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Local influences of geothermal anomalies on permafrost distribution in an active volcanic island (Deception Island, Antarctica)

G. Goyanes [a,*], G. Vieira [b], A. Caselli [c], M. Cardoso [b], A. Marmy [d], F. Santos [e], I. Bernardo [e], C. Hauck [d]

[a] Instituto de Estudios Andinos "Don Pablo Groeber" (UBA-CONICET), Departmento de Ciencias Geológicas, Universidad de Buenos Aires, Int. Güiraldes 2160, Ciudad Universitaria, Pab.2. C1428EHA, Buenos Aires, Argentina
[b] Centro de Estudos Geográficos, Universidade de Lisboa, Alameda da Universidade, 1600–214 Lisbon, Portugal
[c] Universidad de Río Negro, Isidro Lobo y Belgrano, 8332 Gral. Roca, Río Negro, Argentina
[d] Alpine Cryosphere and Geomorphology Group, University of Fribourg, Chemin du Musée 4–1700 Fribourg, Switzerland
[e] Centre of Geophysics, IDL, University of Lisbon, Alameda da Universidade, 1600–214 Lisbon, Portugal

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ABSTRACT

This study aims at understanding the spatial distribution and characteristics of the frozen and unfrozen terrain in an alluvial fan on Deception Island, which is an active strato-volcano located in the Bransfield Strait (South Shetland Islands) with recent eruptions in 1967, 1969 and 1970. The alluvial fan is dominated by debris-flow, run-off and rock fall processes and permafrost occurs in several parts in the vicinity of anomalous geothermal heat flux. The aim is to assess the ways volcanic activity controls permafrost development and associated geomorphic dynamics using shallow subsurface, surface and air temperature measurements as well as thaw depth and electrical resistivity tomography (ERT) surveys.

Results show a temperature increase with depth in the lower part of the fan reaching 13 °C at 0.80 m depth, without the presence of permafrost. The shallow borehole located at this site showed a stable thermal stratification all year-round, with only the upper 0.20 m reacting to meteorological forcing. In the upper part of the alluvial fan and debris cones, c. 100 m from the coast, frozen ground is present at c. 0.70 m depth. There, the shallow borehole shows a good coupling with air temperatures and the thermal regime favours the presence of permafrost. ERT shows the lowest resistivity values in the lower part of the alluvial fan and a highly resistivity zone in the upper sector of the fan and in the debris cones. These large variations in resistivity mark the presence of a saline water wedge from the sea into the fan, reaching frozen ground conditions about 100 m inland. It can be shown that the volcano-hydrothermal activity only inhibits frost development very locally, with frozen ground conditions occurring about 100 m away.

1. Introduction

The western Antarctic Peninsula is one of the regions in the World with the strongest climate warming trend, with an increase of c. +3.4 °C in the mean annual air temperatures since 1950 (Turner et al., 2005, 2007). While glaciers and ice-shelves are being monitoring to evaluate the effects of climate change, permafrost, an important component of the Antarctic cryosphere has been largely neglected and only recently started to be monitored systematically (Vieira et al., 2010; Bockheim et al., 2013). Permafrost, which occupies only 0.36% (49,800 km^2) of the Antarctic region, is present beneath virtually all ice-free terrain, except at the lowest elevations of the maritime Antarctic and sub-Antarctic islands (Ramos et al., 2012). Permafrost occurrence has been confirmed in the South Shetlands by many authors (Ramos et al., 1989; Serrano and López-Martinez, 2000; Hall, 2002; Bockheim et al., 2007; Vieira et al., 2010, among others), who also noted several permafrost-free sites at low altitude. Due to a tectonic setting of Bransfield strait opening (rift aperture), some of these sites show a high geothermal heat flux, such as Bridgeman, Penguin and Deception islands (De Rosa et al., 1995; Gràcia et al., 1996), inhibiting the development of large thickness of permafrost.

In recent decades there has been a growing interest in volcano-ice systems, mainly by those involved on research on the similarity between the terrestrial and Martian processes. Four important themes drive this trend: volcano hazard awareness and prevention, the Pleistocene global climate record, potential feedbacks between deglaciation and volcanism, and Martian geoscience research (Smellie and Chapman, 2002; Edwards et al., 2009). Despite this, only a few works refer to the interaction between permafrost and terrains under geothermic effects, both in what relates to spatial variability of ground thermal state, but also on the seasonal behaviour of the ground thermal regime. Such studies could be relevant for understanding the

* Corresponding author at: Int. Güiraldes 2160, Ciudad Universitaria, Pab.2 C1428EHA, Buenos Aires, Argentina. Fax: +54 011 4576 3400.
E-mail address: goyanes@gl.fcen.uba.ar (G. Goyanes).

