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HOLOCENE CLIMATE VARIABILITY AND ECOSYSTEM CHANGES IN THE COASTAL «HOLANT»

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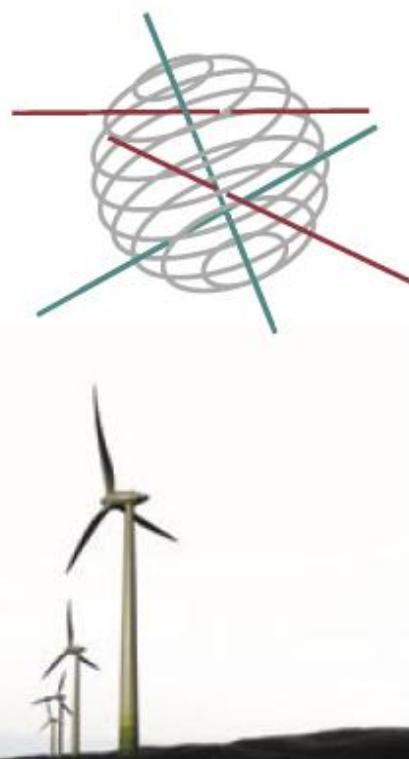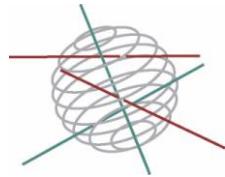
Antarctica - Climate

FINAL REPORT

HOLOCENE CLIMATE VARIABILITY AND ECOSYSTEM CHANGES IN COASTAL EAST AND MARITIME ANTARCTICA "HOLANT"

SD/CA/01

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SUMMARY

The Earth's climate undergoes significant changes, which are not yet fully understood. Recent climate models revealed that the Southern Hemisphere and Antarctica in particular could have been of significant influence in past abrupt and large climate change events. Although the Holocene has not experienced climate changes of the same magnitude as during the major Quaternary glaciations, it has been marked by many, often rapid, global temperature and precipitation anomalies. In order to understand how Antarctic temperature variation can impact other regions on Earth and to test competing models concerning the causes, the spatial interrelationships and characteristics of these climate anomalies, it is necessary to learn from the record of past natural climate variability. The IGBP has recognised this need by starting a global coordination of paleoclimate studies along 3 North-South transects (i.e., the PAGES-project PEP 1, 2 and 3 traverses) in order to build a strong high-resolution network of paleoclimate studies. The goal of the PEPs is to reconstruct paleoenvironments and paleoclimate along three terrestrial transects using a multi-proxy data and modeling approach. However, these transects currently end at Southern latitudes of 52°S, and are not yet fully interlinked with the ice cores from the Antarctic plateau.

HOLANT explicitly extended the PEP 1 transect towards Sub- and coastal Maritime Antarctica and contribute to the PEP2 and 3 transects by establishing and comparing a series of high-resolution records of Holocene climate variability in coastal Antarctica based on biological and sedimentological proxies in (coastal) lake sediments. Since 2006, PAGES science has been redefined; within this new science structure, HOLANT will contribute to all 4 PAGES scientific foci (www.pages.unibe.ch) through three specific research questions: (i) What are the timing, duration and magnitude of Holocene climate anomalies in coastal areas in maritime, east and Sub-Antarctic regions and how are these anomalies related to climatic events recorded in inland locations (ice cores) ? (ii) How did Holocene climate changes affect regional ice sheet/glacier dynamics ? and (iii) How did Holocene climate changes affect the diversity of primary producers in Antarctic lakes ?

The **main findings** of HOLANT can be summarized as follows:

(1) Past Climate variability in South Georgia

The sediment record from Fan Lake (Annenkov Island, South Georgia) extends back to c. 8 ka, which postdates a period of marked early Holocene warmth identified in Antarctic ice cores, and marine and lacustrine sediment records.

High-ultra high resolution (mm-sub mm) variability in both gamma density and major element geochemistry (measured using ITRAX-XRF down to 200 microns) suggest the lake system possibly responds to annual/multi-annual and/or decadal/multi-decadal variations in climate in this part of the South Atlantic in the last 4 ka. In combination with newly retrieved sediment cores (field season 2008-2009) within the BAS CACHE-PEP program, this will allow us to reconstruct past climate variability on a high temporal resolution in a region which lacks such data.

(2) Long-term Westerly dynamics during the Holocene on Kerguelen Archipelago

Within the four seismic-stratigraphic units identified in the sedimentary infill of Lac d'Armor (Kerguelen Archipelago), the upper unit is characterised by the presence of distinct mounded depocentres, which closely resemble drift deposits and thus suggest the influence of strong bottom currents. Given the specific setting, such bottom currents are likely wind-driven. We interpret the occurrence of these drift deposits as an indication of a strengthening of the influence of the westerlies during this period. Future long cores may provide confirmation of this hypothesis and may allow dating this important environmental change on Kerguelen Archipelago.

(3) Paleoprecipitation and paleoclimate in Kerguelen during the Late Holocene

Up to present, very little paleoclimatic, and even less paleohydrological, records exist of the Holocene in the oceanic realm of the southern hemisphere. In the Kerguelen Archipelago, the sedimentary records from Lac d'Armor are characterized by a main transition toward lower detrital input –and hence very likely to lower precipitation– since 1400 AD. Despite a weaker chronological control compared to ice core records, our Si_{bio} signal presents a significant correlation with the Naxs signal from Siple Dome. This implies that to some extent, high-frequency variability of the westerlies impacted the climate on Kerguelen Archipelago through an anti-correlation between strength of the westerlies and precipitation over the last millennium. It remains unclear if the high terrigenous input in Lac Armor represents the local expression of the Little Ice Age (LIA) in the Kerguelen Archipelago, or if a local LIA expression is actually out of phase with the northern hemisphere.

(4) Transfer functions for paleoclimate reconstructions

Transfer functions were developed to quantitatively reconstruct past changes in the nutrient concentration of Maritime Antarctic lakes. Together with the fossil pigment concentration, this will allow us to infer temperature dependent changes in lake primary productivity. The transfer function for the Lützow Holm Bay region extends an existing model and will allow us to reconstruct temperature dependent changes in salinity in a wide sector of East Antarctica between 10 and 110°E. Both models have good to excellent predictive power and the error statistics are sufficiently low.

We anticipate that our models will become critical research tools in future and other ongoing paleolimnological research programs, such as in the Belgian DELAQUA project and the AAD research proposal ICEMATE, in which HOLANT members are involved.

(5) Holocene climate variability in the Antarctic Peninsula

The PEP 1 transect was extended with well-dated sediment cores from both the eastern and western margin of the Antarctic Peninsula (AP). In summary, in both regions marine sedimentation at the start of the Holocene provides a minimum age for deglaciation. Between c. 3.5 and 1.7 cal. ka BP, a wetter and milder climate in Beak Island likely resulted in higher organic sedimentation rates and a well developed planktonic community, which we link to the Mid Holocene Hypsithermal (MHH) previously recorded elsewhere in the north and northeastern Antarctic Peninsula. This MHH is not evident in the Marguerite Bay region, where primary productivity gradually declined after the isolation of the lake basin. A neoglacial cooling is evident in Beak Island from c. 1.7 cal ka BP, which is interrupted by an increase in primary productivity and a shift in diatom diversity and species composition. Similar trends in lake primary productivity and more pronounced changes in the diatom record are present in the Marguerite Bay region and likely related to the recent temperature rise recorded in several regions of the Antarctic Peninsula.

(6) Changes in the autotrophic communities in Maritime Antarctic lakes in response to climate variability

The use of fossil DNA in combination with HPLC analysis and microscopy allowed us to assess the effect of past and recent climate variability on the autotrophic communities in Maritime Antarctic lakes. The most striking result is the increase in fossil pigment and the shift from a chlorophyte to a cercozoan and bryophyte dominated community during the recent decades. Cyanobacteria also show a similar transition in the core of BK1, with a higher diversity in the deeper samples, including filamentous and unicellular cyanobacteria. Even a moss plastid sequence was retrieved. These changes passed the threshold of natural variability for at least the past 5400 years, with species going extinct and being replaced by newly colonized taxa. The observed changes are most likely the result of regional climate warming and we conclude that the opportunity to study one of the most pristine ecosystems on Earth known to contain a large amount of endemic taxa may have disappeared.

(7) Past climate changes in East Antarctica during the Holocene

In East Antarctica, geological evidence is starting to show us that the deglaciation was asynchronous in the different regions and that nearly all regions studied so far experienced a near-synchronous early Holocene climate optimum, coincident with the continued deglaciation of the Antarctic Peninsula Ice Sheet and an optimum recorded in ice cores from several Antarctic regions. Preliminary results revealed that the deglaciation of parts of the Lützow Holm Bay region commenced later and it remains to be seen whether the Holocene regional climate evolution is comparable with other East Antarctic oases.

(8) Relative sea level curves and past ice sheet dynamics and extent

Relative sea level curves were developed for the Prince Gustav Channel region (Antarctic Peninsula) and for the Lützow Holm Bay region based upon dating of raised beaches and the transition from marine to lacustrine sediments in isolation lakes. These datasets will be used in modeling experiments to assess the thickness and dynamics of the regional ice sheet in collaboration with our international partners.

Dissemination, policy support, outreach and publications

Our results were used in 5 Bachelor and Master courses and the subject of 3 Bachelor projects, 5 MsC projects and 4 PhD projects. In terms of Policy support, the project contributed to all of the three strategic objectives of the "Science for a Sustainable development – research areas Climate and Atmosphere" program. It reduced the scientific unknowns about the role of Antarctica in Holocene climate events through a consolidation and further development of the Belgian expertise in polar and paleoclimate research. Hence, the results of our research contributed directly and significantly to the scientific support which is necessary for the preparation, implementation and follow-up of the supranational and federal policy (e.g. in the framework of the Antarctic Treaty). In addition, because of the close collaboration with international partners throughout the project and participation to symposia, we substantially contributed to the integration of our results into relevant research initiatives on the European and international levels (e.g., the International Polar Year 2007-2008, the BAS CACHE and CACHE-PEP, and the IGBP PAGES PEP programs).

More in particular, HOLANT members contributed to the writing and compilation of reports for the Global Climate Observing System (GCOS), the SCAR reports of the Evolution and Biodiversity in Antarctica (EBA) working group, the SCAR EBA newsletters, the International Geosphere and Biosphere program PAGES, the 2006 report of the World Climate Research Program CliC (Climate and Cryosphere) and the SCAR report Antarctic Climate Change and the Environment (ACCE). HOLANT members also contributed to events related to the Belgian Antarctic Princess Elisabeth Station. More in particular, we have compiled lists of equipment for the station laboratory, participated in discussions about the science plan, and attended several meetings. In addition, a member of HOLANT is a Belgian delegate to the *Life Sciences Scientific Standing Group* of SCAR and as such participated to the business meeting in 2008. She was vice-chair of the 'ad hoc' National IPY Coordination Committee of the Academy of Sciences, and she is associated member of the Belgian National Committee for Antarctic Research of the Academy of Sciences. She has attended several workshops and events within the International Polar year (IPY Discussion Forum in 2004, Opening ceremony in 2007) and was second contact-person of the IPY MERGE programme. At the same time Dominic Hodgson (HOLANT Partner at BAS) has remained active on the Scientific Steering Committee of the SCAR EBA programme, as a leader of EBA Workpackage 1 and as a representative at SCAR cross-linkages workshops.

HOLANT participated in several events and workshops and data were presented in over 35 contributions during symposia and conferences. Up to now the project contributed to 12 peer-reviewed publications and we anticipate that our results will lead to more publications in the near future.

Keywords: Antarctica, Sub-Antarctica, Holocene, past climate change, ice sheet thickness, sea level change, fossil DNA, global change, primary production, salinity, cyanobacteria, green algae, diatoms, seismic surveys

1. INTRODUCTION

1.1. Context

The Earth's climate undergoes significant changes, which are not yet fully understood. Recent climate models revealed that the Southern Hemisphere and Antarctica in particular, could have been of significant influence in past abrupt and large climate changes (Knorr and Lohmann 2003). Although the Holocene has not experienced climate changes of the same magnitude as during the major Quaternary glaciations, it has been marked by many, often rapid, global temperature and precipitation anomalies (Mayewski et al. 2004). Recently, parts of the Antarctic Peninsula (AP) region have experienced some of the most rapid warming events on Earth, whereas a decline in the temperature record was observed in other Antarctic areas (Vaughan et al. 2003, Doran et al. 2002), but see Steig et al. (2009). This temperature rise near the AP has already led to ice shelf disintegration (e.g. Hodgson et al. 2006) and rapid glacier retreat (Cook et al. 2005) and influenced marine and terrestrial ecosystems (Convey and Smith 2006, Walther et al. 2002). This could have severe consequences for further global sea level rise, as the Antarctic holds over 70% of the worlds freshwater. However, the relations between climate changes in coastal Antarctic regions, ice shelf and glacier dynamics, and climate anomalies in inland Antarctic regions are not yet understood. In order to understand how Antarctic temperature variation can impact other regions on Earth and to test competing models concerning the causes, the spatial interrelationships and characteristics of these climate anomalies, it is necessary to learn from the record of past natural climate variability. The IGBP has recognised this need by starting a global coordination of paleoclimate studies along 3 North-South transects (i.e., the PAGES-project PEP 1, 2 and 3 traverses) in order to build a strong high-resolution network of paleoclimate studies. The goal of the PEPs is to reconstruct paleoenvironments and paleoclimate along three terrestrial transects using a multi-proxy data and modeling approach. The PEP transects – time-stream 1 will ultimately provide the evidence needed to test competing models about the causes of the most important climate changes of the past 10,000 years, and constraints for models predicting the future. However, these transects currently end at Southern latitudes of 52°S, and are not yet fully interlinked with the ice cores from the Antarctic plateau.

1.2. Objectives and research questions

HOLANT explicitly extends the PEP 1 transect towards Sub- and coastal Maritime Antarctica and contribute to the PEP2 and 3 transects by establishing and comparing a series of high-resolution records of Holocene climate variability in coastal Antarctica based

on biological and sedimentological proxies in (coastal) lake sediments. Since 2006, PAGES science has been redefined; within this new science structure, HOLANT will contribute to all 4 PAGES scientific foci (www.pages.unibe.ch) through three specific research questions:

<u>1. What are the timing, duration and magnitude of Holocene climate anomalies in coastal areas in maritime, east and Sub-Antarctic regions and how are these anomalies related to climatic events recorded in inland locations (ice cores)?</u>

Different Holocene climate optima have been observed in Antarctic paleoclimatic records (Hodgson et al. in press, Verleyen et al. in prep.). However, a lot of uncertainty remains about their causes and effects, and about whether they represent single, contemporaneous events in different regions in Antarctica. Our goal is to generate a spatial and temporal high-resolution record of Holocene climate anomalies, in order to minimize these uncertainties.

<u>2. How did Holocene climate changes affect regional ice sheet/glacier dynamics?</u>

We will use lake-sediment cores from isolation lakes to construct relative sea level curves (RSL). Through this we aim at gaining more information about former regional ice thickness, in order to minimize the persisting uncertainties regarding spatial differences in response of Antarctic sheets to climate changes, and in order to constrain the contribution of the Antarctic ice sheet melting to global sea level changes.

<u>3. How did Holocene climate changes affect the diversity of primary producers in Antarctic lakes?</u>

Monitoring and paleolimnological studies in different parts of the Antarctic revealed that lake water depth, salinity, and nutrient levels already changed drastically during the past decades in response to recent temperature anomalies (Hodgson et al. 2006, Quayle et al. 2002). Little is known however about the response of microbial components of the basal food web to climate changes in the past. We will investigate the effect of Holocene climate changes on primary producers in coastal Antarctic lakes, by the combination of traditional paleolimnological techniques, and modern techniques for DNA extraction and molecular paleodiversity.

2. METHODOLOGY AND RESULTS

2.1. Study regions

HOLANT benefited from previous field campaigns within related projects (BAS SAGES) and contributed and organized sampling campaigns to six ice-free regions in collaboration with the BAS CACHE-PEP, the Japanese REGAL, and the French PEISACG projects. The Sub-Antarctic Islands include the Kerguelen Archipelago and Annenkov Island (Fig.1). In Maritime Antarctica lakes in Beak Island, Trinity Peninsula and Pourquoi-Pas Island were sampled. In east Antarctica lakes in a couple of ice-free islands and peninsulas in the Lützow Holm Bay region (Syowa Oasis) will extend the PEP transects towards coastal East Antarctica.
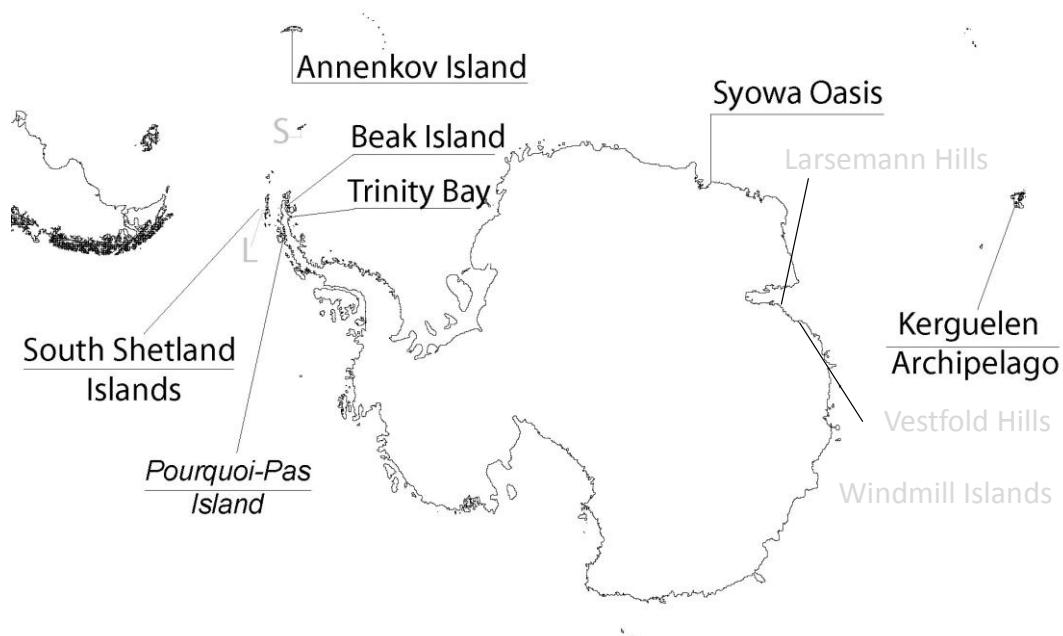

Fig.1: Map showing the locations in Sub-, East and Maritime Antarctica sampled during the HOLANT project (indicated with their name in black and underlined), and during previous projects (black italics). Other sites mentioned in this text are shown in grey (L: Livingston Island, S: Signy Island).

2.2. Field measurements, sampling and laboratory techniques

The methods used during field campaigns included reflection seismic and bathymetric exploration (Kerguelen Archipelago), lake sediment core retrieval, limnological analyses, sampling of biota in the lakes and their catchment areas, sampling of macrofossil remains in raised beaches for ^{14}C dating (Lützow Holm Bay), surveying of sill heights of lakes, and geomorphological mapping. Field reports with detailed information regarding the samples are stored at the British Antarctic Survey and Ghent University and available upon request (Ref. AD6/2R/2002/NT3; R/2005/NT3).

Coring, sampling and seismic survey of Lac d'Armor in the Kerguelen Archipelago

During the field campaign of November-December 2006, which was carried out in cooperation with the Université de Savoie and IPEV, Lac d'Armor (3.5 km long, 0.5 km wide) was selected for a first prospection with high-resolution reflection seismic profiles and short sediment cores. Lac d'Armor turned out to be better suited in terms of wind direction, glacial context and accessibility than the initially targeted lakes in Val Studer. The lake was surveyed with a C-Boom seismic source and a short single-channel streamer. All data were recorded digitally with an Elics Delph-2 system, allowing them to be subsequently converted to SEG-Y format. Navigation was done by GPS. In total, 37 profiles were acquired with a total length of 35.7 km.

The data were subjected to a first quality control on the field, which showed that the seismic signal penetrated the entire sediment infill of the lake, with an excellent dm-scale resolution. Based on the evaluation of the seismic data, 10 locations were selected from which short cores –ranging in length between 33 and 79 cm– were retrieved using a UWITEC gravity corer. The cores were shipped to France onboard of R/V Marion Dufresne.

Post-expedition processing of the seismic data was conducted on the Promax seismic processing system at RCMG, and included a frequency band-pass filter of 500-4000 Hz. Interpretation was performed using the Kingdom Suite 7.5 program. Grids and maps were created with Golden Software Surfer 8, Global Mapper v8.3 and GMT v4.2, using the interpreted horizon picks exported from Kingdom Suite 7.5.

Coring and sampling of lakes and catchment areas in the other regions

Bathymetric measurements were carried out to find the deepest part of the lakes for coring and surface sediment retrieval. This involved aerial photograph inspection and echo-sounding at 1-5 m intervals along a fixed rope attached across the lakes using a hand-held echo-sounder. Following the survey the fixed rope was adjusted to intersect over the deep spot and used as an anchor line for the coring raft.

The coring raft consisted of 2 inflatable boats or a platform in case the UWITEC piston corer was used. Surface sediment cores were collected using a UWITEC short (0.6 m) gravity corer fitted with a ball core catcher. For deeper sediments a Livingstone corer was used in Beak Island, Pourquoi-Pas Island and the Lützow Holm Bay region and a UWITEC piston corer in Fan Lake and the South Shetland Islands. Where multiple cores were taken, two adjacent holes were used and successively deeper cores taken with an overlap of at least 20 cm. Cores were sectioned at 1 cm intervals and stored in small Whirlpack sample bags, or if consolidated they were kept intact. Samples were frozen in the field and stored at -20°C. The sill height of the lakes was surveyed using a Leica Trimble base station GPS run for c. 30 minutes.

A reference data set comprising biota from lake littoral areas together with inflow and outflow streams were collected for all the regions. These will be used to identify catchment inputs into the lake sediments. They will also ensure that we have a reference set of diatoms and other microbiota from the full range of habitats in the lake catchments. Surface sediment samples were taken in the deepest part of the deeper lakes (>0.5m). Vertical measurements of water column temperature, conductivity, salinity, total dissolved solids (TDS), oxygen concentration (% saturation and in mg/L), and pH were carried out using a YSI MDS 600 water quality meter. Water samples were collected and stored frozen until analysis for nutrients and ionic composition. Light profiles of the water column were measured with a Skye Spectrosense meter (all data available in the field reports and the HOLANT database). The biological and environmental data will be used to generate a reference data set defining the relationship between the diatoms and the limnology of the lakes. Field reports are available for all campaigns and archived at the British Antarctic Survey and Ghent University.

During the sampling campaign we have also collected the necessary field data (e.g., elevation measurements of the outflow, and sediment characteristics). Macro samples for ^{14}C dating from raised beaches were collected. The height of the raised beaches were surveyed using a Leica Trimble base station GPS as described above. Different analyses needed to accurately construct relative sea level (RSL) changes using lake sediment cores are being conducted or partly accomplished in our laboratories and in those of our partners (e.g., measurements of magnetic susceptibility, diatom and pigment analyses, dating of marine-lacustrine and/or lacustrine-marine transitions in the sediment cores; see below).

Establishment of sediment chronologies

Cores from Maritime Antarctica, East Antarctica and Sub-Antarctica were dated using ^{14}C AMS measurements. The samples for ^{14}C analysis were selected based on sedimentological measurements and core descriptions and sent to the NERC Radiocarbon Laboratory and Beta Analytic Inc (USA). The dates are reported as uncalibrated ^{14}C measurements after subtraction of 1300 years (Berkman et al. 1998) to correct for the marine reservoir effect in Antarctic samples if needed. In cores from Lac d'Armor (Kerguelen Archipelago) a prominent marker tephra layer was used together with the ^{14}C dates.

Sedimentological and geochemical analyses

Most of the sedimentological analyses of the short cores from Lac d'Armor (Kerguelen Archipelago) were conducted at the Université de Savoie. All cores were photographed, macroscopically described and smear-slides were taken of the main visible sediment units in the core. The sediments were measured for magnetic susceptibility every 5 mm and analysed for grain size every 2 cm. Elemental composition of the cores was analysed using an Avaatech XRF core scanner (at 5 mm intervals). Biogenic silica was measured every cm using a classical method based on NaOH extraction and subsequent Si concentration measurement by a photometric method.

All the cores from Annenkov Island, and Maritime Antarctica were photographed, macroscopically described, and analysed for wet density, dry weight, % weight loss on ignition (LOI, after combustion at 550°C for two hours) and % carbonate composition (% weight loss after combustion at 950°C for two hours) (Dean, 1974). LOI$_{550}$ will serve as a proxy for primary productivity, which was recently shown to vary in response to climate warming in Maritime Antarctic lakes (Quayle et al. 2002). Wet density (g cm^{-3}) and magnetic susceptibility (g^{-1} cm^3) were measured at 1 cm resolution. Wet mass, volume specific magnetic susceptibility was measured using a Bartington 1 ml MS2G sensor. Geochemical analyses for some cores included measurements of carbon and nitrogen concentrations (%) from which C/N is derived, and bulk organic carbon isotopic ratios ($\delta^{13}C_{org}$) by combustion on a Carlo Erba 1500 on-line to a VG Triple Trap and Optima dual-inlet mass spectrometer. $\delta^{13}C_{org}$ values were calculated to the VPDB scale using a within-run laboratory standard calibrated against NBS-19 and NBS-22. TOC and total organic nitrogen (TON) values were determined simultaneously when measuring the isotope ratio. Replicate analyses of sample material gave a precision of ± 0.1% (1 sigma). Similar analyses are being carried out/processed for the cores from the Lützow Holm Bay region and will be an integral part of the final report.

Analysis of biological proxies

Diatom slides were made according to a slightly modified protocol by Renberg et al. (1990). For each diatom calibration dataset the analysis was done following the methodology described in Verleyen et al. (2003). Diatoms allowed us to quantitatively infer past changes in lake primary production (Maritime Antarctica) and the moisture balance (East Antarctica) through lacustrine sediment sequences and reconstruct past sea-ice dynamics in marine sediments from isolation basins (e.g. Verleyen et al. 2004).

Sediment samples for macrofossil analysis were prepared by washing bulk sediment samples (2 cm^3) through a 125 µm sieve using de-ionised water to remove fine inorganic particles. The remaining material was placed in a perspex counting chamber and macrofossils systematically enumerated using a low-powered dissection microscope. Macrofossils included Anostracan eggs (Fairy Shrimp, *Branchinecta gaini*) and moss fragments. All macrofossil data are expressed as an annual flux calculated from the dry mass accumulation rate

Fossil pigments were analyzed using an Agilent 1100 High Performance Liquid Chromatograph (HPLC) series following standard protocols described in detail in Leavitt and Hodgson (2001) and Squier et al. (2002). The HPLC system was calibrated using authentic pigment standards from the US Environmental Protection Agency and compounds isolated from reference cultures following SCOR protocols (Jeffrey et al. 1997). Total chlorophylls and carotenoids were expressed as organic matter-specific concentrations (ng g^{-1}TOC) and the individual pigments as percentages, relative to the total carotenoid and chlorophyll concentration. The taxonomic affinities of the pigments were derived from Jeffrey et al. (1997).

All steps for the analysis of fossil DNA were completed in a laminar flow hood and the extraction involved several steps and procedures to prevent contamination, such as the disinfection of the laminar flow hood and the instruments with sodium hypochlorite solution and RNase Away (MβP, USA). Ultraviolet light was additionally turned on for 20 minutes with all the disposable material inside before each use. We only used new sets filtertips and dedicated pipettes. DNA extractions, pre- and post-PCR steps were carried out in separated rooms, with dedicated material. Moreover, a negative control consisted of water extracted in parallel and used through subsequent analyses. Several protocols were tested and finally, the FastDNA Spin Kit for Soil (QBiogene, USA) was used for fossil DNA extraction.

To analyze the eukaryotes in general, a PCR was performed with the GC1 and GC2 primers (van Hannen et al., 1998).

