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Session CGC-05 Fennoscandian uplift and global sea level changes

Programme and abstracts

Willy Fjeldskaar, Lawrence Cathles, Nils-Axel Mörner, Arto Miettinen (IGCP 495)

Oral presentations

An adjustment of glacio-isostatic rebound of the peripheral areas of the last Scandinavian glaciation
Szymon Uscinowicz (invited)

Caspian rapid sea level changing reconstructing by use bioindicator at the holocen epoch
Homayoun Khoshravan

Contemporary problems of geomorphology and paleogeography of the northern and southern seas
Gennady G. Matishov

Early Holocene sea-level rise and sedimentary architecture of the Rhine mouth (Rotterdam area, Netherlands)
Kim Cohen, Marc P. Hijma, Esther Stouthamer, Ad J.F. Van der Spek, Sytze Van Heteren

Evidence of Holocene near-shore sea-level similarity in Australasia: What does this mean for the predicted sea-level rise in the future?
Robert Baker

Holocene relative sea level changes in the Loviisa area, southern coast of Finland
Arto Miettinen

Large-scale development of the mid-Norwegian shelf during the last 3 million years with implications for corresponding land denudation and uplift
Dag Ottesen, Leif Rise, Julian Dowdeswell (invited)

Long-term sea level fluctuations driven by ocean basin dynamics
Dietmar Muller, Maria Sdrolias, Carmen Gaina, Bernhard Steinberger, Christian Heine

Post-glacial eustatic changes leading to present-day hydro-isostatic subsidence of the ocean floor
Willy Fjeldskaar, Aleksey Amantov

Sea Level Changes in the far-field and in the near-field
Nils-Axel Mörner

Sea-level fluctuations imply that the younger dryas ice-sheet expansion in western norway commenced during the Allerød
Øystein S. Lohne, Stein Bondevik, Jan Mangerud, John Inge Svendsen

Sea-level record in a N-S transect, from Western Mediterranean to Eastern Atlantic Margin in last 2 Myr

Cari Zazo, Jose Luis Goy, Teresa Bardaji, Cristino J. Dabrio, Claude Hillaire-Marcel, Angel González-Delgado, Jorge Civis, Ana Cabero, Javier Lario, Pablo G. Silva, Vicente Soler, Pierre Y. Gillot

Secular variations of the mean sea level in northern and southern hemispheres of the Earth
Jose M. Ferrandiz, David Garcia, Yuri V. Barkin

The Fennoscandian Uplift? the interplay of various processes
Willy Fjeldskaar, Aleksey Amantov

The Fennoscandian Uplift: Introduction and overview
Nils-Axel Mörner

Very low term (250 Myr) quanification of the eustasy during Mesozoic - Cenozoic time based on coastal onlap measurement at the tethys and world-scale
Cécile Robin, François Guillocheau, Bruno Vrielynck

Posters

Geoinformational metallogenic model of the East Europe - Barents sea megaprovince
Grigoriy Gusev, Victor Kilipko, Arkadiy Golovin, Nikolaiy Mezhelovskiy

Numerical reconstruction of palaeotidal elevations since the last glacial maximum
Shaun James O'Callaghan, Sarah Bradley, Richard Hardy, Glenn Milne, Ian Shennan

Paraná Pleistocene barrier, Southern Brazil
José Carlos Branco, Rodolfo José Angulo, Maria Cristina de Souza, Rita Scheel-Ybert, Thais Alves Pereira Gonçalves, Sibelle Trevisan Disaró, Daniel Vicente Pupo

Reconstruction of sea/lake-level changes in an active strike-slip basin (Gulf of Cariaco, NE Venezuela)
Maarten Van Daele, Franck Audemard, Christian Beck, Marc De Batist, Aurélien van Welden, Jasper Moernaut, Shipboard Party 2006 GUAIQUERI II

The Holocene evolution of the tropical island of Inhaca, Mozambique
Mussa Achimo, Bjørg Stabell, Sylvi Haldorsen, Jõao Muabe, Fatima Momade

An adjustment of glacio-isostatic rebound of the peripheral areas of the last Scandinavian glaciation

Szymon Uscinowicz, *Polish Geological Institute (Poland)*

The last Scandinavian ice-sheet advance started c. 22 000 y. ago, reached the maximum extent in Central European Lowland c. 20 000 y. ago. The glacier covered mainly the East European Precambrian platform. Only minor, western part of the glacier, advanced the West-European Palaeozoic platform. The ice sheet weight induces gravitational disturbances in the astenosphere and results in crustal subsidence. As the ice cover has decayed, the uplifting movement picks up. The subsidence relaxed at the earliest in the marginal part of the ice-sheet covered area, while the disequilibrium affects the central part of the ice sheet-covered area for a long time to come. Authors of a number of studies assumed that areas of southern Baltic and northern Poland were not subjected to glacio-isostatic uplift. Only the Fjeldskaar's (1994) geophysical model demonstrates the area of northern Poland and southern Baltic to have been subjected to uplift during and following deglaciation.

The aim of this paper is to reconstruct the glacio-isostatic rebound of the northern Poland and southern Baltic area basing on comparison of the relative sea level curve of the southern Baltic (Uscinowicz 2003) with eustatic curves of the ocean level (Fairbanks 1989, Blanchon & Show 1995, Morner 1976). Because of available data about level changes of Baltic Sea only since c. 13.0 ka BP, the total history of glacio-isostatic rebound of the area could be reconstructed only by extrapolation of calculated part of the curve basing on general knowledge about glacio-isostatic movements (e.g. Peltier et al. 1978) and about deglaciation of northern Poland and Southern Baltic (eg. Uscinowicz 1999). The basic assumption is that restrained rebound started c. 17.5 ka BP during the deglaciation of northern Poland. Transition from restrained rebound to essential uplift took place c. 14.0 ka BP, at the beginning of the southern Baltic deglaciation. Approximated uplift during the phase of restrained rebound was c. 20 m and rate of uplift increased up to c. 15 mm/y at 14.0 ka BP that time. The basic uplift took place between 14.0 and 11.0 ka BP. At that time the area was uplifted 85 m with max. rate of 45 mm/y at 12.4-12.2 ka BP, just after ice-sheet retreat from the Southern Middle Bank. At 11.0 ka BP rate of uplift decreased to 16 mm/y. The residual uplift ended 9.4-9.2 ka BP. Fast termination of the residual uplift was related to hydro- and sedimento-isostasy. Total uplift between 17.5-17.0 and 9.4-9.2 ka BP reached c. 120 m.

