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# Properties and processes of recently established soils from deglaciation of Cierva Point, Western Antarctic Peninsula

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ABSTRACT

For more than sixty years the Antarctic Peninsula has experienced significant temperature increases that have accelerated glacial retreat. Glacial losses, along with the relatively warm and moist climatic conditions of the region, have increased the rate of soil development. The objective of this study is to study the properties and genesis of soils at Cierva Point, which is located in the zone of maximum warming along the western Antarctic Peninsula. Cierva Point is a terraced, steeply sloping, ice-free peninsula containing a small retreating glacier. The peninsula contains a large penguin rookery and significant areas of moss buildup. Twenty-seven soils were described; physical and chemical properties from each horizon were analyzed. Four categories of soil were identified: acidic (pH < 5), neutral (pH > 5), moss-dominated (high organic matter accumulations), and ornithogenic (high phosphorus accumulations). Neutral soils were newly formed soils which had undergone the least development and were located closest to the glacier margin. Acidic soils were located farthest from the glacier margin, allowing for a greater nutrient leaching to occur; these soils have extremely low pH values (as low as 3.5) but did not have the high phosphorus accumulations found in ornithogenic soils or the high soil carbon content found in moss-dominated soils. In a region with rapidly retreating glaciers, such as the Antarctic Peninsula, proximity to the glacier margin becomes an important factor determining soil properties. Soils farther from the glacier have had more time to be affected by leaching, penguin activity, and moss buildup.


## 1. Introduction

Since the 1950's air temperature along the Western Antarctic Peninsula (WAP) has risen at a rate of 0.56 °C per decade (Turner et al., 2005). These temperature increases have led to rapid glacial retreat and subsequent land exposure. The newly exposed ice-free regions are subjected to physical and chemical weathering processes which contribute to the development of soils throughout the WAP. Relatively warm summer temperatures and moist climatic conditions that are common along the peninsula enhance biologic and chemical processes, which increase the rates of mineral transformation and translocation of materials (Blume et al., 2004).

Research on soil forming factors on the WAP and their relative influence on soil development is currently in its inception stage, with many studies focusing on regions having experienced no previous soil investigations (Jeong et al., 2004; Lee et al., 2004; Navas et al., 2008; Simas et al., 2008; Francelino et al., 2011; Moura et al., 2012; Souza et al., 2014). With the large presence of abundant penguin rookeries throughout the WAP, there has been an emphasis on 'ornithogenic soils,' or soils that are significantly affected by avian activity (Tatur, 1989; Blume et al., 2004; Michel et al., 2006; Simas et al., 2007; Moura et al., 2012; Mendonça et al., 2013; Souza et al., 2014). These studies are very comprehensive and have reported that guano from nesting penguins not only contributes nutrients such as phosphorus but also significantly acidifies soils within and adjacent to nesting areas. Another point of research interest along the WAP has been on the effect of moss presence on soil properties; these studies have found that moss growth significantly increases soil carbon and increases acidity through organic acid release (Beyer et al., 1999; Bölter, 2011). However, the moss cover in many of these studies has been thin or intermittent, making it difficult to assign soil properties directly to the presence of moss beds. Although most present day soils on the WAP are developing in proximity to retreating glaciers, few studies have focused on how physical or chemical soil properties change with distance from the glacial margin (Strauss et al., 2009).

The objective of this study was to analyze the physical and chemical properties of the soils throughout Cierva Point, and assess the key soil-forming factors and processes.

## 2. Site description

Cierva Point (64.15°S, 60.95°W) is a small, ice-free peninsula (1 km north to south and 1.5 km east to west) pointing to the north-northwest; the peninsula is protected from local climatic

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extremes by the larger Vivot Point and Mt. Pepino on opposite (northern) side of the cove (Fig. 1). Brabant Island, located to the west, protects the Cierva coastline from the effects of the open ocean. The climate is cold marine, with a mean annual air temperature of approximately −3.2 °C and annual precipitation ranging between 400 and 1100 mm. Winter snow depths could exceed 1 m; however, during the summer most of the seasonal snow completely melts. The study area generally slopes to the north exposing it to high solar radiation inputs during the summer. Ground temperatures throughout the peninsula were high enough that permafrost could not be detected within 2 m of the ground surface, and a borehole at the site suggests that it currently might be 6 m or more below the surface (Bockheim et al., 2013).

Bedrock of Cierva Point is of intrusive igneous origin. The northernmost lowlands consist of granodiorites with very large dolerite xenoliths (>1 m). The middle of the peninsula (uphill and to the south) is dominated by crystallized orthoclase feldspar granites. Both granitoid regions contain dikes composed of dolerite. The contact region between the granodiorite and granite show signs of contact metamorphism. The eastern side of the peninsula, along with the southern peaks, is dominated by basalts containing olivine and quartz crystals.

Polished bedrock, striations, and chatter marks on bedrock throughout the peninsula indicate that, at one time, nearly the entire region was glaciated. Based on the current glacier position it is likely that the entire slope was glaciated as recently as a couple hundred years ago. The one exception to this was at the highest elevation of this study (301 m above sea level) where there were no signs of glaciation on the ridgetops. Currently, a majority of the peninsula is ice-free; however, the eastern portion contains a large, but quickly retreating glacier (estimated to be on the order of several meters every year). The terrain of Cierva Point is steep, punctuated by several marine terraces. Slopes vary from 0 to 20% on benches and 30 to 60% on bedrock cliffs. Terraces contain several permanent ponds and unconsolidated materials with soils derived from weathered bedrock. These terraces are occupied for much of the year by Gentoo penguins (*Pygoscelis papua*) (ASPA No. 134, 2006).

