Pleistocene centennial-scale vegetational, environmental and climatic change in the Colombian Andes: based on biotic and abiotic proxy analyses from Lake Fúquene sediments

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Chapter 1

General Introduction

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1. Sediments as paleoarchives of environmental and climate change

Measurements of temperature, precipitation, and humidity among other variables over a period of thirty years characterize and define the climate of a region. Since many factors influence climate, such as latitude, altitude, solar activity, atmospheric composition, and even human activities, this can be understood as a dynamic system that continuously changes in time and space. In general the coupled ocean-atmosphere interactions play a key role in modulating climate at different time scales. Independent of the causes of climate change, such as astronomical forcing, solar forcing, internal forcing by system earth, and anthropogenic forcing by human activities, any variation in climate causes alterations in ecosystems structure and functioning. Thus, past reorganizations of ecosystems reflect their response to a dynamic climate of the past. By identifying those changes in the sedimentary record past climate change can be reconstructed.

Paleoclimatic reconstructions have shown that climate change follows characteristic cyclic patterns. Paleoclimate research has identified climate oscillations at orbital (10^5-10^6 years) and suborbital time scales (10^1-10^6 years). Among long term climate changes associated to global ice volume variations, glacial-interglacial cycles are well known from marine sediment sequences. More than 90 of those cycles, building the marine isotope stratigraphy have influenced global climate during the last 5.3 million years (Lisiecki and Raymo, 2005). At suborbital time-scales the Heinrich events (HE), associated with massive and periodic (~7 kyr) discharge of rock debris to the Atlantic Ocean by icebergs, have been documented in high resolution records from the North Atlantic and influenced climate during the last glacial (Bond and Lotti, 1995). Paleoclimatic records from the Greenland ice sheet, such as GRIP, GISP and NGRIP (Dansgaard et al., 1993; Grootes et al., 1993; NGRIP project members, 2004) have also documented abrupt and rapid climate change during the last 120000 years (120 ka). The identified stadial-interstadial climate oscillations currently named Dansgaard-Oeschger cycles (DO-cycles) show a recurrence of ~1500 years (1.5 kyr) and are characterized by a rapid warming of ~7 °C within a few decades (interstadial) followed by gradual cooling over several hundred of years (stadial). The impact of DO cycles and HEs on climate has been identified at different latitudes suggesting their global signature (Leuschner and Sirocko, 2000, Hessler et al., 2010). At the interannual to decadal band of periodicities, El Niño-Southern Oscillations has been documented affecting climate in the tropics during the last 15 ka and particularly the last centuries (Latif and Barnett, 1994; Rodbell et al., 1999). Identification of past climate change and understanding operating mechanisms is fundamental to understand the present setting of climatic conditions and for predictions of future climate change. Comprehension of past climate change will help to separate between operating forces and mechanisms and particularly to understand potential contributions of natural and human induced climate change.

For the period beyond instrumental measurements time series of climate change are lacking. However, climatic and environmental change has left many signals in the sedimentary archive. Analyzing and interpreting these proxies is the domain of paleocology and paleoceanography. Most common are the archives in terrestrial sediments, marine sediments, ice cores, and speleothems. These archives contain both macroscopic and microscopic fossils, inorganic and organic materials that constitute proxy records, i.e. informative signals of past variations in the local and regional environment from which climate change and/or human impact can be inferred (Bradley, 1985; Smol et al., 2001). Paleoclimatic proxy records are informative of past conditions, but depending on the source, length of the record, and the resolution of the analysis proxies offer information on particular aspects. Variations between proxy-records, therefore, may be associated with the spatial variety on local to global scales, the period that is recorded and the level of resolution in which the changes and processes are documented (10^1 to 10^7 years).

2. Lake Fúquene as a sensor of climate change in the Northern Andes

On the continents lakes serve as sensors and recorders of the changes that occurred through time in the basin and the surroundings (Robinson et al., 1993; O’Sullivan and Reynolds, 2005). Lakes located in areas close to sharp ecotones are more sensitive to register past changes (Peteet, 2000). Therefore, the identified local and regional vegetation changes may be directly understood as a response to climate variation. Many pollen-based records from different latitudes have permitted to establish relations-
hips between events occurred in continents and variations in global ice volume identified in ocean and ice sheet records. Those pollen records have shown changes in vegetation composition, a reflection of both the global glacial-interglacial cycles and the superposed stadial-interstadial climate variability (i.e. Wijmstra 1969; Allen and Huntley, 2000).

The tropical Lake Fúquene located in an intramontane basin of the Eastern Cordillera of Colombia at 5°28’N and 73°45’W at 2540 m elevation is well known for its thick sequence of Pleistocene sediments and its sensitivity to record past environmental and climatic change. Considering the current regional vegetation distribution and the altitude of the lake, it is evident that Lake Fúquene is situated close to the Upper Forest Line (UFL), an ecotone that currently lies at 3200 m. The UFL marks the altitudinal limit between the Andean forest and the open treeless páramo vegetation. Since this ecotone coincides with the ~9.5 °C mean annual temperature (MAT) reconstructing its altitudinal migrations is instrumental to develop a record of past temperature change. Calculation of the ratio between arboreal pollen and non-arboreal pollen is used to deduce past altitudinal UFL migrations in pollen records from the Northern Andes. Using a temperature gradient of 0.65 °C per 100 m altitudinal vegetation displacement paleotemperatures can be determined for every altitudinal level (Van der Hammen, 1974; Hooghiemstra, 1984; Wille et al., 2001). On the basis of previous paleoecological studies in the Northern Andes, it can be concluded that Lake Fúquene is located halfway the maximum amplitude of the UFL during a glacial-interglacial cycle, i.e. at ~3500 m during warmest interglacial conditions and at ~2000 m during the coldest glacial conditions. Therefore, this sediment archive is remarkably sensitive of even small changes in climatic conditions at millennial time-scales.

