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Macrofossils in Raraku Lake (Easter Island) integrated with sedimentary and geochemical records: towards a palaeoecological synthesis for the last 34,000 years

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ABSTRACT

Macrofossil analysis of a composite 19 m long sediment core from Rano Raraku Lake (Easter Island) was related to litho-sedimentary and geochemical features of the sediment. Strong stratigraphical patterns are shown by indirect gradient analyses of the data. The good correspondence between the stratigraphical patterns derived from macrofossil (Correspondence Analysis) and sedimentary and geochemical data (Principal Component Analysis) shows that macrofossil associations provide sound palaeolimnological information in conjunction with sedimentary data. The main taphonomic factors influencing the macrofossil assemblages are run-off from the catchment, the littoral plant belt, and the depositional environment within the basin. Five main stages during the last 34,000 calibrated years BP (cal yr BP) are characterised from the lithological, geochemical, and macrofossil data. From 34 to 14.6 cal kyr BP (last glacial period) the sediments were largely derived from the catchment, indicating a high energy lake environment with much erosion and run-off bringing abundant plant trichomes, lichens, and mosses into the centre of Raraku Lake. During the early Holocene the infilling of the lake basin and warmer conditions favoured the growth of a littoral plant belt that obstructed terrigenous input. Cladoceran remains and Solanaceae seeds are indicative of reduced run-off and higher values of N and organic C indicate increased aquatic and catchment productivity. From 8.7 to 4.5 cal kyr BP a swamp occupied the entire basin. The increase of Cyperaceae seeds reflects this swamp development and, with oribatid mites and coleopteran remains, indicates a peaty environment and more anoxic conditions in Raraku. At around 4.5 cal kyr BP dry conditions prevented peat growth and there is a sedimentary hiatus. About 800 cal yr BP, peat deposition resumed. Finally, in the last few centuries, a small lake formed within the surrounding swamp. Evidence of human activity is recorded in these uppermost sediments.

1. Introduction

Lakes are natural sediment traps and preserve an archive of the history of the past ecosystems (Smol and Glew, 1992; Battarbee, 2000; Cohen, 2003). Proxy data for the physical, chemical, and biotic composition of the lake and its water can be retrieved from lake sediments and used to provide information about environmental and biotic changes that have occurred over time. Many factors influence the proxy record, such as temperature, precipitation, terrestrial and aquatic biota, human activities, lake-bottom topography, depth, hydrological regime, size and composition of the catchment and other environmental parameters together with their corresponding interactions (Smol and Glew, 1992; Battarbee,

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2000; Birks et al., 2000; Fritz, 2008; Giralt et al., 2008). A lake is integrated with its catchment and geological processes such as weathering, run-off, and deposition can play an important role in influencing the sediment composition (Tschudy, 1969; Birks et al., 2000; Cohen, 2003; Lotter and Birks, 2003). Processes such as bioturbation and diagenesis can modify lacustrine sediments.

Many recent palaeolimnological studies have been directed at reconstructing external environmental variables such as climate, rather than being interested in the lake's history for its own sake (Cohen, 2003; Anderson et al., 2008). However, the lake itself interposes an important filter between our reconstruction of the past external environment and the sedimentary record we use to derive this reconstruction (Cohen, 2003). Understanding the sedimentary evolution of the lake basin is therefore essential in palaeolimnological studies, because it determines the nature of the palaeolimnological record and our ability to infer environmental changes from it.

Macrofossils are one of the most useful biological proxies in palaeoecological studies because they reflect local biota and ecosystems and hence local environmental conditions (Birks and Birks, 2000; Birks, 2007). Macrofossil studies have been developed mainly in Europe and North America in temperate and arctic areas. Plant macrofossils are most frequently used, although other organisms, particularly invertebrates such as coleoptera, chironomids, oribatids, cladocerans, etc. also give useful palaeoecological and palaeoenvironmental information (Birks et al., 2000).

The main within-basin processes that influence the sedimentary patterns of macrofossils are transportation, sorting, redeposition, decomposition, and reworking (Tschudy, 1969; Scheihing and Pfefferkorn, 1984; Birks, 2001; Cohen, 2003). A sound interpretation of fossil evidence cannot be made without considering the influence of these taphonomic processes which act on the chemical and physical attributes of the sediments and the fossils themselves (Tschudy, 1969; Rubensdotter and Rosqvist, 2003). Many studies have shown the importance of taphonomy in the interpretation of a macrofossil record, mainly by the use of modern sediment samples (see review by Dieffenbacher-Krall, 2007).