Caspian rapid sea level changing reconstructing by use bioindicator at the Holocene epoch

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At now in the earth science activities, bio indicators are the most important tools for paleogeographic and paleoceanology researches and natural phenomena reconstructing. Quaternary Bivalve and Gastropod species of the Caspian Sea could help us perfectly to reconstruct past water way between the Caspian Sea and other basin of parathetis (Black Sea, Aral and east part of Mediterranean Sea) (khoshravan H. 1995). In fact in this region they are very important and useful bio indicator from paleogeographic and biostratigraphy point of view (Khoshravan H. 1999). In this paper we are trying to reconstruct Quaternary corridor between The Caspian Sea and other basins of parathetis along the Quaternary period with use Gastropod indicator. Therefore Gastropod species have been evaluated considering biostratigraphy and paleogeography condition along the Quaternary period with use of 254 Quaternary sediment core samples from exploring petroleum wells (M-1, G3-A) in the Southern coasts of the Caspian Sea(Fotoohi. M. 1965, Stoklin J 1957). After fossil Species determination (Moore R.C., 1969) our investigation results show that Gastropods were originated from three resources in the Caspian Sea basin at the Quaternary period. Some of them were native and from upper Miocene till now live in this basin without changing and evolution (Theodouxsus Sp). Many of them belong the around basin and they are immigrant species (Truncatela Sp, Baicalia Sp) and other have related to fresh water basin like rivers and marginal lagoon (planorbis Sp). Biostratigraphy and sedimentary facies records show that there are many periodic sea levels raising that could connect the Caspian Sea to other around basin like Aral Sea and Black Sea. Data results also are showing that in the studied area there were many periodic rapid sea levels changing during the Holocene epoch. The Caspian Sea has several fluctuations along 10,000 years ago and its latest begin about 25 years ago. Finally we can conclude that Caspian Sea could connect to other around basins at future similar past time and climatologic impact and tectonic movement are important agents for this natural phenomenon in this region.

Contemporary problems of geomorphology and paleogeography of the northern and southern seas

Gennady G. Matishov, *Southern Scientific Centre of the Russian Academy of Sciences (SSC RAS) (Russian Federation)*

MMBI KSC RAS and SSC RAS conduct integrated geological-paleogeomorphological researches in the southern and northern seas of Russia. Expedition activities are carried out on the shelves of the Barents, Norwegian, Kara, White, Caspian, Azov Seas and focused on studying the bottom topography, geomorphology, lithology, biostratigraphy of the Holocene sediments, seismic stratigraphy of quarternary sediments of glacial and periglacial shelves, and inner-continental shelves with arid climate.

The ancient ice covers reconstruction is the basic issue of the Pleistocene paleogeography. Of heated discussion is the Barents-Kara shelf glaciation. Complex, but rather orderly, glacial morphosculpture of the Barents Sea shelf, apparently, was formed in the process of active spread of the peripheral parts of the Scandinavian, Novaya Zemlya, and Spitsbergen glacial covers from the continent to the shelf. This is proved by detailed bathymetry maps, bottom relief regularities, lithology of underwater moraines. The newest radiocarbon dating of the Franz Josef Land, Novaya Zemlya, and Kola Peninsula ancient coastlines turned out to be especially convicting.

The influence of earth glaciation on the ocean outside the shelf boundaries got a name of oceanic periglacial. In 1980 the term "oceanic periglacial" was formulated and developed into a scientific theory. But only now a whole gamut of these processes linked in space and time is perceived as different manifestations of a genetically unified process of ancient and contemporary glaciation's appearance and disintegration.

The largest scale periglacial zones appeared in quarternary glacial epochs on land and in the ocean outside the continental glaciations. Novo-euxian regression became typical of the Azov-Black Sea basin shelf in Late Pleistocene. The Azov Sea water area dried out; the main territory of the bottom was taken by the lake-alluvial plain crossed by the valleys of the Azov Sea area steppe rivers. The tributaries entered the Paleo-Don, which in the Scandinavian Glacial Shield deglaciation period was a valley of snowmelt waters' runoff.

Analysis of the Azov Sea paleogeography is on the basis of bottom seismic profiling data, correlation of data with lithological composition of more than 40 ground columns from the Taganrog Bay. An assumption is made that there was the Paleo-Don riverbed in the epoch of Late Quarternary regression. In the present moment, almost everywhere, the bay is recovered by a net of almost horizontally lying stratified sediments with a capacity ranging from 0.5 to 2.5 m. Denudation section (surface A) should be linked to Phanagorian regression phase. The contemporary axis hollow-like depression stretches for 150 km from the Don front delta to the Panov underwater plain in the Azov Sea open part. It gets deeper in the hollow in the southwestern direction (the bottom depth changes from 5 to 10 m). One of the lowest sedimentation levels on the Azov Sea shelf is linked to the bottom depth.

Early Holocene sea-level rise and sedimentary architecture of the Rhine mouth (Rotterdam area, Netherlands)

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The Early Holocene landscape of Rotterdam was a wide Rhine river plain flanked by slightly higher terrain of last glacial age. It is now buried below 15-20 m of Holocene sediment. 12000 years ago sea-level stood over 50 m lower than today and the shoreline was at distance downstream. By 9000 years ago, the area started to experience post-glacial transgression and coastal prism aggradation set on. By 6000 years ago, sea level had risen to within 5 m of the present level, and great volumes of early-middle Holocene Rhine sediment had been accommodated below it. The landscape had evolved from a low land alluvial valley into a barrier-lagoon system, with several river outlets that functioned as estuaries. Upstream in the back-barrier lagoon the Rhine-Meuse delta developed coevally.

