PDB. Common reports of the presence of finely dissiminated pyrite indicating anaerobic conditions is not correct. Pyrite is found in secondarily formed nodules on the chalk/Fish Clay boundary but also at the contact between the truncated banks and the overlying Danian bryozoan limestone. The very low values of trace elements in the pyrites point to their late diagenetic origin (maybe even of Quaternary age formed at the groundwater barrier at the chalk/Fish Clay or chalk/brz limestone interface). They were not formed in contact with seawater.

In the lower part of the black material the amount of $CaCO_3$ is zero. It steadily increases in the overlying greyish-brownish Fish Clay and finally passes into the overlying *Cerithium* Limestone (only found on Stevns and named after the gastropod *Cerithium*.) In the literature the Fish Clay has often been described as being laminated. However, the lamination does not consist of laminae, but of compressed burrows, the filling material of which forms very flat lenses, but no laminae. This is easy to observe when the clay is cleaved with a knife. The filling material is mostly "powdery" bryozoans and other invertebrate fossil fragments. The age of the burrow fill is Danian !

In the lower part of the black Fish Clay is a horizon of rusty appearance. It consists of compressed burrows filled with rusty material in which red 0,5 - 1 mm spheres are prominent. They are also dissiminated in the Fish Clay. The layer (not being a true layer) may be absent over distances of 1-5 cm. The horizon of burrow-fill has been interpreted to represent the fall-out layer following a postulated meteoritic impact. The horizontal parts of the red burrows are found also higher up in the Fish Clay as cm-wide red, horizontal lenses. They have no relationship to Heavenly Bodies ! The red spherical bodies are predominantly filled with the mineral goethite. Each obtains its spherical shape from a surrounding Prasinophyte alga. These algae are so well preserved, that biological ultrasectioning is possible. The algal wall is highly porous and the ferri-compounds filling them, have formed *in situ* inside the algal spheres.

The trace elements of the spheres show high enrichment in siderophile elements. The algal spheres found with the filling of pyrite on Stevns all are present in the near vicinity of the secondary pyrite nodules. They are of secondary diagenetic origin. By contrast, the identical spheres from the locality Karlstrup, 20 km further to the north, contain primary pyrite-fillings. The difference is also expressed in cerium-anomalies of fish debris analysed from the two localities. Stevns is aerobic while Karlstrup is an-aerobic. The spheres have been interpreted as altered impact-related micro-tectites. The same algae occur at the K/T boundary in New Zealand, Tunisia, Gubbio and Caravaca. However, in Caravaca and Gubbio the filled algae are sometimes overgrown by later-formed sanidine. Sanidine is a high-temperature K-feldspar. However, sanidine is known also to form in submarine tuffs. We dated the sanidine by Ar/Ar and it gave 49,4 Ma $\pm$ 0,98 for Caravaca and 59,3 Ma $\pm$ 1,18 for Gubbio.

The width of the compressed burrow-fill is up to 20 mm. The actual width of the corresponding burrow probably was larger. It does, however, allow the conclusion, that the compaction of the Fish Clay is no less than 1:20. Since the depth of the basins is around 80 cm and the black clay around 4 cm thick we arrive at the conclusion, that at the time of formation of the burrows, the black clay almost filled the basins. This raises the question of why all the red burrows terminate (or develop their horizontal component) at the bottom of the Fish Clay? Organisms that make burrows in organic soup like the Fish Clay at that time, did not burrow into chalk. We have never observed burrows with a fill of Fish Clay extending down into the chalk.

The truncation of the tops of the grey chalk bioherms took place in Fish Clay time. This is the only time where a non-carbonate environment existed. The tops of the bioherms were exposed, while the remaining part of the shallow basins were covered by “organic soup”. The truncation of the bioherm-tops took place in a quiet environment, where no signs of wave or current action have been found. However, part of the erosion may have taken place at the time of the formation of the hardground capping the *Cerithium* Limestone.

