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Abstract

We present a 1:33,333 geomorphological map of the Rees Valley, Otago, New Zealand. The Rees River drains an area of ~405 km^2 and feeds into the head of Lake Wakatipu. This area has been affected by a range of geomorphological processes including tectonic activity, glacial erosion and deposition, mass movement, fluvial action, and base (lake) level change. Mapping was achieved by a combination of interpretation from SPOT 5 HRG satellite imagery and ground-truthing. The map presents the current distribution of landforms and sediments associated with the wide variety of contemporary and past geomorphological processes. It represents the most detailed and finest resolution geomorphological map of this region to date, and hence a number of features have been mapped and described for the first time. The map will assist on-going studies in the Rees catchment that seek to understand fluvial sediment transport and associated flood hazards, the dynamics of former glaciers, base level change associated with a drop in the level of Lake Wakatipu, and mass movement hazards.

Keywords

Base level change; Fluvial processes; Geomorphology; Mass movement; New Zealand, Palaeoglaciology.

1. Introduction

The Southern Alps of New Zealand represent an exceptionally dynamic geomorphological terrain. There are numerous peaks in excess of 3000 m.a.s.l. along the Main Divide and overall this mountain range experiences rapid tectonic uplift on the order of 5 mm a^{-1} (Beaven et al., 2010), with extremely high mean annual precipitation of up to 14 m per year (Henderson and Thompson, 1999). These factors combine to drive a range of geomorphological processes including glaciation, fluvial incision and deposition, and mass movement. Consequently, landscape evolution in the Southern Alps is complex, representing significant challenges to the quantification of erosion and sedimentation rates associated with different geomorphological processes and to unravelling the palaeo-environmental archive recorded by terrestrial landforms and sediments. In addition, the same geomorphological processes represent significant challenges to geohazard management in the region. Seismic, mass movement and flood hazards pose risks to the local population, tourists, and regional infrastructure (e.g. Otago Regional Council, 2010).

There has been extensive and repeated glaciation of the Southern Alps throughout the Quaternary (e.g. Newnham et al 1999; Barrell, 2011; Barrell et al., 2011). Seven glacials have been correlated with Marine Isotope Stages (MIS) 2, 3, 4, 6, 8, 10 and 12, as well as five interglacials correlated with MIS 1, 5, 7, 9 and 11. Two older glaciations have been identified between 1.8 and 2.6 Ma BP (Barrell, 2011). Despite the wealth of potential information about former glacier extent and palaeoclimate preserved in the geomorphological record, the landform-sediment archive in New Zealand has received relatively little attention compared with glaciated areas of the northern hemisphere. Yet, New Zealand represents one of the few mid-latitude landmasses in the southern hemisphere where a terrestrial glacier-climate record could be preserved (Alloway et al., 2007; Sutherland et al., 2007), and so it is important that this record be exploited. Recent research in the region has sought to understand the large-scale palaeoclimatic and palaeoglacial record of the Southern Alps. For example, Barrell et al. (2011) have mapped the glacial geomorphology of the central South Island associated with the Last Glacial Maximum (LGM; known locally as the Otiran Glaciation), and Golledge et al. (2012) have modelled LGM ice extent and climate for the Southern Alps.

In this study, we describe a 1:33,333 geomorphological map of the Rees Valley, Otago, New Zealand. The location of the study area is shown in Figure 1. The map represents the only detailed geomorphological map of the Rees catchment, which (1) contains an important and hitherto unstudied palaeo-glaciological archive of landforms and sediments; (2); experiences widespread mass movement events that are important both in terms of landscape evolution and sediment supply to rivers, and in terms of potential hazards to people and infrastructure (e.g. McSaveney and Glassey, 2002; Otago Regional Council, 2010; (3) plays host to a dynamic and complex braided river system that serves as both an aggregate resource for local communities, and as a hazard because of the flood risk that it poses (e.g. Mabin, 2007; Otago Regional Council, 2008); and (4) has experienced significant changes in local base level associated with post-glacial variations in the level of Lake Wakatipu, into which the Rees River drains (e.g. Bell, 1992; Thomson, 1996; Wellman, 1979). In this respect, the geomorphological map of the Rees catchment provides an important context for other on-going investigations in the area concerned with modern braided river dynamics (e.g. Brasington et al., 2010; Williams et al., 2011; 2013), former glacial conditions and processes, and changes in the level of Lake Wakatipu since the LGM (e.g. Wild et al., 2008).

2. Site Location and Description

The Rees Valley is located at the head of Lake Wakatipu on New Zealand's South Island (Figure 1). The valley is occupied by the Rees River, which is ~41 km in length and drains a catchment area of ~405 km^2 (Williams et al., 2011). The Richardson Mountains are located to the east of the river and the Forbes Mountains to the west, and both mountain ranges attain altitudes exceeding 2000 m.a.s.l. The bedrock geology along the course of the Rees River channel is composed of pelitic schist belonging to the Mount Aspiring lithologic group (Turnbull, 2000). To the west of the main channel, the bedrock beneath the tributary valleys feeding into the Rees River comprises metamorphosed volcaniclastic sandstones and siltstones of the Caples Terrane, whereas to the east both of the aforementioned bedrock types are present (Turnbull, 2000).

The Rees Valley was carved by the Tyndall Glacier (sometimes referred to as the Rees Glacier) during the Quaternary. The Tyndall Glacier was one of the main tributary glaciers that fed the Wakatipu Glacier, which itself was responsible for carving Lake Wakatipu. Today, glaciers within the Rees catchment are confined to high altitude cirques. The nearest sizeable valley glaciers include the ~6 km-long Dart Glacier and ~4.5 km-long Whitbourn Glacier, both located approximately 6.5 km to the north of the area mapped here, and the ~3.6 km-long Margaret Glacier located approximately 2.3 km to the northwest of the mapped area. These glaciers contribute meltwater to the neighbouring Dart River.

The boundaries of the map presented here are determined by the Rees River catchment watershed and the areas immediately adjacent to the watershed. The head of the Rees River is at a prominent col known as the Rees Saddle. The col is ~80 m above Snowy Creek to the north, a former tributary of the Rees River that was captured by the Dart River (Williams et al., 2011). The southernmost boundary of the mapped area is at the junction of the Rees-Dart delta with Lake Wakatipu, taking in Glenorchy. The map also includes other small catchments in the southeast of the mapped area (Buckler Burn at ~46 km^2; Stone Creek at ~6 km^2) as well as parts of the Dart River catchment to the north and west. Overall, the mapped area is 16.5 km wide and 38 km long.

