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# Active layer thermal monitoring of a Dry Valley of the Ellsworth Mountains, Continental Antarctica

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ABSTRACT

The Ellsworth Mountains are located along the southern edge of the Ronne-Filchner Ice Shelf and are subdivided by the Minnesota Glacier into the Heritage Range to the east, and the Sentinel Range to the west (Figure 1). The climate of the Ellsworth Mountains is strongly controlled by proximity to the Ronne-Filchner Ice Shelf and elevation. The entire ice free area is underlain by continuous permafrost of unknown thickness, most in the form of dry permafrost. Active-layer depths in drift sheets of the Ellsworth Mountains range from 15 to 50 cm. Detailed knowledge on Antarctic permafrost is patchy, especially at the continent. Two adjacent active layer monitoring sites were installed at Mt. Dolence, Ellsworth Mountains, in the summer of 2012. Two dry-valley soils at Mt. Dolence area, on quartzite drift deposits were studied: (i) a convex-slope site exposed to the wind (Lithic Haplorthel 886 m asl, 5 cm, 10 cm, 30 cm); and a sheltered concave-slope site protected from winds (Lithic Anhyorthel 850 m asl, 5 cm, 10 cm, 30 cm). Data was recorded at hourly intervals from January 2nd 2012 until December 29th 2013. The soil climate temperature at 5 cm reaches a maximum daily mean in late December, reaching a minimum in mid July at both sites. Active layer thickness reaches a maximum of 48.4 cm at P1 on January 17th 2013 and 47.8 cm at P2 on January 7th 2012. The soil thermal regime at the dry valley of Mt. Dolence, Ellsworth Mountains is characteristic of cold desert affected by dry-frozen permafrost. Although air temperature does not reach elevated positive values, variations in soil temperature are intense, showing the soil's response to solar radiation. The origins of typical surface periglacial features and landform on the widespread Ellsworth drifts may be inherited from past events of warmer climates, since liquid water is unlikely to play any significant role under the present climate.

## 1. Introduction

The Ellsworth Mountains form a 360 km (224 mi) long and 48 km (30 mi) wide mountain range; they are divided by the Minnesota Glacier into the Heritage Range and the Sentinel Range. Discovered by Lincoln Ellsworth, during a trans-antarctic flight, they are aligned north to south on the western margin of the Ronne Ice Shelf, being considered the highest mountain range in Antarctica and the largest portion of ice-free area (30,400 km$^2$).

Due to recent climate change trends, human effects on the active layer and permafrost have received increasing attention (Bockheim, 1993; Campbell et al., 1994). Realistically 25% or less of the Antarctic region contains permafrost (Bockheim, 1995); much of the area under the eastern and western ice sheets is above the pressure melting point and remains unfrozen. The concept of an active layer is less meaningful in interior Antarctica, where soil moisture content is <3% (Bockheim, 1995; Campbell et al., 1994; Black and Berg, 1963; Bockheim and Tarnocai, 1998). Therefore, much of the permafrost in interior Antarctica is ‘dry’ (Bockheim and Tarnocai, 1998; Bockheim, 2002).

A complete model describing the genesis of dry permafrost is yet to be achieved, though speculations point to materials deposited by dry-based glaciers that undergo ice loss though sublimation over time, in a cold and arid environment (Bockheim and Tarnocai, 1998; Black and Berg, 1963; Ugolini, 1964; Ugolini and Bull, 1965). Dry permafrost occurs throughout the dry valleys of the Transantarctic Mountains in southern Victoria Land, especially at elevations below 900 m (Cameron, 1969). In some cases, ice-cemented permafrost exists

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below dry permafrost to depths approaching 1000 m (Cartwright et al., 1974; Decker and Bucher, 1977).

Active layer depths in drift sheets of the Ellsworth Mountains range from 15 to 50 cm and the entire area is underlaid by continuous permafrost of unknown thermal regime and thickness (Bockheim and Schaefer, 2015). Based on data collected from 22 pits, 41% of the sites contained dry permafrost below 70 cm, 27% had ice-cemented permafrost within 70 cm of the surface, 27% had bedrock within 70 cm, and 5% contained an ice-core (Bockheim and Schaefer, 2015).

The shortage of information about dry permafrost is applicable to most of Antarctica, with the possible exception of the McMurdo Dry Valleys, where substantial research has taken place over the past several decades (Vieira et al., 2010). Elsewhere in Antarctica, permafrost research has been less systematic. Additionally, there has not been a coordinated effort to monitor permafrost properties and active-layer dynamics, except by individual countries and researchers, mostly in the vicinity of their research stations (Vieira et al., 2010). Such initiative is uncommon on remote continental areas such as the Ellsworth Mountains due to difficulties regarding installation and maintenance of the monitoring equipment.

This study is an essential part of the 'Antarctic and sub-Antarctic Permafrost, Periglacial and Soil Environments' (ANTPAS) project, coordinated by the International Permafrost Association and the Scientific Committee on Antarctic Research Expert Group on Permafrost and Periglacial Environments, aims at addressing key issues of Antarctic permafrost science.

The comprehension of the properties, thermal regime and distribution of Antarctic permafrost, including dry permafrost, is crucial to monitor and predict climate induced changes. Permafrost degradation affects the surface energy balance, snow cover, soil hydrologic properties and the effectiveness of the buffering action of the active layer. All which can lead to an increase in the mean summer surface temperature accompanied by deeper thawing of the active layer.

