Neogene Climate–Inducing Northern Gateways and Boundary Conditions

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Abstract

The Neogene is a time of fundamental paleoenvironmental changes, paleooceanographic, paleoclimatic and of course tectonic in almost any part of the world, from the Tibet–Plateau over the gradual closing of the Straits of Panama, pliocene El–Nino conditions in the tropical Pacific, ice rafted detritus, e.g. at least ice–floes from about 5.9 Ma on in the Norwegian Sea and in the North Pacific. This implies that during almost the entire Pliocene the Arctic Ocean was at least as cold as today. Around 2.6 Ma boundary conditions, to be studied, changed such, including passing threshold values, that large glaciations occurred.

While in the past the subsidence history of the Greenland Scotland Ridge appeared to be known, recently well–known boundary conditions are reassessed by various authors. These include: Nature, even existence, of the Iceland hot–spot, its trace through time (Tamyr–Iceland hot–spot, dated volcanics in NE, NW, W and E Greenland), nature of the Iceland anomaly (compact: intersection of two mid–oceanic ridges as one cause for the large amount of basalts), compressional tectonic in the North Atlantic, type of the crust beneath the basalts (such as Paleogene sediments as off Norway, comparable to the situation of the Tulipan oilfield), e.g. non–Sclater conditions and others.

All aspects need to be integrated, not in the term of one alternative over they other but in terms of integrating different, sometimes counteracting factors.

Pliocene: The Norwegian Sea colder than today coexisting with El–Nino in the tropical Pacific

The Neogene is a time of fundamental paleoenvironmental changes, paleooceanographic, paleoclimatic and of course tectonic. These changes show up in almost any part of the world, from the Tibet–Plateau over the gradual closing of the Straits of Panama, pliocene El–Nino conditions in the tropical Pacific, (Smolka, 2000, 2002, 2004, 2008 and submitted, Wara et al., 2005), contemporaneous with the reduced inflow of surface waters from the Atlantic into the Pacific to widespread Northern Hemisphere (NH) glaciations from 2.6 Ma on.

Small but consistent amounts of ice rafted detritus (IRD) observed in sites 881 (Aleutians, Krissek, 1995) and 642B, Voering–Plateau, Norwegian Sea (Jansen et al., 1990) showed that at these sites during almost the entire Pliocene, from about 5.9 Ma onward, ice–rafting occurred (Fig. 1). As at site 642B today no ice–rafting is observed, neither in summer nor in winter, pliocene conditions had been in the Norwegian Sea colder than today (Smolka 2004, 2008 and submitted), e.g. cold enough to allow ice–floes to occur. This implies that during almost the entire Pliocene the Arctic Ocean was at least as cold as today. This is no contradiction to PRISM scenarios (Dowsett et al., 2005):

PRISM authors recognized that their own reconstructions, as well as those of the author (Smolka, 2000, 2002), show sometimes considerable temperature fluctuations during the Pliocene. Authors of PRISM select, expressly stated, only the warm peaks of a certain time–interval. This they call the PRISM–MAX situation (PRISM-MIN for the cold scenario). This compares to selecting only the warm interglacials for the Quaternary: No glaciation would appear for the entire Quaternary if for the Quaternary reconstructions would be done by selecting only the warm peaks. Thus PRISM with PRISM-MIN and PRISM-MAX aims at maximum/minimum–scenarios – not at reconstructins.

Driving a climate model (ccm3.6) with the SST reconstructions that include warm, El–Nino–type tropical SSTs (such as in Smolka, 2002 and Fig. 2) in coexistence with cold high–latitude oceans, Artic Sea ice and ice–floes in the Norwegian Sea shows that during the Pliocene on the NH continents extremely cold and snow–rich winter–conditions occur – while the summers are quite comparable to the present (Figs. 2–5, Smolka 2000, 2004, 2008 and submitted).

As PRISM selects explicitely only the warm peaks (scenario calculations) results of reconstructions must differ from PRISM as time–series show, as well as in the Quaternary, considerable SST fluctuations

As during the Pliocene until about 2.6 Ma no large NH glaciations are observed the interplay of Neogene and Pliocene boundary conditions needs to be studied – not with the aim to decide for the one or the other alternative hypothesis but with the aim to integrate all known and sometimes contradicting hypotheses into sets of possible syntheses. If applicable necessary data may or may not be needed by drilling (such as redrills to close coring gaps or first drillsites in the Denmark Straits).

The mechanism of environmental changes, both towards and during warm times but also in cold times can be regarded as understood if – in the future – a coupled climate–ocean–land–ice model, such as CSM at T42 resolution can be started with the conditions for example at the base of the Pliocene and the SST and environmental fluctuations between the base of the Pliocene and now (YD asteroid, Kennett et al., 2009, prescribed for the model) are overall met synoptically as result.

