DGF

Forenings-meddelelser

Kommende Møder

DGF København

Asger Berthelsen symposium

Fredag d. 2. oktober 1998 kl, 9.00–17.00 på Geologisk Institut, København, Øster Voldgade 10, auditorium B.

Program:

Kl. 9.00: Velkomst.
Kl. 9.15: Michael Houmark: *En moderne dansk nedisningskronologi for Weichsel.*
Kl. 9.40: Stig Schach Pedersen: *Superimposed deformation i glaciotektonik.*
Kl. 10.05: Kaj Strand Petersen: *Iso- og eustatiske havniveauændringer i Danmarks Senkvartær.*
Kl. 10.30 Kaffepause.
Kl. 11.00 Hans Thybo: *Lithosfærens struktur og den tektoniske udvikling af »Tornquist fan« området.*
Kl. 11.25: Ole Graversen: *Intra-plade deformation af de palæogene og neogene formationer i Danmark.*
Kl. 11.50: Lilian Skjernaa: *Deformerede monzonitgange i udeformeret sidesten.*
Kl. 12.15: Frokost.
Kl. 13.15: Mogens Marker: *Titel ikke fastlagt*.
Kl. 13.40: Adam Garde: *Tovqussaq Nuna, Akia terrænet i SV Grønland. Et tilbageblik i lyset af pladetektonik.*
Kl. 14.05 Bjørn Hageskov: *Den Sydlige Nagssugtoqidiske Front.*
Kl. 14.30: Kaffepause.
Kl. 15.15: Svend Pedersen & Jens Konnerup-Madsen: *Setesdalregionen: En vigtig brik i det Sveconorwegiske puslespil.*
Kl. 15.40: Carl-Henric Wahlgren & Michael Stephens: *Strukturel og geokronologisk udvikling af den nordøstlige del af det Sveconorwegiske orogen.*
Kl. 16.05: Asger Berthelsen.
Kl. 16.45: Bar i kantinen.
Kl. 19.30: Middag i Søpavillionen.

Dansk Mineralogisk Selskab

Møderne afholdes fredage på Geologisk Museum, Øster Voldgade 5–7, København.

DGF FORUM

For Anvendt Geologi

Mødet onsdag d. 23. september 1998 er aflyst grundet tilsvarende møde i Dansk Geoteknisk Forening d. 24. september. Der planlægges ét efterårsmøde – se DGF's hjemmeside eller kontakt Poul Henrik Due, DTI Byggeri, tlf. 4350 4118.

Palæontologisk klub

Møderne finder normalt sted på tirsdage kl 15.15 i biblioteket på afd. f. Historisk Geologi og Palæontologi, Geologisk Institut i København, Øster Voldgade 10 (i stuen).

Tirsdag d. 22. september 1998: S. Baciu (Rumænien): *Oligocene Fauna from Vrancea Nappe, Eastern Carpathians, Romania.*
Tirsdag d. 29. september 1998: T. Jinnan (Wuhan, Kina): *On Marine Triassic from China.*
Mandag d. 5. oktober 1998: D. Harper (Geol. Mus.): *Sun, Sand, and Brachiopods – a Tertiary-Pleistocene Caribbean Cocktail.*
Tirsdag d. 20. oktober 1998: R. Reisz (Toronto) / N. Krupina (Moskva): *On Early Ammonites and Lungfish.*
Tirsdag d. 27. oktober 1998: Ph. Currie (Alberta): *On Feathered Dinosaurs and Birds from China.*
Tirsdag d. 3. november 1998: M. Benton (Bristol): *Biodiversity in the Past, Present, and Future.*
Tirsdag d. 17. november 1998: M. Rasmussen (Geol. I.): *Hadrosaurer – funktionel anatomi og fylogeni.*
Tirsdag d. 1. december 1998: S. Kragballe (Geol. I.): *Bentiske foraminiferer fra Skrivekridtet i Danmark.*
Tirsdag d. 15. december 1998: Julemøde: S. Turner (Brisbane) *om palæozoiske vertebrat mikrofossiler og stratigrafi.*

Petrologisk klub

Møderne finder sted onsdage kl. 12.15–13.00 i mødelokale 3, trappe B, 3. sal på Geologisk Institut, Øster Voldgade 10, København.