Especially for the episode of rapid sea-level rise and rapid drowning (9500 - 6000 years ago) interlinked reconstruction of developments at the Rhine mouth is a challenge. We collected archived data from various sources, obtained new material from cores and underground railway construction pits. >100,000 corings/cone penetration tests, detailed offshore seismics, >200 relevant ^{14}C and OSL datings, and numerous pollen/diatom counts were made available (efforts of Utrecht University; TNO B&O Netherlands Geological Survey; BOOR Rotterdam City/Harbour; others).

The material so far allowed to:
(1) Reconstruct early Holocene ground water level rise during valley, initial transgression and lagoonal stages by dating laterally-extensive basal peats that overly Early Holocene floodplains and flanks of inland dunes. This extends the window of sea-level rise reconstructions in the Rotterdam area back in time by ~1000 years to ~9000 cal BP at ~22 m-MSL.
(2) Reconstruct the sedimentary architecture of the Early-Middle Holocene base of the Holocene coastal prism in detail. This includes avulsive backstepping and termination of fluvial sand bodies into the rapidly drowning area, the nature of tidal inlet channels and associated floodbasins during eustatic transgression, and initial coastal barrier formation when eustatic high stand was approximated ~6000 years ago.
We present the interlinked coastal and fluvial development of the lower Rhine-Meuse delta, based on the accumulated data set and our mapping approach.

Evidence of Holocene near-shore sea-level similarity in Australasia: What does this mean for the predicted sea-level rise in the future?

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The reconstruction of mid- to late-Holocene marine environments using the calcareous remains of fixed inter-tidal biological indicators (FIBIs) as sea-level proxies, allows a comprehensive reconstruction of near-shore conditions over the past 6000 years. It also provides a comparison between past and present environmental conditions on a site-by-site basis, as well as making possible a comparison between regions. The proxy for the temperate coastlines of Australia is the tubeworm Galeolaria caespitose, while for the tropical Australia and SE Asia, it is the oyster Saccostrea cucullata. The time-elevation similarity in the formations in Australia and Southeast Asia strongly suggest global rather than regional or local forcing functions to account for their distributions. This paper presents further evidence from new FIBI sites from South Australia using G. caespitosa and S. cucullata and a new tubeworm proxy (Pomatoleios crosslandi) in north Queensland This is highly relevant to the validity of the hydro-isostatic rebound models and the application of the eustacy model in the debate of sea-level change during the Holocene. There is circumstantial evidence that Holocene climatic events in Greenland have a greater impact than Antarctica in Holocene sea-level behaviour in the southern hemisphere within a sea surface temperature range of ~ 2°C to present. This has implications for modelling projected sea-level rise from current global warming.

Holocene relative sea level changes in the Loviisa area, southern coast of Finland

Arto Miettinen, *Norwegian Polar Institute (Norway)*

The reasons for relative sea level (RSL) changes in the Baltic Sea basin are the glacio-isostatic land uplift and the eustatic movement of the ocean level. The drop in RSL has been the dominant feature of the Holocene shoreline displacement in most of the Baltic basin, except for relatively short periods of transgressions during the Ancylus Lake and Litorina Sea stages.

The Holocene relative sea level changes were investigated in Loviisa area, where the present apparent land uplift rate varies from 2 to 2.5 mm/yr. The investigated 13 isolation basins are located between 1.1 and 29.7 m above present sea level. The methods employed were lithostratigraphic interpretation, diatom analyses and radiocarbon dating (26 conventional and 2 AMS).

The uppermost basin (Lake Pitkajarvi) became isolated from freshwater Baltic Sea basin c. 9000 cal. yr BP, and after that is has been remained as an independent small lake basin. Lake Ryttarjarvi (26.5 m a.s.l.) was also became isolated from freshwater Baltic Sea basin c. 8800 cal. yr BP, but the marine (Litorina) transgression crossed the threshold altitude of the basin c. 8300 cal. yr BP. The reason for this transgression was the global sea level rise, which exceeded the rate of uplift in the study area. However, land uplift rate and sea level rise were almost in balance in this area, as results indicate the amplitude of around one metre for the transgression. The sea level curve for the Loviisa area both indicates a relatively regular uplift and an overall relative sea level lowering during the last 6000 years.

Large-scale development of the mid-Norwegian shelf during the last 3 million years with implications for corresponding land denudation and uplift

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The Norwegian shelf is one of the best investigated glaciated margins in the world. This is due to the large potential for hydrocarbon exploitation in the area. Through several large joint industrial projects we have had access to an extensive seismic database on the mid-Norwegian shelf (c. 100,000 profile kilometres of 2D-seismic lines and 20,000 km2 of 3D-seismic). Based on these data, we have mapped the Naust Formation, comprising mainly glacigenic sediments deposited on the Mid-Norwegian shelf during the last 3 million years. During this period, large quantities of glacially derived material were transported westwards from the Norwegian mainland and inner shelf, and deposited mainly as prograding sediment wedges into a basin of intermediate depth offshore of mid-Norway. During the Late Pliocene and Pleistocene, the shelf edge migrated up to 150 km westwards, and sediments more than 1000 m thick were deposited over an extensive area. Throughout this period, the middle/outer shelf areas have subsided due to the added load and compaction, whereas the inner shelf and corresponding land areas have been uplifted. About 100,000 km3 of sediments were deposited in the area of the present mid-Norwegian margin between 63°N and 68°N (160,000 km2) during the last 3 million years. This volume is equivalent to an average erosion of c. 450 m of the corresponding denudation area (c. 160,000 km2) which covers the inner shelf and the land areas of Norway eastwards to the main watershed. The redistribution of these sediments has led to an isostatic land uplift in the order of a few hundred metres.