Palaeoecological research on Rano Raraku and Easter Island has largely involved palynological studies (see studies of Flenley and King, 1984; Flenley et al., 1991; Dumont et al., 1998; Butler et al., 2004; Azizi and Flenley, 2008; Mann et al., 2008; among others). A few studies include macroremains, such as the palaeoecological work of Dumont et al. (1998) and Mann et al. (2008) on Raraku Lake, the study of Peteet et al. (2003) on Rano Aroi, and archaeological work on the island (Orliac and Orliac, 1998; Orliac, 2000; Horrocks and Wozniak, 2008). This paper presents a macrofossil analysis of the glacial to Holocene lake sediments (34,000 calibrated years BP -cal yr BP-) of Rano Raraku and relates the results to previous lithological, sedimentological, and geochemical analyses (Sáez et al., 2009), in order to determine the influence of sedimentological processes on the macrofossil assemblages and the relationship between biological remains and geochemical parameters. The main aim is to improve our knowledge of the palaeolimnology of Rano Raraku and the palaeoenvironment of Easter Island.

2. Study site

Easter Island is a tiny (164 km^2) volcanic island situated in the southern Pacific Ocean (27° 07′S, 109° 22′W) (Fig. 1). It is one of the most isolated places on Earth, about 3700 km from the Chilean coast and 2030 km from the nearest inhabited island (Pitcairn). The climate is subtropical, with an average annual temperature of 21 °C and a range of average monthly temperatures between 18 °C in August and 24 °C in January (Mann et al., 2008). The total annual precipitation is highly variable, ranging between 500 and 2000 mm, with large alternating dry and humid periods (Horrocks and Wozniak, 2008). The island's topography is characterised by volcanic cones and the rolling surfaces of the lava flows between them. The highest point is the summit of the Terevaka volcano (511 m). No permanent surface streams are present due to the high permeability of the volcanic rocks (Herrera and Custodio, 2008). At present, only the craters of Rano Raraku and Rano Kau (occupied by lakes), and Rano Aroi (filled by a swamp) permanently contain freshwater. The floral and faunal diversity have been described as very poor (Skottsberg, 1956; Zizka, 1991). Nowadays the island is mostly (90%) covered by meadows dominated by grasses, with a few tree plantations, shrub areas, and pioneer vegetation (Etienne et al., 1982).

Raraku Lake is a small (0.11 km^2) shallow (2–3 m depth) freshwater lake, situated at 75 m altitude inside a volcanic crater more than 300,000 years old (Baker et al., 1974) (Fig. 1). The crater is famous as the quarry of the moais, the gigantic stone sculptures erected by a vanished civilization. The catchment area is about 0.35 km^2 and it is composed of volcanic tuff rich in glass, feldspar, and ilmenite (González-Ferran et al., 2004). The lake is hydrologically closed and disconnected from the island's main groundwater by impermeable lacustrine sediments, being fed solely by precipitation in the crater (Herrera and Custodio, 2008). The lake water is well mixed, acidic (pH around 6.3), dilute (average specific conductivity is 640 mS cm^{-1}, Geller, 1992) and of a Cl–HCO_3–Na type (Sáez et al., 2009). Today the lake bottom is flat and it is surrounded by a littoral belt formed mainly by a mat of *Scirpus californicus*, which also forms large floating patches. In recent years water has been episodically siphoned out the lake for human consumption and irrigation.

The lithology and main characteristics of the sedimentary infill of Lake Raraku were characterised from eight sediment cores recovered in 2006 (Fig. 2). The nine sedimentary facies described by Sáez et al. (2009) have been generalised here to four major sedimentary facies (Table 1). The lowest facies consists of dark grey-reddish organic-rich muddy silt laminated by water currents, including frequent turbidite episodes. It is interpreted as a being derived largely from the steep catchment slopes by water transport and slope-wash, and is termed the High Gradient Lake facies (HGL). It has the lowest organic content (60% of dry weight) and the largest mineral fraction of the sequence which consists of volcanic minerals (glass, feldspar, and iron oxide), clay minerals, and pyrite aggregates (Sáez et al., 2009). The overlying facies consists of horizontally coloured laminated algal and organic brown banded mud, including rare turbidite episodes, and massive brownish organic mud, all consisting mostly of non-particulate, amorphous organic matter. It is interpreted as being derived from less steep lake-bottom slopes and autochthonous production with little input from the catchment. It is termed the Low Gradient Lake facies (LGL). The sediment above is composed of reddish-brown massive or banded muddy peat, composed mainly of macroremains of sedges (*Scirpus* and *Cyperus* spp.). It is termed the Swamp facies association (SWA). A transitional facies between the LGL and the SWA, composed of organic mud rich in macroremains of sedges, has also been recognised. At the top, a silica-rich silty peat represents shallow water surrounded by floating peat (LFP, Low Gradient Lake with Floating Peat facies).

3. Methods

Core RAR 03 and the lower part of core RAR 07 (Fig. 2) were combined into a complete and continuous stratigraphic section 19 m long. Fifty-six samples for plant macrofossil analysis were