Before the Hearings Panel
For the Queenstown Lakes Proposed District Plan

Under	the Resource Management Act 1991 ('RMA')
In the matter of	District Wide Hearing Stream 15 – Visitor Accommodation

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Legal Submission and Statements of evidence of DJA Barrell and DJA Barrell, BW Riddolls, PM Riddolls and R Thomson - (Submitter 2175)

Dated 10 September 2018

Nicola Vryenhoek
for and on behalf of Dynamic Guest House Ltd

1. This submission is presented on behalf of Dynamic Guest House Ltd ('DGH' formerly Dynamic Living Ltd). I am co-owner and director of DGH who owns a property on Frankton Road in an area zoned High Density Residential (HDR). DGH was zoned Visitor Accommodation under the Operative District Plan when the property was purchased by the directors and subsequently when the initial investment was made redeveloping the property in 2001-2002.[1] The HDR zone is now predominantly visitor accommodation and is properly considered a mixed-use zone.

2. I disagree with Ms Bowbyes comments at para 9.46 of the s42A Report provided under the Resource Management Act 1991(RMA). The only 'environmental effects' that now potentially fall outside the permitted baseline of effects in the VA/HDR zone are positive effects (although arguably anticipated effects). These flow directly to DGH and onwards to the local community through the exchange of money for services.[2] Positive effects also include less pressure on Council infrastructure when properties are not occupied 100% of the time. 'Boutique' accommodation is therefore a residential activity in the HDR zone.

3. Relevant to this submission, in 2001 I appeared as Barrister sole in the Environment Court for and on behalf of the Wakatipu Environmental Society Incorporated (WESI) in three subdivision appeals heard in conjunction with the outstanding natural landscape reference.[3] That reference sought by WESI (originally entered by Mr Barry Lawrence, now deceased) was to determine the ONL and visual amenity landscape lines for the Wakatipu basin. That decision has been referred to as the "eighth landscape decision" and is sometimes referred to as the "Arthurs Point to Dalefield decision".[4]

4. When representing WESI (the Society is no longer active), I was instructed through the Ministry for the Environment. Legal fees were paid from the Legal Assistance Fund. That fund also subsidized evidence prepared by Mr David Barrell of the Institute of Geological and Nuclear Science (GNS Science).[5] In addition to providing his consent to filing the annexed report with the Hearings Committee, Mr Barrell has provided a Wakatipu Basin Geology Report as supplementary evidence. That report was prepared in 1994.[6] In his view little has changed in the underlying geology/geomorphology of the Wakatipu Basin in the 24 years since that report was written that would diminish the value to the Panel of either report.

5. While not placing didactic stress on the educative component of the landscape, I draw your attention to one of the planning lessons learned from the Canterbury Earthquake events.[7] That lesson is the susceptibility of flood prone land to earthquake-induced

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[1] Development and use of the property (364 days) for visitor accommodation was a permitted activity under the Operative District Plan.

[2] *QLDC v Hawthorn Estate Ltd* [2006] NZRMA 424.

[3] *Stewart v Queenstown Lakes District Council* EnvC C105/02; *Wakatipu Environmental Society Inc v Queenstown Lakes District Council*; *Little's Stream Ltd* EnvC C135/02; *North Ridge (Queenstown) Development Ltd v Queenstown Lakes District Council* EnvC C208/01 and 1043/98.

[4] *Wakatipu Environmental Society Inc; Stewart, R v Queenstown Lakes District Council* EnvC C003/02.

[5] Annexure I – Origins of Landforms in the Arthurs Point Area Wakatipu Basin, DJA Barrell, June 2001, GNS Science.

[6] Annexure II – Surficial geology of the Wakatipu Basin, Central Otago, New Zealand, DJA Barrell, BW Riddolls, PM Riddolls, R Thomson, 1994, GNS Science.

[7] *Wakatipu Environmental Society Inc; Stewart, R v Queenstown Lakes District Council* EnvC C003/02 paragraph [10].

liquefaction.[8] In the context of the Wakatipu Basin those areas that would be susceptible to earthquake-induced liquefaction are assessed as those parts of Glenorchy, Kingston, central Queenstown and Gorge Road that are flood prone (terrace alluvium).[9]

6. GNS Science shall within the next 18 months or so be making available a greatly updated version of the 1994 map that shall include a landform-specific map in the style developed elsewhere for the Southern Alps. A link to the Central South Island Glacial Geomorphology (CSIGG) map follows. The map forms part of a comprehensive paleoclimate research project investigating the history of glacier behaviour in the Southern Alps of New Zealand. Regional-scale geological map information for all of NZ is also accessible.

CSIGG data: https://data.gns.cri.nz/csigg/

Regional data: https://data.gns.cri.nz/geology/#

7. Further to my submission (2175) Visitor Accommodation, I support rules that (i) further the Objectives and Policies of the Proposed District Plan that give effect under s75 of the RMA to the National Policy Statement - Urban Development Capacity (NPSUD); and (ii) are consistent with urban intensification where appropriate within Urban Growth Boundaries (UGB).[10]

8. Residential Visitor Accommodation forms a link for many people in the community between employment and retirement, full-time residential activity and small business development. "Policy" and rules restricting economic growth are contrary to the purpose of the RMA. Objectives and policy should support rules that encourage a smooth transition of built infrastructure uses within urban zones, where effects between different types of uses are *de minimis*. The policy direction (9.124 s42A Report) referred to by Ms Bowbyes is not appropriate in light of proposed changes to the Local Government Act 2002 that propose to incorporate The Treasury's Living Standards Framework aiming to achieve long-term sustainability and inter-generational wellbeing by amending the purpose provisions of that Act to include local government promoting the social, economic, environmental, and cultural well-being of their communities.[11]

9. I support rules that promote visitor and residential accommodation activity in the HDR zone and other mixed residential/tourist zones that are close to urban shopping centres, integrated with: (i) public transport nodes and walkway connections, (ii) appropriate landuse, and (iii) stormwater and other service infrastructure. Integrated management of

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[8] See DJA Barrell, SC Cox, PJ Glassey, BS Lyttle, "Assessment of liquefaction hazards in the Dunedin City district", GNS Science Consultancy Report 2014/068.

[9] Above n6 at p.13 and 26.

[10] For a summary of the economic theory that supported the decision-making process in developing the NPSUD my essay is included as Annexure lll. The essay was completed at Canterbury University in 2016 while involved in consultation with the Ministry for the Environment as a Canterbury Executive Member of the RMLA.