To approximate this long–range goal methodological improvements are necessary (such as in addition to SSTs based on Pforams, SSTs based on diatoms, radiolaria, rapidly measured Ca/Mg SSTs, improvements in MRI analysis (steps towards automated species recognition), acceleration of climate models to cover such ultra–long time–intervals transiently, many stepwise improvements possible and necessary). On the other hand the boundary–conditions in key–areas, such as the Greenland–Scotland Ridge (GSR), need to be accurately known, e.g. much more accurate than the current cores, with sometimes coring–gaps of 100 meters, permit.

The carbonate formation in oceans, chemical reactions in oceans and parametrizations in respective models depends obviously on the ocean chemistry. Hydrocarbon and coal deposits that are currently produced end finally in the atmosphere. They affect the acidity of the oceans. The same rationale applied to the past: Before oil, gas, coal and carbonates had been deposited the carbon was in the oceans and the atmosphere. Although first approximations beyond geocarb–type approaches (various contributions of Berner and others) had been made (such as Beckmann et al. 2000) assessing such curves with an increased degree of precision is one open task.

Around 1998 Bill Hay presented on various colloquia, also within the ODP, the rationale, also modelled: Before the known evaporites had been evaporites they had been in the oceans: This lead to a curve of variable salinity. This implies: The salinity in the pre–Messinian Neogene was different from the post–Messinian Neogene. Depositing 2000 m flat–lying evaporites as they show up in the Levantine Basin seismically (Dümmong et al., 2009) requires at 35 permille salinity about 14 000 m water, e.g. a deposition from supersaturated brines and steady reflow (with self–organizing cylcicity, see Peschel and Smolka, 2000) until desiccation (considering the known conditions from Messinian near–shore environments, including cyclicity, as correct) or – in case of complete one–step evaporation a higher salinity. In the first case evaporites in the Levantine Basin should contain marine microplankton from the water–column above. In the second case a higher salinity as brought forward by Bill Hay contributes to improved syntheses. Setting up respective test–scenarios is an open task.

Carbon removal during the Neogene, both from the atmosphere and the oceans might, near sensitive “bifurcation points” have contributed to threshold values for paleoenvironmental changes around 2.6 Ma. Running in the future coupled climate models across this time requires knowledge regarding necessary parametrizations (ocean pH, e.g. beyond limits of Boron, ocean salinity) and of course respective data (Messinian, properties of, if applicable, salinity–changes).

Most important data and boundary conditions to be known are SSTs in and around the Norwegian Sea (summer–winter SSTs, so far, available from Pforams, annual averages from diatoms and radiolaria, data in Smolka, 2000, improvements, such as summer–winter diatom–SSTs, summer–winter radiolarian–SSTs needed, higher spatial resolution no coring gaps, needed as well). The existing diatom–SSTs show, formulated compact, at the resolution of the available samples, quite high in site 338 (Fenner et al., 1976), improvable in others, quantitatively considerable SST fluctuations within the Norwegian Sea (Smolka, 1988, 2000). The same resolution, covering the entire Norwegian Sea (and beyond) both in time and regarding aereal coverage, both E–W and across the GSR is a prerequisite for syntheses regarding Neogene environmental changes – including the change across 2.6 Ma.

Establishing improved methods, improved SSTs based on existing data (faunal/floral census) and samples (Ca/Mg and other) and improved syntheses using various boundary conditions are part of a to–do list.

To run various syntheses, for example by coupled models, one needs either firm data on bathymetry of the GSR or a suite of alternative scenarios.

GSR: Tectonic development reopened by various authors

Based on subsidence–models for mid–ocean ridges (“Sclater–curves”) and known submergence of sites 337 at the foot of the GSR and site 336 further up water–exchange across the GSR appeared to be solved since a long time. In the past the question was “when” – implying forever (see for an overview Wright and Miller, 1996).

Strong faunal/floral differences across the GSR in the Miocene and pre–Gelasian Pliocene (Fig. 6) are consistent with this. The followed easy Oligocene water–exchange across the GSR. They had been succeded by easy Gelasian and Quaternary water–exchange across the GSR. Thus from faunal/floral evidence during the Miocene and pre Gelasian Pliocene water–exchange across the GSR was strongly inhibited (Smolka 1988, 2008). Easy Oligocene water–exchange is a standard view. The large coring gaps make faunal/floral gradients unlikely as one reestablished water–exchange during such long time–intervals would wipe out such gradients on maps that integrate over such long time intervals.