Long-term sea level fluctuations driven by ocean basin dynamics

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Bernhard Steinberger, *Geological Survey of Norway (Norway)*
Christian Heine, *School of Geosciences (Australia)*

Enormous sea level variations have occurred in "hothouse" climates in the geological past, when neither humans nor inland ice caps existed, raising the question what drove these changes. However, there is enormous disagreement on how much sea level has actually varied. Miller et al's (Science, 2005) preferred sea level curve is derived from the sedimentary record of the US New Jersey margin and results in a low (~40 m) amplitude of sea level change since the Late Cretaceous sea level highstand (80 Ma). In contrast many other methodologies suggest sea level change of the order of 200-250 m since the Cretaceous. We show how one can unravel all major factors contributing to sea level change over geological time. These include the creation and destruction of mid-ocean ridges, seafloor spreading rate fluctuations, the formation and subduction of large igneous provinces, and marine sedimentation. We reconstruct paleo-oceans by creating "synthetic plates", the locations and geometry of which is established on the basis of preserved ocean crust (magnetic lineations and fracture zones), geological data, paleogeography, and the rules of plate tectonics.

Based on this approach we have created a set of global oceanic paleo-isochrons and paleo-oceanic age grids. The grids provide the first complete global set of paleo-basement depth maps, including now subducted ocean floor, for the last 140 million years based on a depth-age relationship. After adding effects of oceanic plateaus, sedimentation, and changes in oceanic area, we derive a best estimate for the late-Cretaceous sealevel highstand of 170 m above present sea level. The subsequent long-term drop in sea level was primarily caused by the changing age-area distribution of Pacific ocean floor through time, and to a much lesser extent by the "supercontinent breakup effect", which resulted in the creation of the mid-Atlantic and Indian Ocean ridges at the expense of subducting old ocean floor in the Tethys. We use regional outputs from a global geodynamic model to demonstrate that the New Jersey margin has subsided by at least 100 m over the last 70 million years while global sea level dropped. The gradual sinking of New Jersey was driven by the westward motion of North America over the subducted Farallon plate, now descending in the lower mantle underneath the east coast of North America, drawing the surface down. A corrected New Jersey sea level curve is in reasonable agreement with other sea level estimates, resolving the controversy over seemingly conflicting sea level estimates.

Our results imply that long-term sea level fluctuations have been over two times larger than the 54 m sea level rise that would follow the melting of all present-day ice sheets. This adds a geological dimension to understanding the nature and magnitude of planetary climate change, especially considering that this debate tends to consider change on a human timescale only.

Post-glacial eustatic changes leading to present-day hydro-isostatic subsidence of the ocean floor

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The classical definition of eustasy is vertical movements of sea level, which were originally believed to be worldwide simultaneous uniform changes. However, changes in distribution of the Earth's mass bring about geoid changes, and sea level changes lead to significant subsidence of the ocean floor (hydro-isostasy) and uplift of the continents. Resulting changes of sea level may vary significantly over the globe.

This paper focuses on the hydro-isostatic effect of the eustatic change after the last glaciation; the eustatic change being 120 m over the last 20 000 years. The hydro-isostasy is approximately one third of the sea-level change, while the mean magnitude of the continent uplift is twice the deflection of the ocean floor.

We have modelled the hydro-isostatic effects along the coast of Norway with a model that accounts for the viscous and elastic properties of the Earth. It is shown that the ocean floor and coastal areas are still adjusting significantly after the eustatic deglaciation. Hydro-isostasy is thus a factor that has to be accounted for in predicting future sea level changes.

11

Sea Level Changes in the far-field and in the near-field

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The word "eustasy" has, by tradition, been used to denote changes in the oceanic level as opposed to changes in the crustal level. Originally, it was assumed that changes in the ocean level were identical all over the globe. Hence, eustasy was defined as "simultaneous changes in global sea level". Later, it was understood that changes in the ocean level are not simultaneous and similar over the globe, but differential and sometimes even opposed.

Therefore, Mörner proposed a redefinition of the term "eustasy" to denote "changes in ocean level (regardless of causation)". It has been proposed that global sea level can be both reconstructed and predicted by means of a geophysical global loading model. The basic assumption of these models is that the loading and deloading by the waxing and vanning ice caps of the Ice Ages generate a global isostatic adjustment of coasts and sea-floors all around globe. This is only possible, however, if the Earth has a linear viscosity profile in the mantle. The reality and efficiency of the model can be easily tested in (1) the near-field, and (2) in the far-field with respect to the ice caps.

If actual observational data are used, the test fails in the near-field (at least in Fennoscandia) and in the far field (the Indian Ocean and the Pacific). In Fennoscandia and surrounding areas, all available facts seem to indicate the existence of a low-viscosity asthenospheric channel, where the loading and de-loading were fully compensated by regional horizontal flow. Besides, the input data used in the models do not concur with available field evidence. This led me to conclude: "As long as the global modelling does not consider these facts, they are bound to be unrealistic". The loading models predict high Mid-Holocene sea levels in the Pacific and Indian Ocean. This does not concur with observational facts, either in the Indian Ocean or in the Pacific. The new sea level curve of the Maldives, exhibits a long term base-curve not above present sea level and a number of rapid oscillations driven by dynamic forces.

In the Pacific, observed short and rapid fluctuations in sea level do not concur with the loading model but represent high-frequency dynamic sea surface changes. Grossman et al. (1998) reconstructed the spatial distribution of Mid to Late Holocene sea level changes in the Pacific. Their reconstruction does not concur with the prediction from the loading models, but with geoid deformation and/or changes in sea surface topography. In conclusion, global eustasy seems to be driven by five main factors controlling water volume, basin volume, geoid topography, sea surface topography and rotational distribution of water. In the last 5000 years, the redistribution of oceanic water masses has been the dominant factor. No signs of any significant on-going rise in sea level are found; on the contrary, the flooding-scenario of IPCC is strongly contradicted by available observational facts.