We studied the thermal regime of two contrasting sites with cold desert soil at the largest dry valley at Mt. Dolence, Ellsworth Mountains. The objective of this study is to contribute to the knowledge of the properties, thermal regime and distribution of Antarctic dry permafrost where no information on permafrost and active layer is available.

## 2. Materials and methods

### 2.1. Regional setting

The mean annual air temperature along the Transantarctic and Ellsworth Mountains, ranges from −15 to −20 °C in coastal areas to −35 °C along the polar plateau; the mean annual accumulation of water-equivalent precipitation likely ranges from 150 to 175 mm year$^{-1}$ (Bockheim and Schaefer, 2015). Elevation and the proximity to the surrounding ice shelf are the main variables controlling climate (Fig. 1). The vegetation cover is very rare, and restricted to a few lichen in the highest mountains (Øvstedal and Schaefer, 2013; Bockheim and Schaefer, 2015).

Geological formations include the Late Precambrian Minaret Group (marble), the middle to late Cambrian Heritage Group (sedimentary rocks), the upper Cambrian to Devonian Crashsite Group (predominantly quartzites), the Permo-Carboniferous Whiteout Conglomerate, and the Permian Polestar Formation (marine and terrestrial tillites) (Webers et al., 1992). At the study site, Mt. Dolence, quartzites prevail,

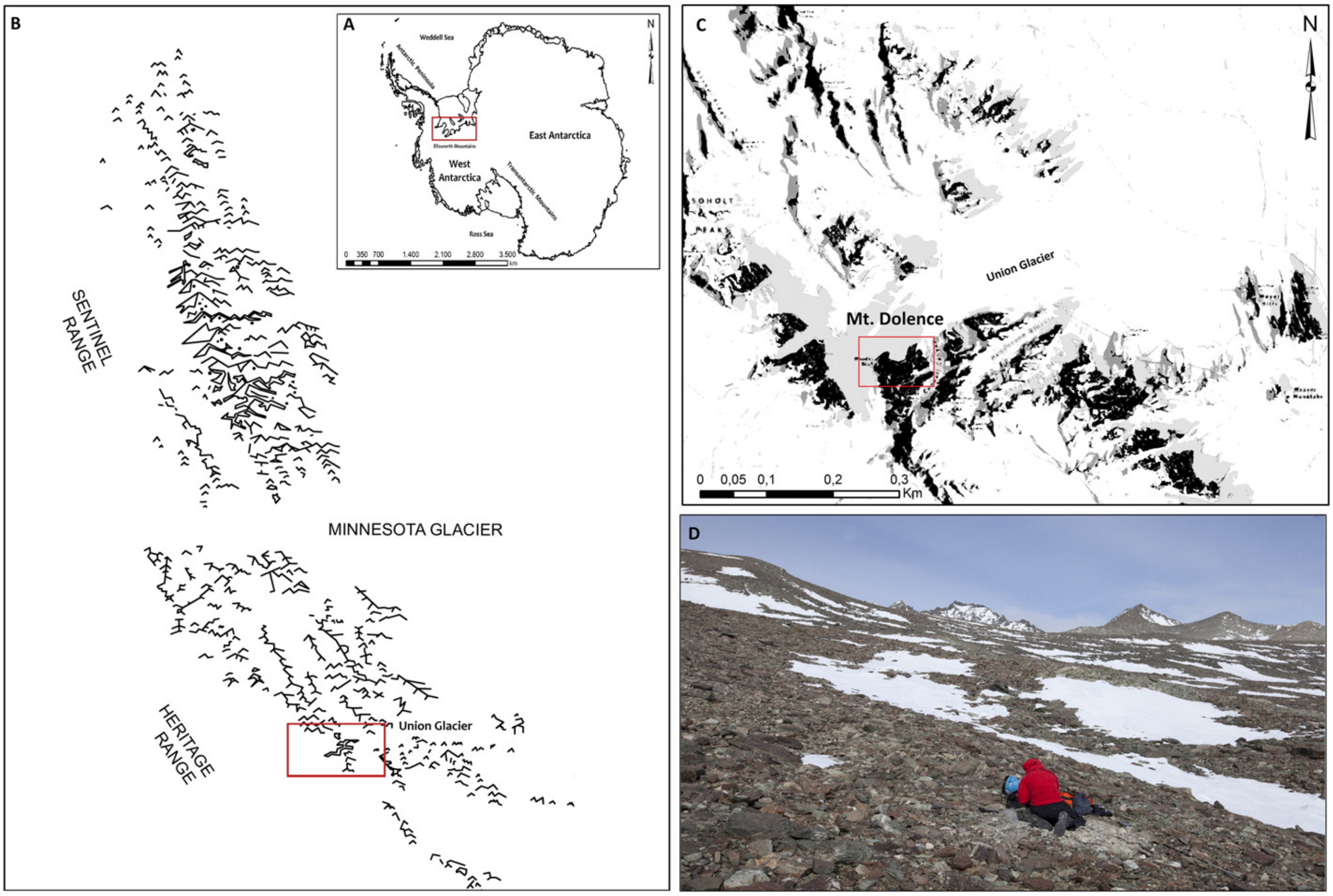

**Fig. 1.** Ellsworth Mountains in Antarctica context (A); Union Glacier area (B); Mt. Dolence area (C); Mt. Dolence, location of the monitored profiles (D).