A nested PCR with the Euk1A (Diez et al., 2001) and CHLO02r (Simon et al., 2000) primers in the first PCR and the Euk1A and Euk516r-GC (Diez et al., 2001) primers in the second PCR was performed to specifically analyze the chlorophytes. Further analysis consisted of Denaturing Gradient Gel Electrophoresis (DGGE). The gel contained a 30-55% denaturing gradient for Eukaryota and 25-45% for Chlorophyta. For the cyanobacteria, PCR for DGGE was performed with specific primers for cyanobacteria, by direct or nested PCR (Boutte et al., 2006). Primers N359F (K. Waleron, personal communication) and 781R(GC)(a) or 781R(GC)(b) (Boutte et al., 2006), specific for filamentous and unicellular cyanobacteria respectively, were used. The direct PCR was possible only when 751R(GC)b was used. The DGGE was run in 6.5% polyacrylamide gels (40-65%) and analysed with the Bionumerics software (Applied Maths, Belgium). Visible bands were sequenced and compared with GenBank/EMBL using the BLAST algorithm (Altschul et al., 1997) and the option Seqmatch on the website RDPII (http://rdp.cme.msu.edu/). OTUs were calculated for cyanobacteria to group the sequences sharing more than 97.5% of 16S rRNA similarity, using a distance matrix made with PHYLIP and the DOTUR software (Schloss & Handelsman, 2005). For the plastids, clusters were delineated only on the basis of the topology of the distance tree, as there are no quantitative criteria based on plastid 16S rRNA for the algal taxonomy.

In order to increase the low concentrations of fossil cyanobacterial DNA present in the samples, we additionally tested the use of Multi Displacement Amplification (MDA), a kind of Whole Genome Amplification (WGA), as an initial step before PCR. A classical MDA is using random primers for the amplification, and we tested the use of HIP1 primers. According to Robinson (1995), octameric palindromes called HIP1 (GCGATCGC) are over-represented in cyanobacterial genomes but rare in other bacteria. A range of variants was tested, as GCGATCGCNA (HIPNA) and GCGATCGCNT (HIPNT), because the addition of two nucleotides at the 3'end had been advised by Smith et al. (1998) to generate reproducible banding patterns to distinguish isolates. However, our results showed that these variants did not seem to anneal sufficiently frequently. We therefore have used the octameric HIP1 primers and compared their specificity with the Repli-g kit (Promega, USA), that is using random primers.

Another strategy was used to favour the recovery of fossil sequences of cyanobacterial origin, rather than from bacterial heterotrophs, namely the use of *rpoC1* gene sequences. The *rpo*C1 gene only appears in cyanobacteria and plastids, but not in eubacteria, so we could expect more specific amplifications with this marker.

Statistical analyses

In all statistical analyses, species data were log $(x+1)$ transformed to reduce the influence of dominant taxa and all environmental variables (except pH) were log $(x+1)$ transformed to reduce or remove skewness. Standard multivariate analyses were performed to explore the distribution of diatom taxa (indirect ordinations), and their relationship to the environmental variables (direct ordinations). All ordinations were performed using CANOCO 4.5 for Windows (ter Braak and Smilauer 2002). For a more complete description of the different techniques used the reader is referred to Sabbe et al. (2004). Diatom-based transfer functions were developed for chlorophyll a and total phosphorous in C2 v. 1.3 (Juggins 2003) using weighted averaging partial least squares (WA-PLS) and simple weighted averaging (WA) algorithms (see Birks 1998). Outliers were detected according to Jones & Juggins (1995). The optimal number of components in the WA-PLS model was determined following the criteria in Verleyen et al. (2003). In order to assess the amount of turnover in diatom communities in the sediment cores a dentrended canonical correspondence analysis was run with core depth as the sole constrained variables. Differences in down-core DCCA sample scores provide an estimate of the amount of compositional change between samples along core depth (Smol et al. 2005).

2.3. RESULTS

The laboratory analyses of the sediment cores and the diatom reference datasets are finalized for Beak Island, Pourquoi-Pas Island and Annenkov Island. The analyses of the cores and surface sediment samples from the Lützow-Holm Bay region (Syowa Oasis) are finalized for diatoms and being processed for fossil pigments and sedimentological parameters. The main results were grouped below according to geographic region, i.e., Sub-Antarctica, Maritime Antarctica and East Antarctica (Fig.1).

2.3.1. Sub-Antarctica

Kerguelen Archipelago (Lac d'Amor)

Seismic stratigraphy

The seismic data from Lac d'Armor reveal a complex bathymetry and structure, with 2 sub-basins: a southern sub-basin of 50 m deep and a northern sub-basin of 98 m deep. They are separated by a shallow sill of 20 m deep, which comprises a small perched, sediment-filled sub-basin as well (Fig.2).

The sedimentary infill comprises a series of sedimentary units with distinctly different acoustic character and distribution. As the signal penetrates the complete sedimentary infill, it is possible to use the succession of infilling units to reconstruct the evolution of

the dominant sedimentary processes in the lake through time since the last glacier retreated from the lake basin. In general, four units, each with a distinct seismic facies, can be discerned in the lake basin infill (Fig.3 and Fig.4).

The bottom facies (unit I) directly overlies the acoustic basement and is a chaotic unit with generally high reflection amplitudes. This unit is generally thicker in the deepest parts of the basin and has an unconformable upper and lower boundary. In the southern sub-basin, two sub-units (Ia and Ib) can be distinguished.
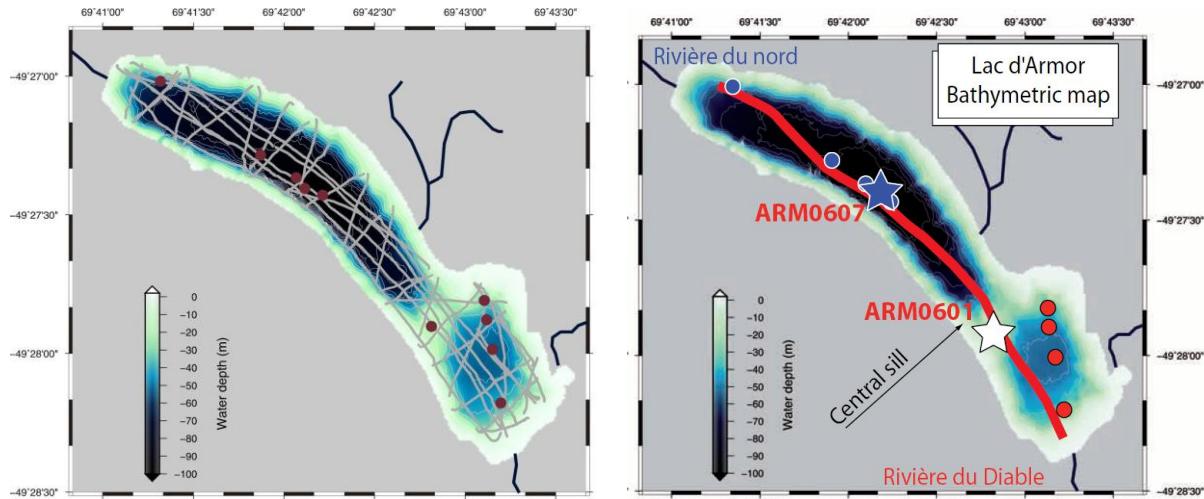
Fig.2: Bathymetry of Lac d'Armor with its two sub-basins and the location of the 37 seismic profiles (left) and 10 short cores (right). Key cores ARM0601 and ARM0607 are highlighted with a star sign.

The overlying unit II is a unit with some (sub)-parallel reflections, which are sometimes discontinuous. The seismic facies contains much lower amplitudes than in unit I or is almost transparent. This unit only occurs in the deepest parts of both sub-basins and smoothes the initial U-shaped morphology of the lake basin.
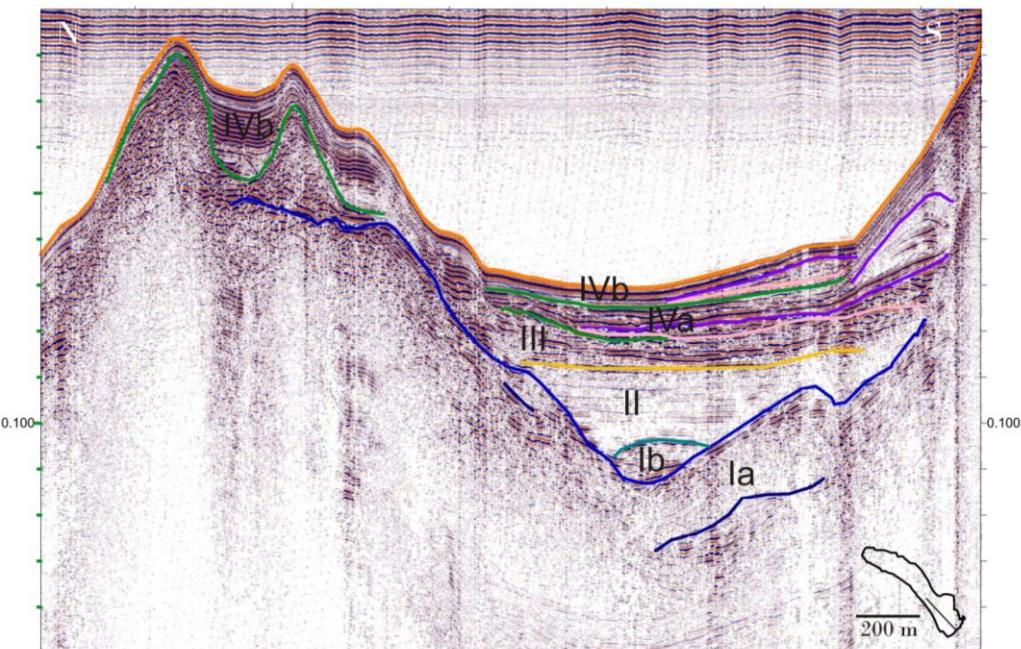
Fig.3: The different units identified in the seismic stratigraphy in the southern basin. On this profile some of the prograding features typical for unit IV are present.

The top units III and IV are no longer focused in the deepest parts of the basin. Both units mostly consist of sub-parallel high-amplitude reflections. The boundary between unit III and IV is marked by the onset of mounded structures located in the southern corner of each sub-basin (Fig. 5). In both units chaotic, almost transparent wedges are present (Fig. 4).

The acoustic stratification of unit IV is often disrupted by prograding features from the southern or northern shore, where the river inlets are located. These features have a more chaotic character, but they also display an internal structure, mostly consisting of downlapping reflections. There is quite a sudden shift in how far these structures reach down into the basin. This shift marks the boundary between two sub-units (IVa and IVb).
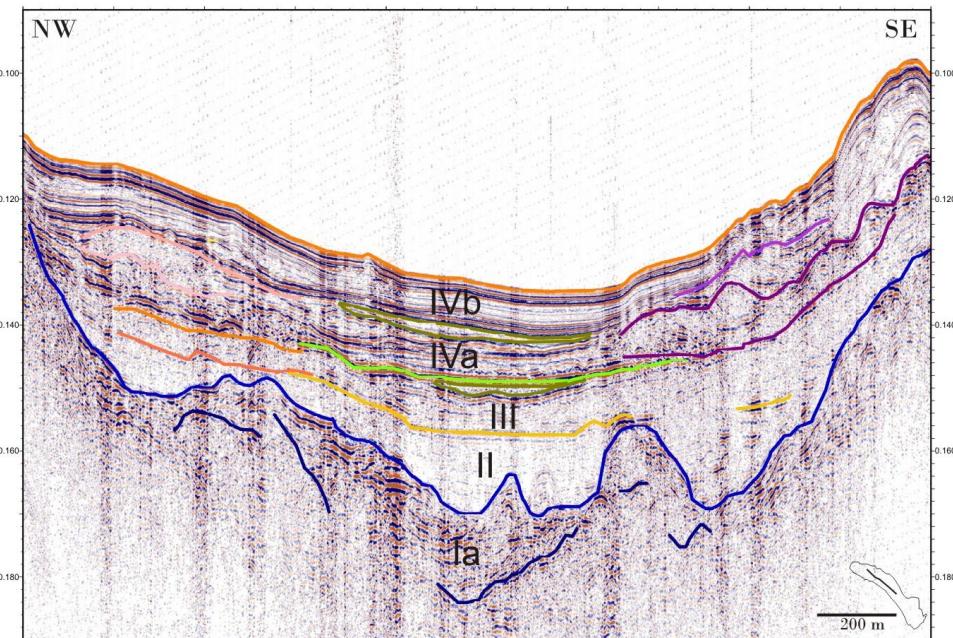
Fig.4: The different units identified in the seismic stratigraphy in the northern basin. On this profile some of the transparent wedges present in Unit III and IV are visible.
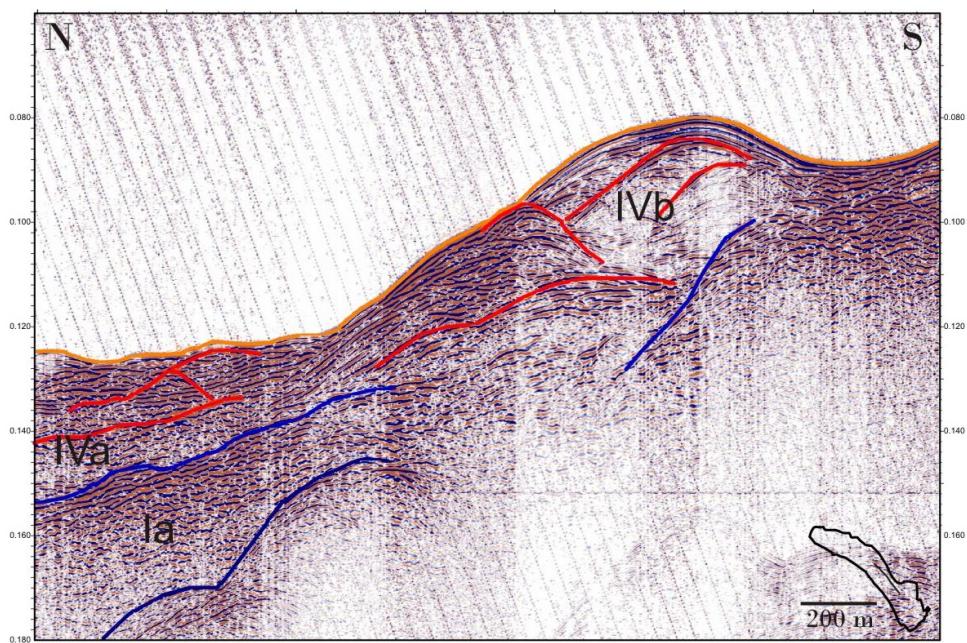
Fig.5: The mounded structure in unit IV in the northern basin.

In the northern sub-basin there are also some chaotic wedges coming down from the sill and the northern shore. They are associated with thin ponded facies in the deepest parts of the northern sub-basin.

In the southern corner of each sub-basin a large mounded structure can be distinguished. The onset of the build-up of these mounded structures marks the boundary between sub-units IIIa and IIIb (Fig.4).

A very small basin is located on top of the sill. This basin has a continuous draping infill, which only contains sub-unit IVb, but this sub-unit is much thicker here than anywhere else in the basin (Fig.3).

In general, these four seismic facies can be associated with the following sedimentary environments. The bottom facies (unit I) is associated with a subglacial and ice-contact environment. The overlying unit II was most likely deposited in a proglacial environment, in which a combination of underflows and turbidity currents caused the sediment to focus in the deepest parts of the basin, hereby smoothing all previously created morphology on the lake floor. During the deposition of unit III the glacier had retreated from the Lac d'Armor basin and sediment-laden meltwater entered the basin. Unit IV is characterized by the presence of mounded sediment accumulations. The river-derived sediments appear to have been concentrated in fan-like depocentres, as opposed to the more evenly distribution across the entire basin floor in Unit III. The mounded depocentres resemble drift deposits and suggest the influence of strong, possibly wind-induced, bottom currents, which are probably indicative for a strengthening of the westerlies during this period. In Lago Cardiel, Argentina (49°S), this event has been dated as 6800 cal a BP (Gilli et al. 2005) and in Lago Potrok Aike (52°S) around 6000 cal a BP (Anselmetti et al. 2009). Towards the top of Unit IV, the fluvial influence decreases. Unit III and IV, are also characterized by the presence of distinct mass-wasting deposits.

Core analysis and interpretation

The seismic and coring data (Arnaud et al. 2009) show that the southern basin is dominated by strong contour currents and is not well suited for sediment-core-based paleo-recontructions. The central shallow basin (on the sill) is highly interesting as it is susceptible to record the atmospheric part of detrital input. The deep northern basin is well suited to record changes in detrital input due to variations in run-off and precipitation, as it is directly fed by Lac Armor's main tributary. Two cores were investigated in more detail: core ARM0601 in the central basin and core ARM0607 in the northern basin (Fig.2).

Lac d'Armor sediments consist of a mixture of terrigenous particles, diatom remains and organic matter (Fig. 6). In core ARM0601, diatoms and organic matter are predominant, whereas the terrigenous fraction dominates in cores taken in the northern basin. This repartition reflects the influence of river-borne sedimentation in the northern basin.
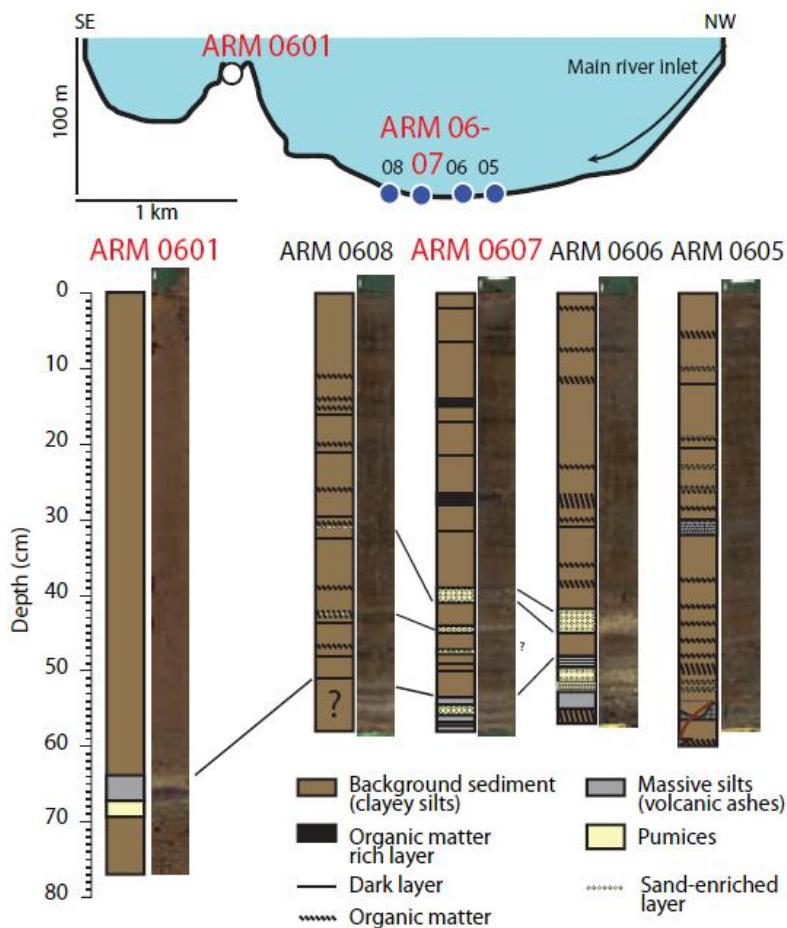
Fig.6: Simplified lithologies of the Lac d'Armor cores.

Within the terrigenous fraction, two sources dominate: i) the erosion product of the local watershed, mainly consisting of basalts, and ii) the sporadic input of acid volcanic ashes. The along-core variation in K/Ca ratio allows distinguishing the basaltic and acidic terrigenous fractions. This shows that the former is by far the dominant fraction, except within the individual levels of volcanic ash, which are easily identifiable by eye. In such a context, the titanium content can be considered as a direct proxy of terrigenous input. This assumption is, however, not valid for the bottom part of the core where significant amounts of volcanic material bias the relation between Ti and the total terrigenous fraction. The terrigenous fraction is here mainly diluted by biogenic silica (Si_{bio}), i.e. diatom remains (4 to 12 weight %). Si_{bio} can be assessed using XRF data through the K/Si ratio, and it appears to be less disturbed by volcanic input than Ti (Fig.7).
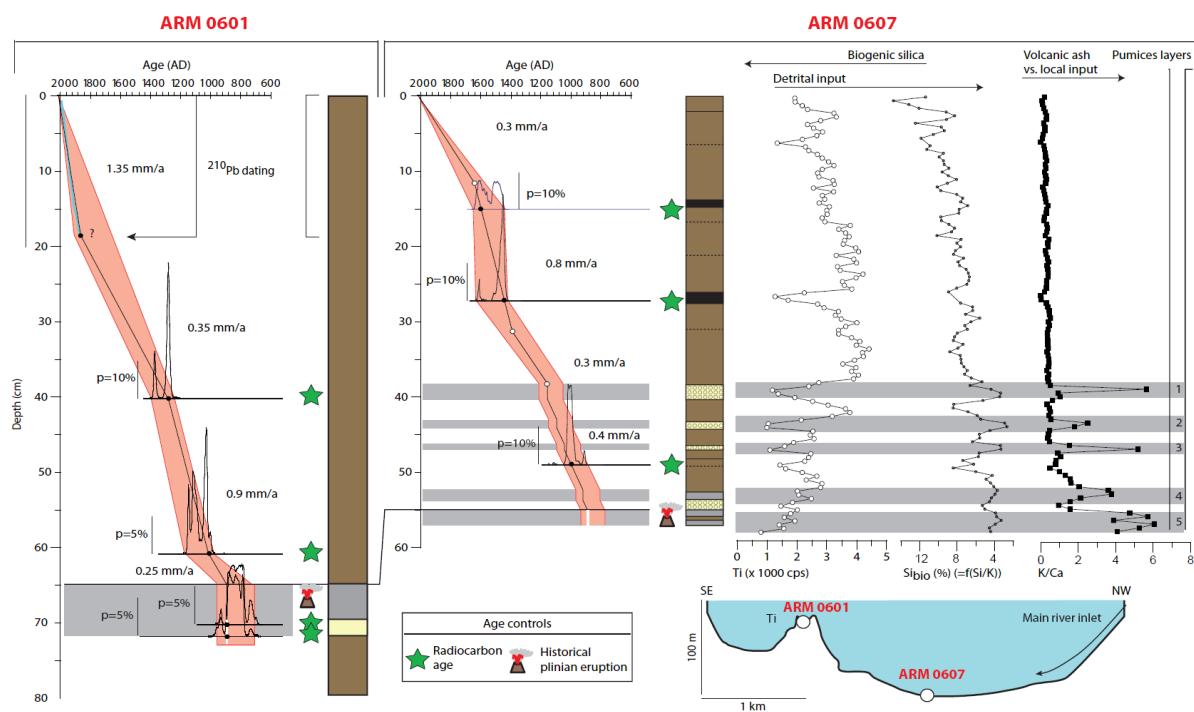
Fig.7: Age model and geochemical analyses of the Lac d'Armor cores.

The age model of ARM0607 indicates that high accumulation rates correlate with a strong detrital signal (Fig.7). This implies that they cannot be interpreted as a biogenic productivity signal. Comparison of these results with NCEP/NCAR re-analyses (resampled to match our sampling interval) reveals an excellent match between annual precipitation and Ti content signal. This indicates that the Ti signal can be confidently used as a paleohydrological signal (Fig.8).
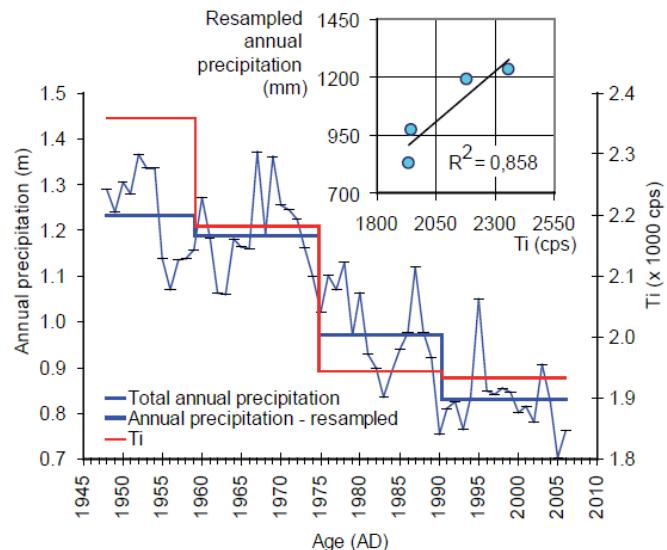
Fig.8: Correlation between annual precipitation and Ti content in the Lac d'Armor cores.

Annenkov Island, South Georgia (Fan Lake)

Core description

An 18 cm surface core was taken on the deepest spot (18 m) in Fan Lake (FL) using a UWITEC short corer. The core was sectioned at 0.5 cm intervals. A long sediment core was taken (in duplicate) with a UWITEC piston corer, in successive drives of 2 m, and comprised in total nearly 6 m of sediment.

Sedimentology

The most important shift in lithology occurred at 330-338 cm depth, where sediments changed from laminated organic rich muds into sand and silt (Fig.9). The sediments showed transitions from gravely sand and gravel (450 cm/410 cm - 554 cm/550 cm), to sand/silt (338 cm/330 cm - 450 cm/410 cm), to laminated green-grey black organic rich mud (10 - 338 cm/330 cm) and finally changing into laminated black-orange dark grey layers (0 - 10 cm).

Loss on ignition 550 (LoI550) is relatively low from the bottom of the core until 400 cm and high at 400-380 cm, 300-110 cm and from 90 cm to the top of the core (Fig.10). LoI 550 and LoI 925 are generally positively correlated except between c. 150 cm and 50 cm. The clear minimum in LoI 550 between 110 and 90 cm is not present in the LoI 925 measurements. Instead LoI 925 gradually declines from c. 110 until 41 cm.
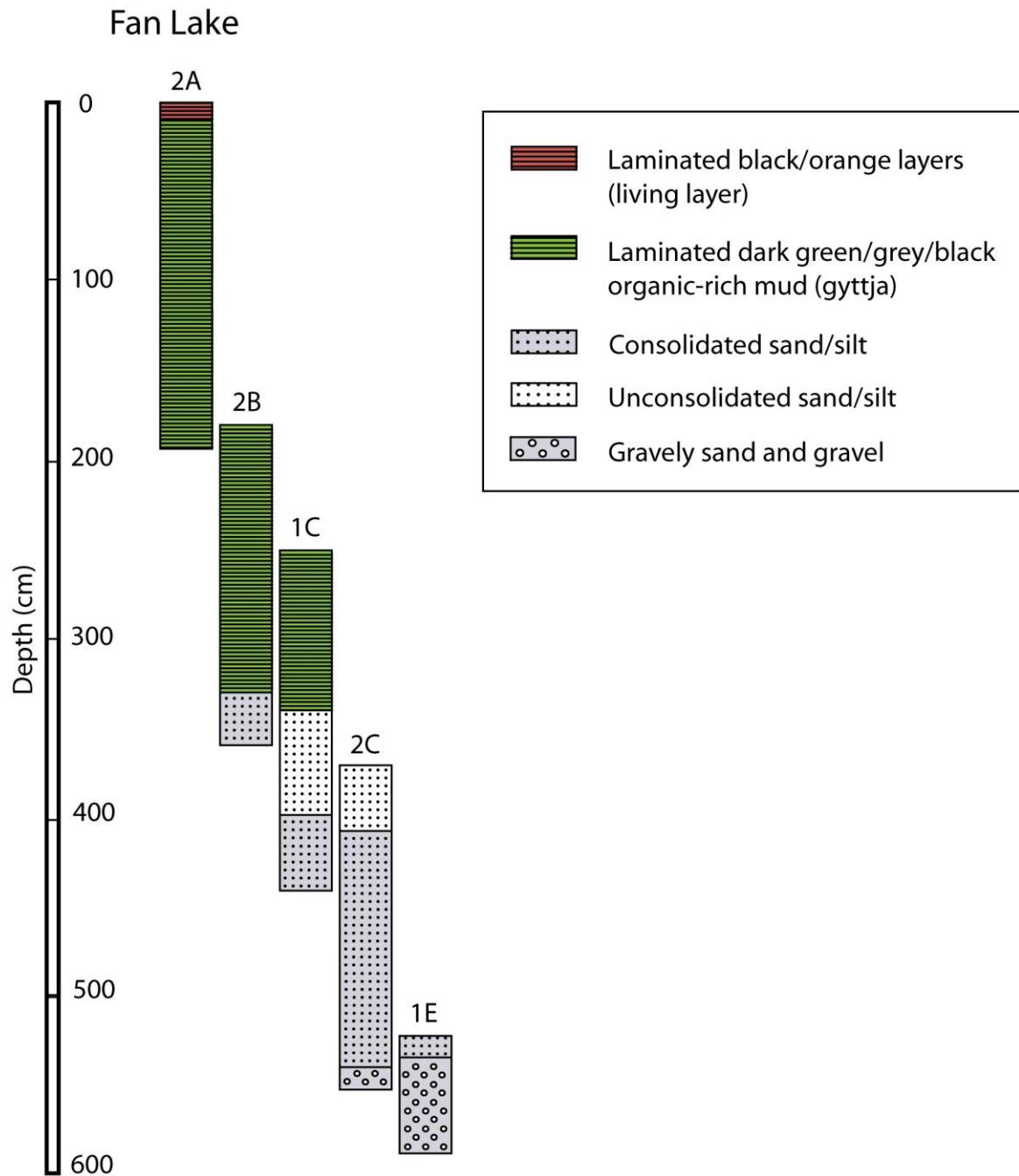
Fig.9: Simplified lithologies of the Fan Lake core

Gamma ray density (GRD) was relatively high between the bottom of the core (c. 1.9-2.4 g cm^{-3}) until 400 cm (c. 1.7 g cm^{-3}). Values were low (approx. 1.2 g cm^{-3}) between 0 and 250 cm (Fig.10). A sharp decline is present (1.2 g cm^{-3}) from c. 400 cm onwards (minima at 380 cm). The GRD subsequently increases with a peak (1.8 g cm^{-3}) at 350 cm depth, after which it gradually decreases towards the top of the core. Low frequency magnetic susceptibility showed a similar pattern, with high values (c. 2300 SI units) from the bottom of the core to 400 cm.