[11] The Treasury Approach to Living Standards Framework, New Zealand Treasury, February 2018 >>https://treasury.govt.nz/publications/tp/treasury-approach-living-standards-framework-html; see also the latest version of the Local Government (Community Well-being) Amendment Bill >> http://legislation.govt.nz/disclosure.aspx?type=bill&subtype=government&year=2018&no=48

effects is the core to integrated management of visitor accommodation.[12] Management of visitor growth should be coordinated to occur in a sequenced rather than ad-hoc manner, through the use of zones (within a circumference of city nodes of transport and commercial activity) to achieve integrated management of natural and physical resources through a balanced approach of higher order plan provisions of the Proposed District Plan.[13] While affordable housing for all who wish to live in the District is aspirational, regulatory interference in the market economy in the absence of a clearly articulated RMA purpose lacks validity.[14]

10. I do not propose calling Mr Barrell to appear in support of the evidence filed. And no further expert evidence is required to establish the undeniably stunning views of the mountains and adjacent lakes (open space), particularly the views from the urban centres of Queenstown, Wanaka and Frankton Highway. After all, those landscapes provide good cause for many tourists to visit our District. People and communities experiencing that natural resource is a significant reason for the existence of Queenstown and Wanaka as tourist destinations (s.5-7 RMA).

11. In respect of the matters covered in this submission I seek consequential amendments to the Proposed District Plan that satisfactorily address those matters raised in paragraphs (1) to (10) above.

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[12] *Long Bay-Okura Great Park Society Incorporated v Auckland Regional Council* A78/2008, paragraphs [20],[36],[40] and [167].

[13] *Environmental Defence Society Inc v The New Zealand King Salmon Co Ltd* [2014] NZLR 593 discussed in *Royal Forest and Bird Protection Society of New Zealand Incorporated v Bay of Plenty Regional Council* [2017] NZHC 3080; see also s30(1)(a) of the RMA. Also refer Chapters 3 and 4 of the QLDC Proposed District Plan, in particular Objective 4.2.2.2B (policies 4.2.2.1-4.2.2.4) and Objective 3.2.2 (policies 3.3.13-3.3.15).

[14] *Infinity Investment Group Holdings Ltd v Queenstown Lakes District Council* [2011] NZHC 321.

Client Report 2001/61

ORIGINS OF LANDFORMS IN THE ARTHURS POINT AREA WAKATIPU BASIN

D J A Barrell

June 2001

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Prepared for

Wakatipu Environmental Society Incorporated

Institute of Geological & Nuclear Sciences client report 2001/61

Project No: 43088D.10

June 2001

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1. INTRODUCTION

This report presents an evaluation of landforms in the vicinity of Arthurs Point, approximately 5 km north-northeast of Queenstown (Figure 1). The Institute of Geological and Nuclear Sciences (GNS) was commissioned to do this work by the Wakatipu Environmental Society Incorporated (WES). The project brief, conveyed by Barry Lawrence of WES, is to assess the origin and scientific significance of landforms in a valley traversed by Malaghan Road, for a distance of 5 km northeast of the Shotover River. In addition comment was sought on the landforms on the broad ridge lying immediately east of Malaghan Road. The brief also called for an assessment of the general relationship between these landforms and the Wakatipu Basin landscape as a whole[1,2].

The work described in this report is based on a "desktop" review of existing information, and interpretation of vertical aerial photos viewed stereoscopically. No field inspection was carried out as part of this report, although the writer has previously carried out field examinations of landforms in this area.

Information sources used in this report are a regional 1:250,000 scale geological map (Turnbull 2000), a geological overview of the Queenstown region (Turnbull and Forsyth 1988) and a 1:50,000 scale map and report describing the near-surface geological deposits of the Wakatipu Basin (Barrell *et al.* 1994). The landform map presented in this report (Figure 2) is based largely on the map of Barrell *et al.* (1994), with modifications based on more detailed interpretation of aerial photos done as part of the present project.

2. LANDSCAPE SETTING

This section presents an overview of the general geomorphology (the science of the origin of landforms) of the Wakatipu Basin, to provide context for the landform detail near Arthurs Point that is the focus of this report.

A large ice tongue (Wakatipu Glacier) that advanced into the Lake Wakatipu trough and Wakatipu Basin during periods of cold climate (glacials or "ice ages") and retreated during warmer periods (interglacials, such as the present day) is the primary influence that has shaped the Wakatipu Basin landscape. These climate cycles have had an approximately 100,000 year frequency and have affected the earth during the past 2 million years or so (the Quaternary Period). Thus, glacier ice has entered and retreated from the Wakatipu Basin on a number of occasions (Fig 13 in Turnbull and Forsyth 1988; Fig 31 in Turnbull 2000). During the Last Glaciation which reached its peak 18 – 22 thousand years ago, the glacier extended as

[1] In this report, the term landscape means the full range of natural landforms produced by geomorphological processes in a given area. The term excludes vegetation and all human modifications or construction.
[2] Wakatipu Basin refers to the broad area below about 1000 m elevation extending from Queenstown to Arrowtown and the head of the Kawarau Gorge.

far south as Kingston, and a lobe of the glacier filled much of the Wakatipu Basin. Schist, a layered metamorphic rock, forms the bedrock of the Wakatipu Basin area. The ice scoured and shaped the schist bedrock, producing an irregular morphology of hillocks and basins, and depositing patchy accumulations of rock debris known as till. Moraine is a distinctive hummocky landform developed on top of deposits of glacial till. In areas where schist bedrock was left exposed after retreat of the ice (Slope Hill is a good example), the rock surface typically has a morphology of hummocks and ridges. This type of landform is referred to as ice-sculpted bedrock, and may in some cases look very similar to moraine.

As the climate began to warm rapidly towards the end of the Last Glaciation about 15,000 years ago, the ice began to melt, forming Lake Wakatipu in the trough carved by the glacier. When first formed, the lake was many tens of metres above its present level and extended through part of the Wakatipu Basin, forming distinctive beach cliffs and deposits. At that time, what now is Lake Hayes was an arm of the enlarged Lake Wakatipu. The Shotover River built a very large fan of sandy and gravely sediments out into the enlarged lake, creating a landform referred to as a "fan-delta", that eventually cut the Lake Hayes arm off from the rest of the enlarged Lake Wakatipu. The Shotover fan-delta forms the broad plain extending from the south end of Lake Hayes to Frankton airport. The head of the Kawarau Gorge was then cut down by river erosion, progressively lowering Lake Wakatipu to its present level and causing the Shotover River to cut a sequence of river terraces below the level of its fan-delta.

The landforms of the Wakatipu Basin are therefore for the most part younger than the peak of the Last Glaciation, and comprise a complex array of ice-sculpted bedrock forms, glacial moraines, fan-deltas, river terraces and raised lake beaches. At the basin margins, streams have built alluvial fans out onto the basin floor, and the surrounding schist mountain slopes are characterised by extensive landslides and, to a lesser degree, by accumulated aprons of slope-wash or rock-fall debris (colluvium).

3. ARTHURS POINT LANDFORMS

3.1 Landform description

The mapped distribution of landforms (Figure 2) is based in part on existing work (Barrell *et al.* 1994), supplemented by additional geomorphic interpretation by the writer, using aerial photos. The landforms are classified according to an interpretation of their character and/or their mode of formation, as described in the key of Figure 2. The landform units are listed in the key in approximate order of age with older landforms at the bottom, younger landforms towards the top. There are some exceptions, including the landslide and slope colluvium landforms, that probably span a range of ages.

