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A case for chemical weathering in soils of Hurd Peninsula, Livingston Island, South Shetland Islands, Antarctica

Nicholas W. Haus [a], Kelly R. Wilhelm [a,*], James G. Bockheim [a], John Fournelle [b], Michael Miller [b]

[a] Department of Soil Science, University of Wisconsin, Madison, WI, USA
[b] Department of Geoscience, University of Wisconsin, Madison, WI, USA

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ABSTRACT

The soils of the South Shetland Islands, Antarctica are considered weakly developed. Chemical weathering processes are generally considered to be negligible except in areas that receive large additions of seabird guano. In this paper we describe and analyze 19 soils on Hurd Peninsula, Livingston Island in the South Shetland Island Archipelago. The soils were classified according to US Soil Taxonomy and were generally weakly developed Gelorthents, Humigelepts and Haplorthels. However, B horizon formation, rubification and increases in extractable Fe and Al were observed on toposequences of raised beaches. The deposition of tephra and/or guano is likely responsible for the chemically driven processes. Guano deposits contain phosphates and oxalic acid, causing phosphatization and/or dissolution of silicates. Input of tephra with easily weatherable minerals may account for metastable mineral formation. Tephra deposition in the oldest raised beaches has formed a fine-textured mantle overlying the coarser textured subsoils. Highly weatherable tephra, as opposed to guano deposition, appears to influence soil formation at Hurd Peninsula.

1. Introduction

The main processes driving soil formation in the South Shetland Islands have been cited as ornithogenic and physical or mechanical weathering (Simas et al. 2008). The literature bears little support for chemical weathering as an important soil forming process in maritime Antarctica. Ornithogenic soils (i.e. soils with properties produced by avian activities) have been described in several locations in the South Shetland Islands, on the Antarctic Peninsula, and at several maritime locations along continental Antarctica (Michel et al. 2006; Simas et al. 2007; Tatur 2002). Phosphatization is an ornithogenic soil forming process that produces a unique suite of phosphate minerals that is indicative of zones of active or relict manuring by seabirds (mainly penguins). Phosphatization occurs when phosphorus rich guano, mostly from penguins, interacts with water and soils. Fresh guano has a neutral pH and initial stages of degradation enrich the surface of penguin rookeries with urates, ammonium, chitin, struvite ($[NH_4]MgPO_4 \cdot 6H_2O$) and apatite ($Ca_5[PO_4]_3[OH, F, Cl]$) (Myrcha and Tatur 1991). Volatilization and nitrification of ammonium ions and various hydrolysis reactions cause phosphorus laden acidic solutions to percolate downwards, causing the following set of phosphate minerals to precipitate: leucophosphite ($KFe^{3+}{}_2[PO_4]_2[OH] \cdot 2H_2O$); minyulite ($KAl_2[PO_4]2[OH]_{0.75}F_{0.25} \cdot 4H_2O$); metavariscite ($Al[PO_4] \cdot 2H_2O$); vashegyite ($Al_6[PO_4]_5[OH]_3 \cdot 22H_2O$); arctowskite ($Al_9[PO_4]_8[OH]_3 \cdot 27H_2O$); and vivanite ($Fe^{2+}{}_3[PO_4]_2 \cdot 8H_2O$) (Myrcha and Tatur 1991; Pietr et al. 1983; Simas et al. 2007; Tatur 1989). The unique chemistry of ornithogenic soils and the identification of phosphate minerals in abandoned rookeries hundreds of years old have prompted several researchers to suggest "Ornithogenic" as an additional subgroup to Soil *Taxonomy* (Michel et al. 2006; Simas et al. 2007).

Soils at Hurd Peninsula, Livingston Island, in the South Shetland Island Archipelago, are not only impacted by ornithogenic activity, but also receive some of the highest levels of tephra deposition from volcanic activity at nearby Deception Island (Baker et al. 1975; Lee et al. 2007). Tephra is a pyroclastic material dominated by amorphous glass-like materials that weather to produce Al and Si rich minerals. The majority of tephra is andesitic origin and weathers to produce an acidic environment favoring the formation of allophane and Al-organic matter complexes typical of Andisols (Schaetzl and Anderson 2005).

