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General information

All nonresident participants will stay in the Costa Río Apart Hotel (Avenida San Martín 673) in Rio Gallegos (phone: +54-2966-423-412, fax: +54-2966-421-446, email: costario@infovia.com.ar). All scientific talks will be held in the Conference Hall at the Complejo Cultural Santa Cruz, Av. San Martín and Ramón y Cajal, located in walking distance for the hotel.

If there should occur any question, do not hesitate to contact the PASADO organizing committee consisting of Hugo Corbella, Nora Maidana, Christian Ohlendorf and Bernd Zolitschka.

City map of Rio Gallegos
Introduction

This international workshop is based on the research initiative “Potrok Aike Lake Sediment Archive Drilling Project” (PASADO) within the framework of the “International Continental Scientific Drilling Programme” (ICDP). PASADO addresses several challenging issues of geoscientific and socioeconomic relevance related to Earth history and climate (quantitative climatic and environmental reconstruction, palaeosecular variation of the Earth's magnetic field), natural hazards (fire history, frequency of volcanic activity including tephra fallout, dust deposition) and volcanic systems (evolution of phreatomagmatic craters, history of volcanic activity) for the last several hundred thousand years. Moreover, dust and tephra records will provide means to link this terrestrial record to marine sediment archives and to ice cores from Antarctica. Finally, obtained reconstructions of climate variability will be compared statistically with the output of Global Circulation Model (GCM) simulations to improve our understanding of forcing mechanisms of the global climate. This international and highly interdisciplinary research approach needs a detailed pre-planning to be carried out successfully. Therefore, we will focus during the ICDP-Workshop PASADO on discussing and planning of objectives and achievements, required laboratory analyses and techniques, forms of scientific collaboration, anticipated drilling sites and operations as well as on logistics, funding, political and legal issues.

The ICDP-Workshop PASADO (2nd milestone) follows up an ICDP pre-proposal which was submitted by January 15, 2005 (1st milestone) and is organized to summarize all currently available information related to the Pali Aike Volcanic Field, in which the target of this initiative – Laguna Potrok Aike, Santa Cruz (southern Patagonia, Argentina) – is located (day 1). During day 2 of the workshop a field trip introduces the site of the maar lake to all participants. On day 3 a variety of additional methods not yet applied or not yet fully exploited will be proposed. Finally, on day 4 of the workshop the PASADO organizing committee expects from the scientific community to stimulate the discussion about which methods need to be applied, to join in with their own ideas and methods and to streamline the overall conceptions about the strategy and the aims that should be considered for the full coring proposal due January 15, 2007 (3rd milestone). The output should be a collectively developed science plan, which will serve as the nucleus for international multidisciplinary collaborations. Ideally, the GLAD 800 coring expedition is anticipated not before southern summer 2007/08. Upon coring, individual researchers will need to write proposals to their national funding agencies and apply for soft money to do the actual work on the core material.

In addition to sediment coring it would be desirable to organize and continue the monitoring approach, which helps tremendously to improve our understanding of modern processes. This in turn is essential for a better interpretation of the environmental records of the past. Monitoring aspects could include e.g. lake water, runoff, groundwater, limnology and climatic conditions (precipitation, evaporation, wind, temperature).

Finally, we wish to thank some persons and organizations for their support. Without the scientific support of Vera Markgraf (University of Boulder, Colorado), Jörg Negendank (GeoForschungsZentrum Potsdam) und the late Arturo Amos (PROGEBA, San Carlos de Bariloche) we would never have started to work on lakes in southern Patagonia. Fieldwork in Santa Cruz would not have been possible without the political support of Francisco Anglesio (Subsecretario de Medio Ambiente e Ministerio de Economia y Obras Publicas, Río Gallegos), the tireless logistical support through Cpt. J. Daniel Moreteau (Puerto Madryn), Cristobal Kennard (Río Gallegos) and Gabriel Oliva (INTA Río Gallegos). For their financial incentives we thank the German Ministry of Science and Education (BMBF) for funds to the project SALSA in the framework of the German Climate Research Programme (DEKLIM), the German Research Council (DFG) for funding the pre-site seismic surveys and the ICDP for making this PASADO workshop happen.
Scientific programme

Wednesday, March 15:
Arrival in Rio Gallegos at the International Airport. A bus of the Universidad Nacional de la Patagonia Austral (UNPA) will serve as a shuttle between airport and hotel. If the bus should not be available, please take a taxi to the Costa Rio Apart Hotel.
21:30h Get together (meeting at the hotel)

Thursday, March 16:
Welcome
09:00h Bernd Zolitschka & Hugo Corbella: Opening of the ICDP-Workshop PASADO
09:10h Welcome addresses
  o Ing. Héctor Aníbal Billoni (Rector of the Universidad Nacional de la Patagonia Austral, Rio Gallegos – UNPA)
  o Eduardo Quargnolo (Director of Instituto Nacional de Tecnología Agropecuaria – INTA Santa Cruz)
  o Ing. Francisco Anglesio (Subsecretario de Medio Ambiente e Ministerio de Economía y Obras Publicas de Santa Cruz, Rio Gallegos)

Regional background information
09:40h Bernd Zolitschka et al.: Water at “world’s end” – Laguna Potrok Aike: Introduction to an old and deep lake in southernmost Patagonia (Santa Cruz, Argentina)
10:00h Hugo Corbella: The Pali Aike Volcanic Field
10:20h Andrea Coronato & Jorge Rabassa: Glacial history of Patagonia, Southern South America.
10:40h Eduardo Piovano & Daniel Ariztegui: Cold-dry vs. warm-wet events in the South American extratropics since the Last Glacial Maximum
11:00h Coffee break
11:30h Gervasio Humano & Gabriel Oliva: Modern vegetation in the Pali Aike Volcanic Field
11:50h Marta Paez: Modern regional pollen rain in southern Patagonia – a pollen trap study to provide background information for pollen-based climate reconstruction (in Spanish)
12:10h Elizabeth Mazzoni et al.: Lake level fluctuations during the last decades in southern Patagonia – an approach using satellite images (in Spanish)
12:30h Christoph Mayr et al.: Precipitation origin and evaporation of lakes inferred from stable isotopes ($\delta^{18}$O, $\delta^2$H) in southeastern Patagonia (Argentina)
12:50h Luis Borrero: The archaeology of the Pali Aike lava field
13:10h Gabriel Oliva, Guillermo Clifton & Liliana Gonzalez: Scientific background and aims of INTA research at Potrok Aike
13:30h  Lunch Break

**Limnogeological results from Laguna Potrok Aike**

15:00h  Daniel Ariztegui, Flavio Anselmetti & Marc de Batist: High-resolution pinger, airgun and sparker seismic surveys in Laguna Potrok-Aike: Imaging the sediment infill prior to deep drilling

15:20h  Frank Niessen & Catalina Gebhardt: Deep seismic survey at Laguna Potrok Aike

15:40h  Sabine Wulf, Torsten Haberzettl et al.: Tephrochronology of Laguna Potrok Aike sediments

16:00h  Christian Ohlendorf: Lake level fluctuations at Laguna Potrok Aike and how they are recorded in the sediments

16:20h  Torsten Haberzettl: Sediment core from the center of Laguna Potrok Aike covering 16,000 years – 1. coring, chronology and sedimentology

16:40h  Coffee break

17:10h  Andreas Lücke et al.: Sediment core from the center of Laguna Potrok Aike covering 16,000 years – 2. Potentials and experiences of stable isotope approaches

17:30h  Nora Maidana: Sediment core from the center of Laguna Potrok Aike covering 16,000 years – 3. Diatoms and paleoenvironmental reconstructions

17:50h  Michael Wille et al.: Sediment core from the center of Laguna Potrok Aike covering 16,000 years – 4. Late Glacial and Holocene vegetation and climate history of the Pali Aike Volcanic Field inferred from a 17 m pollen profile

18:10h  Frank Schäbitz et al.: Sediment core from the center of Laguna Potrok Aike covering 16,000 years – 5. Pollen-based approach of qualitative and quantitative climate reconstruction

18:30h  Martin Widmann et al.: Downscaling of climate simulations for comparison with climate reconstructions from Laguna Potrok Aike records (presented by ?)

18:50h  Bernd Zolitschka: Perspectives for PASADO

21:30h  Dinner

**Friday, March 17:**

**Field trip to Laguna Potrok Aike**

08:00h  Departure from the hotel to the one-day field trip to Laguna Potrok Aike. Bring warm clothes as well as wind, sun and rain protection (just to be prepared – the weather can change instantly!) and sturdy shoes for off-road walking. Packed lunches and drinks will be provided; an Asado (BBQ) will be prepared for early dinner, departure from the field is anticipated for about 19h, return to Rio Gallegos is scheduled for 21h. For the fieldtrip please consult the excursion guide in this volume.
Saturday, March 18:

The International Continental Scientific Drilling Program (ICDP)

09:00h  Ulrich Harms: Funding and support through the International Continental Scientific Drilling Program (ICDP)
09:15h  Dennis Nielson: GLAD800 Drilling in Laguna Potrok Aike, Argentina
09:30h  Daniel Ariztegui et al.: Reconstructing late Quaternary environmental change in the lowland neotropics – The Lake Petén-Itza Drilling Project (January-March 2006)

Understanding the evolution of maar volcanoes

09:45h  Marcelo Paterlini & Hugo Corbella: Magnetometric survey of Laguna Potrok Aike
10:00h  Ulrike Martin & Helga de Wall: Reconstruction of the volcanic history of the Potrok Aike Maar: Part 1: Volcanological and sedimentological characterization of volcaniclastic units
10:15h  Helga de Wall & Ulrike Martin: Reconstruction of the volcanic history of the Potrok Aike Maar: Part 2: Rock physical and geochemical characterization of volcaniclastic units
10:30h  Miguel J. Haller et al.: Understanding the evolution of maar craters

Deciphering high-frequency environmental variations

10:45h  Thomas Wonik: Physical properties, structural features, and climate signals in lake sediments and phreatomagmatic breccias of the Potrok Aike Maar derived from downhole logging
11:00h  Coffee break
11:30h  Pierre Francus & Scott Lamoureux: Microfacies characterization using image analysis, physical and chemical properties for understanding sedimentary processes and reconstructing climate at high-resolution at Laguna Potrok Aike
11:45h  Juergen Thurow et al.: High-frequency climate variability in Laguna Potrok Aike

History of volcanic eruptions and dating of the sediment record

12:00h  Christel van den Bogaard: Tephrochronology - A high potential correlation tool in palaeoenvironmental investigations
12:15h  Stefan Wastegard: Tephrochronology in the North Atlantic region – a potential to link marine, terrestrial and ice-core records from the last glacial cycle

Reconstruction of the Earth’s magnetic field and characterization of minerogenic sediment fractions

12:30h  Laurie Brown: Magnetic Studies at Laguna Potrok Aike
12:45h  Guillaume St-Onge & Pierre Francus: CT-scan image analysis and magnetic properties at Laguna Potrok Aike

13:00h  Lunch Break
Reconstruction of lacustrine and catchment-related environmental conditions

15:00h Cathy Whitlock, Maria Martha Bianchi & Vera Markgraf: Understanding the links between fire, vegetation, and climate change in Patagonia: records and opportunities
15:15h Hedi Kling: Non-siliceous microfossils in paleolimnological reconstruction
15:30h Beata Messyasz: Phytoplankton and algal microfossils in the crater lake Laguna Azul
15:45h Julieta Massaferro: Fossil chironomids (Insecta – Diptera) as indicators of environmental change in Laguna Potrok Aike, Argentina
16:00h Isabelle Larocque: Potrok Aike Lake Sediment Archive Drilling Project, southernmost Argentina (PASADO): chironomid analysis (represented by Pierre Francus)
16:15h Reinhard Pienitz & Finn Viehberg: Diatoms and ostracods as palaeoclimate proxies in the Laguna Potrok Aike sediment record
16:30h Maria Virginia Mancini: Vegetation and climatic conditions in the southeast of Patagonia, Argentina
16:45h Aldo R. Prieto et al.: Magallanes maar fossil pollen record re-interpreted by using a pollen-climate calibration model

17:00h Coffee break

Tracing atmospheric dust and volcanic aerosols

17:30h Diego Gaiero, Barbara Villoslada & Santiago Gassó: Dust sources and westerly storms in Patagonia: Comparison of in situ measurements with remote sensing estimations
17:45h Martin Fleisher: Isotopic investigations at Laguna Potrok Aike sediments to determine recent sedimentation rates and dust fluxes
18:00h Kyeong J. Kim, A. J. Tim Jull & Mineo Imamura: Study of paleoclimate change using cosmogenic nuclides produced in the atmosphere
18:15h Paul Vallelonga et al.: Lead (Pb) and Strontium (Sr) isotopic composition for reconstructions of dust fluxes and volcanic aerosols

Human impact and modelling

18:30h Ramiro Barberena & Fabiana M. Martin: Bones in Pali Aike – The Late Holocene archaeological record of Cóndor and Potrok Aike localities
18:45h Horatio Toniolo: Numerical modelling of sedimentation processes in Laguna Potrok Aike – Argentina

21:30h Dinner
Sunday, March 19:

Break-up groups to discuss the concerted action with regard to the drilling proposal (due: January 15, 2007) and envisaged scientific aims

To allow everybody to participate in at least two different break-up groups, two blocks are scheduled. Each break-up group has to appoint a rapporteur who will minute the session (e.g. what methods will be applied, in case of sediment-related analyses: amount of sample material needed, scientific aims) and present the summary report.

Meeting of the different break-up groups

09:00h  1. Scientific drilling
        2. Logging techniques
        3. Volcanology and pre-lacustrine sediments
        4. Other aspects
           4.1 Process studies
           4.2 Archaeology
           4.3 Modelling

10:45h  Coffee break

11:15h  5. Lacustrine sediment facies
        5.1 Dating
        5.2 Sedimentology
        5.3 Magnetic studies
        5.4 Isotopic investigations
        5.5 Microfossils
           5.5.1 Pollen
           5.5.2 Chironomids
           5.5.3 Diatoms and other algae

13:00h  Lunch break

15:00h  Rapporteurs: Presentation of summary reports from break-up groups
15:45h  Discussion

16:45h  Coffee break

17:15h  Discussion and preparation of the scientific background for the formal proposals to funding agencies

18:45h  Vera Markgraf: Wrap-up session
19:30h  Closing remarks

21:30h  Farewell Dinner

Monday, March 20:

Departure from Rio Gallegos (at any time)
Water at “world’s end” – Laguna Potrok Aike: Introduction to an old and deep lake in southernmost Patagonia (Santa Cruz, Argentina)

Bernd Zolitschka, Christian Ohlendorf and the SALSA team

Geomorphologie und Polarforschung (GEOPOLAR), Institut für Geographie, Universität Bremen, Germany

There is increasing evidence that the Southern Ocean plays a key role for a better understanding of the global climate system. The southern hemisphere contains >90% of the worlds ice and 81% of its total surface area is covered by oceans. Globally, the most extreme oceanic character is encountered between 40° and 60°S where 98% of water are juxtaposed to only 2% of land – Patagonia, “world’s end”. Hence, terrestrial palaeoclimatic archives are extremely scarce and therefore valuable sources of climatic information and may act as a continental counterpart to marine and ice core records, all of which are necessary for a comprehensive understanding of past climate changes. As this area east of the Andean volcanic chain is subject to shifts in polar and mid-latitude winds, pressure fields and precipitation regimes as well as to variations related to the El Nino Southern Oscillation (ENSO) and to the Antarctic Oscillation (AO), it has the potential to provide unique records of long-term variations in (a) the hydrological cycle, (b) changes in aeolian dust deposition, (c) consequences and frequencies of volcanic activities and (d) of other natural forces controlling climatic conditions. Moreover, in Patagonia the longitudinal differences in climate are extreme. Evergreen rainforest with up to 5000 mm of annual precipitation (P) at the Pacific coast west of the Andes contrasts with the dry Patagonian steppe with P <200 mm east of the Andes where most lakes are periodically dry or ephemeral.

One of the very few permanent lakes in this steppe region is the 100 m deep crater lake Laguna Potrok Aike (52°S, 70°W; 113 m a.s.l.; diameter: 3.5 km), a 770 ±220 ka old maar situated in the province of Santa Cruz, Argentina. Reflection and refraction seismic data revealed a lacustrine sediment infill of 200 to 400 m in thickness. As Laguna Potrok Aike has not been reached by the last glaciation (Llanquihue) nor by any other Pleistocene ice advance during the last 1 Ma it is potentially the only site that has archived a continuous and high-resolution sediment record covering several glacial/interglacial cycles for the southern hemispheric mid-latitudes. Moreover, it will provide ideal means for linking this unique terrestrial record to ice cores from Antarctica and to marine records from the Southern Oceans where dust and tephra of Patagonian provenance have been detected. Drilling this sedimentary record should thus achieve highest priority in the framework of the International Continental Scientific Drilling Programme (ICDP).

In addition to climatic and paleoenvironmental research related to its lacustrine deposits this maar opens up also another window for research: investigations into the structure and composition of the diatreme in a relatively young maar structure. Never before scientific drilling was carried out into the deep part of a diatreme underneath a maar lake. Studies of deep maar structures until now include only records from Tertiary or older dry maars. The site of Laguna Potrok Aike for the first time will allow
to analyze the early evolution of a maar probably including its phreatomagmatic formation.

In the framework of the project “SALSA” (South Argentinean Lake Sediment Archives and Modeling) which is part of the German climate research program (DEKLIM) we started to study several lakes with an integrated research approach, finally focusing on Laguna Potrok Aike (Zolitschka et al., 2004, in press). This program includes a wide variety of studies, e.g. geomorphology, limnology, biology, geophysics, sedimentology, geochemistry, stable isotopes and climate modeling. Especially the modeling component is of importance, e.g. in order to decide whether the hydrological balance of this region is mainly modulated by latitudinal migration of the Southern Westerlies as it is common sense in the literature or if other circulation anomalies like polar outbreaks (e.g. Bradbury et al., 2001) play a more important role then previously assumed. As a terminal lake Laguna Potrok Aike is very sensitive to changes in the hydrological regime and thus can be regarded as an ideal site although being located at a very remote location called the “world’s end”.

References

The Pali Aike Volcanic Field

Hugo Corbella

*Universidad Nacional de la Patagonia Austral, Rio Gallegos and Museo Argentino de Ciencias Naturales, Buenos Aires, Argentina*

Pali-Aike, the southernmost back-arc Neozoic volcanic field of South America and one of the youngest in Patagonia, outcrops between latitude 50° and 52°S in the Magellan Basin area, 300 km behind the actual Andean volcanic front. The volcanic outcrops, mostly basaltic and basanitic, appear in an area of 50 km by 150 km. Thirty K/Ar and Ar/Ar age determinations show that most of the volcanic activities occurred between the Late Pliocene (3.82 Ma) and the Holocene. But there is also evidence of earlier Late Miocene basalt layers. Most of the young volcanics lie on top of the Miocene Santa-Cruz Formation or on fluvio-glacial gravels and conglomerates.

In Pali-Aike, two principal fracture systems of parallel or sub-parallel faults controlled the outpouring of the lavas and the close alignment of the scoria, ash
cones and maars. Occasionally, some fractures are underlined by long linear depressions (15 km) due to the coalescence of several maars. The predominant fault system has a NW direction, followed by less frequent faults of E and ENE strike.

The NW system is emphasized by a regional alignment of geothermal anomalies (up to 6°C/100 m) developed on the vertical of an underlying Jurassic rift zone that was formed during the breaking up of Gondwana. Seismic information shows a close correspondence between the surficial tectonic structures, 27 sills (30-60 m thick) at around 1000 and 2000 m depth and the Jurassic basement faults. The vertical development of these NW gravitational faults shows that they were active during the Permo-Jurassic and remained active during the Cretaceous and Lower-Tertiary, though with declining throws. The vertical movements seem to have stopped during the Tertiary. Given the absence of modern vertical throws detected in the surface and underground, it is possible to infer that the old NW fractures of the Jurassic rift were rejuvenated by modern strike-slip movements.

