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Variation in the characteristics and development of soils at Edmonson Point due to abiotic and biotic factors, northern Victoria Land, Antarctica

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ABSTRACT

The lack of baseline surveys of soil environments in many areas of Antarctica provides an impediment to understanding their suitability for supporting biotic communities and limits abilities to monitor and predict impacts of environmental changes. A soil survey was conducted at Edmonson Point (Victoria Land) within representative local environments to identify their variability and drivers of soil processes and geochemistry. The soils were coarse-textured and lacked cohesion and structural development. The parent material was homogenous, and consisted of weathered and unconsolidated basaltic lavas and scoria. Despite these similarities, the soils varied significantly with the variation driven by local environmental and biotic factors. Penguins had the greatest influence, deposited guano altered soil processes leading to profound changes in soil characteristics. The ornithogenic soils were rich in penguin bio-elements, with low C/N, high EC and large variation in pH. Contents of N and C declined at comparable rates as C/N values did not change with time. Ornithogenic P was not readily lost, resulting in its high concentrations in relict soils. Abundant bacteria played a key role in these processes, but after cessation of guano inputs bacterial numbers and activity declined considerably. Alternatively, rich autotrophic microflora had a little influence on ornithogenic soil geochemistry. Characteristics and development of mineral soils were driven by hydrology and associated biological processes. Dry fellfield soils were the most immature, as indicated by more coarse-grained material, neutral pH, low EC and C/N values, scarce microflora and elemental content corresponding to typical background values. Alternatively, soils from moss communities and wetlands had higher amounts of fine-grained material, C, N and C/N values and lower pH that resulted from accumulation of organic matter. Elemental concentrations in soils from moss communities were similar to those in fellfields, but were elevated in wetland soils. While C and N contents seemed to be controlled by biotic communities, geochemistry of other elements was driven by external inputs. Although some inputs may originate from substratum weathering in the surrounding areas, marine-derived elements redistributed with penguin guano seemed to be the major source of the enrichment. Analyses of the origin and distribution of the soil elements may provide valuable records for reconstruction of geochemical and environmental processes in Antarctic terrestrial ecosystems.

1. Introduction

Terrestrial, ice-free environments in Antarctica are restricted to only ~0.34% of the entire Antarctic continent, equating to ~45 000 km^2, with the reminder permanently covered by glaciers and snow (Convey et al., 2009b). Most of these ice-free environments occur as isolated patches of ground scattered along the continental coasts and relatively few are found inland. These locations are characterized by frigid climate with very low temperatures, humidity and precipitation and strong katabatic winds. Due to such extreme climatic conditions, Antarctic terrestrial environments are some of the harshest on Earth. Moreover, many of the Antarctic ice-free areas have emerged from retreating glaciers during the past few thousand years and glacial erosion is still the dominant land-forming factor. Therefore, the ground is mostly barren of any visible vegetation and is primarily covered with glacier till, unsorted rock rubble, gravel and scattered erratic boulders (Campbell and Claridge, 1987; Beyer and Bölter, 2002).

As a consequence of the extreme climatic conditions and relatively short exposure in most of the Antarctic ice-free areas, the soils are weakly developed and lack cohesion and structural development

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(Campbell and Claridge, 1987). Moreover, in specific conditions pedological processes might be restricted to endolithic environments (Mergelov et al., 2012). Consequently, until recently many scientists were unwilling to identify them as soils. In fact, in many of the Antarctic ice-free areas, the existence of soil in a strict sense is still disputed. Given their very limited and widely scattered distribution, poor development and lack of suitability for any potential land use, Antarctic soils were considered of minor importance and received relatively little attention by soil scientists. Therefore the study of Antarctic soils is comparatively new, but their significance is drawing more attention, particularly with respect to environmental and ecosystem relationships (Beyer and Bölter, 2002; Kimble, 2004; Wall, 2005; Ugolini and Bockheim, 2008).

Because of their extreme environmental conditions, Antarctic soils are regarded as sensitive indicators of environmental changes and human impacts (Wall, 2005; Ugolini and Bockheim, 2008). The three most important physical factors in context with climate change for Antarctic terrestrial habitats are temperature, water availability and solar irradiance (Kennedy, 1995; Convey and Lewis Smith, 2006). Rapid changes in all three of these major environmental variables have been documented in the Antarctic, particularly in the maritime region (Kennedy, 1995; Turner et al., 2014). Although there is no evidence of rapid climate change on the Antarctic continent, its terrestrial ecosystems are climatically very sensitive (Ugolini and Bockheim, 2008) and it is widely expected that current global climate changes are likely to have major impacts on the ice-free environments (Kennedy, 1995; Wall, 2005; Convey et al., 2009a; Turner et al., 2014).

Soils also provide information on environmental changes in Antarctica as they record variation in past and present conditions (Navas et al., 2008; Liu et al., 2013; Nie et al., 2014). Antarctic soils could, therefore, be one of the more significant baseline environments for the study of global climate changes. This application using soils and the biota they support to assess impacts of climate change necessitate a full understanding of Antarctic soil processes and geochemistry (Beyer and Bölter, 2002; Wall, 2005; Barrett et al., 2006a, 2006b). Previous research on Antarctic soils, their properties and biotic communities, however, has focused mostly on those in the McMurdo Dry Valleys and relatively little is known about them at other localities (Beyer and Bölter, 2002; Kimble, 2004; Ugolini and Bockheim, 2008). Only a few studies were conducted at other Victoria Land localities (e.g. Cannone et al., 2008; Cannone and Guglielmin, 2009), at Wilkes and Dronning Maund Lands and on soils of the maritime Antarctic (see Everett, 1976; Beyer and Bölter, 2002; Bölter, 2011). The relationship among soils, the landscape and the glacial history were the focus for most of these studies (Ugolini and Bockheim, 2008).

