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Geomorphology and weathering characteristics of erratic boulder trains on Tierra del Fuego, southernmost South America: Implications for dating of glacial deposits

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ABSTRACT

Erratic boulder trains (EBTs) are a useful glacial geomorphological feature because they reveal former ice flow trajectories and can be targeted for cosmogenic nuclide exposure dating. However, understanding how they are transported and deposited is important because this has implications for palaeoglaciological reconstructions and the pre-exposure and/or erosion of the boulders. In this study, we review previous work on EBTs, which indicates that they may form subglacially or supraglacially but that large angular boulders transported long distances generally reflect supraglacial transport. We then report detailed observations of EBTs from Tierra del Fuego, southernmost South America, where their characteristics provide a useful framework for the interpretation of previously published cosmogenic nuclide exposure dates. We present the first comprehensive map of the EBTs and analyse their spatial distribution, size, and physical appearance. Results suggest that they were produced by one or more supraglacial rock avalanches in the Cordillera Darwin and were then transported supraglacially for 100 s of kilometres before being deposited. Rock surface weathering analysis shows no significant difference in the weathering characteristics of a sequence of EBTs, previously hypothesized to be of significantly different age (i.e., different glacial cycles). We interpret this to indicate that the EBTs are much closer in age than previous work has implied. This emphasises the importance of understanding EBT formation when using them for cosmogenic nuclide exposure dating.

1. Introduction

Erratic boulder trains (EBTs) are a poorly understood glacial geomorphological feature. These linear clusters of erratic boulders record the flow lines of former glaciers by pinpointing the parent rock from which they have originated (Kujansuu and Saarnisto, 1990; Evans, 2007) and have frequently been targeted for cosmogenic nuclide exposure dating (Jackson et al., 1997, 1999; McCulloch et al., 2005; Kaplan et al., 2007, 2008; Ward et al., 2007; Evenson et al., 2009; Vincent et al., 2010; Wilson et al., 2012). Consequently, they offer a valuable tool for reconstructing the nature and timing of former glacial advances.

Despite their importance to palaeoglaciology, these features are rarely reported in detail, and understanding their formation will help contextualise dating studies. This paper brings together previous literature on EBTs to assess how they form and presents detailed observations of examples from Tierra del Fuego, southernmost South America. The Tierra del Fuego EBTs make an excellent case study because they are well preserved and easily distinguishable. They have also been investigated using cosmogenic nuclide exposure dating, but the resultant ages can be interpreted in two quite different ways (McCulloch et al., 2005; Kaplan et al., 2007, 2008; Evenson et al., 2009). This study aims to test between these two opposing hypotheses by combining spatial and volumetric measurements with weathering proxies to gain a better understanding of EBT formation. In this way, we test the interpretation of cosmogenic nuclide exposure dates.

2. Definition and previous work on erratic boulder trains

The EBTs are a subset of dispersal trains, which includes any dispersal of a particular lithology by former ice flow (DiLabio, 1981, 1990; Dyke and Morris, 1988; Evans, 2007). However, whilst EBTs are linear clusters of boulders, other dispersal trains are not necessarily linear or clustered and can include a wide range of grain sizes, surficial and within glacial deposits. Given the lack of any previous compilation in the literature, we begin by providing a brief review of the limited number of detailed studies of EBTs, summarised in Fig. 1 and Table 1, focusing on their formation and dating. Likely other EBTs exist, but they are rarely reported in the literature and are often only given cursory mention in wider studies.

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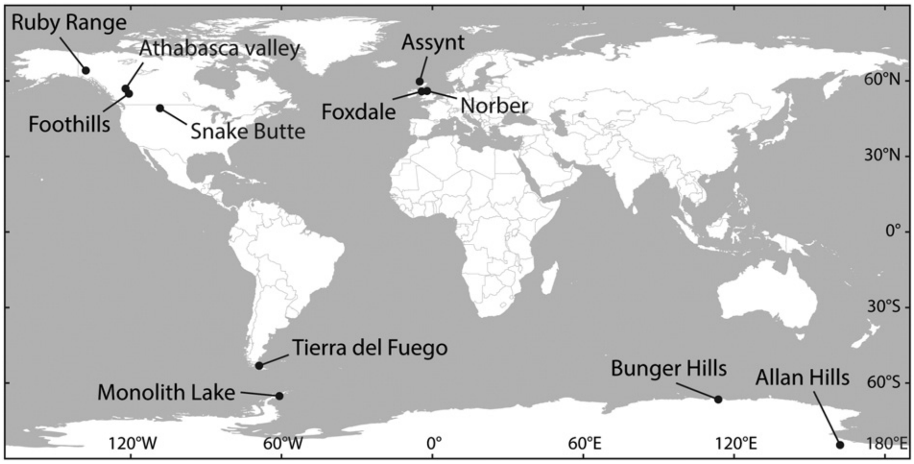

Fig. 1. Map showing the locations of erratic boulder trains reviewed in this paper (see Section 2).