Sedimentologisk klub

Alle foredrag holdes onsdage kl. 15.00 i mødelokale 3, trappe B, 3. sal på Geologisk Institut, Øster Voldgade 10, København.

Malmgeologisk klub

Møderne afholdes på Geologisk Institut, Øster Voldgade 10, København, og vil blive annonceret løbende ved opslag til Geologisk Institut og Geologisk Museum i København.

DGF

Afholdte Møder

Palæontologisk klub

Mandag d. 18. maj 1998: **Palaeoceanography** – (Geologisk Museum).

R. V. Dingle: *Characteristics and history of upwelling in the Benguela system, SE Atlantic Ocean.*

Large-scale oceanic upwelling is estimated to account for 80–90% of new biological production in the worlds ocean. It has a major effect on the CO_2 budget (by transfer of carbon from shallow to deep water, and removal to organic sediments), and so modulates the global climate. Clearly it is a phenomenon of great interest to geoscientists.

There are two main categories of large scale upwelling: open ocean and coastal. These are both largely wind-driven, and at the present-day, the former includes the subpolar and equatorial latitudinal belts, while there are 5 major coastal zones along the eastern boundaries of the mid-latitude Pacific, Atlantic and Indian oceans (California, NW Africa, Peru, SW Africa, and Australia).

This presentation deals with the area of the SE Atlantic Ocean, where coastal upwelling occurs from the equatorial regions to the southern tip of the African continent. The most important zone lies between ca. 20°S (Walvis Ridge area) and the southern Cape, where the west coast of southern Africa is flanked by the anti-clockwise flowing Benguela system. This bathes the coast in relatively cool water, in contrast to the tropical Agulhas and Angola coastal currents to the south and north, respectively.

At present, upwelling off Angola, Nambia and South Africa occurs in 7 semi-permanent cells that lie over the continental shelf and upper slope. They result in great biological productivity which supports a large fishing industry, and strongly influence the climate of the adjacent hinterland which is hot, windy, arid and desolate. Upwelling is sustained by strong S-SE winds round the semi-permanent South Atlantic High. These drive nearshore surface waters farther to the N-NW (i.e. to the left in the southern hemisphere), so that the Eckman flow (undercurrent) moves the top part of the water column westward across the shelf, causing the underlying, cold, nutrient-rich Antarctic Intermediate Water to replace it by moving eastwards over the shelf and upwards to the surface. It is this cold upwelled water which causes the coastal fogs that deprive the hinterland of moisture (= Namib Desert: 10mm/yr), and results in the periodic replenishment of nutrients that sustain the high biological productivity in the photic zone. The boundary between the cold nearshore upwelled water, and the warmer oceanic waters farther west is not a simple one, however. Huge filaments and vortices periodically disrupt the boundary, partly caused by instability in the frontal systems and partly by detached plumes of warm water that have broken from the Agulhas system in the south and have drifted northwards. These particular oceanographic and climatic circumstances give rise to a variety of very distinctive sedimentological and palaeontological features:

- organic rich sediments (combination of high flux of phytoplankton and other biological debris and low values of benthic dissolved oxygen)
- low fluvial sediment input (arid coast), but high wind-borne terrigenous flux (aridity & strong winds)
- opal-rich sediments (diatomites)
- carbonate-rich sediments (high plankton productivity/low terrigenous flux)
- high trace element concentrations (e.g. U, Cu, Ni, Zn, Cd) (chemical scavenging in geochemical microenvironments)
- high authigenic mineral production (glauconite, phosphorite, dolomite: low terrigenous sediment flux, high benthic organic concentrations, low oxygen environments, large coastal embayments).

The distibution of these various sedimentary/biological environments is complex, but varies depending on the physical characters of the individual upwelling cells. Each cell is characterised by differences in intensity and frequency of upwelling, which is summer-dominant in the south, and winter-dominant in the north. In the centre (near Luderitz), this results in year round intense upwelling. In addition to sedimentological and geochemical variations from north to south, a study of the benthos (Ostraocda = microcrustaceans) shows that the cells sustain subtly different bentic faunas, which can be linked to, amongst other things, changes in benthic temperature, salinity and dissolved oxygen. Comparing faunas in cores from the Luderitz shelf, which is the area of present maximum intensity of upwelling, shows that during Quaternary times, the position and intensity of upwelling has varied greatly.

