Miocene Workshop at GEUS, Copenhagen

Open lectures, Thursday 6./10. 2011 in Theodor Sorgenfrei Auditoriet

GEUS

Nordic Center for Earth Evolution

Program for oral presentations

Miocene Workshop at GEUS, Copenhagen
Thursday 06.10.2011, Theodor Sorgenfrei Auditoriet

The entrance (Trappe N) is open half an hour before the morning (9:00) and afternoon (13:30) sessions; otherwise contact the GEUS reception at the main entrance

Program for oral presentations

Miocene, North Sea

9:00 Introduction to the Danish Miocene and correlation to Germany and Norway
Erik S. Rasmussen, GEUS, Denmark

9:25 Miocene Stratigraphy in Northern Europe
Tor Eidvin, NPD, Norway

9:50 Miocene of the Lusatia (Saxony, Brandenburg) Germany
Gerda Stanke, LfUGL, Germany

10:15 Cenozoic Lower Rhine Basin (Germany) - origin, sediment fill and sequence stratigraphy
Andreas Schäfer and Thorsten Utescher, University of Bonn, Germany

10:40 Break

11:00 Climate coupling of terrestrial and marine Miocene: examples from the Netherlands
T.H. Donders[1], J.W.H. Weijers[2], D.K. Munsterman[1], R.D. Pancost[4], S. Schouten[2, 3], J.S. Sinninghe Damsté[3], and H. Brinkhuis[5], The Netherlands*

11:25 Late Cenozoic delta deposition in the German North Sea; first results of the project Geopotential of the German North Sea (GPDN)
Hauke Thöle, BGR, Germany

Biostratigraphic framework

11:50 High-resolution composite biostratigraphy for the Miocene of the North Sea Basin
Chris King, UK

12:15
Neogene dinoflagellate cyst zonation of the eastern North Sea Basin, Denmark
Karen Dybkjær, Stefan Piasecki and Erik S. Rasmussen, GEUS, Denmark

12:40 Lunch

Miocene New Jersey Passive Margin

13:30 Chasing the Record of Sea-Level Change: Preliminary results of IODP Exp313
Gregory Mountain, Rutgers University, USA

14:15 A 100 million years record of global sea-level change: Should I sell my shore house?
Kenneth Miller, Rutgers University, USA

15:00 Break

Miocene delta environments and analogues

15:20 Distribution of Miocene sediments in the Norwegian Sea and the Norwegian sector of the North Sea, and their relation to the uplift of Fennoscandia
Fridtjof Riis and Tor Eidvin, NPD, Norway

15:45 Delta vs shoreface: a Quaternary perspective
Serge Berné, University of Perpignan, France

16:10 Rapid sea level changes recorded by prograding sand bodies in the Gulf of Lions (western Mediterranean Sea) during Quaternary
Maria-Angela Bassetti, University of Perpignan, France

16:35 Distribution and grain size of sand in the Miocene wave-dominated Billund delta, Denmark
Erik S. Rasmussen, GEUS, Denmark

16:50 Utsira Formation; NPD assessment
Ine Gjeldvik, OD, Norway

17:10 Break

Palaeoenvironments

17:25 Reconstruction of continental Miocene climate based on the palaeobotanical record
Torsten Utescher[1,4], Abdul R. Ashraf[2], Karen Dybkjær[3], Volker Mosbrugger[4], and Andreas Schäfer[1]
Germany and Denmark**

17:50 Sea level variations in a Miocene succession from Denmark.
Caterina Morigi, GEUS, Denmark

18:15 Clay mineralogy in Palaeogene and Neogene sediments in the North Sea Basin
Ole Bjørslev Nielsen, University of Aarhus, Denmark

*
1) TNO, Geological Survey of The Netherlands, P.O. Box 80015, 3508 TA Utrecht, The Netherlands
2) Department of Earth Sciences – Geochemistry, Faculty of Geosciences, Utrecht University, Budapestlaan 4, 3584 CD Utrecht, The Netherlands
3) Department of Marine Organic Biogeochemistry, NIOZ Royal Netherlands Institute for Sea Research, PO Box 59, 1790 AB Den Burg – Texel, The Netherlands
4) Organic Geochemistry Unit, Bristol Biogeochemistry Research Centre, School of Chemistry, Cantock's Close, Bristol University, Bristol BS8 1TS, UK
5) Biomarine Sciences, Laboratory of Palaeobotany and Palynology, Utrecht University, Budapestlaan 4, 3584 CD Utrecht, The Netherlands

**
[1]Steinmann Institute - Geology, Bonn University, Bonn, 53115, Germany (utescher@geo.uni-bonn.de)
[2]Institute for Geosciences, Eberhard Karls University, Tübingen, 72076, Germany
[3]Geological Survey of Denmark and Greenland, Copenhagen K, 1350, Denmark
[4]Senckenberg Research Institute and Natural History Museum, Frankfurt, 60325, Germany

MIOCENE OF DENMARK AND THE NORTH SEA BASIN

Erik S. Rasmussen
Geological Survey of Denmark and Greenland, GEUS

The Oligocene – Miocene transition is onshore Denmark characterised by a distinct shift from deposition of marine clay to fluvio-deltaic sand-rich sediments. During the early Miocene, three deltaic units prograded into the eastern North Sea Basin. The sediments were sourced from present-day southern Norway and central Sweden. The change in sediment supply to the basin was associated with an inversion phase that culminated in the early Miocene. The deltas were strongly influenced by wave processes and asymmetric wave-dominated deltas predominated the shoreline with lagoons developed east of the main delta lobes. Extensive coal formation occurred during the third and final progradation.

A major transgression commenced in the early middle Miocene and the area became sediment starved. This permitted deposition of glaucony-rich sediment during the remaining part of the middle Miocene. Resumed progradation took place in the late Miocene. At the end of the Tortonian the shoreline was displaced to the central part of the North Sea Basin. The late Miocene shoreline is incised by a number of deep canyons, c. 90 m deep which probably were formed associated with the Messinian lowstand of sea level.

Regional correlation of the Danish Miocene within the North Sea Basin shows a number of differencies in the development of the Miocene successsion around the basin. The southeastern part was more influenced by tidal processes and the three fold development of delta progradation has not been recognised here, but are instead characterised by two periods of progradation with widespread coal formation. In the southwestern part of Belgium the lowermost Miocene is represented by a hiatus probably due to inversion and therefore not flooded during the early Miocene transgression. The remaining part of the early Miocene was also dominated by widespread coal formation deposited within coastal environments. This continued along the southern North Sea Basin margin in the Middle Miocene. From the late Miocene, fluvial depositional systems far dominated the southern margin of the North Sea Basin. In the western part of the Basin only scattered informations are available, but the British Isles seem not to be an important source area during the Miocene, only the Shetland Platform which provided sediment source area for the lower Miocene Skade Formation and the upper Miocene Utsira Formation.

MIOCENE STRATIGRAPHY OF NORTHERN EUROPE

Tor Eidvin,
Norwegian Petroleum Directorate, P. O. Box 600, N-4003 Stavanger

Based on an extensive study of biostratigrapic and strontium isotope data from 32 wells and boreholes from along the entire Norwegian shelf, one ODP borehole off Scoresby Sund (East Greenland), two stratigraphic boreholes from onshore Denmark and new strontium isotope data from a number of other boreholes and outcrops from Denmark, we present an improved chronology of Miocene strata in Norden. Emphasis has been placed on sandy deposits. Most wells and boreholes have been integrated with wire-line log and seismic data.