In the future many well–known items, also well–known and accepted by the author, need to be reassessed as almost anything what was well–known in the past, even fundamentals like the Iceland–hotspot (Tamyr–Iceland hotspot, Lawyer et al., 2004) is questioned by some authors (Foulger, 2005).

In the past interpretations had sometimes been considered as alternatives of the type: either the one or the other. In the future – and this requires much work by many – all alternatives need to be integrated such as: When and where was water exchange across the GSR possible and when and where not (spatially resolved differential subsidence, Fig. 7 and several other lines) interpretation for the Denmark Straits from seismics; even spatially resolved differential emergence in both extensional and compressional tectonic settings in and around the Norwegian Sea interpreted by other authors (such as Dore et al., 2008, Nielsen et al., 2002, Ritchie et al., 2008).

In the past, also by the author, Iceland was considered the result of a normal hot–spot (related discussion in Korenaga, 2004). Increased magma–production lead to the GSR by normal seafloor spreading. Hawaii has quite steep flanks immediately off the hot–spot. The width of the Iceland–shelf was never a reason for questions. Large amounts of rhyolithes in Iceland, both on the geological map and in the field and gabbros (on the geological map of Iceland near Hoefn i Hornafirdi, SE Iceland) and reported granodiorites had been considered as differentiates (of course tectonic processes, documented for example near the Logatchev hydrothermal field can exhume deep parts of the crust in normal mid–ocean ridges – to be checked regarding Hoefn).

In connection with the known normal seafloor spreading on the line North Atlantic – Labrador Sea around 60 Ma dyke swarms appear in England and Ireland. Lundin and Dore (2004) extend these trends westward across the position of proto Iceland close to Greenland, across Greenland to respective igeneous rocks in West Greenland and to contemporaneous (around 60 Ma) seafloor spreading in the Baffin Bay (see Fig. 8).

The igneous rocks in West Greenland, that are considered by Lawyer et al. (2004) as trace of the Tamyr–Iceland hotspot (Tamyr Peninsula – North Greenland – West Greenland – East Greenland(Thule Basalts) – Iceland) are considered by (Lundin and Dore, 2004) as results of normal rifting on the line Ireland–Baffin Bay, about parallel to the "main rifting" (North Atlantic–Labrador Sea) at this time. This would enable massive production of basalts without any hot–spot necessary (or a hotspot in addition – part of a to do list). A position of proto Iceland close to Greenland around 60 Ma could explain one aspect of the thick Iceland crust: One of several non–Sclater conditions. Formulated compact: If the interpretation of Lundin and Dore, 2004 is applied, Iceland and the thick basalts would be the result of two intersecting mid–cean ridges: One around 60 Ma on the line Ireland–Baffin Bay as outlined by Lundin and Dore 2004. The other is the known mid–Atlantic ridge.

Whether the position of Proto–Iceland in Fig. 8 would even make remnants of Greenlandic crust possible in Iceland (Gabbro on the geological map near Hoefn, SE Iceland, reported granodiorites, both considered normally as results of deep differentiation due to the thick crust) is a possible task for geochemists. Regarding the reported gabbro(s) the author has a neutral position. The large amounts of rhyolites in Iceland have been seen by himself.

Off Norway – as shown on the IGC in Oslo by various speakers (such as in context of the Tulipan oilfield) beneath the thick basalts Paleogene sediments had been observed. Information that was accessible in winter 2008 (whether intentionally or unintentionally is not known) regarding the Faeroes showed sediments beneath the basalts of the Faeroes – another non–Sclater condition. While some of the mentioned authors appear to favor one hypothesis over another, future integrated syntheses regarding the GSR and the tectonical setting of the Norwegian Sea possibly integrate each set of observed phenomena at its respective place and time: A Tamyr–Iceland hotspot (that would be a logical consequence of an Iceland hotspot and the known plate–movements) is for example no contradiction to a mid–ocean ridge at 60 Ma from Ireland through the position of proto Iceland (coast of East Greenland, respectice crust beneath Iceland(?) to the Baffin–Bay–spreading). Sediments beneath basalts at suitable positions (off Norway as analogon for the Denmark Straits?) and on the Faeroes are no contradiction to above. Altogether produce non–Sclater subsidence and – for climate models – quite different bathymetric boundary–conditions compared to for example Wright and Miller, 1996.

Considering above compact items (changed subsidence compared to the existing model) might have contributed to passing a threshold–value at 2.6 Ma, e.g. amount of moisture and energy that flowed into an already cold (IRD at site 642B as shown by Jansen et al. 1990) Norwegian Sea – with glaciers advancing on already "pre–cooled" NH continents, Figs. 3–5 (cold NH winters as model–result from driving Pliocene oceans with high tropical SSTs and a Norwegian Sea / Artic Ocean that enables ice–floes as shown by IRD there, Smolka 2008 and submitted).