Bedrock landforms

Bedrock landforms include a variety of forms, such as rough, steep, mountain or hill slopes at the basin margins, and smooth to irregular ice-sculpted bedrock at lower altitudes within the basin. These different forms are not identified separately on the map, but key aspects are explained here. The bedrock ridge southeast of Malaghan Road has an ice-sculpted surface, probably formed in a glacial advance pre-dating the most recent major advance. In Queenstown Gorge, the lowermost slopes and valley floor have areas of ice-sculpted bedrock while rough, steep bedrock slopes are present at higher levels. The gorge has most likely been formed by ice spilling over the edge of Queenstown Hill from the main Wakatipu Glacier. As a result, bedrock at the base of the main mass of ice moving through Queenstown Gorge would have been scoured, smoothed and sculpted. At the same time the uppermost parts of the glacier ice would have been undercutting and plucking away at the rock in the steep sides of the gorge, creating a steep, rough bedrock landform. It may have taken more than one cycle of glaciation to cut the gorge to its present size and form.

Moraines

Glacial moraine landforms are associated with deposits of mixed, generally gravely debris (till) that was carried within or on a glacier, and was deposited directly from the melting ice. Moraines provide definitive evidence of the past existence of a glacier at a particular location. A variety of types of moraines may be recognised, including terminal moraine formed at the snout, or down-valley end, of a glacier, and lateral moraine formed at the side of a glacier, but in this report no attempt is made to differentiate between types of moraine. Moraines are not always formed or preserved at all locations along a glacier, so that, as an example, a few small isolated moraines may be the only remaining record of the location and extent of a major glacial advance.

Moraines are characterised by irregular and in some places hummocky ground surfaces. They may have a similar appearance to ice-sculpted bedrock, but the latter generally has some uniformity in the arrangement of ridges and hollows, reflecting alternating variations in strength (and thus resistance to glacial erosion) of different layers within the underlying schist bedrock. Also, the presence of glacial moraine may be revealed where minor streams, which have very little erosive power, have cut deeply into the surface of an irregular landform, indicating that it is underlain by relatively weak glacial till rather than by harder more resistant bedrock.

This criterion of relative effectiveness of stream erosion was used to identify an area of thin moraine over bedrock on the southeast side of the bedrock ridge north of Littles Road (Figure 2). The upper limit of this landform is marked by a subtle but distinctive linear ridge (moraine ridge, Figure 2) that the writer interprets as defining the maximum height reached by the last major ice advance into this part of the basin. Prominent moraine ridges are also present on Queenstown Hill. Based on their form and preservation, the writer interprets at least the lowermost of these ridges to be related to the last major ice advance in the basin.

Ice-melt landforms

Kettle holes are generally small, broadly circular depressions formed by the melting of buried glacier ice and resulting collapse of overlying gravely deposits. Kettle holes are characteristic of moraine, but can also occur where, for example, river terraces were formed over buried ice near a glacier terminus (see below).

An additional map unit is "ice-evacuated basin", used to describe a large "embayment" in the landscape immediately north of the Shotover River (Figure 2). This basin is floored by irregular topography that the writer interprets as moraine. This moraine is not shown separately in Figure 2, because the moraine floor is an integral part of the "ice-evacuated basin" landform unit. The significance of this feature is that its floor is more than 20 m below the level of the Shotover fan-delta, but there are no river landforms on the basin floor to indicate either deposition of river sediments, or any subsequent removal of sediments by river or stream action. Nor is there any suggestion of human influence in sediment removal (e.g. landforms indicating sluicing by gold miners). This leads the writer to the conclusion that a mass of ice remained in this basin for some length of time, during melting of the main glacier and the consequent formation of the Shotover fan-delta. After the Shotover had begun cutting down into its fan-delta, forming its flight of alluvial terraces, the ice finished melting, leaving behind the ice-evacuated basin as a prominent "hole" in the developing landscape.

Glacial outwash landforms

Outwash refers to the sediments deposited by glacial meltwater streams. Outwash surfaces are the landform characteristically extending downstream from glacial termini and they typically have well-defined channel patterns with a criss-crossing braided form. Where meltwater streams have cut down into their bed over time, a flight of abandoned outwash terraces may be formed. A series of these are mapped along Malaghan Road (Figure 2).

Terrace 1 is the highest and therefore oldest terrace. The progressively younger terraces 2, 3, 4, and 5 are respectively 5, 10, 15 and 20 m below the level of terrace 1. These heights were estimated using aerial photo interpretation in conjunction with 20-m topographic contours from the published 1:50,000 topographic map (Land Information NZ NZMS260: F41-Arrowtown). The writer interprets these landforms to be outwash terraces formed at or very close to the terminus of a significant glacier advance. This interpretation is based on three lines of evidence:

(i) the presence of relict river channel patterns on the terrace surfaces

(ii) kettle holes on the terraces indicating that the terraces formed over buried glacier ice

(iii) a rim of hummocky moraine along the margin between terrace 1 and terrace 4 just north of, and at one point is crossed by, Malaghan Road, that indicates the presence of ice during terrace formation.

The writer interprets the hummocky moraine rim as demonstrating that terrace 1 formed at the northwest margin of a lobe of ice, which then melted, and the deposits of terrace 4 infilled the hollow evacuated by the ice. A remnant of moraine near the Dalefield-Malaghan Road intersection surrounded by the terrace 4 outwash surface, and encircling a small kettle-hole at the level of terrace 4, indicates that buried ice was still present and melting at the time the terrace 4 outwash surface formed. A remnant terrace immediately north of Arthurs Point is correlated with terrace 4 on the basis of relative height. Downeys Dam, located on outwash terrace 5, appears to the writer to be a natural pond formed by blockage of drainage immediately northeast of the pond by a small alluvial fan (too small to be mapped separately in Figure 2). There is no indication of disturbed ground around the pond that might indicate that the depression containing the pond was excavated or dammed by people (e.g. miners).

Landslide movement in more recent times has overridden and obscured part of the area of the terraces, as evidenced by the abrupt truncation of terrace 5 southwest of Downeys Dam. It is likely that the terraces extend some distance to the west beneath this landslide mass.

Shotover fan-delta and alluvial terrace landforms

As discussed in section 2 of this report, the Shotover River transported a large volume of sediment into the enlarged Lake Wakatipu, and the fan-delta surface is the landform developed on these deposits. The surface is broad, locally with fine braided or dendritic channel patterns, and grades to the main higher lake level, about 45 m above present-day lake level (Barrell *et al.* 1994). West of Ferry Hill, river erosion during the downcutting of the Shotover following the natural lowering of lake level has removed most of the fan-delta, in places leaving a flight of alluvial terraces.