Sea-level fluctuations imply that the younger dryas ice-sheet expansion in western norway commenced during the Allerød

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After the first emergence following deglaciation, relative sea level rose by 10m in western Norway and culminated late in the Younger Dryas (YD). The relative sea-level history, reconstructed by dating deposits in isolation basins, shows a sea-level low-stand between 13 640 and 13 080 cal yr BP, a 10m sea-level rise between 13 080 and 11 790 cal yr BP and a sea-level high-stand between. 11 790 and 11 550 cal yr BP. Shortly after the YD/Holocene boundary, sea level fell abruptly by 37 m. The shorelines formed during the sea-level low-stand in the mid-Allerød and during the sea-level high-stand in the YD have almost parallel tilts with a gradient of 1.3m km^{-1}, indicating that hardly any isostatic movement has taken place during this period of sea-level rise. We conclude that the transgression was caused by the major re-advance of the Scandinavian Ice Sheet that took place in western Norway during the Lateglacial. The extra ice load halted the isostatic uplift and elevated the geoid due to the increased gravitational attraction on the sea. Our results show that the crust responded to the increased load well before the YD (starting c.12 900 cal yr BP), with a sea-level low-stand at 13 640 cal yr BP and the subsequent YD transgression starting at 13 080 cal yr BP. Thus, we conclude that the so-called YD ice-sheet advance in western Norway started during the Allerød, possibly more than 600 years before the Allerød/YD transition.

Sea-level record in a N-S transect, from Western Mediterranean to Eastern Atlantic Margin in last 2 Myr

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Several marine terrace flights were selected in a roughly N-S transect, covering different geodynamic and climatic settings from Western Mediterranean (Balearic Is. - Peninsular coasts, Spain) to Cape Verde Archipelago. Climate ranges from Mediterranean to subtropical and tropical. Geodynamic framework includes collisional plate boundary (Mediterranean sections) and volcanic Islands (Canary and Cape Verde sections), tidal range also varies from tideless to mesotidal coasts. The comparative study of all sequences was based on a detailed geomorphological mapping of marine, transitional and terrestrial deposits as well as facies analyses, petrology and palaeontology. Chronological determinations include U-Th (alpha, TIMS), ^{14}C, K-Ar, AAR and palaeomagnetic measurements. Present elevation of marine terraces refer to mean high tide (datum=0) and altitude is given for the inner marine edge, so if we consider the paleo sea-level position at 2m asl in stable areas for the peak of MIS 5.5, and an altitude similar than present for other Pleistocene interglacials, the studied sequences developed in areas submitted to low uplifting trend (0.03 to 0.05 mm/yr).
Marine terrace heights range from 65m asl to 0m. Number of outcropping terraces is similar in the studied sequences of Cape Verde, Canary Islands and Almería (~15 levels) showing a similar morphostratigraphic pattern. The following groups of sequences can be established: First, Early Pleistocene with a first part characterized by superposed marine deposits and fan deltas, both recording superimposed marine cycles, changing to a staircased-like arrangement during the last part of this period; Second, Middle Pleistocene sequences can also be subdivided into two subgroups separated by a major palaeocliff. In some cases, as in Balearic Islands (Mediterranean) warm "Senegalese" fauna starts to appear in the most recent terrace of the older subgroup that may also be wider than older and younger terraces. The age of this wide terrace (~13-8m asl), difficult to state, correlates with a highstand of MIS9 or most probably MIS11, according to field and geochronological data. Third, last part of Pleistocene usually includes marine terrace from MIS5.5, outcropping at heights not exceeding 2-3m. So considering the altitudinal difference between inner edges of both terraces, the palaeo sea-level record for MIS 9 or most probably for MIS 11, never exceeded +7-9m on these coasts. Summarizing, Early Pleistocene marine terraces record small amplitude sea level oscillations that increase in the last part of the cycle, with more evident staircases during the Middle and Late Pleistocene, reflecting major amplitude of sea-level changes. A prominent sea level highstand occurred during the Middle Pleistocene, suggesting a palaeosea-level at 7-9m asl possibly during MIS 9, or more probably MIS 11. *Supported by Spanish Proj. CGL/05-01336, CGL/05-04655, CGL/06-05473; IGCP-495; INQUA Comm. Coastal-Marine Proc.; GEOTOP Lab. (Can)*

Secular variations of the mean sea level in northern and southern hemispheres of the Earth

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Our analysis of satellite altimetry data in the period 1993-2007 reveals differences between the velocities of secular variations of the mean sea level in northern and southern hemispheres of the Earth (Garcia, 2007). Those differences are about 1.2 - 1.5 mm / yr. In this report we try to ascertain the mechanisms of that fact and discuss their dynamic interrelation as well as possible interpretation of the observational data.The slow (secular) drift of the centre of mass of the Earth in the direction of North Pole with velocity about 5-6 mm/yr, predicted in 1995 (Barkin, 1995), now may have been confirmed with methods of space geodesy (Gajazov, 2004; Tatevian et. al, 2003; Barkin et. al., 2007). It is possible to explain this fundamental planetary phenomenon under the assumption that a similar northward drift of the the centre of mass of the liquid core, relatively to the centre of mass of the elastic mantle, is taking place with a velocity around 2-4 cm/yr (Barkin, 1995). The polar drift of the Earth core represents a huge movement of mass, which result is an increase of gravity in the northern hemisphere with a mean velocity of 1.5 mGal/yr, and conversely, a decrease of gravity of the same order in the southern hemisphere (Barkin, Ferrandiz, 2008).

This conclusion-prediction hypothesis seems to be confirmed by some precise gravimetric observations in last decade. Naturally, drift of the core is accompanied by the global changes (deformations) of all layers of the mantle and the core, by inversion changes of their tension states, that is, when the tension increases in one hemisphere, it decreases in the other one. On the other hand, the displacement of the mass core, which is 22 times the mass of the Moon, produces gravitational changes that can cause a planetary inversion tide of air masses of the Earth from the south hemisphere to the north one (Barkin, 2000). By our estimations the atmospheric masses can give the basic contribution to the expected secular redistribution of masses between hemispheres. So the mean atmospheric pressure in the northern hemisphere accrues with velocity about 0.20 mbar/yr (Barkin, 2007). The predicted phenomenon of a slow redistribution of air masses from the southern hemisphere in northern (Barkin, 2007) has already obtained confirmation according to meteorological observations (Burluzkii, 2007). So changes of mean atmospheric pressure in northern and southern hemispheres are estimated by velocities 0.17-0.22 mbar/yr and -0.18 mbar/yr. However, this conclusion concerns to rather short interval of time of observations since April 2002 till April 2005.

