Quaternary International xxx (2017) 1–14

Contents lists available at ScienceDirect

Quaternary International

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

Reconstruction and paleoclimatic significance of late Quaternary glaciers in the Tararua Range, North Island, New Zealand

Martin S. Brook [a, *], Martin P. Kirkbride [b]

[a] School of Environment, The University of Auckland, Auckland, 1142, New Zealand
[b] Geography, School of Social Sciences, University of Dundee, Dundee, DD1 4HN, UK

A R T I C L E I N F O

Article history:
Received 7 April 2017
Received in revised form
25 July 2017
Accepted 13 October 2017
Available online xxx

Keywords:
Niche glaciation
Southern mid-latitudes
Glacier reconstruction
Tararua range
New Zealand

A B S T R A C T

Reconstructed mountain glaciers are routinely used as a proxy for climate in the search for evidence of interhemispheric climate fluctuations during the Quaternary. In New Zealand, valley glaciers at the Last Glacial Maximum (LGM) extended from an ice sheet centred on New Zealand's Southern Alps to below present-day sea level. In contrast, evidence of LGM glacial activity on the North Island is rare. Here, a glacioclimatic reconstruction is presented of two former glaciers in the Tararua Range (41°S) in the southern North Island. At Mt. Aston, an isolated cirque basin contains landform evidence of a marginal niche glacier. At Park Valley, the lateral moraine of a larger cirque glacier has yielded published cosmogenic isotope ages. The paleoglacier reconstruction shows that paleoequilibrium line altitudes increased northwards across New Zealand during the local LGM. Hence, at this latitude only topography >1200 m above present day sea-level was of sufficient elevation to allow small glaciers to form. The Mt Aston glacier covered only 0.18 km^2 with an equilibrium line altitude (ELA) of *c.* 1287 m above present sea level. A mean ELA glacier thickness of *c.* 25 m gives a basal shear stress at the ELA of *c.* 100 kPa^{-1}, with a mean summer (December, January, February, DJF) temperature at the ELA of no lower than 5.5 °C below present, below which precipitation would have been insufficient to support the reconstructed glacier. Implied LGM paleo-temperatures from both the ELA reconstruction and the glaciological reconstruction broadly accord with other paleo-temperature proxies from the North Island. Park Valley glacier covered *c.* 0.45 km^2 with an ELA of *c.* 1270 m and a mean ELA basal shear stress of 65 kPa. Its balance discharge was 9 × greater than at Mt Aston. It appears to have been glaciologically viable across a wide range of paleotemperatures: thus, the more marginal glacier is a more useful paleoclimatic indicator because it places a maximum limit on LGM temperature depression, which the larger glacier does not. ELAs of both glaciers closely approximate the regional LGM ELA trend surface. The paleo-glacier reconstructions imply that together with temperature driving LGM paleo-ELA depression, changes in south-westerly airflow over New Zealand, bringing moisture-laden but cool air, maximized snowfall and minimised winter melt. The corollary is that patterns of Quaternary glacier fluctuations may be interpreted as responses, at least in-part, to precipitation-driven changes, and secondly, North Island glaciation was probably more extensive than previously assumed.

1. Introduction

Explaining the growth and decay of glaciers during the late Quaternary in the Southern Hemisphere remains an unresolved question, especially during the last glacial cycle. New Zealand is one of the few locations in the Southern Hemisphere where a range of paleoclimatic records are available, and a range of proxy records indicate that climate was influenced by the interaction of oceanic, cryospheric and atmospheric factors (Barrell et al., 2013). The strong topographic and climatic control on glacial activity on both the South and North Islands currently allows glaciers to form between 39° and 46° S latitude (Purdie et al., 2014; Eaves et al., 2016a). Geological evidence has often been used to record and infer the distribution of former glaciation during the (*c.* 30-18 ka) New Zealand “Last Glacial Cold Period” (LGCP; Barrell et al., 2013), which coincides with the global Last Glacial Maximum (LGM). Along with other proxy records, this has led to marked spatial differences in terrestrial LGM temperature reconstructions,