Alluvial fans

Where a stream exits from a confined channel, most especially at the foot of a slope, sediments carried by the stream may accumulate in a broad cone-shaped or fan-shaped (i.e. convex-up) distribution, creating a landform known as an alluvial fan.

Landslide and colluvial landforms

The landslides are mostly developed as a result of instability and failure of the schist bedrock in some of the steeper slopes within the Wakatipu Basin. Landslides are recognised on the basis of three main characteristics:

(i) a slope with irregular, stepped or hummocky topography
(ii) a downhill-facing step, known as a head-scarp, at the top of an irregular, stepped or hummocky slope
(iii) in some cases the presence of a general hollow in the slope formed by evacuation of material (e.g. the landslide on the northern flank of Queenstown Hill - Figure 2).

Colluvial aprons are variably shaped and orientated, and are found on or at the foot of moderate to steep slopes. They are characterised by rough to smooth ground surfaces, without bedrock outcrops, and are related to debris accumulations formed as a result of surficial slope processes such as rockfall and the sheet-wash of finer sediments.

3.2 Interpretation of landscape history, Arthurs Point

Two maps illustrate the writer's interpretation of the way the landscape would have looked at two key points in the comparatively recent geological history of the Arthurs Point area. One (Figure 3) represents the maximum extent of ice at the peak of the Last Glaciation, for which the writer adopts a nominal time of 20,000 years before present. Note that there is no direct dating of this event in the Wakatipu Basin – the age is inferred from correlation with dated deposits elsewhere in New Zealand. The second diagram (Figure 4) depicts the onset of deglaciation, and initial development of the Shotover fan-delta, at an assumed nominal time of about 15,000 years before present.

Reconstruction of the glacier extent and height is based in large part on the moraine ridge north of Littles Rd, and the ice terminus position indicated by moraines and kettle holes near the Malaghan-Dalefield Rd intersection, which indicate that ice advanced at least as far as Dalefield Rd. An ice surface height of at least 800 m above sea level over Queenstown is assumed to be needed to give the Wakatipu Glacier sufficient gradient to have flowed to its terminal moraines at Kingston, 400 m above sea level and 35 km down-valley from Queenstown. This assumption is compatible with the height of moraine ridges on Queenstown Hill.

The reconstruction implies that a steep ice gradient existed through the Queenstown Gorge. This is consistent with the narrowness of the gorge, which would have enhanced friction on the ice lobe. The ice lobe through Queenstown Gorge would probably have had an ice fall morphology, with extensive cracking and crevassing. The ice lobe that spread into the wider part of Wakatipu Basin east of Queenstown Hill would have had a less steep gradient commensurate with its greater width.

The reconstruction infers, speculatively, that the Shotover River had sufficient flow to erode the toe of the glacier, and prevent it extending north up the Shotover gorge. In order to achieve this the Shotover would have had to build up its bed to approximately 500 m above sea level near Arthurs Point (Shotover outwash plain, Figure 3). It is referred to as an outwash plain because the Shotover was carrying meltwater from glaciers in its headwaters. On this map there is an anomaly implied by the placement of this reconstructed outwash plain against the present-day topographic contours shown on the landslide slope immediately to the north. The contours imply that the river flows uphill and then downhill. This is an artefact resulting from the landslide having subsequently moved and bulged out into the valley, following melting of ice, and downcutting by the Shotover River.

As the ice advance began to wane (after the point in time depicted in Figure 3), the height of the ice surface would have begun to lower. Outwash deposits were built out over part of the ice in the Malaghan-Dalefield Rd area during this phase and the main mass of ice must still have occupied the area mapped as the ice-evacuated basin (Figure 2). Outwash terrace 1, formed at this time, is probably a late-stage remnant of the Shotover outwash plain depicted in Figure 3. As the glacier continued to diminish, meltwater streams would have begun issuing from the glacier front at progressively lower levels, causing the streams to cut down into their beds. The result was the formation of the flight of outwash terraces at Malaghan Road.

The second reconstruction (Figure 4) depicts the development of a new course of the Shotover down into the newly-forming enlarged Lake Wakatipu, after the slowly melting ice created a hole that captured the river flow, causing it to abandon its likely earlier course down the Malaghan Road valley. The absence of fan-delta deposits in the ice-evacuated basin, and moraine topography well below the level of the fan-delta, implies that ice was still occupying this basin during formation of the fan-delta. This is assumed to be "dead ice" that had been cut off from or abandoned by the flowing glacier. This reconstruction assumes that the Wakatipu Glacier had only retreated a short distance at this time, and was still occupying much of the Lake Wakatipu basin. The reason for this assumption is that just north of Ferry Hill, gravely sediments of the fan-delta are overlain by glacial till, indicating a late-stage re-advance of the glacier while the fan-delta was forming.

3.3 Significance of Arthurs Point landforms

The moraine, ice-sculpted bedrock, terrace and landslide landforms of the Arthurs Point area provide dramatic evidence of the nature, relationship and timing of the events and complex processes that have formed the general Wakatipu landscape. The ice-evacuated basin, and sequence of outwash terraces complete with remnant moraines and kettle holes, between the Shotover River and the Malaghan–Dalefield Rd intersection, is the best preserved, most easily accessible example of a glacier terminus in the Wakatipu Basin. It has the advantage of having clear features that could be readily explained to and understood by a layperson in their gaining of an understanding of glacial processes. It is rare to have, in an easily accessible location, such a well-preserved ice-evacuated basin. Commonly, lake-water and/or younger sediments fill and obscure the detail of such basins. The Arthurs Point landforms are as good a set of examples of these features as can be found anywhere in New Zealand, although other similar examples exist elsewhere in the South Island.

Of special note is the very large landslide that is traversed by Skippers Road (Figure 2). This is as good and dramatic an example of a large schist landslide as found anywhere in New Zealand, and is clearly visible from many aspects, and accessible by road. In addition it is rare for a landslide of this size and type to have left such clear evidence of it having overridden and truncated terrace landforms at its toe.

Of particular scientific significance is the evidence, preserved by landforms near Arthurs

Point, of how glacial advances have modified the course and behaviour of the Shotover River. Another scientifically significant feature is the moraine ridge on the slope north of Littles Road. This ridge records the maximum height and position of a major ice advance, and provides key data control for glacial reconstruction, as is demonstrated in Figure 3.

In summary the landforms in this small area between Arthurs Point and Dalefield contain all the key elements that both specialists and lay-people need to gain an insight into the processes that created the Wakatipu Basin landscape. They include the best and clearest examples of Last Glaciation glacier terminus moraine and outwash landforms in the Wakatipu Basin.

4. CONCLUSIONS

The Arthurs Point area contains a suite of landforms produced by the following sequence of events:

- glacial advance, accompanied by erosion and scour of bedrock by moving ice
- erosion and accumulation of sediments by meltwater streams and by the glacier itself
- ice melting and glacial retreat, accompanied by formation of lakes, and the progressive infilling of depressions, including the lakes, with river sediments
- progressive readjustment of the landscape following final ice melting, including collapse of the ground by melting of buried ice, downcutting of streams, rivers and lake outlets, and the adjustment of slopes towards less steep, more stable configurations by landsliding and colluvium accumulation.