The Fennoscandian Uplift - the interplay of various processes

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Fennoscandia has experienced major uplift in postglacial time, which is assumed to reflect a glacial isostatic process connected to the melting of the last ice sheets. Extensive modelling of the *Glacial Isostasy* show that the applied deglaciation and uplift model fit the observations well, when the asthenosphere has a thickness less than 150 km and viscosity less than 7.0×10^{19} Pa s beneath the lithosphere. The mantle viscosity below the asthenosphere has been set to 10^{21} Pa s, and the effective elastic thickness of the lithosphere is increasing from 20 km along the coast of Norway to 50 km in the Gulf of Finland.

However, there are other processes responsible for the Fennoscandian uplift, besides the Glacial Isostasy. In this paper we will illustrate the relative importance of the following factors in the observed post-glacial uplift:

Geoid changes. We will show that theoretical late- and post-glacial eustatic changes varies even within the Fennoscandian area because of significant changes in gravity associated with deglaciation and crustal uplift.

Hydro Isostasy. Eustatic changes lead to significant subsidence of the ocean floor and uplift of the continents. The hydro-isostasy is approximately one third of the sea-level change. The mean magnitude of the continent uplift is twice the deflection of the ocean floor.

Elasticity. When a force is applied to the Earth's surface, there is an immediate elastic deformation, proportional to the stress. The elastic deflection is a function of the wavelength of the load and of the elastic properties of the crust. It is a significant factor in the post-glacial uplift.

Erosion. There has been significant amount of erosion during the last glaciation, up to 90 m of sediments seems to be removed in zones of most active erosion during the last glaciation.

Accumulation. The eroded sediments have accumulated in peripheral areas. Tills, fluvioglacial and other relevant deposits should be accounted for in the isostatic calculations of the peripheral accumulation belt.

The Fennoscandian Uplift: Introduction and overview

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One of the most outstanding contributions from Scandinavia to international geology and geophysics is undoubtedly the record of glacial isostatic uplift (as reviewed in GeoJournal, 3: 287-318, 1979). Early observations of tilted shorelines gave evidence of a differential uplift. In 1888, De Geer published his true benchmark paper presenting the dome-like uplift and its close correlation with the centre of the last glaciation maximum; the glacial isostatic theory was established, and from that time on, it has been a classical concept in geology and geophysics. The observational database improved through the years. A second benchmark paper was the varve-dated shorelevel displacement curve of Lidén (1938) from the centre of uplift. The picture has, in the last 40 years, been improved and sharpened thanks to repeated levelling and C14-dating.

This remarkable "postglacial uplift experiment" in nature, became a standard tool for modelling and calculation of rheological parameters of the Earth. If there is a linear viscosity profile with depth, the loading forces have to be adjusted on a global basis. If, on the other hand, there exists a low-viscosity channel in the astenosphere, the loading would be compensated on a regional basis. All observational records of the Fennoscandian uplift seem to indicate the existence of such a low viscosity channel flow. Central uplift commenced at about 12,700 C14-years BP.

This implies that, in most areas, a significant part of the uplift occurred when ice still covered the area and, hence, no sea level records are available. Still, we can, from the shoreline gradients, calculate the amount of uplift even for this period. In the centre, the maximum uplift amounted to ~830 m and in the Stockholm area to ~450 m. The uplift is often expressed as a simple, single process. Multiple facts of different character indicate, however, that we, in fact, are dealing with two different forces and process: one typical glacial isostatic process dying out with time and distance from the periphery, and one linear process, commencing about 8000 C14-years BP, that has remain constant with time with a fixed axis of tilting (isostatic zero-line) in the outer Great Belt region.

The evidence for this "double-nature" will be highlighted. The isostatic and eustatic components, interacting in the uplift as recorded by the relative changes in sea level, can be separated. This provides a detailed record of the regional eustatic changes, including that of the last centuries. Finally, we have recently come to understand that the peak rates of glacial isostatic uplift is causally linked to a very high seismicity (both in magnitude and frequency). The uplift and paleoseismicity will be highlighted during Excursion No. 11; all from the centre of uplift to the periphery.

Very low term (250 Myr) quanification of the eustasy during Mesozoic - Cenozoic time based on coastal onlap measurement at the tethys and world-scale

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Eustasy is a reference level of primary importance in the Earth Sciences. That control part of the stratigraphic record, the area of continental surfaces exposed to erosional processes, and the base level of the fluvial systems. Several long term sealevel curves for the past 250 My were published. The most popular one is the one proposed by Haq et al.(1987). Most agree that sea level rise occurred from the Permian to the Upper Cretaceous, and was followed by a sea level fall that continues today. Controversy persists, however on the amplitude of this variations, on the kinematics of the sea level fall or rise and about the required mechanism, which must be related to the plate movements, associated with the Wilson Cycle.

Our first objective is to question and to quantify the sea level variations for long (250 My) term time durations. We will focus on the Cretaceous, which displayed the highest sea level during the last 250 My.

The first part of our study will be based on the measurement of the marine flooding of continents through time. This method requires new style world-scale paleogeographic maps, quantified in term of paleotopography, to measure both the coastal onlap and the hypsometry of the Earth at each time-interval. The main challenge is the quantification of the topography of the Earth for Mesozoic times. Our technique is based on a global-scale measurement of the marine flooding of continents on Earth paleogeographic maps. Sea level is inferred, for a given time interval, from the intersection of this world-scale flooding with the distribution of the world elevation, or hypsometry. The continental flooding is the percentage of the continental domain flooded by the sea. This percentage is defined from a specific geographic reference level that can be the shelf break or the present-day shoreline. The hypsometric curve is the cumulative curve of areas of land between pairs of contour lines as a percentage of the total land area.

