Science

Glacial geomorphology of the Brabazon & Butler Downs, Rangitata Valley, South Island, New Zealand

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ABSTRACT

The inland valleys of New Zealand’s South Island were heavily glaciated during the last glacial cycle. Subsequent fluvial incision has eroded out glacial deposits from the valleys in many locations, making it difficult to reconstruct glacial dynamics and chronology. The Brabazon and Butler Downs lie in a fault-controlled intra-montane basin that has been largely protected from fluvial erosion and the area contains extensive evidence for multiple glacial margins. This paper presents a detailed glacial geomorphology map of the Brabazon and Butler Downs at a scale of 1:20,000. Glacial landforms have been mapped and subdivided into three main zones: an upper zone distinguished by a flight of kame terraces, a middle zone containing kettles and meltwater channels, and a lower zone of lateral moraines. The new map provides insight into former glacial environments in the region and provides a related framework for future paleoclimate reconstructions.

1. Introduction

The details of the geomorphological and sedimentary records in New Zealand provide high-quality evidence for investigating past climate fluctuations. New Zealand has become a focus for research of this kind because New Zealand mountain glaciations are regarded as highly sensitive to climate forcing (e.g. Chinn, Winkler, Salinger, & Haakensen, 2005; Oerlemans, 1997; Winkler et al., 2010), and because it is isolated from the major northern hemisphere ice sheets, it is an excellent location to examine inter-hemispheric synchrony or asynchrony of glaciations (e.g. Putnam et al., 2012; Rother et al., 2014). Terrestrial cosmogenic radionuclide studies of moraine boulders have unlocked the chronology of the largest advances in the last glacial cycle (e.g. Schaefer et al., 2015; Shulmeister, Fink, Hyatt, Thackray, & Rother, 2010a), but advances of intermediate size are hard to reconstruct as the moraines are often destroyed by subsequent advances. Our limited understanding of these advances is mainly derived from luminescence studies of glaciofluvial and glacio-lacustrine sediments (e.g. Rowan et al., 2011; Shulmeister et al., 2010b).

Fault-controlled intra-montane basins provide an unusual opportunity to investigate these intermediate-sized advances. These basins are areas where glacial flow diverges and glacial records, both sedimentary and geomorphological, may be preserved on the flanks of the basin. Many of these basins contain flights of kame terraces, other ice-marginal drainages, and lateral moraine sequences. While reconstructing the timing and extent of past glaciations gives insight into how forcing mechanisms drive past millennial-scale climate change, the preservation and spatial distribution of glacial features has additional implications for glacial dynamics, which can substantially enhance the paleoclimatic reconstructions by giving insights into seasonal climates. The geomorphological map of the Brabazon and Butler Downs presented here supports ongoing sedimentary and geochronological investigations of this part of the Rangitata Valley in New Zealand, and is intended to enhance our understanding of glacial conditions during the last glaciation.

2. Study area

Located in the foothills of New Zealand’s Southern Alps (Figure 1(a,b)), the study area is the Brabazon and Butler Downs (43°37’ S and 170°54’ E), a triangular-shaped intra-montane basin within a formerly glaciated valley (Figure 1(c)). There are currently small glaciers in the headwater reaches of the Rangitata River; in the past, the glaciers extended beyond the Rangitata Gorge into the Canterbury Plains (Mabin, 1987). The steep-sided valley walls are formed primarily from late Mesozoic Torlesse Supergroup greywacke...
Uplifted by movement along the Forest Creek Fault as a result of the South Island’s position on a tectonically active plate boundary. The basin measures approximately 20 km north-south and up to 10 km east-west, and is constrained by the Sinclair Range to the west, the Ben McLeod Range to the south, and the Harper Range to the east (Figure 2).
3. Climate

The climate of the Brabazon and Butler Downs reflects the overall climatic setting of New Zealand as modified by their position in an inter-montane basin in the immediate lee of the Southern Alps. In summary, the climate is humid, cool, and temperate with the year-round influence of cyclonic fronts from the Southern Ocean. These are modified by the obstruction of the Southern Alps that rise to 3000 m in this part of South Island. The montane basins east of the mountains are relatively dry owing to a rainshadow effect and the same obstruction also creates common föhn winds (the Nor’-wester), while the relatively high elevation of the downs (600–1200 m) means that they are cooler than the lowland areas to the east. The nearest full weather station at Peel Forest (43.90° S, 171.26° E) lies near the mouth of the Rangitata Gorge, 35 km downstream and at an elevation several hundred metres lower than the lowest parts of the downs. It has a Mean Annual Temperature of 10.2°C with July means typically around 4–5°C and January means of 16–17°C (all meteorological data from NIWA’s National Climate Database: http://cliflo.niwa.co.nz). There are no published temperature records from the downs, but the values are likely to be several degrees cooler year round. Rainfall measurements have been recorded from Mesopotamia Station (43.64° S, 170.89° E), which is situated on the downs. It has a mean annual precipitation of 935 mm (1948–2013 data). This is significantly lower than Erewhon Station (43.51° S, 170.86° E), some 15 km upstream from Mesopotamia Station, which receives over 1500 mm (1948–1995 data) of rain annually, while Peel Forest on the edge of the Canterbury Plains receives 1140 mm of rainfall (Figure 1(b)). These values reflect the penetration of rain from the west coast to Erewhon Station under north-westerly conditions, while Peel Forest receives more rain from southerly fronts than Mesopotamia does, as the hill ranges around the gorge partially block the penetration of these fronts into the upper parts of the Rangitata basin.