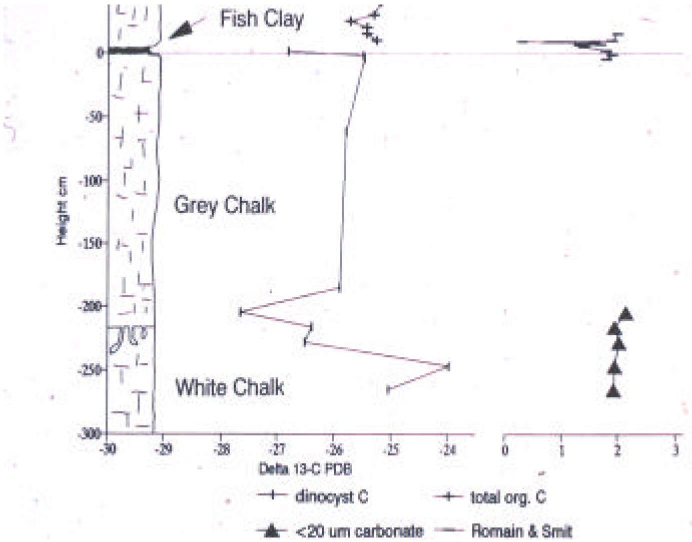
The upper transitional part of the Fish Clay with higher carbonate content contains the so-called Danian ammonites and baculites. They are all partly phosphatized, and their fill is of Maastrichtian age as documented by coccoliths from the fills.

The upper part of the brownish-grey Fish Clay gradually changes into the overlying *Cerithium* Limestone. The limestone is truncated by a hardground. The hardground is heavily burrowed and much loose debris of Lower Danian age fill the burrows. This is the place to find extremely well preserved Lower Danian bryozoa. The *Cerithium* Limestone is hardened, partly glauconitized and phosphate impregnated. “Danian” scaphites and baculites are found here too. The cut off tops of the grey chalk bioherms were also heavily burrowed along with the *Cerithium* limestone. In some cases the *Cerithium* Limestone fills the Fish Clay basins, in other cases it covers also the tops of the truncated tops of the grey chalk bioherms.

The material composing the *Cerithium* Limestone is difficult to find in a diagenetically unaffected state on Stevns. The equivalent layer in the remaining part of the country (the "dead layer") shows a very peculiar and strange fine-structure. The carbonate grains are small and of rather uniform size (below 5 microns). Many have developed scalenohedra and the rock is very poorly cemented. The trace element content is low in comparison with the white chalk. It is interpreted as a chemical precipitate formed in the free watermass. Traditionally the lack of dinocysts in the *Cerithium* Limestone has been blamed on preservation. However, preparations of pure, non-burrowed *Cerithium* Limestone from Stevns showed presence of few (but significant) pollen grains. This means that sporo-pollenine is preserved, and the lack of dinocysts is therefore a primary feature. The dinoflagellates were not encysting in the Stevns region in *Cerithium* Limestone time.

Judging from dinocysts the age of the white and grey chalk is Maastrichtian. The age of the black part of the Fish Clay plus 0.5 cm of the overlying brownish-grey clay is also biostratigraphically speaking Maastrichtian. The content of the compressed burrows is of Danian age, as indicated by the find of the earliest Danian dinoflagellates.Thus a sample of the Fish Clay shows a mixture of Maastrichtian and Danian dinocysts unless sampled very carefully.

An Ir anomaly of 185 ppb (highest ever recorded) is found in the black clay above the red burrow layer at the locality Harvig. At Rødvig (Rocchia, pers. comm.) the Ir anomaly starts 40 cm below the bottom of the Fish Clay in the grey chalk. We have looked for shocked quartz in the Fish Clay proper, but have never found any. The world-wide occurring carbon-isotope ano-maly associated with the K/T boundary was never found at Stevns in carbonates. This is not strange, considering the complete lack of carbonate in the Fish Clay. However, a carbon-isotopic anomaly of –2 ‰ is found between dinocyst carbon from below the Fish Clay and in the Fish Clay proper.