We used a new paleogeographical dataset for the Meso-Cenozoic: one at a world-scale (Vrielynck & Bouysse, 2001), and one at a Tethys-scale (Dercourt et al., 2000). These first results are based on the present-day continental hypsometry. But does the present-day altitude distribution apply for the past? Present-day continents are mainly subjected to erosion, and few subsiding domains occur. The present-day continental topography is different from the past one, mainly Upper Jurassic - Lower Cretaceous time, where large intracontinental basins with low relief, occurred. The present-day altitude distribution, which could be the best analogue of this period, is the Amazon watershed.
Using this last one and the world-scale paleogeographic map, the highest sea level occurs during Upper Cretaceous time and the amplitude would be +100 m above present-day sea level. Using Tethys-scale paleogeographic maps, the highest relative sea level occurs during Cenomanian time and the amplitude would be +250 m above present-day sea level.

Geoinformational metallogenic model of the East Europe - Barents sea megaprovince

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East Europe - Barents Sea platform megaprovince belongs to a mineragenic unit of global level. It has Archean, Paleo-Proterozoic (Karelskiy), MesoProterozoic (Grenvilskiy) and Neoproterozoic (Baikalskiy) basement overlapped by Meso-Neo-Proterozoic (Riphean - Vendian) and Phanerozoic sedimentary cover. In the territory of Russia the megaprovince encompasses mineragenic areas of Baltic and Voronezh crystalline rock mass. Within the areas Riphean basement is exposed on the day surface or is overlapped with thin platform cover (from 1-10 to 200-500 m).

The geoinformational model of the territory comprises its geological characteristics; ore characteristics as ore areas, deposits and ore manifestations; prognostic-mineragenic characteristics of mineragenic areas (basins) with ore-formation features of each of the stages of the geological history; the structure of basement relief and of the sedimentary cover of basins of East European and Pechora - Barents Sea plates; paleo metallogenic reconstructions of the Riphean ? Phanerozoic.

Geoinformational models of individual metallogenic areas were developed and constructed and assessments were made of their prospects for raw minerals. Geoinformational model of metallogenic area with account for its general scientific and applied targets shows material composition, geometry (thickness, area) and age characteristics of mountain and rock structures, geodynamic settings of their formation; geodynamic settings and content of structural, metamorphic, metasomatic and hypergenic transformations; structural settings of their location, geodynamic settings, age, composition and resources of useful components of ore formations, paragenetic relations with mountain-rock bodies and transformations. Thus geoinformational model of a mineragenic area has "block" structure and summarizes data on geological history, geodynamic and structure-matter conditions of formation and mineral resources.
The construction of geoinformation model is based on databases, formalized information, usage of single terminology and concept base. It has certain advantages. First, it is a system continuously updated and changed owing to new geological, geophysical and geochemical data. Second, the model has "enclosed" structure in a single scale, which allows us to add to in both smaller and greater scale and thus to solve different problems with the use of the model. Third, besides horizontal plane we can observe and analyze the deep structure using vertical sections of geological and ore formations.

Numerical reconstruction of palaeotidal elevations since the last glacial maximum

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Existing models of palaeotides predict changes in tidal ranges since the time of the Last Glacial Maximum (LGM) of more than 50% compared to present. These changes result from: i) fluctuations in sea level; ii) the changing location of the coast, and; iii) sedimentation influx and other local processes. Accurate reconstruction of palaeotides requires correct quantification of these terms. Since most geological indicators of past sea level record a palaeo-tide level rather than paleo-mean sea level accurate reconstructions of palaeotidal amplitudes are an essential factor within the larger context of Quaternary environmental change.

Previous studies vary in i) the number of tidal constituents used; ii) the geological time scales for which reconstructions are made, and; iii) the extent to which a correct quantification of sediment infill exists for inner coastal areas. The number of tidal constituents needed to accurately explain tidal behaviour increases in shallow water areas where bottom friction and localised sedimentary processes dominate. Existing studies include the application of a uniform depth reduction technique, which neglects the spatial and temporal effects of isostatic rebound processes on a continental shelf scale. They apply either one (M_2) or six (M_2, S_2, μ_2, M_4, M_6 and MS_4) tidal constituents which limits the accuracy of palaeotidal amplitude predictions especially in shallow water areas such as the southern North Sea and adjacent estuaries. Secondly, limited availability of sea level index points restricts some previous studies to the Holocene. Finally, previous studies, limited to only a few estuaries, underline the importance of sediment based processes by demonstrating that isostatic rebound processes alone are insufficient to explain differences in tidal ranges within estuaries as these changes are also a function of sediment infill.

This paper applies an existing tidal model of the present day to produce numerical reconstructions of palaeotidal elevations in 1,000 year intervals from the LGM to present using twenty six tidal constituents. Subtracting independently derived relative sea level reconstructions from present day bathymetry for each 1,000 year interval provides the model palaeobathymetry. Using this bathymetry as the primary boundary condition produces palaeotidal amplitude reconstructions from the LGM to present for a range of scenarios of vertical Earth movements due to the loading of ice and water through time. Our results provide new reconstructions of palaeobathymetry and coastline position over the past 20,000 years and confirm bathymetry as an important process driver for palaeotidal amplitudes at the continental shelf scale. At present we are coupling the existing palaeotidal model with a river basin model to predict sediment flux at the estuarine scale and asses its importance in paleotidal amplitudes at inner coastal, shallow water areas.