2.1. Formation: subglacial versus supraglacial

No single model for the formation of EBTs exists, and it is possible that they can be formed in a variety of ways. This is not surprising given the reported variety in boulder size, train length, number of boulders, transport distance, and lithology (Table 1). Two hypotheses prevail: (i) subglacial entrainment and (ii) supraglacial debris.

The Norber EBT in England, Foxdale EBTs on the Isle of Man, Bunger Hills EBT and Allan Hills EBT in Antarctica, and Snake Butte EBT in the USA (see Fig. 1 and Table 1) are all interpreted to have formed subglacially. The Norber boulders have been transported laterally more than 1 km and 120 m vertically upward from their source lithology (Huddart, 2002; Wilson et al., 2012). Given that the ice flowed over the source outcrop (Vincent et al., 2010), we suggest that subglacial transport of the boulders is most probable (though the formation mechanism has not been investigated further). The two Foxdale boulder trains were interpreted to have been initially transported and deposited subglacially by ice flowing southeastward, but with subsequent ice flowing southwestward and dispersing the larger train subglacially across a broader area of the southern part of the island (Roberts et al., 2007). In the Bunger Hills, Augustinus et al. (1997) suggested that a lack of glacial polish or facetting on the boulders implied subglacial transport over only a very short distance, thereby explaining the limited extent of the EBT. Likewise, Atkins et al. (2002) considered the boulders of the Allan Hills EBT to have been eroded by plucking of the Beacon sandstone bedrock prior to subglacial dragging and deposition on the stoss side of a bedrock ridge. Knechtel (1942) suggested that striations and polished surfaces of boulders of the Snake Butte EBT resulted from transport at the base of ice flowing southeastward and that they were then deposited with ground moraine.

Table 1
Summary of the key characteristics of EBTs based on a review of the literature (NR = not reported).

EBT name	Location	Length of train(s)	Max. distance from source	Boulder diameter	Lithology	Suggested transport pathway	CNE dated?	Age	References
Foothills	Canada	>580 km	>580 km	1–41 m	Quartzite and pebbly quartzite	Supraglacial	^{36}Cl	18–12ka	Stalker (1956); Mountjoy (1958); Stalker (1976); Jackson et al. (1997); Jackson et al. (1999); Jackson and Little (2004)
Athabasca valley	Canada	ca. 70 km	ca. 120 km	Up to 1 m	Metamorphic schist	Supraglacial	–	–	Roed et al. (1967)
Ruby Range	Canada	ca. 5 km	ca. 5 km	Some >1.5 m	NR	NR	^{10}Be	54–51 ka	Ward et al. (2007)
Snake Butte	USA	ca. 79 km	ca. 80 km	Up to 23 m	Shonkinite	Subglacial?	–	–	Knechtel (1942)
Assynt	Scotland	9–14 km (4 trains)	>9 km	NR	Sandstone	NR	–	–	Lawson (1990); Lawson (1995)
Norber	England	>1 km	>1 km	Up to 4 m	Greywacke	Likely subglacial over a short distance	^{36}Cl	22–17 ka	Davis (1880); Goldie (2005); Huddart (2002); Vincent et al. (2010); Wilson et al. (2012)
Foxdale	Isle of Man	Up to 1 km	≤2 km	Up to 1 m	Granite	Subglacial	–	–	Roberts et al. (2007); Roberts (*pers. comm.*)
Bunger Hills	Antarctica	Up to 4 km?	≤4 km	NR	Dolerite	Subglacial but only a short distance	–	–	Adamson and Colhoun (1992); Augustinus et al. (1997)
Allan Hills	Antarctica	Up to 3 km?	≤3 km	Up to 3 m	Sandstone	Subglacial	–	–	Atkins et al. (2002)
Monolith Lake	Antarctica	ca. 9 km	ca. 12 km	Up to 5 m	Hyaloclastite	Likely supraglacial	–	–	Davies et al. (2013)
Tierra del Fuego	Chile/Argentina	4–15 km (4 trains) 95 km total	ca. 250 km	Up to 21 m	Granodiorite	Supraglacial	^{10}Be ^{26}Al ^{36}Cl	222–15 ka	Darwin (1841); Meglioli (1992); Coronato et al. (1999); Bentley et al. (2005); McCulloch et al. (2005); Kaplan et al. (2007); Kaplan et al. (2008); Evenson et al. (2009); This study