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Geomorphological processes and frozen ground conditions in Elephant Point (Livingston Island, South Shetland Islands, Antarctica)

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ABSTRACT

Elephant Point is an ice-free area in the SW corner of Livingston Island (Maritime Antarctica). The retreat of Rotch Dome glacier during the Holocene has exposed a land area of 1.16 km^2. Up to 17.3% of this surface has become ice-free between 1956 and 2010. A detailed geomorphological mapping of this ice-free environment was conducted in late January 2014. A wide range of active periglacial landforms show that periglacial processes are widespread. From the glacier to the coast four different geomorphological areas are identified: proglacial environment, moraine complex, bedrock plateaus and marine terraces. In situ measurements of the thawed soil depth show evidence of the widespread frozen ground conditions in the area. Field observations of permafrost exposures suggest that these frost conditions may be related to a soil permafrost regime, almost down to sea level. The activity of penguin colonies and elephant seals has created minor geomorphological features in the raised marine terraces. Here, several archaeological sites related to early human colonization of Antarctica were also found in natural shelters.

1. Introduction

Only 0.4% of the Antarctic surface is ice-free terrain (Cary et al., 2010). The ice-free environments correspond to: (a) nunataks standing out of the glacial ice, (b) dry areas in the interior of the continent conditioned by the topography (e.g. Dry Valleys), and (c) coastal enclaves especially along the Antarctic Peninsula (AP) region, where mean annual temperatures are close to 0 °C and glacier retreat has exposed the land surface. It is one of these ice-free areas, Elephant Point (Livingston Island, South Shetland Islands), where this paper focuses.

The deglaciation process of the coastal ice-free areas in the AP started after the Last Glacial Maximum (Ingólfsson et al., 1998, 2003; Seong et al., 2009; Balco et al., 2013). This long-term pattern towards less glacial ice continued thorough the Early and Mid Holocene when warmer climate conditions prevailed in the western AP region as inferred from ice cores (Bentley et al., 2009) and marine sediments (Bentley et al., 2011; Shevenell et al., 2011). The timing and magnitude of Holocene climate oscillations are significantly different in the West and East of the AP (Bentley et al., 2009). Our study area is located in the western AP, where conditions are warmer than in the eastern part and summer temperatures closer to 0 °C, thus the impact of warmer conditions in the terrestrial ecosystems is larger. In fact, Holocene climate variability has resulted in significant palaeoenvironmental and palaeoecological changes in ice-free areas in Maritime Antarctica, namely in the distribution of coastal fauna (Sun et al., 2000; del Valle et al., 2002), glacio-isostatic uplift and formation of raised beaches (Fretwell et al., 2010), variations on the pattern of the sedimentological processes prevailing in lakes (Toro et al., 2013) as well as advances and retreats of glaciers (Hall et al., 2010). In this sense, in Livingston island, fluctuations of the Rotch Dome glacier during the Holocene glacier are confirmed by lake records from the nearby Byers Peninsula (Björck et al., 1991, 1996).

During the Late Holocene colder and warmer periods alternated until the second half of the past century, when an accelerated warming trend has been recorded in the entire AP region (Mulvaney et al., 2012; Abram et al., 2013; Steig et al., 2013). In fact, the warming rate in the AP has been quantified in the order of 0.5 °C/decade, one of the largest temperature increases on Earth (Turner et al., 2005; Steig et al., 2009). These climate conditions have led to an acceleration of snow melt and glacier mass loss in the AP region (Rückamp et al., 2011; Abram et al., 2013). For the South Shetland Islands (SSI), the retreat between 1956 and 2000 involved loss of 4.5% of the total ice volume of 1076 ± 0.055 km^3 that existed in 1956 (Molina et al., 2007). In Livingston the glacierized area has decreased from 734 km^2 in 1956 to 703 km^2 in 1996 (Calvet et al., 1999) and 697 km^2 in 2004 (Osmanoglu et al., 2013); an approximately decline of 0.8 km^2 of the total glacier surface per year. However, a deceleration of the mass losses has been detected between 2002 and 2011 in this island (Navarro et al., 2013).

These shifts in mass balance have implications for the extent of the ice-free areas, which have significantly expanded over the last decades.

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With the gradual displacement of the Equilibrium Line Altitudes to higher elevations in the SSI, the margins of these islands mostly covered by ice-caps have become ice-free. The terrestrial ecosystem in the ice-free areas in Livingston Island, and in general in all the SSI, is strongly conditioned by the lack of permafrost in coastal environments up to 20 m a.s.l., discontinuous permafrost at altitudes between 20 and 40 m a.s.l., turning to continuous permafrost at higher elevations (Serrano et al., 2008; Ramos et al., 2009; Vieira et al., 2010; Bockheim et al., 2013). In all elevation belts periglacial landforms are widespread and periglacial processes are very active. The spatial distribution of these landforms in the ice-free areas in the islands surrounding the north of the AP is well-known, since most of these areas have been subjected to geomorphological mapping (López-Martínez et al., 1996, 2012; Serrano and López-Martínez, 1997; López-Martínez and Serrano, 2002; Guglielmin et al., 2008).

Byers Peninsula, located in the westernmost part of Livingston, is the largest ice-free area in the SSI and includes the largest biodiversity in Maritime Antarctica (Toro et al., 2007). A wide range of multidisciplinary studies has been conducted in this area over the last decade (Quesada et al., 2013). However, this knowledge is strictly limited to Byers Peninsula, and does not extend to neighbouring areas, such as the focus of this research, Elephant Point.