During Early Miocene global climatic variations and major sea-level changes combined with uplift of the southern part of the Fennoscandian Shield, led to increased sediment transport from the north (present day Finland, Sweden and particularly Norway) towards present day Denmark. Deltas (Ribe Group) covered large parts of the present day Jylland area. In the western part of the Viking Graben in the North Sea, sand-rich gravity deposits of the Skade Formation were sourced from the Shetland Platform. To the east, in the central part of the basin north of 60ºN and in the Central Graben fine-grained sedimentation occurred. The pronounced out-building of coastal plains and deltas all along the inner Norwegian Sea continental shelf (Molo Formation), which started in the Oligocene, continued in the Early Miocene. To the west, thin sections of fine-grained deposits are recorded on the Trøndelag Platform, and mainly pelagic ooze was laid down in the Norwegian Sea (Brygge Formation).

The uplift culminated at the Early to Middle Miocene transition, and the deposition of the Skade Formation sands was followed by a large relative sea-level fall. In the Norwegian Sea, major compressional features, e.g. the Helland Hansen Arch, were formed. In the southern North Sea and Norwegian-Danish Basin subsidence continued. During the Middle Miocene mainly fine-grain sediments were deposited in most parts of the Viking and Central Graben, and in parts of the Trøndelag Platform on the Norwegian Sea continental shelf. Hiatuses are either minor or absent in the Viking Graben. Pelagic sedimentation continued uninterrupted in most of the Norwegian Sea (Kai Formation). However, hiatuses are probably present on large dome structures. Also the Barents Sea margin was lifted, and a hiatus is recorded below the Middle Miocene in the Sørvestnaget Basin. In the Vestbakken Vulcanic Province there is a break between the Upper Pliocene and Lower Miocene. The climate was probably warm temperate during the Early Miocene and culminated with a subtropical climate in the early Middle Miocene.

In the Late Miocene, a marked relief of the Fennoscandian Shield, accompanied by continued uplift, colder climate and a low global sea level, resulted in a continued and pronounced out-building of coastal plains and deltas along the inner Norwegian Sea continental shelf (Molo Formation). During the same period the northern North Sea formed a narrow seaway between deeper water in the Møre Basin and the central North Sea. The strait received large amount of coarse clastics (Utsira Formation) mainly from the East Shetland Platform in the west, but also from the Sognefjorden area in the east. Offshore West Norway further to the south, only thin and shaly sections are recorded, while deposition continued towards Denmark and the Norwegian Sea, probably using the drainage systems which were established in the Oligocene. This situation lasted through the Early Pliocene when the global temperature and sea level temporarily rose.

The investigation of the large sediment wedge off the Scoresby Sund fjord system shows that the build-up of substantial continental ice on Greenland started in Late Miocene at approximately 7.5 Ma.

MIOCENE OF THE LUSATIA (SAXONY, BRANDENBURG) GERMANY

Gerda Standke
Landesamt für Umwelt, Landwirtschaft und Geologie
Abt. Geologie, Halsbrücker Str. 31a, D – 09599 Freiberg
E-mail: Gerda.Standke@smul.sachsen.de

The Miocene sediments of Lusatia (Saxony and southern Brandenburg) are deposited on the southern rim of the northwest European Tertiary basin.
They are the most southerly Tertiary deposits, while Paleocene and Eocene sediments are lacking on the southern rim. The Tertiary sediments reach a thickness up to 250 meters. They are well exposed by tens of thousands of borehols and numerous lignite open-cast mines. The sediments consist of mainly shallow marine deposits with intercalated alluvial to estuarine fan sediments.
There are four coal seams within the succession. One of them, the 2nd Miocene coal seam is still exploited by five open-cast mines in Saxony and Brandenburg. There were more than 20 active mines before 1990.
A middle to upper Miocene succession was exposed over kilometres with a thickness up to 100 metres within the open-cast mines.
Trends in lithofacies are obvious due to the spatial distribution of the mines. Hence, a reconstruction of the paleogeographic distribution is possible.
The Miocene succession is characterised by strong changes in lithofacies, resulting from sea level changes of different orders.
Global trends, as well as weak oscillations of the coast line can be proved.

The following trend can be displayed:
- Lower Miocene (early Aquitanian): marine Sediments. Sedimentation of prograding alluvial fans from the southern main-land. Intercalation of terrestrial and marine sediments, origin of the paralic 4th Miocene coal seam.
- Late Aquitanian: Regression, widespread distribution of terrestrial alluvial fan sediments followed by a hiatus.
- Early Burdigalian: Transgression, origin of the 3rd Miocene coal seam on the margin of the transgressive sea. Alternation of lagoonal deposits and marine sands.
- Late Burdigalian: Almost complete marine conditions in Lusatia. Hiatus.
- Lower middle Miocene (Langhian): Regression, gradual shift of the coast line to the north (Mecklenburg), paralic swamp deposits and origin of the 2nd Miocene coal seam. Hiatus.
- Middle Miocene (Serravallian): Transgression, several marine cycles, maily tidal deposits. Hiatus. Regression, origin of the 1st Miocene coal seam.
- Middle to upper Miocene: Gradual increase of fluvial sedimentation from the south.
- Upper Miocene (Tortonian): Alluvial fan sediments, terrestrial conditions in Lusatia. Patchy distribution of the sediments due to later (Pleistocene) erosion.
- Cycles of up to 5th order are detected within these above described trends (3rd order cycles).By means of the distribution and the facies interpretation of the Tertiary successions the Paleogeography of individual periods of time can be reconstructed.

References

Alexowsky, W.; Standke, G. & Suhr, P. (1989): Beitrag zur weiteren lithostratigraphischen Untergliederung des Tertiärprofils im Niederlausitzer Braunkohlenrevier. - Geoprofil, 1: 57-62, Freiberg.
Berggren, W. A.; Kent, D. V.; Aubry, M.-P. & Hardenbol, J. [Hrsg.] (1995): Geochronology, Time Scales and Global Stratigraphic correlations. - SEPM Spec. Publ., 54, 129-212, Tulsa.
Köthe, A. (2003): Dinozysten-Zonierung im Tertiär Norddeutschlands. - Revue Paléobiol., 22 (2), 895-923, Genéve.
Menning, M. & Deutsche Stratigraphische Kommission (2002) (Eds.): Stratigraphische Tabelle von Deutschland 2002, Potsdam.
Rasmussen, E. S., Dybkjaer, K. & Piasecki, S. (2010): Lithostratigraphy of the Upper Oligocene - Miocene succession of Denmark. – Geological Survey of Denmark and Greenland, Copenhagen, Bulletin 22, 1-92.
Standke, G., Rascher, J. & Volkmann, N. (2002): Lowstand Cycles and Coal Formation in Paralic Environments: New Aspects in Sequence Statigraphy. – In: Guers, K. (Ed.): Northern European Cenozoic Stratigraphy; Proc 8th Biann. Meet. RCNNS/RCNPS, 153 – 161, Flintbek.
Standke, G. (2006): Paläogeographisch-fazielle Modellierung des Unter-/Mittelmiozän-Grenzbereichs in der Lausitz (Briesker Folge/Formation). - Schriftenr. f. Geowiss. 14, 1-130, Berlin.
Standke, G., (2010): Tertiär. In: Autorenkollektiv, 2010: Die geologische Entwicklung der Lausitz. – Vattenfall Europe Mining AG, Cottbus, 39-75.
Standke, G., (2011): Das Tertiär – Ablagerungen, Regionale Verbreitung, Schichtenfolge. In: Schroeder, J. H. (2001): Führer zur Geologie von Brandenburg, Nr. 10: Cottbus und Landkreis Spree-Neiße. In print.
Suhr, P. (1998): Sequenzstratigraphische Interpretation des Tertiärprofils der Lausitz.- GEO- Berlin ´98 – Gemeinsame Jahrestagung DGG, DGM; GGW & Pal. Ges.-Vorträge: V 357. Berlin.

