ARTICLE IN PRESS

Catena xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Genesis of a Holocene soil chronosequence from the southernmost Andes Mountains, Tierra del Fuego

Mariana M.F. Sá[a], Carlos E.G.R. Schaefer[b], James G. Bockheim[c], Diego C. Loureiro[d], Roberto F.M. Michel[e,*], Felipe N.B. Simas[b]

[a] Embrapa Agrobiologia, Rodovia BR-465, Km 7, Seropédica, RJ, Brazil
[b] INCT/Criosfera, Universidade Federal de Viçosa, Departamente de Solos, Av. PH Rolfs, Viçosa, MG, Brazil
[c] University of Wisconsin, 1525 Observatory Drive, Madison, USA
[d] Universidade Federal de Sergipe, Rua Cláudio Batista, s/n, Aracaju, SE, Brazil
[e] Universidade Estadual de Santa Cruz, Dep. De Ciências Agrárias e Ambientais, Rodovia Jorge Amado, km 16, Ilhéus, BA, Brazil

ARTICLE INFO

Keywords:
Soil development
Soil classification
Podsolization
Andisolization
Cordillera Darwin
Soil chronosequence

ABSTRACT

At the southernmost Andes Mountains, the Martial cirque glacier has retreated 2 km in distance and 500 m in elevation since the mid-Holocene. This study examines soil properties, processes, and classification in relation to soil age and elevation. Soils were sampled at elevations from 430 to 925 m a.s.l. on drifts periodically influenced by volcanic ash that represent five age classes: 5.0 to 6.0 kyr BP under deciduous *Nothofagus pumilio* forest; 1.3 to 3.2 kyr BP under *N. pumilio* and *N. antarctica* forest and tundra; 0.3 to 1.4 kyr BP under tundra; 0.3 Kyr BP CE under tundra; and 0.007 Kyr BP CE under scattered lichens and mosses. The soils represent a developmental sequence on metapellitic rocks ranging from: Cryorthents, Dystrocryepts, Humicryepts, and Humicryods. In general the soils contain abundant coarse fragments, sandy loam textures, and high levels of organic C. Clays have been altered in the soils from chlorite to a hydroxyl-interlayered vermiculite and ferrihydrite. The most developed soils are very strongly acid, Al saturated, and have illuvial horizons enriched in fulvic-acid C and organic-bound forms of free Fe and Al. The following properties are highly correlated with soil age: pyrophosphate soluble iron (Fe_p) in the B horizon (R^2 = 0.97), color-development equivalence in the B horizon (R^2 = 0.87), clay content of the B horizon (R^2 = 0.68), and fulvic-acid C in the B horizon (R^2 = 0.65). The results of this study imply that soil formation in magellanic subantarctic forests and tundra is rapid and involves podsolization, andisolization, and humification as primary soil-forming processes.

1. Introduction

Soil chronosequences decode spatial differences among soils into temporal differences (Huggett, 1998), comprehending genetically associated sets of soils evolved under similar conditions of parent material, vegetation, topography, and climate (Harden, 1982). Changes in soil properties through time reflect the pedogenetic development and the rate in which these processes take place, providing valuable information for testing theories of pedogenesis. Also, they are central to much soil–geomorphic research (Birkeland, 1990). Proglacial and periglacial areas frequently provide a good opportunity to observe pedogenetic development due to well-established date of exposure of the parent material. Mavris et al. (2010) found weathering trends that could be measured within only 150 yr of soil development, including physical and chemical weathering as well as mineral transformation occurring at high rates. Dümig et al. (2012) found increasing age after glacier retreat, organic carbon (OC) contents of clay fractions strongly increased resulting in lower mineral specific surface area and higher CECpH7. Thus, OC accumulation was faster than the supply of mineral surfaces by weathering.