Soils on penguin occupied benches are considered ornithogenic (Michel et al., 2006), due to the large number of nesting sites found in the region. Features of ornithogenic soils include relatively high accumulations of P and Ca and extreme acidity (Moura et al., 2012). Typically, ornithogenic soils occur in regions where penguins nest and have easy access to food, such as low-elevation sites that are far enough inland that guano deposits are not easily washed away (Tatur, 1989). The lowest elevations of Cierva Point are occupied by penguin activity, as would be expected; however, nesting sites at elevations up to 280 m a.s.l. have been noted.

The northern (lowest elevation) region of Cierva Point is covered by significant moss (*Polytrichum strictum* and *Chorisodontium aciphyllum*) accumulations. Moss on Cierva Point is ubiquitous and unusually thick (up to 0.8 m deep). Other studies report moss buildup along the Antarctic Peninsula of <0.1 m thick (Guglielmin et al., 2008).

## 3. Materials and methods

Twenty-seven pedons were described and classified from Cierva Point (Soil Survey Staff, 2014a). Soils were sampled to best represent the many geomorphic, topographic, and organic features found on Cierva Point (Tables 1 and 2). Areas affected by moss buildup were identified by O horizons and significant accumulations of soil organic carbon (SOC) (Bölter, 2011). Ornithogenic soils were selected based on observation of penguin activity and confirmed from phosphorus and calcium accumulations in the soils (Tatur, 1989). The soils were examined by hand-dug pits and described according to the *Field Book for Describing and Sampling Soils* (Schoenenberger et al., 2012). The symbol "D" was used to describe surface stone layers.

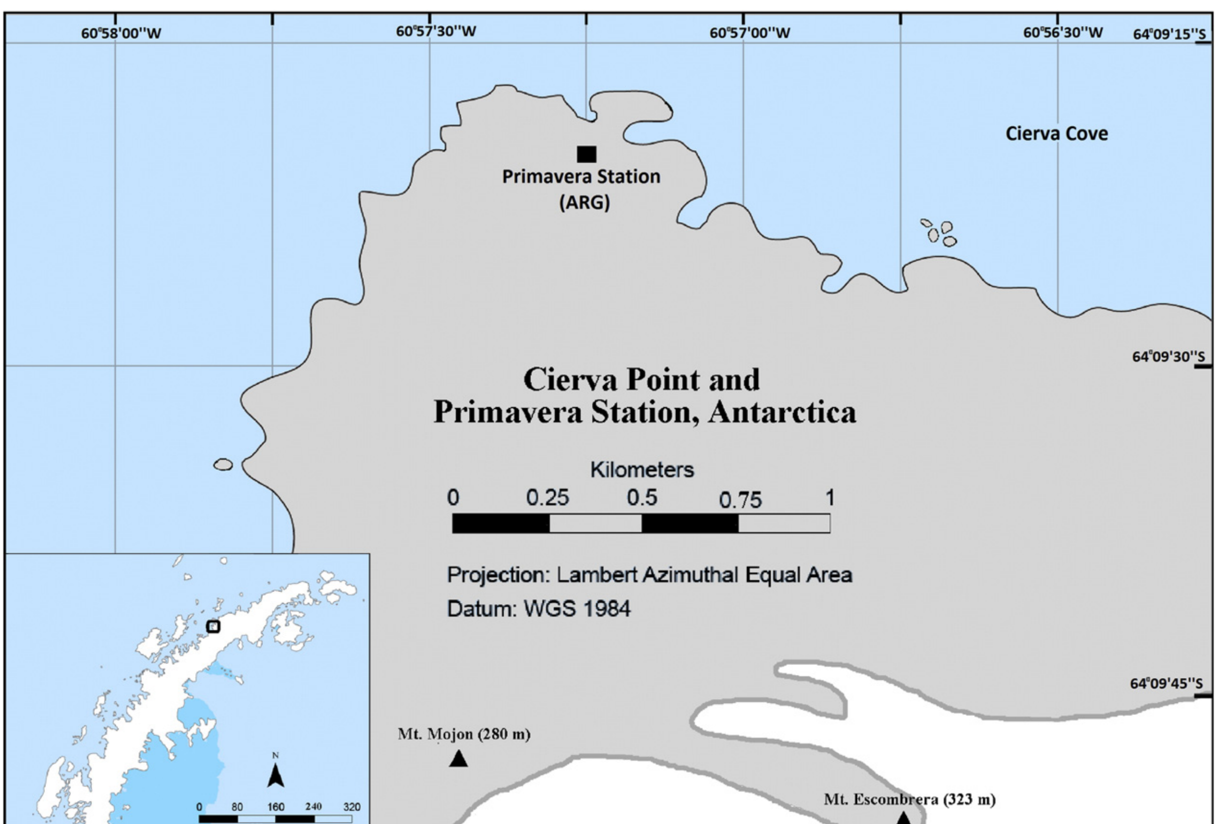


**Fig. 1.** Cierva Point Map. Modified from ASPA No. 134, 2013.