A through of 420 SI units is present at 380 cm, a peak of 1900 SI units around 350 cm, and low values (c. 300 SI units) between 300 cm and the top of the core.
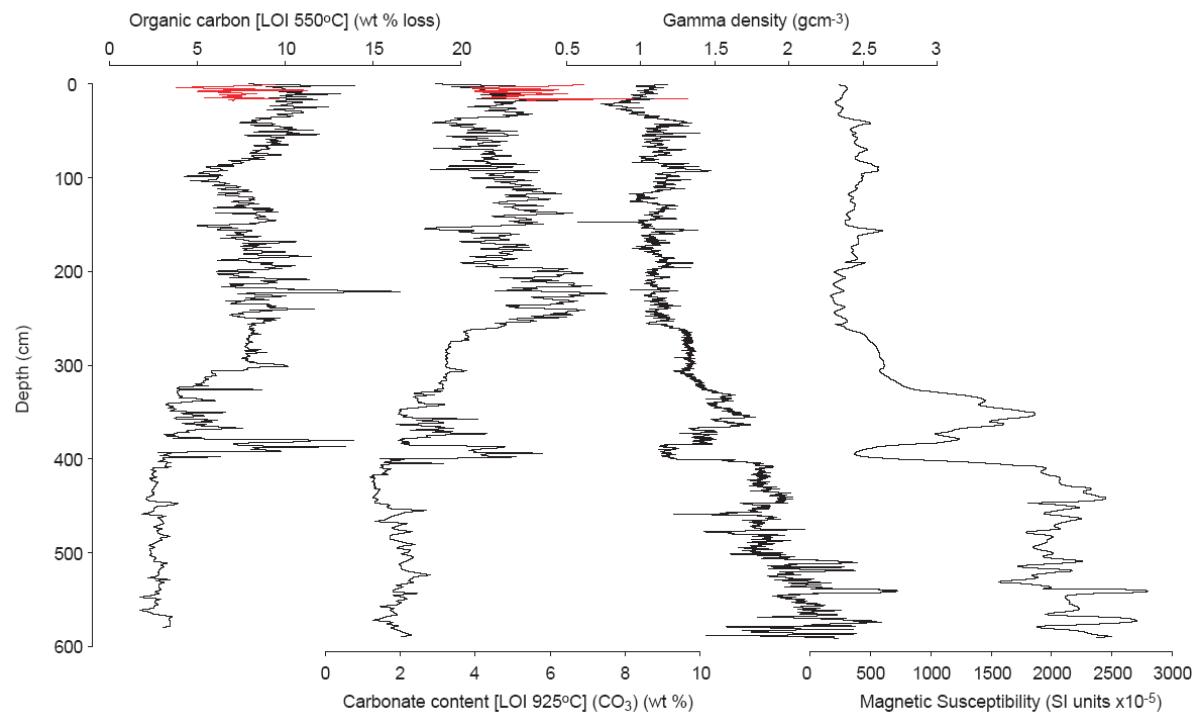
Fig.10: Loss on Ignition values, gamma ray density and magnetic susceptibility in the sediment cores from Fan Lake.

Chronology

24 samples were radiocarbon dated to establish an age-depth model. The base of the core is c. 6950 ^{14}C yr BP and a reservoir effect of c. 690 yrs is apparently present (Table I).

Table I: ^{14}C dates of the sediment core from Fan Lake

Material ID code	stratigraphic position (cm)	AMS Lab number	^{14}C age	^{14}C age error
FAN2A-1:0-1	0.5	SUERC-12578	692	35
FAN2A-1:39-40	39.5	SUERC-12585	523	35
FAN2A-1:41-42	41.5	SUERC-12586	793	35
FAN2A-1:54-55	54.5	SUERC-12587	1108	35
FAN2A-1:58-59	58.5	SUERC-12588	809	35
FAN2A-1:68-69	68.5	SUERC-12589	822	35
FAN2A-2:27-28	109.5	SUERC-12579	2118	35
FAN2B-1:11-12	186.5	SUERC-12593	2504	35
FAN2B-2:79-80	255.5	SUERC-12594	3966	35
FAN1C-1:2-3	252.5	SUERC-12595	3490	35
FAN1C-1:53-54	303.5	SUERC-12596	3627	35
FAN1C-1:71-72.5	321.5	SUERC-12598	3571	35
FAN1C-1:72-73	322.5	SUERC-12599	3536	35
FAN1C-1:75-76	325.5	SUERC-12600	3489	35
FAN1C-2:32-33	363.5	SUERC-12603	3543	35
FAN1C-2:44-45	374.5	SUERC-12604	3763	35
FAN1C-2:74-75	404.5	SUERC-12605	3521	35
FAN1C-2:83-84	413.5	SUERC-12606	3521	35
FAN1C-2:86-87	416.5	SUERC-12607	3731	35
FAN1C-2:91-92	421.5	SUERC-12608	3524	35
FAN1C-2:95-96	425.5	SUERC-12609	3714	35
FAN1E:1-2	511.5	SUERC-12580	6346	35
FAN1E:29-30	539.5	SUERC-12583	5368	35
FAN1E:69-70	579.5	SUERC-12584	6953	37

Diatom stratigraphies

The diatom composition in the Fan-Lake core (Fig.11) is prone to small changes, but these small shifts are in accordance with variations in lithology (Fig.9, 10). The core is dominated by *Cyclotella stelligera*, *Fragilaria capucina*, *Planothidium lanceolatum*, and a group of diatoms found in girdle view, which is probably *Staurosira pinnata*. A gradual decrease of *Cyclotella stelligera* and an increase in *Fragilaria capucina* towards the top of the core culminates in a remarkable peak of *Fragilaria* between 80 and 60 cm depth. A sudden rise in the 'girdle view' group coincided with a transition from sand/silt to laminated dark organic-rich mud, and a change in magnetic susceptibility and gamma-ray density (Fig.10).
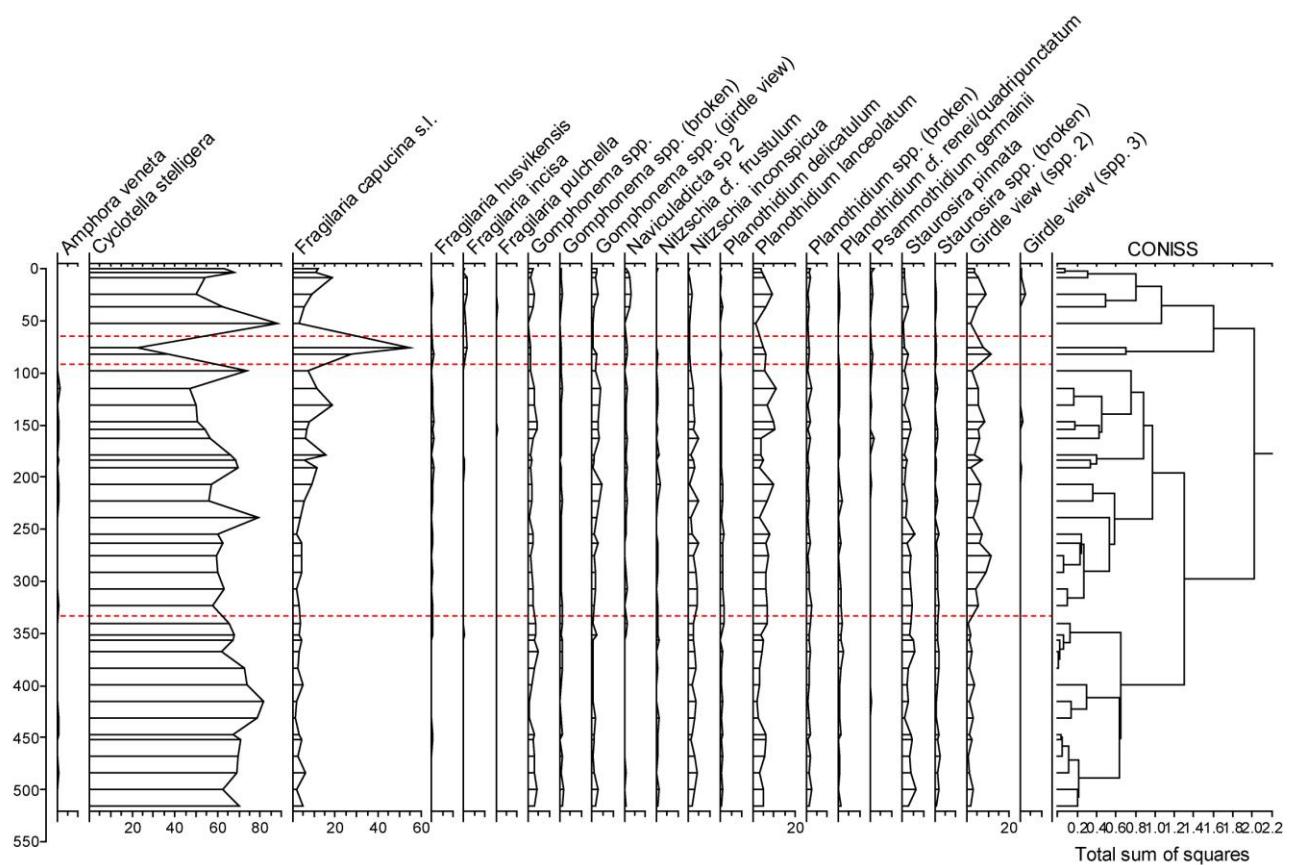
Fig.11: Diatom stratigraphy of the Fan Lake core. Only species with a relative abundance exceeding 1% are shown.

2.3.2. Maritime Antarctica

In Maritime Antarctica, lake sediment cores from the Narrows Lake in Pourquoi-Pas Island (PQP), one lake in Trinity Peninsula (VP7), and three lakes in Beak Island (BK1, BK2 and BK3; Fig.1).

Core descriptions

Narrows Lake (Pourquoi-Pas Island, Fig.1)

A sediment core of 1.27 m was recovered from the Narrows Lake and is divided into six stratigraphic zones based on stratigraphically constrained cluster analysis of the diatom data (see below; Fig.18). These consist of two basal zones which are composed of dark olive grey fine marine mud and sands (Zone 1, 127-110 cm) phasing upwards into black sediments with coarse gravel and clasts and olive grey fine marine muds (Zone 2, 110-73 cm). This is followed by a distinct transition to olive grey mud and black remains of

microbial mats (Zone 3, 73-65 cm). After the transition there are three zones defined by laminated microbial mats (Zone 4, 65-53 cm; Zone 5, 53-22 cm; and Zone 6, 22-0 cm).

View Point Lake 7 (Trinity Bay, Fig.1)

A thick mat of mosses on the bottom of VPL7 prevented coring using the UWITEC gravity corer. A core of 15 cm long was retrieved using the Livingston piston corer (Fig.12). This sequence mostly contained grey and red microbial mats (0-4 cm), dark brown (4-4.5 cm) to light grey clay rich (4.5-9 cm) microbial mats, finally layered light grey microbial mats and dark brown organic muds (9-15 cm). Due to the relatively short core length we decided not to focus on View Point.
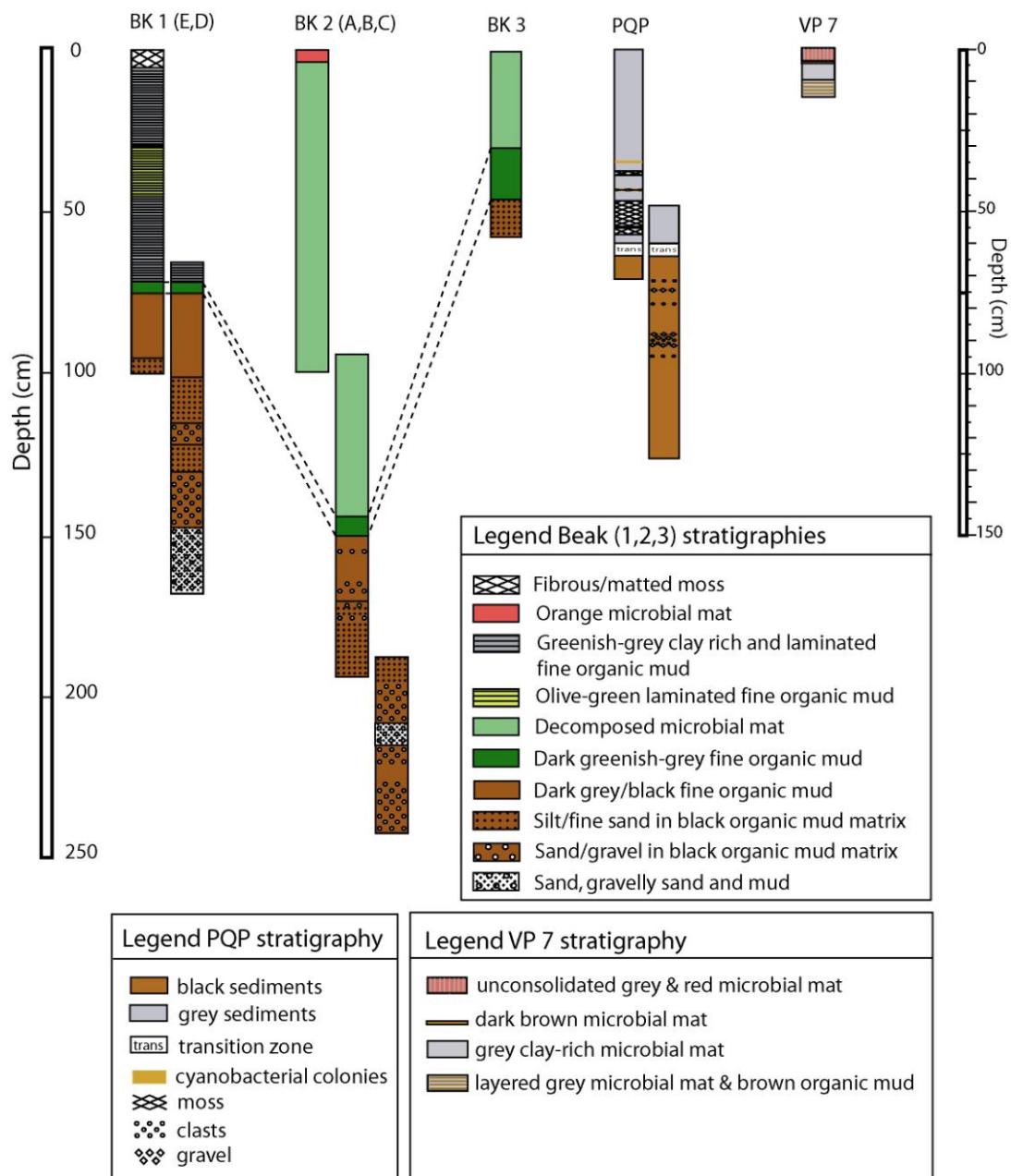
Fig.12: Simplified lithologies of the lake sediment cores from Viewpoint (VP 7), Pourquoi-Pas Island (PQP) and Beak Island (BK 1, BK 2 and BK 3).

Beak Island Lake 1, 2, and 3 (Beak Island, Fig.1)

In BK1, a core of 165 cm was retrieved. The main shifts in lithology occurred at 75 and 100 cm depth (Fig.12). At 75 cm the fine organic muds changed from greenish-grey to dark grey/black. From 100 cm depth towards the bottom of the core, coarser material (silt, fine sand, sand and gravel) was imbedded in a black/dark grey organic mud matrix. Sediments changed from matted moss (0-5 cm) to light greenish grey clays and olive green laminated fine organic material (approx. 5-27 cm). Between 30 and 45 cm olive green, fine organic mud prevailed, followed by light greenish grey, clay rich and olive green, laminated fine organic sediments between 45 and 73 cm depth. From 73 to 102 cm dark grey/black fine organic mud prevailed, followed by a black organic mud matrix with clay/silt and with sand/gravel between 102 and 147 cm. The bottom part of the core contained sand and gravel (147-167 cm).

The core from BK2 comprised 245 cm of sediments, of which the upper 144 cm consisted of an orange microbial mat (0-5 cm) and reworked/decomposed mats (5-144 cm; Fig.12). Between 144 and 162 cm, and between 166 and 170 cm dark fine organic muds are present which are similar to those found at 73-75 cm depth in the BK1 core. Between 173 and 198 cm clay/silt in a black organic mud matrix prevailed. The bottom part of the core (198-245 cm) mainly contained silt and fine sandy organic mud with clasts and was interrupted by medium-coarse sand with clasts and gravel at 208-214 cm.

The core of BK3 was 58 cm long and comprised a diffused/reworked decomposed microbial mat between 0 and 30 cm (Fig.12). Between 30 and 45 cm dark (grey/black) fine organic muds were present. The bottom part of the core (45-58 cm) contained clay/silt in a black organic mud matrix with some clasts.

Sedimentology

Narrows Lake

The principal feature of the Narrows Lake is the transition from marine sediments to freshwater lake sediments. In the marine zones of the Narrows Lake core (Diatom Zones 1&2; Fig.18) the organic content, measured as TOC and LOI_{550} remains below 3% and 5% respectively and carbonate (LOI_{950}) is relatively stable. The low $\delta^{13}C$ (<-18 ‰) and C/N values (6-10) are consistent with marine sediments. C/N shows a step change at the Diatoms Zone 1 – Zone 2 boundary and there is a weak positive shift in $\delta^{13}C$ towards the top of Zone 2. The marine-freshwater transition in Diatom Zone 3 exhibits changes in all parameter. In particular there are increases in organic content, carbonate content, $\delta^{13}C$ and C/N. The transition is also marked by the first appearance of aquatic mosses and *Branchinecta* eggs. Above the transition in Diatom Zone 4 organic content reaches

its highest levels in the core coinciding with the presence of thick moss layers and then steadily declines through the upper freshwater Diatom Zones (5-6). $\delta^{13}C$ is high through Diatom Zone 4 and most of Diatom Zone 5 and then declines in the upper part of this zone into Diatom Zone 6 (Fig. 13). C/N is similarly high but declines from about 35 cm at the same time that there is a marked reduction in the presence of aquatic mosses. Concentrations of *Branchinecta* eggs peak in Diatom Zone 4 and then steadily decline through Diatom Zones 5 and 6.
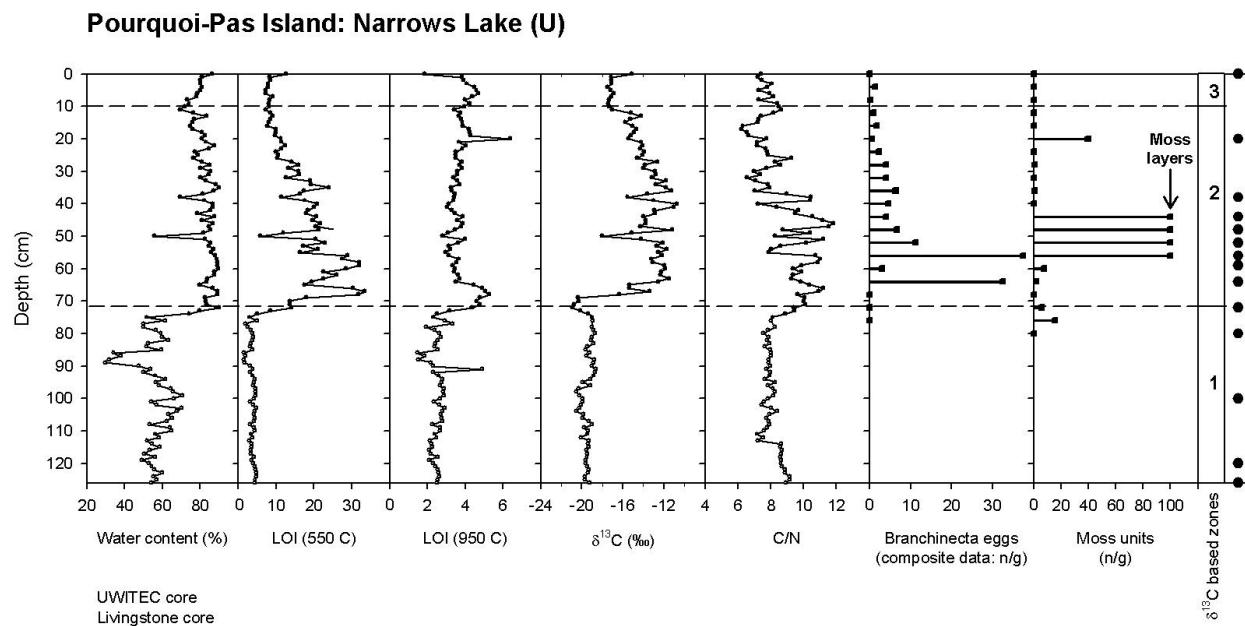
Fig.13: Stratigraphic analyses of the 1.27 m was recovered from the Narrows Lake

Beak Island

Wet density (g cm^{-3}) and magnetic susceptibility (g^{-1} cm^3) were measured at 1 cm resolution for the BK1 core (Fig.14). A sharp decrease (towards the top of the core) in wet density was visible around 80 cm depth, which is in agreement with the core description made on site. An increase in magnetic susceptibility was similarly visible between 75 and 100 cm depth, coinciding with the presence of a dark grey/black organic mud zone (Fig.12).

In the core from BK2, wet density and magnetic susceptibility were measured every 2 cm, except for the upper 20 cm, which were measured every cm. In the BK2 core, wet density values were high between 205 and 160 cm, coinciding with an increased magnetic susceptibility and with low LOI$_{550}$ values (Fig.15).

A change in lithology was also visible in the core descriptions (Fig.12), where a transition was seen from decomposed microbial mats towards dark grey/black organic muds, silts, sand and gravel at 160-150 cm.

In the core from BK3, an increased density between 58 and 46 cm coincided with a distinct lithological unit (Fig.16).
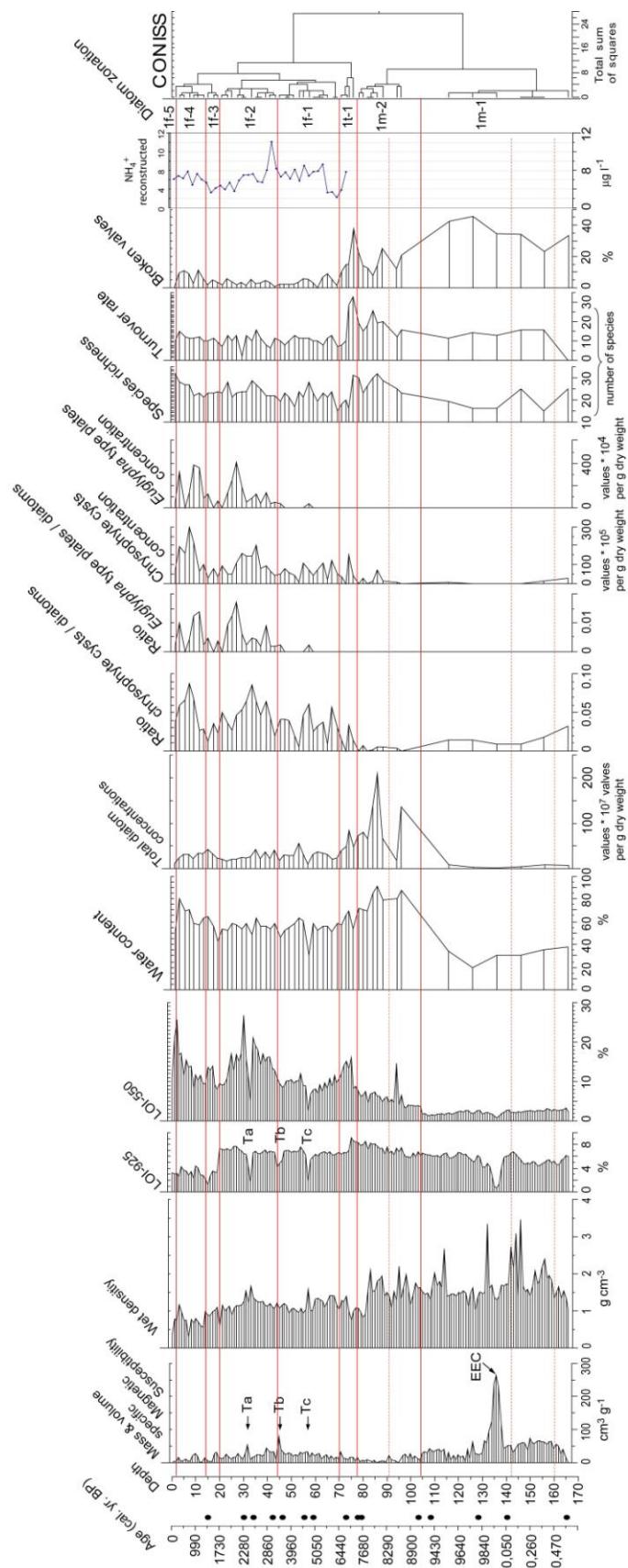
Fig.14: Sedimentological properties, diatom, cyst and *Euglypha* concentration, the beta diversity in diatom communities, the number of broken valves and diatom based reconstruction of NH4 in the sediment cores from Lake Beak 1.