How long has this situation been sustained? Clearly, it is a result of the modern regional circulatory system, which is itself a consequence of the Southern Ocean geography. From plate tectonic considerations, a Miocene age has been put on the final, deep-water opening of the Drake Passage, but some workers maintain that the Namib desert (which is a consequence of the oceanographic climate) is at least as old as late Cretaceous/early Tertiary (»the oldest desert in the world«). I believe that the limited onshore evidence does not favour an age older than Lower Miocene.

Three ODP/DSDP legs have investigated the offshore sediments. Only preliminary data are available from the latest leg (175, Feb. 1998), but a summary of

the main features of the development of the upwelling phenomena within the Bengula system is:
- spasmodic upwelling began in late Oligocene time
- major upwelling began in late Miocene time
- there was an overall increase in upwelling intensity at ca. 2.8 MA (coinciding with major onset of Northern hemisphere glacation
- a maximum in productivity (= diatom production) at the Pliocene/Pleistocene boundary
- considerable variation in diposition of individual upwelling cells during Quaternary time

Carsten Israelson & Barbara Wohlfarth: *Timing of Last Interglacial High Sea-level on The Seychelles Islands, Indian Ocean.*

Here we present new U-Th datings of the last Interglacial based on corals from the Seychelles Islands, Indian Ocean. Corals occur mainly as small coral-algae-vermetid remnants found in cavities between huge granite boulders, adhering to the rock surface and they rarely attain more than a few m^2 in area. Samples of *Goniastrea* and *Porites* from elevations between 1.7 and 6 m above present mean sea-level were dated by TIMS ^{238}U-^{234}U-^{230}Th techniques. The ages from well-preserved corals lie between 122.000 and 131.000 yrs B.P. These ages are in agreement with most other observations of last Interglacial sea-level. High marine limestones (HML) from two sections at La Digue island indicate a period of coral build-up until 131.000 yr B.P. followed by a drop in sea-level between 131.000 and 122.000 yrs B.P. The sea-level drop can probably be regarded as a result of glacio-hydro-isostatic rebound following initial interglacial sea-level rise and stabilization.

Svend Funder: *From the North Sea to the White Sea: Oceanigraphy and climatic significance of a sea-way in the Eeminan interglacial.*

During the Eemian interglacial a more than one hundred kilometre wide seaway existed along the east-Fennoscandian border from the southern North Sea through the Baltic, Karelia, and northwards to the White Sea-Barents Sea.

Since then, no seaway has existed in this area, and the question of energy transfer and its implications has been debated: was energy transported to/from the Atlantic and the Arctic Ocean along this route, and did it influence the NW European climate ?

Marine sediments with mollusc faunas from this seaway are best exposed in southern Denmark and northern Russia, but known also from smaller exposures and numerous borings between these areas. Pollen studies of the marine sediments indicate that they are of the same age, spanning several millenia in the early half of the interglacial. However, comparison of the faunas evoke a complex and apparently contradictory picture of the seaway's hydrography. At its two ends, in the southwestern Baltic and northern Russia, conditions were considerably warmer than now, and saline waters penetrated far into the Baltic and into the North-Russian river basins as indicated by the thermophilous *Divaricata divaricella* and *Cerastoderma edule* and others. However, in the middle, in the »Karelian passage« from the Gulf of Finland to northern lake Onega, *Portlandia arctica* faunas indicate cold and low-saline water.

These steep heat and salinity gradients are difficult to reconcile with water exchange through the Karelian passage. As a tentative solution to the problem it is suggested that the connection over the narrow continental water divide to the north of Lake Onega functioned only for a short period, at the time of rapid eustatic sea-level rise in the early Eemian. During the main part of the Eemian the Karelian passage was probably not a passage but an oceanographic cul-de-sac extending from the Gulf of Finland to northern Lake Onega, as a parallel to the Gulf of Bothrua. The climatic significance of the extensive marine cover would then have been mainly as an oceanic heat/cold reservoir lending an oceanic aspect to the climate in adjacent land areas. Alternatively, the faunas of the Karelian passage could be interpreted to show that a cold southward going undercurrent compensated for a warm northward directed surface current. There is indeed evidence for highly stratified water masses in the North Russian marine faunas. However, this solution entails that all traces of the warm surface current should have been removed from the extensive region of the Karelian passage.