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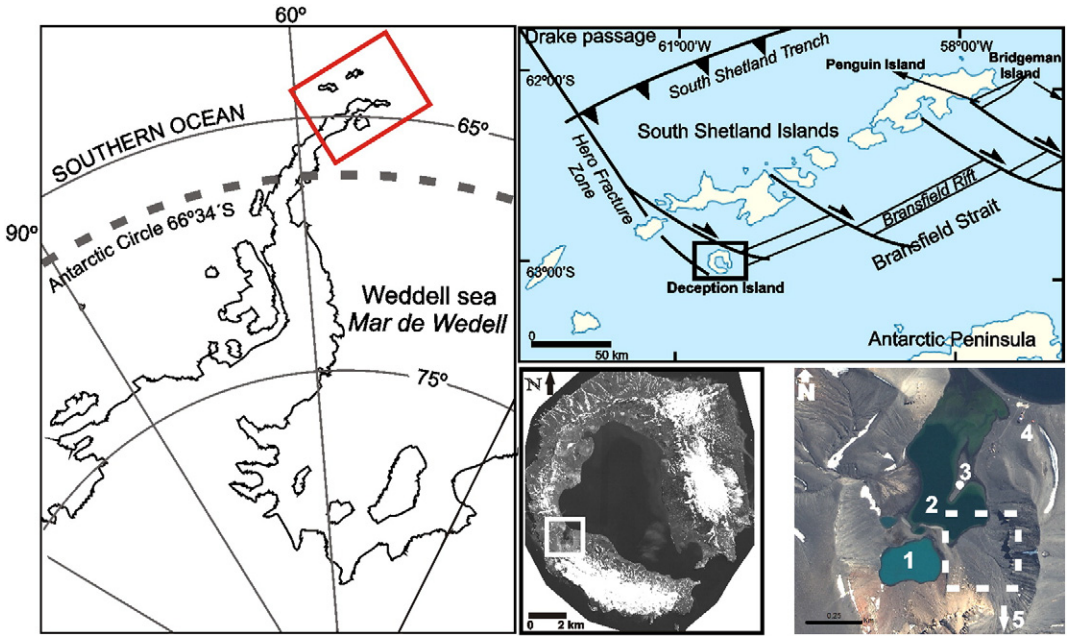

Fig. 1. Location of study area at Deception Island (Antarctica) (adapted from Maestro et al., 2007). (1) Lake Irizar, (2) Lagoon, (3) Old meteorological station, (4) Argentinean base Decepción, (5) Mount Irizar. The area enclosed in the dotted line is the Irizar alluvial fan detailed study area.

mechanism of lahars caused by permafrost melt, thermokarst collapse features, the geomorphic dynamics associated with such areas, but also to investigate adaptations of extremophiles.

On Earth, ice-permafrost-volcano interactions are common at high altitude or latitude stratovolcanoes (Iceland, Andes, Alaska, Kamchatka peninsula, Antarctica, among others) (Kellerer-Pirklbauer, 2007). Bleick et al. (2013) mention signs of abnormal heat flow in the summit crater of Redoubt Volcano (Alaska) preceding the 2009 eruption and triggering melting and ablation of Redoubt's glaciers and a variety of morphological changes, like the deposition from a large amount of debris flows. Tormey (2010) showed how glacial melting and magmatic activity have triggered landslides and sector collapses at

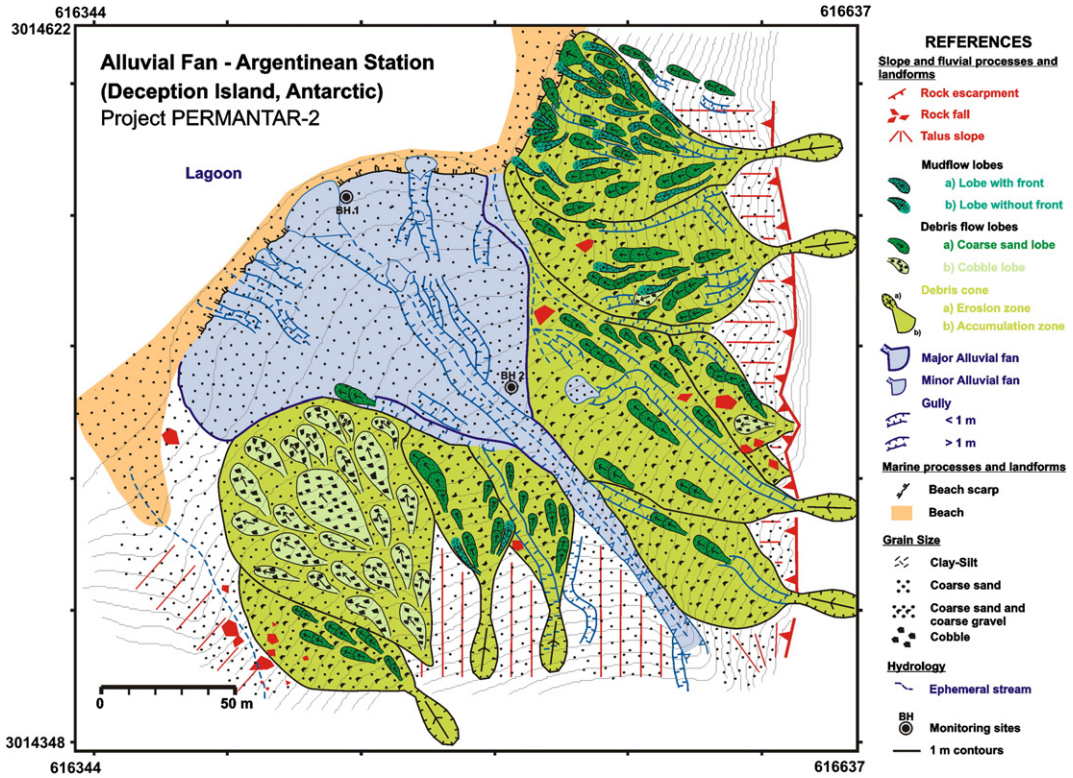

Fig. 2. Geomorphology of the Irizar alluvial fan detailed study area.