To come to a conclusion regarding the environmental change around 2.6 Ma all phenomena, paleoclimatic, paleooceanographic and of course tectonic boundary–conditions, as outlined extremely compact above, need to be integrated.

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Figures:

Fig. 1: A cold Norwegian Sea from 5.9 Ma on with ice–floes – coexisting with El–Nino conditions in the tropical Pacific.

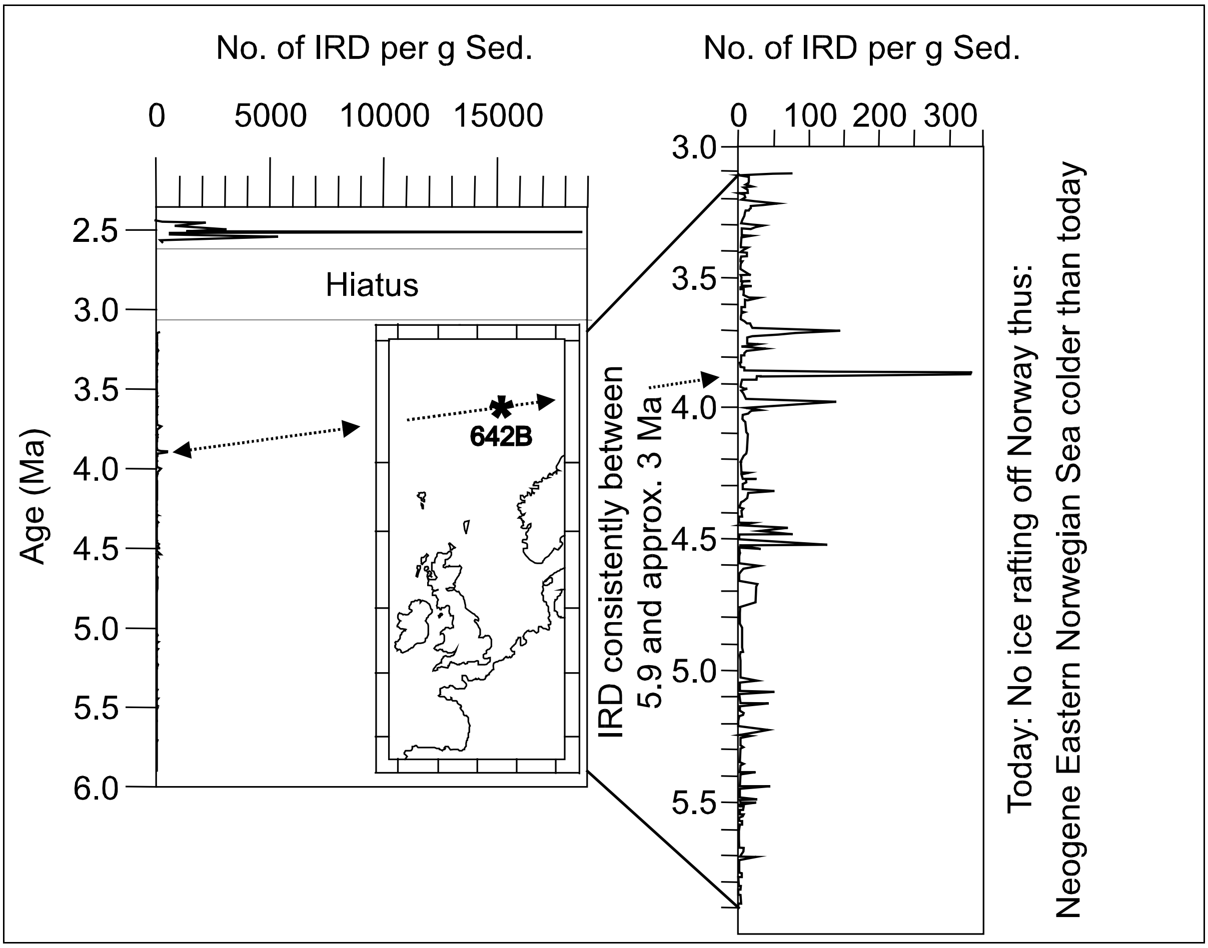

Fig. 1: Ice rafted detritus (IRD) at ODP Site 642B, Voering–Plateau (redrawn from Jansen et al., 1990). During the entire Pliocene (right enlarged subfigure) can be observed in the Norwegian Sea. Today no ice–floes can be observed in the Norwegian Sea, neither in summer, nor in winter. Thus, during almost the entire Pliocene, the Eastern Norwegian Sea was colder than today. This implies: Coexisting with a Pliocene El–Nino cold temperatures in northern high latitudes existed. Thus the often–cites PRISM–scenarios (such as Dowsett et al. 2005) regarding the Pliocene cannot be regarded as reconstructions but, as scenario