These results are preliminary products of ongoing field-work in northern Russia (the PECHORA and ARKHANGELSK Projects) and Denmark (the CATLINA Project).

Niels Bonde: *A coastal upwelling system at the Paleocene-Eocene boundary: Models and tests.*

Two models have been proposed for the oceanographic regime in which the Mo-clay (Fur Formation, latest Paleocene or basal Eocene, pending the decision of a stratigraphic committee), a marine, mostly laminated diatomite was deposited. In both models the diatomite is seen as evidence of an upwelling system with very rich bioproduction.

Exposures of The Fur Fm. today is restricted to the western Limfjorden area, most important the islands Mors and Fur. Exposures are distributed within an area of c. 40 x 30 km^2 between Thy and Ertebølle, resp. Lild Fjord and Junget. The original extension to the north is unknown, removed by glaciers, which have strongly modified all known diatomite exposures. The diatomite is unknown in deep tests south of Harre (N-Salling).

Fur Fm. and its precise chronological equivalents contains a series of nearly 200 volcanic ash layers numbered -33 to +140. The series is recognizable in most of the North Sea drillings (Lower Balder Fm.) and some specific ash layers can be identified in deep sea drillings even west of Ireland and in Bay of

Biscaye. The easternmost occurrence is exposed in Røsnæs (W-Sealand), while probably equivalent but more irregular ash layers are found on the tiny island Greifswalder Oie east of Rygen.

South of the »Mo-clay area« the ash series was deposited in mostly smectitic clay, the Ølst Fm. and the thickness here of the clay/ash series is about one fourth to one fifth of that in the diatomite. In the Central North Sea (cf. Bonde 1982) the ash is also comprised in smectitic clays and further north these mudstones with ash are strongly silicified. In the Harre drilling there is diatomite only between ash –33 and +l, the upper ash series is in clay like in southern Denmark and UK (exposed in E-Jutland, W-Sealand and A-1 of the London Clay at Harwich) and in Holland and N. Germany (drillings, but exposed near Hamburg in the 1920-ies).

Two models of the supposed upwelling area have been proposed: I) Bonde (1987, 1979, 1973) reconstructed the Mo-clay area as the southern part of a long narrow sea with upwelling driven by northerly winds paralleling the »Scandinavian« west coast with consequences for the entire »North Sea Bay«. II) Pedersen (1981, also Pedersen and Surlyk, 1983) suggested that the upwelling with diatomite deposition was a local phenomenon surrounded and partly controlled by salt diapirs and restricted to NW-Jutland (with little effect on other parts of the North Sea region). A possibility mentioned as a secondary less heuristic model by Bonde (1973).

Can these models be exposed to serious testing – and has such been done? Bonde (1979, 1973) suggested that North Sea drillings sufficiently close to the Norwegian SW-coast might constitute such a test, as his model predicted diatomite in the ash series along the coast (and further north?).

Thomsen and Danielsen (1995) demonstrated that diatomite was in fact deposited in between part of the ash series in most of the relevant drillings in the Danish and Norwegian sector in direction WNW from the »Mo-clay area«. Thus they confirmed the model of a coastal upwelling zone.

Malm *et al.* (1984) further suggested that the siliceous mudstones in the ash series much further north along the Norwegian westcoast was generated by diagenesis of original diatomite. This tends to confirm that the upwelling zone may have existed further northward.

Pedersen in the elegant model (1981) for the deposition history of the »Mo-clay area« proper suggested that decreasing amounts of lamination towards the top of Fur Fm. indicate upfilling of that local basin structure with longer periods of nonstagnant water and finally the terminationn of the upwelling system in this area as a consequence.