During more than four decades sediments of the shallow lake basin of Fúquene have been analyzed for paleoecological purposes. Previous pollen analyses show the development of the basin influenced by climate change. Pollen records documented regional changes associated to glacial-interglacial cycles as well as the occurrence of short term stadial-interstadial climate oscillations influencing tropical montane ecosystems (Van Geel and Van der Hammen, 1973; Mommersteeg, 1998; Van der Hammen and Hooghiemstra, 2003). However, all these previous cores were taken from the margin of the lake, pollen analyses were performed at low sampling resolution, and radiocarbon dating was insufficient. Current interests in paleoecology focus on records of climate change, concurrent changing forest associations, and estimates of the speed of change. The possibility of gaps in the sediment record is larger at the borders of the lake than in the centre and strategically chosen core location may improve the quality of the record substantially.

The potential of palynological analysis of lacustrine sediments to infer climate change at submillennial time scales has maintained the international interest, for lakes located in the tropics in particular. In order to provide meaningful past climate information, new palynological projects of lakes must ensure a robust chronology, present proxy analysis at high temporal resolution, and if possible include other proxies (Colman, 1996). Only in that way continental paleoclimate records can result in more precise land-sea-ice correlations and allow to improve the understanding about climate change. An independent and absolute chronology for new continental palerecords avoids circular reasoning which may be introduced when chronologies depend too much on visual matching of climate records. Independent chronology allows more reliable intersite correlations. High temporal resolution analysis permits to identify abrupt and rapid climate changes at submillennial to decadal scales. The use of different proxies permits to analyze and correlate changes of different components of the basin system that are operating simultaneously. Such parallel time series show responses of terrestrial ecosystems to variations in the hydrological system, and changes of the landscape caused by climate change or human impact.

In previous studies Lake Fúquene provided promising records showing changing ecosystems and climate change and this motivated to revisit the sedimentary archives of this lake to improve the quality of the records substantially. A ‘new generation’ project was developed and the present thesis makes part of it. In this project the deepest part of the lake was explored to collect a sediment core with potentially minimum disturbance. It was aimed to collect a core long enough to encompass the complete last interglacial-glacial cycle. However, during the project it became clear that the 60 m cores reflect two interglacial-glacial cycles. The discrepancy between originally expected age and the reconstructed age of the sediments at 60 m core depth followed from a wrong age model of the Fúquene-3 record.
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(Van der Hammen and Hooghiemstra, 2003) as explained in Chapter 4 of this thesis. Two parallel 60 m deep cores Fq-9 and Fq-10 were drilled and formed the basis of the present study.

3. Aim of this study

This thesis focuses on the interglacial-glacial cycle before the Eemian interglacial, thus reflecting marine isotope stages 7 and 6. The last interglacial-glacial cycle, reflecting marine isotope stages 5 to 2, is presented in the thesis of M. Groot. We analyzed the sediments of the composite core Fq-9C at 1-cm intervals for the following proxies: pollen, grain size distributions, organic matter content, and geochemical composition of the sediments. The objectives formulated in this thesis were:

1. To improve the temporal resolution with an order of magnitude
2. To obtain a robust age model for the composite Fq-9C record that allows establishing paleoclimate comparisons with marine sediment and ice core records.
3. To reconstruct downcore changes in grain size distributions and changes in the local vegetation to evaluate how the biotic and abiotic evolution in the basin in terms of source of sediments, energetic conditions for sediment transport, and lake size/level fluctuations were related.
4. To reconstruct past vegetation change in the study area considered representative of the northern Andes, and to infer climate change at orbital, millennial, and submillennial time-scales.
5. To compare climate change in the northern Andes at submillennial time-scales with records of climate change from Greenland and Antarctic ice records, and from marine sediment records located near the Iberian margin.
6. To compare the pollen records from Lake Fúquene and to assess how representative they are in documenting the evolution of the basin in terms of paleovegetation and paleoclimate.
7. To establish environmental change based on variations in geochemical composition of sediments, to relate sediment components to geological sediment sources, and to integrate the abiotic basin dynamic with the changing vegetation cover in the basin.

The results are presented in chapters 2 to 5 of this thesis. Chapter 2 presents the age model for the Fq-9C record which is based on a new approach in the study of long continental Quaternary records, and highlights the sensitivity of the Andean ecosystems in recording abrupt temperature change. Correlation with records from marine sediments and Greenland and Antarctic ice cores, and implications of the role of atmospheric CO\(_2\) concentrations in climate change is shown. Chapter 3 shows the evolution of vegetation and climate representative for the northern Andes, during the period from 284 to 133 ka. In Chapter 4 previously published pollen records from the Fúquene Basin are re-visited. Records are re-calculated and uniformly presented on linear time scale. We showed and discussed how representative a single pollen record from Lake Fúquene is. Chapter 5 shows the potential of using changing proportions of geochemical elements to reconstruct the abiotic evolution of the drainage basin. We showed relationships between source, i.e. the rock formations in the drainage basin, and sink, i.e. the sediment archive in the lake. This chapter provides an integrated reconstruction of the evolution of the basin with focus on changes in regional and local vegetation, grain size classes of the sediments, geochemical composition, and organic matter accumulation. Chapter 6 presents a general synthesis of results.

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