There has been relatively little geomorphological research undertaken in the Rees Valley. Barrell (2011) included part of the Rees catchment in a broader reconstruction of the Wakatipu Glacier during different stages of the Quaternary. McSaveney and Glassey (2002) reported on a fatal debris flow from Cleft Peak in the upper reaches of the Rees River, and more broadly, Otago Regional Council (2010) reported on the variety of geohazards to the community of Glenorchy. DeScally et al. (2010) examined some examples of debris flow fans and alluvial fans in the Rees Valley and surrounding area as part of a wider study of the morphometric properties of these two landforms. Modern fluvial sediment transfer processes have been examined by Brasington (2010) and Williams et al. (2011, 2013) who made detailed studies of the evolution of the braided lower reaches of the Rees River using Terrestrial Laser Scanning. Wild et al. (2008) have also reconstructed recent sedimentation rates to the Rees and Dart delta. The surficial and bedrock geology of the Rees Valley has been mapped by Turnbull (2000). Overall, however, a comprehensive and detailed examination of the geomorphology of the Rees Valley has not been undertaken thus far.

3. Methods

Geomorphological mapping was achieved through computer-based mapping in ArcGIS supported by satellite image interpretation and field-based mapping. The map has been produced at a 1:33,333 scale using the NZTM 2000 New Zealand Transverse Mercator co-ordinate system. Orthorectified false-colour SPOT 5 HRG satellite images were used as a base map. This imagery, acquired in 2008, has an object-space (ground) spatial resolution of 2.5 m. Geomorphological features were digitised in ArcGIS and then ground-truthed in the field. The focus of the ground-truthing was the main Rees River channel and surrounding valley sides between Glenorchy and the Rees Saddle, as well as the area between Mt Alfred, Earnslaw Burn, the Rees River braidplain and the Buckler Burn. Oblique aerial photographs of the lower Rees River were also used to assist with mapping. Computer-based mapping was aided by hillshade models generated in ArcGIS from a 10 m resolution DEM (Digital Elevation Model) interpolated from LINZ (Land Institute of New Zealand) contour data. These contours were also used in the final map production. In order to map areas for which no ground-truthing was undertaken, we used a combination of geomorphological interpretation from the satellite imagery and oblique views in Google Earth, with cross-referencing to the geological map of Turnbull (2000), especially for surficial sediments and landslides.

The labelling of place names and significant landscape features was completed with reference to LINZ 1:50,000 maps of Lake Williamson (NZTopo50-CA10) and Glenorchy (NZTopo50-CB10), both produced in 2009. The road layer in our map is derived from the downloadable LINZ GIS layers (www.linz.govt.nz).

In order to elucidate the origin of some landforms and sediments, sedimentary sections were examined where they existed. Sections were exposed in a number of locations along the sides of the Rees River between McDougalls Creek and Muddy Creek. Sediments were logged and described following standard techniques (e.g. Evans and Benn, 2004), although we do not present the full sedimentological dataset here.

The mapped features are classified according to the primary process systems that have shaped this landscape, and which are the subject of on-going study. Hence, geomorphological features are grouped in the key according to whether they were generated by processes associated with glaciation, mass movement, fluvial action or lake level change.

4. Results and Discussion

We discuss the geomorphology of the Rees Valley in four sub-sections related to different earth surface processes, namely: Glacial, Mass Movement, Fluvial, and Lake Level Change.

4.1 Glacial

Glacier outline mapping yields a total glacier cover of 15.6 km^2 within the mapped area. The Rees Valley has been strongly conditioned by glacial action, and a number of glacial geomorphological features are mapped including moraine ridges, ice-sculptured bedforms, kame terraces, kettle holes and arêtes.

Evidence of glacial erosion is abundant in the form of ice-sculptured bedforms, which are glacially smoothed bedrock landforms, elongated in the direction of former glacier flow (Figure 2). Ice-sculptured terrain is best developed in the central Rees Valley, on Mt Alfred, and in the high altitude cirques that remain partly glacierized (e.g. Mt Earnslaw), or have only recently become ice-free. Almost all of the mapped area would have been covered by ice during the LGM (Barrell, 2011; Golledge et al., 2012), and hence most of the catchment has been conditioned by glaciation to some extent. In some areas, however, the glacial imprint on the landscape is complicated by other influences. For example, between Big Devil Creek and Twenty Five Mile Creek (in the vicinity of 1242000, 5049000) glacial erosion has accentuated the structural grain and sedimentary layering of the bedrock, giving particularly well-developed ice-sculptured bedforms. At the same location, however, the slope has been disturbed by landslide activity, giving the bedforms a warped appearance. Other slopes that are likely to have been conditioned by glacial action have been heavily disturbed by landslide activity, giving them a hummocky appearance (e.g. to the east of Glenorchy and Buckler Burn in the vicinity of 1239000, 5022000, and to the east of Chinamans Flat at 1238000, 5026000).

In general, glacial depositional landforms are scarce. Moraine ridges are common in high altitude cirques currently occupied by glaciers, or where ice has been present until relatively recently. Barrell (2011) also noted that moraines were relatively rare in the wider Wakatipu area, but that evidence for ice sculpting was common. Moraines may not have good long-term preservation potential in such a dynamic geomorphological environment characterised by high rates of fluvial incision and mass movement, driven by high precipitation and high tectonic uplift rates. There are, however, valley-side sediment exposures that contain reworked glacial deposits along the course of the main Rees River channel (e.g. at Muddy Creek). However, because of the extent of reworking of these deposits by mass movement processes, we describe these in the subsequent sub-section.