CENOZOIC LOWER RHINE BASIN (GERMANY) – ORIGIN, SEDIMENT FILL, AND SEQUENCE STRATIGRAPHY

Andreas Schäfer, Thorsten Utescher
Steinmann Institute - Geology, University of Bonn, Germany
(schaefer@uni-bonn.de, utescher@geo.uni-bonn.de)

In front of the Hercynian orogen and its promontories, the Northwest European Cenozoic Basin originated by steady subsidence of the late Paleozoic and Mesozoic underground (Vinken et al. 1989; Knox et al. 2010). The basin deepened along the central rift of the Cenozoic North Sea and widened towards Central Europe (Köthe 2007; Hansen & Rasmussen 2008). Its southern coast can be traced from Belgium in the West (Vandenberghe et al. 1998) to Poland in the East (Widera 2004) owing variable coastal outlines (Standke 2008; Schäfer et al. 2005). Only in early Oligocene time, in the Rupelian, the Cenozoic North Sea transgressed to the Upper Rhine Graben following the Mid Rhine valley and the Hessen strait when major parts of Europe had been flooded (Sissingh 2003).

From surface research and industrial well logs, the Lower Rhine Basin is well known. It forms a rift structure at the SE end of the Dutch-German Central Graben (Klett et al. 2002; Schäfer et al. 2005; Wong et al. 2007), dissected by numerous NW-SE running syngenetic faults. During the early Neogene, marginal marine environments developed in a tide-dominated estuary with a high tidal range (Schäfer et al. 1996). Water temperatures of the open sea were moderate, yet fairly sufficient to provide a warm and moist climate on land (Utescher et al. 2000) allowing shrublands and forests to grow (Figueiral et al. 1999) and a diverse mammal fauna to live (Mörs et al. 1998). In places, enrichment and preservation of organic materials as peats were favourable, thus lignite measures generated with impressive thickness. In late Neogene times, the uplift of the Variscan block became significant and initiated a wide fluvial network that eroded much of the parent fill of the Lower Rhine Basin. The fluvial drainage culminated in early Pleistocene (Heumann & Litt 2002), when the rate of the uplift of the Variscan block reached its maximum. This and also the Pleistocene climate change favoured coarse-grained fluvial freights.

Depositional environments in the Lower Rhine Basin have been analyzed in open-cast mines and by industrial well profiles. They are interpreted under the auspices of sequence stratigraphy, tracing an Oligocene transgression, a Miocene highstand, and a subsequent Pliocene and Pleistocene regression (Schäfer et al. 2005).

Figueiral, I., Mosbrugger, V., Rowe, N.P., Ashraf, A.R., Utescher, T. & Jones, T.P. (1999): The Miocene peat-forming vegetation of northwestern Germany: an analysis of wood remains and comparison with previous palynological interpretations.- Rev. Palaeobot. Palynol., 104, 239-266.
Hansen, J.P.V. & Rasmussen, E.S. (2008): Structural, sedimentologic, and sea-level controls on sand distribution in a steep-clinoform asymmetric wave-influenced delta: Miocene Billund Sand, Eastern Danish North Sea and Jylland.- J. Sediment. Research, 78, 130-146.
Heumann, G. & Litt, T. (2002): Stratigraphy and palaeoecology of the Late Pliocene and Early Pleistocene in the open-cast mine Hambach (Lower Rhine Basin).- In: Schäfer, A. and Siehl, A. (eds): Rift Tectonics and Syngenetic Sedimentation - the Cenozoic Lower Rhine Graben and Related Structures. Netherlands Journal of Geosciences / Geologie en Mijnbouw, 81, 2, 193-199.
Klett, M., Eichhorst, F. & Schäfer, A. (2002): Facies interpretation from well-logs applied to the Tertiary Lower Rhine Basin fill.- In: Schäfer, A. & Siehl, A. (eds.): Rift Tectonics and Syngenetic Sedimentation – the Cenozoic Lower Rhine Graben and Related Structures.- Netherlands Journal of Geosciences / Geologie en Mijnbouw, 81, 2, 167-176.
Knox, R.W.O.B., Bosch, J.H.A., Rasmussen, E.S., Heilmann-Clausen, C., Hiss, M., De Lugt, I.R., Kasińksi, J., King, C., Köthe, A., Słodkowska, B., Standke, G. & Vandenberghe, N. (2010: Cenozoic.- In: Doornenbal, J.C. and Stevenson, A.G. (editors): Petroleum Geological Atlas of the Southern Permian Basin Area. EAGE Publications b.v. (Houten): 211-223.
Köthe, A. (2007): Cenozoic biostratigraphy from the German North Sea sector (G-11-1) borehole, dinoflagellate cysts, calcareous nannoplankton.- Z. dt. Ges. Geowiss., 158, 287-3127.
Mörs, Th., von Koenigswald, W. & von der Hocht, F. (1998): Rodents (Mammalia) from the late Pliocene Reuver Clay of Hambach (Lower Rhine Embayment, Germany).- Mededelingen Nederlands Instituut vor Toegepaste Geowetenschappen TNO, 60, 135-159.
Schäfer, A., Hilger, D., Gross, G. & von der Hocht, F. (1996): Cyclic sedimentation in Tertiary Lower-Rhine Basin (Germany) – the 'Liegendrücken' of brown coal open-cast Fortuna mine.- Sediment. Geol., 103, 3-4, 229-247.
Schäfer, A., Utescher, T. & Mörs, Th. (2004): Stratigraphy of the Cenozoic Lower Rhine Basin, northwestern Germany.- Newsletters on Stratigraphy, 40, 73-110.
Schäfer, A., Utescher, T., Klett, M. & Valdivia-Manchego, M. (2005): The Cenozoic Lower Rhine Basin – rifting, sediment input, and cyclic stratigraphy.- Internat. J. Earth Sci., 94, 621-639.
Sissingh, W. (2003): Tertiary paleogeographic and tectonostratigraphic evolution of the Rhenish Triple Junction.- Palaeogeography, Palaeoclimatology, Palaeoecology, 196, 229-263.
Standke, G. (2008): Paläogeografie des älteren Tertiärs (Paleozän bis Untermiozän) im mitteldeutschen Raum.- Z. dt. Ges. Geowiss., 159, 81-103.
Utescher, T., Mosbrugger, V. & Ashraf, A.R. (2000): Terrestrial climate evolution in northwest Germany over the last 25 million years.- Palaios, 15, 430-449.
Vandenberghe, N., Laga, P., Steurbaut, E., Hardenbol, J. & Vail, P.R. (1998): Tertiary sequence stratigraphy at the southern border of the North Sea Basin in Belgium.- SEPM Spec. Publ., 60, 119-154.
Vinken, R. (ed. 1989): The Northwest European Tertiary Basin.- Geol. Jb., A100, 508 pp.
Widera, M. (2004): Phases of Paleogene and Neogene tectonic evolution of selected grabens in the Wielkopolska area, central-western Poland.- Ann. Societatis Geologorum Poloniae, 74, 295-310.
Wong, Th.E., de Lugt, I.R., Kuhlmann, G. & Overeem, I. (2007): Tertiary.- In: Wong, Th.E., Batjes, D.A.J., de Jager, J.: Geology of the Netherlands. 151-171, Royal Netherlands Academy of Arts and Sciences.