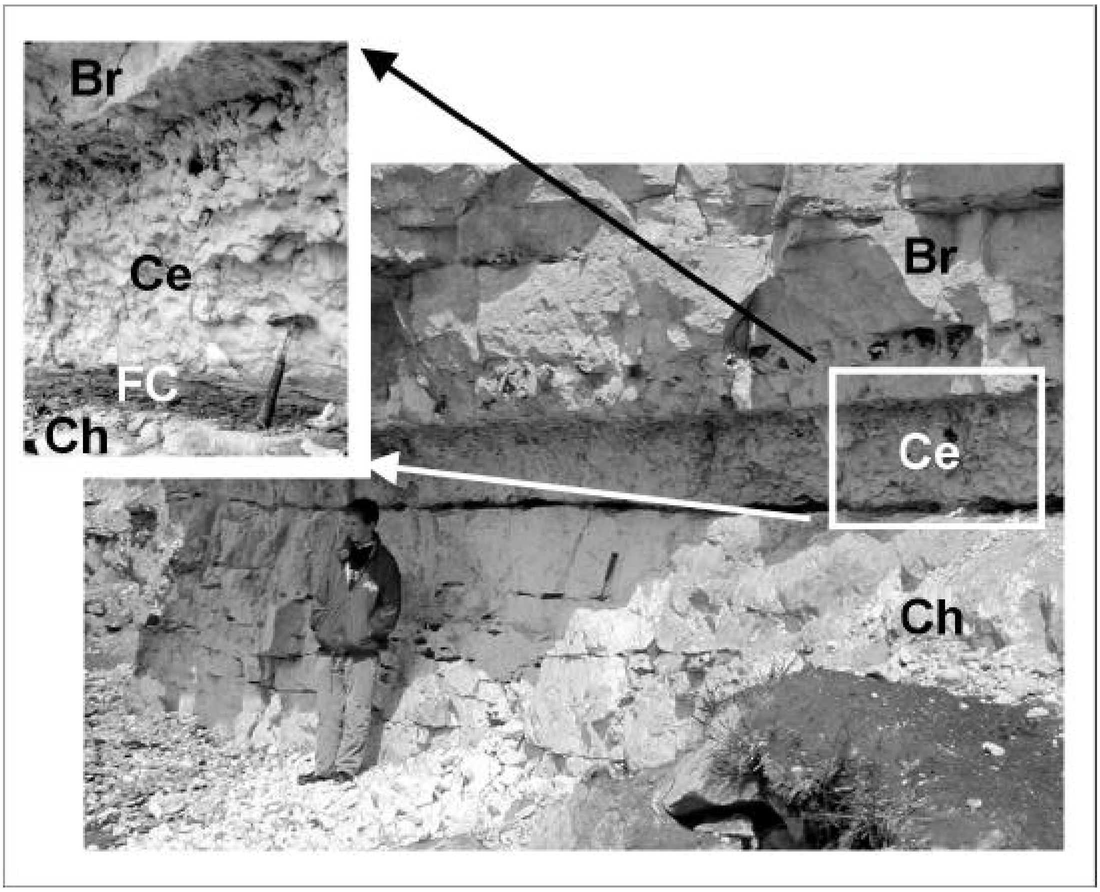


In north Jylland, at Nye Kløv, a corresponding anomaly in dinocyst carbon was found 15 cm below the Fish Clay equivalent. At Nye Kløv a small (4 ppb) Ir anomaly was found in the Fish Clay. The two boundaries and the disappearence time of coccoliths and planktonic foraminifera therefore are diachronous. The carbonate in the white chalk does not preserve the signal faithfully (fig).