Previous soil investigations at Hurd Peninsula have been conducted by Moura et al. (2012); Ganzert et al. (2011) and Navas et al. (2008). Navas et al. (2008) described and analyzed the chemical properties, physical properties, and mineralogy of 7 profiles from nearby Byers Peninsula, the largest ice-free area in South Shetland Islands at 60 km^2 and 4 profiles from Hurd Peninsula to determine how soil properties varied with lithology. The study concluded that bedrock lithology was more correlated with soil properties than physiographic location or geomorphic unit and that physical weathering by freeze–thaw

* Corresponding author at: University of Wisconsin-Madison, Department of Soil Science, 1525 Observatory Dr., Madison, Wisconsin 53706, USA.
E-mail address: krwilhelm@wisc.edu (K.R. Wilhelm).

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processes, as opposed to chemical weathering, controlled soil formation. The goal of this study is to study soil-forming processes on Hurd Peninsula, particularly in response to guano deposition from nearby penguin colonies and volcanic ash deposition from the nearby Deception Island.

2. Materials and methods

2.1. Study area

Hurd Peninsula, Livingston Island (62°39′S) is a 20 km^2, north facing bedrock upland with a maximum elevation of 400 m (Fig. 1). The peninsula receives approximately 800 mm of precipitation per year and has a mean air average temperature (MAAT) between −1.5 to −3.2 °C at 15 m above sea level (a.s.l.), and approximately −4.5 °C at 275 m a.s.l. (recorded between 2000 and 2006), with a range of 10 °C to −35 °C (Ganzert et al. 2011; Hauck et al. 2007; Moura et al. 2012). Air temperatures are generally positive from December to March and negative from April through November, with very high humidities (80–90%) encountered during the summer months due to the influence of the polar front (Hauck et al. 2007).

Hurd Peninsula is comprised of Mesozoic sedimentary rocks of the Miers Bluff Formation, which are mainly shales, siltstones, arkosic greywackes, and sandstones with some interbedded conglomerates derived from volcanics and erosion of a volcanic island arc, subsequently deposited as deep-water turbidites (Hobbs 1968). The ice-free areas of Hurd Peninsula are located along the coast while the center of the peninsula is covered by an ice dome rising to 330 m a.s.l. The southern part of Hurd Peninsula is a rugged ice-free coast bordering False Bay that has a maximum elevation of 400 m a.s.l. and terminates as coastal cliffs or very steep bedrock slopes. The northerly side along South Bay has a more gentle topography with a maximum height of 275 m a.s.l. and a marine eroded platform between 60 to 200 m a.s.l. that is bisected by sloping glacially cut valleys filled with raised marine beaches.

The raised beaches on Hurd Peninsula have been classified as 1) lower beaches (1–3 terraces) under 2 m a.s.l. to the modern beach that have clean pebbles without lichens; 2) intermediate beaches (4–8 terraces) between 2.8 and 8 m a.s.l. with lichens; and 3) upper beaches (1–4 terraces) between 12 and 18.6 m with lichens and *Deschampsia antarctica* (Lopez-Martinez et al. 1992). The radiocarbon dates of raised beaches at nearby Byers Peninsula suggests the lower beaches formed less than 200 years BP; the intermediate beaches formed about 200 to 2000 years BP; while the upper beaches formed between 2000 to 6000 years BP (Clapperton and Sugden 1988).

Above the raised beaches are early Pliocene to late Miocene marine eroded platforms 60–200 m a.s.l. which are mostly sediment-free with the exception of a veneer of frost shattered materials and the occasional rounded stone (Pallàs et al. 1995). Regional tectonic uplift is likely responsible for the marine eroded platforms which bear evidence of faulting, while the raised beaches which show no evidence of fault deformation are likely the result of isostatic and glacioeustatic changes. Geomorphic descriptions and maps of Hurd Peninsula can be found in Lopez-Martinez et al. (1992) and Pallàs et al. (1995).

