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'Lake' Alaotra, Madagascar: A late Quaternary wetland regulated by the tectonic regime

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ABSTRACT

Lake Alaotra, a large but shallow lake in NE Madagascar, has been the focus of prophecies about its future life span. None of the formulated predictions, however, are calibrated against a precisely defined modern limnimetric benchmark or former lake shoreline. As a result, existing scenarios of lake evolution in relation to its surrounding landscape have been predicated on incomplete and uncoordinated information. Here we present a chronology of landscape evolution in the Alaotra Basin based on a coordinated reconstruction of environmental change. The evidence draws upon an inventory of regolith and landforms, hydrological data, a compilation of unpublished boreholes and geophysical surveys of the sedimentary fill sequences, and a record of radiocarbon ages obtained from peat and diatom layers in the stratigraphy. The record indicates that Lake Alaotra has been in existence for at least 30,000 years, with evidence of climatically-driven fluctuations but no evidence of the lake ever being much larger or having occupied the entire floor of the topographic basin. The spatial distribution and sedimentology of the age-bracketed deposits suggest instead that the Alaotra is fundamentally a wetland, or fen, which has been buffering its externally-drained lake from irreversible siltation by heavily loaded streams. The tectonic regime in this distinctly seismic part of Madagascar appears to have regulated basin subsidence and accommodation space, steadily maintaining the basin floor below the level of the water table. If the lake today is under any threat of extinction from excess sediment influx, this is chiefly on account of hydrological alterations to the girdle of fenland by irrigated rice monoculture, with artificial drainage channels recently cut through the wetland buffer and fast-tracking the turbid water of tributary rivers directly to the lake.

1. Introduction

Lakes record throughput of water and sediment and respond to change occurring in the surrounding river catchments, on the floodplain, as well as farther downstream (e.g. in response to headward stream erosion, to the incidence of natural or artificial dams, etc.). Depending on their sediment budgets, lakes may persist or disappear on a range of time scales. As such, lake catchments are ideal for recording land degradation problems through an integrated approach between geomorphology, hydrology, the analysis of soil erosion and sedimentation patterns, and for evaluating how human action feeds back on these variables. The strongest insights on these matters are probably gained when land systems that are perceived as undergoing degradation are analyzed in the perspective of longer-term landscape evolution because this allows the magnitude of perceived change to be appreciated within a broad reference frame. Given, furthermore, that lacustrine basins contain regolith and sediments that lend themselves to radiometric dating, histories of environmental change can be potentially constrained with a dependable degree of precision.

The 1800 km^2 Alaotra topographic basin contains the largest lake of Madagascar (Ferry et al., 1999). The lake itself is currently ~450 km^2, i.e. slightly smaller than other, globally better known lakes such as Tahoe, Geneva, or Balaton. The Alaotra Basin is situated ca. 250 km to the NE of Madagascar's capital, Antananarivo, and is bounded to the west and east by major fault-controlled escarpments (Fig. 1). The Angavo escarpment to the west is the tallest. Meanwhile, the basin is