Some valley slopes exhibit conspicuously flat or gently sloping areas, especially along the true left valley side between Twelve Mile Creek and Stone Creek. Geological mapping of surficial deposits by Turnbull (2000) identified some of these materials as alluvial (i.e. fluvial) and glaciofluvial sediments. However, our mapping indicates that these deposits are more extensive than reported previously. Perhaps the most notable example of these deposits is at Chinamans Flat where Buckler Burn takes a sharp turn from its east-west flow upstream, to a southerly direction downstream (Figure 3). Chinamans Flat is a 3.4 km-long strip bounded to the west by a glacially sculptured hill, and to the east by steeper glacially conditioned slopes that experience mass movement. At the southernmost extent of Chinamans Flat are a number of water-filled depressions, interpreted here as kettle holes (Figure 3c). We suggest that Chinamans Flat is a kame terrace derived from glaciofluvially worked debris, with sediment deposited on a decaying, stagnant part of the Tyndall Glacier hemmed-in between the valley side and the bedrock rise, which melted to produce the kettle holes. The sharp bend in the course of Buckler Burn may have resulted from the stream following this ancient meltwater route. To the north of Buckler Burn, both Davidsons Creek and Twelve Mile Creek exhibit a similar pattern where they flow sharply to the left (i.e. southward) in association with valley parallel flats.

4.2 Mass Movement

Geomorphological features related to mass movement are common within the Rees catchment, as is evident in the 1:250,000 scale geological map by Turnbull (2000). Mass movement features include mass movement scarps, zones of slope deformation, scree, and hummocky rockfall deposits.

On the map, slope deformation refers to hillslope failure by creep, heave and sliding where in each case the slope itself moves en masse. Scree is mapped for debris accumulations composed of unconsolidated debris, which occur on or at the foot of slopes, from rockfall or weathering processes. Continued slope deformation, rockfall and scree production result from weathering, tectonic activity and possibly from paraglacial slope instability related to glacially oversteepened slopes. Slope deformation may also result from earthquake activity and from debuttressing of valley slopes following deglaciation, or indeed from deformation processes occurring contemporaneously with glaciation. McColl and Davies (2012) demonstrated that slopes push into the nearby Dart Glacier, raising the possibility that some of the slope deformation within the Rees Valley may also have occurred before deglaciation.

The generally west-to-southwest dipping foliation of the schistose rocks also exerts an important influence on mass movement within the mapped area (Turnbull, 2000; DeScally et al., 2010). For example, whilst mass movement affects most slopes in the mapped area to some extent, landsliding often has a profound effect on westward-facing slopes where entire hillslopes are deforming (e.g. along the western side of the Rees valley and the western side of Earnslaw Burn). Such large-scale deformations are less common on east-facing slopes.

There are well-developed mass movement scarps in a number of locations within the Rees catchment (e.g. Earnslaw Burn; north of Twelve Mile Creek; above Chinamans Flat). Figure 4a shows scarps located on the northeast-facing slope of Mt Alfred, indicative of a creeping landslide. Along the central Rees valley, there are a number of scarps from which blockfalls have occurred, especially to the south of Lennox Creek. Scree has accumulated at the base of the slope along this valley side, although it is generally covered in vegetation and is no longer active. To the north of Arthurs Creek, there is an accumulation of rounded hillocks (Hummocky rockfall deposits; 1240200, 504400; Figure 4b), interpreted here to be rockfall debris blocks that have fallen on top of the Rees braidplain and been covered by loess and subsequently vegetated. There is some similarity between these mapped features and 'The Hillocks', which are found along the course of the neighbouring Dart River (McColl and Davies, 2011). Until recently, the Hillocks had been interpreted as moraine mounds or kame deposits, but McColl and Davies (2011) re-interpreted these features as the product of a large rock avalanche, highlighting the occurrence of other such features in New Zealand and Austria. We consider it unlikely that the features in the Rees valley are moraines or kame deposits because of their close proximity to steep scarps from which rockfalls have likely taken place, and because the debris has been deposited on top of fluvial sediments laid down after the recession of the Tyndall Glacier. Nonetheless, careful interpretation is required in order to differentiate rockfall and rock avalanche debris from glacial landforms such as moraines and kame deposits.

Perhaps the most impressive mass movement in the mapped area is at Muddy Creek. Here, there is a large scar on the valley slope that covers an area of ~4.6 km^2 (Figure 5a). This zone of mass failure is responsible for delivering a significant amount of sediment into the Rees River, resulting in the formation of an alluvial fan immediately downstream (the 'Muddy Creek Fan'; Figure 5b).

There are a number of exposures through the valley slopes from Muddy Creek toward the south, as far as Invincible Creek. At Muddy Creek, a section up to ~8 m in height (Figure 6) reveals diamicton containing mostly sub-angular clasts with dominantly bladed, platy and elongate shapes (based on 2 samples of 50 clasts each). The flatter clasts probably inherit their shape from breakdown of the dominant schist bedrock along cleavage planes (e.g. Brook and Lukas, 2012; Lukas et al., 2013), although the presence of elongate clasts with a generally sub-angular form is consistent with subglacial wear. Much of the sedimentary sequence comprises structureless diamicton with subglacially worked clasts, although there is some crude layering (Figure 6b) and a number of pockets of sorted, water-worked sediment (Figure 6c) that may represent slack water deposits formed in eddies behind boulders. These observations are not consistent with an interpretation as glacial till, but are consistent with an interpretation as a debris-flow deposit where the parent material was glacial diamicton. The top ~2 m of the deposit is composed of a muddy gravel that has distinct layering (Figure 6c). We interpret this uppermost material to be fluvial gravel that has been emplaced on debris flow deposits. This top surface of fluvial material probably belonged to the prominent, and now relict, alluvial fan that extends from Muddy Creek toward the north (Figure 8b). From this sequence, we suggest that, following deglaciation, unstable till-mantled slopes gave rise to paraglacial debris flows. Over time, paraglacial debris flow activity reduced and fluvial processes began to rework debris flow and glacial deposits and generate an alluvial fan on top of the debris flow deposit. Subsequently, the large alluvial fan shown in Figure 8b has been incised by Muddy Creek, which now delivers significant quantities of sediment from the active Muddy Creek catchment into the Rees River through the Muddy Creek Fan.

4.3 Fluvial

We identify a number of geomorphological features associated with fluvial processes, including ephemeral or relict channels, sections of active braid plain, active gravel bars within channels, alluvial fans, and alluvial sediment (i.e. relict fluvial sediment). There are also several well-defined terraces mapped within the Rees catchment, although some have been cut by fluvial erosion and others cut by wave action when the level of Lake Wakatipu was higher than today (see next section).

