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Late Quaternary palaeoenvironmental change in western Staaten Island (54.5° S, 64° W), Fuegian Archipelago

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ABSTRACT

Late Glacial – Holocene environmental conditions were interpreted in western Isla de los Estados (Staaten Island) from geomorphological and palynological analysis. The geomorphological data from Caleta Lacroix (54°50′ S; 64 40′ W) indicate the presence of a fossil dune field that suggest exposition of a larger land surface and stronger wind intensity predominantly from SW and W probably during Late Glacial times, when sea level was lower than today. Deglaciation and onset of peat formation in the western coastal area began prior to 12,600 cal BP in response to warmer conditions. The pollen data indicates initial treeless herbaceous and paludal vegetation with scarce *Empetrum*/Ericaceae type heaths and scrubs as a result of plant invasion and short-term succession vegetal communities spreading over the shoreline areas under locally more humid conditions. The vegetation between 10,300 and 8300 cal BP included dwarf shrub heaths, scrubs, cushion plants and grasses with scattered trees, under warmer and drier climate conditions than today. After 8300 cal BP, more humid conditions allowed the expansion of an open *Nothofagus* forest associated with dwarf shrub heath communities. It was followed at 6700 cal BP by a gradual closed forest development in association with *Drimys winteri* and shrub and herb vegetation indicative of Subantarctic Evergreen Forest-Magellanic Moorland vegetation transition under cold and wet conditions. After 5500 cal BP, the rate of evergreen beech forest greatly increased with the development of almost pure Subantarctic Evergreen Forest communities. These vegetation changes accompanied a modification of the climate toward colder and wetter conditions. After 2700 cal BP, the closed forest was replaced by an open *Nothofagus* forest indicative of warm and dry conditions. The minimum of *Nothofagus* pollen registered between 1000 and 500 cal BP may correspond to the Medieval Climate Anomaly (MCA) period. All these vegetation changes are in turn related to the positioning and intensity of the Southern Westerlies wind belt, sea-ice Antarctic extent and changes in the sea level.

1. Introduction

Isla de los Estados (54°45′ S, 64°15′ W), is located at the southernmost end of South America, forming part of the province of Tierra del Fuego, Antarctica and South Atlantic Islands. The island, due to its geographical location, conforms a unique and sensitive area for Quaternary palaeoecological and palaeoclimatic studies giving information on the atmospheric and environmental conditions from cold-temperate high latitudes in the Southern Hemisphere.

Pollen records from peat deposits from Isla Grande de Tierra del Fuego (Heusser, 1987, 1989a, 1989b, 1990, 1994, 1995, 1998, 2003; Heusser and Rabassa, 1987, 1994; Markgraf, 1983, 1991a, 1991b, 1993a, 1993b; Markgraf and Anderson, 1994; Borromei, 1995; Quattrocchio and Borromei, 1998; Borromei and Quattrocchio, 2001, 2007, 2008; Borromei et al., 2007, 2010; Pendall et al., 2001; Grill et al., 2002; Mauquoy et al., 2004), have provided palaeoenvironmental and palaeoclimatic information for the late Pleistocene and Holocene. Only two studies report on the palaeoecology and paleoclimate of Isla de los Estados. The first one is a palynological study by Johns (1981) based on three peat cores collected in 1971. No numerical dates are available for these sequences. The second one is based on geochemical analyses from

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a peat core and a lake sediment core from the northern coastal area covering a record of 16,000–10,000 cal BP (Unkel et al., 2008).

This paper focuses on the pollen analysis of a peat-bog located at Caleta Lacroix (Bahía Franklin, western Isla de los Estados) and the geomorphological analysis of the area to infer the palaeoenvironmental and palaeoclimatic conditions during the last 13,000 years. The comparison with other records from high latitudes of Southern South America will contribute to evaluate the similarities and differences in the patterns of the environmental changes during the late Pleistocene-Holocene and their relation with climatic conditions.

2. Regional setting

Isla de los Estados, at the southernmost end of South America, is part of the Argentine Province of Isla Grande de Tierra del Fuego. It is located between 54°38′ S and 54°55′ S and 63°48′ W and 64°46′ W (Fig. 1a) ca. 30 km southeast from Península Mitre, Isla Grande de Tierra del Fuego, and separated from it by the Le Maire Strait. Isla de los Estados has a surface area of 496 km^2, a maximum E–W length of 62 km, and an average width of 6 km (Niekisch and Schiavini, 1998). It is the southeastern end of the Andes range above present sea level. The topography is rugged, with maximum elevation just below 1000 m a.s.l. Overall, the topography is characteristic of terrain repeatedly glaciated during the Quaternary (Ponce, 2009). At the western area of the island, however, the topography is less rugged than at its central and eastern areas.

The current climate of Isla de los Estados is cold and humid. According to García (1987), the climate of the island corresponds to general classification of Oceanic Insular Cold Climate. Summer has a mean temperature of 8.3 °C, with mean daily extremes of 16.2 °C and 3 °C. Winter mean temperature is 3.3 °C, with mean daily extremes of 7.4 °C and −4 °C (Dudley and Crow, 1983). Though no reliable records are yet available, rainfall is estimated to be in the range of 2000 mm/y (Niekisch and Schiavini, 1998), but actual precipitation may be highly variable across the island, particularly by altitude. Prevailing winds are from the southwest and the northwest and they are active throughout the year (Kühnemann, 1976).