Fig.15: Sedimentological properties, diatom, cyst and *Euglypha* concentration, the beta diversity in diatom communities, the number of broken valves and diatom based reconstruction of NH4 in the sediment cores from Lake Beak 2.
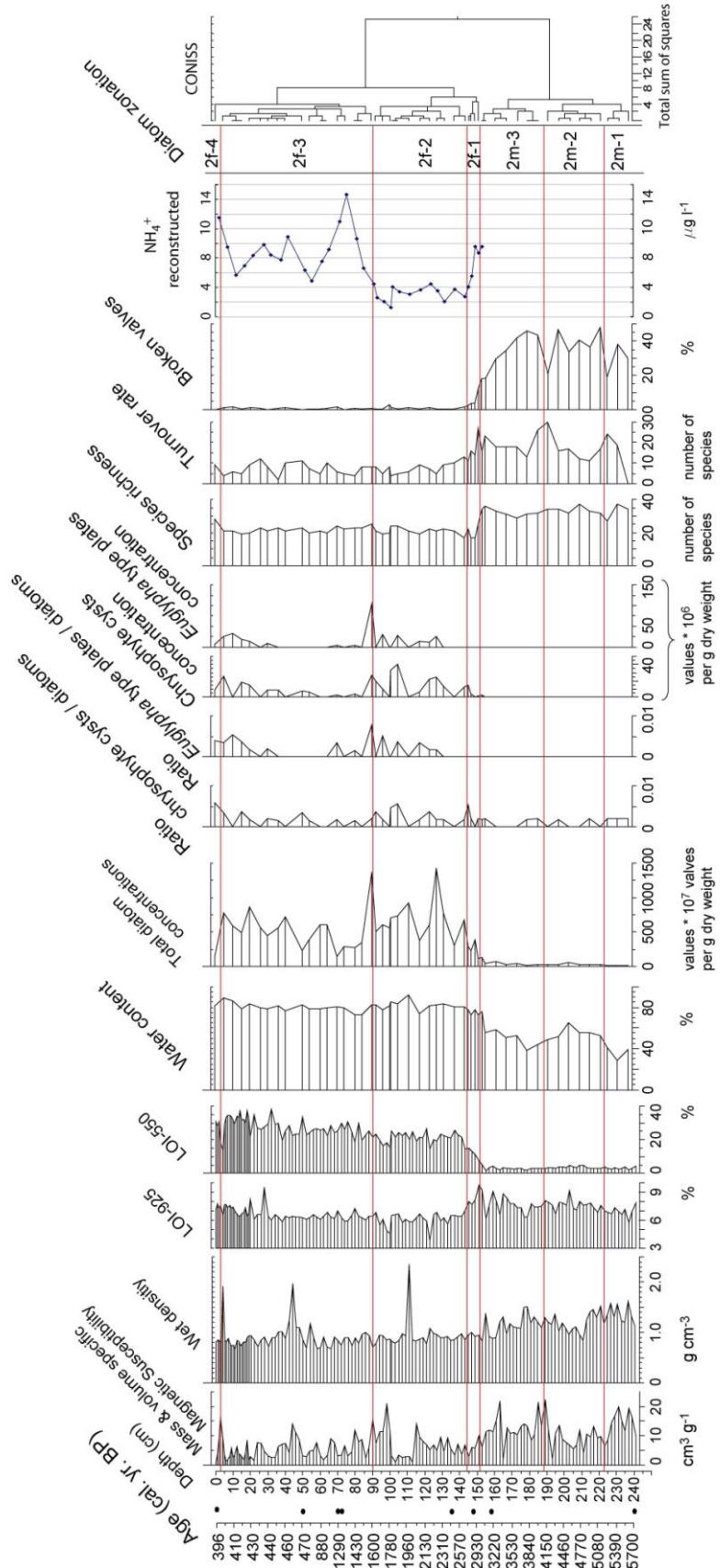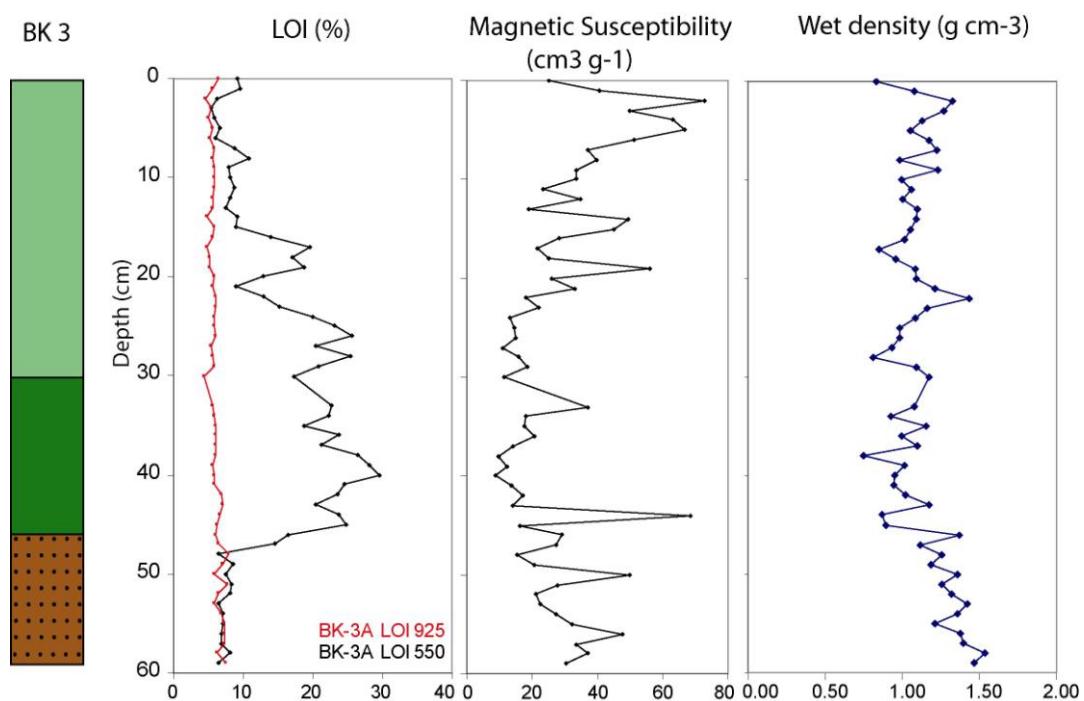
Fig.16: Wet density, magnetic susceptibility and loss-on-ignition in the sediment cores from Lake Beak 3. Symbols in stratigraphic logs (overlapping sections excluded) as in Fig.8.

Geochronology

Radiocarbon dating (13 samples) of the core from Pourquoi-Pas Island shows that the dates are in stratigraphic order. The oldest dated material in Zone 1 is 8489 ^{14}C yr BP and the major transition (Diatom Zone 3) dates between 7413 and 6705 ^{14}C yr BP (Table II). The Zone 6 surface date is 663 ^{14}C yr BP indicating that a limited reservoir correction might be required at this site.

Eighteen samples were ^{14}C dated from Lake Beak 1 (Table II). Most dates were chronologically consistent. Exceptions occurred at 32.5 cm, where the dated moss-stem was probably translocated downward during the coring process, and at 103.5 and 129.5 cm depth, where ages of 10,901±53 and 10,752±62 ^{14}C BP were older than the basal sediment age of 10,625±54 ^{14}C BP (166-167 cm depth). These last two age inversions might indicate disturbance in the marine environment or even more likely reflect an instantaneous deposit of the sediments between 167 and 100 cm depth. This is confirmed by the lack of visual laminae in this part of the core.

The age-depth model of Beak-2 is based on 8 ^{14}C dates (Table II), of which only one resulted in an age inversion (i.e., at 72.5 cm depth), after which we decided to assign an intermediate age of 1285 cal yr BP between 70.5 and 72.5 cm depth.

The top sediments of this core were 339 ± 35 ^{14}C years old, which is almost equal to the date at 50 cm. This most likely points to disturbance in the topmost c. 50 cm as the lake is only four meters deep.

The sediments in Lake Beak 3 are likely disturbed. The transition from marine to lacustrine sediments is dated at approximately 1686 ^{14}C yr BP (Table II), but should be treated with caution.

Table II: ^{14}C dates of the sediment core from Narrows Lake (PQP) and Beak Island Lake 1-3.

Material ID code	stratigraphic position (cm)	AMS Lab number	^{14}C age	^{14}C age error
NARROWS LAKE				
PQP-1U-B	1.5	SUERC-5052	663	25
PQP-9U-B	9.5	SUERC-5053	1270	22
PQP-21U-B	21.5	SUERC-5054	2622	24
17 PQP-38U-M	38.5	SUERC-5589	3467	27
19 PQP-56U-M	56.5	SUERC-5590	5765	37
20 PQP-56U-E	56.5	SUERC-5593	5690	37
PQP-64U-B	64	SUERC-5059	6582	39
22 PQP-64U-E	64.5	SUERC-5594	6705	42
PQP-70U-B	70.5	SUERC-5060	7413	44
PQP-30L-B	78.5	SUERC-5061	7709	46
PQP-41L-B	89.5	SUERC-5063	8138	56
PQP-51L-B	99.5	SUERC-5064	8097	48
PQP-78L-B	126	SUERC-5067	8489	51
BEAK 1				
BK1E:0-1	0.5	SUERC-12385	modern	
BK1E:15.5	15.5	SUERC-12394	1563	35
BK1E:31	31.5	SUERC-12395	2305	35
BK1E:32-33	32.5	SUERC-12386	1101	35
BK1E:34	34.5	SUERC-12396	2345	35
BK1E:43.5	43.5	SUERC-12397	2940	35
BK1E:46	46.5	SUERC-12398	3280	35
BK1E:55	55.5	SUERC-12401	4048	35
BK1E:59	59.5	SUERC-12402	4346	35
BK1E:73.5	73.5	SUERC-12403	6010	36
BK1D:8.5	73.5	SUERC-12564	6098	35
BK1E:78.5	78.5	SUERC-12404	6735	35
BK1D:14.5	79.5	SUERC-12565	7393	36
BK1D:38.5	103.5	SUERC-12943	10901	53
BK1D:43.5	108.5	SUERC-12566	9626	48
BK1D:64.5	129.5	SUERC-12944	10752	62
BK1D:75.5	140.5	SUERC-12945	10147	46
BK1D:101	166.5	SUERC-12567	10625	54

Material ID code	stratigraphic position (cm)	AMS Lab number	^{14}C age	^{14}C age error
BEAK 2				
BK2A:0-1	0.5	SUERC-12568	339	35
BK2A:50-51	50.5	SUERC-12387	400	35
BK2A:70-71	70.5	SUERC-12388	1377	35
BK2A:72-73	72.5	SUERC-12391	1329	35
BK2B:43-44	136.5	SUERC-12569	2374	35
BK2B:55-56	148.5	SUERC-12946	2780	35
BK2B:66-67	159.5	SUERC-12570	3632	35
BK2C:53-54	240.5	SUERC-12947	4990	36
BEAK 3				
BK3A:0-1	0.5	SUERC-12574	471	35
BK3A:8-9	8.5	SUERC-12392	modern	
BK3A:28-29	28.5	SUERC-12575	1453	35
BK3A:44-45	44.5	SUERC-12576	1686	35
BK3A:48-49	48.5	SUERC-12577	1806	35
BK3A:58-59	58.5	SUERC-12948	2684	35

Diatom calibration dataset

The diatom stratigraphies (see below) were interpreted using a diatom calibration dataset and a transfer function, which forms an extension of the inference model developed by Jones & Juggins (1995). To this end, the diatom data from the 6 surface samples from Beak Island were intercalibrated with the diatom dataset from Livingston Island (South Shetland Islands; 62°40'S, 61°00'W) and Signy Island (South Orkney Islands; 60°43'S, 45°38'W) using the original slides kindly provided by Dr. V.J. Jones. The diatom taxa from all 75 samples were subject to a floristic and taxonomic survey (Sterken et al., unpubl. res., Van de Vijver et al., unpubl. res.). The original 133 taxa from the Livingston and Signy Island database were examined and recombined into 113 operational taxonomic units, of which the taxonomic boundaries of 84 taxa/complexes were traced back and illustrated. This taxonomic inventory will be published as a separate paper (Sterken et al. in prep.). The addition of the Beak surface samples to this database yielded five additional taxa (i.e. *Achnanthes* cf. *muelleri*, *Chamaepinnularia cymatopleura*, *Hantzschia* spp. (containing *Hantzschia* sp. 1 and *Hantzschia* sp. 2), *Navicula cincta* and Species 12. In the Beak samples, 45 taxa were identified, and 99 taxa were found in the Livingston dataset, while 78 taxa were identified in the Signy dataset.

Ordination analysis revealed that the surface samples from Beak Island are dominated by the *Nitzschia frustulum/inconspicua* complex, and their species compositions are intermediate between those from the Signy and the Livinsgston Island samples (Fig.17).

The diatom communities of the Signy Island lakes are mainly characterized by *Stauroforma inermis, Planothidium renei, Maeamaya* cf. *atomus* var. *permitis* and the virtual absence of *Planothidium* cf. *lanceolatum* s.l. The Livingston inland (high elevation) lakes are characterized by the Antarctic endemic *Brachysira minor* generally living in association with bryophytes, by the epilithic *Eolimna minima, Planothidium* cf. *lanceolatum* s.l., *Psammothidium abundans* (although this species is also present in lakes from Signy Island), and *Staurosirella pinnata*. The Livingston coastal lakes are characterized by *Fragilaria alpestris,* the *Nitzschia frustulum/inconspicua* complex*, and Planothidium delicatulum.*
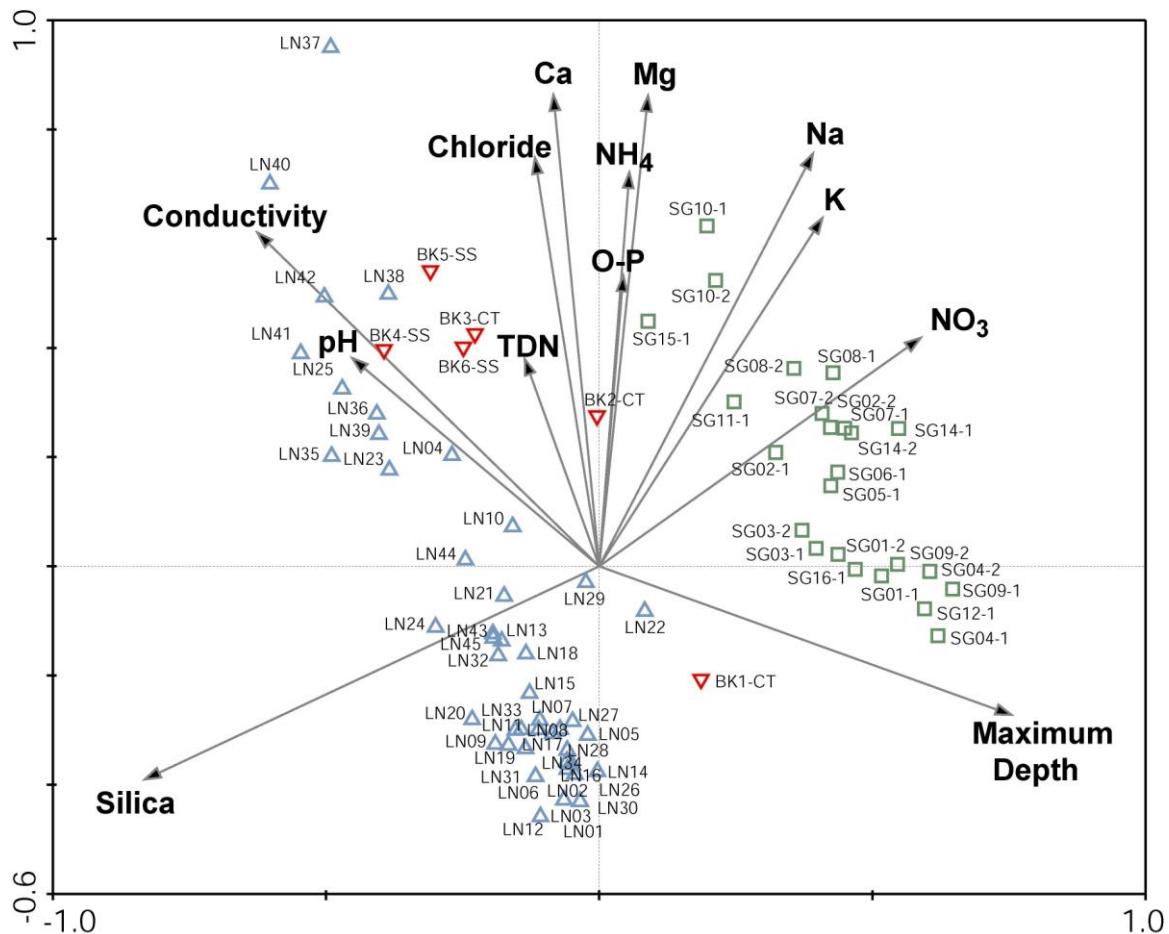
Fig.17: CCA sample plot of the dataset from Livingston and Signy Island (Jones & Juggins 1995) combined with the Beak Island samples. Red downside triangles represent Beak samples; blue triangles: Livingston samples; green squares: Signy Island samples.

Canonical correspondence analysis (CCA) with forward selection and Monte Carlo permutation tests (999 permutations), using the complete dataset containing all species (species data log (x+1) transformed, analysis with downweighting of rare species), revealed that 36.6 % of the variance in diatom composition (Total inertia: 1.728) could be significantly explained by all variables together.

The variables explaining the largest portions of all variance were related to location (L) and conductivity/hardness (C-h) (Table III). However, both of these have a strong spatial component, the first one caused by the geology of the islands, and the second one being partly related to the distance from the coast. Therefore, we sought the best nutrient/trophy related variable, since these variables are largely climate-dependent in Maritime Antarctica (Quayle et al., 2002). CCA-tests of each of the nutrient-related variables showed that they all significantly explained a portion of the diatom distribution in the dataset (Table III). NH_4 explained the largest part (6.3% of total variation), and was the only nutrient-related variable that still significantly explained part of the variation in diatom data after partialling out all the better explaining (forward selected) variables. Initial WA and WA-PLS regression and calibration for NH_4 showed the best results (RMSEP = 0.323 log (x+1) units, and jackknifed R^2 = 0.607) for the WAPLS-2 analysis. This analysis produced seven outliers with an absolute residual greater than the standard deviation of the observed values, which were deleted from the model. The new model had a jackknifed R^2 of 0.724 and an RMSEP of 0.267 log (x+1) units. WAPLS-2 was preferred above WAPLS-1 since the addition of one component improved the model by 13.4 %.

Table III: Summary of the CCA analysis on the combined Livingston-Signy-Beak dataset for all measured variables. 'Group' refers to location (L), conductivity/hardness (C-h), maximum depth (MD) or trophic state/nutrients (Troph). Expl. var. is the total variance explained by the respective variable, and it is given as a % of the variance explained by all significant variables together, and as a % of the total variance in diatom data. Significance levels are indicated (p value).

Group	variable	expl. var.	% of explained variance	% of total variance	p value
L	Silica	0.158	25.0	9.1	0.001
C-h	Na^+	0.135	21.3	7.8	0.001
C-h	Mg	0.131	20.7	7.6	0.001
C-h	Cond	0.125	19.7	7.2	0.001
C-h	Ca	0.125	19.7	7.2	0.001
MD	Max Depth	0.123	19.4	7.1	0.001
L	K	0.118	18.6	6.8	0.001
Troph	NO_3^-	0.109	17.2	6.3	0.001
Troph	**NH_4^+**	**0.108**	**17.1**	**6.3**	0.001
C-h	Cl^-	0.103	16.3	6.0	0.001
C-h	pH	0.088	13.9	5.1	0.001
Troph	O-P	0.079	12.5	4.6	0.001
Troph	TDN	0.049	7.7	2.8	0.003

Diatom stratigraphies

Narrows Lake (Pourquoi-Pas Island, Marguerite Bay)

Diatom analyses in the 126 cm long sediment core from Narrows Lake (Fig.18) revealed the presence of marine and freshwater sediments with a clear transition zone with brackish, marine and freshwater diatoms in between both zones. Zones 1 (127-110 cm) and 2 (110-73 cm) are dominated by *Chaetoceros* resting spores, *Nanofrustulum shiloi*, and a *Pseudostaurosira* species. The relatively high abundance of *Chaetoceros* resting spores between 120 and 110 cm at 100 cm and prior to lake isolation might indicate increased primary productivity. The diatom stratigraphy shows that the transition (zone 3: 73-65 cm) from marine to freshwater sediments is complete by 65-64 cm. *Navicula phyllepta* is abundant in this transition zone and has been recorded in similar isolation basin transitions in east Antarctica (Verleyen et al., 2004; Verleyen et al., 2005). The diatom community is highly variable following lake isolation in zone 4 (65-53 cm); a succession is observed of communities characterised by sea-ice taxa and *Pinnularia microstauron*, over assemblages dominated by *Navicula veneta* and *Planothidium quadripunctatum,* culminating in a flora in which *Gomphonema* cf. *parvulum* is abundant. Zone 5 (53-22 cm) following this unstable succession phase is characterised by the presence of an unknown Naviculoid species, as yet not reported from other (Sub-)Antarctic lakes (Verleyen et al. 2003, Sterken et al. unpubl. res., Van de Vijver et al. 2002). From 42 cm onwards *Psammothidium subatomoides* gradually increases. *Gomphonema* cf. *parvulum* decreases in zone 6 (22-0 cm) and stomatocysts reach a maximum at 18 cm. *Achnanthidium modestiforme* appears for the first time in the core. *Diadesmis langebertalotii,* which was also present in the transition zone, becomes subdominant in the most recent sediments. This diatom is currently found in slightly acidic soils which are often influenced by marine animal input (Van de Vijver et al. 2002) and thus related to higher nutrient concentrations. *Psammothidium oblongellum*, a diatom found in Sub- and Maritime Antarctic lakes and ponds (Van de Vijver et al. 2002) is only present in the first top 2 cm of the core.
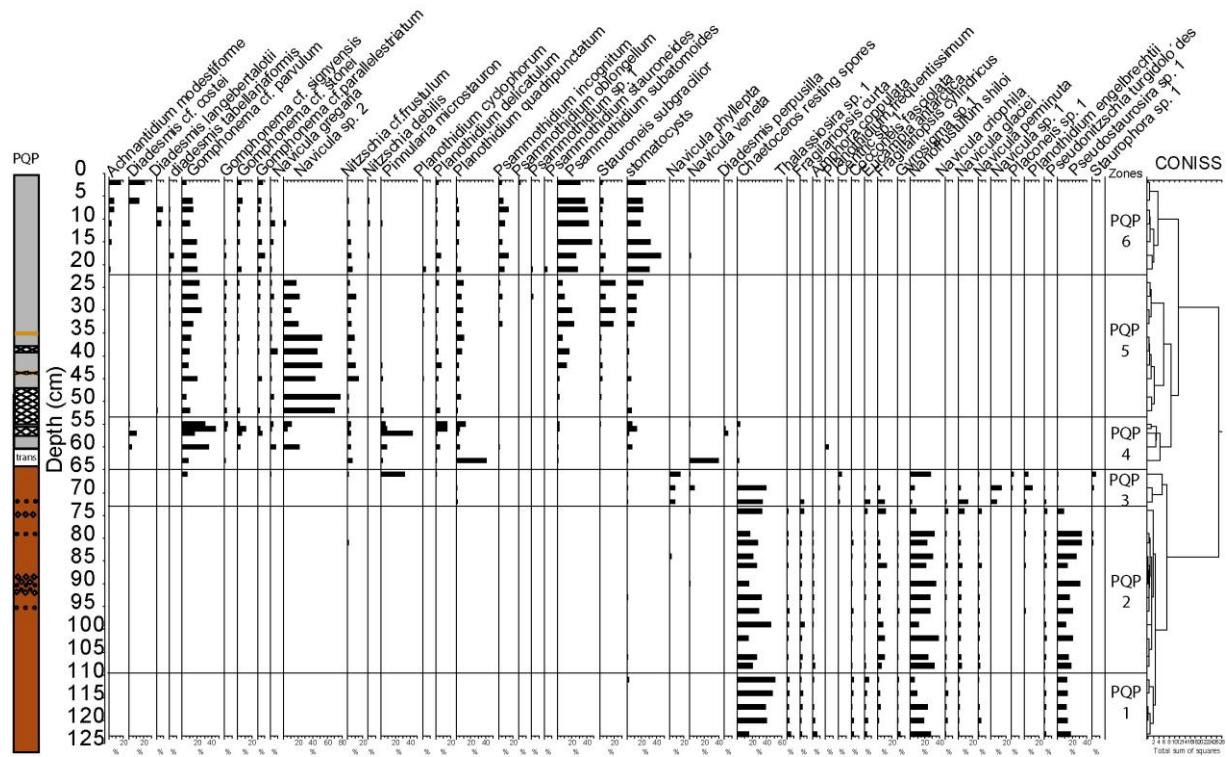
Fig.18: Diatom stratigraphy of the Pourquoi-Pas sediment core. Marine diatom species are grouped to the right of the diagram. Only species with a relative abundance exceeding 2% are shown. Symbols used in the stratigraphic log as in Fig.12.

Beak Island Lake 1

The diatom record in BK 1 (Fig.19) starts with the occurrence of marine and sea-ice related species between 167 and 102 cm, which coincides with the deglaciation of nearby regions and a well defined climate optimum in ice cores (see Hodgson et al. in press for a review). The occurrence of sea-ice zone related taxa (e.g., *Fragilariopsis cylindrus*), brackish water diatoms (e.g., *Craspedostauros laevissimus*), the high abundance of *Chaetoceros* resting spores, and a sudden decline in *Achnanthes* cf. *brevipes* is observed at 100 cm depth. The main transition from marine to lacustrine diatom communities occurs at 76 cm depth, which is coincident with the marked transition in sedimentary properties. *Naviculadicta seminulum* s.l., *Nitzschia frustulum/inconspicua*, *Brachysira minor*, and *Achnanthidium exiguum* are dominant between 76 and 67 cm depth. After 67 cm depth, *Chamaepinnularia australomediocris* appears and the relative abundances of *Planothidium renei* increase towards a maximum of 71 %. *Planothidium delicatulum* and the tychoplanktonic species *Staurosirella pinnata* become slightly more important between 43 and 21 cm. Moss-dwelling species (e.g., *Psammothidium incognitum/investians, Psammothidium abundans*) and taxa known to occur in oligotrophic conditions (e.g., *Planothidium delicatulum, Psammothidium abundans*) are present in the top 20 cm of the core.

In the freshwater zones of BK1, reconstructed NH_4 values show a minimum between 72 and 64 cm (Fig.14). Values are high between 64 and 36 cm and in the upper 10 cm, and are below 7 μg/l between 28 and 14 cm.

Beak Island Lake 2

A stratigraphically constrained cluster analysis on all fossil diatom compositions divides the Beak-2 sediment core in two marine sections between 237-153 cm and four freshwater zones between 153 cm and the top of the core (Fig.19). In general, the marine sections are dominated by the sea ice related diatom *Navicula glaciei*, and by *Craspedostauros*, *N. criophila*, *N. phyllepta*, and an increasing abundance of *N. cryptotenella* towards the top (153 cm).
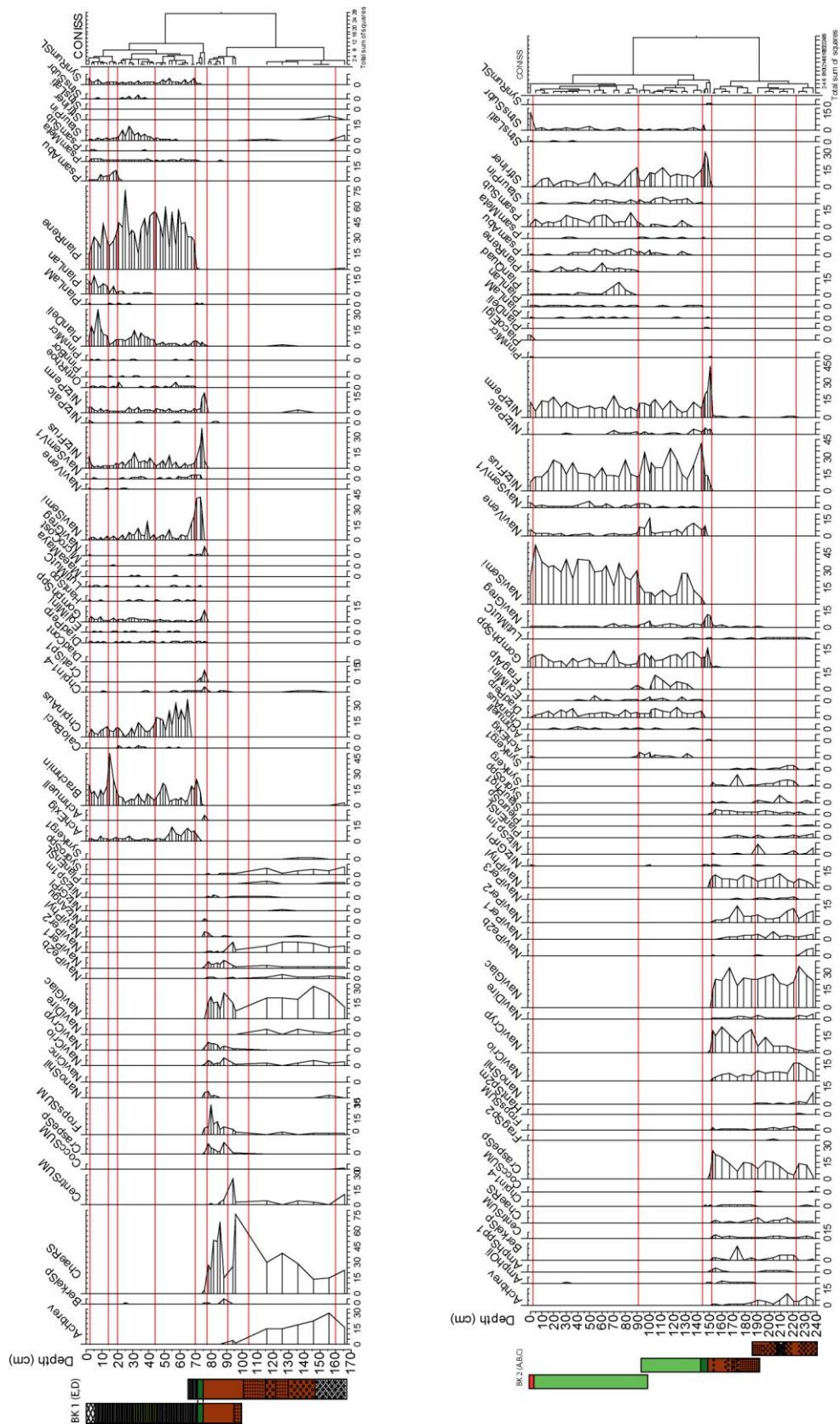
Fig.19: Diatom stratigraphy of the BK1 (left) and BK2 (right) cores. Only species with a relative abundance exceeding 2% or occurring in more than 5 samples are shown. Symbols used in the stratigraphic log as in Fig.8.