* Corresponding author.
E-mail address: m.brook@auckland.ac.nz (M.S. Brook).

https://doi.org/10.1016/j.quaint.2017.10.018
1040-6182/

from +0.5 to −9 °C (summarised in McKinnon et al., 2012). Much of this work is limited to the South Island, where large valley glaciers extended out from a small ice sheet formed along the axis of the Southern Alps (Porter, 1975; Doughty et al., 2013; Putnam et al., 2013). In contrast, on the North Island, terrestrial evidence for former glaciation is much less obvious, and appears to have been limited to volcanoes (Mathews, 1967; McArthur and Shepherd, 1990; Eaves et al., 2016b) and the Tararua Range on the southern North Island (Brook and Brock, 2005; Brook et al., 2005, 2008; Brook and Crow, 2008; Brook, 2009). Indeed, while quantitative reconstructions of paleoclimate (namely temperature and precipitation) during the LGM based on glacier fluctuations have shown some consistency across the South Island, independent estimates of paleoclimatic variables based on evidence from North Island glaciers are extremely rare (Brook et al., 2008; Eaves et al., 2016a,b). While the equilibrium line altitude (ELA) reconstructions and paleoclimate modelling from Eaves et al. (2016b), is a valuable additional dataset, effects of effusive volcanism and post-glacial flank collapse on the North island volcanoes hamper the delineation of glacial-geomorphic landforms, making ELA reconstructions problematic (Donoghue et al., 1997).

The forcing factors behind southern mid-latitude glaciation during the last glacial cycle are ambiguous, with insolation appearing to not be the sole factor controlling Southern Hemisphere climate change (Doughty et al., 2015). Indeed, recent work (Darvill et al., 2016) has highlighted that glacier expansion was broadly synchronous between New Zealand and Patagonia, and that climate forcing was related to an equatorward shift in the moisture-bearing south-westerly winds and oceanic fronts. Within New Zealand, the topography, maritime mid-latitude position and high precipitation gradients across the landmass mean that glaciers are highly sensitive to climate changes. Indeed, current glaciers in the Southern Alps, are particular sensitive to climate change with estimates of the mass balance sensitivity at between 1.3 and 2.0 m we K^{-1} (Anderson et al., 2010). High annual precipitation rates in some catchments of >12 m a^{-1} leads to mass balance response at the termini of some valley glaciers of less than a decade (Purdie et al., 2014). Nevertheless, current ELAs across the Southern Alps vary markedly, from around 1500 m in the south and west, to 2500 m in the east in the Kaikoura Range (Lamont et al., 1999; Bacon et al., 2001). Moreover, on the North Island, current ELAs on Mt Ruapehu are much higher, close to the summit altitude (2797 m; Brook et al., 2011). Thus, large spatial variabilities in current ELAs occur, with paleo-ELAs depressed by *c.* 1000 m, thought to indicate *c.* 6–6.5 °C of temperature depression, although the effects of precipitation on mass balance and ELA depressions remain debatable (Shulmeister et al., 2004, 2010). Hence, resolving the magnitude of late Quaternary glacier fluctuations outside of the Southern Alps, and identifying other established formerly glaciated sites on the North Island will provide insights into the prevailing climatic gradients during the LGM.

Here, we report evidence of two cirque glaciers in the southern Tararua Range (40°55′S, 175°18′ E). Below the summit of Aston (1376 m a.s.l.) a shallow cirque basin lies ~25 km south of established former glacial sites further north in the Tararua Range (Brook and Brock, 2005; Brook et al., 2005, 2008; Brook, 2009). Among the latter, the well-documented Park Valley moraine forms the basis for a second glacier-climate reconstruction. In contrast to the established Park Valley glacial site, evidence for former glaciation at the Aston basin is more tentative. The aims of this research are to: (1) present geomorphological evidence supporting late Quaternary glaciation of the Mt Aston basin; (2) reconstruct the glaciological and paleoclimatic environments that would have led to glaciation of the Aston and Park Valley cirques; (3) examine paleoclimatic implications of glaciation during the LGM in the southern North Island of New Zealand.