Following the last glacial maximum, the ice sheet had retreated to at least the location of the upper raised beaches by 6000 BP, but readvanced at least twice between 720 and 330 BP and after 300 BP, depositing occasional recent moraines over raised beaches (Pallàs et al. 1995). The unconsolidated sediments that make up the soils on the peninsula include marine alluvium on the raised beaches and glacial tills at Bulgarian Bay. Both sources are intermixed with frost shattered rock of the Miers Bluff formation and volcanic ash derived from eruptions of nearby Deception Island. Hurd Peninsula is particularly prone to tephra deposition from pyroclastic eruptions of Deception Island volcanism, as shown by isopachs of a 1970 pyroclastic eruption of Deception Island (Baker et al. 1975).

At least five known tephra layers, ranging in thickness from a few millimeters to 0.03 m, crop out of ice cliffs on the site. These five layers are correlated to pyroclastic eruptions that took place between the early

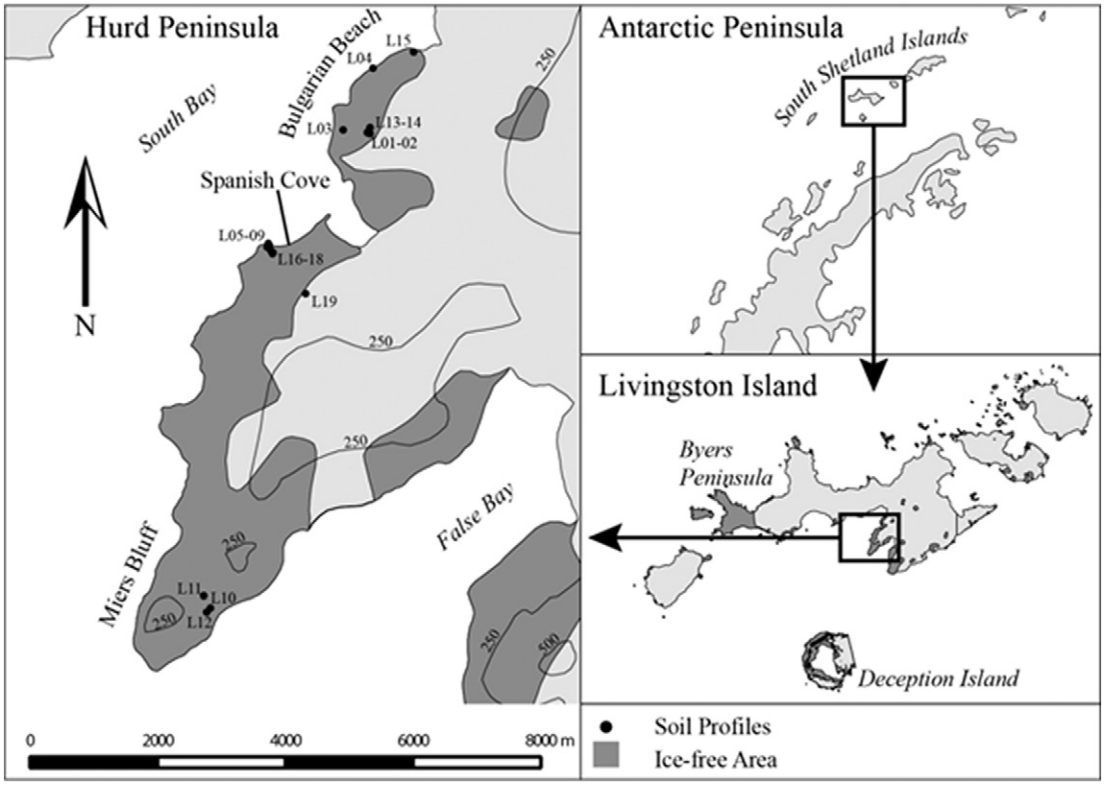

Fig. 1. Site map of location of Livingston Island (upper right), Hurd Peninsula (lower right) and the sampling sites on Hurd Peninsula.