The main transition to freshwater conditions occurred between 153 and 144 cm depth, and starts with high relative abundances in *Nitzschia perminuta*, *N. palea* and *Navicula gregaria*. The first freshwater zone is dominated by the *Nitzschia frustulum/inconspicua* complex, *N. perminuta*, *Naviculadicta seminulum* s.l., *Gomphonema* spp. and *Stauroforma inermis*. The second freshwater zone (91-3 cm) starts with the disappearance of *Staurosira alpestris* and *Achnanthidium exiguum*. Diatom species compositions in this zone are dominated by *Naviculadicta seminulum* s.l., which increases towards the top of the core. In the core top sample, *Stauroneis cf. subgracilior* and *Placoneis elginensis* become abundant, while *Naviculadicta seminulum* s.l. dramatically decreases in relative abundance.

Reconstructed NH_4^+ values in BK2 are high (c. 8.5 µg/l) at the marine-freshwater interface (Fig.15), and rapidly decrease towards values below 6 µg/l between 144-91 cm. Values are high again in the upper 91 cm, with peaks at 74 and 0 cm.

Diatom compositions in core BK 3 (Fig.20) change in accordance with the lithological descriptions of the core with a marine to lacustrine transition at 46 cm depth, and a sudden decline in *Nitzschia acidoclinata* at 30 cm. The diatom diversity in the lacustrine part of the core is much lower in core BK 3 than in core BK 1, and is mainly dominated by *Nitzschia* species.
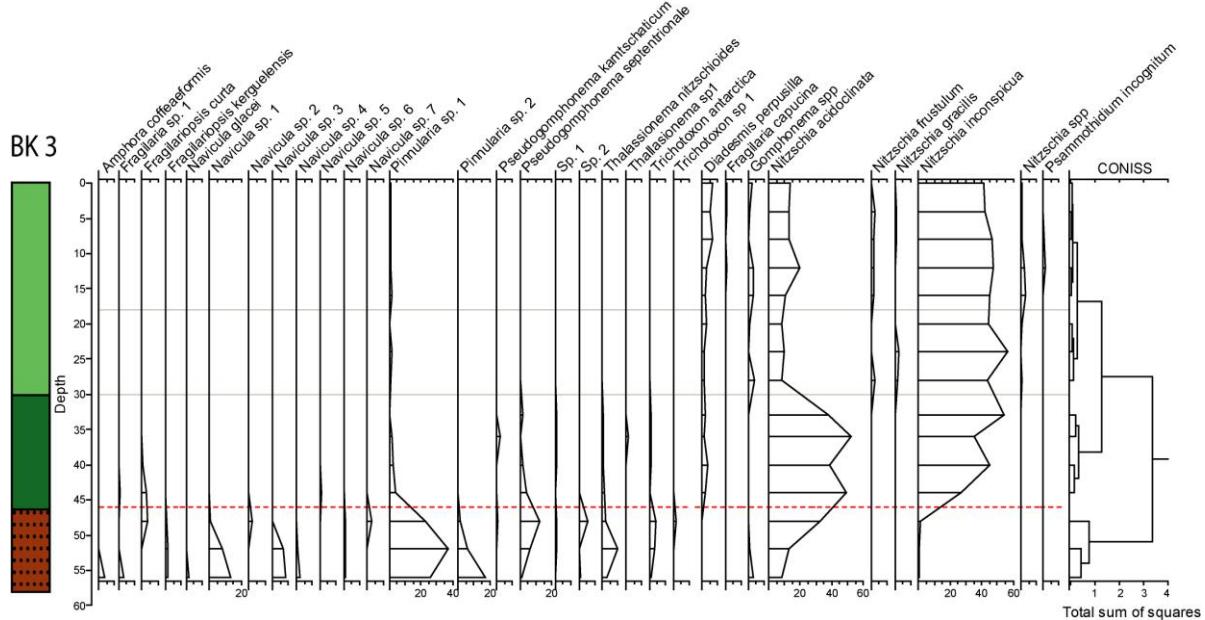
Fig.20: Diatom stratigraphy of the BK3 core. Only species with a relative abundance exceeding 1% are shown. Symbols used in the stratigraphic log as in Fig.12.

Fossil pigments

The PQP core yielded inaccurate results due to a failure of our HPLC. A new Agilent 1100 series HPLC system was used for the analysis of the Beak Island Lake 1 and 2 cores from Maritime Antarctica. Because the sediment core from Lake Beak 3 is likely disturbed, we decided to concentrate on the other two lakes in the region.

<u>Beak Island Lake 1</u>

Changes in pigment concentrations and relative abundances in the core are broadly consistent with the zones based on diatom species compositions and the sedimentological characteristics. Total carotenoid and chlorophyll concentrations are highly correlated, both in the marine and freshwater sections of the core (Fig.21).

The total pigment concentrations were moderately low throughout the first marine zone (166-105 cm) and the carotenoid concentration is composed of pigments produced in diatoms, dinophytes and chrysophytes (diatoxanthine), and chlorophytes (lutein). The carotenoid and chlorophyll composition in the second marine zone (105-76 cm) is largely similar to that observed in the bottom parts of the previous zone, but the total pigment concentration is generally higher, pointing to more productive conditions. At the marine-lacustrine transition in core Beak-1 (76 cm depth), the diversity in pigment composition and the total concentration were high, with zeaxanthin and lutein being present together with some small peaks of rare pigments with characteristics similar to those of hexanoyloxi-fucoxanthin, canthaxanthin and vaucheriaxanthin. The first freshwater zone is characterised by very low total pigment concentrations. The increased pigment concentrations in the second freshwater zone (44-20 cm) coincide with high LOI values and a diverse pigment composition, comparable with the samples at the marine-freshwater transition. In the third freshwater zone (20-14 cm) the samples are devoid of carotenoids and contain only small concentrations of chlorophyll-derived pigments, which is coincident with the sudden shifts in diatom communities. The fourth freshwater zone (14-2 cm) shows slightly higher total pigment concentrations. The core-top sample differs from other samples, by its high peak in fucoxanthin (a pigment produced by chrysophytes and diatoms), lutein (chlorophytes and bryophytes), beta carotene (chlorophytes and cyanobacteria), chlorophyll b (likely related to mosses) and a chlorophyll-a derivative.
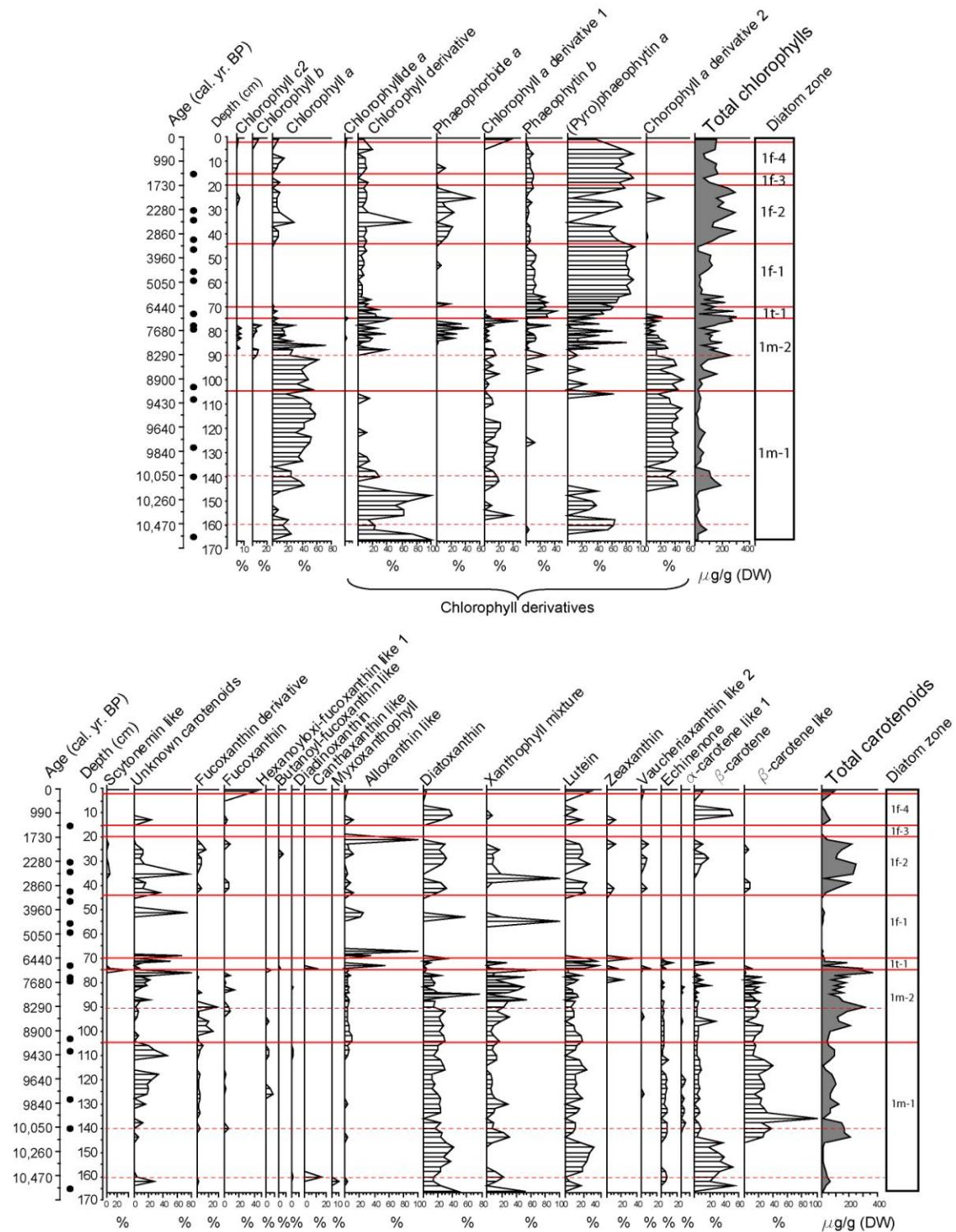
Fig. 21: Fossil pigment stratigraphy of the Beak 1 sediment core, plotted against depth (cm). Corresponding interpolated calibrated ages are given, and depths of ^{14}C dates are indicated by black dots. Only pigments constituting more than 2% of the total carotenoids or total chlorophylls are shown. Total pigment concentrations (grey shaded graphs) are expressed in µg/g dry weight (DW). The zonation of the core is based on the CONISS analysis of the diatom species compositions (Fig.19).

Beak Island Lake 2

The fossil pigment stratigraphy of core Beak 2 (Fig.22) broadly follows the diatom Stratigraphy (Fig.19). The marine zones are characterised by the low amount of pigments, which are dominated by xanthophylls (luteine and diatoxanthin) and mixtures of chlorophylls and carotenoids. The transition zone contains high peaks of total carotenoid and chlorophyll concentrations. Carotenoids shift from being dominated by xanthophylls towards scytonemin at 144 cm, where total carotenoid concentrations declined. The Freshwater zones contain maximal concentrations of both total carotenoids and chlorophylls, although the total carote noid concentration shows a large variability in this zone. The carotenoids are highly dominated by scytonemin in this zone, together with modest fractions of diatoxanthin, lutein/zeaxanthin and β-carotene. Between c. 100 cm and the top the core a myxoxanthophyll like pigment is relatively abundant. Fucoxanthin and canthaxanthin like pigments, as well as some unknown carotenoids appear in this zone for the first time, and remain present throughout the whole freshwater core section. Echinenone is apart from one single sample in the bottom most sediments also characteristic for this zone.
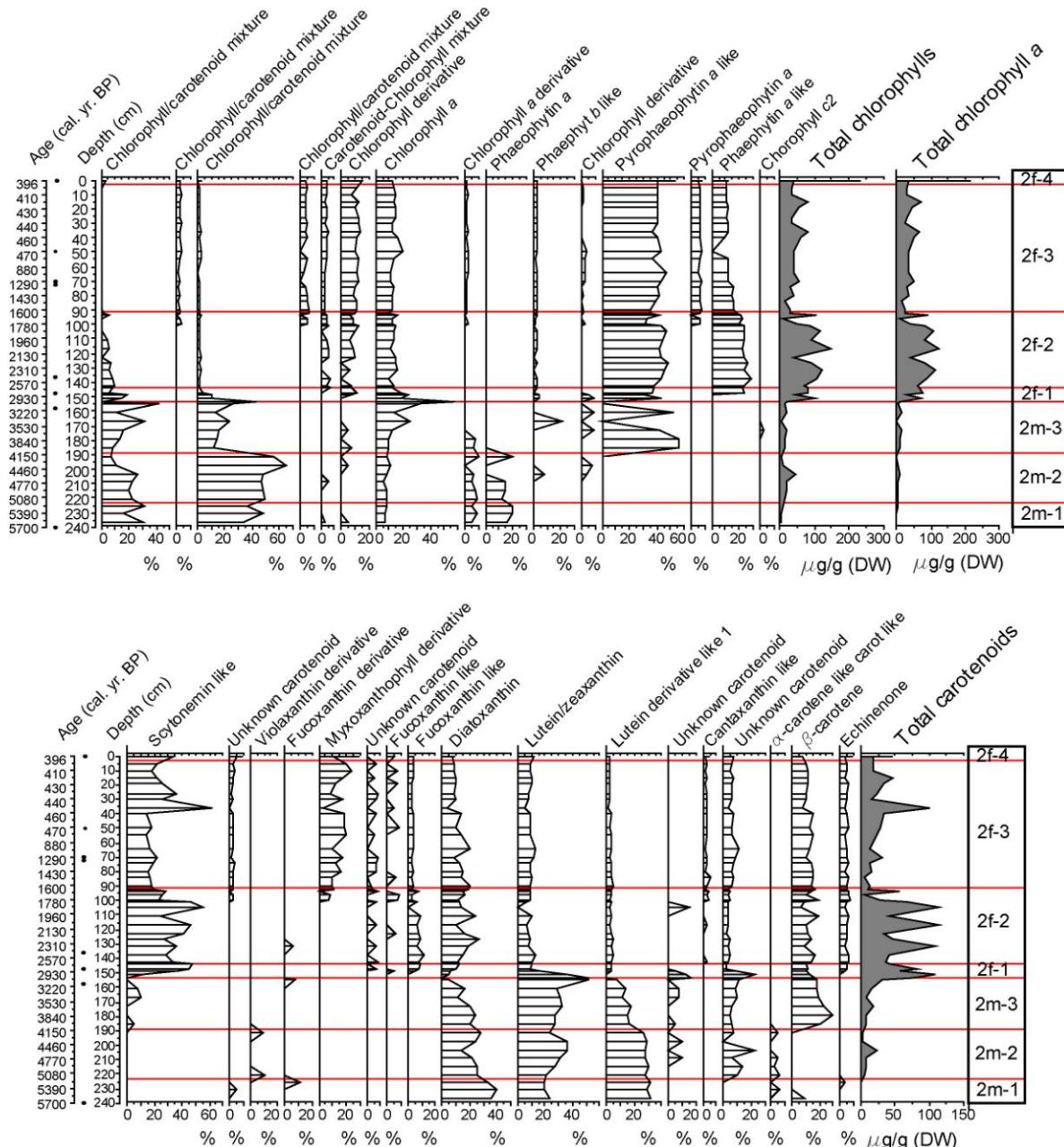
Fig.22: Fossil pigment stratigraphy of the lake Beak-2 sediment core, plotted against depth (cm). Corresponding interpolated calibrated ages are given, and depths of ^{14}C dates are indicated by black dots. Only pigments constituting more than 2% of the total carotenoids or total chlorophylls are shown. Total pigment concentrations (grey shaded graphs) are expressed in µg/g dry weight (DW). Zonation of the core is based on a CONISS cluster analysis performed on the diatom data (Fig.19).

Fossil DNA

DNA was extracted from 19 and 7 layers in the sediment cores from BK1 and BK2, respectively, covering a period from the present time till c. 3500 y BP (Fernandez Carazo et al. in prep.).

Amplification of long fragments (ca. 1700 bp) of 16S rRNA genes was difficult or impossible because of the fragmentation of fossil DNA. However, amplification of smaller fragments (ca. 450 bp or 250 bp) was possible with direct PCR (primers N359F-781R or 533F-781R) by optimization of previous protocols. Samples were studied by DGGE, with two pairs of primers per sample (N359F-781R(GC)(a) and N359F-781R(GC)(b).

A first test of the *rpoC1* marker with sediment core layers from Progress Lake (Larsemann Hills, Eastern Antarctica), allowed us to obtain amplicons until 30 cm depth with specific primers for *rpoC1* (3F, 4R, 7F, 8R; K. Waleron, unpubl. data), as deep as for 16S rRNA based PCR.

Sample BK1-12 cm was too degraded or the DNA concentration was too low for direct PCR amplification. Therefore, it was treated by Multi Displacement Amplification (MDA) as an initial step in order to increase the concentration of fossil DNA. Subsequent PCR allowed us to detect several genotypes. Preliminary tests with HIP and random primers showed similar results (Fig.23). Our results suggest that MDA can enable the study of samples containing low amounts of DNA that would otherwise be impossible to analyze by direct PCR, which is in agreement with previous studies (e.g. Gonzalez et al., 2005; Binga et al., 2008 and references therein).

We have also investigated whether the MDA could introduce biases in the biodiversity of a sample. We therefore analyzed the PCR products using DGGE from sample BK1-46.5cm both with and without MDA. MDA did not give a different diversity than the method using direct PCR (Fig.23, 24).

— Synechococcus sp. LS0535 DQ526409 (99%)

— Chloroplast 1 99%)

— Chloroplast 2 (99%)

— Chloroplast 3 (99%)
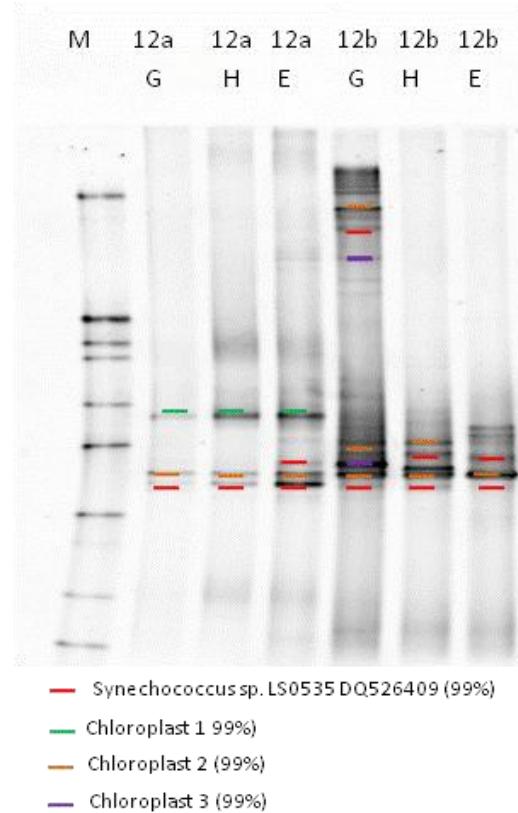
Fig.23: MDA amplification of sample BK1-12 cm with Repli-g kit (G), HIP1 primers (H) and random primers (E). The diversity was similar using all methods.

— Synechococcus sp. LS0535 DQ526409 (99%)

— Chloroplast 1 (99%)

— Chloroplast 2(96%)
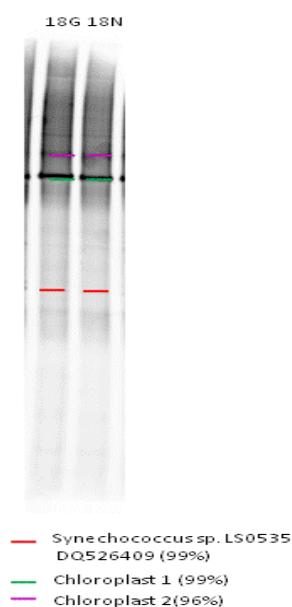
Fig.24: PCR amplification of sample BK1-18 previous MDA amplification (G) and by direct PCR from the sample (N). MDA did not alter the diversity found in the original sample.

Beak Island Lake 1

Based on the fossil cyanobacterial sequences from 19 layers, we can divide the 48 first centimeters of the BK1 core in two major sections (Fig.25). Section 2 (5.5 cm to 48 cm) contains three groups of sequences that are constantly present in all the samples. OTU58 is only composed of unicellular cyanobacteria related to *Synechococcus* sp. This OTU includes strains from different types of freshwater lakes (Lake Constance in Germany, Lake Superior in USA, Lake Hovsgol in Mongolia, etc) and coastal waters, but also fossil sequences which are up to 9500 years old found in sediment cores from Heart Lake, the Larsemann Hills, East Antarctica (LAQUAN report; www.BelSPO.be). Although cyanobacterial mats generally mainly consist of filamentous organisms a unicellular OUT was dominant in the sediment core. This was also observed in the LAQUAN project and suggested that the preservation of the DNA of unicellular taxa is better than filamentous cyanobacteria. The two other clusters appear to be of plastid origin. Cluster I (Fig.25) includes sequences of enigmatic affiliation, most probably plastids. The close relatives include only uncultured sequences from the Baltic Sea, Lake Kinneret (Israel), and soil of the Antarctic Peninsula, but no strain sequences. The closest strain is *Koliella sempervirens*, a green algae. Species belonging to this genus were found in polar regions (Stibal & Elster). A 'Prochlorales' is also found in Genbank (DQ059300) but the strain was lost by the authors before they had sufficient data (M. Gantar, personnal communication) and the data were not published. Therefore, we consider this affiliation as doubtful. Moreover, D. Scanlan (U. Warwick, UK) kindly analysed a sequence of this cluster and found that it was situated on a branch halfway between a group of Prasinophyceae and *Chlorella* sequences (D. Scanlan, personal communication). This analysis supports the hypothesis that cluster I represents plastids of a new lineage of green algae of which the 16S rRNA has not yet been sequenced (though the nuclear 18S rRNA might be known). We also observed another cluster of plastid sequences in all the studied layers (cluster III) that is clearly related to green algae.

Depth (cm)	Sample	OTU101 (Anabaena)	OTU102 (Nostoc 1)	OTU58 (Synechococcus)	Cluster I (Enigmatic)	Cluster II (Enigmatic 2)	Cluster III (Green algae)	Cluster IV (Moss)	
0	BK1	■		■	░		■	░	
0,5	BK2			░	░		■	░	Section1
1	BK3	░		░				■	
1,5	BK4	░		░	░			░	
2	BK5	░		■	■		░	░	
2,5	BK6		■	░	░	░	░	░	
5,5	BK7			■	░		░		
6	BK8			■	░		■		
6,5	BK9			░	░		░		
7,5	BK10			■	░		░		
8	BK11			░	░		░		
24	BK12			░	░		░		
27	BK13			■	░		░		
36	BK14			░	■		░		
38	BK15			■	░		░		
42	BK16			░	■		░		Section2
45	BK17			░	░		░		
46,5	BK18			░	■		■		
48	BK19			░	░		░		
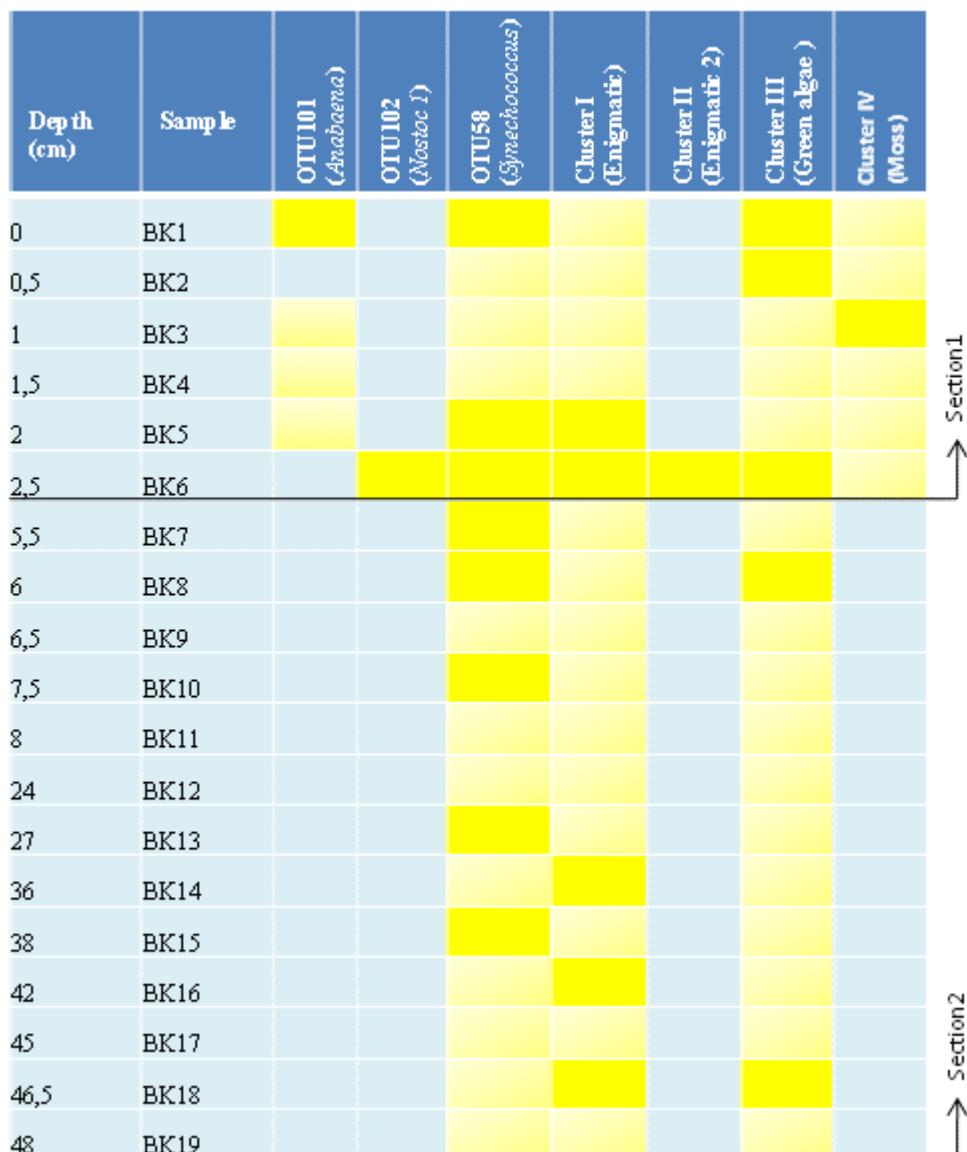
Fig.25: Presence of OTUs and plastid clusters per sample. The OTU denomination follows the one in the distance tree of figure 26. Cells in dark yellow indicate that the DGGE bands have been sequenced. Pale yellow cells represent the genotypes that were inferred by their DGGE band positions.

The smaller section (section 1) is situated in the first 2.5 cm of the core. It includes four additional groups, compared to section 2, with filamentous heterocystous cyanobacteria related to the Nostocales order, a moss plastid (cluster IV) and one sequence related to the enigmatic cluster I but sufficiently distant to make a distinct cluster (cluster II). In OTU101, the closest related sequences are derived from freshwater bodies in Finland (*Anabaena flos-aquae* strain (AJ630420) and *Anabaena solitaria* (AJ293105); Fig.26).