In general, in Antarctica the areas with little information about the dynamics of the terrestrial ecosystem are those distributed in areas where access and logistics are particularly difficult. This is also the case of Elephant Point, from where geomorphological knowledge in the scientific literature is inexistent. A field reconnaissance survey was conducted in January 2014 with the purpose of filling this gap. The specific objectives of this paper are to:

- Introduce a high-resolution geomorphological map and an accurate description of the geomorphological features distributed in this ice-free area.
- Discuss the present-day distribution and characteristics of the frozen ground conditions.
- Interpret the palaeoenvironmental evolution in Elephant Point based on geomorphological and sedimentological evidences.

2. Study area

Elephant Point constitutes a small ice-free area in the SW fringe of Livingston, an island covered nowadays by glacier ice over approximately 84% (~690 km^2) of its surface (818 km^2). The retreat of Rotch Dome glacier has generated several ice-free areas in the western margins of Livingston, such as Byers Peninsula, located only 3 km west from Elephant Point (Fig. 1). At present-day, the deglaciated area in Elephant Point comprises a surface of only 1.16 km^2.

Climate conditions in the western half of Livingston are characterized by colder temperatures and windier conditions than in the other islands of the SSI (Bañón et al., 2013). At the nearby Byers Peninsula the annual average temperature for the period 2002–2010 was −2.8 °C at 70 m a.s.l. (Bañón et al., 2013). Annual precipitation in these islands is relatively high, ranging from 500 to 800 mm. The

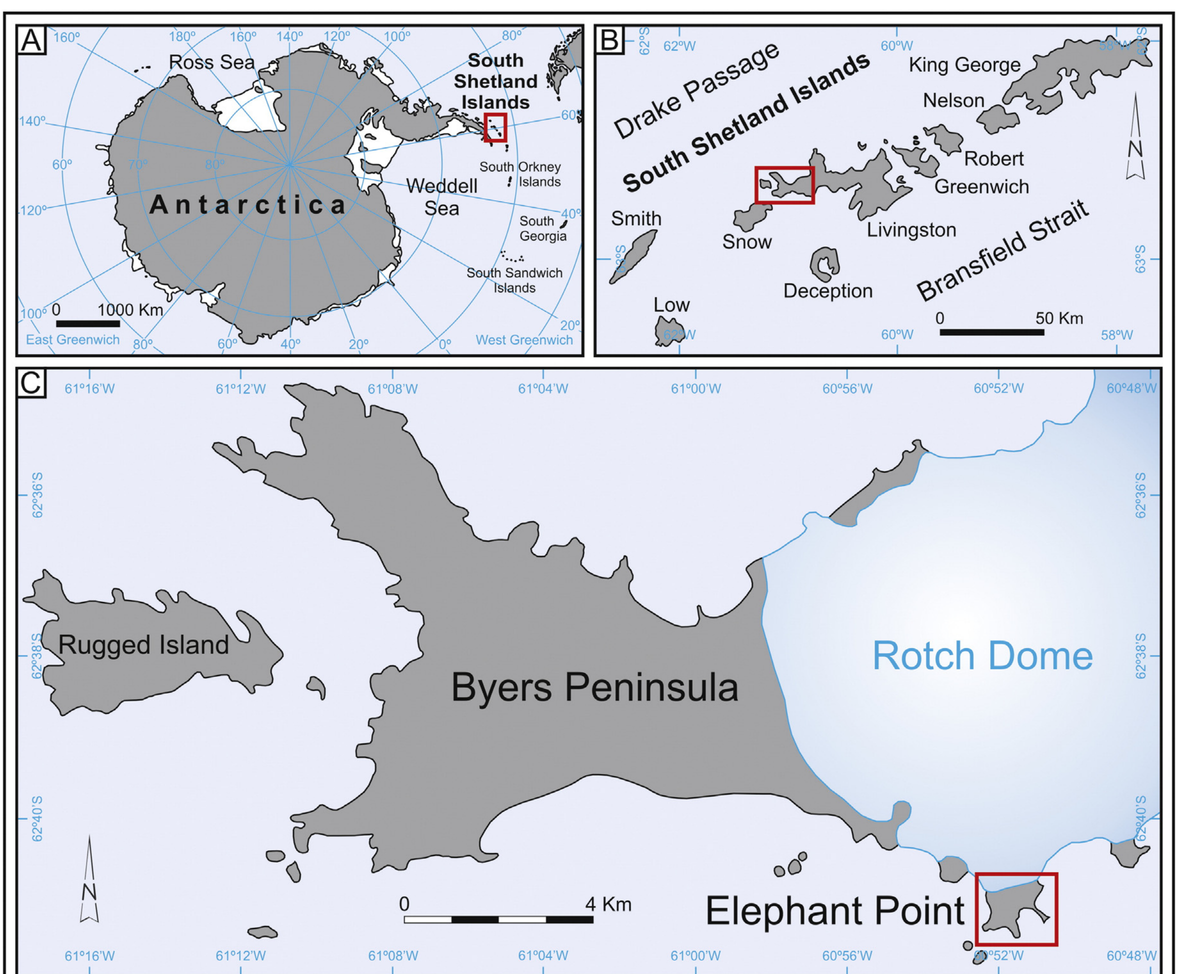

Fig. 1. Location of Elephant Point in Livingston Island.

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