4. Methods and data

The production of the detailed glacial geomorphology map is based on the interpretation of remotely sensed imagery and ground-truthing of glacial landforms during field survey.

4.1. Data sources

Aerial imagery and a digital elevation model (DEM) were obtained from Land Information New Zealand (LINZ). Taken during the 2012–2013 summer, the chosen imagery set was orthorectified for the NZTM projection. The 1:5000 tile layout (orthophoto sheet BX18, and photos: 504–508; 602–610; 702–710; 802–810; 902–910; and 1001–1010) had a high spatial resolution (0.4 m pixel resolution with ±0.6 m accuracy), allowing the visual distinction and identification of small-scale features. The 8 m DEM was used to generate 20 m interval contours. These base maps were used both to develop familiarity with the landscape and to delimit the areal extent prior to fieldwork (Hubbard & Glasser, 2005). Additional photo-analysis using stereoscopic aerial photos (run number: SN1580, photos: 3730/16 to 3730/20) taken on February 25, 1964 and printed at approximately 1:67,000 were georeferenced to the remote-sensing imagery (Khalsa, Dyurgerov, Khromova, Raup, & Barry, 2004), and used to interpret landforms obscured by recently planted vegetation.
4.2. Ground-truthing of data

Fieldwork was conducted in the Brabazon and Butler Downs in January 2016. Glacial landforms were visually identified based on their morphology. The topographic and contour maps were used to locate and orient features such as meltwater channels. A draft map was produced in the field using the orthophoto imagery mosaic scaled to A1 size as a base map.

4.3. Map production and design

There are a large range of geomorphological mapping concepts, systems, and individual symbols (cf. Dramis, Guida, & Cestari, 2011; Griffiths, Smith, & Paron, 2011; Kneisel, Lehmkuhl, Winkler, Tressel, & Schröder, 1998; Leser & Stäblein, 1985; Verstappen, 2011). The mapping symbology was selected to address the chronological and dynamic aspects of glacial geomorphology, following the mapping conventions developed for eastern New Zealand valley systems (Hyatt & Shulmeister, 2013). Conventional symbols and block colours were used to delineate individual glacial features and surface covers, respectively (Hyatt & Shulmeister, 2013). The map was constructed at a 1:5000 scale to match the orthophotographs, allowing the inclusion of a high level of detail to reduce field errors (Hyatt & Shulmeister, 2013). The scale of the map was adjusted to 1:20,000 to allow the final map to fit on an A0 page, resulting in the removal of smaller landforms to enhance visibility and clarity. More than 2700 landforms have been mapped, across eight main landform types.

4.3.1. Software and digitisation

Glacial landforms and patterns were identified and digitally mapped using ESRI ArcGIS 10.3.1 software to allow continued corrections and modifications (Hubbard & Glasser, 2005). Data were stored as vector lines or polygons and organised thematically by landform type (Napieralski, 2011). A hillshade DEM provided topographic context and was used to ascertain the quality of georeferencing. The DEM was also used to generate 20 m interval contours to aid the interpretation of downslope features such as meltwater channels.

4.3.2. Accuracy and completeness of the map

The most important factor governing the accuracy and completeness of the map is the skill and experience of the person constructing the map (Smith & Wise, 2007), as the formal identification of features is often subjective and open to interpretation (Napieralski, Harbor, & Li, 2007). In order to minimise errors, the map was reviewed by experienced glacial geomorphologists. The accuracy of the final map relies on the quality and resolution of the original data sets; landforms smaller than 2 m were not mapped.

5. Description of mapped landforms and interpretation of glacial environments

The mapped landforms include kame terraces, kettle holes, hummocky and lateral moraines, meltwater channels, debris fans, and alluvial fans (Main Map). Repeated geomorphological features and processes have been classified based on the landform element model (Speight, 1974), in order to produce a process inference map (Hyatt & Shulmeister, 2013).