calculations. As the PRISM–authors call it themselves “PRISM–MAX” (only the warm peaks selected) and “PRISM–MIN” (only the cold peaks selected) PRISM does not contradict Jansen et al. (1990) or Smolka (1988, 2000, 2004, 2008 and submitted). PRISM sets up a scenario (such as PRISM–MAX) while Jansen et al. 1990 and Smolka aim at reconstructions – with different and independent methods. Respective IRD data from the North Pacific that show consistently ice–floes during the Pliocene in different ODP sites (Krissek, 1995) are consistent with this (from Smolka 2008 and submitted).

Fig. 2: Example of reconstructed SSTs, tropical El–Nino conditions.

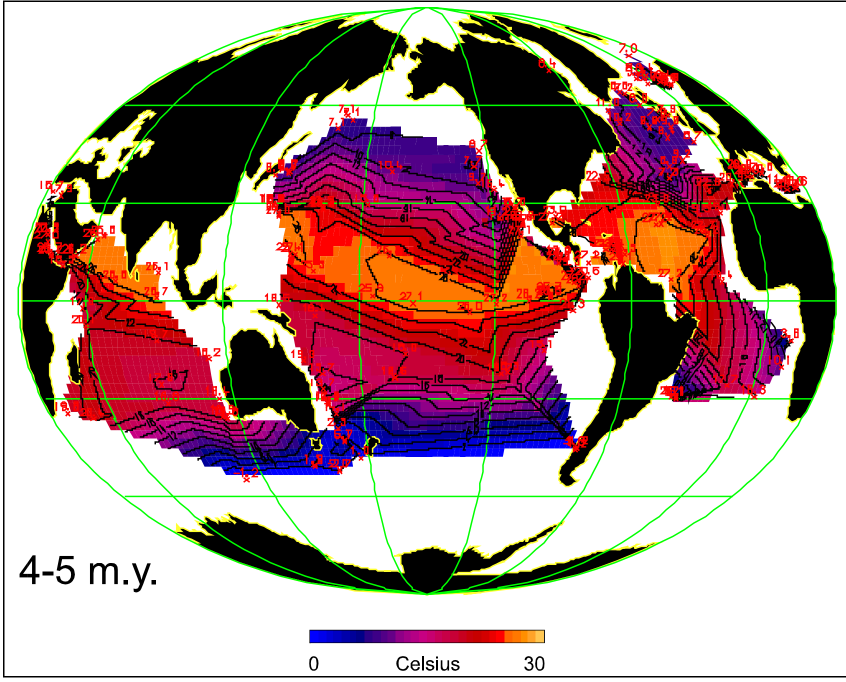

Fig. 2. Reconstructed average sea–surface temperatures **(NH summer)** for the time interval 4–5 Ma (from Smolka 2000, 2008 and submitted).

Fig. 3: Driving ccm3.6 with reconstructed SSTs, sea ice and environments yields for the Pliocene NH summer conditions to about the present.

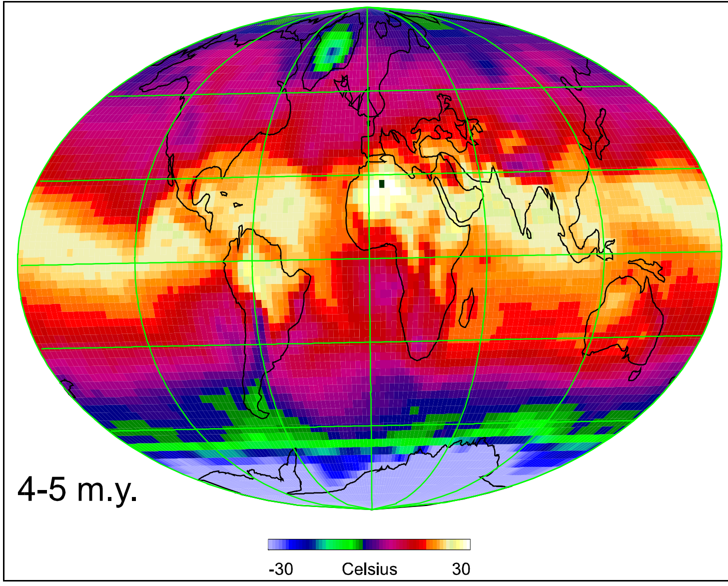

Fig. 3. Resulting modelled air temperature (bottom layer) during NH summer.