Bonde (1987, 1979) envisaged the opening of the »English Channel« in Early Eocene as a factor completely changing the systems of ocean currents in the semienclosed basin.

These two suggestions may both be valid, but a consequence of Bonde's idea is that further NW of the »Mo-clay area« upwelling (with diatomite) may have remained active a little longer in Early Eocene – this has not (yet) been confirmed.

Eckart Håkansson: *Lunulite bryozoan biogeography, Cretaceous to Recent; a walk on shelves?*

Lunulite bryozoans constitute probably the most conspicuous group in cheilostome history, with a prominent presence in many soft bottom shelf communities from the Late Cretaceous to the present. The unifying morphological characteristics of the group are all more or less directly related to the particular way of life of its members: free-living directly on the soft, particulate sea-floor, supported by stiff marginal setae emanating from highly characteristic polymorphs. Co-ordinated movement of these setae make lunulite bryozoans capable of slow directional locomotion, a feature unknown from virtually all other colonial animals. In addition to their highly organized colonies and very unusual mode of life, lunulites share a very complex biogeography, combining dramatically changing global diversity through time with distinct shifts in geographic distribution. Thus, in the latest Cretaceous they experience their all-time diversity peak in NW Europe, while the rest of the World has yielded just a handful of species; in the Eocene they had a prominent presence in North America (allthough a fair number of species have been recorded from the rest of the World) and, finally, in recent faunas they constitute a prominent endemic element in the shelf seas of Australia and New Zealand. The complexity of this biogeographic pattern naturally raises the question to what extent lunulite history involves complex migration along the continental shelves, as opposed to independent, local evolution of free-living clades of lunulite body plan. Unravelling this puzzle requires insight into the nature and composition of intermediate lunulite faunas – both in terms of age and geography. Such data are presently being brought together. Thus, recent investigations already indicate that very few lunulite species survived the Cretaceous-Tertiary boundary, and possibly none of the survivors lived through the Paleocene. Hence the Eocene peak in lunulite history may have to be derived entirely from lunulite clades evolved independently during the early part of the Paleogene. In view of this possibility, the predominantly Neogene lunulite history of Australasia is also being reconsidered, with the interesting possibility that the Australasian branch of the lunulite tree may have been derived entirely within this biogeographic realm.

On balance, the data so far gathered are entirely compatible with the notion that »lunulite« bryozoans are close enough to the basic, encrusting cheilostome body plan that one should expect »lunulites« to evolve iteratively whenever ambient conditions are conducive. Hence, the peculiar biogeographic pattern of the

»lunulites« may result predominantly from local evolution of essentially unrelated clades sharing a few essential and conspicuous skeletal features.

C. J. Bjerrum & F. Surlyk: *Numerical ocean model investigations of Jurassic meridional seastrait paleoceanography.*

Analytic and numerical ocean model results predict that pale-ocean currents in Mesozoic meridional seaways/straits responded to the global thermohaline circulation in a predictable manner. This is especially important for paleoclimatic investigations since no significant deep ocean sediments are preserved for pre-Cretaceous time.

Using the Jurassic North Atlantic epicontinental seastrait as an example, it will be illustrated how the strait-oceanography would have responded to changes in the global thermohaline circulation. The Jurassic seaway connected the Boreal sea at 60°N and the Tethys Ocean at ca. 20°N, had a 100 to 300 km wide strait at 45°N between Norway and Greenland. Further south the seaway was up to ca. 1000 km wide.

Analytical and numerical solutions of a simplified seaway/strait geometry show that the flow was frictionally governed and that coastal arrested shelf waves originating from the straits was important. Salinity and temperature differences between boreal and tethys regions would furthermore have generated density contrasts which resulted in depth integrated steric height differences. The steric height differences could have driven a dominating flow of up to 3 Sverdrups, in either a northward or southward direction dependent on the state of the global thermo-haline circulation. This means that if global deep-water formation principally occurred at northern high latitudes the flow was toward the north. Conversely if deep-water formation was at southern high latitudes the flow was toward the south. However if deep-water formation occurred in tropical regions, the steric effect would be minimal and the flow would principally be wind generated. Theory further predicts that the steric driven currents would always occur at the same side of the seaway.