While there are other similar examples within the wider South Island context, the Arthurs Point landforms are well-preserved, accessible, textbook examples of features that reflect these types of landscape-shaping processes. Collectively, in this small area, they are the best example of these landforms in the Wakatipu Basin. They are of value not only to scientists seeking to reconstruct and understand the nature and rate of landscape-shaping processes, but are also an ideal example for conveying to laypersons an understanding of the processes that shaped the Wakatipu landscape.

ACKNOWLEDGEMENTS

Phil Glassey and Ian Turnbull of GNS, Dunedin, have reviewed this report.

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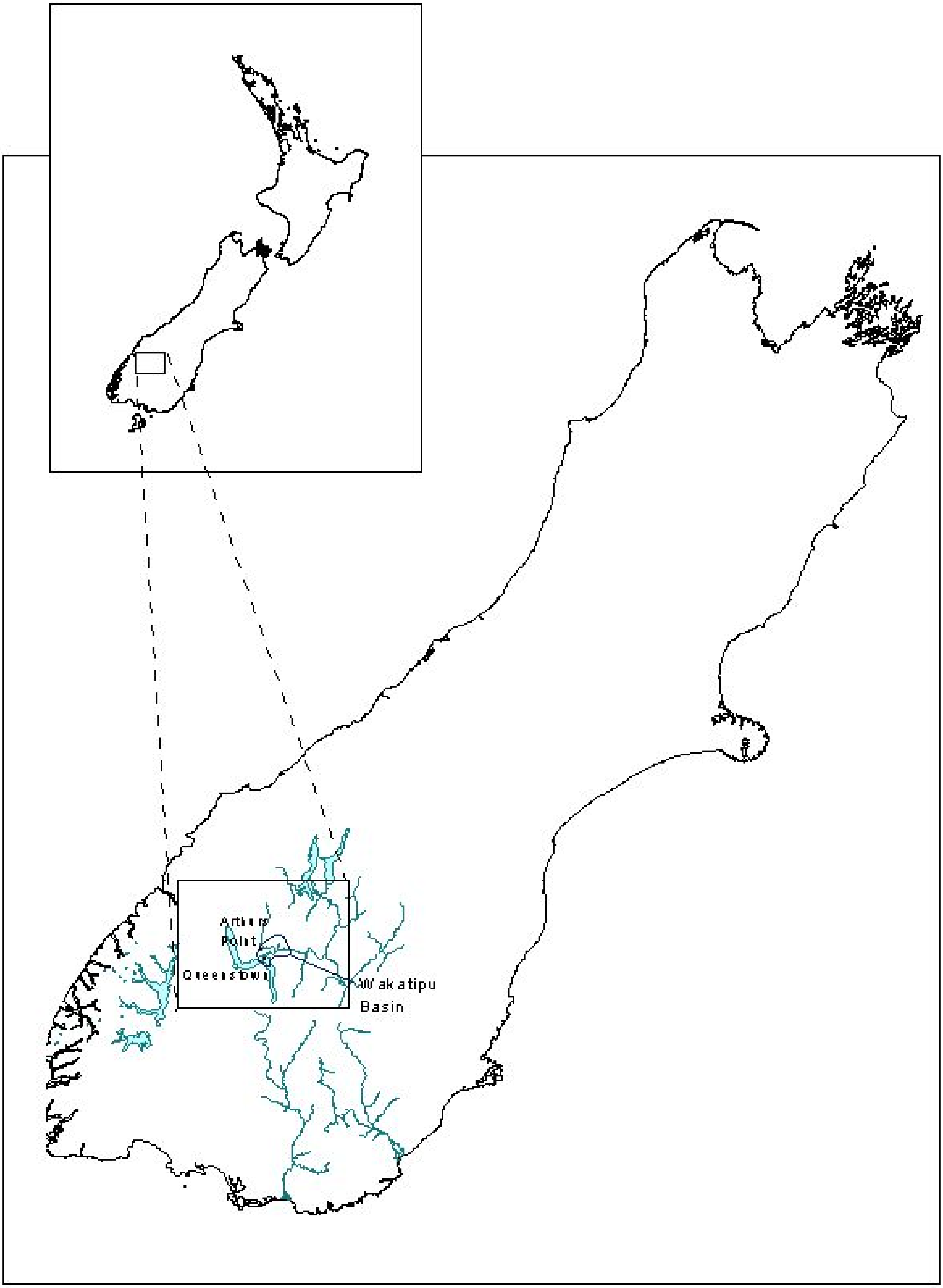

FIGURE 1 - Location

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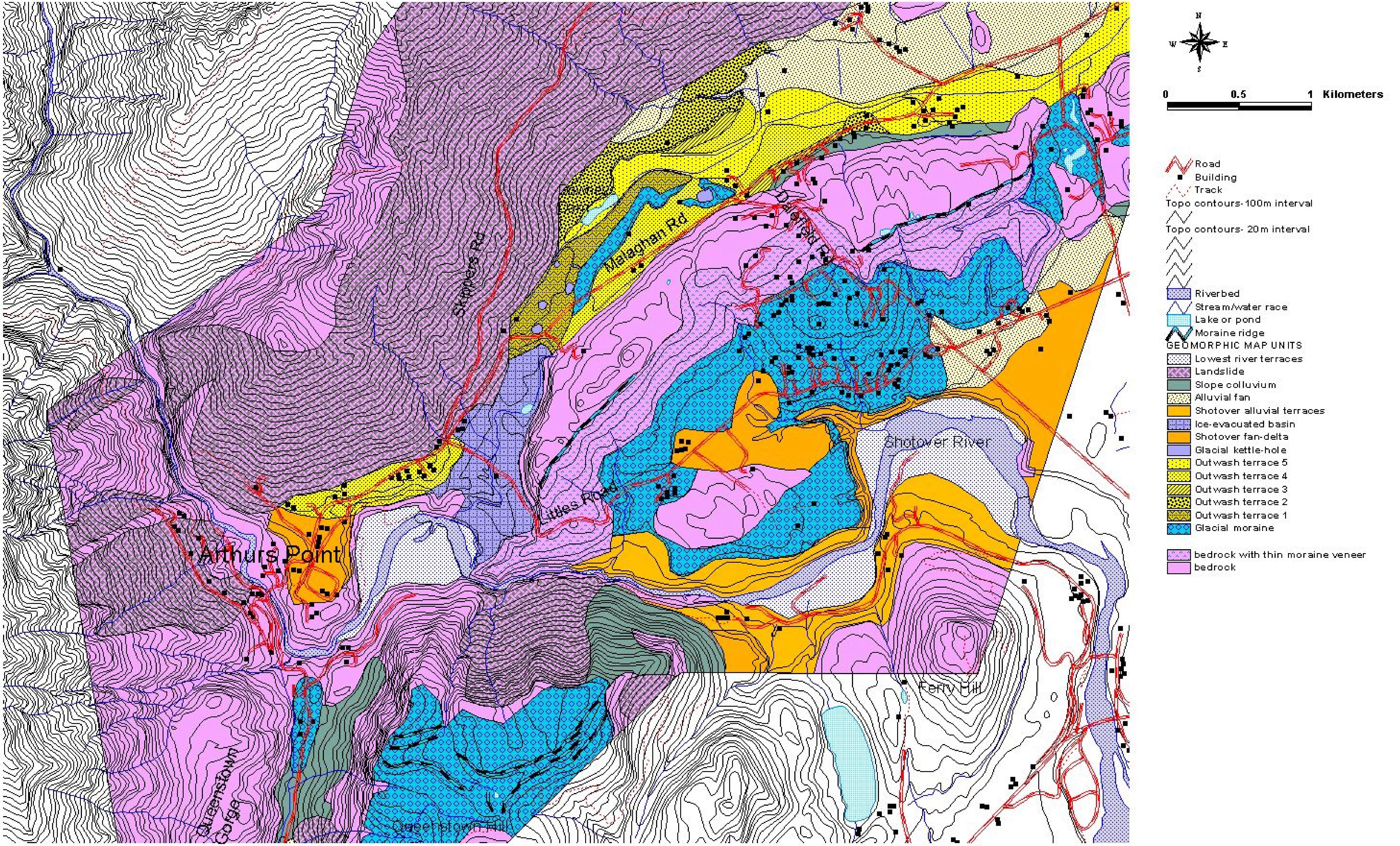

