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Evidence for slow late-glacial ice retreat in the upper Rangitata Valley, South Island, New Zealand

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ABSTRACT

A suite of cosmogenic radionuclide ages taken from boulders on lateral and latero-terminal moraines in the Rangitata Valley, eastern South Island, New Zealand demonstrates that relatively thick ice occupied valley reaches inland of the Rangitata Gorge until c. 21 ka. Thereafter ice began to thin, and by c. 17 ka it had retreated 33 km up-valley of the Rangitata Gorge to the Butler-Brabazon Downs, a structurally created basin in the upper Rangitata Valley. Despite its magnitude, this retreat represents a minor ice volume reduction from 21 ka to 17 ka, and numerous lateral moraines preserved suggest a relatively gradual retreat over that 4 ka period. In contrast to records from adjacent valleys, there is no evidence for an ice-collapse at c. 18 ka. We argue that the Rangitata record constitutes a more direct record of glacial response to deglacial climate than other records where glacial dynamics were influenced by proglacial lake development, such as the Rakaia Valley to the North and the major valleys in the Mackenzie Basin to the south-west. Our data supports the concept of a gradual warming during the early deglaciation in the South Island New Zealand.

1. Introduction

The extensive moraine records of mid-latitude glacial systems are established archives for understanding regional climate change forcings via atmospheric (greenhouse gas and/or dynamics), oceanic (thermohaline) and global hemispheric climate teleconnections during the last glaciations (e.g. Turney et al., 2007). They also hold the key to testing the southern hemisphere westerly wind carbon cycling hypothesis (Toggweiler et al., 2006) and indeed, the late-glacial records from New Zealand have been specifically argued to respond to these changes (e.g. Putnam et al., 2010a). Detailed glacial records are available from New Zealand and southern South America in the southern mid-latitudes (e.g. Kaplan et al., 2008; Hein et al., 2010; Putnam et al., 2013; Rother et al., 2014) but despite the availability of extensive cosmogenic chronologies (Darvill et al., 2016) the nature of their transitions from the last glacial maximum (LGM) to the present interglacial remains contested, at least in New Zealand (Shulmeister et al., 2010a; Putnam et al., 2013; Barrell and Read, 2014; Shulmeister, 2017; Koffman et al., 2017).

A key widely held interpretation of last glacial-interglacial transition chronologies from the South Island New Zealand is that the transition out of the LGM was marked by an abrupt warming (Schaefer et al., 2006) and though the calculated timing of the warming has shifted as the local production rate of 10Be (which controls absolute dating with cosmogenic ages) has been refined (i.e. Putnam et al., 2010b) the concept of an abrupt warming persists in the literature (Putnam et al., 2013; Barrell and Read, 2014). The implications of this interpretation are important because it implies an initial major glacial collapse and retreat which is the result of a rapid climate transition (warming) at the end of the LGM that is followed by a significant re-advance during the Antarctic Cold Reversal (ACR, 14.8–13.5 ka, e.g. Putnam et al., 2010a).

An alternative viewpoint has been presented in Shulmeister

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et al. (2010a) and Rother et al. (2014). They argued that the post-LGM to Holocene retreat of the South Island glaciers could be explained as a response to monotonic warming, with the variations in the behaviour of individual glaciers a function of valley morphology and glacier geometry, and particularly the impact of the formation of large, persistent, pro-glacial lakes in many valleys creating calving margins during the deglaciation. Resolving these divergent interpretations is important for comparative palaeoclimatic analysis of southern and northern hemisphere LGM/deglaciation chronologies and their respective proposed triggers. A key consideration is what happened in the three millennia preceding the ACR? Was it a period of very rapid retreat to well behind ACR glacial limits or a more gradual retreat to a still stand at or near the ACR limits? What was, the influence of local topography and glacier geometry on the deglacial pattern and its timing?

The idea of abrupt warming at the end of the LGM (here defined as 26–19 ka – Clark et al., 2009) has some support in the paleoecology literature of the North Island of New Zealand with evidence for rapid warming and a return to near full interglacial conditions by c. 16 ka (e.g. Alloway et al., 2007). In contrast, for South Island, however, the return to full interglacial conditions are long delayed with tall forest returning as late as 10–9 ka in Otago and Fiordland in the far south (e.g. McGlone and Wilmshurst, 1999). A late glacial reversal during the ACR is observed in both North (e.g. Pepper et al., 2004) and South Islands (e.g. Vandergoes et al., 2008) but the duration and scale of the reversal varies between records (e.g. Pedro et al., 2015).

Consequently, despite the intensive geochronological work on New Zealand glacial moraines there are still major questions to be answered about the termination of the last glaciation. The morphology of the major valleys, with troughs occupied by lakes and bedrock gorges that are scoured by post-glacial rivers, has severely limited the preservation of cross-valley glacial moraine sequences of deglacial age and this is one of the primary reasons why this interval remains relatively poorly described. This paper focusses on glacial deposits preserved intact, in a fault controlled intra-montane basin that has created a wide valley reach, in the upper Rangitata Valley (Fig. 1); a major river valley which drains the Alps of South Island eastward across the Canterbury Plains. Using both detailed geomorphic mapping of glacial features including lateral moraines, kames and kame terraces and a suite of cosmogenic exposure ages, we provide further evidence to support the idea of a slow late-glacial ice retreat during the deglaciation phase with a minor hiatus in retreat during the ACR.