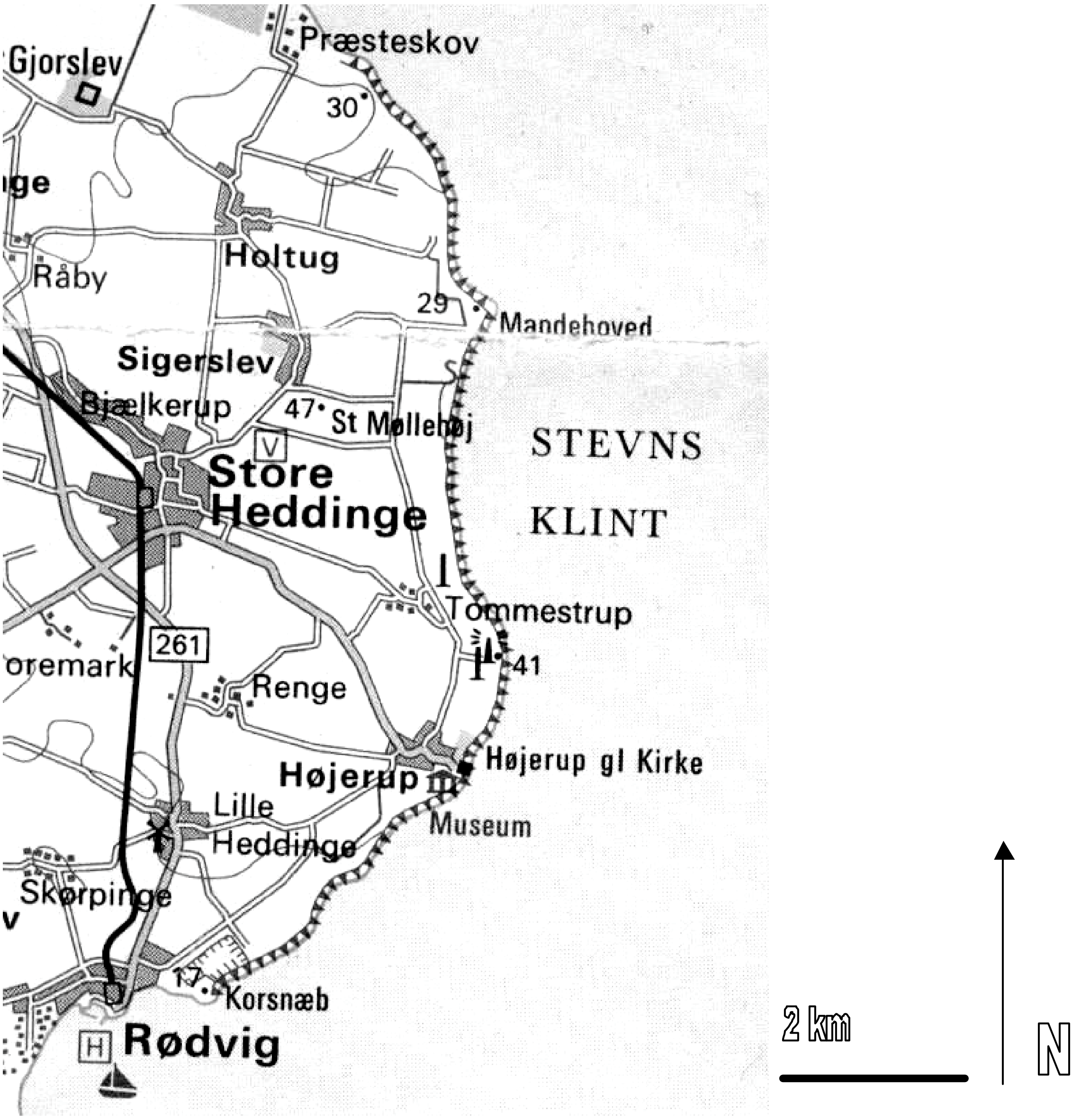
The section at Stevns Klint is rather unique in its paleogeographical setting close to the former dry Swedish horsts, causing all air-borne particles to be concentrated. Thus, there is no grey chalk at Karlstrup and the recorded Ir-anomaly is small because of its geographic position further away from the paleo-coast while Stevns in its slightly deeper parts of deposition (i.e. Rødvig in south relative to Kulsti in the north) has both grey chalk and high Ir content.

The three hardgrounds found in the Stevns section namely the white chalk/grey chalk boundary, the Fish Clay and the *Cerithium* Limestone top, each represents a marine regression. The drop in sealevel can be estimated from the incised channels in the terrestrial Upper Maastrichtian Hell Creek Formation in North America. The earliest channels cut to 10 m, the one at the K/T boundary cuts at least 16 m, while the youngest cuts to 25 m. This probably corresponds to a 20, 30 and 50 m sealevel-drop.

During the glaciations, the Prequaternary deposits were subjected to a stong stress from the passing ice. This made the Danian bryozoan limestones (with their coherent flint-layers) move against the rather massive white chalk, causing tectonic disturbances in the Fish Clay, which acted as a kind of banana-peel between the two units. This has caused the majority of flat-lying Fish Clays (and equivalents) to be tectonically disturbed. Karlstrup and one spot at Stevns Klint were not affected. This is regretfully not so at Rødvig.



Ch- Maastrichtian chalk. FC – Fish Clay. Ce–Cerithium Limestone (Danian).
Br – Bryozoan limestone (Danian).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