They belong to a cosmopolitan OTU that had not yet been observed in Antarctica before. In OTU102, that was found at the bottom of the section 1 only, the closest related sequences are from a DGGE band from a lake in the Vestfold Hills (Fig.1) and a *Nostoc* strain isolated from the Finnish lake Sääksjärvi. This OTU is also cosmopolitan. Sequences related to a bryophyte plastid (cluster IV) were also only found in section 1, which is in agreement with the occurence of mosses in the upper sediments.

Four different zones could be identified in the BK1 core (Fig.27) based on fossil DNA studies using the primers specific for eukarya and chlorophytes. The first zone (48-46 cm) is characterized by a low amount of bands using both primers. According to the BLAST search *Choricystis minor* (HE4) and *Choricystis sp.* (HC2) were the dominant taxa, together with an unknown eukaryotic taxon (HC13). Zone 2 is characterized by the appearance of a large amount of sequences belonging to the Chlorophyta (6 bands on average) and the disappearance of a *Choricystis minor* sequence (HE4). Zone BK1-3 is characterized by a high amount of bands (10 on average), the appearance of a larger cercozoan community (4 different bands) and the disappearance of *Choricystis* or *Nannochloris* sequences. Zone BK1-4 is the most recent part of the core and characterized by the most pronounced changes in microbial community structure and the highest diversity. The diversity of bands related to chlorophytes is lower compared to the previous zone. The most striking result is the sudden disappearance of sequences belonging to the Chlorophyta (a *Choricystis* sequence) that was dominant in the other three zones (HC2), the local extinction of three of the four cercozoan species, and the appearance of a large amount of new species.

Distance 0.1

BK115D05b
BK220D07a
BK101D03b
BK113D01a
BK110D03b
Synechococcus LS0535 DQ526409
BK108D01b
Synechococcus hub-5 DQ297464
BK224D03a
BK105D036
BK107D05b
BK221D08b
82 BK223D05b5
Synechococcus LS0534 DQ526408
79 BK106D03b
Synechococcus sp. BO984127
cl FALLScyano02C11 DQ398338
78 DGGE Heart Glewl-0 B2 (2seq)(OTU58)
DGGE ProgressP41b (0 1)(3 seq)(OTU58)
Cl ReidJ105 (4 seq) (OTU58)
95 Cl Heart glewl 14 48 (59 seq) (OTU58)
DGGE_Heart_Glewl-4 B3 (2 seq)(OTU58)
Cl Heart surfC02 (12 seq)(OTU58)
DGGE ProgressB13 (1 2) (OTU58) (4 seq)
100 92 Synechococcus sp. WH 5701
DGGE Heart Liv4-84 B5 (2 seq)(OTU58)
DGGE Heart Liv4-76 A8 (OTU58)
DGGE_Heart_Liv3-61 B4 (OTU58)
100 Synechococcus-like str. ACE (OTU59)
Cl Heart glewl_14_15 (9 seq) (OTU59)
99 BK226D02a7
cl Raunefjorden 18 AM706654
100 Anaba flos-aquae 0tu33s15 AJ630420
BK101D03a
99 DGGE Heart Liv4-76 KA11 (NewOTU81)
89 DGGE_Heart_Glewl-2 KA4 (NewOTU81)
Calothrix sp. PCC 7714
BK106D04a
100 BK224D01a
96 DGGE band Burgess-91a EU009675
Nostoc 152 AJ133161
Nostoc 117.8.2 AY328898
9 BK223D03a7
87 BK226D01a
BK221D03a
Nostoc M carnosa cyanobiont DQ185235
Nostoc commune EV1-KK1 (OTU33)
Cl_Heart_glewl-14_15_19 (OTU33)
BK220D05a
Nostoc commune KU002: AB088375
100 Uncult Ant cyanobact cl SalP09 (OTU63)
Cl_Heart_glewl-14_E4 (OTU63)
Cl ReidJ093 (5 seq) (OTU16)
Cl Heart surfC25 (7 seq) (OTU16)
100 DGGE ProgressP33b (0_1) (2seq)(OTU16)
DGGE ProgressP46b (1_2) (5 seq) (OTU16)
DGGE ProgressP48b (2_3) (3 seq) (OTU16)
Cl_Reid 34 22 (OTU7)
Cl_Heart_glewl-14_35 (NewOTU79)
DGGE ProgressB43 (7_8) (NewOTU80)
DGGE ProgressP44b (1 2) (OTU19)
100 Cl ReidI078 (13 seq) (OTU19)
Cl_Reid_34_68 (2 seq)(OTU19)
Uncult Ant cyanobact cl Fr252 (OTU19)
DGGE ProgressP45b (1 2)(2 seq)(OTU19)
DGGE ProgressB32_(2_3) (4 seq)(OTU19)
80 Oscillatoria sp. E17
100 Arctic_51 EF379232
BK222D01a
94 DGGE ProgressP93a (7 8) (2 seq) (New OTU8ðÖ¥)
77 DGGE progressP107a (8_9) (NewOTU82)
91 Synechococcus sp. PCC 7502
DGGE ProgressP4 (1_2)(New OTU83)
Cl ReidJ116 (OTU2)
79 Cl Progress_surfA10 (11 seq) (OTU2)
92 DGGE_Heart_Glewl-0 A3 (2seq)(OTU02)
Uncult Ant cyanobact cl FreP07 (OTU2)
Cl Progress surfB13 (2 seq) (OTU3)
Pseudanabaena PCC7403
100 DGGE ProgressA11 (1 2) (6 seq) (OTU1)
Cl ReidD107 (2 seq)(OTU1)
Uncult Ant cyanobact cl FrE313 (OTU76)
99 Cl Heart_glewl-14_A6 (OTU76)
100 Cl_Heart_glewl-14_15_45 (OTU76)
Pseudanabaena PCC6903
Limnothrix sp. MR1
Cl ReidD010 (2) (76)(DGGE H glewl_4a4)
BK226D04b
100

OTU58
OTU59
OTU 100
OTU 101
OTU81
OTU102
OTU33
OTU63
OTU16
OTU07
OTU79
OTU80
OTU19
OTU44
OTU82
OTU83
OTU02
OTU03
OTU01
OTU76

Fig.26: Distance tree of partial 16S rRNA sequences (255 bp), using Neighbor-joining algorithm and the Jukes and Cantor correction for multiple mutations. A boostrap analysis was carried out, involving the construction of 500 resampled trees.

The bootstrap values higher than 70% are indicated besides the concerned nodes. Sequences are from core layers of BK1 (red), BK2 (dark red), Heart lake (blue), Progress lake (green) and lake Reid (purple), together with reference sequences from GenBank and modern microbial mats of Heart Lake, Progress Lake and Lake Reid (black). The data for the latter three lakes are taken from the LAQUAN report.
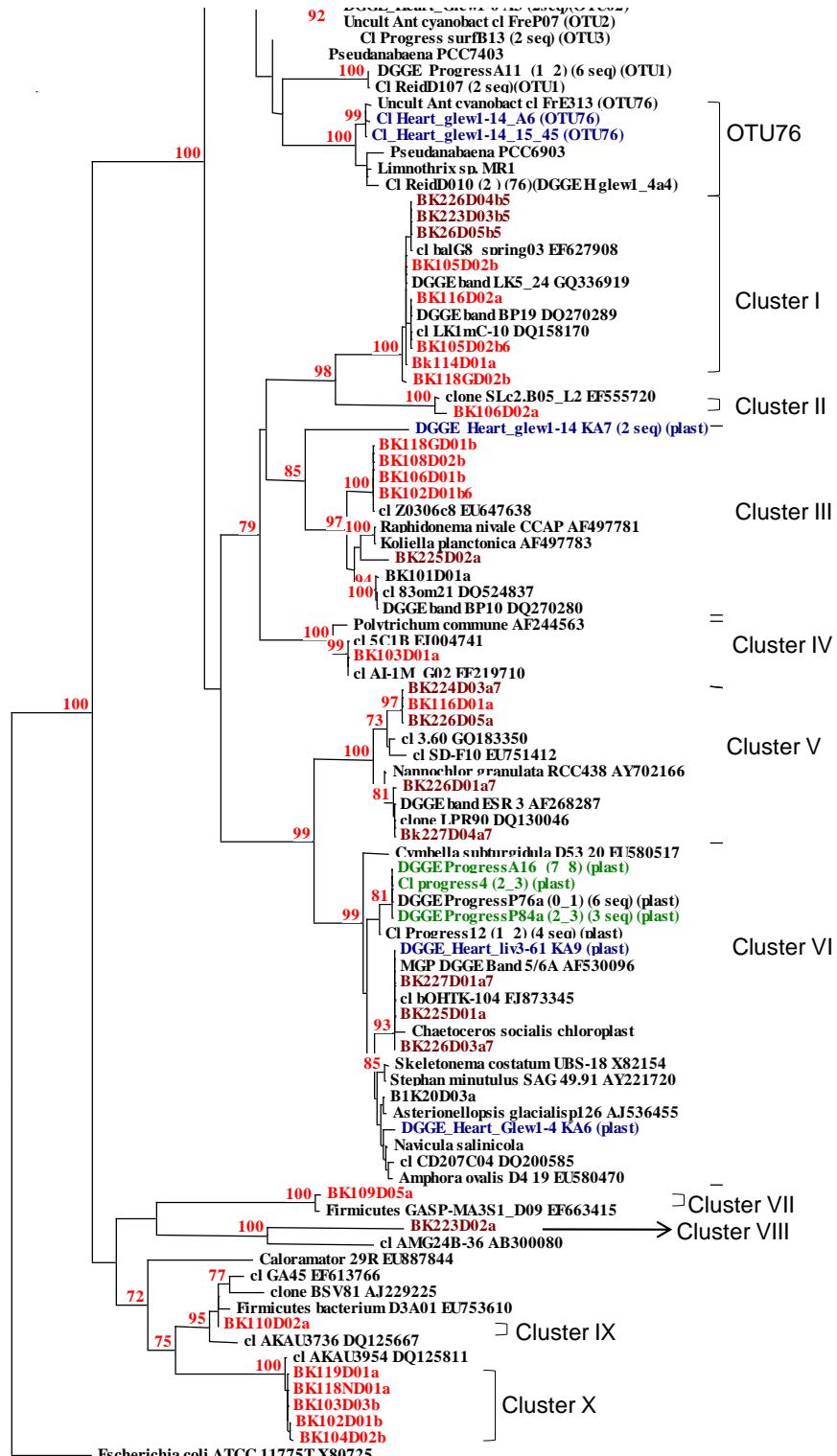

Fig.26: continued
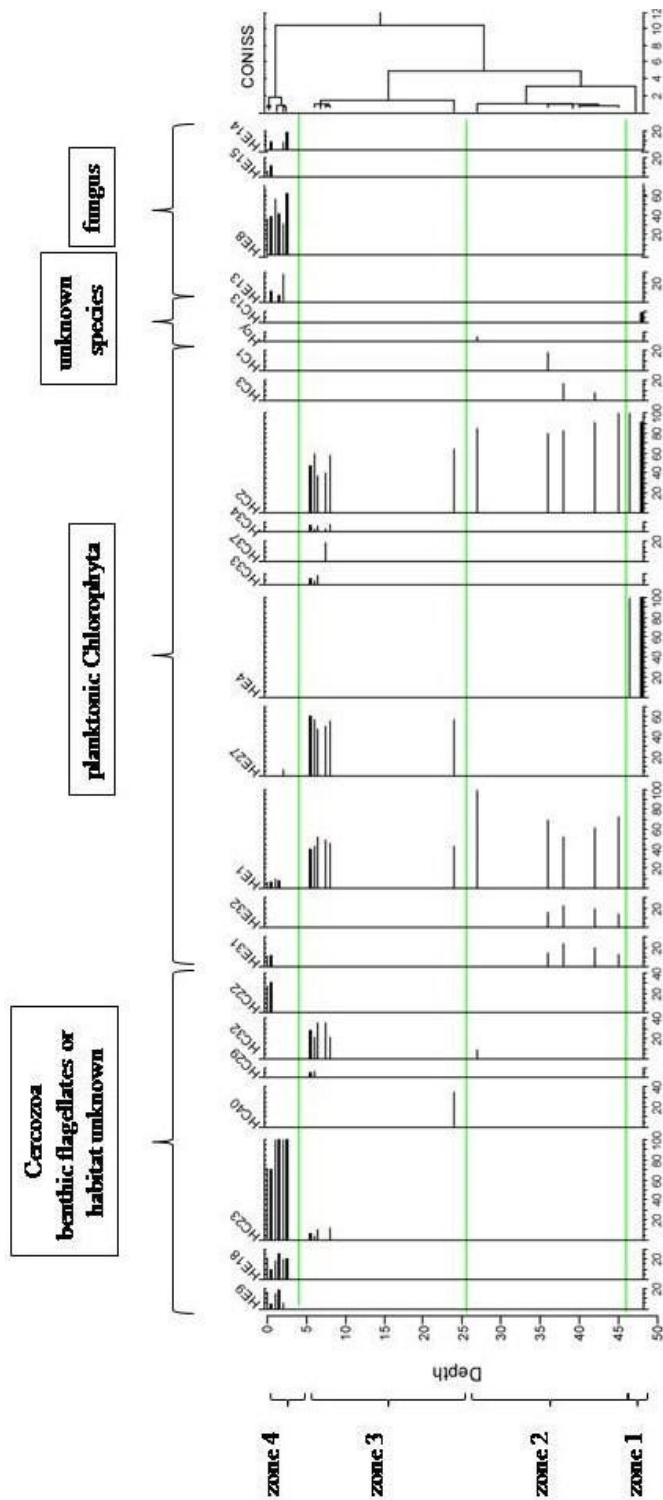
Fig.27: Stratigraphic plot and CONISS cluster analysis of core BK1. Relative abundances (%) of taxa and the subdivision in zones are shown. The identification of the excised DGGE-bands was performed with the BLAST algorithm. Bands with the prefix HE were obtained using the general eukaryote primers and bands with the prefix HC with the chlorophyte specific primers.

Beak Island Lake 2

For the core of BK2, seven layers were to a core depth of 156 cm. The changes in community structure in this core seem to be less pronounced as in BK 1, and unlike in BK1, filamentous cyanobacteria were found throughout the entire core, except in section 5 (156 cm). Two OTUs are present throughout the entire core, the unicellular OTU58 and a cluster (VI) of diatom plastids (Fig.28). The latter was not present in the studied layers of BK1. Five main sections can be recognized.

In the oldest layer of Section 5 the two permanent groups plus the enigmatic cluster I (described for BK1), the cluster V of sequences related to the plastids of Eustigmatophyceae algae, and the cluster III of green algae plastids are present.

Section 4 (130-150 cm) contains OTU100 (Fig.26), OTU33 that contains *Nostoc* sequences (different from the other *Nostoc* OTU102 from BK1) including some cyanobionts of mosses, the enigmatic plastid cluster I (as in BK1), the cluster V of Eustigmatophyceae plastids and the cluster III of green algae.

Section 3 (60-64 cm) seems slightly less diverse and includes the permanent OTUs, OTU33, and two plastid clusters (I and V).

Section 2 (10-5 cm) is the most diverse in cyanobacterial OTUs. A classical filamentous mat-former is represented by OTU44, and both *Nostoc* OTUs (102 and 33) are present. Moreover, the enigmatic plastid cluster disappears, as well as the Eustigmatophyceae and green algae. Only two clusters of diatom plastids remain, namely one related to *Chaetoceros* and *Cymbella* (cluster VI) and one including taxa like *Skeletonema* and *Navicula* (cluster VII). These diatom clusters also include fossil sequences from the sediment cores of Progress Lake and Heart Lake (LAQUAN report).

Section 1 is the layer at 1 cm depth. Only 4 groups, already observed at 5 cm depth occur, namely OTU33, OTU58 and the two diatom clusters.

| Depth (cm)	Sample	OTU44 (Oscillatoria)	OTU100 (Unknown)	OTU102 (Nostoc 1)	OTU33 (Nostoc 2)	OTU58 (Synechococcus)	Cluster I (Enigmatic)	Cluster VI (Diatom 1)	Cluster VII (Diatom 2)	Cluster V (Eustigmatophyceae)	Cluster III (Green algae)	
1	BK20				■	■		■	■			Section1
5	BK21	■			■			■				Section2
10	BK22	■		■	■			■				
60	BK23				■	■	■					Section3
64	BK24				■	■						
132	BK25				■			■	■		■	Section4
146	BK26		■		■	■			■			
156	BK27				■	■		■	■	■	■	Section5
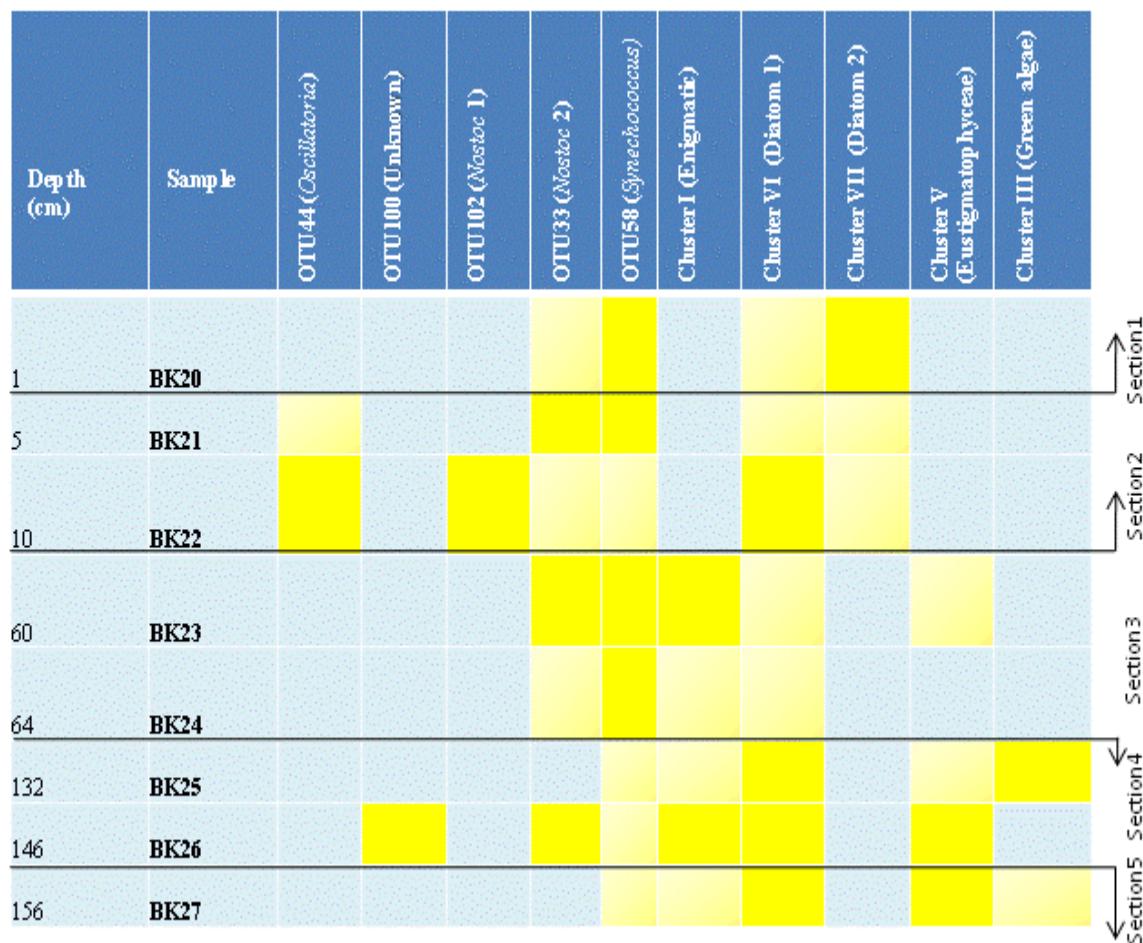
Fig.28: Presence of OTUs and plastid clusters per sample. The OTU denomination follows the one in the distance tree of figure 26. Cells in dark yellow indicate that the DGGE bands have been sequenced. Pale yellow cells indicate that the genotypes were inferred by their DGGE band positions.

In both cores bacterial sequences were sometimes retrieved. Particulalry Gram-positive bacteria occurred in the layers from BK1 (Fig.26). As they are probably due to non specific amplifications, we can only infer that they were quite abundant in these layers.

Table IV: Closest related sequences found by BLAST analysis. Accession numbers and percentages of similarity are shown into brackets. A "-" indicates no significant match within the database (less than 90%).

DGGE band	Uncultured closest relative (%)	Strain closest relative (%)
BK101D3a	Uncultured cyanobacterium cln_OTU27CN45 (AM259248) (98%)	*Anabaena* sp. (AJ630439) (99%)
BK106D4a	Uncultured bacterium clone H04_SB4A (FJ592868.1) (98%)	*Nostoc* sp. SKS8 (EU022706) (98%)
BK220D05a; BK221D03a; BK224D01a; BK226D01a; BK226D02a; BK223D03a7	Uncultured *Nostoc* sp (EU359045) (99%)	*Nostoc commune* (AB088375) (100%)
BK222D1a	Uncultured cyanobacterium (DQ388957) (98%)	*Phormidium autumnale* SAG78 (EF654084) (98%)
BK113D01a; BK220D07a; BK224D03a, BK115D03b; BK115D04b; BK115D05b; BK106D03b; BK106D04b; BK107D05b; BK108D01b; BK110D02b; BK110D03b; BK221D02b; BK221D03b; BK221D06b; BK105D03b5; BK221D08b; BK221D07b; BK223D05b5; BK115D04b7	Uncultured *Synechococcus* sp clone hub-5 (DQ297464) (99%)	*Synechococcus* sp. LS0535 (DQ526409) (99%)
BK114D01a, BK116D02a; BK101D02b; BK105D01b; BK105D02b; BK118GD02b; BK106D01b; BK105D02b6; BK223D03b5; BK226D04b5; BK226D05b5; BK115D03b7; BK115D06b7;	Uncultured cyanobacterium clone balf5 (EF62790) (100%)	*Prochlorales* cyanobacterium EV-7 (DQ059300) (97%)
BK116D01a; BK226D05a; BK227D04a7; BK226D01a7; BK224D03a7	Uncultured cyanobacterium LPR90 (DQ130046) (98%)	*Nannochloropsis salina* CCMP527 (AY702112) (96-98%)
BK220D03a	Uncultured bacterium band c-4D (EU140526) (98%)	*Amphora coffeaformis* (FJ002183) (98%)
BK107D03a, BK109D05a	Uncultured *Firmicutes* bacterium clone (EF663415) (99%)	-
BK110D02a	Uncultured *Firmicutes* bacterium clone (EU753610)) (99%)	-

BK223D02a	Uncultured *Firmicutes* clone AUVE-03H10 (EF651019) (80%)	-
BK225D01a; BK227D01a7; BK226D03a7	Uncultured eukaryote clone CB41E05 (EF471605) (99%)	*Chaetoceros socialis* chloroplast (AJ319825)(99%)
BK101D01a; Bk225D02a; BK106D01b; BK118GD01b; BK102D01b6; BK227D02a7	Uncultured phototrophic eukaryote clone 830m21 (DQ524837) (96%)	*Koliella spiculiformis* (AF278746) (96%)
BK118D1a, BK119D01a, BK119D02a, BK119D03a, BK2-b1; BK103D03b1; BK103D04b; BK103D05b ; BK103D07b; BK104D01b; BK104D02b; BK106D02b	Uncultured bacterium clone AKAU3954 (DQ125811) (98%)	-
BK226D02a7	Uncultured bacterium clone (AB355043) (96%)	*Chlorella mirabilis* plastid (X65100) (90%)
Bk103D1a	Uncultured bacterium clone SC/8 (EU340231) (99%)	*Myurum hochstetteri* chloroplast (DQ629577) (100%)

Relative sea level curve

Relative sea level (RSL) curves can inform us about changes in former ice thickness, which is a function of internal ice-sheet dynamics, regional climate settings and global sea-level variations (e.g., Bentley et al. 2005). For the construction of RSL curves different types of data were collected. During the sampling campaign we collected the necessary field data (e.g., elevation measurements of the outflow, and sediment characteristics; see field reports).

A preliminary RSL curve was constructed for Beak Island (Fig.29). Marine to lacustrine transitions are present at 76 cm (6936 cal yr BP) in BK1, 151 cm (3327 cal yr BP) in BK2 and 46 (1991 cal yr BP) in BK3. This information is being summarized together with a detailed geomorphological description of the region (Hodgson & Roberts, in prep.).
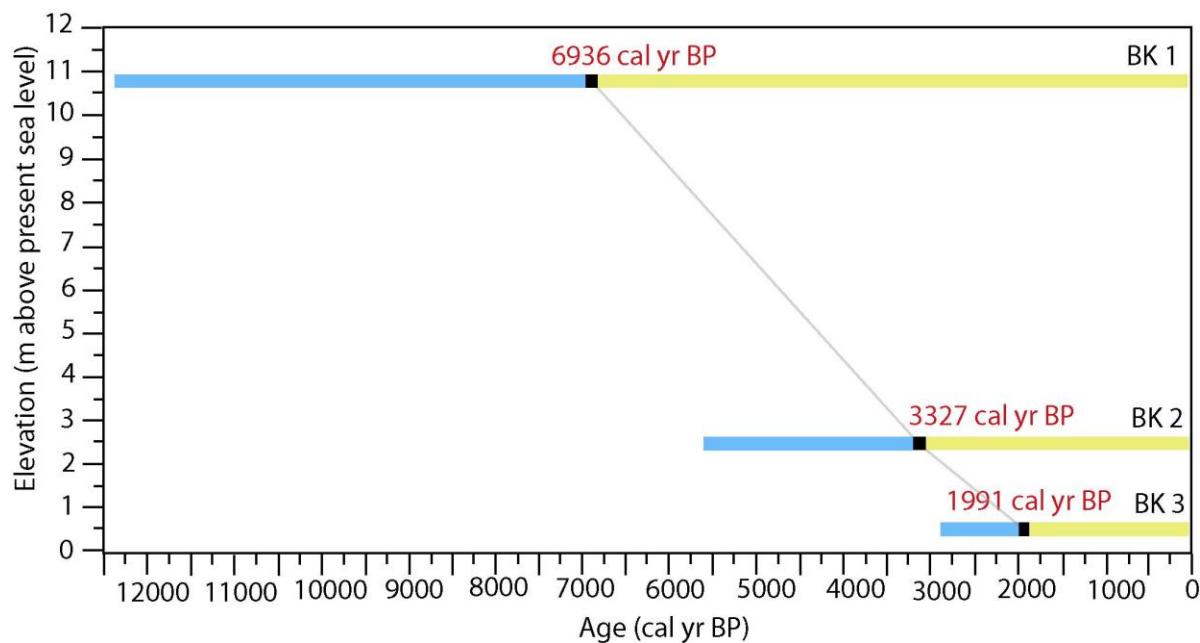
Fig.29: Tentative RSL curve for the Beak Island region. Marine sediments are indicated in blue and lacustrine sediments in yellow. Transition zones between marine and lacustrine sequences are indicated in black. For error bars and dating uncertainty see Table II.