Topographic information is from
Land Information New Zealand
1:50,000 scale digital data

Arthurs Point area - landform interpretation

FIGURE 2
Scale: 1:30,000 (at A3 size)
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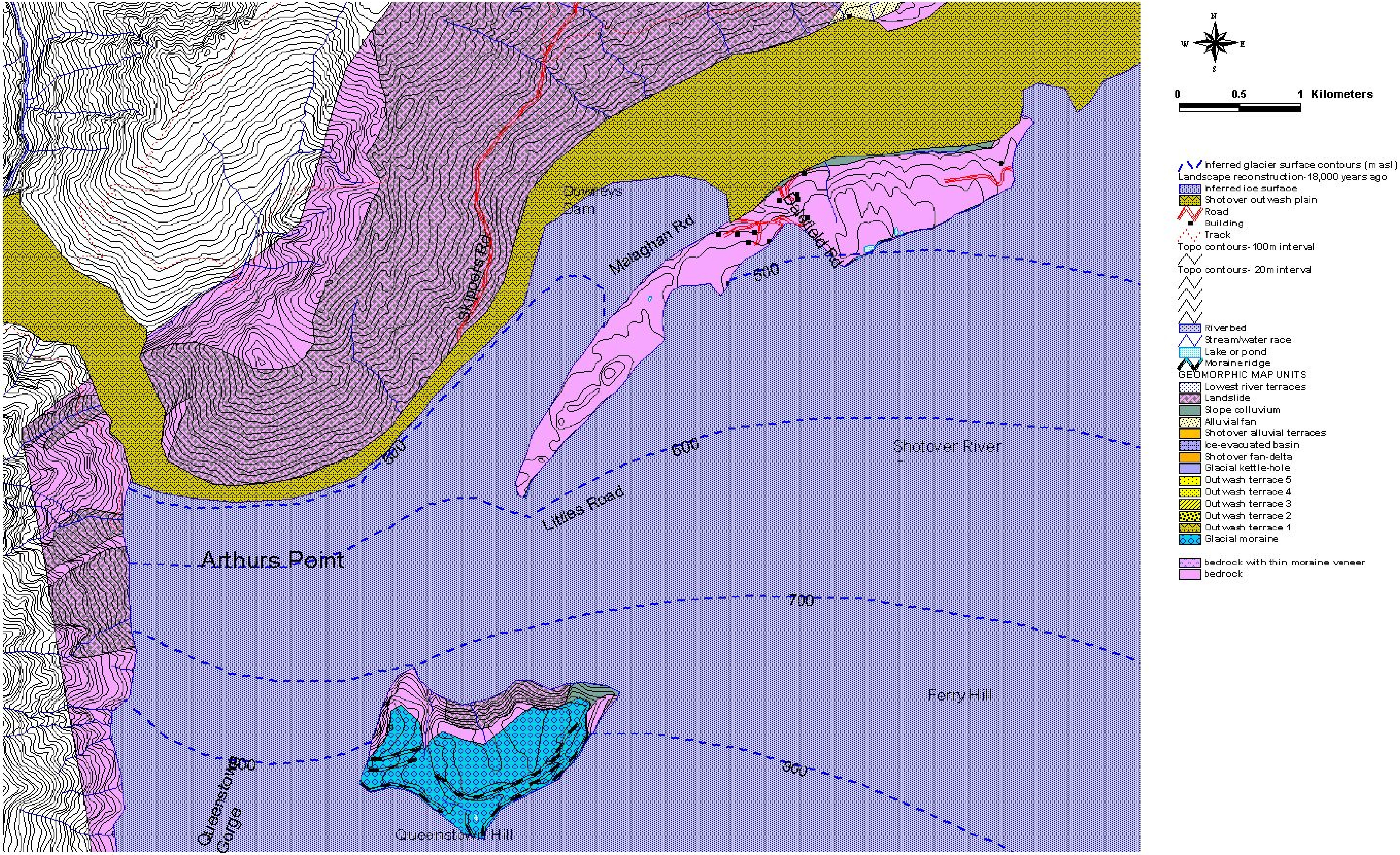

Topographic information is from
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Arthurs Point area - landscape reconstruction ~18,000 years ago