Located in the southern-most Andes Mountains of Tierra del Fuego, the terminus of the Martial Glacier has retreated 2 km in distance and 500 m in elevation since the mid-Holocene (Planas et al., 2002; Strelin and Iturraspe, 2007), offering an excellent opportunity for studying changes in soil development in a sub-Antarctic environment periodically influenced by volcanic ash. Soil-forming processes in Tierra del Fuego are poorly understood, and the few published works generally describe properties and the broad distribution of soil taxa across the region (Frederiksen, 1988; Gutiérrez et al., 1991; Colmet-Daage et al., 1991; Nóvoa-Muñoz et al., 2008). Understanding early system soil evolution in a subantarctic environment is poorly constrained specially regarding soils with andic and spodic properties. A better

* Corresponding author.
E-mail address: roberto@michel.com (R.F.M. Michel).

https://doi.org/10.1016/j.catena.2017.11.002
Received 13 February 2017; Received in revised form 23 October 2017; Accepted 1 November 2017

understanding of age-related trends, elevation-related trends as well as dominant soil-forming processes in such a particular environment is relevant for soil science and can help understanding soil development as a whole.

Frederiksen's (1988) pioneering study employed GIS accompanied by ground truthing to examine soil-landscape relations in Tierra del Fuego. These soils often are shallow and enriched with organic matter (OM) at the surface, with the following order of abundance: Cambisols/Inceptisols > Chernozems/Mollisols > Spodosols > Andisols > Histosols > eutric Ultisols (del Valle, 1998). The deciduous temperate *Nothofagus* forests of Tierra del Fuego frequently are associated with Spodosols, non-allophanic Andosols/Andisols, and dystric Cambisols/Inceptisols (Mazzarino et al., 1998). Frederiksen (1988) and Colmet-Daage et al. (1991) also reported the presence of spodic and andic features properties in soils of Tierra del Fuego.

The purpose of this study is to examine the evolution of soil properties and soil-forming processes in a subantarctic environment, with an emphasis on time of exposure and elevation of soils with andic and spodic properties.

2. Materials and methods

2.1. Setting

The study was carried out in the Martial Glacier Valley (54°46′-54°48′S; 68°22′-68°25′W), on Isla Grande (Tierra del Fuego), Argentina (Fig. 1). Tierra del Fuego, encompasses a group of Islands separated by channels and straits from continental Patagonia, is located 1200 km from the Antarctic Peninsula. In this extreme part of the southern Andes, soils and vegetation vary strongly according to elevation. The Martial Glacier, part of the Darwin Cordillera, is located north of the city of Ushuaia. Due to its proximity to Ushuaia (~5 km), it is a field area for long-term glaciological monitoring (Strelin and Iturraspe, 2007). Meltwater from the glacier represents an important source of water for the city (Planas et al., 2002; Strelin and Iturraspe, 2007).

The Darwin Cordillera is composed of strongly folded Cretaceous metamorphic rocks, which form an east-west aligned mountain range (Strelin and Iturraspe, 2007). The metamorphic rocks of Cordillera Darwin are comprised of black shales with quartz veins, interbedded marine turbidites, and andesitic tuffs, known as the Yaghan Formation (Olivero and Martinioni, 2001). Common minerals in these rocks are: chlorite, sericite, quartz, albite, and epidote. The crest of the Andes is about 1000 m lower in the Ushuaia area than in the western portion of the Cordillera. The lower altitude and drier climate result in a smaller glaciated area than in the Chilean portion of the Cordillera (Strelin and Iturraspe, 2007).