2.3.3. East Antarctica

Diatom calibration dataset

In total, the diatom composition in 41 surface samples (Fig.30) was analyzed in order to construct a diatom based transfer function. Salinity is the most important factor and significantly explained 15% of the variation in diatom communities. The brackish and saline lakes are characterized by the presence of *Craspedostauros laevissimus*, *Synedropsis spp* and *Chaetoceros* resting spores, similar to saline lakes in the Vestfold Hills (Verleyen et al. 2003). *Diadesmis* spp., *Psammothidium* spp. and *Amphora* cf. *veneta* dominate the oligosaline lakes.
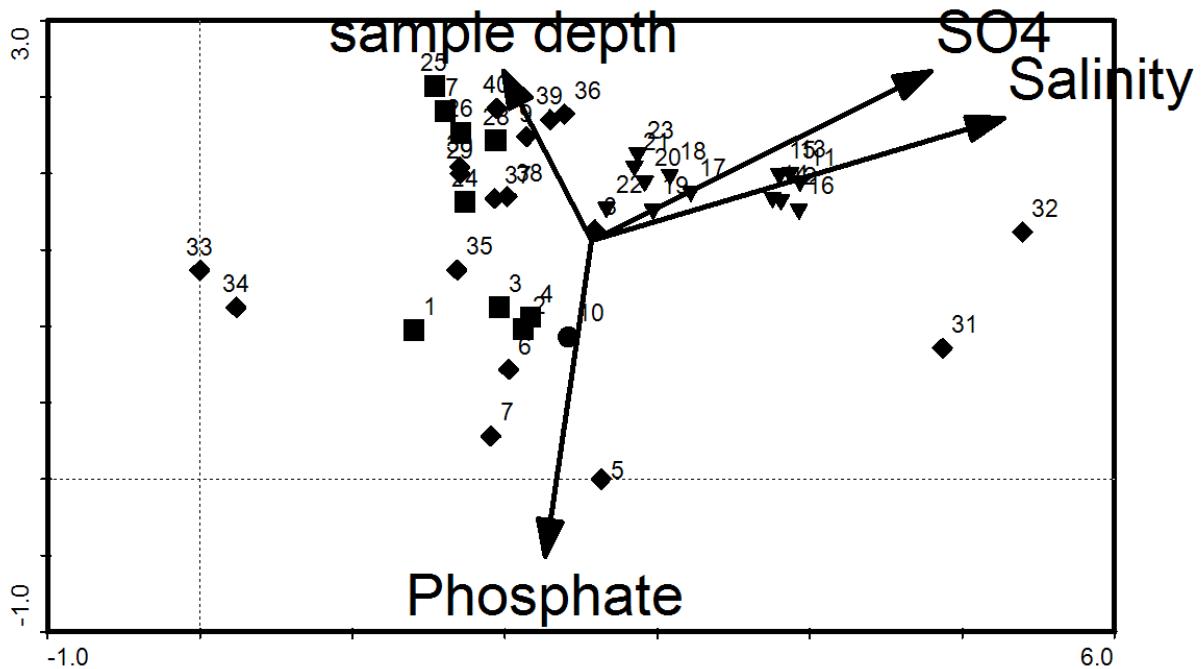
Fig.30: Detrended correspondence analysis of the diatom assemblages in the Lützow Holm Bay region with the significant environmental factors plotted as supplementary variables (Tavernier et al. unpubl. res.). Different symbols represent the different peninsulas and islands in the region; triangles: Langhovde, diamonds: Skarvsnes, squares: West Ongul, circles: East Ongul.

The dataset allowed us to develop a transfer function to quantitatively reconstruct past changes in lake water salinity throughout sediment cores. The model has a jack-knifed r^2 of 0.74 and a RMSEP of 0.1. These values are close to similar models from other east Antarctic oases (Verleyen et al. 2003).

Sedimentology

All cores which were not sliced in the field (9 cores in total), have been scanned with the MSCL Geotek scanner of Durham University for density and magnetic susceptibility. Five of these cores have been sedimentolocaly logged in great detail and were also photographed. The magnetic susceptibility graphs can be used as a crude and fast method to detect changes in lithofacies. Organic-rich sediments generally have a lower magnetic susceptibility signal than sediments which contain a larger detrital component.

If only using the magnetic susceptibility these changes seem quite sudden, but the sedimentary description and the measured changes in density do reveal that mostly short transit periods between the organic-rich or detritus-rich ends of the spectrum are present. All data are currently being integrated and will be part of the final project results.

Geochronology

37 samples from 8 sediment cores contained enough carbon for radiocarbon dating. The oldest measured date equals 8019 ^{14}C yr BP in West Ongul and 7650 ^{14}C yr BP in Skarvsnes (Table V).

Table V: ^{14}C dates of the sediment cores from the Lützow Holm Bay region

Material ID code	Stratigraphic position (cm)	AMS lab number	^{14}C age	^{14}C age error
SK1 LIV1 1-2	1-2	Beta - 261160	320	50
SK1 LIV1 51-52	51-52	SUERC-19466	413	37
SK1 LIV2 38-39	59-60	SUERC-19467	788	37
SK1 LIV2 40-41	61-62	SUERC-19468	919	37
SK1 LIV2 50-51	71-72	Beta - 261161	1300	40
SK1 LIV2 97-98	118-119	SUERC-18048	2785	35
SK1 LIV3 44-45	199-200	SUERC-18049	2993	37
SK1 LIV3 70-71(Matrix)	225-226	SUERC-18050	3208	35
SK1 LIV 3 70-71 spicules	225-226	SUERC-18348	2902	35
SK1 LIV3 96-97 (Matrix)	251-252	SUERC-18062	3274	37
SK1 LIV3 96-97 shells	251-252	SUERC-18349	2974	35
SK4 LIV1 57-58	57-58	SUERC-18051	1875	35
SK4 LIV1 70-71	70-71	SUERC-18063	2234	35
SK4 LIV1 80-81	80-81	Beta - 261164	2410	40
SK4 LIV2 50-51	126-127	SUERC-18352	3527	38
SK4 LIV3 18-19	178-179	SUERC-18353	4176	35
SK4 LIV3 45-46	205-206	SUERC-18354	5282	37
SK4 LIV3 94-95	254-255	SUERC-18355	3466	36
SK4 LIV4 54-55	274-275	Beta - 261166	7650	60
SK4 LIV4 59-60	279-280	SUERC-18356	7219	41
LA1 LIV2 37-38	69-70	SUERC-18053	3349	37
LA1 G 0-1	0-1	SUERC-18337	4277	37
LA1 G 16-17	16-17	SUERC-18052	2981	35
WO1 LIV1 39-40	39-40	SUERC-18056	3970	35
WO1 LIV1 73-74	73-74	SUERC-18066	5893	38
WO2 LIV1 28-29	28-29	SUERC-18057	2673	37
WO2 G 0-1	0-1	SUERC-18339	12	37
WO5 LIV1 22-23	22-23	SUERC-18058	5528	37
WO5 LIV1 23-24	23-24	SUERC-18069	5500	38
WO5 LIV1 33-34	33-34	SUERC-18070	5090	38

WO5 G 0-1	0-1	SUERC-18343	281	37
WO4 LIV1 0-1	0-1	SUERC-18342	149	35
WO4 LIV2 6-7	92-93	Beta - 261171	1130	40
WO4 LIV2 73-74	157-158	SUERC-18067	4583	36
WO4 LIV2 75-76	159-160	SUERC-18068	4856	38
WO4 LIV2 86-87	170-171	Beta - 261174	7240	50
WO8 LIV1 35-36	35-36	SUERC-18071	8019	40

Diatom data

Between 250 and 70 cm the SK1 core is characterized by the presence of marine diatoms with small *Fragilaria* spp being dominant until 170 cm and *Chaetoceros* resting spores being the dominant taxon from 170 onwards until c. 80 cm (Fig.31). Before the transition from marine to lacustrine conditions, the diatom assemblages are dominated by *Navicula phyllepta*, a species which is often found in intertidal communities and similar environments in Antarctica (e.g. Verleyen et al. 2004). In the lacustrine communities there is an increase in *Amphora veneta* and a decrease in *Craticula antarctica*. The latter species is almost absent in the most recent sediment samples. A diatom analysis at a higher temporal resolution will allow us to better assess recent turnover patterns in the diatom communities.
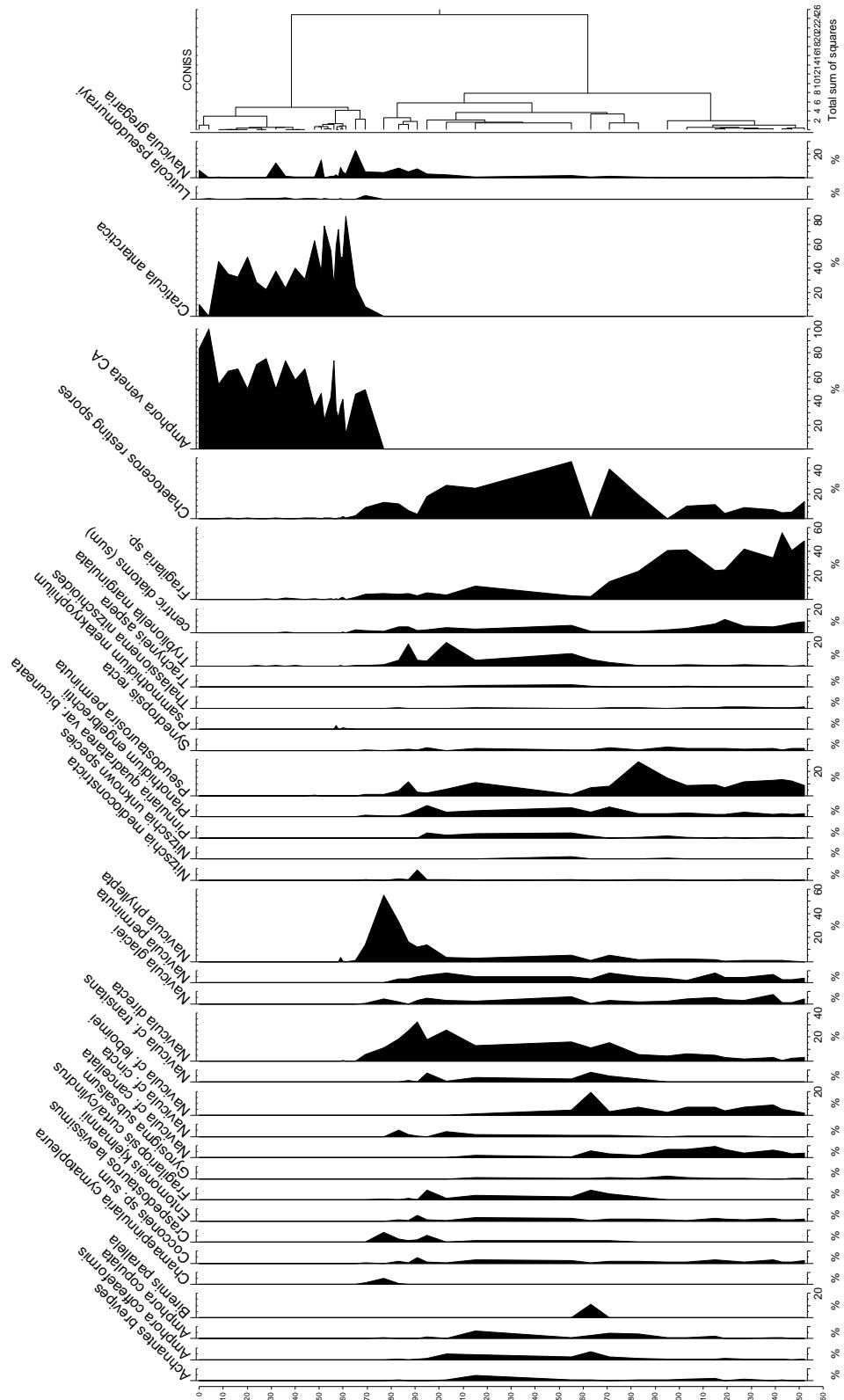
Fig.31: Diatom stratigraphy of the SK1 cores. Only taxa exceeding 2% relative abundance are shown.

Fossil pigment data

The fossil pigments were successfully analysed for the SK1 sediment core and will be integrated with the other data and included in the final report.

Relative sea level curve

The diatom communities in four lakes (SK1, WO1, WO4, SK4) were screened to develop a tentative relative sea level curve for the Lützow Holm Bay region (Fig.32). The transition in the other cored lakes will be assessed and added to the dataset. These preliminary data revealed that the uplift rate in the Skarvsnes region is different than that observed in West Ongul Island. Detailed diatom analyses of the sediment cores will allow us to better pinpoint these isolation events.
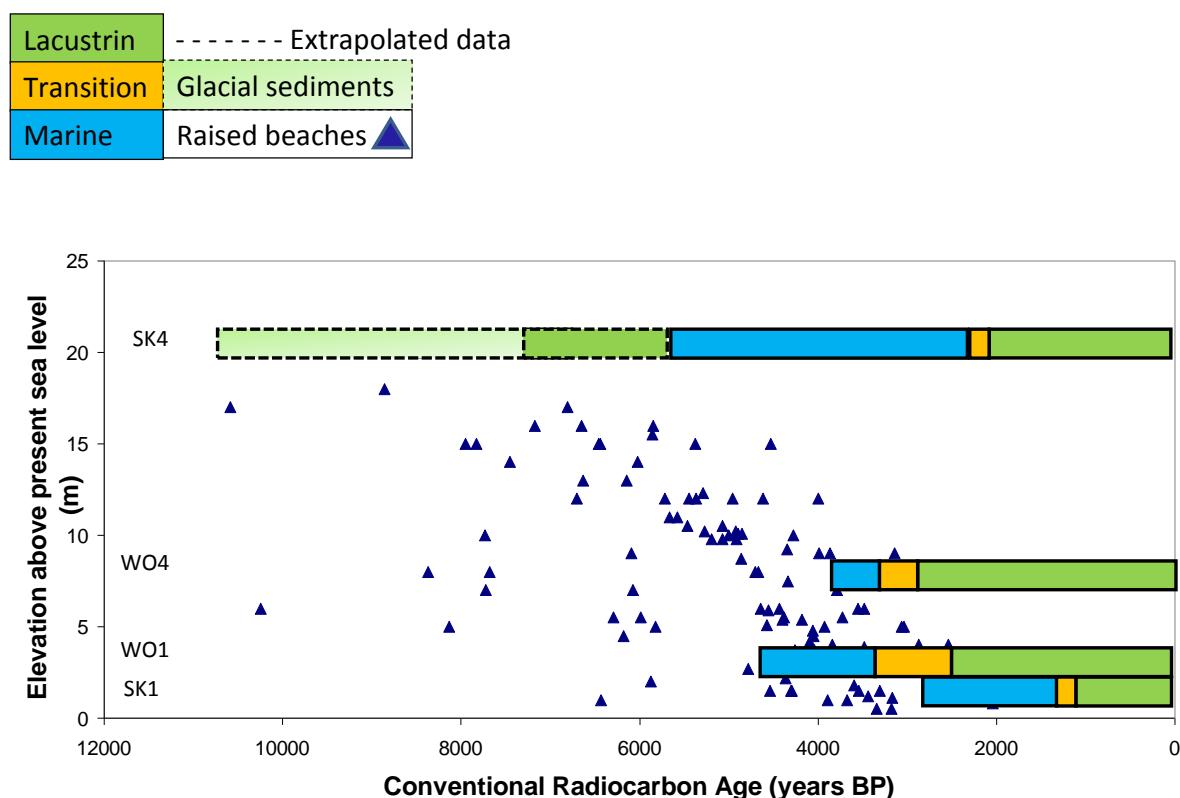

Fig.32: Preliminary relative sea level curve for the Lützow Holm Bay region based upon previously published raised beach data (Miura et al. 1998) and isolation lakes (HOLANT project) from West Ongul Island (WO) and Skarvsness (SK).

2.3.4. Integration and importance of the results

Past climate variability and deglaciation history in Sub-Antarctica

The sediment record extracted from Fan Lake extends back to c. 8 ka, which postdates a period of marked early Holocene warmth identified in Antarctic ice cores, and marine and lacustrine sediment records (see below). There are four main lithological units in the Fan Lake cores: a basal gravelly-diamict, overlain by finely-laminated glacial clay/silt, c. 8-4 ka; a disturbance unit at c. 4 ka; a finely-laminated organic-rich mud and clay c. 4-0 ka. The diatom record is dominated by a single species throughout, suggesting no major changes in palaeoenvironmental conditions in the last c. 8 ka. Conversely, high-ultra high resolution (mm-sub mm) variability in both gamma density and major element geochemistry (measured using ITRAX-XRF down to 200 microns) suggest the lake system possibly responds to annual/multi-annual and/or decadal/multi-decadal variations in climate in this part of the South Atlantic in the last 4 ka. In combination with newly retrieved sediment cores (field season 2008-2009) within the BAS CACHE-PEP program, this will allow us to reconstruct past climate variability on a high temporal resolution. Our record from Annenkov Island will form the basis for a comparison of past climate change records in the Sub-Antarctic region, which are being obtained by our colleagues from the British Antarctic Survey and the Australian Antarctic Division (see further).

Seismic stratigraphic indications of intensification of the westerlies during the Holocene on Kerguelen Archipelago

Within the four seismic-stratigraphic units identified in the sedimentary infill of Lac d'Armor (Kerguelen Archipelago), the upper unit is characterised by the presence of distinct mounded depocentres, which closely resemble drift deposits and thus suggest the influence of strong bottom currents. Given the specific setting, such bottom currents are likely wind-driven. We interpret the occurrence of these drift deposits as an indication of a strengthening of the influence of the westerlies during this period. In Lago Cardiel, Argentina (49°S), a similar event has been dated as 6800 cal a BP (Gilli et al. 2005) and in Laguna Potrok Aike, Argentina (52°S) around 6000 cal a BP (Anselmetti et al. 2009). Future long cores may provide confirmation of this hypothesis and may allow dating this important environmental change on Kerguelen Archipelago.

Sediment-core record of variations in paleoprecipitation on Kerguelen Archipelago

Up to present, very little paleoclimatic, and even less paleohydrological, records exist of the Holocene in the southern hemisphere oceanic realm. Most data come from Antarctic ice cores. Kreutz et al. (1997) evidenced a synchronous intensification of northern and southern westerlies (both tracked by marine aerosol-borne Naxs in GISP2 and Siple Dome ice core records, respectively) around 1400 AD as one of the main fingerprints of the Little Ice Age (LIA). On Kerguelen Archipelago, the sedimentary records from Lac

d'Armor are characterized by a main transition toward lower detrital input –and hence very likely to lower precipitation– since 1400 AD. Despite a weaker chronological control compared to ice core records, our Si_{bio} signal presents a significant correlation with the Naxs signal from Siple Dome (R = 0.5). This implies that in some extent, high-frequency variability of the westerlies impacted the climate on Kerguelen Archipelago through an anti-correlation between strength of the westerlies and precipitation, over the last millennium (Arnaud et al., 2009).

However, there is a distinct a 300-years time-lag between the increase in intensity of the westerlies and the first imprints of the LIA on the glaciers and hydrological records of the European Alps (Fig.33). By that time detrital input in Lake Armor was at its maximum, whereas it is currently at a minimum. It therefore still remains unclear if the high terrigenous input in Armor really represents the local expression of the LIA on Kerguelen Archipelago, or if a local LIA expression is actually out of phase with the northern hemisphere.
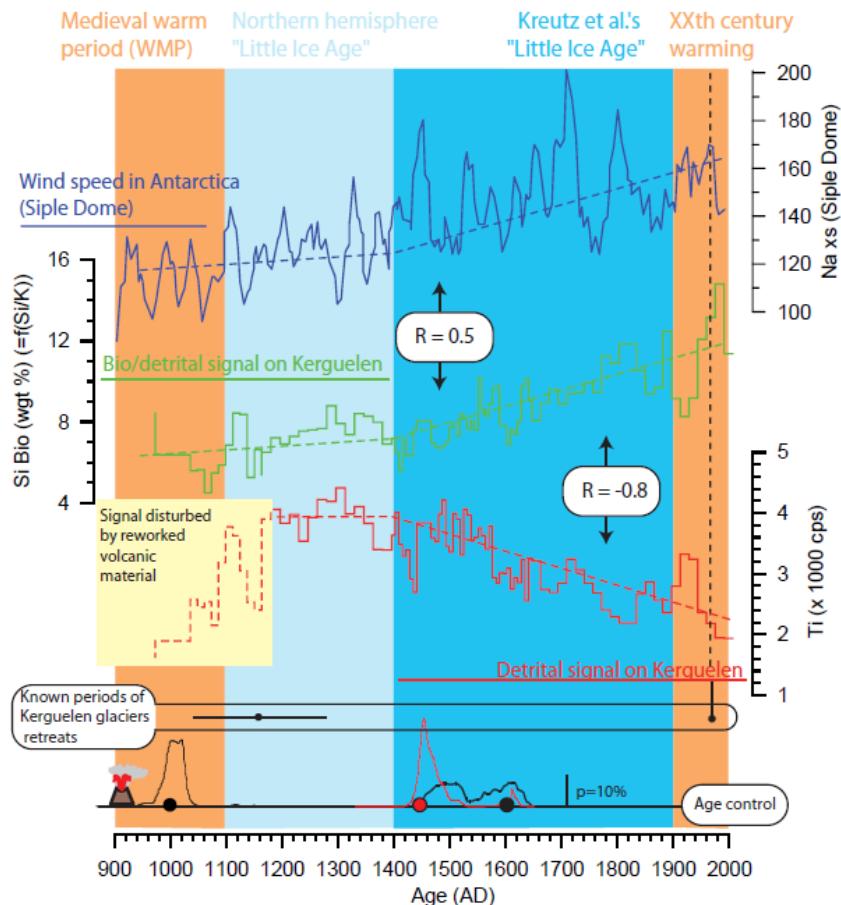

Fig.33: Overview of selected paleoclimate records in relation to the Kerguelen lake sediment cores

Diatom datasets, transfer functions and biogeography

During the HOLANT project we developed transfer functions to quantitatively reconstruct past changes in the nutrient concentration of Maritime Antarctic lakes. Together with the fossil pigment concentration, this will allow us to infer past temperature variability as it was shown that lake primary production and nutrient concentrations were directly related to air temperature in these lakes (Quayle et al. 2002). The transfer function for the Lützow Holm Bay region extends an existing model (Verleyen et al. 2003) and will allow us to reconstruct past changes in salinity in East Antarctica between 10 and 110°E. In East Antarctica salinity in mesosaline to saline lakes appears to be directly related to temperature (Verleyen et al. 2003). Both models have good to excellent predictive power and the error statistics are sufficiently low. We anticipate that our models will be critical research tools in paleolimnological research programs, for example in the Belgian DELAQUA project, the AAD project ICEMATE led by Dr. M. Riddle in which HOLANT members are involved and the Spanish Byers Peninsula project.

The diatom datasets used for the development of the transfer functions were intercalibrated at the species level, thereby ensuring that the data were taxonomically consistent with existing datasets from East, Maritime and Sub-Antarctica. This database complements a global diatom dataset at the genus level, which was used to study metacommunity dynamics in microbial communities (e.g. Vyverman et al. 2007, Verleyen et al. 2009). The database contains over 500 lakes and will be used in biogeographical research projects aimed at studying the distribution of diatoms in the Southern Hemisphere. A preliminary analysis revealed that the number of endemic species was unexpectedly high and that each region is characterised by different diatom communities (Verleyen et al. unpubl. res.). As some of these lakes were recently shown to respond very quickly on climate variability (see above and Hodgson et al. 2006), these results have obvious consequences in the light of future climate changes and the conservation of these pristine ecosystems.

Past climate variability in Maritime Antarctica

We extended the network of existing records with well-dated sediment cores from both the eastern and western margin of the Antarctic Peninsula (AP). In summary, in Beak Island the onset of marine sedimentation at the start of the Holocene provides a minimum age for deglaciation. Conditions remained cold and perennial sea ice persisted in Prince Gustav Channel until c. 9.2 cal. ka BP when a transition took place from near perennial sea ice cover and high iceberg concentrations, to a seasonally open marine environment until at least 6.6 cal ka BP. In Marguerite Bay open water conditions are inferred from the diatom communities until c. 8 ka BP. The isolation of

the lake in Beak Island prevents paleoclimate reconstructions to be made for the period between c. 6.6 and 6 ka BP. Between c. 6 and 3.5 ka BP relatively cold climate conditions on land prevail as reflected in low primary productivity levels. Between c. 3.5 and 1.7 cal. ka BP, a wetter and milder climate likely resulted in higher organic sedimentation rates and a well developed planktonic community, which we link to the Mid Holocene Hypsithermal (MHH) previously recorded elsewhere in the north and northeastern Antarctic Peninsula. This MHH is not evident in the Marguerite Bay region. There lake primary productivity gradually declined after the isolation of the basin. Neoglacial cooling is evident in Beak Island from c. 1.7 cal ka BP, which is interrupted by an increase in primary productivity and a shift in diatom diversity and species composition. This increase in lake primary productivity and clear changes in the diatom record are more pronounced in the Marguerite Bay region (Fig.34) and likely related to the recent temperature rise recorded in several regions of the Antarctic Peninsula with the western part being among the fastest warming regions on earth (Steig et al. 2009). Our records thus enabled us a comparison to be made between the eastern and western coastal margin of the AP. This is important as all the available records were either not sufficiently dated or either retrieved from different environments which prevented an in depth comparison. It is for example well known that marine records likely reflect spring conditions, whereas lacustrine records summer when lake ice is absent/minimal (Bentley et al. 2009).
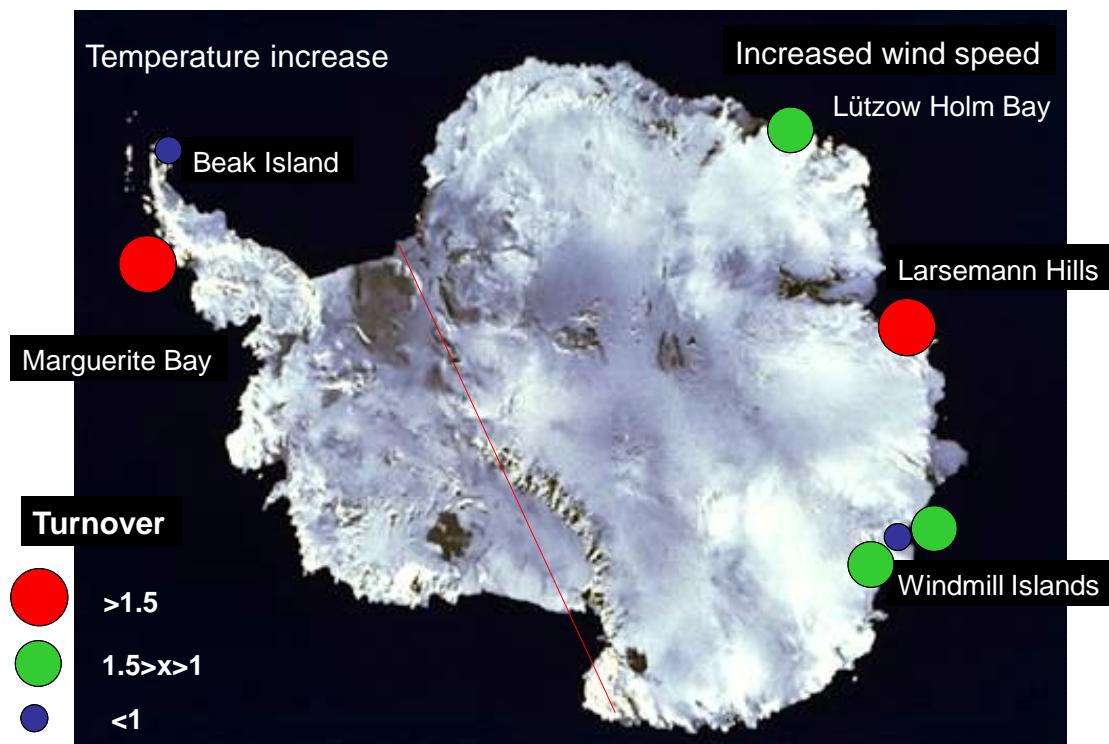
Fig.34: Mapped increases in the beta-diversity of the past decades expressed in SD units as estimated by detrended canonical correspondence analysis for the different diatom proxy records obtained within HOLANT and the previous LAQUAN project (Larsemann Hills). The data from the Lützow Holm Bay region are preliminary and based upon a diatom analysis of a sediment core from SK1 at a low temporal resolution. The turnover patterns need to be confirmed by the analysis of additional cores from the region.

Changes in the autotrophic communities and fossil DNA in Maritime Antarctica

The use of molecular techniques in combination with HPLC analysis and microscopy allowed us to assess the effect of past and recent climate variability on the autotrophic communities in Maritime Antarctic lakes. Sequences of cyanobacterial and plastid origin were obtained from the core layers of both lakes. The cyanobacterial diversity encompasses 3 OTUs in BK1 and 5 in BK2, with two common OTUs (unicellular OTU58 and *Nostoc* OTU102) that also show a similar temporal. Similarly, the diversity of plastid clusters is higher in BK2 (5) than in BK1 (4, including a moss). The changes in community structure studied using the cyanoabcteria specific primers are more pronounced in BK2. The major difference between both cores is the presence of heterocystous cyanobacteria in old layers of BK2, whereas these taxa were only detected in recent sediments in BK1. In addition, typical mat-forming Oscillatoriales are present in recent sediments in BK2, but absent in BK1.