South of Muddy Creek there are other prominent sediment exposures, which are interpreted to represent proximal fluvial outwash deposits associated with a higher stage of Lake Wakatipu (Figure 7). Sediment within these exposures is dominated by sub-angular clasts with shapes that are mostly bladed, elongate and platy. The sediment is well bedded (Figure 7a and b) and there are channels filled with sand and gravel (Figure 7c) consistent with water-working of sediment. Subsequent base level change and/or tectonic uplift have promoted incision into these outwash sediments by the Rees River to leave the significant sediment exposures shown in Figure 7.

Up-valley from the Muddy Creek Fan the valley floor is up to ~1 km in width, with an average slope of 0.3º (Figure 8a). This wide and flat morphometry contrasts with the area down-valley from Muddy Creek, which, apart from the 350m-wide Muddy Creek Fan, is generally less than 150 m in width, and has an average slope of 1.1º. We speculate that the valley fill north of Muddy Creek could owe its origin to sedimentation in a lake that developed because of valley blockage and damming of the Rees River. The timing of such an event is unclear, but could have resulted from a single mass failure from Muddy Creek, or series of debris flows that promoted progressive encroachment of the Muddy Creek fan across the valley. The thick debris flow sediments in the section at Muddy Creek could represent a large mass failure or series of debris flows that blocked the Rees valley, leading to deposition into the lake of the several alluvial fans that enter the flat valley to the north of Muddy Creek (Figure 8b). The sedimentary evidence in Muddy Creek is consistent with this, since the debris flow deposits are capped by fluvial gravels (Figure 6).

Further south at Invincible Creek, the valley floor widens to up to 300 m, before entering the wide braidplain at Lovers Leap. From here toward Lake Wakatipu, the active Rees braidplain is up to ~700 m wide, although accumulations of alluvial (fluvial) sediment on either side of the Rees River extend up to ~2.5 km across the valley.

Patterns of aggradation and degradation in the Rees River are complex and are the subject of on-going high-resolution survey investigation (e.g. Williams et al., 2011, 2013). Surveys reveal that the river bed has been aggrading around the road bridge that crosses the Rees River close to the southeast flank of Mt Alfred (1235800, 5030400), and in the braided reach down-river of the bridge (Otago Regional Council, 2008; Williams et al., 2011). One possibility for this aggradation is that the input of material from the mass failures at Muddy

Creek, and associated build-up and release of sediment in the Muddy Creek Fan, has generated a sediment wave that has been transmitted downstream (Williams et al., 2011). Additionally, the aggradation may result from the constraint of the active braidplain between stopbanks, as has been observed elsewhere in New Zealand (Davies and McSaveney, 2006; Williams et al., 2011). There is some evidence that the Rees River is degrading upstream of this area, between the bridge and Twenty Five Mile Creek / Ox Burn, and through the narrow gorge section between Muddy Creek and Invincible Creek. A report by Otago Regional Council (2008) links the degradational regime between the bridge and Twenty Five Mile Creek / Ox Burn to changes in sediment supply within that tributary catchment. Our observations indicate that just downstream of the narrow gorge section between Muddy Creek and Invincible Creek, bar surfaces are significantly above the current active channel bed and, unlike bars downstream, are heavily vegetated. This indicates a pattern of recent degradation in this stretch of the river associated with sediment supply changes along the main channel of the Rees River.

Together with the Dart River, the Rees River is one of the primary drainage pathways into Lake Wakatipu. Both rivers contribute to the building of the Dart-Rees delta where they meet Lake Wakatipu. The delta is advancing into Lake Wakatipu at a rate of between 1.4 to 1.6 m a^{-1} (Mabin, 2007) with an annual sedimentation rate estimated to be 2.7 x 10^5 m^3 a^{-1}, equivalent to an average catchment denudation rate of 0.3 mm a^{-1} (Wild et al., 2008). Progradation of the delta poses a significant flood risk for the small settlement of Glenorchy as elevated river bed levels upstream of the township comprise the standards of protection provided by historic flood defences. High rates of channel aggradation further upstream, in the vicinity of the Rees River Bridge, are estimated to be in the order of 27 mm a^{-1} (Mabin, 2007), and represent a significant problem for the maintenance of this vital river crossing, which provides access to popular alpine trails, including the Routeburn, Caples, Greenstone and Dart-Rees Tracks.

Diamond Lake and Lake Reid are thought to have once been part of a larger Lake Wakatipu (Kober, 1999). Diamond Lake in particular is progressively silting-up with sediment delivered by Earnslaw Burn and River Jordan. The Rees River receives little sediment from these streams because of the buffering effect of Diamond Lake and Lake Reid (Mabin, 2007). The large fan that emanates from Earnslaw Burn has been incised both by the Rees River to produce distinct terraces in the vicinity of Lovers Leap and Camp Hill that are up to 40 m higher than the modern river, and by Earnslaw Burn itself to produce terraces to the north and west of Camp Hill.

4.4 Lake Level Change

Mapped geomorphological features associated with lake level change include relict lake shorelines and beach strandplains. Relict lake shorelines are erosional features whereby wave action has cut a terrace into the valley side. Hence, the map shows areas of relict lake shorelines associated with terraces. Terraces are mapped as a generic feature since similar features are also cut by fluvial erosion. Beach strandplains are relatively flat beach areas with a series of small sediment ridges built by wave action.

The lower reaches of the Rees catchment have been affected by the changing level of Lake Wakatipu since its formation at the end of the LGM. Much of Glenorchy village is situated on a former beach strandplain (Turnbull, 2000; Mabin, 2007), whilst the wetland area to the north was connected to Lake Wakatipu as recently as the 1860s (Mabin, 2007).

Perhaps the clearest evidence for lake level change can be found along the eastern side of the lower Rees River. The prominent Bible Steps are a flight of terraces etched into the valley side (Figure 9) and into the Buckler Burn fan. These features record a drop of ~43 m in the level of Lake Wakatipu since its formation, most likely connected with a switch in drainage from Kingston, where outflow breached a large terminal moraine complex, to the Kawarau River near Queenstown (Figure 1). Since Lake Wakatipu is the local base level, this drainage is likely to have led to enhanced fluvial incision in the Rees catchment, and ultimately, therefore, enhanced fluvial sediment production.

