Water Resources in the Arid Mountains of the Atacama Desert (Northern Chile): Past Climate Changes and Modern Conflicts

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1. Introduction

The Atacama Desert of the Central Andes (18°S to 28°S) has become a focal point of environmental research in recent years. Indeed, this area is a key site in several respects. It is located between the tropical and extratropical precipitation belts: the vertical gradients of ecozones range from sea level at the Pacific Coast up to high mountains that reach into the mid-troposphere at 6000 m elevation. The prominent mountain chain of the Andes stretches N-S, perpendicular to the zonal westerly airflow of the mid-latitudes, which creates distinct environmental gradients at meso- and micro-scales. Due to their sensitive location at the juncture between tropical and extratropical climate zones, paleoclimatic records from this area may potentially provide important insights into the dynamics of the large-scale atmospheric circulation in the Central Andes in the past. This region therefore provides an ideal natural laboratory for paleoclimatologists.

One of the geocological key features of this high-mountain desert is the extremely high sensitivity to changes in effective moisture (precipitation minus evaporation). Even smallest changes in the moisture budget result in significant and amplified responses of the mostly saline and shallow lakes, in modifications
of geomorphological forms and processes (particularly in glacier variability), in vegetation changes and in other variations in the bio-geochemical systems. Different paleoclimate archives show evidence of abrupt, dramatic and high-amplitude moisture changes in the Atacama Desert during the late Quaternary epoch, especially during late-glacial and Holocene times (Betancourt et al. 2000; Baker et al. 2001; Grosjean et al. 2001; 2003; Latorre et al. 2002; and references therein). It is worth noting that such paleoenvironmental information from tropical-subtropical areas balances the view of the “climatically stable Holocene” as is inferred from temperature-sensitive proxy-data in high-latitude ice records (e.g. Blunier et al. 1995).

The highest mountains of this extreme desert range up to 6700 m and show a unique geocological feature, the lack of glaciers even in the continuous permafrost belt above 5600 m. Glaciers in this extremely arid climate would not form and grow even with colder temperatures. Instead, glacier inception and advances in this area are almost exclusively triggered by increasing moisture (Kull and Grosjean 2000; Kull et al. 2003). Thus, it is moisture and not primarily temperature that plays the key role regarding environmental changes. This observation is critically important when the paleoclimatic history of the Atacama Altiplano is compared with other areas in South America or along the meridional Pole-Equator-Pole transect through the Americas (PEP-I) (Bradbury et al. 2001; Clapperton and Seltzer 2001; Schotterer et al. 2003).

In recent years, scientific evidence has increased that modern groundwater recharge in the extremely arid Atacama Desert is very limited and restricted to high elevation areas above 3500 m (> 100 mm precipitation yr\(^{-1}\)), whereas no modern water component was observed in the lower-elevation aquifers (< 20 mm precipitation yr\(^{-1}\)) (e.g. Fritz et al. 1979; Aravena 1995; Grosjean et al. 1995; Pourrut and Covarrubias 1995). There is increasing concern that large proportions of the current water resources might have formed during past periods of humid conditions, when the climate was very different from today, and that the water resources are renewed slowly or are non-renewable today and thus might be the limiting factor for economic growth in this region. Furthermore, the centers of water consumption (large cities and mines) are mainly found in the coastal and mid-elevation areas below 2500 m, whereas water resources are located in the high-elevation areas - a “classic” highland-lowland interaction problem.

The aim of this article is to review late Quaternary climatic conditions in the Atacama Desert and to discuss pluvial phases with regard to current water resources. We focus on the area along the western Altiplano (above 2500 m) from 18°S to 28°S (Fig. 1). Beside glacial deposits, pollen profiles from wetlands, paleosols and archaeological sites (Messerli et al. 1993; Nüüez et al. 2002; Kull et al. 2003), plant macrofossils in rodent middens (Betancourt et al. 2000; Latorre et al. 2002) and sediments from closed-basin Altiplano lakes (Grosjean 1994; Grosjean et al. 1995; 2001; Geyh et al. 1999; Bobst et al. 2001) proved to be the most suitable paleoclimatic archives to investigate short- and long-term moisture changes and climate variability at decadal to millennial scale. We summarize the geological evidence for lake level changes in the Atacama Altiplano during the pre-LGM humid phase between >35,000 and 23,000 \(^{14}\)C yr B.P. (radiocarbon years before present) and the humid late-glacial/early Holocene phase between ca. 13,000 and 8500 \(^{14}\)C yr B.P. These intervals may