For the plastid sequences, clusters I (enigmatic) and III (green algae) are common to both lakes but they disappear between 132 and 60 cm depth in the BK2 core, whereas they are still present in the top layer in BK1. In BK2, they are replaced by diatom-related plastid sequences.

The most striking result however is observed in BK1 around 2.5 cm depth, associated with an increase in fossil pigment concentrations, the appearance of heterocystous cyanobacterial OTUs, a plastid sequence related to mosses and a shift from a chlorophyte to a cercozoan and bryophyte dominated community (studied using green algae specific primers). These changes clearly passed the threshold of natural variability for at least the past 5400 years, with species going extinct and being replaced by newly colonized taxa. The observed changes are most likely the result of regional climate warming, which is apparently amplified in polar lake ecosystems as was also the case in Arctic water bodies (Smol et al. 2005, Smol & Douglas 2007). We conclude that (1) fossil DNA is a useful proxy in Antarctic lake sediment cores, but a larger dataset is clearly needed, and (2) the opportunity to study one of the most pristine ecosystems on Earth known to contain a large amount of endemic taxa may have disappeared.

Past climate variability in East Antarctica

In East Antarctica, a recent review by the HOLANT partners within the framework of the SCAR Antarctic Climate Change and the Environment report (Hodgson et al. in press; Verleyen et al. in prep.) highlighted the need for well dated past climate change reconstructions. Geological evidence is starting to reveal that deglaciation was asynchronous in the different regions, but that the currently ice-free regions deglaciated in general earlier in East Antarctica compared with the Antarctic Peninsula. This is not the case in the Lützow Holm Bay region, where the oldest date equals 8019 ^{14}C yr BP in West Ongul. These findings are however in contrast to raised beach evidence in which *in situ* fossils were dated to be as old as >40 ka BP (Miura et al. 1998). Our records from Lützow Holm Bay will be compared with the existing datasets which showed that nearly all regions experienced a near-synchronous early Holocene climate optimum (11.5-9 ka BP), coincident with the continued deglaciation of the Antarctic Peninsula Ice Sheet and an optimum recorded in ice cores from several Antarctic regions. A Mid Holocene warm period is present in many ice, lake and coastal marine records and it remains to be seen whether this part of the East Antarctic coastline follows this trend. There is no geological evidence in East Antarctica for an equivalent to the northern hemisphere Medieval Warm Period and there is only weak circumstantial evidence in a few places for a cool event crudely equivalent in time to the northern hemisphere's Little Ice Age. To date however, high resolution records from the coastal regions in East Antarctica are largely lacking.

Our well-dated past climate change records in Lützow Holm Bay (Enderby Land) are crucial in this respect and will extend the existing reconstructions in east Antarctica (Fig.34). A diatom analysis of a sediment core from a lake which isolated less recently is needed to confirm whether the turnover in diatom communities is related to recent climate variability or to lake evolution following isostatic uplift. In addition, the retrieval of a finely laminated sediment core (Fig.35) holds promising potential for high resolution studies in future projects. This is important as a recent synthesis of similar climate records, including ice cores, tree rings and lake sediments showed that Antarctica is highly understudied in this respect (Mann et al. 2008).
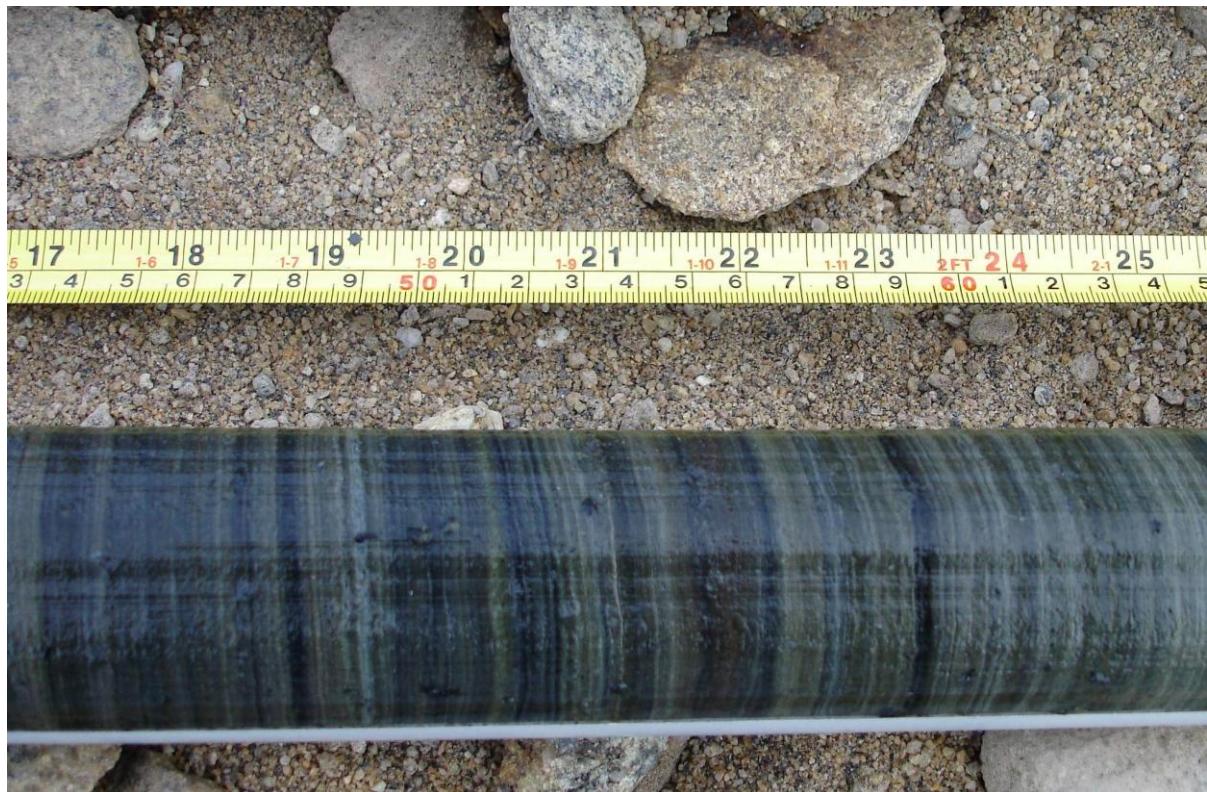

Fig.35: Finely laminated sediment core from Ô Ike (West Ongul Island) which can be used as a high resolution record of past climate variability.

Relative sea level curves

Two relative sea level curves were developed during the HOLANT project, one for the region near Prince Gustav Channel and one for the Lützow Holm Bay region. Although the Antarctic Ice Sheets are the biggest wild card in their contribution to post glacial sea-level rise, only a small amount of relative sea level curves for Antarctica is available at present (e.g. Bentley et al. 2005; Verleyen et al. 2005). Our data will be used in modeling experiments to analyse the ice thickness and dynamics consistent with the obtained RSL (cf. Bassett et al. 2007) in collaboration with our international partners. In addition, the preliminary RSL in the Lützow Holm Bay region has several important implications.

First, it suggests that the uplift and thus deglaciation history is different between Skarvsnes and West Ongul Island although the maximum distance between both regions is only c. 60 km. Our data suggest that RSL curves cannot be extrapolated from the local to the regional scale in this part of Antarctica. Second, the uplift rate in Skarvsnes is relatively high, which might be due to (1) a bigger ice mass being present over the region during the LGM than previously suggested and/or (2) a late deglaciation of the region compared with other East Antarctic Oasis (Verleyen et al. in prep.).

2.3.5. CONTRIBUTION OF HOLANT TO COURSES AND STUDENT PROJECTS

So far results from HOLANT were presented in the 5 courses, namely Ba2 Biology UGent: Biogeography, Ma1 Biology UGent: Paleoecology and Global Changes, Ma2 MARELAC UGent: Lacustrine Systems, Ma1 MARELAC UGent: Marine and Lacustrine Geology, and Ma1 Geology-MARELAC UGent: Paleoclimatology.

HOLANT directly contributed to 2 Bachelor projects, 4 MsC projects and 2 PhD projects at the Biology Department of Ghent University; 1 Master1 student training in Biochemistry, Molecular and Cellular Biology, 1 MsC project and 1 PhD project at the Centre for Protein Engineering of the University of Liège; and 1 PhD project at the Geology Department of Ghent University.

3. POLICY SUPPORT

HOLANT contributed to all of the three strategic objectives of the "Science for a Sustainable development – research areas Climate and Atmosphere" program. It indeed **reduced the scientific unknowns** about the role of Antarctica in Holocene climate events through a consolidation and further development of the Belgian expertise in polar and paleoclimate research. Hence, the results of our research contributed directly and significantly to the **scientific support** which is necessary for the preparation, implementation and follow-up of the supranational and federal policy (e.g. in the framework of the Antarctic Treaty). In addition, because of the close collaboration with international partners throughout the project and participation to symposia, we substantially contributed to **the integration of our results** into relevant research initiatives on the European and international levels (e.g., the International Polar Year 2007-2008, the BAS CACHE and CACHE-PEP, the IGBP PAGES PEP, and the SCAR EBA programs). More in particular, HOLANT contributed to the writing and compilation of the following reports:

- the Global Climate Observing System (GCOS) report 2008 and 2009,

- the SCAR reports of the Evolution and Biodiversity in Antarctica (EBA) working group, and to SCAR EBA newsletters

- the International Geosphere and Biosphere program PAGES and its special newsletter (09/2007) regarding past climate dynamics in the southern hemisphere

- the 2006 report of the World Climate Research Program CliC (Climate and Cryosphere)

- the SCAR report Antarctic Climate Change and the Environment (ACCE), which is expected to be as widely distributed and used as the Arctic counterparts ACIA.

In addition, a member of HOLANT is a Belgian delegate to the Life Sciences SSG of SCAR and participated to several meetings, and attended several workshops and events within the International Polar year and as such participated to the business meeting in 2008. She was vice-chair of the 'ad hoc' National IPY Coordination Committee of the Academy of Sciences, and she is associated member of the Belgian National Committee for Antarctic Research of the Academy of Sciences.

She has attended several workshops and events within the International Polar year (IPY Discussion Forum in 2004, Opening ceremony in 2007) and was the 'second contact-person' of the IPY MERGE programme. She is also a member of the Belgian delegation to the Antarctic Treaty Consultative Meetings (more specifically of the Committee for Environmental Protection) and has attended the yearly meetings since 2008. At the same time Dominic Hodgson (Holant Partner at BAS) has remained active on the Scientific Steering Committee of the SCAR EBA programme, as a leader of EBA Workpackage 1 and as a representative at SCAR cross-linkages workshops.

HOLANT members also contributed to events related to the Belgian Antarctic Princess Elisabeth Station. More in particular we compiled lists of laboratory equipment, participated in discussions about the science plan, and attended several meetings.

4. DISSEMINATION AND VALORISATION

HOLANT members participated to several events aimed at disseminating and vulgarizing our results:

- The 'UGent aan Zee' event aimed to present the work of marine scientists affiliated with Ghent University. HOLANT contributed through a poster and an oral presentation of the main results

- Presentations at various workshops for young scientists, the general public, secondary school teachers, and lectures in primary, secondary and high schools

- HOLANT appeared in Belgian newspapers (e.g. De Standaard, De Morgen) and magazines and members were interviewed for radio and television programs.

- All members participated to the PolePosition contest for secondary schools organized by BelSPO

- HOLANT made a contribution to Science Connection, a BelSPO publication

- Presentations during the opening of the Belgian Antarctic Base (Brussels)

In total, HOLANT made 60 contributions during symposia and conferences:

1. Verleyen E., Hodgson D.A., Sabbe K., Sterken M. & Vyverman W. Coastal Antarctic lakes: archives of past climate change and ultraviolet radiation. BELQUA workshop, Liége, Belgium (10/02/06). Oral
2. Verleyen E., Hodgson D.A., Sabbe K. & Vyverman W. Antarctische kustmeren: sedimentarchieven voor de reconstructie van veranderingen in de waterbalans, ultraviolette straling, ijsplaatdynamiek en omvang van de continentale ijskap. NecoV wintersymposium, Brussel, Belgium (15-16/02/06). Oral
3. Vyverman W., Verleyen E., Hodgson D.A., Squier A.H., Leavitt P.R., Keely B.J., Lionard M. & Sabbe K. De reconstructie van de hoeveelheid ultraviolette straling gedurende de laatste 120 000 jaar / Reconstruction du rayonnement ultra-violet durant les 120 000 dernières années. BE-POLES workshop 23-25/03/2006, Brussel. Oral.
4. Vyverman W., Verleyen E., Hodgson D.A., Squier A.H., Leavitt P.R., Keely B.J. & Sabbe K. Coastal Antarctic lakes: archives of past fluctuations in the moisture balance and ultraviolet radiation. BE-POLES workshop 23-25/03/2006, Brussel. Oral.
5. Vyverman W., Wilmotte A., De Batist M., Hodgson D.A., Verleyen E., Taton A., Schmoker C., Cousin S., Van der Gucht K., De Groot L., Waleron K., Balthasart P., Sterken M. & Sabbe K. LAQUAN and HOLANT: coastal Antarctic lakes - Archives of past changes in climate, ultraviolet radiation, relative sea level, and autotrophic community structure. BE -POLES workshop 23-25/03/2006, Brussel. Poster.

6. Vyverman W, Verleyen E, Cousin S, Van der Gucht K, Hodgson DA, Sabbe K. Patterns in phenotypic and genotypic diversity of photosynthetic protists in microbial mats of Antarctic lakes. International Conference on Alpine and Polar Microbiology, 27-31/03/2006, Innsbruck, Austria.

7. Verleyen E., Hodgson D.A., Sabbe K., & Vyverman W. Preservation of biogeochemical and microfossil markers in Antarctic microbial mats. Workshop Astrobiology and habitability, 13/06/2006, Brussel. Oral.

8. Verleyen E., Hodgson D.A., Sabbe K., Sterken M. & Vyverman W. Coastal Antarctic lakes: archives of past changes in climate, ultraviolet radiation, relative sea level, and autotrophic community structure. Workshop Koninklijke Academie voor Overzeese Wetenschappen, 20/06/2006, Gent. Poster.

9. Verleyen E., Hodgson D.A., Sabbe K., Leavitt P.R., Squier A.H., Keely B.J. & Vyverman W. The reconstruction of past changes in ultraviolet radiation using diatoms and fossil algal pigments in Antarctic lake sediments. 10th International Paleolimnology Symposium, 25-29/06/2006, Duluth (Minnesota, USA). Oral.

10. Verleyen E., Hodgson D.A., Sabbe K., Wilmotte A., De Wever A., Vyverman W. High latitude lacustrine microbial biodiversity in response to future climate change. Belgian Biodiversity workshop, 21-22/05/2007, Brussel. Poster

11. Verleyen E., Hodgson D.A., Sabbe K., Wilmotte A., De Wever A., Vyverman W. Biodiversity assessments of lacustrine microbial communities in Antarctic lakes. Astrobiology workshop, Royal Academy of Sciences, Brussels, 12/06/2007. Oral

12. Fernandez-Carazo R, Zakhia F, Taton A, Verleyen E, Vyverman W, Hodgson D.A and Wilmotte A. Diversity and distribution of cyanobacteria in Antarctica. Proceedings of the 17th Symposium of the International Association for Cyanophyte Research, June 25-29 2007, Mérida City, Mexico. Oral.

13. Vyverman W., Sabbe K., Vanormelingen P. and Verleyen E. Dispersal limitation constrains global patterns in lacustrine diatom diversity and taxonomic turnover. 4th European Phycological Congress, Oviedo, Spain, 23-27/07/2007. Oral.

14. Sabbe K., Verleyen E., Taton A., Wilmotte A., Cousin S., Van der Gucht K., De Wever A., Hodgson D.A. and Vyverman W. influence of environmental and geographic factors on the diversity and distribution of cyanobacteria and protists in microbial mats of Antarctic lakes. 4th European Phycological Congress, Oviedo, Spain, 23-27/07/2007. Poster.

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16. Arnaud, F., Boone, D., Pagni, R., Heirman, K., Van der Putten, N., Verbruggen, C., De Batist, M. & de Beaulieu, J.L. First investigation of deep lake sediments on subantarctic Kerguelen Islands (Lac d'Armor): reconstructing past floods and volcanic eruptions. 4th International Limnogeology Congress (ILIC2007), Barcelona, Spain (11-14/07/07). Poster.

17. Verleyen E., Vyverman W. et al. Global patterns in lacustrine diatom diversity and taxonomic turnover are constrained by dispersal. 30th SIL congress, Montréal, Canada, 12-18/08/2007. Oral.

18. Sterken M., Verleyen E., Hodgson A., Smith J.A., Roberts S.J., Bentley M.J., Sabbe K. and Vyverman W. Holocene marine and lacustrine paleoproductivity in relation to ice shelf break-up and ice sheet history in Antarctica. 30th SIL congress, Montréal, Canada, 12-18/08/2007. Oral. .

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22. Heirman, K., Boone, D., Arnaud, F., Pagni, R. & De Batist, M. Evidence for high meltwater discharge in Lac d'Armor (Kerguelen Archipelago) based on a high-resolution seismic stratigraphic study. Geosur 2007: 'International geological congress on the southern hemisphere", Santiago, Chile (19-20/11/07). Poster

23. De Wever A., Verleyen E., Van der Gucht K., Zakhia F., Fernandez-Carazo R., Sabbe K., Wilmotte A., Vyverman W. Biogeographical patterns in Antarctic microbial communities. Third International Conference on Polar and Alpine Microbiology, Banff, Alberta, Canada, 11-15/05/2008. Poster

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25. Fernandez-Carazo R, Waleron K, Hodgson D.A, Verleyen E, Vyverman W and Wilmotte A. Fossil cyanobacterial sequences in Antarctic lake sediments. 7th European Workshop on the Molecular Biology of Cyanobacteria, Ceske Budejovice, Czech Republic, 31/08-04/09/2008. Poster.

26. Tavernier, I., Verleyen, E., Hodgson, D.A., Sabbe, K. and Vyverman, W. Paleolimnological reconstruction of Holocene climate change and its effect on ice sheet dynamics in the Lützow Holm Bay region (East Antarctica). NICE Winter School 2009. Aussois, France (4-11/01/2009). Poster.

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38. Hodgson Dominic. A. Lake high stands in the Pensacola and Shackleton Mountains Antarctica, 4500-2300 yr BP. SCAR ACCE Symposium Granada 2009. Poster

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56. Roberts S.J., Hodgson D.A., Bentley M.J., Smith J.A., Johnson J.S., Sanderson D.C.W., Leng M.J., Verleyen E., Vyverman W. Palaeoenvironmental history of former subglacial Lake Hodgson, Antarctic Peninsula. XVIII INQUA conference. Bern, Switzerland, 21-27/07/2011. Poster

57. Roberts, S.J., Hodgson D.A., Verleyen E., Vyverman W., Sterken M., Heirman K., Van Nieuwenhuyze W., Tavernier I., Van de Vyver E., Van Wichelen J., Sabbe K., de Batist M., Bentley M.J., Watschman E, Pearson E., Juggins S., Monien P., McCulloch R., Moreton S. Reconstructing Holocene climate change across the Polar Frontal Zone. XVIII INQUA conference. Bern, Switzerland, 21-27/07/2011. Poster

58. Arnaud, F., Révillon, S., Tachikawa, K., Poulenard, J., Fanget, B., Magand, O., Chapron, E., Michel, E., Crosta, X., van der Putten, N., Debeaulieu, J.L., Boone, D., Heirman, K., De Batist, M., Moine, B., Garcia, M. & Bard, E. Late Holocene evolution of precipitation and wind velocity on Kerguelen Islands, Subantarctic Indian Ocean. XVIII INQUA conference. Bern, Switzerland, 21-27/07/2011.

59. Roberts S.J., Hodgson D.A., Sterken M., Verleyen E., Vyverman W., Sabbe K., Bentley M., Watchman E., Whitehouse P., Balbo A.L., Moreton S. Geological constraints on deglaciation and glacio-isostatic adjustment models of relative sea-level change on the northern Antarctic Peninsula. International Glaciological Society (IGS) British Branch Meeting, Cambridge 7-8/9/2011. Oral

60. Hodgson D.A., Roberts S.J., Bentley M. Watcham, E. Fretwell, P. Vyverman W., Verleyen E., Sterken M., Sabbe K., Moreton, S. Whitehouse P. Improving estimates of ice mass loss from Antarctica. All at Sea, York UK 8-9/9/2011. Invited plenary.

5. PUBLICATIONS

Up to now, the HOLANT project resulted in 13 scientific peer reviewed and 1 non-peer reviewed publications and 3 finalized PhD theses and 1 which is in preparation. The publications indicated were initiated during a previous BelSPO funded project (LAQUAN) and finalized during HOLANT.

Peer-reviewed

Vyverman W., Verleyen E., Sabbe K., Vanhoutte K., Sterken M., Hodgson D.A., Mann D.G., Juggins S., Van de Vijver B., Jones V.J., Flower R., Roberts D., Chepurnov V., Kilroy C., Vanormelingen P., De Wever A. (2007) Historical processes constrain patterns in global diatom diversity. Ecology 88 (8): 1924-1931

Verleyen E., Vyverman W., Sterken M., Hodgson D.A., De Wever A., Juggins S., Van de Vijver B., Jones V.J., Vanormelingen P., Roberts D., Flower R., Kilroy C., Souffreau C., Sabbe K. 2009. The importance of dispersal related and local factors in shaping the taxonomic structure of diatom metacommunities. Oikos 118: 1239-1249.

Hodgson D.A., Roberts S.J., Bentley M.J., Smith J.A., Johnson J.S., Verleyen E., Vyverman W., Andy J. Hodson, Leng M.J., Cziferszky A., Fox A.J., Sanderson D.C.W., Sugden D.A. (2009) Exploring former subglacial Hodgson Lake, Antarctica Paper I: Exploring former subglacial Hodgson Lake, Antarctica Paper I: site description, geomorphology and limnology. Quaternary Science Reviews 28: 2689-2696**.**

Hodgson D.A., Roberts S.J., Bentley M.J., Carmichael E.J., Smith J.A., Verleyen E., Vyverman W., Geissler P., Leng M.J., Sanderson D.C.W., Sugden D.A. (2009) Exploring former subglacial Hodgson Lake, Antarctica Paper II: Paleolimnology. Quaternary Science Reviews 28: 2310-2325.

Hodgson D.A.,Verleyen E., Vyverman W., Sabbe K., Leng M.J., Pickering M.D, Keely B.J. (2009) A geological constraint on relative sea level in Marine Isotope Stage 3 in the Larsemann Hills, Lambert Glacier region, East Antarctica (31 366 - 33 228 cal yr BP). Quaternary Science Reviews 28: 2689-2696. These authors contributed equally to this work.

Roberts S.J., Hodgson D.A., Bentley M.J., Sanderson D.C.W., Milne G., Smith J.A., Verleyen E., Balbo A. (2009) Holocene relative sea-level change and deglaciation on Alexander Island, Antarctic Peninsula, from elevated lake deltas. Geomorphology 112: 122-134.

Verleyen E., Hodgson D.A, Sabbe K., Cremer H., Emslie S.D., Gibson J., Hall B., McMinn A., Imura S., Kudoh S., Marshall G.J., Melles M., Newman L., Roberts D., Roberts S.J., Sighn S.M., Sterken M., Tavernier I., Verkulich S., Van de Vyver E., Van Nieuwenhuyze W., Wagner B., and Vyverman W. (2011) Post glacial climate variability along the east Antarctic coastal margin – evidence from shallow marine and coastal terrestrial records. Earth-Science Reviews 104: 199-212.

Verleyen E., Hodgson D.A., Gibson J., Imura S., Kaup E., Hoshino T., Kanda H., Kudoh S., De Wever A., Hoshino T, McMinn A., Obbels D., Roberts D., Roberts S.J., Sabbe K., Souffreau C., Tavernier I., Van Nieuwenhuyze W. Van Ranst E., Vindevogel N. & Vyverman W. Chemical limnology in coastal East Antarctic lakes: monitoring future climate change in centres of endemism and biodiversity. Antarctic Science. (In press).

Smith, C.R., Grange, L., Honig, D.L., Naudts, L., Huber, B., Guidi, L. & Domack, E., (in press). A large population of king crabs in Palmer Deep on the West Antarctic Peninsula shelf and potential invasive impacts. *Proceedings of the Royal Society B.*, doi:10.1098/rspb.2011.1496

Roberts S.J., Hodgson D.A., Sterken M., Whitehouse P.L., Verleyen E., Vyverman W., Sabbe K., Balbo A., Bentley M.J., Geological constraints on glacio-1 isostatic adjustment models of relative sea-level change during deglaciation of Prince Gustav Channel, Antarctic Peninsula. Quaternary Science Reviews. Accepted.

Sterken M., Roberts S.J., Hodgson D.A., Vyverman W., Balbo A., Sabbe K., Moreton S., Verleyen E. Holocene glacial and climate history of Prince Gustav Channel, northeastern Antarctic Peninsula. (submitted).

Tavernier I., Verleyen E., Hodgson D.A., Heirman K., Imura S., Kudoh S., Sabbe K., De Batist M., Debeer A.-E. & Vyverman W. Late Holocene climate variability in Skarvsnes, East Antarctica, East Antarctica. (submitted).

Fernandez-Carazo R., Verleyen E., Hodgson D.A., Roberts S.J., Vyverman W., Wilmotte A. Holocene changes in cyanobacterial communities in Maritime Antarctic lake sediments. (submitted).

Non-peer reviewed

Fernandez-Carazo R., Wilmotte A. Fossil cyanobacterial DNA from sediment cores at Beak Island (Antarctic Peninsula): Challenges for a molecular approach. Belgian IPY Symposium: The contribution of Belgian research to the achievements of the international polar year 2007-2009. Contactforum Royal Academies for Science and the Arts of Belgium, pp. 98-100. (non-peer-reviewed)

PhD theses

Sterken M. (2010) A paleolimnological reconstruction of Late-Quaternary environmental change along a transect from South America to the Antarctic Peninsula. PhD thesis, UGent, pp. 303.

Fernandez-Carazo, R. (2011). Contribution to the study of the present and past diversity of Antarctic cyanobacteria. PhD thesis. Centre for Protein Engineering. University of Liege. pp 312.

Heirman, K., (2011). A wind of change: Changes in position and intensity of the Southern Hemisphere Westerlies during Oxygen Isotope Stages 3, 2 and 1. Ph.D. thesis, UGent. 227 pp.

The project was acknowledged but did not directly contributed data to 6 other publications:

A1-publications

Convey, P., Stevens, M.I., Hodgson, D.A., Smellie, J. L., Hillenbrand, C.-D., Barnes, D.K.A., Clarke, A., Pugh, P.J.A., Linse, K., and Cary, S.C. (2009). Exploring biological constraints on the glacial history of Antarctica. Quaternary Science Reviews 28, 3035–3048.

Convey P, Turner J, Di Prisco G, Mayewski PA, Hodgson DA, Fahrbach E, Bindschadler R, Gutt J, Summerhayes CP, ACCE-Consortium (0000) Antarctic Climate Change and the Environment. Antarctic Science. Accepted

Saunders, K.M., Hodgson, D.A. & McMinn, A. (2008). Quantitative relationships between benthic diatom assemblages and water chemistry in Macquarie Island lakes and their potential to reconstruct past environmental changes. *Antarctic Science* doi:10.1017/S0954102008001442

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Hodgson D.A., Abram N., Anderson J., Bargelloni L., Barrett P., Bentley M.J., Bertler N.A.N., Chown S., Clarke A., Convey P., Crame A., Crosta X., Curran M., di Prisco G., Francis J.E., Goodwin I., Gutt J., Massé G., Masson-Delmotte V., Mayewski P.A., Mulvaney R., Peck L., Pörtner H.-O., Röthlisberger R., Stevens M.I., Summerhayes C.P., van Ommen T., Verde C., Verleyen E., Vyverman W., Wiencke C., Zane, L. (2009) Antarctic climate and environment history in the pre-instrumental period. In: Turner J., Convey P., di Prisco G., Mayewski P.A., Hodgson D.A., Fahrbach E., Bindschadler R., Gutt J. (eds) ANTARCTIC CLIMATE CHANGE AND THE ENVIRONMENT. Scientific Committee for Antarctic Research, Cambridge. pp. 115-182.

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6. ACKNOWLEDGEMENTS

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Annex 1 & Annex 2: see additional online files