CLIMATE COUPLING OF TERRESTRIAL AND MARINE MIOCENE: EXAMPLES FROM THE NETHERLANDS

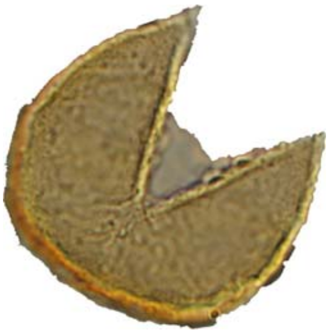
T.H. Donders[1], J.W.H. Weijers[2], D.K. Munsterman[1], R.D. Pancost[4], S. Schouten[2,3], J.S. Sinninghe Damsté[3] and H. Brinkhuis[5]

[1)] TNO, Geological Survey of The Netherlands, P.O. Box 80015, 3508 TA Utrecht, The Netherlands
[2)] Department of Earth Sciences – Geochemistry, Faculty of Geosciences, Utrecht University, Budapestlaan 4, 3584 CD Utrecht, The Netherlands
[3)] Department of Marine Organic Biogeochemistry, NIOZ Royal Netherlands Institute for Sea Research, PO Box 59, 1790 AB Den Burg – Texel, The Netherlands
[4)] Organic Geochemistry Unit, Bristol Biogeochemistry Research Centre, School of Chemistry, Cantock's Close, Bristol University, Bristol BS8 1TS, UK
[5)] Biomarine Sciences, Laboratory of Palaeobotany and Palynology, Utrecht University, Budapestlaan 4, 3584 CD Utrecht, The Netherlands

Summary:
A detailed land-sea correlation on the basis of a Miocene palynological record from the North Sea Basin reveals a coupled climate system between the NW European marine and terrestrial realms. Both palynological and organic geochemical methods reveal the general long term cooling trend for the mid to late Miocene.

Background:
During the Cenozoic the central North Sea Basin has gradually been filled up with over 3 km of siliciclastic sediments providing an expanded record of global and regional climate and sea level evolution from both marine and terrestrial environments. Despite the potential wealth of this record, there is a general lack of directly measured data on the Paleogene and Neogene of the NW European shelf. Particularly the knowledge of Neogene paleoenvironmental evolution is poor at best. A striking feature is the condensed nature of the Miocene in the central North Sea with the distinctive Mid Miocene Unconfomity, while more extensive deposits are preserved to the NE Danish sector and in the SE Netherlands Roer Valley Graben.

New results
A new palynological and organic geochemical record from a shallow marine paleoenvironmental setting in SE Netherlands documents the coupled marine and terrestrial climate evolution from the late Burdigalian (~17 Ma) through the early Zanclean (~4.5 Ma) (Donders et al., 2009). Airlift samples from wells penetrating the siliciclastic Breda Formation at the southern Venlo Block are selected, because this Miocene succession is extensive (over 500 meters in thickness) and relatively complete compared to the northern Dutch (Offshore) territory (condensed sections, usually less than 50 meters in thickness). Recognition of consistent dinocyst events between multiple boreholes allow to propose fourteen zones for the Miocene. Proxy climate records show several coeval variations in both relative sea surface (deduced from percent cool dinocysts) and terrestrial (subtropical vs. cool temperate pollen) temperature indices. The terrestrial climatic trend is confirmed by a quantitative reconstruction of annual mean air temperature based on the distribution of fossil branched glycerol dialkyl glycerol tetraethers, showing a cooling from ~27 ^{o}C to ~14 ^{o}C between 17 and 5 Ma punctuated by short-term variations. Decreases in sea surface temperature broadly correlate to inferred third-order sea level variations and correspond to isotope glacial events Mi-3 through Mi-7. An additional strong SST decrease occurs around ~8.4 Ma, coincident with a strong reduction and regional disappearance of subtropical pollen types. This cooling phase seems associated with lowered sea levels, but it has not yet been described from the deep sea d^{18}O record.



Pollen grain of *Taxodium* typical for "Cypress swamp" conditions of the European Miocene, equivalent of environments in subtropical Florida today

Outlook
The record shows the potential, through quantitative palynological and organic geochemical analyses, of integrated terrestrial and marine records for both paleoclimatic and stratigraphical purposes from the North Sea Basin. An initiative is therefore underway to set up a drilling project within the Integrated Ocean Drilling program (IODP) to recover shallow marine Cenozoic successions of the North Sea Basin shelf. We target a first-time complete recovery of Cenozoic shallow marine sediments in NW Europe in an effort to provide a regional integrated stratigraphic framework with detailed paleomagnetic and biostratigraphic data that currently is not available.

LATE CENOZOIC DELTA DEPOSITION IN THE GERMAN NORTH SEA; FIRST RESULTS OF THE PROJECT "GEO-SCIENTIFIC POTENTIALS OF THE GERMAN NORTH SEA" (GPDN).

Hauke Thöle

Within the framework of the GPDN project (www.geopotenzial-nordsee.de) we study the sedimentary evolution in the southern North Sea Basin during the Neogene. The Neogene sedimentary succession of the southern North Sea Basin is dominated by a large fluvio-deltaic system, also known as the "Eridanos delta system". It drained the Fennoscandian and Baltic Shield through the present Baltic Sea and delivered huge amounts of sediments into the basin. The dimensions of the paleo-drainage area and the thickness of the deltaic deposits as seen in the present North Sea are comparable to those of the largest recent delta systems in the world (Overeem et al., 2001). A wide coverage of the offshore parts of the delta with high-quality 2D and 3D seismic data in the German North Sea, together with new biostratigraphic datings of well samples allow studying the delta system in unprecedented detail, filling the gap between former Dutch and Danish studies. The combined data sets collected within the framework of the "GPDN" project and a previous BGR North Sea project enables us to image the detailed architecture of the prograding delta system, and to identify areas of main subsidence during the Neogene. Initial studies of the delta system have provided detail insights about the location of delta complexes, collapse of the delta slope, migration of depocentres through time and age of delta sequences.

References

Overeem, I., et al. (2001): The Late Cenozoic Eridanos delta system in the Southern North Sea Basin: a climate signal in sediment supply?, *Basin Research*, *13*(3), 293-312.

HIGH-RESOLUTION COMPOSITE BIOSTRATIGRAPHY FOR THE MIOCENE OF THE NORTH SEA BASIN

Chris King

Understanding the evolution of the North Sea Basin during the Miocene requires a high-resolution chronostratigraphic framework. This is currently based largely on biostratigraphy. In marine environments, foraminiferids provided the initial framework, but accurate calibration with the standard geostratigraphic scale has been difficult to achieve. The more recent development of dinoflagellate cyst studies has provided much improved dating, but is limited to relatively few areas.

'Composite' zonations based on foraminiferids, diatoms and *Bolboforma* have been extensively used in the North Sea and onshore areas, and can now be linked increasingly accurately to dinocyst datums. A revised composite zonation is proposed, calibrated through *Bolboforma* and dinocyst datums to the standard chronostratigraphic scale. This type of analysis is quick and cost-effective, enabling high-density sampling, and can be used to extend high-resolution chronostratigraphy to sites and areas which are currently poorly constrained.

A NEW, NEOGENE DINOFLAGELLATE CYST ZONATION OF THE EASTERN NORTH SEA BASIN (DENMARK)

Karen Dybkjær[1], Stefan Piasecki[2] and Erik Skovbjerg Rasmussen[1]

[1]*Geological Survey of Denmark and Greenland (GEUS), Øster Voldgade 10, DK-1350 Copenhagen K, Denmark.*
[2] *Department of Geography and Geology, University of Copenhagen, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark*

E-mail: kd@geus.dk; spi@geo.ku.dk; esr@geus.dk

For the first time a dinoflagellate cyst zonation for the complete Neogene succession in the North Sea Basin has been defined.

