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Eocene paleosols on King George Island, Maritime Antarctica: Macromorphology, micromorphology and mineralogy

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ABSTRACT

We investigated the origin of reddish layers between basalt flows in an Early Eocene volcanic succession in King George Island, Maritime Antarctica. Previous studies in the area classified these layers as regolith surfaces, baked zones and paleosols, but the properties of these layers and the reasons for their classification are not clarified. Since the Early Eocene epoch was one of the warmest phases on Earth during the Cenozoic, a proper investigation of these layers is crucial to obtain additional regional information about the paleoenvironment.

The focus of this study is on three profiles located in the Admiralty Bay on King George Island. They were classified as paleosols based on field, micromorphological and mineralogical properties. Main soil forming processes identified by micromorphological analyses were clay neoformation, pedo-/bioturbation and a weak redoximorphosis. The occurrence of plant residues in all profiles was a reliable indicator that these soils formed a land surface during the Early Eocene. Abundant weathered volcanic glass and pyroclasts may indicate andosolization although the main diagnostic features for Andosols, which are the presence of nanocrystalline minerals and organic matter accumulation, were not detected or only in small amounts, respectively. The long-term burial of the paleosol could be a reason for lacking of these diagnostic features. Clay minerals associated with moderately weathered volcanic soils (smectite) were detected in the X-ray diffraction analysis. A predominantly reddish colour of most of the soil horizons is given by hematite, confirmed by the determination of pedogenic oxides. Nevertheless, rubification was not solely a result of pedogenesis but also of reddening of oxyhydroxides by dehydration during diagenesis. Other diagenetic processes were burial compaction, loss of organic matter and induration. In the horizons directly buried by a basalt flow, voids were filled by zeolite crystals, an effect related to lava cooling. Another possible diagenetic effect was the geochemical rejuvenation and homogenization of the profiles. Despite the occurrence of these features, the results are in agreement with previous studies, indicating a humid temperate paleoclimate for King George Island during the Early Eocene.

1. Introduction

Sequences of lava flows very often display alternating fine-textured red layers (partly weathered) and basaltic layers (unweathered). These red layers have a potential for paleoenvironmental reconstruction because they may indicate a hiatus in the volcanic activity combined with landscape stability and soil formation (Ghosh et al., 2006; Marques et al., 2014; Pietsch and Kühn, 2012; Sayyed et al., 2014; Sheldon, 2003; Shukla et al., 2014; Singer and Ben-Dor, 1987; Solleiro-Rebolledo et al., 2016). On the other hand, red layers can also be a product of other geological processes such as hydrothermal alteration (or “fritting”) (Gérard et al., 2006; Graef et al., 1997; Lange et al., 2002; Müller and Schwaighofer, 1979; Singer, 1970), pyroclast weathering (Emeleus et al., 1996; Widdowson et al., 1997) or sedimentation (Canile, 2010; Srivastava et al., 2012). In the latter cases the red layers do not represent periods of landscape stability and soil formation.

Red layers have been identified in an Early Eocene volcanic succession in King George Island (KGI), South Shetland Islands, Maritime Antarctica (Fig. 1). These layers have been labelled as regolith surfaces (Mozer, 2012), baked zones (Birkenmajer, 1980) and also as paleosols (Birkenmajer and Łydka, 1990). However, is not clear which properties were crucial for these authors to differentiate either paleosols, regoliths or baked zones. Where these were recognized as paleosols, only clay mineralogy was studied, showing a main composition of kaolinite and smectite (Birkenmajer and Łydka, 1990), despite the importance of

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paleosols for paleoclimate interpretation (e.g. Kühn et al., 2013; Schatz et al., 2015; Sheldon and Tabor, 2009).

The major importance of detailed studies of these red layers in King George Island is because they were formed during the Early Eocene, which was one of the warmest periods on Earth during the Cenozoic when climatic differences between the equator and the poles were much smaller than today (Bijl et al., 2009; Greenwood and Wing, 1995; Pearson et al., 2009). There is evidence for near-tropical paleoclimate in Antarctica with frost-free winters despite the polar darkness (Pross et al., 2012; Dingle and Lavelle, 1998). A cool temperate forest similar to the Valdivia Forests, Southern Chile, is often considered the best modern analogue environment in particular for the Antarctica Peninsula (Francis et al., 2009; Mozer, 2012; Poole et al., 2003).

Because no detailed studies of the red layers on KGI have been carried out so far, a proper genetic interpretation is crucial. For this reason, certain criteria must be adopted to recognize paleosols. The main properties to be identified in the field are the presence of root traces, soil horizons and soil structure (Retallack, 1988). Based on thin section analysis, Fedoroff et al. (2010) listed the following micromorphological features formed only by in situ pedogenesis: undisturbed biological activity features such as passage features and channels, pedogenic microstructures, pedogenic b-fabrics and one or more types of undisturbed pedofeatures. Most importantly, however, is the combination of physical properties, micromorphological characteristics and other properties and how they behave in a depth function within a vertical profile (Fenwick, 1985).

The hypotheses of this study are: (i) the Eocene red layers in KGI are paleosols formed during periods of lower or no volcanic activity, and (ii) these paleosols are suitable proxies for paleoenvironmental reconstruction.