The numerical and analytical results point to that paleobiogeographical and isotope investigations in target areas, can contribute significantly to the earth system understanding of the Jurassic period.

Lennart Jeppsson: *An empirical paleooceanographic model and its application to the Silurian.*

The model is partly built on analysing the consequences of previous *theoretical studies*. For example there are two potential sources of oceanic deep water, hence there are two possible stable oceanic states. During a primo episode deep water is produced in high latitudes from cold-dense water rich in oxygen. Carbon dioxide is drawn down, and methan is stored as clathrates. This results in a climate colder than average, reinforcing the deep water production. During a secundo episode deep water is produced at mid latitudes from saline-dense, warm water with little oxygen. The carbon dioxide storage capacity of the ocean is low. The resulting greenhouse effect reinforces that deep water production. Thermal expansion of the deep water rises sea level. That is, sea level changes are an effect, not the cause. There is no intermediate oceanic state with e.g. 8°C warm deep water. The model describes how these two stable oceanic states become destabilized and end. The change in kind of deep water is accompanied by a very large change in atmospheric carbon dioxide content.

An interval of time with unstable, intermittent deep water production is called an event. If long enough, a stop in deep water production causes a stop in the deep upwelling. The disapperance of this source of nutrients for the primary planktic production results in extinctions among benthic taxa with planktic larvae, planktic taxa, other taxa in food webs including any of these taxa, etc. Milankowitch cyclicity triggered a pattern of such stops – datum points – during an event.

Empirical observations regarding the Silurian. Several of the following ones have been used for the development of the model: A. The dry warm climate of secundo episodes resulted in extensive development of carbonates including reefs. The humid low latitude climate of primo episodes was detrimental for reef growth and resulted in argillaceous limestones. B. Patterns in the changes in frequencies of different lithologies and faunas have been found. C. High resolution studies of range ends have e.g. revealed the pattern of datum points, disaster faunas, Lazarus and Lilliput taxa, and very large changes in carbon stable isotopes ratios. D. An episode lasted in average 13Ma, an event up to 200.000 a, and a datum was irresolubly fast, that is, it lasted less than a few hundred years. E. Mass extinctions during the Silurian have not been known before, but several are now identified. For example, the 10 datum points during the Ireviken Primo-Secundo Event may have terminated 50% of all species (c. 80% of conodont species were affected). The Mulde Secundo-Secundo Event has long been considered a catastrophy for graptoloid graptolites only but is now known to have caused both extinctions among other taxa too, and distinct lithological changes. Further, the datum point with the largest effects on both graptolites and other taxa was not Datum 2 at the end of the *C. lundgreni* Zone but Datum 1. 30.000 or 100.000 years earlier. (In contrast to the documented effects of the events, the existence of any so called »back-ground« extinction during the Silurian remains unproven.). F. The cause of many wellknown faunal changes can now be identified although the frequent preference for appearances as zonal boundaries tends to focus both interest and high resolution studies at levels above those of the oceanic change.

Use of the model. There are claims that science is an interplay between predictions and observations resulting in verifications or falsifications. The exclusion of descriptive branches of science is clearly a too restricted definition. However, my model makes it possible to use this powerful method in studies with a stratigraphic aspect. For example, two Silurian events, which caused temporary faunal changes but few extinctions, have been discovered in this way. From field work to final analysis the model indicates what to look for and where to look and indicates the cause of any changes. The model predicts sharp boundaries – centimetre precision – between episodes and events. The relationships between lithologies, faunas, floras, extinctions, sea level changes, geochemical data etc. revealed by the model permit predicting what changes in the other variables to search for, if certain changes are detected in one of them. Several such predictions have now been verified. In the last few years the use of the model has rapidly spread. A year ago over 70 publications and abstracts by over 100 scientists had used or referred to the model. Application has advanced fastest in studies of the Silurian where the sequence of oceanic episodes and events is now identified in its major characters. Further, studies of several events and their characters are also on the way. Among users of this model are e.g. stable isotype geochemists, stratigraphers analysing their regional sequences, palaeontologists studying range ends, other faunal changes and evolution. It has been quoted in studies ranging from the late Precambrian to the Jurassic.