In large areas of onshore Jylland, in western Denmark, sand bodies within the uppermost Oligocene – Miocene succession serve as important aquifers. The Neogene succession is unconformably overlain by Pleistocene deposits, but outcrops in inland pits and several coastal cliffs. The succession comprises three large deltasystems interfingering with marine mud. As the deltaic sand bodies cannot be discriminated upon lithological criteria, dinoflagellate cyst stratigraphy played an important role in mapping these aquifers. A strict biostratigraphic framework has been set up based on analyses of dinoflagellate floras in more than 60 boreholes throughout the region, combined with studies of 28 outcrops. A series of stratigraphic events (first appearances, last occurrences and acmes of dinoflagellate cyst species) occurring in most of the studied wells have been used for correlation of both mud and sand bodies. Parts of the Miocene succession comprise proximal deposits dominated by terrestrial palynomorphs. However, consistent occurrence of dinoflagellate cysts also in these environments provides the most rigid tool for dating and correlation of these deposits. The fully marine parts of the succession provide excellent dinoflagellate cyst floras which correlate with contemporaneous North Atlantic floras. Lateral variations in the dinoflagellate cyst assemblages are ascribed to proximal-distal changes in the depositional environment.

These data, combined with data from a few North Sea offshore wells with more expanded and stratigraphically more complete successions, have resulted in a new dinoflagellate cyst zonation for the Neogene in Denmark. A total of 19 zones have been defined, the four uppermost zones are not recorded in the onshore succession, where the uppermost Miocene (Messinian) and Pliocene are absent. The new zonation thus provides a much more detailed stratigraphic resolution and a better dating of the Danish Neogene than the previous microfossil zonations (foraminifera- and nannofossil zonations).

References

Dybkjær, K. and Piasecki, S. (2010). Neogene dinocyst zonation in the eastern North Sea Basin, Denmark. *Review of Palaeobotany and Palynology*, **161**, 1-29.

CHASING THE RECORD OF SEA-LEVEL CHANGE: PRELIMINARY RESULTS OF IODP EXP313

Gregory Mountain
(Rutgers Universtiy) + the IODP Exp313 Scientific Party

Understanding the history, cause and impact of sea-level change is a compelling goal of Earth system research. Three strategies of study are available: sampling corals as 'dip-stick' archives of past elevations of sea level; using oxygen isotopic variations in marine fauna as proxies for changes in global ice; and mapping facies successions within shallow-water sediments at passive continental margins. The latter can detect changes in water depth throughout the Phanerozoic and provide the sum of all processes that contribute to these changes and to the lateral migration of the shoreline. But therein lies a difficulty: besides responding to eustatic change, shoreline position and accompanying facies variations are affected by several processes, including: changes in sediment supplied to the coastal zone; sediment compaction; isostatic and/ or flexural loading of the crust; thermal subsidence of the lithosphere; and any other vertical tectonic motions of the crust. Furthermore, the magnitude of eustatic change is often considerably smaller than that of these other processes, making the accurate measurement of this record a challenging endeavor.

Nonetheless, the New Jersey margin along the east coast of N America is well-suited for this type of study and has been the focus of several drilling campaigns, both onshore and off, during the last two decades (ODP Legs 150, 150X, 174A and 174AX). Each successfully dated and tied sequence boundaries to the $\delta^{18}O$ proxy of glacioeustasy, but all fell short of capturing the full range of facies successions needed to determine the impact of a complete sea-level cycle.

Consequently, IODP Expedition 313 returned to the region in 2009 to drill 3 sites in 35 m of water, 45-65 km offshore Atlantic City. Efforts were focussed at the rollovers of several Oligocene-Miocene clinoforms where the sea-level signal is expected to be most clear and complete. The tasks of evaluating sequence stratigraphic models, comparing the age of inferred sea-level falls to the $\delta^{18}O$ glacio-eustatic proxy, and estimating the corresponding amplitudes, rates and mechanisms of sea-level change await the completion of several underway studies; what follows is a progress report.

1311 m of very good to excellent quality cores were collected with 80% recovery. The deepest was 757 mbsf; the oldest was upper Eocene. Each hole was located to intersect top-, fore- and/or toeset strata of several clinoforms linked by a grid of high-resolution 2D seismic profiles. Slim-line logs in each hole gathered spectral gamma ray, resistivity, magnetic susceptibility, sonic and acoustic televiewer measurements.

Seismic-log-core correlations, strengthened by MultiSensorCoreLogger measurements, enable us to locate samples in the seismic framework with depth uncertainties of only a few meters. Thus we're able to ground-truth lithofacies at a variety of settings in several depositional sequences. Topsets were well sorted silts and sands deposited in offshore to wave- and river-dominated shoreface settings. Toeset silts and silty clays were deposited below storm wave base and typically interbedded with poorly sorted debrites and turbidites deposited at times of clinoform degradation. Geochronologies based on Sr-isotopic ages, biostratigraphy, limited magnetic reversals and pollen markers show accumulation rates of 50-150 m/my with hiatuses across sequence boundaries from 0 to ~2 Ma. No conclusive evidence has been found of a sea-level fall below a clinoform rollover, but shoreface deposits along clinoform foresets paired with deep-water facies in topsets of the same sequence imply changes in relative sea level on the order of 60 m. We await additional analyses of these data that are certain to lead to a much improved understanding of the magnitude and cause of sea-level change, its impact on the shallow-water record of passive margins, and insight into the climate oscillations of the Oligocene-Miocene 'Ice-House world'.

A 100 MILLION YEARS RECORD OF GLOBAL SEA-LEVEL CHANGE:

SHOULD I SELL MY SHORE HOUSE?

Kenneth G. Miller

Department of Earth and Planetary Sciences, Rutgers University, Pisataway, NJ 08854 USA (kgm@rci.rutgers.edu)

The geological record provides perspective on sea-level change, including global, regional, and local processes and rates of change. We have reconstructed global sea-level variations over the past 100 million years, showing that: 1) glacial eustasy occurred during the greenhouse world of the Cretaceous through Eocene, with typical changes of 15-25 m (i.e., up to about 1/3 of the present-day 65 m stored as ice); 2) large continental scale ice sheets appeared in Antarctica during the early Oligocene (33.8 Ma); 3) following a peak of sea level of 20 m in the early Pliocene when atmospheric CO_2 levels were similar to 2010, large northern hemisphere ice sheets caused sea-level change of 120 m; and 4) the maximum global rate of sea-level rise from 5000 ka to 1850 A.D. was 0.75±0.25 mm/y. Recent studies have documented that the 20th century global sea level rise was 1.8±0.3 mm/y, but has accelerated over the past 15 yr and is rising today at 3.3±0.4 mm/y. Thus, we attribute <<30% of the modern global rise to natural causes. The IPCC best estimate, that global sea level will rise 40 cm by 2100, is too low: we are currently tracking a minimum global rise of 80 cm by 2100. The maximum global rise is poorly constrained but maximum rates observed during meltwater pulse 1A are ~40 mm/yr. We suggest a maximum global rise of <2 m by 2100 A.D. (best estimate 1.2±0.4 m).

DISTRIBUTION OF MIOCENE SEDIMENTS IN THE NORWEGIAN SEA AND THE NORWEGIAN SECTOR OF THE NORTH SEA, AND THEIR RELATION TO THE UPLIFT OF FENNOSCANDIA.