The E and ENE fault system is parallel or sub-parallel to the faults and rift systems that seem to have channeled the large glacial valleys sub-perpendicular to the Andes such as the Magellan Strait, some fiords and bays and also the big Cordilleran lakes. All these valleys formed since 3.5 Ma and suggest a possible N-S stretch of the area due to a new strength field in the southern flank of the Magellan Basin.

These two normal fracture systems form a 60° conjugate fault system that allows, depending on the applied stress field, strike-slip transtensional and transcompressional openings accounting for the eruption of volcanics and the setting of scoria and ash cones and maars. Maars and tuff rings are relevant features of this fissural volcanism. Around 100 maars outcrop along this volcanic field, forming circular or oval depressions 500 to 3000 m wide. To the West, East and South, the Pali-Aike volcanics are flanked by till and glacifluvial deposits forming large moraine arches of different age and belonging to different systems (1.15-0.016 Ma). The widespread phreatomagmatic activity is probably related to the great water availability in a glacial or periglacial environment. The water to trigger the explosions could have come from ice, permafrost or soaked sediments during the washout of deglaciation stages.

Different maar morphologies are present. Most are located along faults. Many of them have coalesced forming "in rosary" alignments. Asymmetric ring morphologies are frequent due to strong westerly winds blowing during and after the eruption. Scoria and spatter cones inside or in the periphery of the maar depression is a consequence of the post-maar strombolian eruptive activity under different conditions of water availability. Lava flooded maars are not uncommon.

The Holocene volcano-tectonic activity is located in the southeastern corner of the Pali Aike Volcanic Field. There, through the NW Diablo Negro fracture, most of the youngest lavas reached the surface. At Laguna Azul an ENE and 700 m wide graben was active during an Holocene eruption.
Glacial history of Patagonia, Southern South America

Andrea Coronato & Jorge Rabassa

CADIC-CONICET, Ushuaia, Argentina

Although glaciations are the most important palaeoclimatic changes of the last 2 million years all over the world, geochronological evidences found in southern Patagonia suggests that they have occurred also in previous times. Thick till deposits interbedded with basaltic flows at the northern margin of Lago Buenos Aires tableland suggest that isolated ice-caps with outlet glaciers extended eastwards more than 30 km and existed during the Late Miocene to Early Pliocene.

Evidences of Middle to Late Pliocene glacial events which had been found in the tablelands surrounding Lago Viedma suggest that Pliocene glaciers expanded from the mountain ice-caps to eastwards locations equivalent to those positions that outlet glaciers achieved during the maximum ice expansion of the Pleistocene.

The glacigenic sequences interbedded between lava flows at Cerro del Fraile, near Lago Argentino, allow to recognize at least seven glacial stages which would have taken place during the Late Pliocene and Earliest Pleistocene times, Oxygen Isotope Stages (OIS) 82-84.

The maximum expansion of the ice out of the mountain area, the Greatest Patagonian Glaciations (GPG) would have taken place at 1-1.1 Ma years B.P. (OIS 28-34). These outer limits are well preserved eastwards of the Andes and reach the Atlantic shelf platform at the southern tip of South America.

Glacial deposits corresponding to at least three younger glaciations are located in inner positions nested by GPG moraines. Post GPG 1 and 2 were recognized in many of the main Andean valleys and assigned to the Middle Pleistocene, e.g. since OIS 16 to OIS 6. Cosmogenic dates obtained at Lago Buenos Aires and Magellan Straits show that the Last Glacial Maximum or the Post GPG 3 has occurred in Patagonia at 25 ka cal. B.P. (OIS 2). After that, at least two standstills or minor glacier advances would have taken place during the Late Glacial reflecting both cool stages, the Antarctic Cold Reversal and/or the northern hemisphere Younger Dryas equivalent.

The definitive ice retreat has been mostly established at ca. 10 $^{14}$C. ka B.P. The absolute chronology up to now available for the Patagonian Glaciations has become one of the most complete in the world and the best available in the southern hemisphere outside Antarctica.
Cold--dry vs warm-wet events in the South American extratropics since the Last Glacial Maximum

Eduardo L. Piovano¹ & Daniel Ariztegui²

¹Centro de Investigaciones Geoquímicas y de Procesos de la Superficie, Universidad Nacional de Córdoba, Argentina
²Institute Forel and Dept. of Geology & Paleontology, University of Geneva, Switzerland

Recent weather patterns combined with results of high resolution paleostudies indicate that the role of tropical and subtropical areas may have been underestimated as forcing factors of changes within the global climate system. Thus, the study of well-constrained paleoenvironmental records in these regions became critical.

Laguna Mar Chiquita (30°54´S, 62°51´W) is a shallow saline lake in the subtropical Pampean plains of Argentina. Temporal variability of the hydrological balance shows dramatic lake level fluctuations, highlighting the sedimentary record of Laguna Mar Chiquita as a sensitive climatic archive. During highstands, as at present, the lake with a surface area of ca. 6,000 Km² becomes not only the largest saline lake in South America but also one of the largest in the world.

²¹⁰Pb ages from short cores allowed correlating and calibrating the lake sedimentary, isotope and biological response to the last 100 years of documented lake levels changes. The comparison among these sedimentological and geochemical features, the stable isotope signals and the diatom record shows a coherent picture that further allows us to formulate a well constrained multiproxy model for the basin (Piovano et al., 2002, 2004a, b). The study of 4.2 m long sedimentary cores allows the reconstruction of lake level variations covering the hydrological changes that occurred in this area since the Last Glacial Maximum (LGM). A semi-quantitative estimation of paleolake levels (Piovano et al., 2004a) shows a recurrent pattern of highstands since the late Pleistocene often with a magnitude equivalent to present-day conditions. A wet phase followed the negative water balance during the LGM that ended ca. 13,700 ± 100 yr BP. A subsequent abrupt negative hydrological balance (Younger Dryas?) was followed by highstand conditions and thus positive precipitation/evaporation ratios since the Early Holocene until before 4200 yr BP when a hydrological reversal started again. Dry conditions were mostly dominant since the Mid-Holocene, including the Little Ice Age (LIA), until the last quarter of the 20th century when an outstanding humid phase started. The hydrological response during LGM, LIA and the last three decades clearly indicate that dry conditions prevail during cold phases whereas wet conditions occur during warm periods.

The 20th century sequence of variations in the hydrological balance of Laguna Mar Chiquita is synchronous and in phase with other hydrological changes observed in SE South American (SESA) rivers (e.g., Rio Paraná) pointing towards the fact that the reconstructed paleohydrology can be extrapolated to the wider region of SESA. Conversely, the hydrological balance in SESA is in antiphase related to conditions in Patagonia and the Central Andes as shown by an important number of limnogeological records (i.e. Lagunas Potrok Aike, Cardiel, Frias and Aculeo among others). In particular, the Medieval Climate Anomaly and the LIA correspond to warm-dry and cool-moist conditions in Patagonia, central Chile and Central Andes but to warm-wet and cool-dry conditions in SESA. Thus, the Laguna Mar Chiquita climate archive has the potential to pinpoint changes at a decadal time scale, affording the opportunity to compare paleo-circulation dynamics and antiphased
hydrological changes in southern South America during the Late Pleistocene and the entire Holocene.

References

Modern vegetation in the Pali Aike Volcanic Field

Humano, Gervasio & Gabriel Oliva

Instituto Nacional de Tecnología Agropecuaria, Estación Experimental Santa Cruz and Universidad Nacional de la Patagonia Austral, Río Gallegos, Argentina

The vegetation of the Potrok Aike area was explored based on 73 Braun Blanquet vegetation censuses performed in the neighboring Potrok Aike experimental field (Humano et al., 2005). This data was analyzed using PCA and cluster analysis, that enabled a supervised classification of a Landsat TM image (December 2001). The vegetation comprises 65 species with variations of the basic tussock grasslands of Festuca gracillima typical of the Magellanic Steppe.

1) Tussock Grass Steppes occupy most of the plateaus and fluvial terraces in good condition, with 61% cover and 16% of tussocks, 26% of short grasses, 6% herbaceous dicots and 13% of dwarf shrubs.

2) Tussock-Dwarf Shrub Steppes are found in more heavily grazed areas of the plateaus and terraces and may be interpreted as a degraded state of the first vegetation unit, with 50% total vegetation cover, 13% tussocks, 21% of short grasses, 5% of herbs and 11% of dwarf shrubs.

3) Mixed Tussock–Shrub–Dwarf Shrub Steppe incorporate deep rooted shrubs of Junellia tridens and are found in the slopes of basaltic plateaus. They show 67% cover, with 15% tussocks, 26% short grasses, 8% herbs and 16% dwarf shrubs and 2% of shrubs.

4) Dry Riparian Steppes occupy the lower terraces and river beds of the Carlota stream, with 59% total cover, 13% of tussocks (Festuca pallescens), 35% dwarf grasses, 5% herbs, 5% dwarf shrubs.

The most diverse sites are the Mixed tussock-dwarf shrub-shrub sites, with 47 species per site. The other units showed 28 species per site (units 1 and 2) and 23 species per site in (unit 4). Dominant tussocks are Festuca gracillima and F. pallescens, short grasses are dominated by Poa dusenii, Carex argentina, and dwarf shrubs are represented by Nardophyllum brioides and Perezia recurvata. Other vegetation units are only found in highly degraded areas or overgrazed areas:
• Dwarf shrublands of Nardophyllum brioides, observed in degraded Potrok Aike lake terraces,
• Stipa Tussock grasslands, in aeolic depositions east of the Carlota river and
• Short grass steppes in the vicinity of the stations and in highly used paddocks.

Reference

Modern regional pollen rain in southern Patagonia-a pollen trap study to provide background information for pollen-based climate reconstruction

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Studies of the relation between pollen and climate undertaken along ecologic gradients in Patagonia have shown that paleoecological and paleoclimatic interpretations for the Holocene are possible using “modern-along” techniques (Mancini, 1993, 1998; Prieto et al., 1998; Paez et al., 2001; Schäbitz et al., 2003). This method was applied for southern South America between 51-53°S and 68-72°W. The study includes 48 pollen spectra taken from surface samples collected between the cities of Río Gallegos, Río Turbio, Punta Arenas and Cabo Vírgenes. Interpretation of the main regional vegetation systems based on pollen analysis and its correlation with the most important climate parameters along the climate gradients reaches from the Atlantic coast to the Andes. Climate data for this approach is obtained from the database of Leemans & Cramer (1991). Based on 18 pollen taxa with percentages exceeding 5% which have been selected by statistical procedures from the entire pollen spectra of the surface samples, three groups with a typical pollen composition were identified by PCA-analysis: Sub-Antarctic forest (BS), humid graminaceous steppe (EGH) and dry graminaceous steppe (EGX). The cumulative variance of these three groups accounts for 65,77% of the total variance.

Pollen spectra of these three groups (BS, EGH, EGX) correlate positively with annual and winter precipitation sums (r ≈ 0,8). In addition, there is a negative correlation with mean summer temperatures. The BS-group including Nothofagus t. dombeyi correlates with an annual precipitation sum between <800 and >300 mm, a winter precipitation sum between <60 and ≥24 mm and a mean summer temperature between 10 and 8,7°C. EGH is represented by Poaceae and associated with Rumex and Asteraceae subf. Cichoroideae as well as with Empetrum correlates with an

annual precipitation sum between ≤400 and ≈240 mm, a winter precipitation sum between ≈32 and ≈18 mm and a mean summer temperature between 10.7 and 9.5°C. EGX is represented by Poaceae associated with Caryophyllaceae, Asteraceae subf. Asteroideae, Azorella, Ephedra t. frustillata and Nassauvia and correlates with an annual precipitation sum amounting to between <300 and ≥140 mm, a winter precipitation sum between ≈20 and >10 mm and mean summer temperature between 10.7 and 12.5°C. Moreover, the mean winter temperature correlates well with some individual pollen taxa of the EGH-group, like Poaceae in the range between 0.4 and 1.3°C and Empetrum with values from 1.8 to 2.2°C. But it also correlates with the entire EGX-group for values between 1 and 2°C.

These results show the great potential of the analysed data in terms of reconstructing climate gradients. They also allow to develop calibration models for pollen and climate data to improve paleoecological and paleoclimatic interpretations of samples from Laguna Poterok Aike.

(translation: FS & BZ)

Spanish original:
Los estudios de la relación polen – clima realizados a lo largo de gradientes ambientales en Patagonia (Mancini, 1993, 1998; Prieto et al., 1998; Paez et al., 2001; Schäbitz et al., 2003) han demostrado su potencial como análogo moderno para las interpretaciones paleoambientales y paleoclimáticas del Holoceno. Esta metodología ha sido aplicada en el rango 51º - 53º S, 68º - 72º O, en el extremo sur de Sudamérica. El estudio comprende el análisis 48 espectros polínicos provenientes de muestras de sedimento superficial ubicadas entre las localidades de Río Gallegos, Río Turbio, Punta Arenas y Cabo Vírgenes; la interpretación de las principales formaciones vegetales del área en términos polínicos y la correlación de estos patrones con las principales variables climáticas que ocurren en el gradiente cordillera-costa. Los datos climáticos provienen de la base de datos elaborada por Leemans y Cramer en 1991. En este análisis se seleccionaron 18 tipos polínicos con porcentajes mayores a 5% y se realizó un análisis de agrupamiento que permitió definir tres grupos polínicos atribuidos al Bosque Subantártico (BS), la Estepa Graminosa Húmeda (EGH) y la Estepa Graminosa Xérica (EGX). En base a estos resultados se realizó un análisis de ordenación (PCA, varianza acumulada 65,77%). Los espectros polínicos del BS- EGH-EGX se correlacionan (r≈0.8) con el gradiente de la precipitación anual e invernal (correlación positiva) y con la temperatura media de verano (correlación negativa). El grupo BS con Nothofagus t. dombeyi se correlaciona con valores <800 - >300mm anuales, < 60 - ≥24mm invernales y 10º - 8,7º C; la EGH, caracterizada por Poaceae asociado con Rumex y Asteraceae subf. Cichoroideae y por Empetrum, con valores ≤400 – ≥240 mm anuales, ≈32 – ≥18 mm invernales y 10,7º - 9,5º C y la EGX representada por Poaceae asociado con Caryophyllaceae, Asteraceae subf. Asteroideae, Azorella, Ephedra t. frustillata, y Nassauvia, con <300 - ≥140mm anuales, ≥20 - >10mm de inverno y 10,7º - 12,5º C. La temperatura media de invierno se correlacionaron las dos asociaciones polínicas de la EGH, la de Poaceae (0,4º-1,3º C) y la de Empetrum (1,8º-2,2º C) y con la EGX (1º- 2º C). Estos resultados señalan el alto potencial climático explicativo del gradiente analizado y garantizan la elaboración de modelos de calibración polen – clima para la interpretación paleoclimática de los testigos lacustres de Patagonia sur.
References

Lake level fluctuations during the last decades in southern Patagonia – an approach using satellite images2

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This study evaluates the changes registered in surface water availability in depressions in the southern part of Santa Cruz, Argentina. The years 1986, 1999, 2002 and 2004 were taken into account, in which precipitation fluctuated between 160 and 416 mm per year.

The methodology used is based in the visual analysis and digital processing of satellite images and their integration in a Geographical Information System (G.I.S.). The area studied has an area of 15.000 km2 and is included in Landsat image 228-96. It lies between parallels 50°50’ and 52° south and the Atlantic coast in the East and meridian 70°40’ in the West. Within these limits 106 depressions, with a diameter larger than or equal to 1 km were identified.

Water availability in these basins showed important changes in the analyzed periods, corresponding to the differences in registered precipitation of the area (weather station Río Gallegos). The amount of water available in all the depressions together varied in the area between 12.000 and 30.000 hectares, with important depth variations. This parameter was inferred from the spectral behavior of the ponds, although it must be said that the sediment in the water may modify their spectral signature.

2 Proyect: Cuencas endorreicas de la Patagonia Austral: Geomorfología y Dinámica del Paisaje. Director: Lic. Elizabeth Mazzoni
Potrok Aike is a lake of greater size in the study area, and one of the few with a permanent water regime. In the analyzed period dimensions varied between a maximum of 792 ha in 1986 and a minimum of 751 ha in 2001.

The results obtained up to now show the importance of closed basins as water gatherers in the semiarid region of Patagonia, as they temporarily store precipitation, thus avoiding quick surface runoff.
(translation: EM)

Spanish Original:

FLUCTUACIONES EN EL NIVEL DE LOS LAGOS DEL SUR DE LA PATAGONIA EN LAS ULTIMAS DECADAS: UNA APROXIMACIÓN USANDO IMÁGENES SATELITALES

El presente trabajo evalúa los cambios registrados en la disponibilidad superficial del agua en las depresiones ubicadas en la porción austral de la provincia de Santa Cruz, Argentina. Se tomaron en consideración los años 1986, 1999, 2002 y 2004, en los cuales el registro pluviométrico ha sido muy variable, fluctuando entre 160 y 416 mm anuales.

La metodología utilizada está basada en el análisis visual y procesamiento digital de imágenes satelitales y su integración en un SIG. El área de estudio comprende unos 15,000 km², incluidos en la imagen Landsat 228-96. Se extiende entre los paralelos 50º 50' y 52º S, la costa atlántica al E y el meridiano de 70º 40' al O. Dentro de estos límites se identificaron 106 depresiones con un diámetro mayor o igual a 1 km.

La disponibilidad de agua en las cubetas mostró importantes cambios en los períodos analizados, en correspondencia con las diferencias pluviométricas registradas en la región (estación meteorológica Río Gallegos).

La cantidad de agua disponible en el conjunto de las depresiones varió entre 12,000 y 30,000 hectáreas, con importantes variaciones de profundidad. Este parámetro fue inferido a partir del comportamiento espectral de las lagunas, aunque debe destacarse que el contenido de sedimentos en el agua puede modificar su signatura espectral.

Potrok Aike es la laguna de mayor tamaño del área de estudio, y una de las pocas de régimen permanente. En el periodo analizado, sus dimensiones variaron entre 792 Ha de superficie máxima (1986) y un mínimo de 751 Ha en el año 2001.
Precipitation origin and evaporation of lakes inferred from stable isotopes (δ^{18}O, δ^{2}H) in southeastern Patagonia (Argentina)

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Water balance calculations with stable isotope approaches require background information about hydrogen and oxygen isotope variability of lakes and their potential inflows. In the framework of the project “SALSA” a stable isotope database (δ^{2}H and δ^{18}O) was established for estimating evaporation to inflow ratios (E/I) of lakes from semi-arid southern Patagonia. Water samples of 23 lakes and ponds were sampled during three subsequent austral summers. Two crater lakes, Laguna Azul and Laguna Potrok Aike, were studied in more detail during a two-years monitoring. Isotope composition of precipitation, groundwater and water vapor of the air were also investigated. The data imply that the isotopic composition of rainfall in southeastern Patagonia is predominantly determined by precipitation amount and moisture source area. The first meteoric water line and evaporation line in δ^{2}H vs. δ^{18}O space for the investigated area were derived. E/I calculations for Laguna Azul and Laguna Potrok Aike suggest that about 50% and 60%, respectively, of the water entering the lakes via surface and subsurface inflow evaporates. The modern isotope data can serve as a starting point for the interpretation of isotope records from e.g. lacustrine cellulose or carbonates.

