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The Holocene deglaciation of the Byers Peninsula (Livingston Island, Antarctica) based on the dating of lake sedimentary records

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A B S T R A C T

The process of deglaciation in the Antarctic Peninsula region has large implications for the geomorphological and ecological dynamics of the ice-free environments. However, uncertainties still remain regarding the age of deglaciation in many coastal environments, as is the case in the South Shetland Islands. This study focuses on the Byers Peninsula, the largest ice-free area in this archipelago and the one with greatest biodiversity in Antarctica. A complete lacustrine sedimentary sequence was collected from five lakes distributed along a transect from the western coast to the Rotch Dome glacier front: Limnopolar, Chester, Escondido, Cerro Negro and Domo lakes. A multiple dating approach based on ^{14}C, thermoluminescence and tephrochronology was applied to the cores in order to infer the Holocene environmental history and identify the deglaciation chronology in the Byers Peninsula. The onset of the deglaciation started during the Early Holocene in the western fringe of the Byers Peninsula according to the basal dating of Limnopolar Lake (ca. 8.3 cal. ky BP). Glacial retreat gradually exposed the highest parts of the Cerro Negro nunatak in the SE corner of Byers, where Cerro Negro Lake is located; this lake was glacier-free since at least 7.5 ky. During the Mid-Holocene the retreat of the Rotch Dome glacier cleared the central part of the Byers plateau of ice, and Escondido and Chester lakes formed at 6 cal. ky BP and 5.9 ky, respectively. The dating of the basal sediments of Domo Lake suggests that the deglaciation of the current ice-free easternmost part of the Byers Peninsula occurred before 1.8 cal. ky BP.

1. Introduction

Glacier retreat in the Antarctic Peninsula (AP) region has accelerated over the last several decades in response to increasing air temperatures (Cook et al., 2005; Pritchard and Vaughan, 2007; Cook and Vaughan, 2010; Shepherd et al., 2012). The AP is experiencing one of the fastest rates of warming on Earth, with temperature increases of ca. 0.5 °C/decade (Turner et al., 2005; Steig et al., 2009) that have led an accelerated ice loss in the region. According to climate projections, this reduction in glacier volumes in the AP will continue in the near future (IPCC, 2013). A consequence of glacier retreat is the appearance of new ice-free land. Therefore, although these ice-free areas currently represent <0.4% of the Antarctic land surface, they are expected to expand in the coming decades.

This research is focused on the South Shetland Islands (SSI), one of the most extensive ice-free regions in the western AP, where ice-free areas are mostly distributed along the coastal fringes and include both nunataks (areas of high relief protruding above the ice sheet) and maritime environments where mean annual temperatures are slightly below 0 °C. Mean annual temperatures in the SSI range between −1 and −2 °C at sea level (Bockheim et al., 2013), and small changes in average temperature and/or precipitation may thus lead to significant changes in glacier mass balances (Navarro et al., 2013; Osmanoglu et al., 2014). The high climate sensitivity of these islands has resulted in multiple glacial advances and retreats in response to climatic fluctuations during the Holocene (Ó Cofaigh et al., 2014; The RAISED Consortium, 2014). These Holocene climatic changes have also had consequences for terrestrial ecosystems, including post-glacial rebound and the formation of marine terraces (John and Sugden, 1971; Fretwell et al., 2010; Watcham et al., 2011), permafrost degradation (Oliva and Ruiz-Fernández, 2015), as well as changes in freshwater ecosystems (Toro et al., 2013) and in the distribution of fauna (Sun et al., 2000; del Valle et al., 2002).

Within the current context, the recent glacial retreat recorded during the second half of the 20th century in many areas in the AP region

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needs to be framed within the natural pattern of glacial and climatic events that have occurred during the last millennia. Consequently, constraining the age of the deglaciation of present-day ice-free areas in the AP has received renewed attention during recent years. This process of deglaciation started after the Last Glacial Maximum and continued throughout the Holocene (Sugden and Clapperton, 1986; Ingólfsson et al., 1998, 2003; Heroy and Anderson, 2005; Simms et al., 2011; Ó Cofaigh et al., 2014). Cosmogenic dating of glacial landforms (Seong et al., 2009; Balco, 2011; Balco et al., 2013) has complemented earlier studies focused on radiocarbon (^{14}C) dating from marine and terrestrial records (Ingólfsson et al., 1998, 2003). Nevertheless, the timing of deglaciation and the resulting geomorphic implications are still poorly constrained in many of these ice-free environments. Byers Peninsula, in the westernmost part of Livingston Island, is one such example where further paleoenvironmental research on the transition between glacial and lacustrine sediments is required (Ó Cofaigh et al., 2014). Although a recent study of the drainage system in the Byers Peninsula proposed that three different glacial centres existed within the Byers Peninsula during the Holocene (Mink et al., 2014), until now absolute ages of the deglaciation in this peninsula have been based almost solely on ^{14}C ages of the basal sediments from Limnopolar Lake, which reported an estimated age of ca. 8.3 cal. ky BP (calibrated thousands of years before present) (Toro et al., 2013), and of several minimum ages from other lake sediment records that ranged between 4 and 5 cal. ky BP (Björck et al., 1996).