Riis, F. and Eidvin, T.
Norwegian Petroleum Directorate

The western part of the Fennoscandian shield is a highland with two dome-shaped culminations, the northern and southern Scandes domes. The highest peaks exceed 2400 m in the south and 2000 m in the north. Onshore outcrops of Mesozoic and Cenozoic sediments are very scarce, and consequently the timing of uplift of these domes has been difficult to establish. The outcropping basement areas extend into the offshore, but in the North Sea and the Norwegian Sea, the distribution and sedimentology of Cenozoic sediments give evidence of the development of the mountain belt. The detailed regional biostratigraphic and strontium isotope stratigraphic studies performed by T. Eidvin have resulted in more precise and consistent ages of these sediments.

Based on a compilation of onshore and new offshore data in the Lofoten-Vesterålen area and the north Scandes dome, it has been suggested that the northern part of this dome was a positive feature since the Late Cretaceous (NPD 2010). Both Scandes domes were strongly eroded in the Paleogene, causing Paleocene and Eocene sediments to prograde out into the shelf areas. Following the plate tectonic reorganization at the Eocene-Oligocene boundary, a new pattern of sedimentation from these two domes was apparently established where less sediments were transported to the west.

The age of the Molo Formation sands on the inner Norwegian Sea shelf, previously believed to be of Late Miocene to Early Pliocene age, is currently under reconsideration by T. Eidvin. Five sidewall cores from well 6610/3-1 in the north-eastern part of Molo gave an Early Oligocene age (Eidvin et al. 1998). Three sidewall cores from well 6510/2-1 in the middle part gave an Early Miocene age. The fossils recorded from these cores were considered to be reworked when Late Miocene to Early Pliocene fossils were recorded in well 6407/9-1, 9-2 and 9-5 from the southern part. Based on new seismic correlation work by F. Riis we now suggest that the fossils are not reworked but in situ. This implies that parts of the Molo Formation may be of Early Oligocene, Early Miocene and Late Miocene to Early Pliocene age. The formation consists of several deltaic sequences building out towards the west, and the youngest Late Miocene to Early Pliocene part of the formation has a larger distribution than the Oligocene and Early Miocene parts (fig. 1).

Three main depositional areas can be distinguished in the North Sea: 1) the north-eastern North Sea, 2) the Norwegian-Danish Basin - Jutland area and 3) the central depression of the northern North Sea (fig. 1). Interpretation of seismic data and sediment provenance studies clearly show that the first two areas received sediments from the south Scandes dome, while the central area was sourced from the Shetland Platform.

In the north-eastern North Sea, the deposition of sands ceased at the transition from the Oligocene to Early Miocene, while in the other two areas a shift in the location of the depocenters has been observed. No obvious regional tectonic event has been observed in the seismic data at that time. Neogene tectonism is mainly related to the early Middle Miocene event which is expressed by reactivation of many fault and dome structures, and by erosion and tilting of the Lower Miocene and older strata towards the uplifted West Norway. Tilting can also be recognized in the paleo oil-water contact in the Troll Field. Another set of erosional surfaces are observed in the central, more basinal parts of the northern North Sea. Løseth and Henriksen (2005) interpreted a substantial regional mid Miocene uplift based on this type of evidence on seismic data, but based on a combination of biostratigraphy, paleo-environment and seismic interpretation, we prefer to interpret the basinal erosion as a sub-marine event.

The Middle Miocene section in the studied area in the North Sea is mainly fine grained, but moderate amounts of sand were derived from the Shetland Platform and deposited as distal parts of the Hutton sand (unformal, fig. 1). In the Late Miocene and Early Pliocene, the Utsira Formation was deposited from the Shetland Platform in a renewed erosional phase. A contemporaneous wedge of conglomerates and sands was derived from the Scandes Mountains in the area of Sognefjorden.

Our study indicates that both Scandes domes were sediment sources throughout the Miocene. Several factors, such as sea level changes, sediment progradation, climatic changes, tectonic events causing uplift and changes in water divides have caused changes and shifts in the sandy input into each depocenter. A regional correlation between the depocenters based on precise dating is essential in a study of the development of the mountain belt.

Eidvin, T., Brekke, H., Riis, F. & Renshaw, D. K., 1998. Cenozoic Stratigraphy of the Norwegian Sea continental shelf, 64° N - 68° N. Norsk Geologisk Tidskrift, 78, 125-151

Løseth H. and Henriksen, S. 2005. A Middle to Late Miocene compression phase along the Norwegian passive margin. In Dore, A. G. & Vining, B. A. (eds): Petroleum Geology: North-West Europe and Global Perspectives-Proceedings of the 6th Petroleum Geology Conference, 845-859. Petroleum Geology. Conferences Ltd. Published by the Geological Society, London.

NPD (2010) http://npd.no/no/Publikasjoner/Rapporter/Petroleumsressurser-i-havomradene-utenfor-Lofoten-Vesteralen-og-Senja---Geofaglig-vurdering/

DELTA VS SHOREFACE: A QUATERNARY PERSPECTIVE

Serge Berné,
Université de Perpignan, France

For sedimentary geologists looking at the rock record, deltas and shorefaces are very distinct sedimentary environments displaying different facies and architecture. On the other hand, for marine geologists looking at analogue Quaternary environments on (high resolution) seismic records and core data, these 2 environments often display a continuum of similar seismic and sedimentary facies. Examples from the Rhone, the Yang Tze (Changjiang), and the Danube deltaic margins , as well as published material from other authors, allow us to propose some general considerations of possible interest for those studying the rock record:

- The "offshore muds" of sedimentary geologists correspond, in the Quaternary, to prodeltas situated immediately at the outlet of streams, or to "mud belts" resulting from advection of mud by general circulation (ex: Adriatic, Yellow Sea).
- In contrast, Quaternary shelves are generally dominated by accommodation (in the sense of Swift, 1991), and exhibit a thin blanket of mud that is episodically reworked by severe oceanic processes and transferred to the deep sea (ex: Eel river margin offshore California)
- The common definition of a shoreface in sedimentary geology (the zone between the foreshore and the "fair weather wave base") has no physical ground. We favor the definition of van Wagoner et al. (1990) where the seaward limit of the shoreface corresponds to the "storm wave base", a boundary that can be defined through wave statistics, and corresponds to an actual transition of sedimentary facies.
- Even in environments subject to huge sediment fluxes such as prodeltas, erosion due to purely autogenic processes occurs commonly because of avulsion of deltaic lobes. This is particularly important for wave-dominated deltas, such as the Rhone, where lobes formed few centuries ago presently display truncated clinoforms. At larger scale, the erosion of the former Yellow River prodelta/delta front, situated in the East China Sea, is presently undergoing major erosion, the stream having be diverted to the Bohai Sea during the 19th century.
- In the rock record, there is no way to distinguish wave-dominated deltas from shoreface deposits when no real 3-dimensional data sets are available. This is due to the fact that tidal inlets may mimic distributary channels, and that lagoonal muds are difficult to distinguish from delta plain deposits.

The spectacular exposures of the Book Cliffs (Utah) are at the origin of several conceptual models for deltaic and shoreface sedimentary environments, later incorporated into the definition of parasequences. Despite their unequaled interest, they cannot account for the entire spectrum of facies and architectures observable in the Quaternary and in the rock record. They should not be used as a *"delta/shoreface mindset"*.

