WP2: Tectonic, climate and biosphere development from greenhouse to icehouse (Karsten Gohl, Rüdiger Stein)

We reconstruct geodynamically and tectonically induced impacts on climate and biosphere evolution

Objectives and challenges

Reconstructing the role of geodynamically and tectonically induced changes in the configuration of polar and sub-polar ocean basins, gateways and magmatism is of fundamental importance to

understand Earth's Mesozoic and Cenozoic climate evolution from an ice-free greenhouse into a bipolar glaciated icehouse world. These processes led to amplified climate sensitivity and variability and set new boundary conditions for changes in oceanic circulation and heat transport, atmospheric CO_2 levels, Arctic/Antarctic ice-sheet development, and biological evolution. However, the link between key tectonic developments and climate change is poorly constrained because only little is known about the evolutionary history and processes of major magmatic and tectonic events (e.g. opening of polar gateways). Moreover, palaeoenvironmental records covering such long-term time-scales are limited. WP2 depends on geophysical data, reliably dated sediment records and palaeoclimate modelling in order to trace and understand the causal sequences from geodynamic and tectonic processes to ocean-atmosphere reorganisations and their consequences for bio-evolutionary patterns. Accordingly, the major challenges of this work package are:

- to reconstruct temporal changes in the geometry of polar and sub-polar ocean basins, gateways and sub-ice geology in order to constrain the impacts of tectonic processes on changes in ocean circulation, heat transfer, nutrient distribution, polar ice volume, erosion, and climate and to assess gateway-induced impacts on climate with numerical models that simulate palaeoclimate processes at regional and global scales
- to examine the formation history of polar and sub-polar ridge segments or oceanic plateaus (submarine volcanism) and palaeo-hydrothermal vent complexes (methane outgassing) and their potential in modifying atmospheric greenhouse gas concentrations (warm climate extremes)
- testing the influence of gateway dynamics on major evolutionary events in marine biota by studying their modern genetic and adaptive information which will enhance our understanding of life-history characteristics and population dynamics of species

Implementation

The combined expertise of geophysicists, geologists, paleoceanographers, modellers and biologists within WP2 offers an excellent opportunity to meet the challenge of reconstructing tectonic-induced impacts on ocean circulation, biosphere and climate. Geophysical investigations aim to reconstruct temporal changes in the geometry and bathymetry of polar ocean basins and gateways as well as in sediment drift deposits associated with the evolution of oceanic current systems. We will undertake high-resolution seismic, deep crustal seismic and seismological observations as well as potential field surveys at relevant sites around the Antarctic and Arctic continental margins, their conjugate sides and in the ocean basins, e.g. using a new digital seismic streamer system, the broadband ocean-bottom seismometer pool, moving seismographic networks and an aerogeophysical surveying facility.

Information from marine paleo-records will be used to reconstruct the oceanographic response to the closing and opening of gateways. These investigations strongly depend on the availability of appropriate long sediment records from the Integrated Ocean Drilling Program (IODP), upcoming IODP Legs (e.g. Bering Sea, 2008), submitted IODP proposals that are under consideration (No. 625 South Pacific; No. 645, 652, 708 Arctic Ocean; all led by AWI), and on seismic surveys to define proper drilling locations in order to support already submitted proposals but also to submit successful proposals in the future (together with T3-WP1). The identification of drilling locations will also consider the likely operation of the ice-breaking research vessel *Aurora Borealis*.

Our studies will focus on relevant time intervals from the Cenozoic. The Neogene time interval includes the opening and closure of northern hemisphere ocean gateways, the first extent of large-scale glaciation of Antarctica and Greenland and provides the best framework of available sediment records to investigate tectonic-climate linkages. The stratigraphic framework for temporal correlations between sediment records will be achieved by radiometric dating, paleomagnetics, biostratigraphic datums and orbital tuning of cyclic variations in sediment composition available from IODP records. Such records will be used to calibrate the seismic stratigraphy. The reconstruction of climate conditions will be based on a variety of well-established and new sediment proxies (linked to T3-WP3) as well as on reconstructed paleo-

seabed geometries, which allow for qualitative and quantitative estimations of changes in physical and chemical ocean conditions. Seismic data and sediment cores will be collected along the Greenland and Antarctic continental margins in order to decipher the dynamics and variations of ice-sheet expansion since early glacial advances across the margins (linked to T1-WP1). Deep penetration seismic reflection/refraction profiling and potential field surveys will significantly enhance our understanding about Late Cretaceous to Oligocene changes in the configuration of polar ocean basins (Arctic) and gateways (e.g. the Drake Passage). In the Arctic Ocean, these surveys are essential for the detection and the recovery of a complete Palaeogene sequence, as available records suffer from a large hiatus at 44-18 Ma. The combination of information from palaeobathymetry, palaeoclimate, ice-sheet records and model simulations is essential to evaluate gateway-related effects on overturning circulation, oceanic nutrient distribution, ocean-atmosphere dynamics, ice-sheet evolution, sea ice extent and global/regional climate. Models have to be adapted to perform past climate simulations with different geometry and biogeophysical feedbacks (linked to T4-WP2).
By focusing on magmatic provinces in East Greenland and in the Southern Ocean, we will further investigate the crust and upper mantle with the aim to quantify the amount of emplaced magmatic material. Igneous rock composition and mass distribution will be targeted by geophysical surveys and drilling proposals. Their contribution to the global carbon budget and their relationship to the Mesozoic calcareous mass and black shale deposits will be studied.

Furthermore, WP2 will examine biogeographic distribution and evolutionary patterns of marine organisms in response to major perturbations in paleogeography and climate. Major tools include population genetics and phylogenies, including comparative genomics bio-informatic tools which allow identifying features of genomes and individual genes linked to those caused by greenhouse-icehouse transitions. As far as possible, this will be linked with available fossil records.

Milestones

- Completion of IODP proposal 625 (AWI) entitled “Cenozoic Southern Ocean Pacific CESOP” to generate the baseline for the first recovery of high resolution Neogene and Paleocene records from the polar South Pacific (year 2)
- Development of a marine, stratigraphic, orbitally-tuned reference section for the late Miocene (5-12 Ma) by integrating magnetostratigraphy, biostratigraphy and benthic stable isotope stratigraphy (year 2).
- Improvement of the International Bathymetric Chart of the Southern Ocean by developing an interdisciplinary Geographic Information System
- Improved assessments about gateway-induced impacts on global climate evolution by combining results from modelling and proxy data

Deliverables

- Acquisition and analysis of geophysical data and development of enhanced geodynamic and plate-kinematic models to assess the lithospheric processes driving the geometric evolution of polar basins, margins, gateways and Antarctica’s interior
- Development of paleobathymetric grids which will be implemented into palaeoclimate model simulations, e.g. for various temporal states of gateway configurations
- Deciphering the evolution of high-latitude sediment drifts and contourites for reconstructing the paths and intensities of past deep water currents
- Generation and/or completion of paleo-records based on existing and upcoming high latitude IODP sediment cores to identify tectonic-induced thresholds in the climate system.
- Assessment of the importance of polar ocean gateways and major Cenozoic climate reorganizations for biological evolution including the distribution and genetic structure of today’s fauna