The climate is cold oceanic, with strong southwest winds in late spring and early summer (Tuhkanen, 1992). The average annual temperature of Ushuaia is 5.5 °C, with an average of 1.6 °C in the coldest month (July) and 9.6 °C in the warmest month (January)

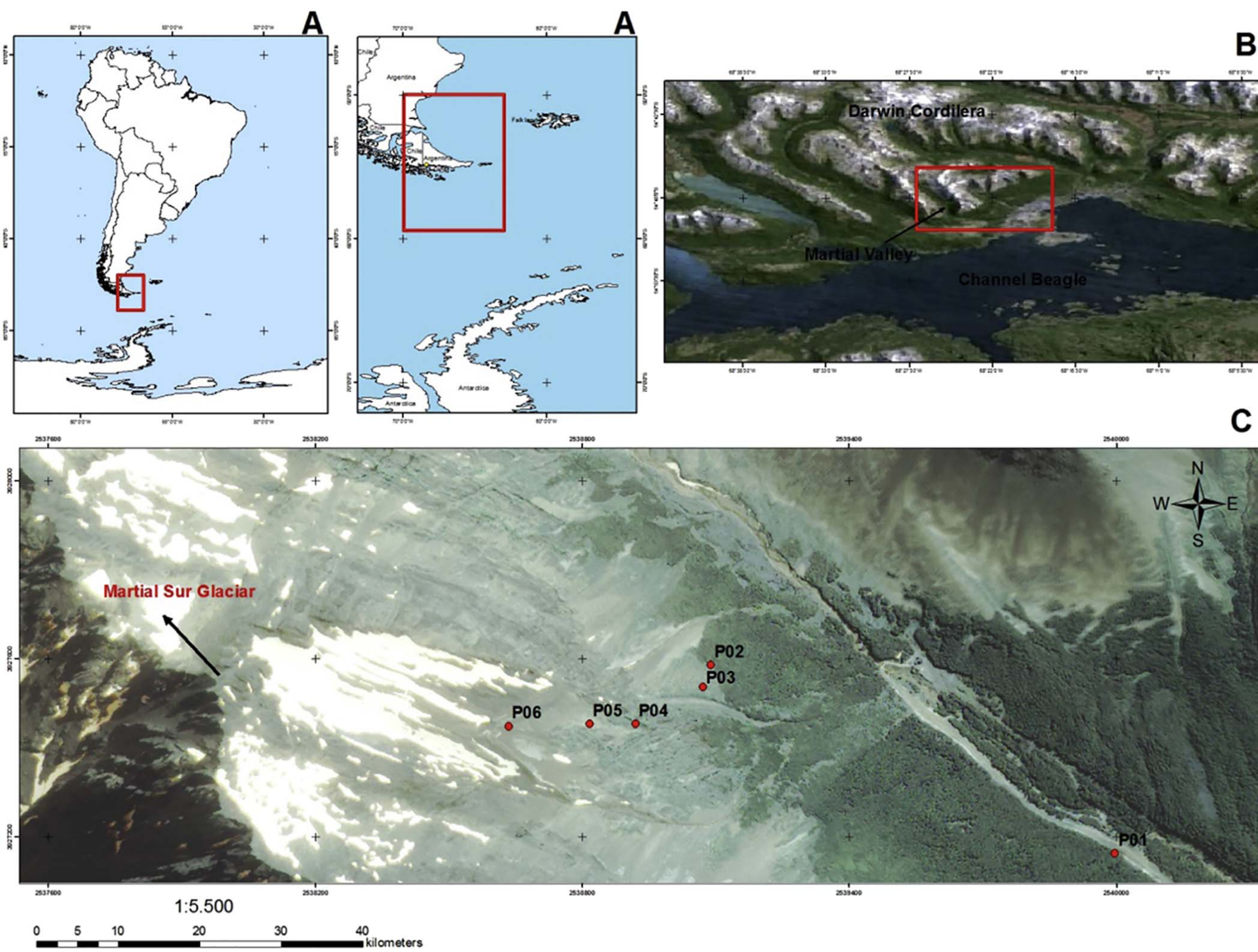

Fig. 1. Location of study area: A) The situation of Tierra del Fuego in South America and the Antarctica Peninsula; B) Martial Valley, in the Darwin Cordillera; C) Location of pedons in Martial Sur sector.