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Active layer thermal dynamics at two lithologically different sites on James Ross Island, Eastern Antarctic Peninsula

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ABSTRACT

The active layer thermal regime was studied at two sites with different lithological properties located on James Ross Island, eastern Antarctic Peninsula, to assess the main driving factors. The Abernethy Flats site (41 m a.s.l.) is located in Cretaceous calcareous sandstones and siltstones of the Santa Marta Formation. In contrast, the Berry Hill slopes site (56 m) is composed of muddy to intermediate diamictites, tuffaceous siltstones to fine-grained sandstones of the Mendel Formation. The data of air temperature at 2 m and ground temperature at two 75-cm-deep profiles were analysed for the period 1 January 2012, to 31 December 2014. Small differences were found when comparing mean air temperatures and ground temperatures at 5, 50 and 75 cm depths, in the period 2012–2014. While the mean air temperatures varied between −7.7 °C and −7.0 °C, the average ground temperatures oscillated between −6.6 °C and −6.1 °C at 5 cm; −6.7 °C and −6.0 °C at 50 cm; and −6.9 °C and −6.0 °C at 75 cm at Abernethy Flats and Berry Hill slopes, respectively. The increasing difference of ground temperature with depth, and a significant difference in active layer thickness – 52 to 64 cm at Abernethy Flats and 85 to 90 cm at Berry Hill slopes, respectively – suggests the significant effect of lithology. The higher proportion of fine particles and more thermally conductive minerals, together with higher water saturation, has been found to be fundamental for higher active layer thickness documented at Berry Hill slopes.

1. Introduction

Permafrost represents one of the key indicators of climate change as its superficial part reacts sensitively to climate variations and global temperature rise (e.g.; Romanovsky and Osterkamp, 1997; Guglielmin, 2006; Turner and Marshall, 2011). It is therefore crucial to fully understand the response of permafrost and the active layer particularly to undergoing climate change in Polar regions. The largest annual surface air warming on the Earth over the last 50 years was reported on the western side of the Antarctic Peninsula (AP): the mean air temperature increased at a rate of 0.56 °C/decade at the Faraday/Vernadsky Station (Turner et al., 2005). The mean annual air temperatures rose substantially along the eastern coast of Antarctic Peninsula as well, accelerating glacier retreats, ice-shelf breakups and permafrost temperature increase (e.g.; Cook and Vaughan, 2010; Turner and Marshall, 2011; Davies et al., 2012; Bockheim et al., 2013). At the same time, a positive trend in precipitation and snow accumulation has been observed and/or modelled on the western AP since 1950, as a result of changes in the atmospheric circulation, and its regional variability and patterns (Van den Broeke et al., 2006; Thomas et al., 2008).

High sensitivity of the active layer thickness (ALT) to climate fluctuations was found to be an important indicator of air and ground temperature increase. However, active layer thermal properties and thickness are not only related to the local air temperature and precipitations, but are also influenced by other variables and factors, such as incoming solar radiation, or ground surface lithology and moisture content (e.g.; Romanovsky and Osterkamp, 1997; Guglielmin et al., 2012).

A general overview of permafrost and active layer thermal dynamics in the AP region by Bockheim et al. (2013) showed that most of the studies have been conducted in areas of the western AP and the sub-Antarctic islands. Still, the overall knowledge about the active layer thermal regime and its dependence on climate factors, the local comprehension of air temperature, snow thickness and the geological conditions controlling active layer dynamics in the AP is still less than that known about the Arctic, or the Dry Valleys region in Antarctica (Vieira et al., 2010).

Results bringing a wider spectrum of information describing different patterns of active layer have been published mainly in the past few years. The main subjects were studies on the general characteristics of the active layer thermal regime (e.g.; Guglielmin et al., 2012; Michel et al., 2012; Almeida et al., 2014; De Pablo et al., 2014), physical thermal properties (e.g.; Correia et al., 2012; Goyanes et al., 2014), snow effect on ground temperature (e.g.; De Pablo et al., 2013; Guglielmin et al., 2014), or the effect of air temperature and vegetation cover

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(e.g.; Cannone et al., 2006) in the western AP region. Although large ice-free areas are also located along the eastern coast of the AP – e.g. on James Ross Island (JRI), Vega Island or Seymour Island – very little information is available about the active layer thermal regime, which suggests significant differences when compared to the western side of the AP (Bockheim et al., 2013). The active layer thermal regime and its relationship to air temperature and snow cover near the Johann Gregor Mendel Station (JGM Station) on JRI was recently described in detail by Hrbáček et al. (2016), while earlier works from the eastern part of the AP bring only limited information on the state of the permafrost and active layer (e.g.; Fukuda et al., 1992; Borzotta and Trombotto, 2004; Ermolin et al., 2004).

The completion of local knowledge about the active layer thermal regime, its variability in different lithological conditions, its physical properties and relationship with climate factors above the JRI, which forms one of the largest ice-free areas in the AP region, represents a further challenge for the future work of the Czech Antarctic geoscientific research team that has been working at the JGM Station since 2006.

The main aims of this study are: 1) to describe the current state and thermal dynamics of the active layer at two distinct sites on James Ross Island in the period 2012–2014; 2) to assess the influence of different lithological conditions on active layer thermal dynamics; and 3) to determine the air temperature effect on the active layer thermal regime.

2. Study area

The study sites are located in the northern part of JRI, which is one of the largest islands located in Antarctic Peninsula region (Nedbalová et al., 2013). The northern tip of JRI, called the Ulu Peninsula (Fig. 1), is considered one of the largest ice-free areas in the region (Nedbalová et al., 2013; Kavan et al., in review), with only small glaciers remaining in the present landscape (Engel et al., 2012), where the deglaciation process of low-lying areas (<60 m) started 12.9 ± 1.2 ka ago (Nývlt et al., 2014).