The Brabazon and Butler Downs have been divided into three zones based on the dominant topology and glacial or glaciofluvial processes. During the Last Glacial Maximum, the glacier occupied most of the Downs and penetrated beyond the Rangitata Gorge (Mabin, 1987). Meltwater flowing around the sides of the glacier formed kame terraces; as the glacier stagnated, kettles formed; and at its smallest extent, recession moraines formed at the edge of the glacier. The valley would have finally de-glaciated between 19,000 and 14,000 years ago (Mabin, 1987).

5.1. Upper level deposits – kame terraces

Kame terraces are continuous depositional ridges of stratified supraglacial sediments and debris formed by the flow of meltwater streams between the glacial margin and the valley wall (Benn & Evans, 2010; Bitinas, Karmazien, & Jusien, 2004). As they reflect the position of the ice margin and approximate surface elevation of the glacier, kames are ideal for paleoclimate reconstruction (Fredin & Höttgestrand, 2002).

There are numerous kame terraces along the western and southwestern hillslopes of the basin at an elevation of approximately 1000 m. These constructional surfaces form a series of parallel sloping ridges (typically less than five degrees), and range from remnants a few metres wide to large terraces more than 100 m wide.

The northern kames are situated along a north to south trending axis, roughly parallel with the western side of the basin (Figure 3). These kames are likely to have been formed by the deposition of sediment carried by water rerouted from Black Birch Creek by the position of the ice sheet against the valley wall. The abrupt southern termination of the kames is the result of debris being incorporated into the flat-graded bed of Bush Stream. The terraces were subsequently incised and largely obscured by post-glacial meltwater streams, scarpes, and gullies oriented west to east, forming a downslope drainage system that reorients northward towards the Black Birch Creek alluvial fan.

The extensive flights of kame terraces in the southern and central areas of the valley are organised
along a predominantly north to south-southwest trending axis and were likely formed by sediment-laden meltwater streams originating in Bush Stream. The lateral drainage patterns suggest that water originally flowed around the western side of Sugarloaf Hill, before terminating at Forest Creek, where contemporary fluvial processes have incised the surface to the level of the Rangitata River.

The alignment of the southern kame terraces is also interrupted by a post-glacial debris fan (Section 5.4). The central kames are less continuous and linear than the southern flight, with a distinct arc trending towards the southwest that continues through the middle-level deposit zone.

5.2. Middle-level deposits – kettle country

The transition from kame terraces to kettle topography is reflective of the gentler slope morphology, and subsequent loss of transport capacity by the meltwater streams (Wohl, 2013). The low slope topography allows the meltwater streams to spread out laterally, distributing sediment across the valley floor as outwash plains (Nagle & Witherick, 2001). These meltwater deposits may also bury large blocks of residual ice, which collapse into kettle holes as the ice melts (Wicander & Monroe, 2008).

There are hundreds of kettle holes concentrated in the central region of the large outwash plain. The disorganised and haphazard arrangement of depressions and mounds amid a complex meltwater network is indicative of a slowly retreating or stationary ice sheet (Goudie, 2013). The kettle holes are on average a circular shape, ranging between 10 and 100 m in diameter, and are oriented along a distinct northwest to southeast trending axis, following the arc established by the central kame terraces (Figure 4).

Meltwater channels typically indicate previous lateral ice-marginal positions (Darvill, Stokes, Bentley, & Lovell, 2014), and are abundant across the Brabazon and Butler Downs; however, many of the meltwater channels are oriented along a southwest to northeast axis, perpendicular to the kettle holes, suggesting that the drainage systems reoriented downslope as the ice sheet pulled back (Soons, 1963), partially obscuring the kame topography in this region.

5.3. Lower level glacial deposits – hummocky ground and lateral moraines

This zone is the most spatially extensive, stretching north to south along the length of the basin. The transition from kame terraces to lower level glacial deposits is dictated by the change in valley wall gradient. The large volumes of sediment and debris and abundant meltwater channels reflect the final melt stages of ice retreat (Knight, 2009).

The hummocky ground moraine occurs across the lower elevations of the Brabazon Downs (43°36′ S, 170°52′ E) within a defined zone above Bush Creek, and is characterised by a chaotic landscape of gentle-relief mounds and depressions (Morén, Heyman, & Stroeven, 2011). As the drainage system from Bush Creek lost energy moving onto the lower slopes of the Brabazon Downs, the water spread out and deposited fluvial material, burying stagnant ice with debris. Although the meltwater streams would likely have been initially responsible for the chaotic landscape, the gullies trending west to east downslope from the kame terraces indicate the slopes have been reworked by fluvial processes (Schomacker, 2011).