RAPID SEA LEVEL CHANGES RECORDED BY PROGRADING SAND BODIES IN THE GULF OF LIONS (WESTERN MEDITERRANEAN SEA) DURING QUATERNARY

Maria-Angela Bassetti
Laboratoire CEFREM, Université de Perpignan (France)
52 Avenue Paul Alduy 66860 Perpignan Cedex 9, email: maria-angela.bassetti@univ-perp.fr

Thick forced regressive units deposited on the wide continental shelf of the Gulf of Lions (Western Mediterranean) have recorded the composite effect of sea-level changes during the Quaternary. They are mostly composed of coastal siliciclastic and bioclastic wedges showing clinoform geometry.
These deposits have been intensively explored through high-resolution seismic investigations, but only recently it has been possible to ground-truth seismic interpretations, beacause of the avalaibility of a long (100 m) borehole that crossed the succession and recovered a large part of the mainly sandy deposits (~84% recovery).

A multiproxy analysis of the sedimentary succession shows that: (1) the stratal architecture of the shelf margin is controlled by major bounding surfaces that are polygenic erosion surfaces made of coarse-grained material incorporating abundant and diverse shells, including cold-water fauna (presently absent from the Mediterranean Sea). Between each surface, coarsening upwards units with steep (up to 5°) foresets are made of massive (more than 20 m thick) sands with possible swaley and hummocky cross-stratification, passing seawards to sands with muddy intervals, then to alternating highly boiturbated sands and silts. Each prograding wedge corresponds to a forced-regressive shoreface, deposited during the overall sea-level falls during (relatively slow) interglacial/glacial transitions and therefore represent the record of 100 ky cyclicity; (2) chrono-stratigraphy and microfossils content of the most-recent sequence show that second-order bounding surfaces, corresponding to abrupt shallowing of sedimentary facies, separate stepped downward-stepping parasequences within the main sequence. These events are in phase with millennial-scale glacial climatic and sea-level variability (Heinrich and D/O events).

They provide a comprehensive and well-constrained Pleistocene analogue to the numerous shoreface deposits attributed to *falling-stage systems tracts* recognized in the stratigraphic record.

Distribution and grain size of sand in the Miocene wave-dominated Billund delta, Denmark

Erik Skovbjerg Rasmussen
Geological Survey of Denmark and Greenland (GEUS), Copenhagen, Denmark
esr@geus.dk

The distribution of sand in deltas is dependent on the type of delta complex: wave-, fluvial- or tidal-dominated delta. During the Early Miocene, three delta complexes built out from the Fennoscandian Shield into the eastern North Sea Basin. The first delta complex is informally named the Billund delta and is of Aquitanian age. This delta complex was dominantly a wave-dominated delta. It has been demonstrated in recent wave-dominated delta environments major sand accumulation occurs on the updrift portion of the delta and alternating mud and sand, i.e. barrier-lagoonal complexes occupy the downdrift flank of the delta system. This study shows that the distribution of sand in the submarine part of the Miocene wave-dominated Billund delta (mainly lower shoreface and delta slope) was deposited downdrift of the delta front and thus differs from the foreshore and uppermost shoreface accumulation found in recent delta complexes.

The delta formed during the Early Miocene in the eastern North Sea Basin. Due to predominantly westerly winds, long shore currents were predominately SE-wards. The long fetch across the North Sea resulted in effective wave action at the coast and hence comprehensive sediment reworking and sorting at the delta mouth. This resulted in sand being preferentially transported in a southeast-ward direction. The Billund delta prograded into a basin with relatively deep water (ca. 100 m) and thus had a relatively steep delta front, c. $7 – 10^0$. The fluvially sourced sand at the delta mouth was transported southeast-wards to form spit and barrier complexes in the downdrift portion of the delta complex. During major storms, sand accumulation was directed towards the outer delta platform either from reworking of the delta mouth bar or from coastal erosion. Some of this sediment might have been shed beyond the slope break and laid down as mass-flow deposits on the prodelta slope. During major floods, sands from migrating fluvial dunes were deposited on the delta platform and mouth bar resulting in an increase in slope. Due to either oversteeped slopes or changes in pore pressure due to wave action, destabilisation of the delta slope resulted in gravity sliding. The flood was also at times so strong that direct input of fluvial sediments onto the delta slope took place. The distribution of submarine sand in the downdrift setting is important, because foreshore and uppermost shoreface sediments are rarely preserved in the geological record. Therefore, in deltaic systems are comparable to the Billund delta, i.e. steeply dipping clinoforms, clinoform heights of 50–100 m and asymmetric morphology, the reservoir sand is most likely to be found in the downdrift portion of the delta complex. This type of delta is best developed in a ramp setting or rift system that has undergone a tectonic phase that resulted in a sudden increase in accommodation space and characterised by a high sediment supply. The fluvial system is here typically dominated by bedload transport, and migration of dunes to the delta front is a common phenomenon. The composition of the river-borne sediment (sand/mud ratio) is also important, although longshore currents and wave processes may remove the fine-grained fraction downdrift and offshore and thereby permit concentration of the sand on the main delta platform.

UTSIRA FORMATION: NPD ASSESSMENT

Ine T. Gjeldvik

Norwegian Petroleum Directorate, P. O. Box 600, N-4003 Stavanger, Norway

The Utsira Formation is a large Late Miocene and Early Pliocene sand deposit with excellent reservoir properties. In the southern part of the formation 1 Mega tons of CO2 from the Sleipner field has been injected pr year since 1996 by Statoil. A remapping and a calculation of the total theoretical capacity in the Utsira Formation with respect to CO2 storage is currently undergoing as a part of an NPD study of the total theoretical capacity of the Norwegian sector of the North Sea. The scope of this study has been to evaluate the communication between the central part of the Utsira Formation and surrounding sandy systems, in particular the Hutton sand (informal name used in british sector of the North Sea).

The Middle Miocene to Upper Pliocene Utsira Formation, extends north-south along Viking Graben near the UK/Norwegian median line for more than 450 km and 75-130 km east-west. The Utsira Formation is a sandy unit in the lower part of the Nordland Group. The Formation occurs as basin-restricted mounded sands with interbedded clays in distinct depositional units along the entire Viking Graben. The Utsira Formation can roughly be divided into three geographical areas where the southern and northern parts exhibit the thickest sands. The Hutton sand is defined in the UK sector of the North Sea and was deposited from Early Miocene to Late Pliocene along the east Shetland Platform. The Utsira Formation is thought to be time-equivalent to approximately the middle part of the Hutton sand. In its northern area, Hutton sand seems to pass laterally from mostly thick sands into basinal clayey facies with isolated sands. In the central part of the Norwegian sector of the North Sea, the Hutton Sand appears to be in contact with the Utsira Formation. However, we prefer not to use the name Hutton sand in the Norwegian sector.

The interpretation in this study is based on a merged seismic dataset covering the quadrant 25 and parts of quadrant 30 offshore Norway and the existing exploration wells. The data quality is fair to good (some multiples and noise in the shallow section). Top and base Utsira were interpreted over quadrant 25 and 30.