There have been previous attempts to reconstruct the lake level history (Bell, 1992; Thomson, 1996) but the exact timing of lake level changes remains uncertain. Analysis of fish population genetics indicates that the Von River (Figure 1) has been draining into Wakatipu from the west for ~12,000 years (Craw et al., 2007). This places an upper limit on the age of the top surface of the Von fan, and provides a starting point for dating of shorelines etched into this fan and others around Wakatipu. This is the subject of on-going investigation. The palaeo-shorelines have also been suggested to display an increase in elevation towards the head of the lake (i.e. toward the north) (Wellman, 1979), therefore possibly representing a glacio-isostatic signal in the landscape. However, this tilting has not been accurately quantified, nor is there any knowledge of whether the tilting process continues today.

5. Conclusions

We have presented a 1:33,333 scale map of the Rees River catchment and immediate surroundings that illustrates the distribution of landforms associated with glaciation, mass movement, fluvial action, and change in the level of Lake Wakatipu. This map provides the fundamental context for on-going geomorphological investigations in the Rees catchment. A number of features within the mapped area are worthy of further investigation. These include: (i) the reconstruction of former glacier limits and glaciological conditions based on the identification of moraines, glaciofluvial landforms and ice-sculptured bedrock; (ii) an assessment of mass movement hazards and the role of mass movement in landscape evolution within the Rees catchment; (iii) the hypothesis that a single landslide or sequence of successive debris flows at Muddy Creek built a dam across the Rees River to create a large lake basin up-stream; (iv) the causes of river bed aggradation, especially around road bridges; and (v) the timing and rate of reduction in the level of Lake Wakatipu recorded in the prominent shorelines in the lower Rees.

6. Software

The primary software packages used in the production of our map were ArcMap10 and 10.1. These were used to visualise remote sensing imagery and to digitise geomorphological features. The map was exported from ArcMap10 to .pdf format.

Map Design

The map has been produced to fit onto A0 paper, which is the largest map size allowable. Hence, our final map has a scale of 1:33,333 to fit that.

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Figure 6: *(A) Overview of the sediment exposure at Muddy Creek (note person for scale); (B) Evidence for crude layering among generally poorly sorted and structureless diamicton; (C) Pockets of water-worked sand and gravel as well as crude layering near the surface of the sequence.*

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Figure 9: *Prominent relict lake shorelines (indicated by arrows) etched into the valley side between Glenorchy and Precipice Creek / Temple Burn.*

Geomorphological map of the Rees Valley, Otago, New Zealand

Simon J. Cook

Duncan J. Quincey

James Brasington

Projected co-ordinate system:
NZTM 2000 New Zealand Transverse Mercator

Map datum:
NZGD 2000 New Zealand Geodetic Datum

Contour interval:
50 m

0 1 2 3 4 5 Kilometers

N

Key:

Glaciers and glacial landforms

- Glacier
- Arete
- Ice sculptured bedform
- Moraine ridge
- Kame terrace
- Kettle hole

Mass movement landforms

- Mass movement scarp
- Slope deformation
- Scree
- Hummocky rockfall deposits

Other features

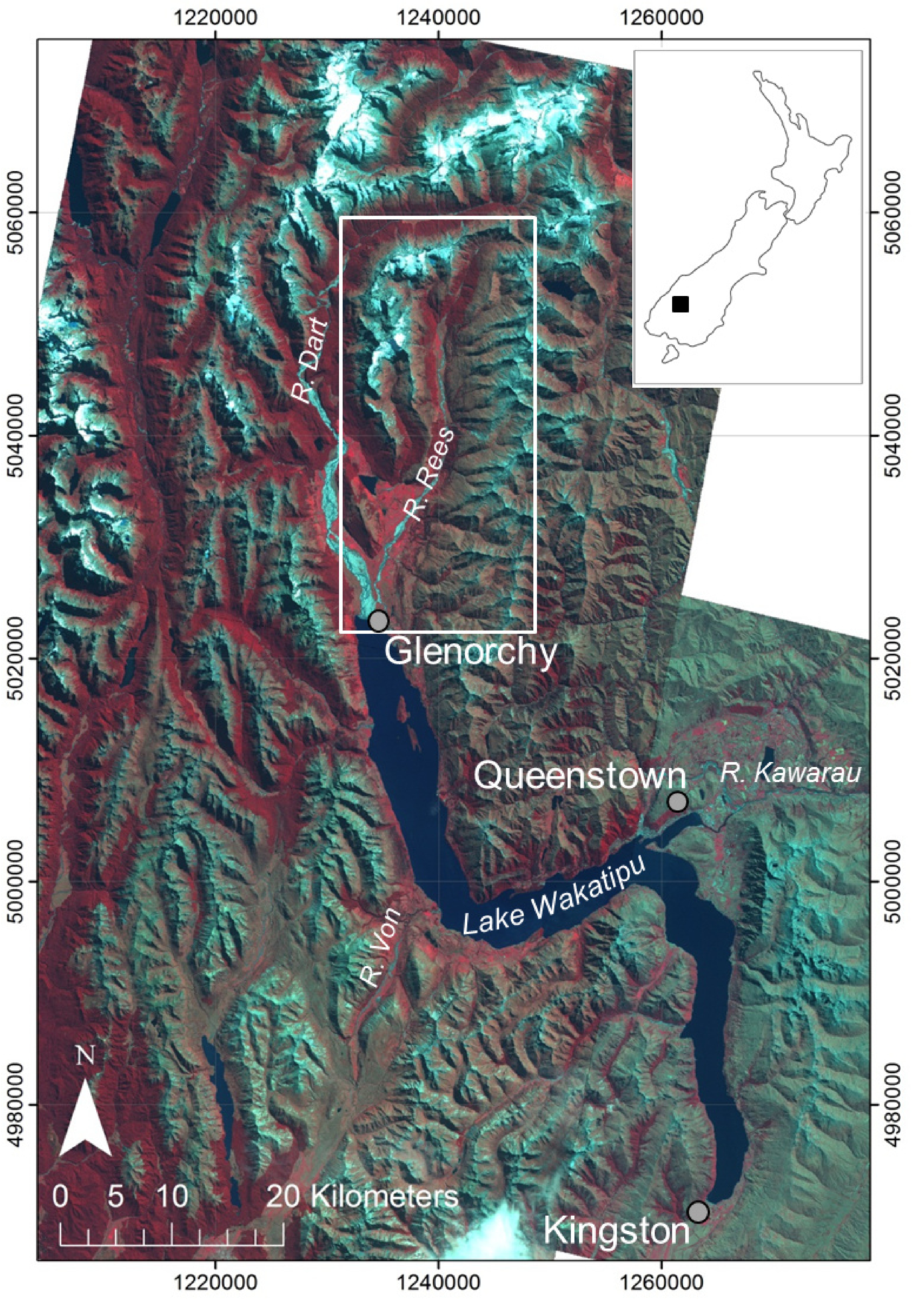
- Terrace
- 50m contour
- Road
- Forest
- Bedrock or sediment-mantled slope