Archaeology of the Pali Aike Lava Field

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The archaeology of the human colonization of Southern Patagonia is relatively well known. Human populations were inhabiting at least at four different Patagonian areas since c. 11,000 yrs BP. The Pali Aike Lava Field is one of these areas, and it was the first Patagonian area to produce convincing evidence of the human presence at the end of the Pleistocene. The association of hearths, artifacts and megamammal bones was clearly indicated in the 1930s at Fell Cave. In the 1950s and 1970s a radiocarbon chronology for human occupations of the cave was constructed,
that covered the end of the Pleistocene and the Holocene. However, recent research at other sites introduced some changes in this chronological scheme. A discussion of the evidence obtained at Fell Cave, Las Buiterras Cave and other archaeological sites will be presented, indicating a pattern of discontinuous use of caves and rockshelters during the last 11,000 radiocarbon years. The distribution of late Holocene sites near Laguna Azul and Laguna Potrok Aike indicates that these water bodies were important nodes for human settlement.

Scientific background and aims of INTA research at Potrok Aike

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The experimental field of Potrok Aike, a 2.500 ha station, is managed by INTA through a joint agreement with the Province of Santa Cruz since 1985. It is adjacent to Laguna Potrok Aike, in the Magallanic steppe, a 3 M ha ecological unit in southern continental Patagonia and north of Tierra del Fuego. The landscape includes volcanic and glacifluvial features at 150 m a.s.l., 5º C mean annual temperature and 240 mm of annual rainfall. Vegetation is a Festuca gracillima steppe with about 60% cover. The field has 14 paddocks, four bores, a shearing shed, and lodging facilities for small research groups. The baseline of the management is to provide an example of a sustainability managed system according to the Extensive Management Technology. They include yearly forage evaluations and stock adjustments to prevent overgrazing, optimize animal production and avoid unfavorable transitions in the vegetation. Baseline studies include maps of vegetation, range condition, soils and topography. Forage production and quality was analyzed. Sheep production alternatives were evaluated comparing production of Merino, Corriedale, Cormo and Corino breeds. Nutritional gaps for animal production were assessed through the Cordero model and Emergency (winter) and strategic (spring) forage supplementation schemes developed. Forage species were introduced in experimental plots in the most productive sites. The introduction of Llamas and Cattle in mixed grazing schemes was tried to diversify production. Progeny tests to objectively analyze the genetic merit of Corriedale rams have been in place since 2000. Sheep behavior was analyzed using GPS collars. Research on water ecology included soil and leaf water potentials in 3 topographic situations. These studies have recently been collated in a GIS information system and a comprehensive review of this research was published (Gonzalez et al., 2005). Ongoing research includes the spatially explicit Savanna model. The field is open to host extension, research and education efforts in collaboration with other institutions.

Reference

Limnogeological results from Laguna Potrok Aike

High-resolution pinger, airgun and sparker seismic surveys in Laguna Potrok-Aike: Imaging the sediment infill prior to deep drilling

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With the initial goals to determine thickness, geometries and distribution of sediments in Laguna Potrok-Aike, a complete assembly of reflection seismic investigations have been carried out in various campaigns. The results allow to identify potential sediment types, associated depositional processes and past lake level fluctuations. All these features are critical to determine ideal coring sites for future deep drilling locations.

In 2003, a high-resolution 3.5 kHz survey imaged the shallower subsurface in great detail and provided crucial information to interpret the up to 20 m-long piston cores that were retrieved following this seismic campaign. The acoustic signal penetrated in the central basin in average down to 20 m below lake floor. In the basin, the sediments are characterized by a well-layered succession that is interrupted in some areas by local mass flows (Fig. 1). These mass flows occur on the lower slopes and are the effect of slope instabilities that potentially could have been triggered by paleo earthquakes. The shallow and gently-dipping shoulder surrounding the lake down to a water depth of ~40 m is separated from the deep basin by very steep slopes and represents a sedimentary system, that is independent of the basinal succession. A prominent unconformity cropping consistently out at ~35 m depth marks the maximal depth of a lake level lowstand. At the unconformity, steeply dipping slope sediments below are truncated and overlain by gently dipping sediments that were deposited during the consecutive lake level rise/highstand (Fig. 2). The transgression occurred in a stepwise fashion, as indicated by a series of paleo shorelines that are located on top of the unconformity.

Because the 3.5 kHz data could not image volcanic bedrock due to a sediment thickness exceeding seismic penetration, a stronger double airgun seismic source was used in early 2004 in order to obtain a higher seismic penetration. Surprisingly, the stronger and lower-frequency double airgun signal did not penetrate the entire lake area to a greater subsurface depth and higher seismic penetration down to ~80 m was only achieved in some windows especially in the southeastern area of the lake. In late 2004, a third survey with an even stronger sparker system further documented in some areas of the lake well-layered sediments down to >100 m sediment depth (Fig. 3), proving that the bottom of the lake holds an extensive sedimentary record. As a peculiar general pattern, seismic penetration is greater in lake-marginal areas of the basin. The deeper reflections seen in both, airgun and sparker data, bend slightly upward towards the edges of the lake, indicating a bowl-
shaped sedimentary architecture that gradually becomes infilled. No clear bedrock signature (e.g., volcanic basement) can be seen, and the deepest reflections gradually have lower amplitudes and less lateral coherency preventing complete evaluation of the thickness of the sedimentary infill. The angles of the basinward dipping marginal layers become steeper with depth indicating that sedimentation is not purely draping, which would simply duplicate the inherited bathymetry. Rather some sediment focusing occurs, that slowly infills the bathymetry resulting in a progressively flat basin floor as a result of partial influence of hyperpycnal flow deposition. The bulk of sedimentation, however, appears still to be of pelagic-type, documenting the large potential of the sediments to record a superb paleoenvironmental history.

An additional seismic survey with an even stronger airgun source was needed, in order to address the total sediment thickness and to define a deep drilling strategy (Niessen & Gebhardt, this volume). A good understanding of sediment dynamics and sedimentary geometries within the basin, as the knowledge of amplitudes of lake level changes and the insights into a bowl-like extensive sedimentary archive, was already achieved using this unique combination of seismic reflection methods.

Fig. 1: 3.5 kHz seismic image of the western margins of the basin, showing a well-layered sedimentary record with intercalated stacked mass flow deposits. Note the base of seismic penetration at ~15 m.

Fig. 2: 3.5 kHz seismic sections showing three examples of the lake shoulder between a depth range of 20 and 50 ms twt (15 and 37 m). A prominent unconformity (white horizon) sharply truncates steeply dipping older sediments and crops out consistently at ~35 m water depth marking the maximal extent of a lake level lowering. The overlying sedimentary succession was deposited after the consecutive lake level rise. A series of paleoshorelines, occurring at consistent depths around the lake, are located on top of the unconformity and witness a stepwise increase of lake level.
Fig. 3: Sparker seismic section showing the deeper subsurface with a well-layered sedimentary architecture all the way down to the multiple reflection at ~100 m sediment depth. No major unconformity nor bedrock can be detected at that depth, indicating that the lake likely holds a continuous and extensive paleoenvironmental archive.

Deep seismic survey at Laguna Potrok Aike

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Within the framework of ICDP and funded by grants of the DFG-project “POTROK” to the University of Bremen, seismic investigations were carried out by AWI in March 2005 as part of an intense site-survey work for future deep drilling at Laguna Potrok Aike. In order to allow deep acoustic penetration and detection of the sediment bedrock interface, different seismic systems were combined in our study. On the lake this included a 20-element single-channel streamer, a 270 m long 14-channel streamer and three sonobuoys combined with two Reftek™ land stations installed near the lake shore. A Mini-G-Gun (Cercel™, France) with a chamber volume of 40 cubic inches was used as the acoustic source for both multi-channel and sonobuoy/Reftek™ data acquisition. In total four single-channel, three multi-channel and two refraction lines were recorded. The data presented here are preliminary because most of the profiles are not fully processed yet.

Multi-channel data exhibits very good signal-to-noise ratios over more than 600 ms two-way travel time (approx. 450 m depth for a velocity of 1490 m/s). The data show overprint by multiples so that the interpretation of strata below the first multiple at about 200 m depth remains difficult until fully processed profiles are available. However, relatively strong reflectors visible on each end of the profiles indicate the steep slope of the bedrock to a depth of about 300 to 400 m. The slope is buried by
what appears to be a well-stratified sedimentary fill. The sonobuoy data exhibit
refractions below 700 ms travel time. A first refraction analysis allows the distinction
of four different velocity layers ranging from 1630 m/s to 3090 m/s. The former
velocity is indicative for muddy lacustrine sediments. The latter is typical for
sandstones forming bedrock and catchment of the Laguna Potrok Aike (St. Cruz
Formation). Assuming horizontal strata, a preliminary depth estimation of the different
layers in the center of the lake suggests the transition from lacustrine sediments to
weathered bedrock (velocity increase to 2120 m/s) being located in a depth of 300 to
400 m below lake surface.

The results indicate a total sediment fill of Laguna Potrok Aike significantly
thinner than the 700 m thickness originally expected from the size of the maar. The
acoustic penetration of our work was deeper than during previous seismic surveys at
Laguna Potrok Aike, where no reflector interpretation was possible deeper than 105
m below lake floor. However, in our single-channel reflection profiles, the sediment-
bedrock interface remains obscure in the center of the lake due to horizontal reflector
geometry overprinted by multiples. So far, no major unconformity or displacement are
visible in the sediments of Laguna Potrok Aike. Also, no sub-bottom velocities were
detected that are indicative for volcanic basement. Possibly the volcanic vent
expected under the maar lake is too small to be detected by the refraction method or
our profiles did not cross such a feature.

Tephrochronology of Laguna Potrok Aike sediments

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During the Late Quaternary southern Patagonia was influenced by intensive
volcanism that occurred along the southern Andes in two separate volcanic zones
(Stern et al., 1984). In the North, the Hudson volcano of the southern part of the
Southern Volcanic Zone (SSVZ, at 46°S) erupted basalts and dacitic to andesitic
pyroclastic rocks. Its last explosive activity occurred in the year 1991. In the South,
the stratovolcanoes of the Austral Volcanic Zone (AVZ, at 49–54°S) produced many
tephra eruptions of andesitic-dacitic to rhyolitic composition. Most of those activities
were confined to the Lautaro, Viedma and Aguilera volcanoes in the northern part
(NAVZ) as well as to the Mount Burney and Reclus volcanoes in the southern part of
the AVZ.

So far, the Holocene explosive history of SSVZ and AVZ volcanoes has been
substantially constrained on the basis of chemical discriminations of numerous distal
tephra layers detected in terrestrial records in Chile and Argentina (e.g. Auer, 1974;
Stern, 1990; Stern & Kilian, 1996; Markgraf et al., 2003; Kilian et al., 2003). Due to
the generally widespread distribution to the East and Southeast those tephras have
been used as effective isochrones for dating and correlation between postglacial
deposits in this region.

The Potrok Aike maar lake, located in a favorable downwind position to those
explosive volcanoes, has turned out to be an important archive for tephra recording.
Up to now, three distal tephras in each of the two sediment sequences recovered
from the centre of the lake (PTA 03/12, 13) and from a sub-aquatic lake level terrace (PTA 03/6) have been detected macroscopically. First tephrochronological studies including the geochemically (EPMA) and microscopically characterization of tephra components have been carried out in order to independently fix the sediment chronologies by the correlation of tephras to specific dated volcanic events. As a result, tephras intercalated in the sediment profile PTA 03/12, 13 have been allocated to Holocene and Late Pleistocene eruptions of Hudson, Mount Burney and Reclus volcanoes providing reliable time and correlation markers at approximately 7.7, 8.0 and 13.0 $^{14}$C ka BP, respectively. Tephras from the profile PTA 03/6 are deposited below the early Holocene unconformity in the lower part of the profile and are roughly dated to between 40 and 50 ka BP. According to the specific dacitic to rhyolitic chemistry of glass components, those ashes have been assigned to eruptions of Mt. Burney and Reclus volcanoes. Even though independent dating of tephra layers are not available at the moment in order to improve the sediment chronology, the correlations of Laguna Potrok Aike tephras to distinct volcanic sources help to increase the knowledge of the explosive activity of southern Patagonian volcanoes for the Last Glacial time period. The results of tephrochronological investigations, however, imply that at least Reclus and Mt. Burney volcanoes were explosively active during the last 50 ka.

The initial tephrochronological studies in the Potrok Aike maar lake sediments have demonstrated that there is a huge potential for tephrostratigraphic constrains in Southern Patagonia and in the western part of the South-Atlantic Ocean that require further volcanological and tephrochronological studies. The finding of older prominent tephras and cryptotephras (ash layers which are hidden to the naked eye) in between the Potrok Aike sediments and their correlation to proximal pyroclastic deposits will immensely help to improve the tephrostratigraphy in this region. Related studies require both the chemically characterization of tephras using high-precision analytical instruments (e.g. Electron microprobe, laser ablation ICP-MS) and the dating of tephras by modern $^{40}$Ar/$^{39}$Ar techniques, which, for instance, is available at the TU Bergakademie Freiberg.

References
Lake level fluctuations at Laguna Potrok Aike and how they are recorded in the sediments

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In the framework of the project “SALSA” we studied several lakes focusing on Laguna Potrok Aike with an integrated research approach. This includes studies in geomorphology, limnology, geophysics, sedimentology, geochemistry, biology and climate modeling. The latter is of importance in order to decide whether the hydrological balance of this region is mainly modulated by the latitudinal migration of the southern Westerlies as is common sense in the literature or if other circulation anomalies play a more important role than previously thought.

Laguna Potrok Aike is a terminal lake and therefore very sensitive to changes in the hydrological regime. With the available meteorological data from the Potrok Aike INTA research station we developed a first hydrological balance model for Laguna Potrok Aike in order to get ideas about the main factors that control the potential evaporation. Modeled lake levels for the past four years compare well with pressure sensor data (which recorded actual lake level fluctuations between March 2003 and March 2005) and field observations (Ohlendorf et al, in prep.). This promising result opens the possibility to model the past much more pronounced lake level variations which are witnessed by several terraces up to 25 m above and at least 35 m below present day lake level. Studies of the recent processes (water chemistry, thermistor chain and sediment traps) clearly indicate that changes in lake water volume lead to changes in the carbonate system and the oxygen isotopic composition of the lake water. Those parameters besides others can be tracked in the lake sediments and thus may serve as proxies for lake level variations in the past.

For a 1 m long sediment gravity core from the deepest part of Laguna Potrok Aike a multiproxy approach including analyses of grain sizes, water content, dry density, gamma ray density, p-wave velocity, magnetic susceptibility, frequency dependent magnetic susceptibility, total inorganic carbon (TIC), total organic carbon, total nitrogen, total sulfur, biogenic silica, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Sr, Pb, $\delta^{13}$C$_{org}$, $\delta^{15}$N, $\delta^{18}$O$_{carb}$, pollen and diatoms was applied (Haberzettl et al. 2005). Rapidly alternating climatic conditions were detected. The TIC-content, supported by $\delta^{13}$C$_{org}$ and C/N-ratios for example, was identified as a sensitive lake level indicator where high lake levels are reflected by low values and vice versa. This proxy suggests that during the late Middle Ages (ca. 1230-1480 AD) the lake level was rather low representing a signal of the Medieval Climate Anomaly in southeastern Patagonia. The existence of lower lake levels in former times was demonstrated by seismic studies which revealed lake level terraces below the present lake level. At the beginning of a period similar to the Little Ice Age of the northern hemisphere the lake level rose considerably staying on a high level during the whole period. As a result several sub-aerial terraces are preserved. This interpretation is supported by several radiocarbon datings of these lake level terraces. Subsequently, the lake level lowered again in the course of the 20th century. Analyses of a 18.9 m long sediment core from the center of the lake indicate that TIC in combination with $\delta^{18}$O$_{carb}$ can be used as lake level indicator further back in time providing a hydrological record of the past 16,000 shcal. BP for southeastern Patagonia.
References

**Sediment core from the center of Laguna Potrok Aike covering 16,000 years. 1. Coring, chronology and sedimentology**

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During a SALSA field campaign in austral summer 2003 two overlapping sediment cores (PTA03/12 & 13) were recovered from the 100 m deep central basin of Laguna Potrok Aike with an UWITEC piston coring system. Immediately after coring cores were cut into one meter sections on board of the research vessel “Lago Cardiel”. Field length of the entire core comprising all sections was 1720 cm. The top of the record was correlated to a short core obtained during an earlier field campaign in 2002. After correlation the total subbottom depth of the core was 1892 cm. In the laboratory sediments were sampled in one cm intervals and analyzed according to the SALSA multi-proxy-approach (geophysics, geochemistry, stable isotopes, pollen and diatoms).

The age model is based on 16 radiocarbon dates performed on different materials (8 sieved samples containing remains of aquatic macrophytes (>100 µm), the calcite fraction of 5 bulk samples, a twig of barberry (*Berberis*), a jaw-bone of the rodent tuco-tuco (*Ctenomys* sp.) and a bulk sediment sample) as well as on the Mt. Burney tephra (Kilian *et al*., 2003). The absence of a hard water effect in the sediments of Laguna Potrok Aike has been demonstrated in an earlier study (Haberzettl *et al*., 2005). The sediment/water interface served as time marker for the year of coring. The calibrated age ranges of the volcanic ashes of the Hudson (Kilian *et al*., 2003) and Reclus (McCulloch *et al*., 2005) volcanoes served as validation of the model. Further confirmation of the model was given by the result of a test dating of the calcite fraction of a bulk sample and remains of aquatic macrophytes located close to each other. Both samples showed similar results, indicating that the calcite fraction of bulk sediment is well suited for dating sediments of Laguna Potrok Aike. Additional support for the age model is given by the fact that a number of different materials used for dating reveal a consistent model.

Analyses of the 16,000 cal. BP record revealed variations in total inorganic carbon (TIC), Ca, Ti, Fe, V, Fe/Mn-ratio which could be interpreted as indicators of lake level fluctuations reflecting the hydrological variability of southeastern Patagonia (Haberzettl *et al*., in preparation).
References


Sediment core from the centre of Laguna Potrok Aike covering 16,000 years. 2. Potentials and experiences of stable isotope approaches

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Stable isotopes of organic materials as well as of inorganic and biogenic minerals are valued as powerful tools in palaeoecological and palaeoclimatological studies on lacustrine sediments. However, to live up to these expectations additional fundamental knowledge about the sources of materials buried in the sediment, about the true discrimination with respect to the isotopic source value, and about syn- and post-sedimentary diagenetic effects possibly leading to an alteration of the initially stored isotope signal has to elaborated. This can best be achieved by an effective multi-proxy approach, realized within the SALSA project, where both samples and knowledge are shared adequate to the requirements determined by the overall goals of the study.

The results of isotopic investigations performed so far on the sediment core from Laguna Potrok Aike will be reported. These comprise carbon and nitrogen isotope composition of bulk organic matter, carbon and oxygen isotope composition of endogenic carbonates, carbon and oxygen isotope composition of cellulose from aquatic mosses as well as the isotopic composition of several source materials from the catchment. So far, contributions from various sources to sedimentary organic matter have been detected and described by a combination of isotopic parameters with element concentrations and bulk organic geochemical indices (HI, OI). Changes in the hydrological cycle were revealed by the oxygen isotope composition of carbonate minerals which indicate, together with other proxies, lake level fluctuations and a major dry period during the Holocene.
The possibilities of further exploiting these parameters for the available Laguna Potrok Aike materials well proven isotope techniques will be outlined which are also scheduled to be applied to the new sediment cores to be recovered within the ICDP-project PASADO. In addition, further new potentials arising from now available novel isotope techniques, e.g. compound-specific isotope analysis, will be illustrated for the planned project.