2. Study area

The currently glacier-free Tararua Range is part of the axial ranges of the North Island, which are oriented north-south along the Australian-Pacific convergent plate margin (Stratford and Stern, 2006). The Tararua Range is a relatively young, deeply entrenched mountain range, a result of major faulting and folding, and in some places still active uplift (Nicol and Beavan, 2003). Bedrock is composed of quartzo-feldspathic metasediments of the Torlesse Terrane (Begg and Johnston, 2000). The Tararua Range summit altitudes are much lower (*c.* 1500 m a.s.l.) and northward of the Southern Alps, so late Quaternary glaciation was much more restricted, with only six cirque and valley glacier sites previously mapped (Adkin, 1911; Brook and Brock, 2005). Cosmogenic radionuclide exposure (CRNE) ages of the timing of glaciation in Park Valley (Fig. 1) indicate that glaciation in the Tararua Range terminated around 18 ka (Brook et al., 2008), coinciding with the global LGM. This termination also accords with the synthesis of late Quaternary New Zealand paleoclimate of Alloway et al. (2007), as well as the recent CRNE ages of moraine boulders from Mt Ruapehu in the central North Island (Eaves et al., 2016a).

The Tararua Range (Figs. 1 and 2) is one of the wettest locations in New Zealand, with mean annual precipitation (1972–2013) exceeding 4000 m a^{-1} (Chappell, 2014). Mean annual temperatures at Kaitoke (223 m a.s.l.), 15 km to the southwest of the Aston basin are 15.3 °C (Chappell, 2014). The Aston basin (40°58′13.15″S, 175°15′52.49″E) is the only valley head in the immediate vicinity with the glacial characteristics of a cirque (Evans and Cox, 1995; Barr and Spagnolo, 2015). It forms a bowl-shaped hollow, with exposed bedrock, perched above an upper tributary of the Tauherenikau River (Fig. 2). The basin lies to the east below the Dress Circle ridgeline (Fig. 3), which is part of the Southern Crossing hiking route across the Tararua Range. The basin is bounded to the south by the Aston summit (1376 m), with the backwall and sides vegetated by tussock.

Park Valley (40°45′0.29″S, 175°25′44.65″E) is an impressive southwest-facing valley (Figs. 4 and 5), U-shaped in its uppermost section (Brook et al., 2005), indicative of glacial erosion. The adjacent summits surrounding the valley head rise to *c.* 1500 m. The head of Park Valley is composed of two cirque-like basins, feeding into the larger U-shaped valley, with a lateral moraine formed on the true right of the valley at the lip of the westernmost cirque. The distal end of the moraine is truncated by erosion, and ends *c.* 70 m above the valley floor. This is the only established moraine in the Tararua Range (Brook and Crow, 2008), and allows accurate constraining of the former extent of the Park Valley glacier. Hence, the Park Valley paleoglacier extent is used here as a comparison with the Mt Aston cirque climate reconstructions.

3. Methods

3.1. Geomorphology

Geomorphological mapping of the basin and surrounding slopes was undertaken using an enlarged 1:50,000 Land Information New Zealand (LINZ) topographic base map ("TOPO 50") overlain on a LINZ aerial image at a scale of 1:5,000, using established methods (Harrison et al., 2015). Landforms and landform assemblages mapped include in situ rock, moraine ridges, slope failure scarps, and small debris flows from mobilisation of weathered soils (Figs. 3 and 5). Interpretation was also focused on identifying features of

Please cite this article in press as: Brook, M.S., Kirkbride, M.P., Reconstruction and paleoclimatic significance of late Quaternary glaciers in the Tararua Range, North Island, New Zealand, Quaternary International (2017), https://doi.org/10.1016/j.quaint.2017.10.018