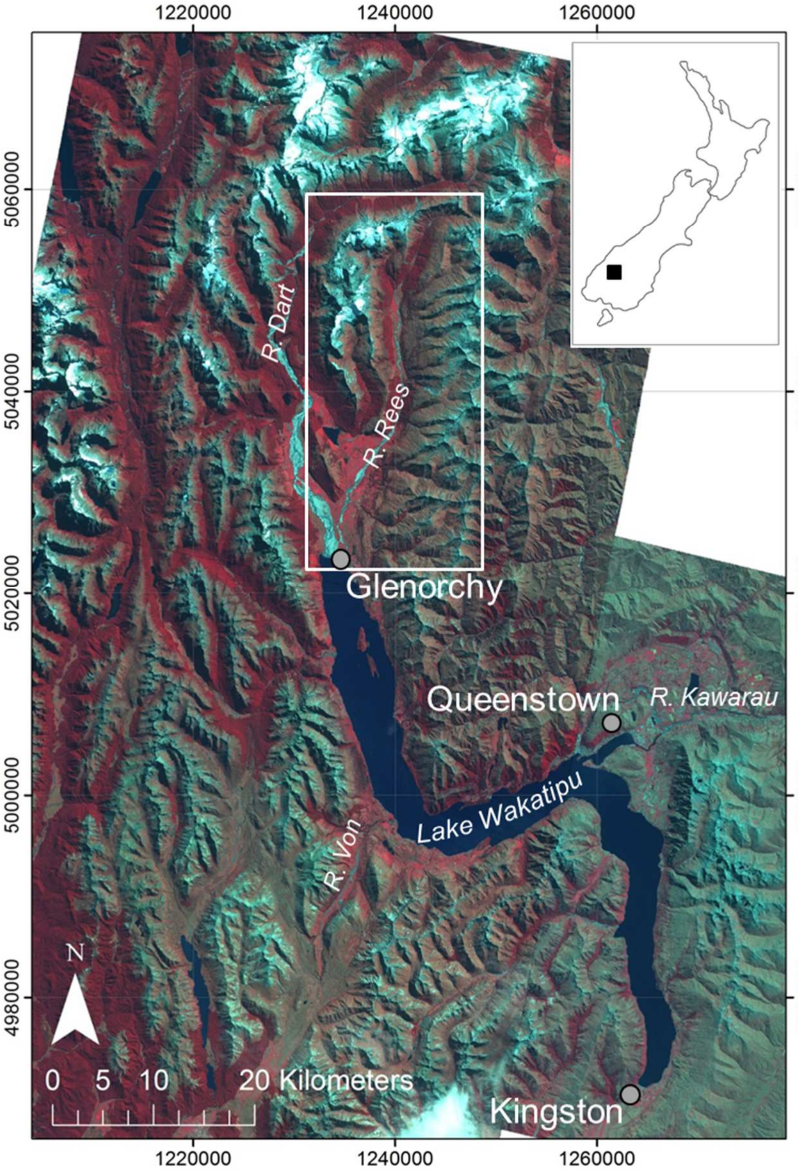
Rivers and fluvial landforms

- River channel
- Ephemeral or relict channel
- Active gravel bar in channel
- Alluvial fan
- Active braid plain
- Alluvial sediment

Lakes and associated landforms

- Lake
- Relict lake shoreline
- Beach strandplain





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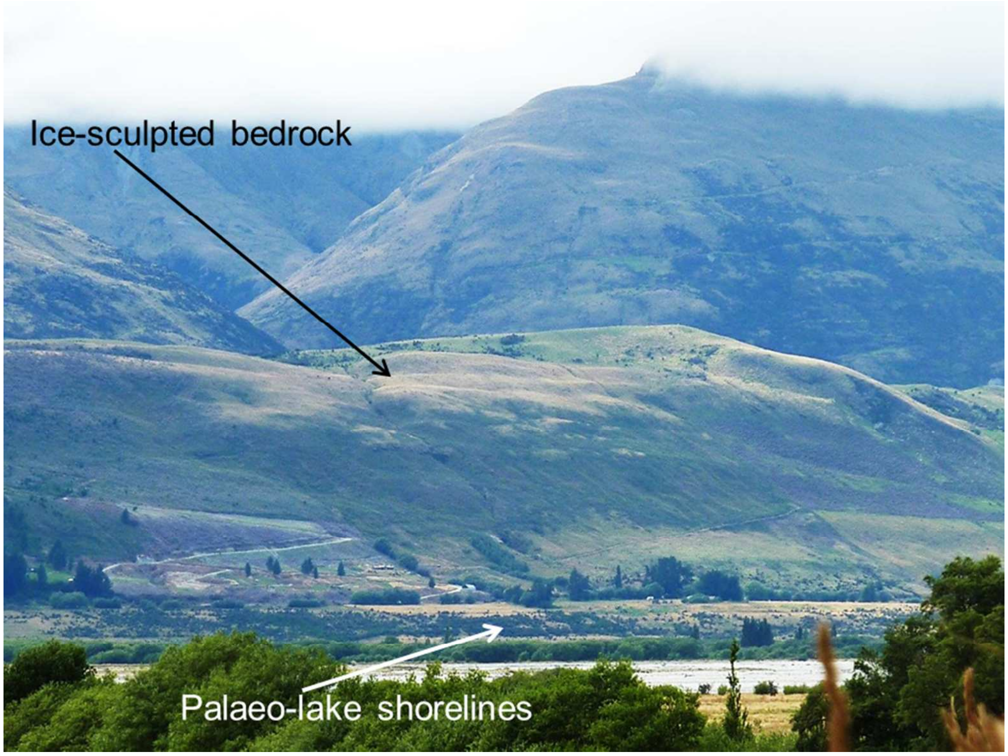
135x190mm (150 x 150 DPI)