Our main objective to test the first hypothesis is to identify the main pedogenic properties and features. To test the second hypothesis, the objective is to identify the diagenetic features because they can eventually interfere with the paleoenvironmental record. In this work, we attribute to diagenesis those features formed after the burial of the paleosols, either by effect of the lava flow or due to long-term burial.

2. Material and methods

2.1. Site description

The samples were collected on King George Island, South Shetland Islands, Maritime Antarctica. The specific outcrop is located in the Cytadela area of the Ezcurra Inlet in the Admiralty Bay (62° 11.057′S–58° 35.209′W) (Fig. 1).

The deposits in the outcrop stratigraphically belong to the Point Thomas Formation, Ezcurra Inlet Group, which comprises a 500 m thick Paleogene (Eocene-Oligocene) volcanic succession (Birkenmajer, 1980; Birkenmajer and Zastawniak, 1989). This formation was deposited during the Arctowski interglacial period (ca 50 to ca 32 Ma), a climostratigraphic unit introduced by Birkenmajer (1988).

Two informal units of the Point Thomas Formation are recognized at the Cytadela, the Lower Member (LM) and Upper Member (UM) (Birkenmajer, 1980). The LM is a 20–40 m thick regular high-Al flow basalt with a thickness of 1–6 m alternating with pyroclastic deposits. The LM corresponds to the Early Eocene humid temperate climate, similar to the present-day Chilean Valdivia Forest (Mozer, 2012). The UM comprises 150–450 m of irregular, lenticular basalt lavas alternating with feldspathic tuff, interbedded with coarse vent breccia and plant-bearing tuff.

There is no dating information for the sampled basalts. Accordingly to Mozer (2012) these layers were deposited in the Early Eocene. Radiometric dating (K/Ar) of basalts of Point Thomas Formation on nearby locations gave an oldest age of 49 Ma (Nawrocki et al., 2011) and youngest of 41 Ma (Birkenmajer et al., 2005).

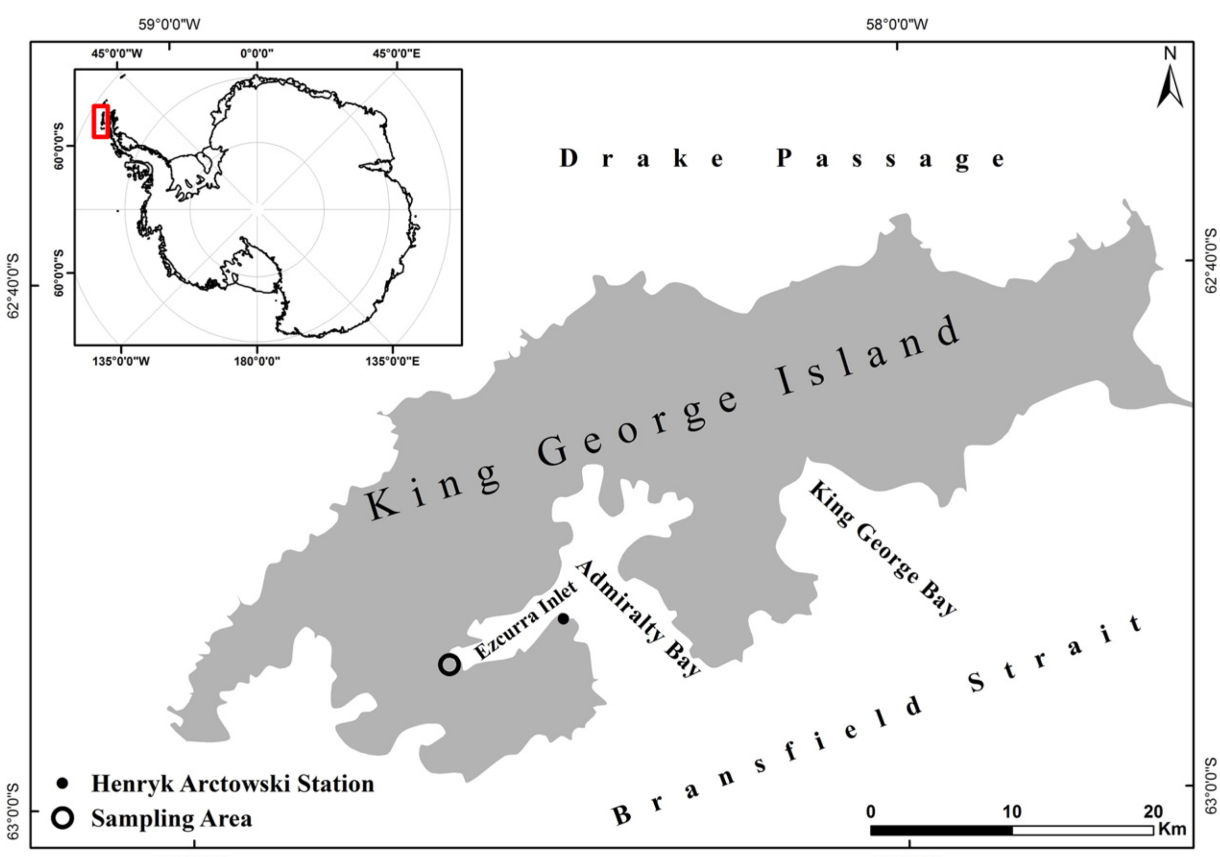

Fig. 1. Location of the sampling site at the King George Island.