Fig. 4: For pliocene (4–5 Ma) NH winters quite harsh conditions exist on NH continents. They result from the interaction of strong latitudinal temperature gradients, the polar night and a resulting wind–system (model output) that advects cold air massively to the south, such as through the Norwegian Sea and, where possible, moist air in large quantities northward, such as over the Parathethys further north (data in Smolka 2000, from Smolka 2004, 2008 and submitted). As a result the zero degree isotherm moves twice a year over NH continents – today often with large amounts snowfall associated.

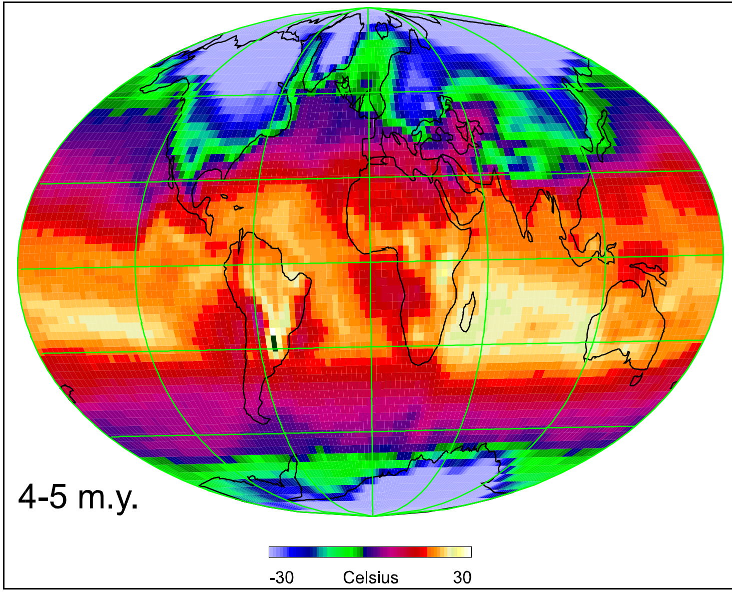

Fig. 4. Resulting modelled air temperature (bottom layer) during NH winter.

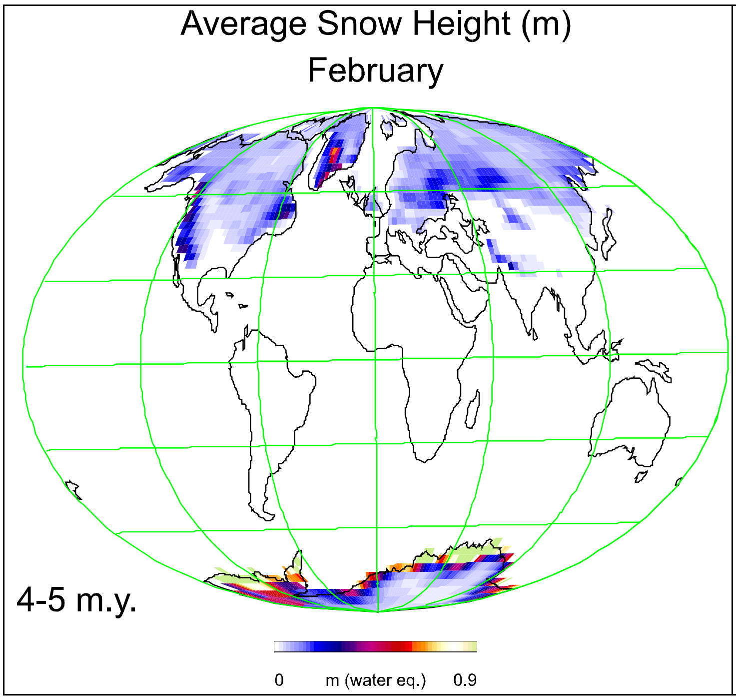

Fig. 5. Average height of fallen snow (meters water equivalent) in February. Monthly (shown here) and cumulated snowfall prepares during the Pliocene the large NH glaciations from 2.6 that follow once threshold values are passed. Glaciers formed either partially in situ after 2.6 Ma or advanced more easily on a “pre–cooled” surface.

Needed (to do): Improved SST reconstructions: In addition to pforams also from diatoms (annually averaged SSTs already available), radiolaria, Ca/Mg and Alkenone SSTs where possible. And: Fast transient model–runs needed.

Figs. 2–5 from Smolka 2000, 2004, 2008 and submitted.

Fig. 6: Strong faunal/floral differences, both calcareous and siliceous, across the GSR in the Miocene and pre gelasian Pliocene. Low differences across the GSR in the Oligocene and Gelasian to Quaternary.