**Sediment core from the center of Laguna Potrok Aike covering 16,000 years. 3. Diatoms and paleoenvironmental reconstructions**

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Climatic changes are the subject of many multidisciplinary studies all around the world and the importance of diatoms is well known as a valuable diagnostic tool in such kind of studies. Their use implies a deep knowledge of the taxonomy and ecology of the recent species, that will allow us to use them to infer past environmental conditions.

The diatomological analysis from a sediment core recovered from the center of Laguna Potrok Aike covering 16,000 years revealed an alternating dominance of three planktonic species. *Cyclostephanos patagonicus* Guerrero & Etchenique dominates in the lower part of the core. This species was found previously only in the type locality (Limay river, northern Patagonia) and it seems to prefer low conductivity waters. *Chaetoceros muelleri* Lemmermann was found as dominant (37% of relative abundance) only in one sample that overlies a tephra layer (*ca.* 8700 y BP). In the upper samples until the present days the dominant species is *Cyclotella agassizensis* Håkansson & Kling, known only for the type locality (Manitoba Lake, Canada) and the Salta province (Argentina).

Diatom concentrations fluctuated between 0 and $3 \times 10^8$ frustules gr$^{-1}$ along the core but there was a tendency to decrease from the bottom to the top of the record. Although the correlation studies between diatom species and the other proxys have not been completed yet, our previous results indicate a significant positive correlation between the concentrations of *Cyclotella agassizensis* and total inorganic carbon (TIC). This would indicate a correlation between the abundance of this species with a lower lake level during the time of sedimentation.
Sediment core from the center of Laguna Potrok Aike covering 16,000 years. 4. Late Glacial and Holocene Vegetation and climate history of the Pali Aike Volcanic Field inferred from a 17 m pollen profile

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The pollen record from the composite core PTA03-12 and 13 spans the last 16,000 years (Fig. 1). With an average temporal resolution of about 70 years it provides very detailed insights into vegetation dynamics since the Late Glacial.

Between 16 and 14 ka cal. BP pollen spectra show glacial conditions with very little Andean forest contribution and strong dominance of Patagonian Steppe taxa. In accordance with sediment and isotope proxies, a relatively high contribution of aquatics and very low charcoal content lead to increased humidity during this period. A strong occurrence of the alga *Pediastrum kawraiskyi* shows that during this period the lake must have been filled with cold, clear and oligotrophic water.

Between 14 and 8.6 ka cal. BP a spread of Andean forest mainly represented by *Nothofagus* pollen indicates increasing temperatures. A contemporaneous decrease of Poaceae pollen might lead to decreasing humidity. A charcoal peak at 12 ka cal. BP is the only major fire event that could be detected during early and mid-Holocene times.

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![Fig. 1: Pollen record from the composite core PTA03-12, 13 from Laguna Potrok Aike versus depth and time.](image-url)
Since about 8,6 ka cal. BP contribution of Andean forest in the pollen spectra has reached the present level. Poaceae pollen decreased until around 6,5 ka cal. BP probably indicating driest conditions at this time. After 6,5 ka cal. BP pollen spectra show few short but strong fluctuations probably indicating periods of drought. The arrival of Spanish and English settlers can be detected by charcoal peaks at 391 and 137 cal BP with the occurrence of alien *Rumex* pollen starting about 70 years ago.

**Sediment core from the center of Laguna Potrok Aike covering 16,000 years. 5. Pollen-based approach of qualitative and quantitative climate reconstruction**

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Pollen analytical data provide a tool not only for qualitative but also for quantitative climate reconstruction. Based on the analysis of modern pollen analogs from southern Patagonia which are closely correlated with vegetation units (Paez, this vol.) and the main climate parameters precipitation and temperature, we will present a first statistical model of quantitative climate reconstruction build up by multiple regression analysis. This model is than applied to the pollen analytic results of the long core from Laguna Potrok Aike (Wille et al., this vol.) in order to show variations in both climatic parameters for the past. These results will be compared with the classical qualitative pollen interpretation of the same profile as well as with interpretations from other proxies gained in the SALSA project. Advantages and disadvantages as well as problems of this methodology will be discussed.

**Downscaling of climate simulations for comparison with climate reconstructions from Laguna Potrok Aike records**

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Climate variability in the pre-instrumental period can be estimated from climate-sensitive proxy records and it can be simulated with climate models. The most detailed global models that can currently be used for paleosimulations are General Circulation Models (GCMs), which include explicit dynamical representations of the atmosphere and the ocean. In order to simulate the climate of the past, the models
can be forced with estimates for the Earth’s orbital parameters, solar irradiance, volcanic aerosol and greenhouse gas concentrations. The current generation of super computers allows simulations of several thousand years with a spatial resolution of several hundred kilometers.

Both, simulations and proxy-based climate reconstructions are associated with considerable uncertainties. Consistency test between simulations and empirical climate reconstructions are needed to assess which aspects of past climate variability can be reconstructed with confidence, to test climate models and proxy-based reconstructions, and to understand the causes for past climate variability.

However, a direct comparison of empirical climate reconstructions and simulations is often not possible, because climate-sensitive proxy records are primarily influenced by the regional climate, whereas the simulations typically have skill on spatial scales larger than around 1000 km (several grid cells). This scale mismatch is particularly relevant for precipitation, which has a high small-scale variability, involves many processes not resolved by GCMs, and thus can not be realistically simulated (e.g. Widmann et al., 2003).

As many climate proxies from Laguna Potrok Aike (PtA) can be expected to be precipitation-sensitive, we have developed statistical downscaling models to estimate regional precipitation in the PTA area from simulated large-scale circulation variability and have applied them to GCM simulations for the Mid-Holocene (Wagner et al., 2006). These statistical models are based on empirical relationships derived from observations during the last few decades.

We intend to contribute to PASADO with improved statistical downscaling models for precipitation in the PTA area. If the analysis of the PTA sediment cores yields proxies for other climate variables, we would attempt to formulate downscaling models for those. We will then apply the downscaling models to GCM simulations. To date, several simulations with time-varying forcing exist for the last millenium (e.g. Zorita et al., 2004) and for the Mid-Holocene. By the time the PASADO cores will be available, more simulations with improved models can be expected to have been conducted, and will be considered for consistency test with the PASADO records.

References


Challenges for the Potrok Aike Lake Sediment Archive Drilling Project (PASADO)

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Based on two studies in the framework of the BMBF-funded German Climate Research Programme (DEKLIM) – “South American Lake Sediment Archives and Modelling” (http://www.SALSA.uni-bremen.de) and “Transient simulation of the middle Holocene with a coupled atmosphere-ocean general circulation model” (http://w3k.gkss.de/staff/wagner/MIDHOL.html) - and on several seismic surveys carried out with the DFG-funded project POTROK (http://www.salsa.uni-bremen.de/homepotrok.htm) we are now at a stage to apply for support for the international research initiative “Potrok Aike Lake Sediment Archive Drilling Project” (http://www.salsa.uni-bremen.de/neue%20Strucktur/homepassado.htm) within the framework of the International Continental Scientific Drilling Programme (http://www.icdp-online.de).

We propose to use the GLAD800 coring system (http://www.dosecc.org) to recover long sediment cores from 100 m deep Laguna Potrok Aike, a maar lake situated in the dry steppe of southern Patagonia (Santa Cruz, Argentina). This is a location of global geological significance and potentially the only site that can provide continuous and high-resolution terrestrial sediment records over glacial cycles for southern hemispheric mid-latitudes. The area is climatically sensitive and an ideal continental counterpart for marine and ice core records necessary for a comprehensive understanding of past climate changes. PASADO continues the incentive of ICDP in a sense that in addition to tropical lake coring activities (Lakes Titicaca, Bosumtwi, Malawi and most recently Peten Itza) also non-tropical sites are considered (Lakes Baikal, Qinghai and soon also El'gygytgyn). However, all these outer tropical sites are from the northern hemisphere. To improve our understanding of climate dynamics and global environments, PASADO will be the first location from the non-tropical southern hemisphere and from the beginning this project also will include climate modelling components.

PASADO addresses several challenging issues of geoscientific and socioeconomic relevance related to Earth history and climate (quantitative climatic and environmental reconstruction, palaeosecular variation of the Earth’s magnetic field), natural hazards (fire history, history of volcanic activity including tephra fallout, dust deposition) and volcanic systems (evolution of phreatomagmatic craters, history of volcanic activity) for the last several glacial to interglacial cycles. Moreover, dust and tephra records will provide means of correlation to link this terrestrial record to marine sediment archives and ice cores from Antarctica (inter-archive comparison). Obtained reconstructions of climate variability will be compared statistically with the output of Global Circulation Model (GCM) simulations to improve our understanding of forcing mechanisms of the global climate.

Due to the unique geographic situation of Laguna Potrok Aike and based on existing information derived from four seismic surveys and sediment cores of up to 19 m length and 45 ka coverage we envisage for PASADO:
Drilling of the complete high-resolution (~1m/1ka) sediment infill (200-300 m) down into phreatomagmatic breccias and the maar diatreme;

High-resolution quantitative reconstruction of temperature, precipitation, hydrological variations, terrestrial vegetation and fire history on absolute orbital and suborbital (multimillennial) down to decadal timescales supported by multiple dating (e.g. $^{14}$C, OSL, Ar/Ar) and stratigraphic approaches (pollen and paleomagnetic records);

Development of records of dust storm events, tephra layers and paleosecular variation of the Earth's magnetic field;

Comparison of the PASADO data set with the high-resolution >740 ka EPICA ice core record from Antarctica focusing on:
  - the magnitude and abruptness of glacial/interglacial transitions and
  - the periodicities and cycles during glacials/interglacials;

Tracing the record of atmospheric dust from Patagonian sources to marine sediments (South Atlantic) and ice cores (Antarctica);

Statistical comparison of PASADO data with climate simulations from GCMs to establish links between climate variability and climate forcing factors such as changes in the Earth's orbit, solar output and greenhouse gas concentrations. Questions to be answered include:
  - Are latitudinal shifts in the position of the southern westerlies reproducible?
  - Are synoptic scale phenomena like polar outbreaks and their recurrence patterns represented?
  - Can interhemispheric synchronous climatic linkages be detected to assess the role of ice sheets, oceanic and atmospheric circulation and astronomic forcing on climate?

This international and highly interdisciplinary approach needs detailed pre-planning to be carried out successfully. Therefore, we will focus during the ICDP-Workshop PASADO on discussing and planning of objectives and achievements, required laboratory analyses and techniques, forms of scientific collaboration, anticipated drilling sites and operations as well as on logistics, funding, political and legal issues. Output should be a collectively developed science plan which will serve as the nucleus for international multidisciplinary proposals to be submitted to national funding agencies of all participating countries.
Field trip to Laguna Potrok Aike

Excursion guide to the crater lake of Laguna Potrok Aike
(Santa Cruz, Argentina)

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Introduction

Sedimentary records from crater lakes are of major scientific interest because they often provide continuous high-resolution climatic and environmental archives (e.g. Negendank & Zolitschka, 1993). The Pali Aike Volcanic Field (52°S, 70°W), located in the Argentine province of Santa Cruz, southeastern Patagonia (Fig. 1, 2), thus came into the focus of limnogeological investigations. During a field survey of crater lakes performed in the Pali Aike Volcanic Field Laguna Potrok Aike with a water depth of 100 m was then selected for further geophysical, sedimentological, palaeolimnological, monitoring and modelling studies. The sediment infill of Laguna Potrok Aike may comprise up to 250 m of lacustrine deposits back to a mid-Pleistocene age (770 ka). Several aerial and subaquatic lake level terraces were identified pointing to lake level fluctuations triggered by past hydrological changes. The fine-grained sediments were subjected to multidisciplinary studies in the framework of the project South American Lake Sediment Archives and Modelling (www.SALSA.uni-bremen.de) which is part of the German Climate Research Programme (www.DEKLIM.de), providing a detailed terrestrial record of past climatic and environmental variations for this region and thus add to the understanding of the climate system in southern mid-latitudes (Haberzettl et al., 2005, 2006a, b; Mayr et al., 2005, 2006; Wagner et al., 2006; Zolitschka et al., 2004, 2006).

Climate and vegetation

The modern climatic conditions of southern Patagonia are very peculiar. Its small landmass does not warm up during the austral summer like continents in the northern hemisphere at comparable latitudes. In addition to the different distribution of land and sea, this is mainly due to the relative proximity to the Antarctic continent, which acts as a “freezer” during the whole year (Weischet, 1996). Large amounts of incoming solar radiation are spent to melt the extensive ice shelves in the southern summer. Moreover, cold ocean currents – the Humboldt Current along the west coast and the Falkland Current along the east coast of South America – transport cold water to the Patagonian coasts additionally reducing atmospheric heating. Thus the advection of cold air masses to the continent causes cool summers whereas the vicinity to the oceans promotes mild winters. Moreover, occasional catabatic winds...
leave Antarctica and add cold air masses to more northerly locations. The temperature decrease related to these so-called polar outbreaks mainly affects more subtropical and tropical regions like Brazil (Marengo & Rogers, 2001). However, polar outbreaks may also be of hydrological importance further south by causing advection of moist air masses from the east to southern Patagonia.

Fig. 1: Investigated area in southern Patagonia (Provincia de Santa Cruz, Argentina) with location of studied lakes, wells and streams. Numbers refer to sites listed in Tab. 3. The Pali Aike Volcanic Field (PAVF) is marked by the frame of B (Zolitschka et al., 2006).

The eastern part of southern Patagonia is a semiarid and cool semi-desert, which lacks any well-defined rainy season (Weischet, 1996). A strong precipitation gradient exists between the west and the east coast of South America caused by the topography of the continent. The southern westerlies transport humid air from the
Pacific Ocean to the Andes leading to annual precipitation sums of 4000 to 6000 mm along the west coast (Weischet, 1996). In the rain shadow east of the mountain chain precipitation decreases to <400 mm, in the Pali Aike Volcanic Field even to values less than 300 mm (Gonzalez & Rial, 2004; McCulloch et al., 2000) and at the Potrok Aike meteorological station values of only 150 mm have been observed (Zolitschka et al., 2006). In addition to the rainout effect of the Andes, precipitation east of the Andes is influenced by the adiabatic increase of mean annual temperature and hence decreasing relative humidity. Other processes cannot compensate this lack of moisture because additional sources of water vapor are absent and evaporation by xeric plants remains low (Weischet, 1996).

The southern westerlies across Patagonia are characterized by high wind speeds with mean annual values of 7.4 ms\(^{-1}\) at Río Gallegos and maxima during summer (Baruth et al., 1998). Wind direction is primarily from the west shifting occasionally to NW and SW (Weischet, 1996; Baruth et al., 1998). The instrumental meteorological record of the Río Gallegos weather station exists since 1931 (75 years) but is rather fragmentary. It shows an annual mean precipitation sum of 251 ± 62 mm (missing values: 11) and a mean annual temperature of 7.4 ± 0.7°C (missing values: 57) with a July (winter) minimum of +1.0 ± 1.5°C (missing values: 20) and a January (summer) maximum of 13.0 ± 1.2°C (missing values: 17). Both, mean annual temperature and annual precipitation sum for the Potrok Aike meteorological station are 30-40 % lower compared to the weather station in the coastal city of Río Gallegos (Zolitschka et al., 2006). While the differences in temperature can be explained by the different degree of continentality, the discrepancy in precipitation may also point towards an eastern source region for rainfall events that may be related to polar outbreaks.

The strong trans-Andean precipitation gradient determines the vegetation patterns in southern Patagonia. However, positive atmosphere-vegetation feedbacks may play an additional role increasing the west-east moisture gradient under present day conditions. Five major vegetation zones are distinguishable for southern South America (Hueck & Seibert, 1981; Moore, 1983; Roig, 1998): Magellanic moorland and evergreen Magellanic rain forest thrives west of the Andes, Andean tundra dominates above the tree line and deciduous *Nothofagus* forest grows near the tree line in the Andes as well as at lower elevations east of the Andes where precipitation is still in excess of 400 mm. In the more arid regions further to the east Magellanic steppe occurs.

The Pali Aike Volcanic Field is located in the lowland between the Andes and the Atlantic coast amidst the Magellanic steppe formation, which is characterized by grassland with occasional shrubs. It can be divided into a moister (mesic) type located closer to the Andes in the west with *Festuca pallescens* as dominant species and a dryer (xeric) type located in the east with *Festuca gracillima* as dominant species (Pisano, 1985; Roig, 1998). Since first European settlers reached this part of the continent in the last decades of the 19\(^{th}\) century, vegetation was altered by sheep farming (Aagesen, 2000; Liss, 1979). As a consequence, overgrazing and hence soil erosion is widespread. Additionally, the flora has been modified by the introduction of European weeds (Huber & Markgraf, 2003). Despite this human influence on lowland vegetation, there is a close correlation between modern pollen rain and vegetation zones (D'Antoni, 1991; Mancini, 1993), which offers the possibility to apply modern pollen analog techniques to fossil pollen records (Paez et al., 2001).
Geology
The study area is located in the Pliocene to late Quaternary Pali Aike Volcanic Field (Fig. 2) a northwest-southeast oriented tectono-volcanic belt about 50 km wide and more than 150 km long. This back arc volcanic area (Mazzarini & D’Orazio, 2003) is situated in the Magellan Basin 80 km west of the city of Río Gallegos, immediately north of the Strait of Magellan and about 300 km east of the active Andean volcanic arc. Petrologically, the Pali Aike Volcanic Field consists of alkali-olivine basalts with an age range from 3.8 Ma (Pliocene) in the western part towards 0.01 Ma (Holocene) closer to the Atlantic Ocean (Fig. 2; Corbella, 2002). Along fissure related eruptions, cinder cones, lava domes and about 100 maars (500 to 4000 m in diameter) have been formed.

![Volcanic map of the Pali Aike Volcanic Field](image)

Fig. 2: Volcanic map of the Pali Aike Volcanic Field with radiometric ages of the Pliocene to late Quaternary volcanic back arc (Corbella et al. 2002; Zolitschka et al., 2006).

The oldest outcropping geological strata in the immediate study area are Oligocene marine sediments (sandstones, shales) related to a Tertiary marine transgression (Patagonia Formation). In the course of the Lower Miocene tectonic uplift of the Andes, fine-grained molasse-type fluvial sediments (Santa Cruz Formation) were deposited until 14 Ma exceeding 1000 m in thickness (Blisniuk et al., 2005, Uliana & Biddle, 1988). During the Plio-/Pleistocene, the investigated area south of the Río Gallegos river (Fig. 1, 2) was covered by glaciers that came from the south originating from the Magellan Strait as well as from Seno Skyring and Seno Otway. Fluvio-glacial deposits (Patagonian Gravel Formation) form the surface of the southern Patagonian Plains today. These so-called “Rodados Patagónicos” make up the Patagonian Plains or “Mesetas Patagónicas”, which are slightly dipping east towards the coast of the South Atlantic Ocean. In the south of Patagonia they are
regarded as glacial outwash deposited during Pliocene and early to mid-Pleistocene glaciations that stretched out to the east beyond the present Atlantic coastline and onto the shelf. Glaciations occurred roughly between 3.5 and 1.0 Ma but evidences and dating are poor (Tab. 1; Mercer, 1976; Rabassa & Claperton, 1990; Meglioli, 1992). The most extensive glacial advance was termed Initioglacial (Caldenius, 1932) or Greatest Patagonian Glaciation (Mercer, 1976). For the same event Meglioli (1992) introduced regionally different terms: Bella Vista Glaciation for the Río Gallegos valley and Sierra de los Frailes Glaciation for Cabo Vírgenes. In the Lago Buenos Aires basin, where at least 19 moraines document glacial advances from the Miocene to the Holocene (Kaplan et al., 2005; Mercer, 1976; Singer et al., 2004), the same glacial advance is related to the Telken VII moraine (Singer et al., 2004).