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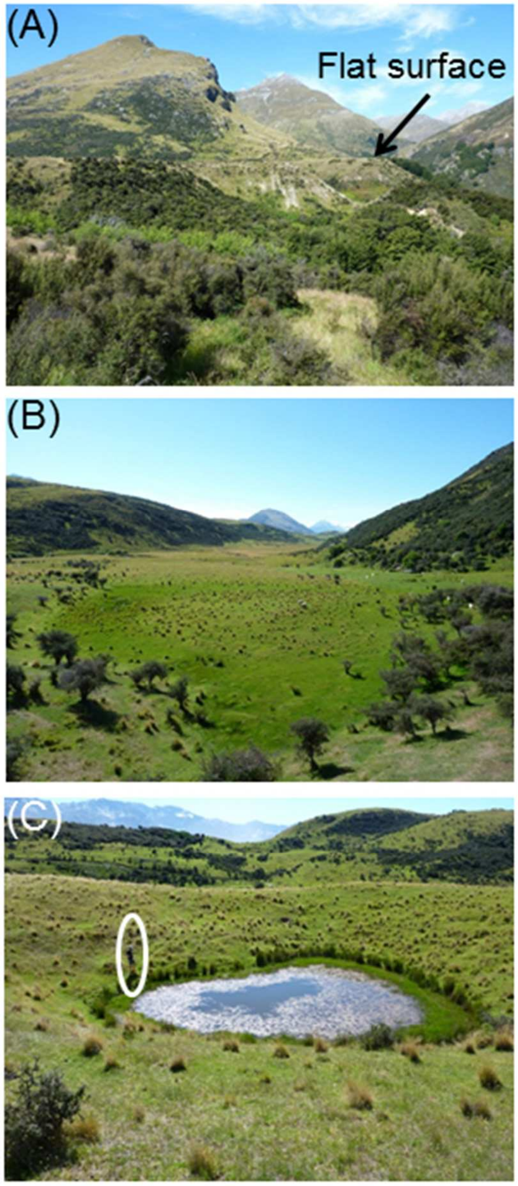

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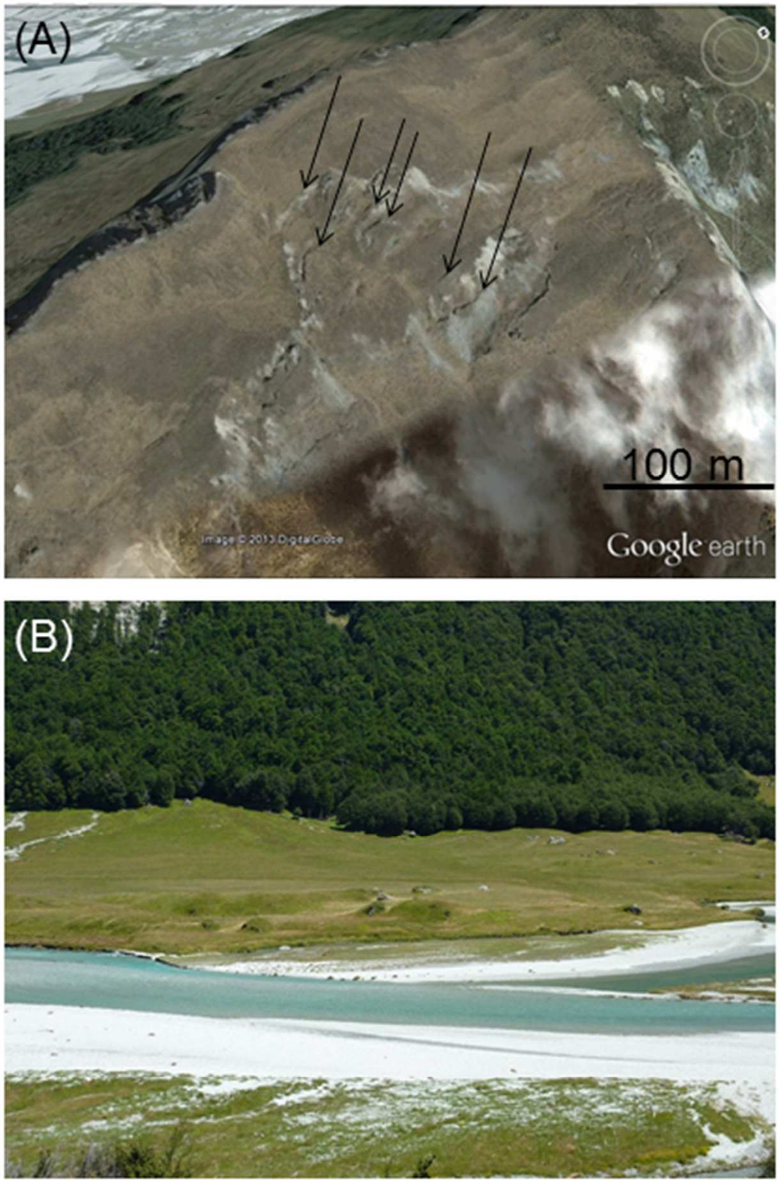
84x184mm (96 x 96 DPI)



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114x168mm (96 x 96 DPI)

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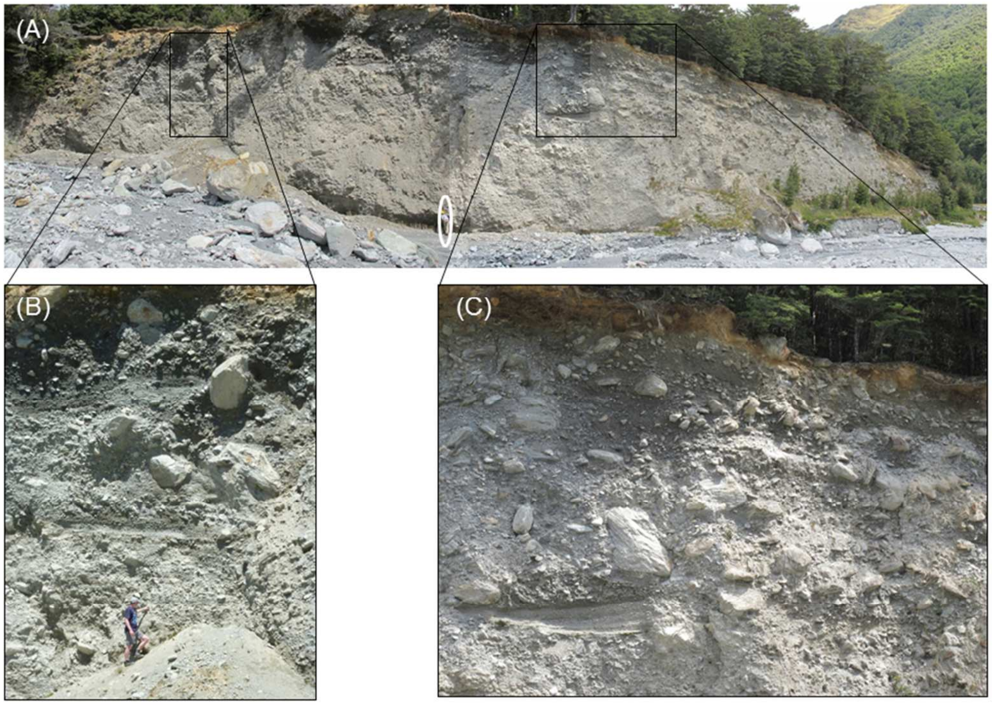
124x164mm (96 x 96 DPI)