David A. T. Harper: *Reconstructing the Ordovician Iapetus Ocean: Implications for Terrane Migration and Changing Biodiversity.*

Early Ordovician fixed benthos, especially the Brachiopoda, has defined the larger, wellestablished biotic provinces associated with the palaeo-continents of Baltica, Laurentia and Gondwana together with the low latitude Toquima-Table Head and the high latitude Celtic marginal faunas and several intra-Iapetus faunal complexes. Mid Ordovican patterns are more complex with an increased flux of faunas coincident with the rapid northward migration of Avalonia and Baltica. The transit of many northern Iapetus terranes from high to low latitudes is reflected in a change through Ordovician successions from Celtic and Gondwanan faunas to Laurentian marginal biotas including thc Scoto-Appalachian fauna. In the southern Iapetus the pattern is different; Laurentian faunas are replaced by Celtic and Gondwanan biotas as terranes moved in opposite sense from North to South America. These key terranes are now located in the Appalachian-Caledonian Orogen and its extension into South America.

Later Ordovician provinces are more clearly defined; during the latest Ashgill the Bani, Kosov and Edgewood provinces were developed across a gradient from high to low latitudes against a background of glaciation and oceanic closure.

High biodiversities and endemism characterize the early Ordovician, concomitant with a phase of intense magmatic and teotonic activity. Associated island complexes are typified by indigenous genera, and assemblages with often mixed provincial signals together with taxa more common in younger platform successions. In contrast, the later Ordovician is characterized by decreased endemism and biodiversity. Thc distributional data provide not only a monitor on thc development of the Iapetus but also a window on changing diversity patterns during radiation and extinction events within a dynamic oceanic system.

J. L. Christiansen & S. Stouge: *Conceptual palaeo-oceanographical modelling: the Arenig Epoch (Early Ordovician) as an example.*

Palaeogeographic reconstructions are normally based on palaeomagnetic, palaeobiogeographic and palaeolithological data. Palaeooceanographic models can however, when combined with palaeobiogeographic data, be used as an essential constraining element in palaeogeographic reconstructions. This approach has been taken using Arenig times (Early Ordovician) as an example.

Based on fundamental physical-oceanographical principles, the planetary ocean-surface circulation has been modelled. This conceptual model outlined here uses shifts in Hadley circulation caused by orbital variations and the rotation rate of the Earth to locate the position of the planetary oceanic low and high pressure systems around which the planetary ocean currents flow.

In Arenig times, the temperate low pressure zones were located at 50° lat., whereas the subtropical high pressure zones were located at 25° lat.

A new palaeogeographical reconstruction has been composed for Arenig times, primarily based on the new conceptual palaeo-oceanographic model combined with palaeobiogeographical data, and in agreement with palaeomagnetic data.

A.T. Nielsen: *Cambrian sea-level changes in Baltoscandia.*

The deeply peneplanised Baltoscandian craton was transgressed in the early Early Cambrian, and on a first order level the sea-level rose all through the Cambrian to reach a maximum in the Early Tremadoc. The craton was almost totally flooded from the late Early Cambrian onwards, a circumstance which led to extreme sedimentary starvation of the epicontinental sea.

The lithofacies distribution shows an overall simple decrease in grain size with increasing depth. A tidal zone with sand characterised the nearshore area. Basinwards this facies was fringed by a silt belt, probably ranging down to about or a little above the storm wave base (estimated at about 40–50 m of depth), below which deposition of mud took place. The latter lithofacies, known as the Alum Shale, ranged to the shelf break (estimated at about 150 m of water depth) and was denoted by dysoxic-anoxic depositional conditions. It appears that the oxygen content of the Cambrian sea was lower than present day levels. Glauconite formation appears to have been concentrated at the sand- and silt-belt transition, i.e. at very shallow water. This may be another result of a low oxygen level. Because of the sedimentary starvation sea-level falls were not accompanied by progradation and lowstands were characterised by wave-driven submarine erosion; profound lowstands were accompanied by deposition of condensed shallow cold-water bioclastic carbonates. Each limestone intercalation typically overlies an unconformity formed during the initial phases of the sea-level lowering. The midshelf was characterised by sedimentary by-pass due to numerous erosional events associated with an oscillating sea-level.