Tab. 1: Compilation of names and related dates for the two last glaciations in the Pali Aike Volcanic Field (PAVF), the coastal area of the Atlantic Ocean and the Lago Buenos Aires basin (references: ¹Caldenius, 1932; ²Mercer, 1976; ³Meglioli, 1992; ⁴Thon-That et al., 1999; ⁵Singer et al., 2004; *Zolitschka et al., 2006).

<table>
<thead>
<tr>
<th>Region</th>
<th>Initioglacial¹ or Greatest Patagonian Glaciation²</th>
<th>Max. age (Ma)</th>
<th>Min. age (Ma)</th>
<th>Last extensive glaciation</th>
<th>Max. age (Ma)</th>
<th>Min. age (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAVF</td>
<td>Bella Vista Glaciation⁴</td>
<td>&lt;1.17²</td>
<td></td>
<td>Rio Ciaike Glaciation</td>
<td>&gt;0.77*</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;1.168⁴,⁵</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Atlantic coast</td>
<td>Sierra de los Frailes Glaciation³</td>
<td>&lt;1.19*</td>
<td></td>
<td>Cabo Vírgenes Glaciation⁵</td>
<td>&gt;0.41³</td>
<td></td>
</tr>
<tr>
<td>Lago Buenos Aires</td>
<td>Telken VII moraines⁵</td>
<td>&gt;1.016⁵</td>
<td></td>
<td>Telken VI-I moraines⁵</td>
<td>&lt;1.016⁵</td>
<td>&gt;0.76⁵</td>
</tr>
</tbody>
</table>

Based on the stratigraphic position of Initioglacial deposits overlying basaltic lava flows in southern Patagonia, it was possible to determine the maximum age for these glacial deposits by K/Ar- and Ar/Ar-dating of the underlying Bella Vista basalts to 1.17 ± 0.05 Ma (Mercer, 1976) and 1.168 ± 0.007 Ma (Ton-That et al., 1999). Stratigraphic evidence from the glacial basin of Lago Argentino points to a minimum age of 1.0 Ma (Wenzens et al., 1997), which together gives an age range for the Initioglacial of 1.2 to 1.0 Ma. Re-dating of the Bella Vista basalt flow in the Río Gallegos valley supported the Ar/Ar age of 1.168 ± 0.014 Ma (Singer et al., 2004). In combination with the dating of the Arroyo Telken basalt flow in the Lago Buenos Aires basin (1.016 ± 0.01 Ma), which postdates the Telken VII moraine, Singer et al. (2004) constrained the timing of this vast Patagonian glaciation to between 1.17 and 1.02 Ma.

Following this largest eastward extent of glaciations in the Lago Buenos Aires basin there is a complex of at least six moraines that were formed between 1.016 ± 0.01 and 0.76 ± 0.014 Ma based on Ar/Ar dating of under- and overlying basalt flows. They mark the second largest ice extent related to the Telken VI-I advances (Singer et al., 2004). South of the Río Gallegos river a glaciation reached a maximum eastward position at the coast of the South Atlantic during the middle Pleistocene (Tab. 1). This Cabo Vírgenes Glaciation was deposited on top of the Sierra de los Frailes Glaciation and was framed by dating under- and overlying basalt flows to between 1.07 and 0.41 Ma (Meglioli, 1992). Geomorphologically contemporaneous but hitherto undated, the Río Ciaike Glaciation, which is related to the Seno Otway lobe, ended in a huge arc of terminal moraines ca. 10 km south of Laguna Potrok Aike. Based on new and more precise data of Singer et al. (2004), it
is very likely that the Cabo Virgenes and Río Ciaike Glaciations coincide with the Telken VI-I moraines and thus terminated before 0.76 Ma.

During the late Pleistocene the studied area was not glaciated. The Llanquihue Glaciation, South America’s equivalent to the European Weichselian and the North-American Wisconsin Glaciations (Rabassa & Clapperton, 1990), did not extend as far east to reach the Pali Aike Volcanic Field.

**Formation and age**

Many lakes are visible on a satellite image of the Pali Aike Volcanic Field. Aerial photographs show that not all lakes are volcanic crater or maar lakes in origin. Some of them have been formed by deflation. The comparison of satellite images taken at different seasons reveals that many of these lakes desiccate towards the end of the austral summer. Especially shallow lakes or lakes in exposed topographic positions are prone to desiccation. Their sediments dry up seasonally and are deflated by the prevailing westerly wind. Consequently, the sedimentary record related to such shallow lakes is discontinuous with hiatuses formed during erosional periods and reworking of older sediments occurring during periods with infilling water. To avoid such erosional unconformities, only the today deep and permanently water-filled lakes of the Pali Aike Volcanic Field (Laguna Azul and Laguna Potrok Aike) have been analyzed in the framework of the project SALSA (Zolitschka et al., 2006).

<table>
<thead>
<tr>
<th>Laguna Potrok Aike</th>
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</thead>
<tbody>
<tr>
<td>Longitude</td>
<td>51°57.337&quot; S</td>
</tr>
<tr>
<td>Latitude</td>
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<tr>
<td>Elevation of lake level</td>
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<tr>
<td>Max. elevation in the catchment area</td>
<td>227 m a.s.l.</td>
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<tr>
<td>Relative relief</td>
<td>114 m</td>
</tr>
<tr>
<td>Maximum lake diameter</td>
<td>3470 m</td>
</tr>
<tr>
<td>Minimum lake diameter</td>
<td>2740 m</td>
</tr>
<tr>
<td>Maximum water depth</td>
<td>100 m</td>
</tr>
<tr>
<td>Mean water depth</td>
<td>44 m</td>
</tr>
<tr>
<td>Theoretical mixing depth</td>
<td>52 m</td>
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<tr>
<td>Water volume</td>
<td>0.41 km³</td>
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<tr>
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<td>7.58 km²</td>
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<td>Catchment area (C)</td>
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<tr>
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<tr>
<td>Length of shoreline</td>
<td>11 km</td>
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<tr>
<td>Shoreline development</td>
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Laguna Potrok Aike has a lake diameter of almost 3.5 km (Fig. 3, Tab. 2) and the crater has a diameter of about 5 km. The difference in elevation between the present day lake level and the Patagonian Plain is ca. 50 m with about half of that difference being occupied by lake level terraces. At the southwestern crater rim there is a cinder cone with a well-developed basaltic lava flow both covered by Patagonian Gravel. The lava flow never entered the lake and probably was not related to the formation of the crater lake. There is no ring wall preserved in the catchment. However, remnants of a hyaloclastic tephra layer have been detected and point to a phreatomagmatic origin. Therefore, a maar explosion is assumed which is also based on the low relief
of this crater. A maar generally is a shallow explosive eruption caused by the contact of rising magma with groundwater that forms craters with a diameter between 50 and 2000 m. Preferably, larger maars develop in valleys that provide a higher amount of groundwater (Lorenz, 1973), which is the case for Laguna Potrok Aike.

Fig. 3: Bathymetric map of Laguna Potrok Aike with positions of obtained sediment short and long cores, water profile (cf. Fig. 4) and installed thermistor chain (cf. Fig. 5) with sediment traps (mooring); depth intervals in m (Zolitschka et al., 2006).

Morphometric data (Tab. 2) reveal an almost circular shape of the lake (shoreline development: 1.1) while the topography suggests a significant influence of the catchment area on the lake system (z-ratio: >26). Therefore, a substantial supply of sediment and consequently a thick sedimentary infill must be expected. Despite the fact that the catchment area is rather large (ca. 200 km²) and extends far south into Chile, the maximum water depth still is 100 m which points to an enormous initial depth of the crater. The bathymetry (Fig. 3) reveals an almost flat and pot-shaped
morphology of the lake floor typical for maar lakes. The theoretical mixing water depth of Laguna Potrok Aike is 52 m. Thus, there is a potential for seasonal anoxic or even meromictic conditions in the hypolimnion below this depth. However, water profile data reveal that under present conditions there is almost no stratification of the water column (Fig. 4). This is due to the strong winds that enforce polymictic conditions and hardly allow the formation of a thermally stratified water body during southern summers.

Concerning the age of the maar two new radiometric dates obtained in the Noble Gas Mass Spectrometry Laboratory (Oregon State University) confirm that this sedimentary archive existed for a long time and thus demonstrates an enormous potential for paleolimnological and paleoclimatological studies (Zolitschka et al., 2006). A whole rock sample at the tip of the lava flow from the cinder cone was Ar/Ar-dated to 1.19 ± 0.02 Ma. As glacial sediments cover the lava flow as well as the cinder cone, the last glaciers reaching this site must have been younger than the lava flow. Most likely the related glacial advance was part of the Sierra de los Frailes ice lobe from the south rather than of the Bella Vista ice lobe from the west (Tab. 1). This agrees in timing with the age for the Initiglacial dated to between 1.17 and 1.02 Ma (Singer et al., 2004). The second newly available Ar/Ar date provides an age of 0.77 ± 0.24 Ma for a basaltic clast from the phreatomagmatic tephra related to the maar explosion (Zolitschka et al., 2006). Based on these dates it is evident that the formation of the cinder cone with the lava flow was not related to the maar eruption but occurred ca. 400 ka earlier. Furthermore, the Río Ciaike Glaciation with its terminal moraines ca. 10 km south of Laguna Potrok Aike needs to be older than 0.77 Ma. If the maar lake had existed already during this glacial advance, the lake basin probably would have been silted-up rapidly by proglacial and fluvioglacial sediments originating from this last glacial advance. Geomorphologically, the ice advance from Seno Otway is considered to be synchronous to the Cabo Virgenes Glaciation dated to a minimum age of 0.45 ± 0.1 Ma (Meglioli, 1992; Corbella, 2002). With the now available Ar/Ar age for the formation of Laguna Potrok Aike (0.77 Ma) it is possible to render this age more precisely because the formation of the maar postdates this glaciation (Tab. 1). Therefore, a new tentative minimum age for the Río Ciaike Glaciation (Cabo Virgenes Glaciation) of 0.77 Ma is suggested. Assuming that the second largest glacial advance in the Magallanes region is synchronous with the second largest glaciation in the Lago Buenos Aires area – the Telken VI-I moraines – the dating of the latter (1.02 to 0.76 Ma) strongly supports this interpretation (Tab. 1).

Sediment cores obtained so far agree with this general time frame. A 19 m long piston core from the center of Laguna Potrok Aike at 100 m water depth provides a calibrated basal radiocarbon age of 16,000 cal. BP. A 10 m long piston core from a submerged lake level terrace at 30 m water depth has a basal \(^1^{14}\)C age of 44,500 BP. This, however, includes an erosional unconformity with a hiatus of unknown duration (Haberzettl et al., 2006b). In addition, preliminary data of an airgun seismic survey carried out in March 2005 indicates a thickness of up to ca. 250 m for the lacustrine sediments (F. Niessen, 2005, pers. comm.).
Table 3: pH, electric conductivity (EC), salinity (calculated from EC according to [http://ioc.unesco.org](http://ioc.unesco.org)) and water chemistry (anions, cations) of surface water from lakes, streams, springs and wells of Laguna Potrok Aike and surroundings in the Pali Aike Volcanic Field (La.: Laguna; for locations see Fig. 1; Zolitschka et al., 2006). Lago Argentino near El Calafate is added for comparison (Diaz et al., 2000).

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<th>Sampling date</th>
<th>pH</th>
<th>EC µS cm⁻¹</th>
<th>Salinity g L⁻¹</th>
<th>Cl⁻ mg L⁻¹</th>
<th>NO₃⁻ mg L⁻¹</th>
<th>SO₄²⁻ mg L⁻¹</th>
<th>TP µg L⁻¹</th>
<th>Fe µg L⁻¹</th>
<th>Na mg L⁻¹</th>
<th>Mg mg L⁻¹</th>
<th>Si mg L⁻¹</th>
<th>K mg L⁻¹</th>
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<td>well INTA Potrok Aike</td>
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<td>13.2*</td>
<td>141*</td>
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</table>
Based on a combination of these data it is possible (1) to estimate a linear sedimentation rate of 0.3 mm yr\(^{-1}\) assuming 250 m of lacustrine sediments and an onset of lacustrine deposition at 770 ka and (2) to estimate the begin of sedimentation by extrapolating the linear sedimentation rate for the last 16,000 years (1.05 mm yr\(^{-1}\)) to the entire 250 m yielding a basal age of ca. 240 ka. As compaction has not been taken into consideration for this calculation, the latter age must be regarded as a minimum age. Altogether, both estimates demonstrate that the sedimentary record from Laguna Potrok Aike covers at least two or maybe up to seven glacial to interglacial cycles, this would be back to the Brunhes/Matuyama boundary.

**Limnology**

To improve the understanding of limnological processes at Laguna Potrok Aike, the surface water chemistry of Laguna Potrok Aike and nearby other lakes, streams and wells has been studied (Fig. 1, Tab. 3). Laguna Potrok Aike falls in the group of subsaline lakes with a salinity ranging from 2.22 to 2.53 ppt.

With regard to the amount of ionic constituents (chloride, sulphate, total phosphorus, Na, K and Mg) Laguna Potrok Aike has very high values (Tab. 3). This is supported by high electric conductivities between 2970 and 3110 \(\mu\)S cm\(^{-1}\) for the years 2002 to 2005. Nitrate concentrations for Laguna Potrok Aike (2002) were below detection limits (i.e. <0.05 mg L\(^{-1}\)). However, in the years 2003 and 2004 increased values of 1.73 and 3.07 mg L\(^{-1}\) for NO\(^3-\) were detected, respectively. Remarkable are the extremely high TP concentrations in the surface water of Laguna Potrok Aike: 2247 \(\mu\)g L\(^{-1}\) in 2002, 3609 \(\mu\)g L\(^{-1}\) in 2003 and 1297 \(\mu\)g L\(^{-1}\) in 2004. According to the OECD classification scheme this would characterize Laguna Potrok Aike as a hypertrophic lake (OECD, 1982). However, as phosphorous is obviously not the limiting factor for lacustrine productivity in this lake, the OECD classification cannot be applied. Potentially the high concentration of chlorides inhibits a higher planktonic productivity and leads to a lower productivity which is also indicated by 6.9 m of secchi depth (Tab. 2). The elevated values of total phosphorous (TP) are difficult to explain but might be related to groundwater and regional geology. This is evident as Laguna Potrok Aike and Arroyo del Roble in its vicinity as well as Laguna Carolina and a spring nearby, all located in the same area, show comparatively high TP values beyond 1700 mg L\(^{-1}\) (Tab. 3).

In a comparative study of temperate steppe and mountain lakes in Patagonia enrichment of TP (steppe lakes: 69-298 \(\mu\)g L\(^{-1}\), mountain lakes: 1.8-11 \(\mu\)g L\(^{-1}\)) is regarded as characteristic for steppe lakes (Diaz et al., 2000). The same is valid for electric conductivity (steppe lakes: 1346-2240 \(\mu\)S cm\(^{-1}\), mountain lakes: 23.9-92 \(\mu\)S cm\(^{-1}\)). This is interpreted as the result of a negative water balance and of the shallowness of most steppe lakes. Both latter facts, however, are not true for Laguna Potrok Aike.

The water column of Laguna Potrok Aike has stable values for pH (8.7), conductivity (2900-3100 \(\mu\)S cm\(^{-1}\)) and temperature (10.4°C) throughout the entire depth profile of 100 m. The absence of any pronounced summer stratification and of an anoxic hypolimnion in the water column of Laguna Potrok Aike (Fig. 4, 5) can only be explained by the pronounced exposure of the lake to the extremely strong wind causing frequent mixing events during the whole year.
Fig. 4: Comparison of depth profiles for electric conductivity, dissolved oxygen, pH, and temperature from Laguna Azul (56 m max. water depth) and Laguna Potrok Aike (100 m max. water depth) in 2003 (Zolitschka et al., 2006).

Fig. 5: High resolution water temperature data (thermo isopleths) recorded with six hour resolution by 7 thermistors attached to a mooring string at the deepest part of Laguna Potrok Aike (cf. Fig. 3 for position of the mooring) (Zolitschka et al., 2006).
Lake level fluctuations

Geomorphological observations along the shore of Laguna Potrok Aike indicate several pronounced lake level terraces. These levels exhibit different states of soil development and give evidence for lake level fluctuations in the order of 20 m (Fig. 6). As the lake can be regarded as a closed basin for the Holocene, this necessarily relates to changing hydrological conditions.

According to own observations seasonal lake level fluctuations are in the range of a few meters (Fig. 6: Late Holocene level A). Beyond this modern range, two distinct lake level terraces without vegetation and soil development are distinguishable about 10 and 15 m above the present lake surface. Both are separated by a step and probably are attributed to a decrease in the amount of effective moisture during the last century (Fig. 6: late Holocene levels B and C). This might eventually be seen in conjunction with the end of a “Little Ice Age” style climate variation in the late 19th century (Haberzettl et al., 2005). Such a natural cause for the drop in lake level can also be inferred from the Fitzroy Valley north of Lago Viedma (400 km northwest of the Pali Aike Volcanic Field) where the formation of sand dunes and a retreat of glaciers are interpreted as the result of a temperature increase and a decrease in precipitation since the late 19th century (Wenzens et al., 1997).

Fig. 6: Lake level fluctuations as recorded by morphology indicating lake level terraces along the eastern shore of Laguna Potrok Aike. Holocene lake level terraces are subdivided into four stages: modern (A), last centuries or late Holocene without soil cover (B, C) and Holocene with soil cover (D) (Zolitschka et al., 2006).

Less precipitation in semiarid environments always includes an increase in rainfall variability, which leads to episodic runoff events. If soils and vegetation are
degraded, as it is the case in southern Patagonia due to the introduction of sheep farming in AD 1890 (Aagesen, 2000), episodic rains cause severe damage by soil erosion. This is evident at the crater rim as well as on the upper terrace levels. They are deeply incised by gully erosion with alluvial fans close to the present lake shore (Fig. 6). On a smaller scale sandy and silty grain sizes of the alluvial fan deposits are exposed to deflation and form small sand dunes (nebkhas) in the lee side of these alluvial fans. On a much larger scale a similar phenomenon is observed, if lakes dry out completely and wind erosion blows out lacustrine deposits (Goergen et al., 1998) as demonstrated for many episodically or periodically dry lakes of the Pali Aike Volcanic Field.

Finally, the highest lake level terrace D at ca. 20 m above the lake (Fig. 6) is covered by steppe vegetation and a steppe-type soil (Aridisol). The timing of this upper terrace level D is uncertain. However, it may be related to a comparable period with very high lake levels that occurred at Lago Cardiel (ca. 350 km to the North of Laguna Potrok Aike) during the early Holocene between 10,000 and 9,000 uncalibrated radiocarbon years BP (Bradbury et al., 2001; Fritz et al., 2001; Gilli et al., 2005; Markgraf et al., 2003; Stine & Stine, 1990). Additionally, a submersed lake level terrace was detected by 3.5 kHz seismic at 30 m water depth (Zolitschka et al., 2004; Haberzettl et al., 2006b) indicating a total range of lake level fluctuations of at least 50 m since the onset of the Holocene.

## Conclusion and perspectives

Laguna Potrok Aike has the potential for a record of the last 770,000 years which would be unique for the higher to mid-latitudes of the southern hemisphere. We envisage recovering this ca. 250 m long sediment record in the framework of the International Continental Scientific Drilling Program (ICDP) using the GLAD 800 coring platform as operational system. Environmental and climatic data obtained from such a record will allow interarchive correlations with marine sediment records from the South Atlantic and with Antarctic ice cores providing new insights into glacial-interglacial variabilities of the climate system on the southern hemisphere.