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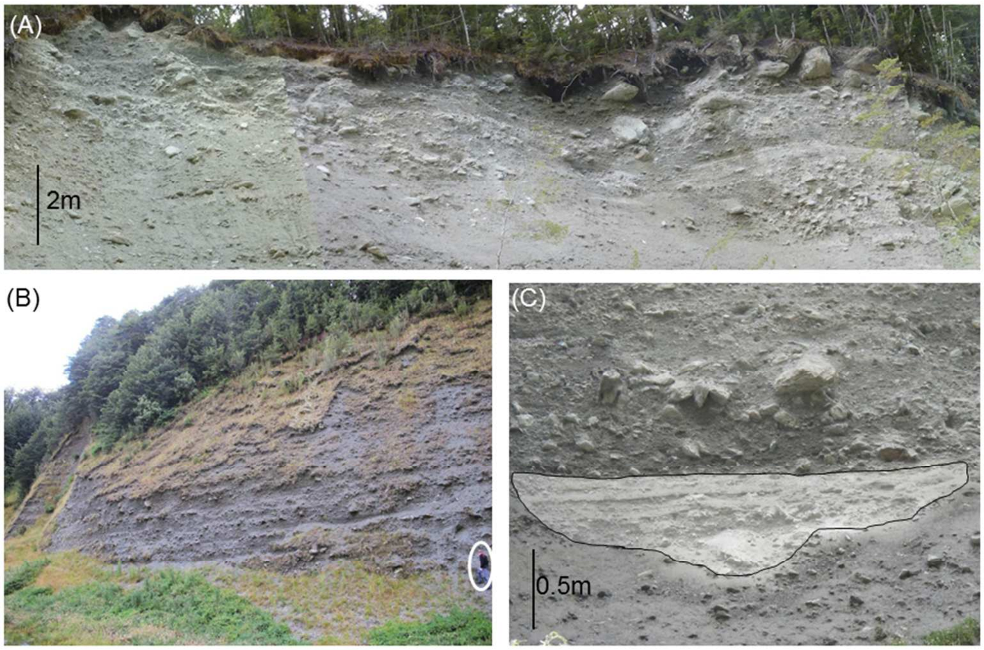
245x174mm (96 x 96 DPI)



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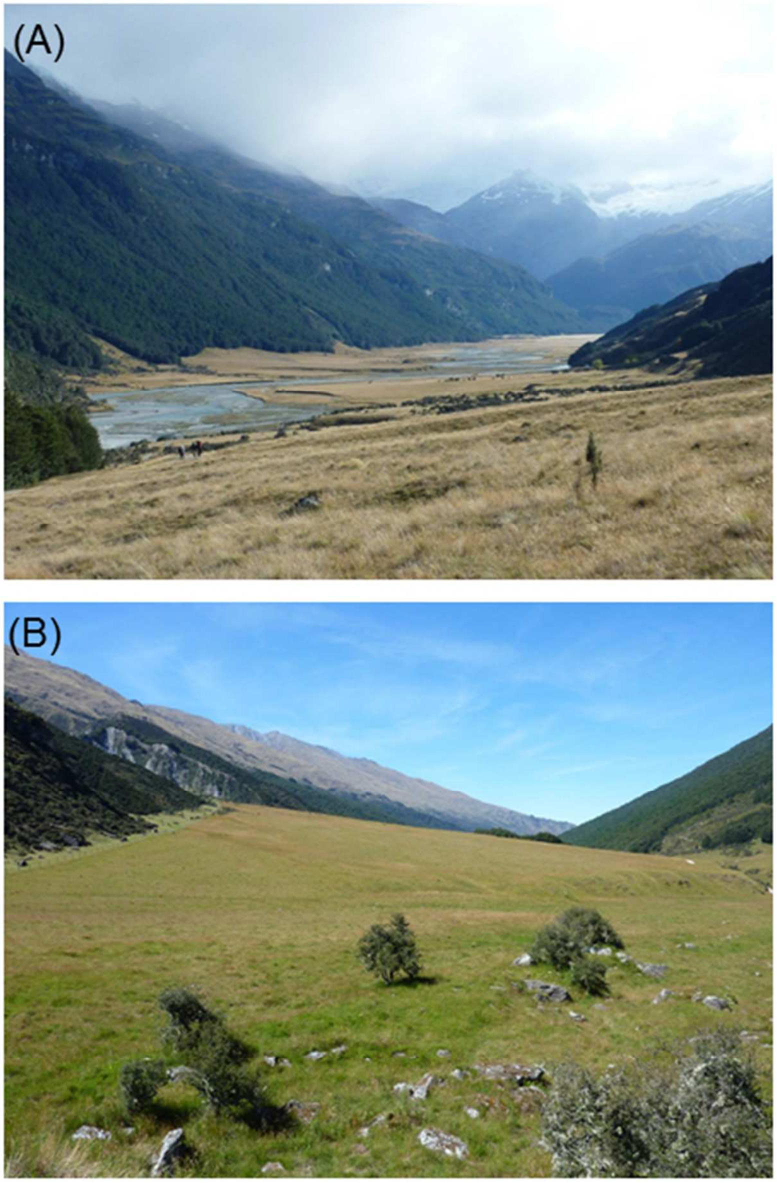
249x165mm (96 x 96 DPI)



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166x125mm (150 x 150 DPI)