RECONSTRUCTION OF CONTINENTAL MIOCENE CLIMATE BASED ON THE PALAEOBOTANICAL RECORD

Torsten Utescher[1,4],
Abdul R. Ashraf[2], Karen Dybkjær[3], Volker Mosbrugger[4], Andreas Schäfer[1]

[1]Steinmann Institute - Geology, Bonn University, Bonn, 53115, Germany (utescher@geo.uni-bonn.de)
[2]Institute for Geosciences, Eberhard Karls University, Tübingen, 72076, Germany
[3]Geological Survey of Denmark and Greenland, Copenhagen K, 1350, Denmark
[4]Senckenberg Research Institute and Natural History Museum, Frankfurt, 60325, Germany

The application of quantitative techniques on the Miocene palaeobotanical record allows for a detailed reconstruction of continental climate and its variability. For Central Europe, studies based on macroflora (e.g., Mosbrugger et al., 2005; Utescher et al., 2009) reveal a temperature evolution that correlates well with the global oxygen isotope signal known from marine archives (e.g., Zachos et al., 2001). The early Miocene is characterized by a general warming trend culminating in the Langhian, in the so-called Mid-Miocene Climatic Optimum. Cenozoic cooling began in the Serravallian, at ca. 13.8 My. In Central Europe, continental cooling was more pronounced for winter temperatures but hardly observable from summer temperatures, and thus was directly associated with an increase of seasonality. In contrast, inferred Miocene mean annual precipitation in Central Europe remained relatively stable, staying at a high level of over 1,000 mm. It is shown that the Miocene climate of Central Europe was all over warmer and wetter than today (mainly of a Cfa-type, according to the Koeppen classification).

To study short-term climate change and variability and thus gain insight into climate dynamics a higher temporal resolution of the records is required. This can be obtained when studying microfloras (pollen and spores). Palynomorphs are frequently encountered in Cenozoic sediment samples. However, they provide a lower climatic resolution when compared to macrofloras. Studies on Miocene wells and profiles of the NW German continental Cenozoic and on marine strata of the North Sea Basin (The Netherlands; Denmark) reveal climate change on shorter time scales suggesting a distinct coupling of continental climate with the marine environmental system (Utescher et al., 2000; Donders et al., 2009; Larsson et al., 2011; Utescher et al., in press). Phases of eustatic sea-level lowstand connected to Neogene glaciation events (e.g., Miller et al., 2005: Mi events) are mirrored in the continental curves. Moreover, the continental climate curves display orbital cyclicity at different scales. In the Miocene of Central Europe, climate variability is characterized by non-proportional changes of climate parameters. Short-term cooling, here mainly expressed by a decrease in winter temperature, commonly was connected to drying (Utescher et al., in press). Currently work is in progress to quantify short-term climate shifts caused by global events.

References

Donders, T.H., Weijers, J.W.H., Munsterman, D.K., Kloosterboer van Hoeve, M.L., Buckles, L.K., Pancost, R.D., Schouten, S., Sinninghe Damsté, J.S., Brinkhuis, B. 2009. Strong climate coupling of terrestrial and marine environments in the Miocene of northwest Europe. Earth and Planetary Science Letters 281, 215–225.

Larsson, L.M., Dybkjær, K., Rasmussen, E.S., Piasecki, S., Utescher, T., Vajda, V., 2011. Miocene climate evolution of northern Europe: A palynological investigation from Denmark. Palaeogeography, Palaeoclimatology, Palaeoecology 309, 161-175.

Miller, K.G., Kominz, M.A., Browning, J.V., Wright, J.D., Mountain, G.S., Katz, M.E., Sugarman, P.J., Cramer, B.S., Christie-Blick, N., Pekar, S.F., 2005. The Phanerozoic record of global sea-level change. Science 310, 1293–1298.

Mosbrugger, V., Utescher, T., and Dilcher D., 2005. Cenozoic continental climatic evolution of Central Europe. Proceedings of the National Academy of Sciences, 102(42), 14964-14969.

Utescher, T., Mosbrugger, V. and Ashraf, A.R., 2000. Terrestrial climate evolution in Northwest Germany over the last 25 million years. Palaios 15, 430-449.

Utescher, T., Mosbrugger, V., Ivanov, D., Dilcher, D.L., 2009. Present-day climatic equivalents of European Cenozoic climates. Earth and Planetary Science Letters 284, 544-552.

Utescher, T., Ashraf, A.R., Dreist, A., Dybkjær, K., Mosbrugger, V., Pross, J., Wilde, V., in press. Variability of Neogene continental climates in Northwest Europe – a detailed study based on microfloras. Turkish Journal of Earth Sciences 20. doi:10.3906/yer-1005-3.

Zachos, J.C., Pegani, M., Stone, L., Thomas, E., Billups, K., 2001. Trends, rhythms, and aberrations in global climates 65 Ma to present. Science 292, 686-293.

SEA LEVEL VARIATIONS IN A MIOCENE SUCCESSION FROM DENMARK

Caterina Morigi[1],
Karen Dybkjær[1], Stefan Piasecki[2], Erik Skovbjerg Rasmussen[1] and Erik Anthonissen[3]

1 Geological Survey of Denmark and Greenland (GEUS), Øster Voldgade 10, DK-1350 Copenhagen K, Denmark, email: cmor@geus.dk
2 Department of Geography and Geology, University of Copenhagen
3 Chevron, 1500 Louisiana St, Houston, TX, 77004, USA

During the Miocene, the shallow epicontinental North Sea Basin experienced major relative sea-level fluctuations leading to significant environmental changes. Recent studies (e.g. Jaspen et al. 2010) indicated that this area was periodically strongly influenced by tectonic events leading to asymmetric subsidence and flux in the sediment supply to the basin. However, as micropaleontological studies of the Miocene from the North Sea area are fairly limited, the effects of these changes remain largely unexplored. This has prevented a clear view of the paleoenvironmental changes and also has prevented correlations of these changes with paleoceanographic events recorded in the deep-sea North Atlantic sites and with emerging high-resolution records from high-latitude sites (e.g., Arctic area, Jakobsson et al., 2007).
Foraminiferal data coupled with dinocysts and spore-pollen analysis, and with sedimentological and seismic data provide the bases for detailed interpretations of chronostratigraphy, paleoenvironmental and paleoclimate evolution of a 260 m thick Miocene onshore borehole record (Sønder Vium borehole) in West Jylland, Denmark.
The benthic foraminiferal microfauna indicated a complex pattern of paleoenvironmental changes marked by different benthic associations, with regard to species composition, diversity indexes, relative abundance of planktonic/benthic foraminifera, relative abundance of infauna/epifauna and oxygen indicators. We introduce five foraminiferal biofacies which, together, are suggestive of several distinct environmental changes from Lower to Upper Miocene. Furthermore, we introduce a semi-quantitative reconstruction of palaeobathymetry employing a simple index that operates on a scale from 0-50 m (inner shelf) to >500 m (middle bathyal). The data document a series of transgressive–regressive (T–R) cycles, characterized by an outer shelf/upper bathyal environment in the Upper Burdigalian (upper part of *Cordosphaeridium cantharellus* Zone to *Cousteaudinium aubryae* Zone; Arnum Formation), and followed by a shallowing trend in the Langhian, reaching the minimum water depth at the beginning of the Middle Miocene Climate Optimum. The subsequent foraminiferal biofacies in Serravallian strata contained rather poorly preserved microfauna and several barren samples. In contrast, the most diverse and abundant benthic foraminiferal assemblage occurred in the Tortonian, and together with a well diversified planktonic foraminiferal assemblage indicated a well-oxygenated outer shelf environment, with a high organic flux to the sea floor.

REFERENCES

Japsen et al. (2010). Episodic uplift and exhumation along North Atlantic passive margins: implications for hydrocarbon prospectivity. In: Vining, B.A. & Pickering, S. C. (eds) *Petroleum Geology: From Mature Basins to New Frontiers – Proceedings of the 7th Petroleum Geology Conference*, 979–1004.

Jakobsson et al. (2007). The early Miocene onset of a ventilated circulation regime in the Artic Ocean. *Nature,* 447, 986-990.