The distinction between the hummocky ground and the upslope kame terraces is a result of how water was constrained in the landscape: meltwater constrained between the valley wall and the glacier formed the distinct elongated kame terraces, while unconstrained or low flow resulted in marginal drainages that flowed around the terminus.
The abundance of meltwater channels and small kettle holes is characteristic of topography formed in a final stagnant ice phase (Kumar, 2011); however, the distinct bands of lateral moraines across the lower elevations of the central and southwest regions of the basin are the result of seasonal oscillations in the glacier margin (Galloway & Hobday, 1996).

Lateral moraines are a prominent ice-marginal landform feature of formally glaciated landscapes (Fredin & Hättestrand, 2002; Lukas, Graf, Coray, & Schlüchter, 2012), and are generally oriented along the same axis as the kame terraces and kettle topography (Figure 5), forming sequences of longitudinal ridges parallel to the lateral glacial margin below the former equilibrium line. The trend is indicative of ice-flow direction, with the position of the lateral moraines themselves indicating multiple positions of continuous ice-marginal retreat or stagnation (Lukas et al., 2012). The sediment is angular and coarse-grained as it is formed by supraglacial debris that has been dumped along the lateral glacial margins (Humlum, 1978; Röthlisberger & Schneebeli, 1979; Winkler & Hagedorn, 1999).

Meltwater channels are abundant across the valley floor, typically flowing between and accentuating lateral moraine ridges; however, the moraines have been cut through in several places as the drainage reworks downslope towards the Rangitata River, resulting in the moraines becoming increasingly chaotic towards the unconfined outwash plains. The region is also bisected by the two branches of Scour Stream, which have also eroded to the level of the Rangitata River; the continuity of the moraines indicates this is also a post-depositional fluvial process (Schomacker, 2011).

5.4. Post-glacial landforms

The surface morphology of the Brabazon and Butler Downs has been both eroded and buried in parts by post-glacial debris fans, alluvial fans, and the dynamic Rangitata River floodplain. Debris fans occur in places of insipient drainage on the western mountain range, with numerous fans disrupting the kame terrace sequence between Sugarloaf Hill and Forest Stream (Figure 6). The extremely variable and high-intensity rainfall of the Southern Alps caused unconsolidated
material lying over the bedrock to become saturated with water (Iverson, 2005; Savage & Baum, 2005), resulting in a loss of shear strength and subsequent rapid downslope mobilisation of the sediment and water mix (Costa, 1984).

Alluvial fans are a depositional feature formed from the accumulation of sediment at the base of a drainage source (Dorn, 2009; Galloway & Hobday, 1996). There are four alluvial fans in the Downs, each associated with important drainages originating in side valleys. Mass-wasting events deliver the sediments to drainages in the mountainous catchment. The material is transported via high-gradient channels during rainfall events, with the sudden deceleration of flow at the gently sloping mouths causing the distinctive radial deposition of sediment across the unconfined valley floor (Blair & McPherson, 2009; Hargitai, 2015). While Forest Creek and Scour Stream result in spatially isolated alluvial fans corresponding to the size of each channel, the proximity of Bush Stream and Black Birch Creek has resulted in the fans coalescing laterally (Figure 7).

The alluvial fan sediment contains sub-angular to sub-rounded and relatively poorly sorted coarse gravels representing high-energy events. These layers alternate with finer, better sorted sediments laid down during less energetic events (Blair & McPherson, 2009).

6. Conclusion

The overall patterns of glacial retreat are manifest in the changing orientation and geomorphological characteristics of the erosional and depositional features across the Brabazon and Butler Downs, with the widening of the Rangitata Basin resulting in the extensive preservation of many smaller glacial structures that would have otherwise been eroded had the glacier been constrained against the valley sides.
Vertical nesting of key glacial landforms is evident; however, the position of the basin within an unconstrained section of the Rangitata River floodplain (For- syth et al., 2003) means that many lower elevation features have been eroded by substantial post-glacial fluvial activity. For example, the burial of moraines under alluvial outwash fans, or the scouring of kame terraces by Forest Creek or Scour Stream. The distinct morphological zones are a function of both the original valley topography and seasonal variations in ice retreat. This map will provide a basis for future age-correlation work in the region (Hyatt & Shulmeister, 2013), and the integration of paleoclimate data can provide a temporal scale through which to interpret and visualise geomorphological landscape formation and change (Bishop, James, Shroder, & Walsh, 2012).

Software

ESRI ArcMap 10.3.1 was used to visualise the remote-sensing imagery, process the DEM, generate contours, and georeference stereoscopic imagery to enable on-screen digitisation of the glacial geomorphology features. Mosaicking of some imagery was conducted in Adobe Photoshop CS4. Google Earth was used to provide 3D perspective visualisation of the study area. Adobe InDesign CS4 was used to create the final map layout.

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