1.1. Site description

The Rangitata Valley is the southernmost of the major river valleys that constructed the Canterbury Plains (Fig. 1b). Its headwaters lie immediately east of the Main Divide along the highest peaks of the Southern Alps and close to the centre of modern glacial activity around Aoraki/Mt Cook, including the Tasman/Pukaki Glacier where a cosmogenic radionuclide (CRN) chronology was derived that generated the ‘rapid deglaciation’ hypothesis (Schaefer et al., 2006). Similar to the other major valleys draining the Southern Alps, the Rangitata hosted a major outlet valley glacier during the late Quaternary (Mabin, 1980) and is one of the few remaining Canterbury valleys where terminal moraines down-valley of the Rangitata Gorge (Fig. 1) have not been directly dated. However, by extrapolation based on ages from the Clearwater Lobe of the Rangitata glacier that spilled into the Ashburton Basin (Rother et al., 2014), ice was beyond the gorge at 28 ka and at, or close to, the gorge at 21 ka.

Our study area lies 20–33 km upstream of the Rangitata Gorge (Fig. 1b) in a tectonic basin generated by long-term movement of the Forest Creek Fault (Upton et al., 2004). The basin is occupied on its western side by broad, gently sloping valley hillslopes called the Butler and Brabazon Downs (hereafter referred to as the Butler-Brabazon Downs (BBD)) (Fig. 1) that are elevated 20–400 m above the modern floor of the braided Rangitata River (see Fig. 1c). The BBD contain well preserved glacial features including suites of kame terraces, stagnant-ice topography and lateral and termino-lateral moraines (Fig. 2). This valley widening is located 18 km up-valley from the mouth of the Rangitata Gorge (Borsellino et al., 2017) which has been interpreted to be the LGM ice limit (Mabin, 1980). As such the BBD were identified as a prime location to examine a deglaciation chronology from the Late Otiran Rangitata valley glacier.

The Rangitata Valley extends 11 km further upstream of the BBD to the junction of the Havelock and Clyde Rivers, where it ceases to be known as the Rangitata River. We consequently call the area between the BBD and the junction with the Havelock and Clyde Rivers, the upper Rangitata Valley. The Havelock and the Clyde Rivers and their tributaries extend a further 20–30 km into the Southern Alps and currently have small glaciers in their upper catchments. The Potts River enters the upper Rangitata Valley from the east, opposite the Brabazon Downs (Fig. 1c). During the last glaciation, ice from the Rangitata Valley overtopped the eastern valley side at the Potts entrance and flowed SE-ward into the Ashburton Basin along a smaller valley occupied by Lake Clearwater (hence the Clearwater Lobe), here termed the Clearwater Valley (Fig. 1c).

As described above, the relationship between moraine formation in the Clearwater basin and the main Rangitata Valley are important for reconstructing the timing and style of deglaciation of the Rangiata Valley and testing hypotheses about the occurrence of abrupt glacial retreat at the end of the LGM in response to warming.

2. Methods

Methods involved field mapping, geomorphic assessment and Beryllium-10 in-situ cosmogenic radionuclide dating of boulders. We mapped in the glacial geomorphology of the BBD in detail (Borsellino et al., 2017) and identified moraine ridges, kame terraces, glacial meltwater channels and post glacial drainage systems in the region (Fig. 2). In addition we availed of stratigraphic information from four key sites constrained by luminescence ages from the BBD (Shulmeister et al., 2018). The chrono-stratigraphy from these sites show that the BBD have thick packages of marine isotope stage (MIS)-4 through MIS-2 glacial and paraglacial sediments, but only sediments in the top metre, or so, relate to the surface geomorphology. This disconnect between surface morphology and underlying glacigenic sediments has been observed in other Canterbury valleys (e.g. Shulmeister et al., 2010b).

A total of 23 samples for 10Be surface exposure dating were collected from the upper surface of boulders ranging from 0.5 to 3.0 m in height above local ground level from moraine ridges on the Butler and Brabazon Downs. These locations are displayed in Fig. 2 and example boulders are displayed in four data sets. 1. A photographic archive of a selection of boulders used for CRN dating in the Rangitata. 2. CRONUS output for Rangitata CRN samples 3. CRONUS input file for CRN ages (https://doi.org/10.17632/t74n5p4b9y.1). Boulders are concentrated in limited areas of the BBD. The distribution of sampled boulders is largely reflective of farming related field clearances of boulders than natural differences in the occurrence of boulders across the Downs.

Individual greywacke boulders were examined visually and tested using a mechanical N-type Schmidt-hammer (Proceq, 2004) to select representative samples. Measurements for the horizon