In this study, we combine absolute and relative dating techniques of lake sediments to clarify the deglaciation process of the Byers Peninsula. The geomorphological distribution of glacial and periglacial landforms provides information that complements the sediment-based geochronology and assists in the interpretation of paleoenvironmental stages. By deriving a chronological framework for five lakes distributed along an east-west transect from the Rotch Dome glacier to the coast of this peninsula, we: (a) improve the limited network of points from which there is chronological information regarding deglaciation, (b) validate the use of radiocarbon (14C) and thermoluminescence dating as complementary absolute dating techniques in Antarctic lakes to determine the onset of lacustrine sedimentation (indicative of the age of lake formation), (c) propose a general model for glacier retreat and landscape evolution in the Byers Peninsula based on geochronological sequences and geomorphological evidence, and (d) compare the evolution of glacier retreat in the Byers Peninsula with regional environmental and climatic proxies.

2. Study area

2.1. Byers peninsula

Livingston Island is the second largest island in the SSI with a surface area of 818 km^2. The Byers Peninsula is a ca. 60 km^2 ice-free area - the largest in the SSI - located at its western end. It has been designated an Antarctic Specially Protected Area (ASPA No. 126). Livingston Island constitutes 23% of the area of the SSI archipelago and represents 25% of its total ice volume (Osmanoglu et al., 2014). At present, approximately 697 km^2 (85% of the surface area) of Livingston Island is covered by glaciers, although the glaciated area has decreased over the last decades: in 1956 glaciers extended over 734 km^2 (89.7%) (Calvet et al., 1999). Byers Peninsula represents today almost half of the total ice-free area of Livingston Island.

On Livingston Island, glacier retreat has been observed over the last decades in both valley glaciers and in the glacier domes that extend across the lowlands. However, the rate of glacier retreat has decelerated between 2002 and 2011 (Navarro et al., 2013), with slightly positive surface mass balances observed from 2007 to 2011 (Osmanoglu et al., 2014). Glacier shrinkage has exposed new land surfaces in the small peninsulas surrounding the Rotch Dome ice cap, including Elephant Point where the new ice-free surface that appeared between 1956 and 2010 represents 17.3% of its 1.16 km^2 surface (Oliva and Ruiz-Fernández, 2015). However, this pattern has not been observed in the Byers Peninsula, where the frontal moraine lies in contact with the Rotch Dome glacier.

The retreat of the Rotch Dome during the last few millennia has been accompanied by the formation of marine terraces at elevations between 2 and 15 m a.s.l. due to post-glacial rebound (Hall and Perry, 2004). These raised beaches surround the central plateau of the Byers Peninsula (90–140 m), above which several volcanic plugs stand out, such as Start Hill (265 m), Chester Cone (188 m) and Cerro Negro (143 m) (López-Martínez et al., 2012). The only two small ice masses on the Byers Peninsula that currently exist outside the Rotch Dome are located in its NW sector, where the land surface reaches its greatest elevation a.s.l. Numerous ponds and lakes have formed in depressions within the hilly landscape of the central plateau of the Byers Peninsula (Toro et al., 2007), five of which are the subject of this study (Fig. 1).

The Byers Peninsula is composed of marine sediments from the Upper Jurassic to Lower Cretaceous and volcanic and volcaniclastic rocks (López-Martínez et al., 1996). The bedrock is heavily weathered and fractured, with extensive evidence of intense frost shattering. As in other ice-free environments of the SSI, periglacial processes and landforms are widespread at all elevations, with the presence of sporadic or discontinuous permafrost up to 20–40 m a.s.l. and continuous permafrost at higher elevations (Vieira et al., 2010; Bockheim et al., 2013). In the central plateau of the Byers Peninsula the permafrost table occurs at 1.35 m depth (de Pablo et al., 2014).

Climate data from 2002 to 2010 show an average annual temperature of −2.8 °C at 70 m a.s.l. and precipitation ranging from 500 to 800 mm (Bañón et al., 2013). Surface runoff is largely restricted to the summer season and is mostly related to snow melt and active layer thawing (Toro et al., 2013). The vegetation cover is moderately abundant in the flat marine terraces, and is largely composed of mosses and grasses (Vera, 2011), with lichens distributed at higher locations. Soils in the Byers Peninsula are shallow and composed of coarse material (Moura et al., 2012).

2.2. Study lakes

The five lakes studied here are distributed across the central plateau of the Byers Peninsula (Fig. 2). They have small areas (<5 ha), shallow depths (1.6–5.3 m at coring sites) and are located at elevations of between 45 and 100 m (Table 1). They are ice-covered except for 2–-3 months during the summer.

Chester Lake is the largest lake, located at the foot of Chester Cone, with a maximum depth of 5.3 m. The catchment is characterised by smooth terrain, with the lake covering over 40% of the catchment area. Limnopolar Lake has the largest catchment, which is mostly devoid of vegetation except for small scattered patches of mosses and lichens in wet areas. The maximum depth of Limnopolar Lake is 5.5 m. However, in certain years snow dams may block its outlet during spring thaw before bursting due to melting, leading to short-term rises in lake level of up to 1 m. Escondido Lake is situated in a depression surrounded by three peaks (110–120 m), with a bare and rounded catchment and an irregular shoreline. The lake is deepest (5.3 m) in its eastern part and it shallows to the west. Cerro Negro Lake is located in a small glacial cirque in the upper part of Cerro Negro hill, between the two summit peaks. The lake is surrounded by steep talus slopes, with fine-grained sediments only in the northern slope. Cerro Negro Lake has the smallest catchment in our study (1.5 ha), and a maximum depth of 4.5 m. Domo Lake is the closest lake to the Rotch Dome, at a distance of only 300 m from the glacial front. It is the shallowest of all the studied lakes with a maximum depth of <2 m. Patterned ground is widespread on the sediments (sands and pebbles) distributed across the Domo Lake catchment, indicating intense cryoturbation processes reworked by the mass-wasting activity.