Additionally, dating of the volcanogenic structure of Laguna Potrok Aike made available new age constraints for the timing of the last large Río Ciaike Glaciation, synchronous with the Sierra de los Frailes Glaciation in the Magallanes region (1.0-0.77 Ma) and probably experienced in entire Patagonia, comparable to the Telken VII moraines in the Lago Argentino basin (Tab. 1). Such a narrowing of the time range for this event is not only of regional importance but also improves our understanding of timing and causes for hemispheric glacial advances and thus for major climatic changes. Moreover,

## Acknowledgements

Frank Schäbitz and Bernd Zolitschka express their thanks to the late Arturo Amos (PROGEBAL, San Carlos de Bariloche), who brought them together and provided encouragement for lake studies in Patagonia. Vera Markgraf (INSTAAR, University of Boulder) and Platt Bradbury (USGS, Denver) introduced both into the Pali Aike Volcanic Field in 1999 and shared their wealth of experience with them. This first field trip to the Province of Santa Cruz was supported by travel money from the “Project Support for Bilateral Cooperation in Science and Technology” (ARG 013/98 GEO) of the DLR-International Office. Fieldwork in Patagonia was only possible with the tireless support of Capt. Jorge D. Moreteau (Pto. Madryn) and Christopher Kennard (Río Gallegos). Furthermore, we thank INTA Rio Gallegos allowing the use of installations at their Potrok Aike field station and the Provincial Police of Santa Cruz,
that allowed entry to the lake. José Larrosa not only cooked unforgettable Patagonian meals but also collaborated with logistics in the field. We are grateful for financial support from the German Federal Ministry of Education and Research (BMBF) in the framework of the German Climate Research Program, DEKLIM (grants 01 LD 0034/0035) and from the German Research Foundation, DFG (grant ZO 102/5-1,2,3).

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The International Continental Scientific Drilling Program (ICDP)

Funding and support through the International Continental Scientific Drilling Program (ICDP)

Ulrich Harms

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The ICDP aims with its international efforts in scientific continental drilling on topics of high scientific priority and its drilling projects are conducted at locations of global geological significance. The program focuses on challenging themes of both geoscientific and socio-economic relevance such as Earth history and climate, natural hazards, volcanic systems and thermal regimes, impact structures and mass extinctions, or deep biosphere (Fig. 1).

Previously supported drilling projects with a major palneo-environmental component comprise the recovery and investigation of lacustrine sediments from Lakes Baikal, Titicaca, Bosumtwi and Malawi. Also in future, the theme “Climate Dynamics and Global Environments” will be one of the major issues addressed by the ICDP.

On the one hand, ICDP funds drilling operations and drilling-related activities with international financial contributions paid from the annual membership fees of the currently 13 ICDP member countries. On the other hand, ICDP provides scientific-technical assistance through its Operational Support Group (OSG) and offers access
to the ICDP equipment pool and operational expertise. This pool comprises drilling tools including the Global Lake Drilling Facility GLAD800 as well as scientific instruments and measurement assistance such as downhole logging sondes with a full suite of slimhole logging tools (Gamma, DLL, Sonic, Mag-Sus, Dipmeter, Televiewer, Fluidsampler). These in-hole facilities are complemented e.g. by downhole monitoring capabilities and core measurement devices including optical and petrophysical scanning. A web-based data and information management system allows direct data entry, exchange, and retrieval for participating scientists. ICDP is striving to provide these capabilities for the PASADO project.

GLAD800 drilling in Laguna Potrok Aike, Argentina

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Drilling in modern lakes presents technical and logistical challenges. Each project is unique and requires planning and close coordination between scientists and drilling personnel. The GLAD800 (Global Lake Drilling to 800 m) was developed as a joint research venture between DOSECC and the International Continental Scientific Drilling Program (ICDP). The components of this system are a modular barge, drill rig and sampling tools. The barge is made up of 8 shipping containers arranged in a 3 x 3 array with the vacant center position serving as the moon pool; the containers are partially flooded to resist heave. Recently, we have added additional containers to form a barge that is 24 m long by 7 m wide that provides additional working space. The barge is not powered and must be towed from site to site by a service boat; position is maintained during drilling operations by four anchors. The drill is a modified CS-1500 diamond coring rig. The sampling tools include the following: push core, hydraulic piston corer, extended nose, extended core bit and non-sampling assembly. These tools are changed by wireline without pulling the bottom hole assembly. They collect cores of 62 mm in diameter standard ODP plastic liners and are available in 3-meter lengths.

There are two aspects that commonly affect the efficiency of the drilling operations. The first is weather. Although the barge is very stable, wind and waves do affect its performance, and storms or sustained winds may result in drilling operations being suspended to protect equipment and personnel. Another common issue is the presence of sands in the stratigraphic section. These are often not identified before drilling commences and commonly lead to operational difficulties. Personnel and environmental safety is an important consideration on all drilling projects, and DOSECC has established a Drilling Environmental Protection and Safety (DEPS) Panel that will review the project before the final proposals are submitted.

Two publications that may be useful in the planning process are “Best Practices in the Development of Scientific Drilling Projects” and “Lake and Marine Drilling Planning and Operations Manual”. Both of these are available on DOSECC’s web site (www.dosecc.org).
Reconstructing Late Quaternary Environmental Change in the Lowland Neotropics – The Lake Petén-Itza Drilling Project (January-March 2006)

Ariztegui D.\textsuperscript{1}, Anselmetti, F. S.\textsuperscript{2}, Hodell, D.\textsuperscript{3}, Brenner, M.\textsuperscript{3} & the Scientific Drilling Party

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All shallow lake basins in the northern lowland Neotropics were dry during the last glaciation due to increased aridity and/or lowered sea level. Detailed high-resolution and airgun seismic surveys of Lake Petén-Itza, Guatemala, have revealed that it is deep (160 m) and possesses a thick (>100 m) stratigraphic record that extends back to at least Marine Isotope Stage 5. It is the only lake known to us from the region that is deep enough (160 m) to have held water continuously through the latest Pleistocene. The lake is presently a drilling target for the International Continental Drilling Project (ICDP). The objective of the Petén-Itza Drilling Project is to recover continuous, high-quality sediment cores and pore fluids that will be used to test hypotheses related to three broad scientific themes:

- Paleoclimatic history of the northern lowland Neotropics on orbital to suborbital time scales emphasizing marine-terrestrial linkages (e.g., Cariaco Basin, Greenland ice cores, etc.),
- Paleoecology and biogeography of the Maya tropical lowland forest including the history of vegetation change and disturbance by humans, climate change, and fire and
- Biogeochemical cycling in deep lake sediments emphasizing integrated studies of microbiology, geochemistry (interstitial waters), and mineral authigenesis/diagenesis.

Six primary and four alternate drill sites have been identified that fall along a depth transect extending from ~30 m to near the deepest point (~150 m) in the lake. A sequence stratigraphic approach will be employed to constrain the vertical range of past lake level variations for glacial, interstadial, and interglacial stages during the late Pleistocene. The integration of seismic profiles and a depth transect of piston cores have shown to be an effective strategy for defining lake level during the last glacial period and reconstructing paleoclimate and paleoenvironmental change for the most recent glacial-to-interglacial transition. Although the basal age of the sections to be drilled is not certain it can be estimated that sequences should extend through the last interglacial (MIS 5). An international team of research scientists has been assembled to produce a comprehensive suite of paleoenvironmental and biogeochemical measurements on the cores and pore fluids recovered from Lake Petén-Itza.
Understanding the evolution of maar volcanoes

Magnetometric survey of Laguna Potrok Aike

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Laguna Potrok Aike (51°58' S, 70°23'W), the largest phreatomagmatic lake in the Pali Aike Volcanic Field in Southern Patagonia, has a diameter of ~3 km and is 100 m deep. The depression is carved into Miocene sandstones and micro-conglomerates of the Santa Cruz Formation, till deposits and ~1 Ma old basaltic lavas. Phreatomagmatic deposits dated to 0.7 Ma and loessic soils follow on top of the sequence.

Bathymetric and on-board seismic surveys carried out with different methods during the summers of the years 2003, 2004 and 2005 allow to infer the presence of 300 m or more of undisturbed pelagic lake sediments. The continuous seismic reflections of the lacustrine sediments showed that they are cut by steep crater slopes with shoulders in the upper part and also some slumping structures. To better know the structure of the Potrok Aike diatreme, the existence of slumping involving the country rock and to check the possible presence of an ultimate eruptive event as a volcanic body hidden inside the lacustrine sedimentary pile, a subaquatic magnetometric survey is proposed.

As field procedures for this research a protonic geometric G877 marine magnetometer will be used. The sensor fish will be towed by a small boat as near as possible to the lake bottom, taking care not to disturb the sediments. For the survey, two multi-line grids are planned. One exploration grid 500 m large will initially be done, followed by a 100 m detail grid to cover the most interesting areas. Along the lines the magnetic field and the GPS position will be simultaneously registered. Additionally, a land proton magnetometer will be located to monitor the diurnal magnetic variation, before, during and after the survey.

After the survey normal data reductions will be applied. IGRF or the local regional magnetic field will be removed to define the anomalies. Modeling methods will be used to define the anomaly origin. Contour maps and profiles will be made to show the results.
Reconstruction of the volcanic history of the Potrok Aike Maar: Part 1: Volcanological and sedimentological characterization of volcaniclastic units

Ulrike Martin & Helga de Wall

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Aim of the study is to prove the phreatomagmatic origin of the Potrok Aike Maar by applying quantitative and qualitative volcanological methods to reconstruct the genesis of the Potrok Aike Maar. This allows a detailed physical volcanological reconstruction of the processes that took place during eruption. The development of the maar from the beginning of the eruptive phase until the sedimentation into the maar basin will be clarified in context to the tectonic volcanological development of the Pali Aike Volcanic Field. Results also should contribute to understand the tephra deposition mechanisms and feeding systems of such systems. The knowledge of volcanological, volcano-tectonic and sedimentological processes is important for the geneses of repositories but also of generally significance for studies dealing with phreatomagmatism which includes

- The reconstruction of the primary and syn-eruptive relocation processes during the formation of maar-diatreme volcanoes and
- A detailed description of the transition zone at the end of volcanic activity into the post-eruptive lake-forming phase.

Depending on the depth of the drilling it would be possible to get a detailed description of the transition from primary erupted tephra to post-eruptive sequences. In addition to these volcanological investigations the post-eruptive tectonic deformations of the sedimentary body can also be studied to get the rate of subsidence.

The base of these studies are macroscopic and microscopic descriptions of the drilled core and the compilation of a profile seen under volcanological aspects. The description of the core should also be done under geophysical aspects (e.g. susceptibility) to get the base of a solid interpretation. The correlation of the beds with geophysical characteristics will be undertaken in cooperation with the second part of the proposal (de Wall & Martin, this volume) and colleagues form the GGA, Hannover (Wonik, this volume).
Reconstruction of the volcanic history of the Potrok Aike Maar: Part 2: Rockphysical and geochemical characterization of volcaniclastic units

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The Potrok Aike Maar structure is envisaged as target area for a drilling project within the frame of the ICDP. The here proposed research project will contribute to the reconstruction of the volcanic history of maar formation and will prove the phreatomagnetic origin of the structure by field studies and interpretation of borehole data. It is designed as a complementary project to the volcanological study described in Part 1 of this proposal (Martin & de Wall, this vol.).

A current research project, carried out in cooperation with colleagues from the GGA institute, Hannover, is situated in a comparable geological setting: a scientific drilling in the Messel pit in Germany (Forschungsbohrung Messel in 2001) has explored the structure of a maar diatreme that forms the host structure for the world-famous fossil-bearing Messel pelites, the so-called oil shales (UNESCO World Heritage Site). Our project focused on the origin of magnetic anomalies in the Messel Maar structure and has shown that rockmagnetic studies can be used for the subdivision of lithological units and can significantly contribute to the reconstruction of the depositional history of volcaniclastics. Furthermore, we found studies of the anisotropy of magnetic susceptibility (AMS) particular useful to evaluate cryptic magnetic fabrics in macroscopically unstructured volcaniclastic units. AMS can be used to detect transport directions of volcanic material as well as to trace post-eruptive deformations of the sedimentary body by tectonic or gravitational stresses.

For a comprehensive model of the maar structure, borehole measurements are particular useful as they provide quasi-continuous information on the drilled section. By compiling log responses from tools sensitive for both, lithological and structural variations a reconstruction of the geological profile can be achieved. In the frame of the ICDP, downhole logging can be carried out by the ICDP operational support group (GFZ Potsdam) if the logging campaign is scheduled and requested by the PI’s and thus forms a part of the financial calculation of the ICDP project. However, borehole measurements can also be integrated into a DFG project proposal.
Understanding the evolution of maar craters

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Two innominate lakes located 12 km SEE of Laguna Potrok Aike at ~51° 59' 51"S; 70° 09' 18"W fill maar related tuff-ring interiors. The more western maar has an ellipsoidal shape, a size of 1.300 m × 700 m and the water level is 70 m below the surrounding topography. The eastern lake, of sub-circular shape is 650 m in diameter and its water level is 40 m below the average surface.

The interior tuff-ring cliffs show ca. 60 m thick succession of tephra bedded in 0,3 m thick beds inferred to have been deposited from high energy pyroclastic density currents. The beds contain predominately olivine crystals, ultramafic xenoliths, basanoid rock fragments, blocky non- to moderately vesicular volcanic glass shards and accretionary lapilli. Plastering of fine grained tephra over larger clasts is prominent. Accidental lithic clasts from deeper seated volcanic sequences as well as lacustrine sediments possible from maar lake(s) have also been recognized. The textural characteristics of the tephra beds and its fragments such as the shape, size, and distribution pattern of different fragments suggest inhomogeneous magma/water interaction events during the eruption.

We propose the detailed volcanological, sedimentary and paleomagnetic study of the pyroclastic succession of the tephra rings. Results should contribute to understand the evolution of maar craters, tephra deposition mechanisms, feeding systems and the palaeoscalar variation of the Earth's magnetic field for the last several glacial to interglacial cycles. A potential drilling through the maar lacustrine beds of the maar lake would give a good base for correlation of events occurred after formation of these craters. Moreover, the detailed study at Potrok Aike and the two mentioned maars are closely spaced and presumably of similar age. These volcanic craters would give a good chance to identify distal pyroclastic fall events. Such tephra beds are likely to have been accumulated in these craters. Moreover, succeeding to drill a core reaching the diatreme below the lacustrine maar succession would give raw data to understand the eruptive history of maar volcanoes developed in a “soft sediment” filled basin. The evolution and the development of a maar in such a setting is not understood yet. Studies over this subject only have been done on old, commonly eroded maar volcanic structures. The proposed research site would be among the very few sites in the world, where during an interdisciplinary approach the evolution of such volcanoes could be well understood. Eventual correlations with the Laguna Potrok Aike sediment record will reinforce regional interpretations.
**Deciphering high-frequency environmental variations**

Physical properties, structural features, and climate signals in lake sediments and phreatomagmatic breccias of the Potrok Aike Maar derived from downhole logging

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Deep drilling in Laguna Potrok Aike will be performed to obtain a complete paleoenvironmental record (lake sediments) over glacial cycles for southern hemispheric mid-latitudes and to study the subsurface structure of the maar (phreatomagmatic breccia).

Downhole logging in lacustrine sediments and diatreme breccia enables to obtain continuous, fine scale, in-situ physical and chemical parameters around the borehole walls. The most important physical parameters/tools are natural gamma ray, density, resistivity, seismic velocities, susceptibility, dipmeter, and borehole televiewer. Geophysical logging in the Laguna Potrok Aike will provide unique continuous data of the evolution and of events recorded in the lake sediments as well as of lithological and structural data of the underlying rocks.

Downhole logging data in the scientific drilling of the Tertiary maar Messel (Germany) allows to correlate the lithological description of the cores with variations in physical and chemical properties. Especially the three major lithological units, laminated lake sediments, lapilli tuff and diatreme breccia, show distinct combinations of physical parameters. The diatreme breccia shows larger changes in the physical properties caused by its composition of clasts (granodiorite, amphibolite or Lower Permian sediment). A separation of these three clast types can be achieved with the help of the down-hole logging data.

Some examples for important information which can be deduced from downhole data: In collaboration with other working groups (e.g. de Wall and Martin, see also this vol.) the characterization of volcanioclastic units will be possible. Variations in the content of total inorganic carbon mirror the lake’s water volume. GGA uses a unique borehole tool that allows to measure the contents of several chemical elements including carbon under in-situ conditions. Furthermore, using geostatistical methods on the downhole logging data allows to determine among other parameters the mean sedimentation rate. Travel-time data from a vertical seismic profile (VSP) experiment can be used to determine velocities to serve as a basis for comparison with downhole sonic and core measurements and can also be used to tie directly into marine seismic reflection data, resulting in a reliable depth-time conversion for seismic reflection data.
Microfacies characterization using image analysis, physical and chemical properties for understanding sedimentary processes and reconstructing climate at high-resolution at Laguna Potrok Aike

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In order to understand and identify the sedimentary processes occurring in Laguna Potrok Aike and to decipher their relationship with climate, we suggest using detailed sedimentology coordinated with a set of advanced imaging and non-destructive techniques.

In collaboration with Saint-Onge & Francus (this vol.), we will coordinate obtaining non-destructive CT scans prior to subsampling U-channels from the core for analyses with an ITRAX core scanner. This instrument permits (1) a good quality visual image of the sediment, (2) a corresponding radiograph with a spatial resolution down to 20 µm and (3) an XRF elemental analysis with a spatial resolution down to 100 µm. Digital sediment color analysis can be used to obtain a high-resolution climate proxy record (Nederbragt et al., 2004). The constant thickness of the U-channel samples results in uniform digital radiographs that can be used to obtain a continuous record of sediment density at high resolution (Ojala et al., 2004). If varves are present, these images can be used to quickly count varves and measure their thickness and density parameters. Preliminary XRF-analyses conducted on a 1 m long section of Laguna Potrok Aike with a lower resolution (1 cm), showed the value of such information (Haberzettl et al., 2005). For instance, these non-destructive chemical analyses can be used to infer and distinguish between detrital and aeolian inputs (and potentially other sources) and to detect tephra. The XRF-analyses and corresponding digital radiograph are particularly valuable for the interpretation of environmental paleomagnetic measurements obtained from the same U-channel (St-Onge & Francus, this vol.).

Then, we suggest subsampling for thin-sections in order to obtain a detailed qualitative and quantitative characterization of the sedimentary facies. Detailed sedimentary characterization and event or lamination thickness measurements can be obtained using conventional light microscopy. Complementary quantitative measurements will be performed using a recently developed technique for image analysis of thin-sections. The technique relies on backscattered electron microscope photographs digitized from undisturbed thin-sections, cut by freeze-drying (Francus & Asikainen, 2001; Lotter & Lemcke, 1999). Processing of the greyscale pictures (256 grey tones) produces binary (black & white) images, where white pixels represent the clay-rich sedimentary matrix and black pixels represent siliciclastic grains. Measurements include grain surface, perimeter, shape, orientation and center of gravity. Processing of the data allows the retrieval of grain-size, bioturbation (Francus, 2001), and quantified sedimentary fabric information. The image analysis-derived grain size information can be compared to measurements made on a laser scattering particle size analyzer at Queen’s University at high depth resolution (1 mm) to resolve changes to fine grained components (<3.9 µm) and verify the image results. We have developed a new software system that integrates and automates
the entire image processing procedure and allows the analysis of a very large number of thin-sections in a reasonable amount of time.

The comparison of instrumental and sediment trap data with the microfabirc of the uppermost sediments is a powerful tool to decipher how the climate signal is recorded in the sediment (Francus et al., 2002). Through advanced time series analysis, we also can identify the recurrence properties of major hydroclimatic events (e.g. floods) and investigate sediment erosion dynamics (Lamoureux, 2000, 2002). Time series analyses will also be performed on the other data we suggest to acquire.