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FIGURE 3
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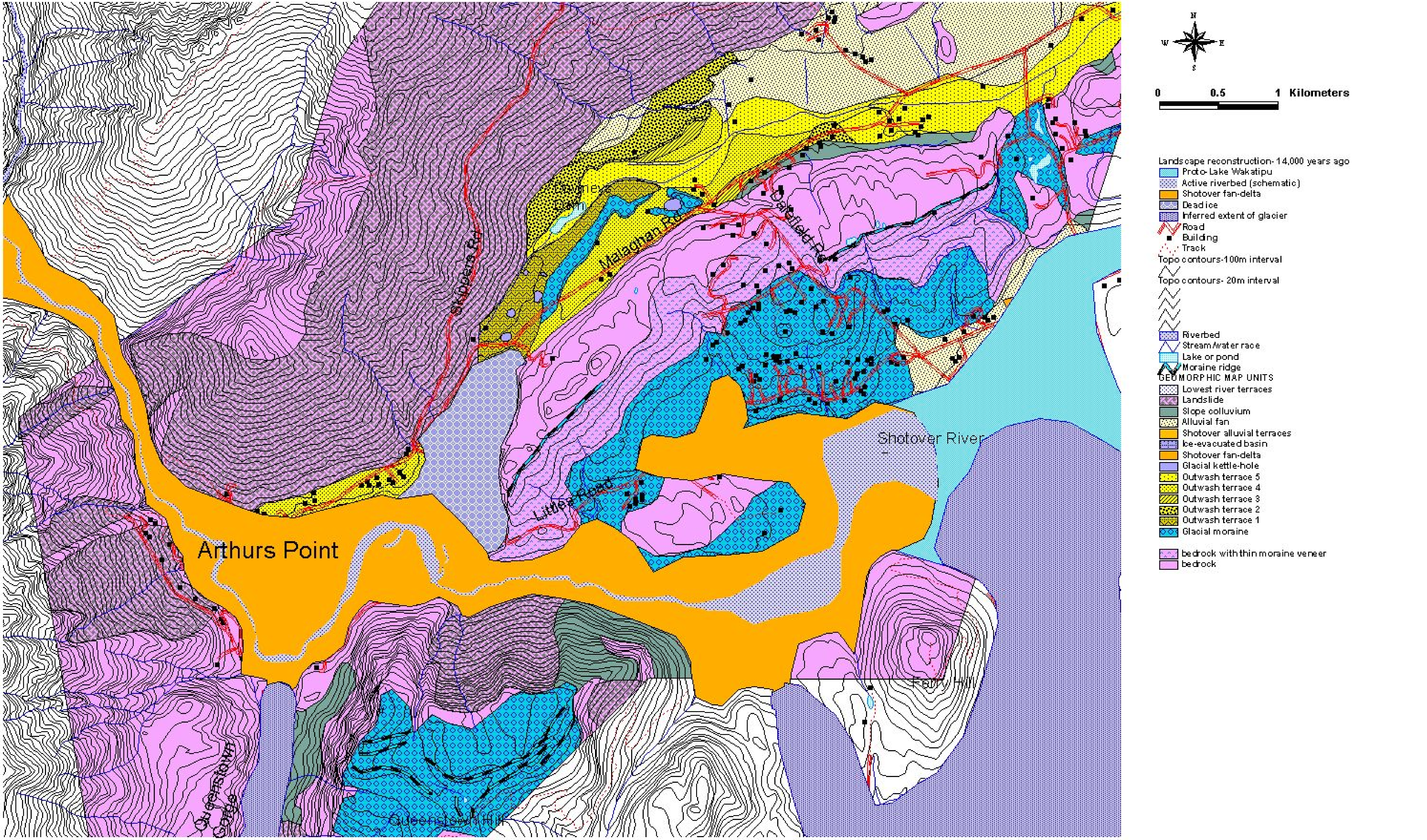

Topographic information is from
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1:50,000 scale digital data

Arthurs Point area - landscape reconstruction ~14,000 years ago

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FIGURE 4
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Drawn: DB
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94/39

Surficial geology of the Wakatipu Basin, Central Otago, New Zealand.

D J A Barrell
B W Riddolls
P M Riddolls
R Thomson

1994

Surficial geology of the Wakatipu Basin, Central Otago, New Zealand

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Institute of Geological & Nuclear Sciences science report 94/39

Institute of Geological and Nuclear Sciences Limited
Lower Hutt, New Zealand
1994

RECOMMENDED BIBLIOGRAPHIC REFERENCE

Barrell, D J A, Riddolls, B W, Riddolls, P M, Thomson, R, 1994. Surficial geology of the Wakatipu Basin, Central Otago, New Zealand. Institute of Geological & Nuclear Sciences science report 94/39. 31 p., 2 maps.

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ISSN 1171-9184
ISBN 0-478-08833-7

ABSTRACT

This report, accompanied by a 1:50 000 scale geological map and illustrative cross sections, outlines the distribution of surficial deposits within the Queenstown-Arrowtown area (Wakatipu Basin), western Central Otago, New Zealand. This geological information is intended to provide a framework for focusing future research, as well as providing basic geological data which may benefit development of the region.

Surficial deposits form a discontinuous cover on a basement of Otago Schist, and on the basis of depositional origin have been broadly subdivided into three groups: (i) glacial deposits; (ii) stream, river and lake deposits; and (iii) slope deposits. On the flanks of the ranges which surround the basin, slope deposits comprising landslides and colluvium predominate, with some remnants of glacial, stream, river and lake deposits which are thought to generally predate the last glaciation. The floor of the basin is mantled by glacial, stream, river and lake deposits, which are thought to have been laid down during and since the last glaciation. Future geological studies need to focus upon detailed mapping of the deposits, which will improve understanding of the geological and geomorphological evolution of the area.

Keywords. Central Otago, Lake Wakatipu, Wakatipu Basin, Queenstown-Arrowtown Basin, Gibbston Basin, The Remarkables, Kawarau River, Shotover River, surficial geology, Quaternary geology, glacial deposits, fans, deltas, lake deposits, beaches, landslides, urban development.

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LIST OF PHOTOS:

1. INTRODUCTION

This report describes the results of a programme of reconnaissance geological mapping, undertaken to define the nature and distribution of surficial geological deposits within the Wakatipu Basin, in western Central Otago. The information is presented on an accompanying 1:50 000 scale map, and interpretative cross sections are provided to illustrate inferred subsurface relationships. The report contains expanded discussion of aspects of the geology.

Wakatipu Basin is an informal geographic term which here refers to the low relief areas extending eastward from the middle reaches of Lake Wakatipu to Nevis Bluff in the Kawarau valley, as well as the slopes of the flanking ranges. It mainly comprises the Queenstown - Arrowtown area, but also includes the north-south trending valley along the foot of The Remarkables mountains as far south as Wye Creek, the lake-margin areas west to Bobs Cove, and the Gibbston Basin (refer to map, back pocket).

1.1 BACKGROUND

Encircled by mountain ranges, the Wakatipu Basin is widely regarded as a rural landscape of outstanding natural grandeur (Boffa Miskell Partners Ltd, 1991). The region is experiencing a major phase of development, largely due to growth of the tourism industry. This is exerting pressure for land-uses and development other than agriculture, which has traditionally been the predominant land-use, and as a result, the demand for natural resources and threats to scenic qualities of the landscape are increasing. Geological and geomorphological factors are integral parts of the resources and landscape, and need to be taken into account in resource management planning (Riddolls Consultants Ltd, 1993).

The geological deposits within the first few tens of metres beneath the ground surface are important, because they form the foundations for buildings and other structures, provide construction materials, and can be a source of water. These near-surface (**surficial**) geological deposits comprise a variety of materials which mantle a basement of older rock. They include poorly consolidated sands and gravels laid down by rivers and streams, fine silty sediments which accumulated in the beds of ancient lakes (now drained or infilled), massive sandy, muddy and gravelly sediments which were deposited by ancient glaciers, as well as debris formed by landslide movement.