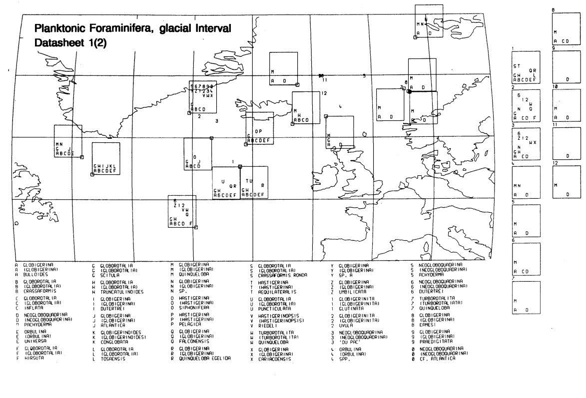	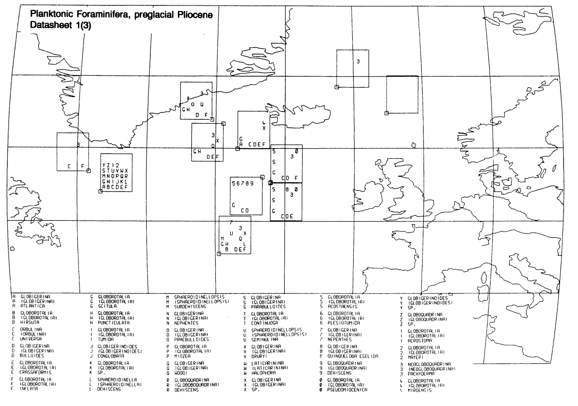
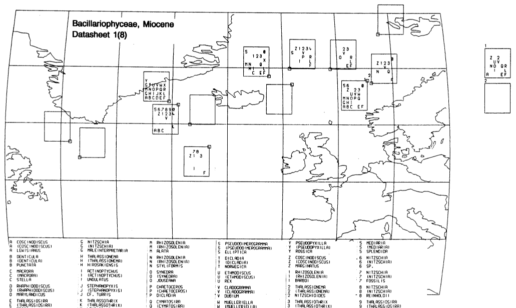	Fig. 6a (top left): Pforams, 2.6 Ma and younger Fig 6b (top right): Diatoms: Pliocene (until 2.6 Ma) Fig. 6c (bottom left): Diatoms (Miocene) See the large faunal/floral differences across the GSR before 2.6 Ma. During the Oligocene the maps show water–exchange across the GSR (from Smolka 1988, 2008).

Fig. 7: Longitudinal seismic cross section through deep parts of the Denmark Straits (unpublished postdoc project by O. Kohnen, Muenster).

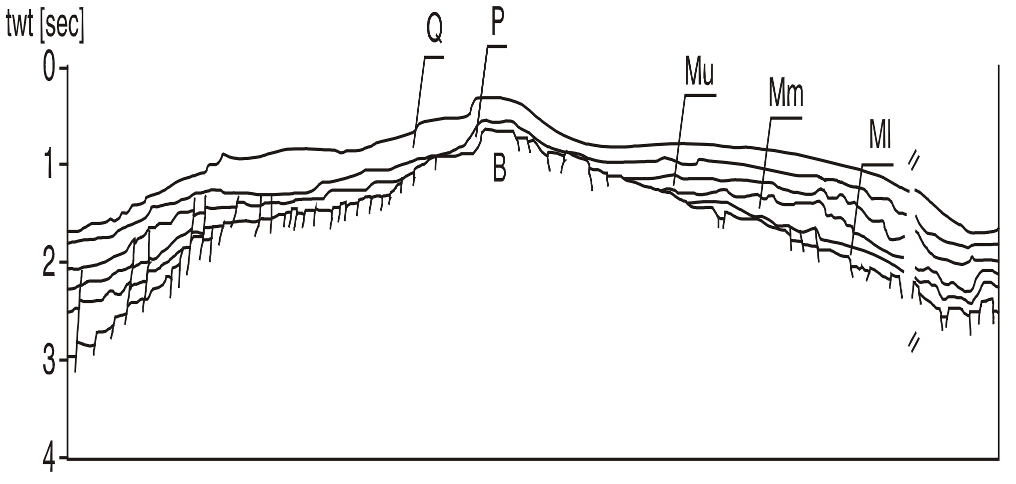

Fig. 7: Longitudinal interpreted transect through the Denmark Straits. Q: Quaternary and glacial Pliocene, P: Preglacial Pliocene, Mu: Upper Miocene, Mm: Middle Miocene, Ml: Lower Miocene, B: Basement. Note the onlap of the Miocene sediments and note the continuous cover of a thin preglacial Pliocene layer. Although the nature of the sediments (terrestrial, which is still possible or marine) can only determined by drilling, a preglacial coverage of water of the deepest parts of the Denmark Straits Channel is inferred.