In brief, information retrieved using a combination of thin section microscopy, image analysis, and sediment physical and chemical properties provides a quality control and sedimentary context for the other climate proxies, and can also be used as important environmental indicators.

References
High-frequency climate variability in Laguna Potrok Aike

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We propose to analyse characteristic interannual to centennial climate variability in the proposed ICDP drill hole in the maar lake Laguna Potrok Aike in southern Patagonia in the context of other high-resolution records in and around South America. The proposed research will be part of a wider project in our group to determine the geographic extent of short climate cycles, like ENSO, NAO, and Southern Ocean climate oscillations, and their interaction with longer centennial cycles, like the Gleisberg cycle. Our aim is to document the temporal and spatial evolution of the Pacific and Atlantic influences across South America, i.e. which climate system is dominating/controlling lacustrine and near-shore marine depositional systems, and how these patterns change at glacial/interglacial time scales. We are currently working on a non-volcanic lake record (last Glacial and Holocene) from near Cusco/Peru, and are trying to develop a programme to take long marine cores near-shore Peru. We also have and are working on very long Marion Dufresne cores (varved) from the Gulf of California and the Cariaco Basin (Venezuela).

The focus of our research will be on fast and non destructive but high resolution methods like digital imaging and XRF-scanning to generate long continuous records of sediment colour and elemental composition. X-radiography and backscatter electron imagery of slab samples will be used in critical intervals in any laminated sediments in combination with mm-scale chemical analysis. The generated time series will be analysed statistically to determine if there are characteristic climate frequencies, how persistent they are, and if they change over time. In addition we would like to test if the sediments are suitable for biomarker palaeothermometry, which works in some, but not in all lakes. All proposed analyses can be carried out in-house at UCL with equipment already in place or arriving soon.

In the wider context of the PASADO initiative I would like to add that I have been mandated (as an SSEP member) by IODP to explore the demand in the scientific community for ultra high-resolution drilling. If there is enough interest, IODP will establish a programme planning group (PPG) as early as next March (2006), which should identify target areas and ideally also develop drilling proposals. I would like to see a PPG which is not only focussed on palaeoclimate records in the marine realm but also addresses together with the ICDP "terrestrial - marine" links, timing and extent of volcanism, geohazards, to name a few. It also seems appropriate to use for such subject areas the full range of drilling platforms available.
History of volcanic eruptions and dating of the sediment record

Tephrochronology - A high potential correlation tool in palaeoenvironmental investigations

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The climatic development of the past is a complex and sometimes rapid process. However, detailed investigations of the Greenland ice cores and annually laminated lake sediments in Europe have shown that conventional dating methods do not yield a satisfying time resolution to correlate single events. To improve the age models an alternative method has been established over the last decade: the correlation of volcanic ash layers. Ash layers from explosive volcanic eruptions are distributed and deposited within hours and days over a wide region, up to several thousand kilometers away from their source. These isochronous marker horizons were used to correlate sediments on a high precision time scale. Tephra layers in these investigations range from several cm thickness close the volcano to a few very small (µm scale) single glass shards thousands of kilometers away from their source. The tephra layers found e.g. in Europe are characterized and correlated by major- and minor element geochemistry and are now valuable fix points in ice cores, lacustrine, terrestrial and marine sediment stratigraphies. They enable a high resolution correlation of these deposits independent of radiometric or stratigraphic dating.

In the Laguna Potrok Aike lake sediment core we expect numerous tephra layers to be present. The tephra layers will be from the vicinity of the volcano, as the core is situated in an active volcanic area, but will also contain wide spread airfall tephra layers derived from Antarctic volcanoes and from the Chilean volcanic chain.

The tephra horizons in Lake Potrok Aike core will allow to develop a detailed record of explosive volcanic eruptions in the area. They will enable a correlation among local stratigraphies and thus provide information on the eruption frequency. The detailed investigation of the core will also enable us to define a stratigraphy of wide spread ash layers and will eventually allow us to independently correlate these with tephra layers found in Antarctic ice cores and sediment cores from the South Atlantic and the South Pacific. The wide spread tephra layers in the Laguna Potrok Aike core will provide fix points in the stratigraphy and support the detailed age stratigraphy gained from radiometric dating.
Tephrochronology in the North Atlantic region – a potential to link marine, terrestrial and ice-core records from the last glacial cycle

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Tephrochronology is a fast developing field in Quaternary sciences and particularly in the North Atlantic region. The need to improve and refine the coverage and recognition of new, older and significant tephra strata is greatly improving detailed event correlation and refinement of chronologies around the Atlantic region, ranging from ice-cores from Greenland, marine cores to terrestrial peat and lacustrine deposits in north-western Europe. I will here report on the work being undertaken to identify and geochemically characterize tephra horizons within the Greenland ice-core records, marine cores from the Faroe Islands region and lake sediments from Scandinavia. Several visible and cryptotephra horizons (a cryptotephra is a tephra horizon invisible to the naked eye) are detected and analyzed by electron microprobe analysis within the NGRIP and GRIP ice-cores spanning the Late Glacial and the Early Holocene (ca 30-10 cal. ka BP; e.g. Davies et al., 2004; in prep.; Mortensen et al., 2005). These include a number of previously unreported tephra deposits of Icelandic origin as well as some well-known marker horizons. One such example is the Fugloyarbanki tephra (ca 23-24 $^{14}$C ka BP) – a widespread marker horizon in North Atlantic marine records. It occurs as a 2-10 cm thick tephra in the Faroe Islands region and is one of two basaltic components in an ash zone dated to ca 23 $^{14}$C ka BP in the Labrador Sea. The Fugloyarbanki tephra occurs in GIS 3 in all analyzed marine cores and in NGRIP, right after the warmest peak of the interstadial. This tephra horizon provides a key tie-point for the correlation of marine and ice-core sequences during oxygen isotope stage (OIS) 2, but also allows an estimation of the magnitude of the marine radiocarbon reservoir error at this time.

A technique for extracting cryptotephra has revolutionized the application of tephrochronology in minerogenic deposits from the Last Glacial/Interglacial transition (LGIT, ca 15-8 cal. ka BP; Turney, 1998), especially in NW Europe. This technique relies upon the difference between the specific gravity of the tephra shards and the host sediment matrix and has led to the first discovery of the Vedde Ash on the British mainland as well as the previously unrecorded Borrobol Tephra. In Sweden and in NW Russia, the technique led to the first discovery of the Vedde Ash, greatly extending the distribution of this important marker horizon (Wastegård et al., 2000). Today, more than 15 tephra horizons from the LGIT have been identified in terrestrial deposits in NW Europe (Turney et al., in press).

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Reconstruction of the Earth’s magnetic field and characterization of minerogenic sediment fractions

Magnetic Studies at Laguna Potrok Aike

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Magnetic parameters from Laguna Potrok Aike sediments will prove useful in establishing a paleosecular variation of the Earth’s magnetic field, providing correlation within the local environment, and augmenting the paleoclimate signal and age model derived for the region. Studies on lakes in other parts of the world indicate that magnetic measurements on the core material can provide detailed paleoclimate information as well as more specific stratigraphic and chronologic data. The volcanic setting of Laguna Potrok Aike ensures a strong magnetic component in the material, and the ability to make detailed magnetic measurements of several kinds.

Magnetic measurements proposed fall into four categories: magnetic susceptibility, paleomagnetic intensity and directions, rock magnetic parameters, and magnetic petrology. Standard magnetic susceptibility measurements will be made continuously on all core sections preferably with spot-reading sensor at 1 mm intervals for the most detailed results. In lieu of spot-readings, discrete samples will be collected and susceptibility measured on them. These measurements will be used to develop a susceptibility stratigraphy, provide correlations to other climate-induced proxies, and help to establish an age model for the entire core. Paleomagnetic directions (inclination and declination) and intensity will be measured on a cryogenic magnetometer, and used for correlation to the geomagnetic time scale for age determinations and for paleosecular variation (PSV) studies. Comparison of the PSV record to ones from Australia and the Northern Hemisphere will provide insight on field variations over millennium and longer time periods. The paleomagnetic data will also be key in establishing the oldest sediments encountered especially if older than 0.79 Ma when reversed directions dominate. Rock magnetic studies on selected core samples will include the measurement of hysteresis properties (saturation remanence, saturation magnetization, coercive force and remanence coercivity), isothermal remanent magnetization behavior, and susceptibility at high and low temperatures. Rock magnetic data will be used to characterize the magnetic carriers (composition, grain size, provenance), investigate variations in magnetic susceptibility (dissolution of magnetite grains, variations in composition), and validate the stability of paleomagnetic directions. Magnetic petrology will provide data on the composition, shape, and state (weathered, exsolved, chemically altered) of oxide particles in the sediment. This will be done using magnetic separates, mounted for optical viewing on a reflected light microscope. When necessary, additional data on the magnetic separates will be collected from microprobe analyses and TEM observations. The resulting magnetic data set from Laguna Potrok Aike will be the most extensive from anywhere in the Southern Hemisphere, and will rival the very best of the records from the Northern Hemisphere.
CT-scan image analysis and magnetic properties at Laguna Potrok Aike

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2-D and/or 3-D radiographic digital images of the entire core can be obtained using our CT-Scanner. This non-destructive analysis allows for a rapid overview of the entire core prior to its opening. Digital radiographic images can be used to direct further sampling towards optimal intervals and to build a composite section among the best sections. In addition, using image analysis software, we propose to extract and construct a continuous log of the pixel intensity (CT number) from these high-resolution CT-scan images (St-Onge and Long, in review). Because CT numbers primarily reflect changes in bulk density, it will allow the rapid setting of a continuous log of bulk density with a 1 mm down-core resolution. These results will be compared with the radiographs obtained using the ITRAX core scanner (Francus and Lamoureux, this vol). The CT-scan images can also be used to identify and quantify bioturbation, erosional features and other sedimentary facies and structures (Dufour et al. 2005).

We also suggest measuring the magnetic properties of the sediments from the U-channels subsampled for micro-fluorescence X-ray analysis (ITRAX core scanner). Using the recently funded Paleo- and Environmental Magnetism Laboratory of ISMER, we propose to continuously measure the magnetic susceptibility, NRM, ARM, and IRM for paleomagnetic, magnetostratigraphic and environmental magnetism purposes. Indeed, we hope to use changes in inclination, declination and relative paleointensity for the identification of well-dated geomagnetic field polarity reversals and/or excursions and for correlation to well-dated Southern Hemisphere marine paleomagnetic profiles (e.g., SAPIS, Stoner et al., 2002; ODP Site 1233, Southern Chile), also allowing the direct comparison of marine and lacustrine records. In addition, we will use the continuous magnetic measurements to determine mineralogical, concentration and magnetic grain size variations, possibly allowing the development of magnetic proxies of environmental or climatic changes. Finally, hysteresis properties will be measured using a few mg of sediment from the U-channel in specific intervals with an alternating gradient magnetometer in order to estimate the impact of para- and superparamagnetic minerals, as well as to provide additional information on the magnetic mineralogy and grain size.

References
Reconstruction of lacustrine and catchment-related environmental conditions

Understanding the links between fire, vegetation, and climate change in Patagonia: records and opportunities

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High-resolution macroscopic charcoal records provide information on past variations in local fire occurrence, which can be compared with other proxy data of environmental change to better understand past climate variations. When pollen, charcoal and other proxy are analyzed in a network of sites, the data permit examination of regional and hemispheric linkages between climate, fire, and ecosystem response. The current network of South American fire records show: (1) an abrupt increase in fire activity at the Pleistocene/Holocene transition at high-latitudes; (2) widespread fire activity and drought in the early Holocene despite the summer-insolation minimum; (3) north-south differences in fire activity in the mid-Holocene suggesting the onset of the current dipole climate, and (4) locally variable fire signals and a shift to smaller surface fires in the late Holocene consistent with cooler conditions and greater interannual variability. Widespread fire activity in southern South America in the early Holocene is consistent with recent model simulations that suggest warmer SSTs, a weakened pole-to-equator temperature gradient, and a southward shift of westerly storm tracks as a result of the strong obliquity forcing.

Pollen and charcoal records from low-elevation forest and forest-steppe ecotone between lat 41 and 42.5°S offer a closer examination of these relationships. The period prior to 15,000 cal yr B.P. was characterized by steppe vegetation with sparse Nothofagus forest, which implies drier but not necessarily colder conditions than today. After 15,000 cal yr B.P., the forest remained open with substantial amounts of steppe and steppe shrub taxa. Increased fire activity between 13,250 and 11,400 cal yr B.P., corresponds with the Huelmo/Mascardi Cold Reversal defined in the region. After 11,400 cal yr B.P., decreased Nothofagus and increased shrub cover at the expense of grass suggest warming. Fires were infrequent in moist sites but frequent in dry locations. Austrocedrus expanded between 6000 and 5500 cal yr B.P. in moist sites and between 3500 and 1700 cal yr B.P. in dry sites. The period between 6000 and 3500 cal yr B.P. was an interval of maximum aridity and increasing climate variability in the region. After 3500 cal yr B.P., increased Nothofagus in moist sites, the eastward expansion of Austrocedrus to dry sites, higher-than-previous fire activity everywhere, and a shift to ground fires indicate the onset of effectively wetter conditions than before and high interannual variability in precipitation.

A high-resolution charcoal record from Laguna Potrok Aike will allow us to extend our understanding of fire-climate-vegetation linkages into steppe regions. The
area experiences year-round precipitation and contrasts with the more seasonal precipitation regime of regions already studied, these differences should be registered in the fire response. Moreover, the possibility of a long record spanning multiple climate cycles will allow us to examine the response of regional climate to a broader array of large-scale changes in the climate system than is current possible.

Non-siliceous microfossils in paleolimnological reconstruction

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In the absence of long term data it is possible to determine lake history archived in sediment records. Siliceous microfossils such as diatoms and chrysophytes leave good historic records of changes in most lakes but in some lakes and under certain conditions siliceous microfossils can leave no record. The remains of non-siliceous algae such as green and blue-green algae can also be used as indicators since they also leave remnants (akinetes or spore cases, mucilage cases, cell walls, zygotes) preserved in sedimentary assemblages. Species of cyanophytes (blue-green algae) and chlorophytes (green algae) become dominant at certain conditions such as natural events like droughts that increase the trophic status along with increased conductivity and pH, flooding, fires or any other event which results in an increased nutrient transfer to a lake as well as anthropogenic eutrophication. In oligo-mesotrophic lakes diversity and numbers of some siliceous algae (such as diatoms and chrysophytes) are usually dominant and they increase during the initial stages of eutrophication but under continued eutrophication and/or hypertrophic conditions these siliceous microfossils decrease in importance and in some case where silica becomes limited they tend to dissolve, sometimes before being incorporated into the sediments. Often, in cases where they disappear, other microfossils such as the gelatinous remains of chroococcoid bluegreen algae, cell walls of green algae, cysts of dinoflagellates or cryptomonads, akinetes of N-fixing bluegreen algae as well as the non-siliceous remains of some protozoans and zooplankton can be used to obtain paleolimnological data. This paper documents the joint use of non-siliceous and siliceous microfossil together with other multiple indicator groups of organisms, chemistry and isotopes for reconstructing the paleolimnological records in some arctic, temperate and tropical lakes.
Phytoplankton and algal microfossils in the crater lake Laguna Azul

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Traditionally, the study of lacustrine productivity is based on the analysis of diatom composition and pigment contents (mainly chlorophyll and carotenoids) in the sediments. Less intensively other algal microfossils are analysed. The majority of well preserved sedimentary microfossil algae are green algae, chrysophyceans, cyanobacterial acinets, fossil cyanobacterial tubular sheaths and cellular trichomes. Analyses of these microfossils enable to observe the natural environmental variability and to estimate the direction of future changes. In Patagonia anthropogenic influence is small and changes occurring in Laguna Azul are mainly controlled by the influence of edaphic and climatic factors. Analysis of algal microfossils preserved in the sediment will enable us to understand the complex environmental conditions and changes in this area much more thoroughly. Fossil algal material becomes very important in cases of diatom absence in sediment core samples. Such a situation can occur in the case of chemical changes, e.g. increased calcification.

The purpose of this work is the reconstruction of environmental conditions based on ecological differences among the algal flora preserved in the sediments. Analysis includes the use of sediment cores from the lake as well as modern algal samples to reconstruct past conditions of the lake and to show the temporary changes. The results of this analysis will be compared with data obtained on fossil diatoms by other investigators.

Spores from chrysophyceans are very well preserved in lacustrine deposits. This allows to use them as an indicator group for the reconstruction of ecological conditions. Observations of the behaviour of algae from the *Chrysophyceae* group show that in short periods of time only particular taxons appear. A qualitative and quantitative determination of the composition of cysts is particularly important. Therefore, their identification will be based on their morphology and sizes. SEM photographs will enable the assessment of the ornamentation of the surface of cysts and the shape of the hole.

In relatively large numbers filamentous green algae are represented by cysts of *Mougeotia* sp. and *Spirogyra* sp. Moreover, in the fossil material the diagnosis of green algae from the following genera is possible: *Pediastrum*, *Tetraedron*, *Scenedesmus*, *Coelastrum*, *Botryococcus*. The analysis of green algae is very important because the phytoplankton of Laguna Azul is dominated by this group (*Coenococcus planctonicus* Korsh., *Oocystis* spp., *Elkatothrix* spp.; Messyasz, unpublished data).

The comparison between modern phytoplankton samples and the algal assemblages in the sediment, especially near the sediment surface, should give an answer whether the present trophic conditions represent a continuation of the natural evolution of the lake or are artificially imposed by external factors such as pollution.
Fossil chironomids (Insecta –Diptera) as indicators of environmental change in Laguna Portrok Aike, Argentina

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In recent years, subfossil chironomids (non-biting midges) have proven to be a powerful independent paleo-proxy indicator of environmental change. They are increasingly used as indicators of eutrophication [1], water-level changes [2] and, especially, as indicators of climatic change [3, 4, 5]. Because midge abundance and distribution are strongly influenced by mean July air temperature, this can be used to infer past climate by analyzing changes in midge assemblages recovered from lake sediments [6, 7].

Chironomid assemblages from lake sediments are extremely sensitive to temperature changes being able to pin-point climatic oscillations of short duration and low amplitude. Nevertheless, the best results have been achieved in studies by using a multi-proxy approach that enables the comparison of chironomids to other lines of evidence such as pollen sequences, diatom profiles, oxygen isotopes [8] or chemical analysis in a sedimentary column.

The use of fossil insects in Quaternary studies at mid-latitudes of South America is relatively limited, and the major reason is the lack of taxonomical information available from these remote areas of the world. Many of these studies have been conducted in the southern part of South America, in Argentina (41° S) [9, 10, 11] and in southern Chile (46°S) [12].

I propose to study the fossil chironomids (insects) of Laguna Potrok Aike sediments in order to reconstruct the environmental changes that occurred in the area during several glacial/interglacial cycles. Results from this study will be compared to other proxies to give an accurate environmental reconstruction for this area in South America. This study will be a contribution to the project “Potrok Aike Lake Sediment Archive Drilling Project” (PASADO), a research initiative within the International Continental Scientific Drilling Program (ICDP) with the ultimate goal to reconstruct climate change in southern South America spanning multiple glacial to interglacial cycles.