Numerous studies also have focused on ornithogenic soils formed within penguin colonies (see recent review by Emslie et al., 2014). Ornithogenic soils have been especially studied on King George Island in the maritime Antarctic (Tatur and Myrcha, 1984; Tatur, 1989, 2002; Myrcha and Tatur, 1991; Michel et al., 2006), but also at a few locations around the Antarctic continent, particularly in the Ross Sea region, i.e. on Ross Island (Ugolini, 1972; Speir and Cowling, 1984; Speir and Ross, 1984; Heine and Speir, 1989), Inexpressible Island (Campbell and Claridge, 1966) and Cape Hallet (Hofstee et al., 2006). These studies concentrated primarily on the ornithogenic soil physical and chemical properties, but some also investigated influences of soil ornithogenic compounds on abundance and distribution patterns of soil biota (Ramsay, 1983; Ramsay and Stannard, 1986; Roser et al., 1993; Porazinska et al., 2002; Smykla et al., 2010, 2012) or vegetation (Tatur et al., 1997; Michel et al., 2006; Smykla et al., 2007; Krywult et al., 2013).

The lack of baseline surveys of Antarctic soils, as highlighted above, provides a serious impediment to understanding their suitability for supporting biotic communities, and it also limits our abilities to monitor and predict the impact of current environmental changes in Antarctic terrestrial ecosystems. To increase the existing knowledge on biogeochemistry of Antarctic soils, we have investigated and sampled several localities in the Ross Sea area (see Smykla et al., 2011). Initially, this work focused on active and relict penguin colonies and influences of these colonies on soil geochemistry and biotic communities. Ultimately, the work was extended to include other soil environments near our surveyed localities to provide background references to the ornithogenic soils.

Here, we present the analysis of the key physical, chemical and biological characteristics of soils at Edmonson Point, Victoria Land, Ross Sea (Figs. 1–2a). Soils in the Edmonson Point area have previously been investigated, but this research focused mostly on the bryophyte communities or lacustrine environments (Bargagli et al., 1998, 1999; Lewis Smith, 1999; Cannone et al., 2008; Cannone and Guglielmin, 2009; Malandrino et al., 2009). Previous investigations have indicated the presence of an exceptionally wide range of terrestrial environments with high abundance of water and rich biotic communities (Harris and Grant, 2003). Thus, Edmonson Point is a useful model site for understanding processes and changes of coastal ice-free ecosystems in this region. During our investigations we included a more representative examination of various soil environments and provide a comprehensive analysis of soil characteristics in this area. We sought to identify soil variability and define the main drivers of soil processes and geochemistry. We hypothesized that the soil, despite being geologically young with similarities to the parent material, will show significant variation in its characteristics across local environments, with differences driven by hydrology and associated biological processes. External inputs, related to the presence of penguin colonies, were also expected to have pronounced effects on soil development and geochemical cycling in this area.

2. Material and methods

2.1. Description of study area

Edmonson Point (74°20′S, 165°08′E) is located in Wood Bay on the west coast of the Ross Sea, northern Victoria Land, Continental Antarctica (Figs. 1–2a). It is an ice-free coastal spur of Mount Melbourne, a dormant volcano showing evidence of very recent activity (Kyle, 1990). The area encompasses ~6 km^2 and is one of the largest non-mountainous, coastal ice-free areas in northern Victoria Land. The landscape of Edmonson Point has been considerably modified by glacial and periglacial activity, resulting in a mosaic of hills (up to 300 m high), knolls and moraines, separated by small valleys with several ephemeral melt-water streams, seepage areas, ponds and a few larger lakes. Such a range of freshwater environments in one area is unusual and the stream network is the most extensive for the whole of Victoria Land. Most of the area, however, is extremely dry with the ground covered by salt encrustations (Fig. 2a–b). The ground is dark colored and consists of volcanic materials (basaltic lavas, scoria, pumice and tuff) which originated from the past volcanic activity of Mount Melbourne. Only in a relatively narrow strip of modern and raised beaches are the parent materials reworked by marine processes and consist also of some marine deposits (Baroni and Orombelli, 1994). The climate is typical of coastal areas in the continental Antarctic, with low temperature, humidity and precipitation. However, the area of Edmonson Point is well sheltered from local katabatic winds, and its climate is milder than in the neighboring areas, with the temperature during the austral summer ranging from −11° to +12 °C and is above freezing every day for about 6–10 weeks (Harris and Grant, 2003; Cannone and Guglielmin, 2009).

As in most of the Antarctic ice-free terrestrial ecosystems low temperatures and aridity are the main limiting factors for life at Edmonson Point. However, owing to a relatively mild climate, availability of liquid water and bird-derived nutrients, Edmonson Point compared with other sites in Victoria Land has a wide range of terrestrial environments and a relatively diverse biota. Flora of this area is entirely cryptogamic, with bryophytes (six mosses, one liverwort) and lichens (~30 species) being the principal composition of plant communities. Although it seems very poor in species, Edmonson Point possesses exceptionally