Fig. 8: The Iceland anomaly can be the result of (a) effects of an early mid–ocean ridge around 60 Ma, north of the "main" NW–trending mid–ocean ridge, e.g. GSR basalts normal mid–ocean ridge basalts, but not from the current mid–ocean ridge, (b) remnants of crust from Greenland (thickness of Icelandic crust, position of proto–Iceland in Fig. 8), (c) effects of the current mid–Atlantic ridge and (d) the "arrival" of the Tamyr–Oceland hotspot in younger times – e.g. various factors superimposing each other, plus, where applicable, underlying Paleogene sediments beneath the basalts, comparable to the Tulipan–oilfield off Norway. Details need to be studied for syntheses. Long transient model runs need reliable bathymetry, e.g. beyond Sclater–curves.

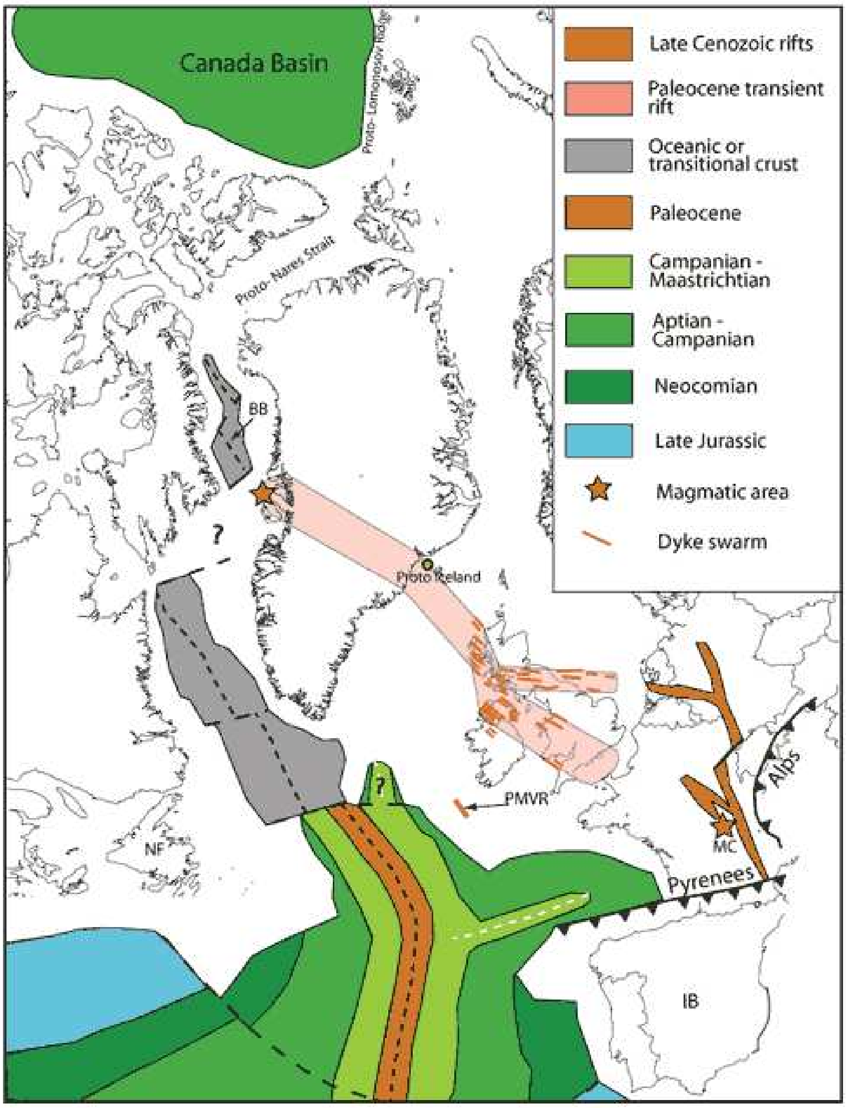

Fig. 8 (figure and text from Lundin and Dore, 2004). Plate reconstruction to 60 Ma (Trond Torsvik, pers. com. 2003) with simplified seafloor. The main dike trend in the British Volcanic Province schematically shown to extend to the West Greenland magmatic area, is invoked to utilize a zone of weak extension. The Late Cenozoic European rift system (from Ziegler, 1992) is included in order to illustrate a more evolved stage extension, also related to compression in the Pyrenees and the Alps. NF: Newfoundland, BB: Baffin Bay, IB: Iberia