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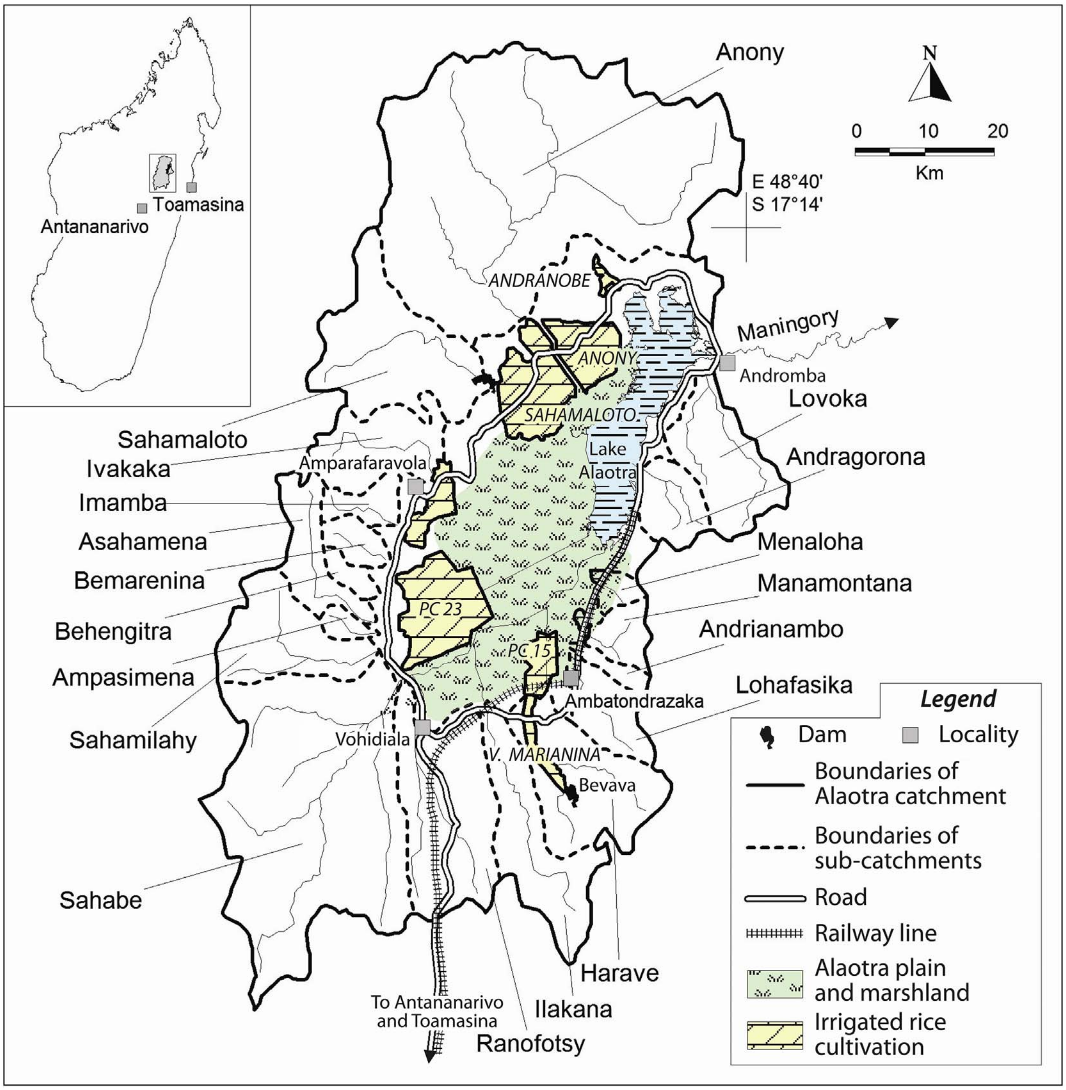

Fig. 1. River catchment and subcatchments feeding into the Alaotra Basin and Lake Alaotra. Note the present-day distribution of marshland and canal-irrigated rice monoculture.

closed off to the north and south by more subdued topography defined as the Andilamena sill (929 m) and Andaingo sill (957 m), respectively. Likewise in the southeast, elevations do not exceed ~1030 m west of the small town of Didy (Fig. 1). The graben itself is effectively a barred basin, with the lake outlet controlled by the Andromba bedrock sill (~755 m, 17°24′10″S–48°38′20″E).

This extensional, intermontane basin has been documented as the most tectonically active area of Madagascar (Rakotondrainibe, 1977; Bertil and Regnault, 1998; Rakotondraompiana et al., 1999). An apparent consequence of the seismicity is that it is also the area in Madagascar with the highest density of *lavaka* — deep gullies that form gaping red gashes of bare soil in vegetated upland hillsides (Bourgeat, 1972; Cox et al., 2009, 2010; Kusky et al., 2010). The outwash from these gullies enters the drainage network and is responsible for high suspended sediment loads in the rivers. Given the very shallow bathymetry of Lake Alaotra (mean depth: ~1 m, maximum: 2.5 m), many development agencies, environmental NGOs, and some scientists (Moreau, 1977; Bakoariniaina et al., 2006) have predicted the short-term extinction of the lake. Explicitly or implicitly, this prediction is based on the assumption that the entire area of the topographic basin once was a palaeolake.

Other scholars have issued warnings against persistent myths of environmental degradation in Madagascar (Kull, 2000). A growing body of research has shown, for example, that *lavaka*, however spectacular or widespread, are a geologically ancient process that predates human settlement on the island (Bourgeat, 1972; Cox et al., 2009; Mietton et al., 2014), and not a historically recent catastrophe caused by poor land stewardship or by historical deforestation.

Alarmist attitudes to environmental degradation rooted in intuition rather than robust evidence are not endemic to Madagascar: a similar myth of land degradation was fostered, for example, in the 1970s in the Himalayas. While initially formulated by concerned scientists, it soon became a profitable arena for development agencies and the media, who became the vehicle for a litany of often spurious causal links between observed processes and environmental events such as flooding and soil erosion (Ives, 2004; Hofer and Messerli, 2006). The prima facie ingredients held responsible for soil erosion and economic ruin on a vast scale were poverty, poor schooling (used as a proxy for human ignorance), and uncontrolled population growth. This theory, however, was based on very limited data or long-term monitoring, often 'common sense' hypotheses (e.g. that landslide frequency was proportional to population density), and 'black box' approaches to deforestation. Thirty years of subsequent research on the Himalayan region, however, provided critical revision of this largely distorted environmental perception, which had been driven by simplistic preconceptions (for a comprehensive summary of the critique, see Ives, 2004).

In the specific context of Lake Alaotra, Ferry et al. (2009, 2013) similarly emphasized misconceptions in the environmental appraisal