In the island, seven vegetation types related to altitude and terrain forms are recognized (Dudley and Crow, 1983). The more protected and lower mountain slopes and valleys show the development of *Nothofagus betuloides* and *Drimys winteri* forest characteristics of the true Subantarctic Evergreen Forest (Fig. 2a). In those sites constantly exposed to continuously strong wind conditions, the main vegetation is the Magellanic Moorland Formation, a mosaic of interfingered and superimposed subunits (*Empetrum rubrum* association, *Caltha* association and *Astelia pumila* association) that may cover a rather small area forming blanket-like patches (Fig. 2b). The Scrub Formation occurs on mountain slopes exposed to the prevailing southwesterly and westerly winds where trees of *Nothofagus antarctica* and shrubs grow low and tortuous. Above approximately 450 m, the so-called Alpine Formation occurs with sparse vegetation cover, and often includes dwarfed forms of *Nothofagus antarctica* and *Empetrum rubrum* (Fig. 2c). Soil conditions also influence the vegetation that characterizes the island. For example, the cold and damp climate favors peat development mainly at low and intermediate elevations (Meadow Formation, Fig. 2d). However, in spite of the constant soil humidity, the topography influences drainage patterns and this is reflected by the composition of the vegetation. Littoral and Maritime Tussock Formations develop along the stony and rocky coastal areas, small peats and soils above the high tide line and in rock crevices at the intertidal zone.

3. Materials and methods

3.1. Pollen analysis

Fossil peat core IDE-1 (Figs. 1b and 3) was taken with a Russian corer. In the laboratory, the core was sub-sampled at 5 cm intervals and the sediments described. A total of 65 fossil pollen samples were obtained. In order to achieve modern pollen data to interpret the palaeovegetation changes from the fossil pollen spectra, 16 surface samples were extracted from the studied area (samples Ms1 to Ms7) and northern coast of the island (samples Ms8 to Ms16) (Fig. 1b). Modern pollen frequencies are plotted in Fig. 4.

For pollen analysis, peat samples were prepared according to standard Faegri and Iversen (1989) techniques. *Lycopodium* spore tablets added to each sample prior to treatment (Stockmarr, 1971) allowed calculation of the pollen concentration per gram of sediment. Frequencies (%) of tree, shrub and herb pollen of terrestrial origin were calculated from sums mostly of ≥300 grains. Pollen of aquatic plants and cryptogams were calculated separately and related to the sum of terrestrial pollen. Fossil frequency and concentration pollen data are plotted in Figs. 5 and 6. Other herbs include taxa with low values, such as Caryophyllaceae, Rubiaceae, *Valeriana*, Scrophulariaceae, *Azorella*, *Acaena*, *Pratia*, *Cardamine*, *Rubus*, *Crassula*, Saxifragaceae, Onagraceae, *Geum* and Solanaceae. Using the Cavalli-Sforza Distance (TGView 2.0.2, Grimm, 2004), a stratigraphically constrained cluster analysis was applied to distinguish pollen zones considering taxa that reach percentages of ≥1% of the sum of terrestrial pollen.

Pollen from the evergreen species *N. betuloides* and the deciduous species *Nothofagus pumilio* and *N. antarctica* are reported as "*Nothofagus dombeyi* type" given the difficulty in species separation Another special case is *Empetrum rubrum*, *Gaultheria/Pernettya* (Ericaceae) and *Lebetanthus myrsinites* (Epacridaceae) which are morphologically similar and occur as tetrads; for these reasons, they are considered as one taxonomic group on the pollen diagrams in the present study, named "*Empetrum*/Ericaceae type".

3.2. Chronology

Five peat samples provided chronologic control for the peat section. The NSF-Arizona AMS Laboratory, U.S.A, undertook the radiocarbon analysis on the samples, and the radiocarbon ages were converted to calendar years BP using the program CALIB 6.0 (Stuiver et al., 2005) and the South Hemisphere curve (SHCal04) (McCormac et al., 2004) (Table 1). A second-term polynomial curve was used to construct an age-depth model for the core (Fig. 7).

3.3. Geomorphology

For the geomorphological analysis was used topographic maps, aerial photographs at scale 1:40.000 of the Servicio de Hidrografía Naval (1971), SPOT satellite images (1995) and free-access, NASA SRTM3 images (S55W065 and S55W064). A barometer provided elevation control for field sites and checked against elevations from the SRTM3 digital model.

4. Caleta Lacroix, Bahía Franklin

4.1. Geomorphology and stratigraphy of the studied area

The area is located at the western sector of the island, in Caleta Lacroix, inside of Bahía Franklin (54°50′ 50.6″ S; 64° 39′ 27.4″ W) (Figs. 2a–d and 3). The site encloses a dune field in an elongated depression limited to the NW and SE by rocky valley sides with steep slopes close to 20°, connecting northeastwards with the