References

**Potrok Aike Lake Sediment Archive Drilling Project, southernmost Argentina (PASADO): chironomid analysis**

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Chironomids (Diptera: Chironomidae) have been used successfully to reconstruct various environmental (TP, chlorophyll-a, oxygen availability, nutrients, water depth) and climatic (water and air temperature) parameters. Chironomids have the potential of being the best quantitative biological indicators preserved in lake sediments (Battarbee, 2000). They have been useful in reconstructing colder period such as the Younger Dryas and the Little Ice Age. In Switzerland and Canada, there were used to reconstruct the 8.2 cal. years BP event. When compared with meteorological data, the inferences obtained by chironomid analysis were statistically valid (Larocque & Hall 2003). Recently, chironomids were also used to reconstruct hydrological variations (Gandouin et al. 2005; Larocque, work in progress). Their relationship to fire events is also being studied in Canada (Tremblay & Larocque, work in progress). Unfortunately, most chironomid studies are located in the northern hemisphere. But chironomids have been shown to react to climatic patterns, metal pollution, human impact, and water level changes in Africa (Eggermont & Verschuren 2005), in Chile (Massaferro & Brooks 2002) and northern Patagonia (Guevara et al. 2002; Massaferro & Corley 1998; Massaferro et al. 2004). In the PASADO project, it would be possible to reconstruct climate, hydrological variations and/or effect of fire events on this lake ecosystem using chironomids in a multi-proxy framework. We should also discuss the possibility of developing a quantitative inference model using chironomids in Patagonia. This could possibly be made by joining the effort of “chironomid teams”.
Diatoms and ostracods as palaeoclimate proxies in the Laguna Potrok Aike sediment record

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Inland saline aquatic ecosystems and their sedimentary sequences are of special interest to palaeoclimatologists (Williams, 1996), as many of the aquatic organisms that respond to fluctuations in salinity leave identifiable fossils in the sedimentary record that can be interpreted in terms of past climatic conditions. For example, the abundance and species composition of microscopic siliceous algae (diatoms) is strongly related to the ionic concentration and composition of saline lakes and lagoons, and changes in diatom communities can be used to infer past salinities by the use of quantitative models (Fritz et al., 1999; Pienitz et al., 2000). Similarly, valves and appendages of calcareous microcrustaceans (ostracods) are often preserved in sediments of saline lakes and offer evidence of past hydrological changes (Holmes & Chivas 2002, Ito et al., 2003). Because species shifts in these saline systems are generated in direct response to the salinity and ionic composition of the brine, the composition of the fossil assemblages in these stratigraphic records has the potential to provide information on changes in water chemistry (temperature, pH, salinity, TP), water-column stratification, water level, as well as changes in atmospheric relative humidity.

Based on the information available through detailed seismic and preliminary biostratigraphic surveys of the Laguna Potrok Aike sediment record, the relative abundance of fossil diatoms and ostracods will ideally be determined in counts of 500 valves and ca. 300 soft part remains, respectively, in subsamples with up to decadal resolution. In addition, valves of time-consistent ostracod species will be collected for isotope ($\delta^{18}O$ and $\delta^{13}O$) and trace element analyses (Sr/Ca and Mg/Ca). Preferably, and if possible within the PASADO project, we would like to develop a training set based on lacustrine sediments from southern Patagonia for the quantitative reconstruction of environmental changes from diatoms and ostracods. Preparation techniques for both indicator groups will follow standard procedures (Pienitz et al. 1992; Schwalb 2003).

References


Vegetation and climatic conditions in the southeast of Patagonia, Argentina

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Pollen analysis from archaeological, mire and soil sequences provide a regional analysis of the vegetational changes and contribute to the understanding of the climatic history during the Late Holocene in southeast Patagonia, Argentina. In the Cabo Vírgenes area shrubland at the mire sites and a grass-shrub steppe allow to infer climatic condition drier than present-day before ca. 1000 yr BP. The increase in Poaceae and Juncaginaceae and later Cyperaceae preponderance in the mire sequence as well as a grass steppe similar to the present-day at regional scales according to soil pollen records suggest a moisture increase after ca. 700 yr BP. Pollen record data from upper sections of the soil profile, buried by recent eolian deposit, present the highest Rumex values probably in relation to impact produced by sheep introduction at the end of 19th century (Mancini, ms). Comparison of these pollen sequences with others sampled in the northern sector of the Pali Aike Volcanic Field allows to evaluate the regional expression of the environmental changes during the late Holocene. These analyses included in archaeological studies provide paleoenvironmental information to evaluate circulation patterns between maritime coastlines and interior Patagonia (Borrero and Franco, in press; Franco et al., 2004).

References


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Magallanes maar fossil pollen record re-interpreted by using a pollen-climate calibration model

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The only pollen record in the latitude of the Pali Aike Volcanic Field (southeastern Patagonia) that predates the Last Glacial Maximum comes from a core drilled at the dry Magallanes Maar (52º 07´S; 69º 16´W) located in the Patagonian xeric grass steppe and is dated between 31,560 at 37 m and >51,700 yrs B.P. at 47 m (Corbella et al., 2000). A major problem with this record is the uncertain chronology, since it is close to the limit of the radiocarbon dating technique. Based on our experience with ongoing pollen studies, we re-interpreted the fossil sequence as either interglacial or interstadial based on the observed type of pollen assemblages. Eighty-six surface samples reflecting modern pollen dispersal from the Andes to the Atlantic coast between 50º and 52ºS represent the Subantarctic forest, the humid and xeric grass steppes and the semi-desert (Quintana, et al., unpubl.). These surface samples have been compared with the Magallanes Maar fossil pollen assemblages. Although only twelve samples between 29 and 56 m from this sequence have enough pollen for analysis, the comparison allows us to interpret that plant composition and climate were similar to humid and xeric grass steppe for different periods during the Marine Oxygen Isotope Stages (MIS) 3 and 4(?). This demonstrates the potential of the pollen-climate calibration model to be applicable as a modern analogue technique for paleovegetational and paleoclimatic interpretations of the anticipated long sequence from Laguna Potrok Aike.

References
Tracing atmospheric dust and volcanic aerosols

Dust sources and westerly storms in Patagonia: Comparison of in situ measurements with remote sensing estimations

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How much aerosol mass is transported from Patagonia to the South Atlantic Ocean? What are the sources, the frequency and the extent of the delivery of those particles? Is the regional forcing directly or indirectly affected by the presence of aerosols in the region? Is the amount of iron present in those particles able to control biological processes of this oceanic region? To answer the above questions we have started a two year program of \textit{in-situ} and remote sensing dust flux measurements in 2004. Hence, four dust samplers equipped with weather stations were installed along 2200 km of the Patagonian coast (Bahía Blanca, Trelew, San Julián and Río Grande). Surface concentrations are compared with aerosol columnar concentrations derived from the MODIS detector onboard the Terra and Aqua satellites following the technique developed by Gassó and Hegg (2003).

Global dust distributions usually are estimated based on global dust cycle models which predict dust emissions, dust transport through the atmosphere and dust deposition. However, these models must be validated with available in situ observations. By means of both, remote sensing (true color pictures) and ground observation (surface visibility observations) between June 2004 and April 2005 we recorded at least 16 ocean-going dust events mainly triggered by strong westerly winds. The horizontal flux measurements were compared with the same estimates derived from MODIS. The scale of these events varied from small (single dust plumes along the coast) to large (dust front extending \(\approx 600\) km). One of the most important of these dust events was perceived at the city of San Julián on October 20\textsuperscript{th}, 2004, where it lasted almost four hours with an average wind speed of 56 km h\(^{-1}\) and maximal gusts of 93 km h\(^{-1}\). Satellite images detected small individual dust plumes clearly transporting dust to the ocean in the San Julián city area.

Although, satellite retrievals help to detect the extent and distribution of dust, the retrievals are uncertain due to the optical properties of the aerosol under observation. Then, our study provides helpful information for validation of both, in situ measurements and satellite estimations. Small-scale events like the squall lines observed in Patagonia cannot be easily represented in global models and are frequently ignored thus causing underestimations of dust emission and of long-distance transport. Such small-scale events like the one of October 20\textsuperscript{th}, 2004, should be taken into account in regional models to simulate specific dust storm events and to test parameterizations in global models.

Finally, satellite images supported by ground observations indicate that at the Patagonian surface the occurrence of topographic depressions (ephemeral lakes or deflation holes) in dry, unvegetated areas are important sources for fine, loose sediment which is easily deflated under strong wind conditions. One important question to elucidate is how changes in the frequency and extent of natural
inundation occurring on ephemeral lakes systems may lead to significant fluctuations in the Patagonian dust loading.

Reference

Isotopic investigations at Laguna Potrok Aike sediments to determine recent sedimentation rates and dust fluxes and to correlate this archive with other ice core records

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My participation in the workshop could potentially focus on 3 aspects of the PASADO project. First, we have extensive experience in measuring natural and fallout isotopes that are used as indicators of recent sediment accumulation in lakes, including Be-7, Pb-210, Cs-137, and Pu isotopes. As part of our previous lake work, we have used freeze corers to collect intact surface sediments with cores up to 1 meter in length. While acknowledging the apparent difficulty of establishing a recent chronology in southern South America using these tracers, the ability to determine the age-depth relationship over the most recent century or so, is the only way to tie variations in geochemical parameters, such as stable isotopes, to the limited historical records of precipitation and temperature that exist for this area.

We are also interested in using Be-10 fluxes to constrain the timing of climate signals from various archives to the climate signals recorded by the Greenland and Antarctic ice cores. We are currently using this method in continental margin sediments off of the west coast of the North America. A complementary application of Be-10 is that it may be used as a quasi constant flux proxy, with a well-dated input history, derived from the ice core records.

Finally, I am interested in southern South America as a potential source area for dust to the southern ocean. We are actively studying changes in the dust flux to the South Atlantic and South Pacific on glacial-interglacial timescales. One of the questions remaining is to identify the source of the dust, which will help to elucidate the mechanisms by which the delivery of continental material to the ocean has varied in the past.
Study of paleoclimate change using cosmogenic nuclides produced in the atmosphere

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¹⁴C, ¹⁰Be, and ²⁶Al are also produced in the atmosphere by nuclear interactions with nitrogen, oxygen, argon, respectively. The best known is ¹⁴C, which is produced in the atmosphere by neutron capture reaction with nitrogen, and then it subsequently is mixed with atmospheric CO₂. Both ¹⁰Be and ²⁶Al are produced by spallation reactions in the atmosphere, and then they are mixed with dust particles and fall out with precipitation to the land and sea. The ¹⁰Be records of four sediment cores forming a transect from the Norwegian Sea via the Fram Strait to the Arctic Ocean demonstrate that ¹⁰Be records with high ¹⁰Be concentration are related to interglacial stages and core sections with low ¹⁰Be concentration are related to glacial stages, as observed in oxygen isotopes. This study confirms that the sharp contrast of high and low ¹⁰Be concentrations at climatic stage boundaries are an independent proxy for climatic and sedimentary change and can be applied for ¹⁰Be stratigraphic dating of sediment core. ¹⁰Be from sediments of the Arctic Ocean covering the past 350 ka shows the well defined trends of Be isotopes are coincident with interglacial/glacial climatic cycles and demonstrate that the sedimentation rates are higher during glacial periods and lower generally due to low sedimentation/accumulation rate during interglacial periods.

Records of studies using radiocarbon and ¹⁰Be in sediments related to the study of paleoclimate change are well established. It was found that the production rate of cosmogenic nuclide is inversely proportional to the paleomagnetic intensity. Studies using the profile of marine oxygen isotope of the ocean sediment and ¹⁰Be or ¹⁴C along with paleomagnetic intensity made new guidance in understanding the paleoclimate change in the Pleistocene. A study of the correlation between ¹⁰Be and oxygen isotope in Wangauni Basin, New Zealand has indicated that this ¹⁰Be stratigraphy is inversely correlated to that of oxygen isotope. In order to study paleoclimate change using cosmogenic nuclides, three types of sample materials are often used: deep drill core from ocean or lake, exposed rock. Especially, ¹⁴C and ¹⁰Be are ‘meteoric’ cosmogenic nuclides. Reconstruction of temperature and precipitation of the past decade to millennial timescale is feasible with meteoric cosmogenic nuclides and stratigraphy of oxygen isotope of the sediment core. The comparison of these meteoric cosmogenic nuclides and the stratigraphy of oxygen isotopes and paleomagnetic intensity will be an essential approach in unravelling paleoclimate change during the last glacial-interglacial cycle. Especially, the comparison of meteoritic ¹⁰Be from the sediment and in situ produced ¹⁰Be from glaciated materials, such as moraine boulder samples will be another approach in understanding time sequence of glacial events. Also, we propose to characterize the stratigraphy of ¹⁰Be in the land and ocean along with the paleomagnetic intensity for a better understanding of ¹⁰Be production and transport in land and sea for other relevant studies.
Lead (Pb) and Strontium (Sr) isotopic composition for reconstructions of dust fluxes and volcanic aerosols


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Lead (Pb) and Strontium (Sr) isotopic compositions measured in Antarctic ice cores have been observed to change with glacial-interglacial transitions, this being attributed to changes in the location, extent and strength of dust sources. Ice core data suggest South America, particularly Patagonia and the Pampas, to be the major source of this dust but the influence of dust from Australia and New Zealand has not yet been excluded. The measurement of Pb and Sr isotopic compositions in Southern Patagonia will provide an isotopic signature of the South American dust source, allowing the provenance of rock dust in Antarctica to be refined and quantified. Climate-related variations in the signature of South American dust should indicate variations in the contributions of various dust sources within South America. By characterising the source(s) of dust within South America and quantifying the proportions of dust transported to Antarctica from different continents of the Southern Hemisphere, climate modellers would have a substantial and valuable data for testing the accuracy of GCMs.

The TIMS laboratory has produced a detailed record of Antarctic Pb isotopic compositions from the present to 220 ky BP from ice cores from Vostok, Dome C, Law Dome and Victoria Land. This record is being complemented by Sr isotopic compositions, to further characterise the rock dust transported to Antarctica, and Nd isotopic compositions may also be measured. An understanding of the fluxes of dust transported from South America and arriving to Antarctica are also important for the evaluation of efficiencies of atmospheric dust transport and quantification of dust deposition over the Southern Ocean, which is relevant to oceanic bioproducitivity in high nutrient-low chlorophyll waters.

Studies of Holocene snow and ice in Antarctica have revealed the role of volcanism as an important source of Pb during interglacials, but the source(s) of volcanic aerosols are still to be constrained. It has been assumed that volcanic aerosols found in Antarctic snow and ice originate primarily from the Trans-Antarctic Mountains, Mount Erebus (Ross Island) and sub-Antarctic volcanoes (South Sandwich and South Shetland Islands), but the influence of other volcanic systems in the Southern Hemisphere are yet to be discounted. A determination of the Pb and Sr isotopic signatures in tephra layers from the Potrok Aike Lake sediments would enable an “extra-Antarctic” volcanic aerosol signal to be established for comparison to the signature of volcanic aerosols observed in Antarctic snow and ice.

To achieve these goals, continuous sampling over the length of the core is required. Sample requirements are small, approximately 1 gram per sample, but it would be necessary to obtain samples from the interior of the core to eliminate the possibility of contamination from the coring device.

Overview of TIMS Laboratory activities: The TIMS laboratory, located at Curtin University of Technology in Perth, Western Australia, investigates various environmental systems through isotopic analyses. The laboratory features a Finnigan Triton TIMS and a Fisons Instruments VG354 90° sector TIMS. The TIMS laboratory recently commissioned the Advanced ultraClean Environment (ACE) facility, containing four Class 10 ultra-clean laboratories, a Class 10 reagent preparation laboratory and a -18°C Class 10 cold clean laboratory.
Human impact and modelling

Bones in Pali Aike: The Late Holocene archaeological record of Cóndor and Potrok Aike localities

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The study of bones is one of the main sources of archaeological information on subsistence and geographical distribution of human populations issued through time. We plan to contribute to the ICDP workshop that will be held in Río Gallegos by presenting a review of our recent work with human and faunal bones in the Pali Aike Volcanic Field, southern Patagonia. We also integrate information produced by other teams working in the area (i.e. Gómez Otero 1993-1994).

We believe that the information already available for the site of Potrok Aike (Gómez Otero 1993-1994) provides a good starting point, on the basis of which a more intensive archaeological survey and sampling of surface and stratified deposits can be designed. Since this will contribute to expand the archaeological knowledge of the Potrok Aike locality, it will provide a stronger basis for the correlation with palaeoclimatic data. This local information, altogether with data from a wider spatial scale, can be used as a measure of the impact of particular climatic variations on human subsistence. In particular, the intensity of the archaeological signal can be used as a proxy for human presence under different climatic situations.

\textit{Brief antecedent information}: human and faunal remains inform on different levels of human subsistence. Stable isotopes values (particularly $\delta^{13}$C and $\delta^{15}$N) from human bones are associated to the main kinds of resources consumed during the last years of an individual. In the Patagonian case, isotopic data allow us to infer the proportions in which marine and terrestrial foods were consumed on a regional scale.

On the other hand, faunal assemblages constitute a direct measure of the food that was locally consumed. Besides, intensity in their consumption can be evaluated on the basis of the degree of butchering and fragmentation displayed by the bones.

In our review, we plan to integrate isotopic data from southern Patagonia and faunal information specifically recovered at Potrok Aike and Cóndor localities. This allows us to infer the existence of periods of nutritional stress for human populations living in the PAVF during the Late Holocene, possibly associated to climatic changes that have been recently identified on a local scale (Zolitschka \textit{et al.} 2004; Haberzettl \textit{et al.} 2005; Mayr \textit{et al.} 2005).
Numerical modelling of sedimentation processes in Laguna Potrok Aike, Argentina

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On one hand, the northern continental slope of the Gulf of Mexico is riddled with numerous subsiding diapiric minibasins bounded by ridges, many but not all of which are connected by channels created by turbidity currents. Recently, Toniolo et al (in press, a) developed a theoretical analysis to describe sediment deposition processes in minibasins by ponded turbidity currents. The analytical work improved our understanding of the "fill and spill" process by which minibasins fill with mud and sand as the intervening ridges are dissected by canyons. An explicit numerical model based on the theory was successfully tested against laboratory experiments by Toniolo et al. (in press, b).

On the other hand, when a river enters to a dam or lake, the stream velocity is reduced and coarse sediment deposits to form a delta. The coarser sediments deposit fluvially to form a topset, and by avalanching to form a foreset. Finer sediments deposit beyond the toe of the foreset to form a bottomset in deep water. The reservoir or lake fills as the topset and foreset prograde downstream into the water body and the bottomset builds upward. This process has been reported in several occasions (see for instance, the bed evolution of Lake Mead on the Colorado River, and Lake Englebright on the Yuba River).

The case of a dam on a sand-bed river carrying fine suspended sediment was recently considered by Toniolo et al. (accepted). In the deltas of sand-bed streams the topset and foreset deposits are built mostly out of sand, while the bottomset consists mostly of mud. The existing numerical model captures the delta evolution in the upstream region of the reservoir and bottomset growth downstream the delta. It is clear that a lake can be considered as a dam without any water exit.

Preliminary inspection of the information available on the PASADO Project web site (Appendixes 1 and 2) indicates sediment deposition patterns associated with ponded turbidity currents in the lake, similar to the deposits found in several minibasins on the continental slope of the Gulf of Mexico and reservoirs.

In consequence, the basic analytical and numerical tools for studying sedimentation processes in the Laguna Potrok Aike are available. It is proposed here to use and expand the actual numerical models to estimate past sedimentological and hydrological conditions. This effort will aid to achieve one of the stated scientific objectives: “quantitative reconstruction of hydrological variations”.

Adequate selection of drilling sites will be a key factor to gain fundamental information (grain size, layer thickness, porosity) to improve our understanding of depositional modes inside the lake.

References


TONIOLO, H., PARKER, G., AND VOLLER, V. (accepted, subject to modification). Role of ponded turbidity in sediment trap efficiency in reservoirs. Journal of Hydraulic Engineering ASCE.
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