Paraná Pleistocene barrier, Southern Brazil

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Only two main barrier systems can be recognized along the coast of Paraná. The first one was formed during the Late Pleistocene and the other during the Holocene. Besides presenting a facies description, this work proposes an evolutionary model for the Paraná Pleistocene barrier. The facies descriptions were performed at sand exploitation quarries near Paranaguá town, where it was possible to see and describe outcrops 100m wide and 15m high. At the bottom quarries 6m vibracores were taken. In the studied area the Pleistocene barrier is composed by fine to medium sand, with granule and gravel, poorly selected and subrounded shape. These sedimentary characteristics differ from Holocene barrier which is composed mainly by fine to medium sand. These differences could be related to the higher contribution of immature continental sediments at the Pleistocene barrier, which is closer to the Serra do Mar mountains. The identified facies in Pleistocene barrier were: sand with swaley cross stratification (Ssc), tabular cross stratification (Sp), trough cross stratification (St), sigmoidal cross stratification (Ssg), flaser lamination (Sf), mud with linsen (Fl) and massive mud (Fm). Tubes, borrows, shell moulds, trunks and root fragments, and vegetal debris were also identified in some facies. The Ssc facies is composed by fine to coarse sand, poorly selected with subrounded grains. Shell moulds and symmetrical ripples were also identified. Sp and SSg facies are composed by fine to medium sand with very fine to medium pebbles and mud drapes. St and Sf facies are composed by fine to medium sand. Preferential paleocurrent directions measured on the large cross stratification sets are to NW. Below the sandy facies barrier there are Fl and Fm facies, highly bioturbated, with transported trunks and root fragments and vegetal debris. A 14C datation performed on a wood sample resulted in 41,200 + 3,400/-2,350 years B.P. Therefore the Paranaguá barrier could be attributed to the 5e stages. The facies association and paleocurrent directions suggest that the barrier, at the studied sector, develops as a spit that grows northwestward over an estuarine inlet. The preliminary analysis of recent vibrocore sediments database indicated the presence of the foraminifer Blysmasphaera brasiliensis, pollens and spores. On trunks and root fragments' samples were identified genders and species that suggest the occurrence of subtropical forest and mangrove, Ilex sp (Aquifoliaceae), Inga sp (Leguminosae Mimosoideae), Calyptranthes sp (Myrtaceae) and Laguncularia racemosa (Combretaceae). The evolutionary model for the barrier estimates the existence of an estuary located behind the Pleistocene protobarrier, where a forest and mangrove areas around the estuary existed. The draining system of the mounts surround would propitiate the formation of fandeltas.

Reconstruction of sea/lake-level changes in an active strike-slip basin (Gulf of Cariaco, NE Venezuela)

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In January 2006, 76 high-resolution reflection seismic profiles were acquired in the Gulf of Cariaco, Northeast Venezuela. In the upper 100 m of sedimentary infill, 17 unconformity-bounded sequences were identified and mapped throughout the basin. Up to now, no core or borehole information is available to provide age constraints on these units. The sedimentary infill is cut by several faults, Riedel faults in the central part and the El Pilar fault (one of the main faults of the South American-Caribbean plate boundary) in the southern part of the gulf.

The connection of the Gulf of Cariaco with the adjacent Cariaco Basin occurs at a present-day water depth of ~ 55 m. This implies that the gulf was disconnected from the world ocean and functioned as a lake during a large part of the last glacial. The main rivers entering the gulf drain the coastal mountain ranges and tend to form pronounced deltas at their inlet. During times when the gulf was a lake, periods with a dry climate resulted in dramatic lake-level lowstands and even complete desiccation/evaporation. The present-day depths of delta offlap breaks and the presence of lowstand/evaporite deposits can thus be used to estimate sea/lake level at the time of their formation. Detailed analysis of these stratigraphic sea/lake-level indicators allowed reconstructing the sea/lake-level history for the period encompassed by the 17 identified sequences. This sea/lake-level reconstruction also needed to be corrected for tectonic subsidence, affecting different parts of the gulf with different intensity.

The reconstructed sea/lake-level curve of the Gulf of Cariaco was compared with the eustatic sea-level curve and with results of previous paleoclimate studies in Venezuela. The striking coherence between the eustatic curve and the amplitudes and absolute heights of successive reconstructed lowstands and highstands compelled us to tune our record to the eustatic curve in order to achieve a rough age estimate for our units. According to this age model, our seismic stratigraphy reaches back to MIS6, and the average sedimentation rate in the central parts of the gulf since MIS5e is 0.92 mm/y. Our data show that reconstructed lake levels in the Gulf of Cariaco, which represent a proxy for climate in NE-Venezuela, are very strongly coupled to the global stadials and interstadials of the last glacial period. Also the Younger Dryas is recognised in the sedimentary record of the Gulf of Cariaco as lowstand deposit resulting from an (almost) complete desiccation.

Our data reveal that the stratigraphy of the Gulf of Cariaco holds a very accurate, complete and promising record of eustasy and climate change, at least since the penultimate glacial maximum. The quality of this record and the vicinity to the iconic Cariaco Basin make the Gulf of Cariaco an ideal target for future ocean drilling (or long coring).

The Holocene evolution of the tropical island of Inhaca, Mozambique

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A series of small sandy islands are found along the coast of Mozambique, with the Inhaca Island being the southernmost of these. The Inhaca island consists of Pleistocene to Holocene dune sand. Two tall NNW-SSE - trending dune cordons form the east and west coasts. The eastern and tallest barrier dunes reach up to 130 m a.s.l and this cordon extends southwards into South Africa. The central part of the island consists of much lower dunes (up to 40 m), separated by intra-dune depressions , which form a series of small lakes and wetlands in the central part of the island.

The lakes are groundwater-fed, and have today no surface water inlet or outlet. Nine sediment cores of length 4-6 m from one of these lakes have been studied. While the two tall dune systems along the east and west coasts are old landscape elements, which have not changed much during the Holocene, the central part of the island has been exposed to major ecological shifts during the last 7000 years. Cores from the wetlands confirm that the Holocene sea-level highstand probably formed a bay from the north deep into the island, with a maximum extension around 5000 yrs B.P. The total marine phase lasted for 4000 years, ending around 2500 yrs B.P.

The marine phase accords well with the earlier recognised Holocene transgression of along the coast of South Africa of +3-5 m. More than 100 diatom species have been identified in the upper part of the sediment cores in Inhaca. This is to our knowledge the first detailed study of fossil diatoms in marine and estuarine Holocene records along the southeast coast of Africa. The study is in this respect a pioneer work, which may form a good background for later studies of coastal sediments in this region.