The Alum Shale contains an abundant trilobite fauna specialised to dysoxic conditions, and a range of biofacies characteristic of different oxygen levels is recognised. Provided the palaeo-oxygen levels in the bottom waters reflect the general depth (decreasing oxygen levels with incresing depth) sea-level changes can be reconstructed for the black shale intervals using biofacies data. Available sedimentary and geochemical information corroborate the resulting sea-level curve.

Minik T. Rosing: *Earth earliest habitats: > 3700Ma ocean floor sediments from the Isua supracrustal belt, West Greenland.*

Geologic evidence of the physico-chemical environments in which life developed may provide better constraints on earlier stages in the evolution of life than the fragmented morphological vestiges of the organisms them selves.

Well preserved Bouma sequences defined by up to 60 cm thick units of graded greywacke separated by black slaty units up to 10 cm in thickness have been found in a low strain domain within the >3700Ma Isua supracrustal belt, and form a depositional continuum with pillowed metabasalts. The black slaty units are laminated on a sub-mm scale with alternating lighter and darker layers. The dark layers are rich in micas and graphite while the lighter layers are richer i quartz. On a cm-scale, packages of such fine layers are interspersed with mm thick layers of slightly coarser grain size, which are rich in plagioclase and poor in graphite. The layered structure is cross cut by mm wide graphite-free quartz veins.

In both greywacke and black slate, graphite is seen as abundant 2–5 μm globular grains included in the silicate phases. The distribution of graphite grains closely follows the sedimentary bedding, and the graphite grains have the same restricted sizerange within the area of a thin section and between different samples separated by meters in the field. The Bouma sequence graphite has depleeted $\delta^{13}C$ values in the range –18.8 to –19.1 which is within the range of biologically reduced carbon.

The association of graded greywackes and laminated slates can be interpreted in the framework of Bouma sequences. The graded units were deposited from turbidity currents, while the laminated slates form the pelagic E units deposited during quiet periods between turbidite pulses. The bouma sequence turbidites are associated with impure banded iron formation, and this sedimentary package occur within a succession of basaltic metavolcanic rocks. This constrain the deposition to a oceanic environment in the vicinity of volcanic edifices. The undisturbed nature of the turbidites and pelagic sediments indicate a water depth below the wave base i.e. probably exceeding 100 m. Thus the sediments were deposited below the photic zone. The strong correlation of globule abundance with individual sedimentary strata suggests that the carbon was deposited during sedimentation of the protolith, and not by secondary processes.

The limited range in size of graphite particles in different parts of the Bouma sequences may indicate that the reduced carbon precursor formed grains with a limited size range in the sediment source. The laminated slaty sediments deposited in a low energy environment have higher total abundance of carbon compared to the sediments deposited by turbidity currents, but both types of sediment have abundant graphite globules. This is in contrast to the coarse grained feldspar-rich mm thin layers within the laminated slaty sediments, which are virtually free from graphite globules. This probably indicates that carbon rich pelagic mud was eroded by the turbidity currents and mixed into their deposits, while the plagioclase-rich interlayers in the pelagic sediments could be airborne volcaniclastic sediments deposited rapidly by setteling through a stagnant water body without disruption of the muddy precursor of the laminated slates. The apparent inverse correlation of graphite abundance to sedimentation rate indicates that the carbon particles most probably sedimented continuously from suspension at a slow rate or formed directly in the pelagic mud during sedimentation. The absence of carbon grains from the coarser grained feldsparrich layers favor an origin by settling from suspension.

The combination of sedimentological and geochemical evidence presented above suggest a biogenic origin of the graphite globules. The precursor organic detritus of the graphite globules probably included planktonic photoautotrophic organisms that sedimented from the surface waters. The limited range in sizes of graphite globules may well be enherited from biological cells, but neither the size nor the shape of the graphite grains can be regarded as representative for the morphology of early life forms.

This study documents the formation and preservation of a sedimentary reservoir of ^{13}C depleted reduced carbon more than 3700Ma ago. The enrichment of the atmosphere and hydrospere in ^{13}C was thus initiated at that time.