The climate on JRI is a semi-arid Polar-continental, influenced by an orographic barrier of the Trinity Peninsula mountains (Martin and Peel, 1978; Davies et al., 2013). The mean annual air temperature (MAAT) at the JGM Station was −6.8 °C in the period 2006–2011 (Láska et al., 2012). The maximum air temperatures during summer can exceed +10 °C, while winter minima drop below −30 °C (Láska et al., 2011). The precipitation falls mainly as snow in the winter season. However, the high wind speed causes snow drifting and irregular snow deposition (Zvěřina et al., 2014; Hrbáček et al., 2016), making standard rain gauge measurement inapplicable (Nývlt et al., 2016). Hence, estimates of precipitation range from 400 to 500 mm of water equivalent per year (Van Lipzig et al., 2004). The snow cover thickness measured near the JGM Station during the winter seasons is highly variable, with a maximum thickness not exceeding 30 cm (Hrbáček et al., 2016).

For the purpose of studying the active layer thermal dynamics, the Abernethy Flats and Berry Hill slopes sites were chosen. The study sites are located at similar altitudes, are not covered by vegetation but have different topographic and lithological properties (Table 1). The northern part of the Ulu Peninsula (Fig. 1) is formed of four Cretaceous formations of James Ross Basin marine sediments (Ineson et al., 1986; Olivero et al., 1986; Whitham et al., 2006), Neogene volcanic rocks of the James Ross Island Volcanic Group (Nelson, 1975; Smellie et al.,

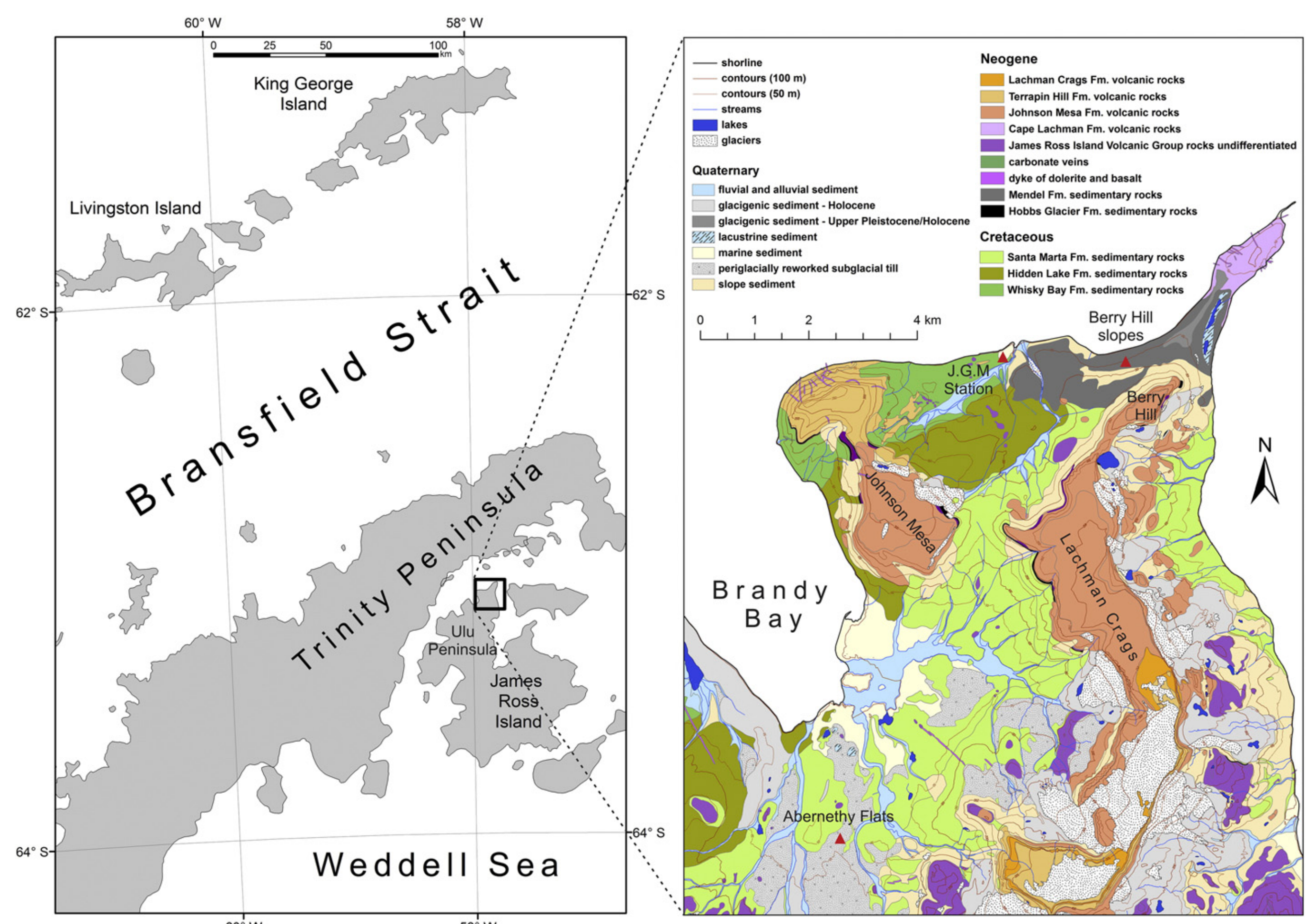

Fig. 1. Regional settings and geological characteristics of Ulu Peninsula, James Ross Island (adopted from Mlčoch et al., 2015).