Many of the surficial deposits are relatively young, and the processes which formed them are often still occurring. These processes, which include slope movement (landslides), flooding, erosion, sedimentation, and earthquake-induced movement, occur episodically and are potential **geological hazards**. The risk posed by these hazards may be minimised by long-term planning, as long as the nature and magnitude of the hazard is understood.

Knowledge of surficial deposits and the processes which formed them, is therefore essential to geological hazard assessment, and such knowledge can consequently be used to minimise the potential for problems associated with land development.

A considerable number of geological, geotechnical and land-use studies have been carried out in the region. They mainly relate to specific sites, areas or features, and have mostly been prepared for particular organisations or clients, and in many cases the information is not widely available.

A geological bulletin on the Queenstown region was published early this century (Park, 1909), containing generalised 1:63 360 scale maps. The best published geological map which covers the Wakatipu Basin is the 1:250 000 scale Wakatipu sheet (Wood, 1962), although it provides information of a regional nature, rather than local detail. There are more detailed published maps for nearby areas (Turnbull, 1980, 1988) but these do not extend into the main Queenstown - Arrowtown part of the basin. The 1:50 000 scale map which accompanies the present report sets out our current understanding of the distribution and general nature of surficial deposits in the Queenstown - Arrowtown area, enabling identification of geological aspects which warrant future research. It is therefore a preliminary database, which it is hoped will encourage and help focus further studies, eventually leading to a better understanding of the geological and climatic history of the area.

1.2 SCOPE OF MAP AND CROSS SECTIONS

The 1:50 000 map shows the **surficial geology** of the Wakatipu Basin, which includes the distribution of surficial deposits as well as indicating areas where basement rock is exposed. The map does not show any of the geological structure within the basement rock, including recently active faults, and readers should refer to Turnbull and Forsyth (1988) and Mortimer (1993), and references therein, for information on structure and faulting. In addition, all issues relating to minerals and mining are excluded from the scope of this study.

Geological cross sections are provided to illustrate the topography of the Wakatipu Basin in relation to inferred thicknesses of surficial deposits. Detailed cross sections are included to illustrate the inferred subsurface extent and interelationships of the different deposits.

The map and cross sections are intended to act as a guide to the nature and distribution of the deposits, and for any project requiring subsurface information, the inferences presented on the map and cross sections should not be used as a substitute for site-specific investigations.

1.3 METHODS OF INVESTIGATION

Information presented here has been collated by a group of geologists, incorporating some existing geological information, but the work is mostly based on new mapping involving both ground-based investigations and aerial photo studies. Areas covered by each method are indicated on the bottom left corner of the map sheet.

Ground-based reconnaissance mapping has involved examination of typical exposures of geological materials in roadcuts, slopes, and in the banks of lakes, streams and rivers. There are extensive tracts of the map area where exposure of geological materials is obscured by vegetation and soil, and many of the boundaries between geological units shown on the map are based upon inference and interpretation of landforms, rather than direct geological information. As a consequence, the positions of geological boundaries are only approximate.

Mapping based upon aerial photograph studies involved interpretation of the nature and extent of geological units from landforms. In many instances, information from earlier maps and field surveys were used as a guide to geological interpretation.

1.4 RELATIONSHIP TO OTHER RECENT GEOLOGICAL MAPPING

Cunningham (1994) has compiled a geological map of the Wakatipu Basin at 1:25 000 scale, as part of a Master of Science research project carried out through the University of Canterbury. The map presented here incorporates a significant amount of Cunningham's mapping, but being at a smaller scale (1:50 000), this map shows fewer units and less detail than Cunningham's map. Some additional data has been gathered since the completion of Cunningham's mapping work, and the interpretations presented here may therefore differ slightly from those of Cunningham (1994). However, these differences are probably not significant at the scales used, particularly given that both maps are the result of reconnaissance-style mapping, and the information on both maps will need modification in the future as more detailed information becomes available.

2. GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

This section provides a brief synopsis of the geological evolution and landscape development of the western Central Otago region, with particular reference to the Wakatipu Basin. More detailed information is given by Turnbull and Forsyth (1988), Mortimer (1993), and references therein.

2.1 PRESENT PHYSIOGRAPHY

Lake Wakatipu occupies a long U-shaped valley which has been scoured out by the action of glaciers. The Queenstown - Arrowtown area lies in a broad, though not as deeply eroded, arm of the valley, extending eastward through to the Gibbston Basin. The lake stands at an elevation of about 310 metres, and is drained by the Kawarau River, which flows generally eastward via the Gibbston Basin and joins the Clutha River at Cromwell, some 15 kilometres (in a straight line) east of the mapped area. Two main tributaries, the Shotover and Arrow Rivers, join the Kawarau River in the Wakatipu Basin.

The landscape in the Queenstown-Arrowtown basin comprises a mixture of fans, terraces and broad ridges or plateaux, at elevations of between about 350 and 500 metres, with several isolated hills which rise to elevations of between 600 and 900 metres. There are numerous small streams and ponds, and several small lakes, including Lake Hayes. In the northeast of the map area, the Crown Terrace is an elevated (600 to 700 metres) area of low-relief which slopes gently towards the main part of the basin. Steep ranges surround Lake Wakatipu and the Wakatipu Basin (see Photos 1 and 2) , and rise to elevations of between about 1000 and 2000 metres, broken in a few places by the gorges of major rivers. The Gibbston Basin is flanked by moderate to steep terrain rising to 1900 metres.

2.2 BASEMENT GEOLOGY

2.2.1 Schist

Otago Schist (Mortimer, 1993) forms the basement rock which underlies the entire Wakatipu Basin area, and is the source of much of the debris and sandy, gravelly and muddy sediments which form the surficial deposits within the basin.

The Otago Schist is a metamorphic rock which has formed from an original sequence of sedimentary rocks (sandstones and mudstones) and minor volcanic rocks. The metamorphism took place during the **Rangitata Orogeny**, a major phase of mountain-building that affected the New Zealand region during the Jurassic and Cretaceous Periods, between about 200 million and 70 million years ago (Mortimer,1993). Many of the structural features and weaknesses within the schist were formed during this time.

Parts of the original rock sequence, which are only slightly metamorphosed, occur to the west of Lake Wakatipu, and are known as the Caples Terrane. Caples Terrane rocks include distinctive, hard sandstones, which are often termed "greywacke". (Gravel derived from these rocks has been transported into the Wakatipu Basin by glacial action, and the presence of greywacke "exotics" within surficial deposits indicates either a glacial origin for the deposit, or that the deposit contains reworked glacial debris).

In typical unweathered exposures, the schist is a hard, strong, well layered rock. The layering (known as "foliation") is due to segregation of particular minerals into bands during the extreme heat and pressure of metamorphism. The dark-coloured layers are rich in platy minerals such as mica, and these inherently weak minerals give the rock a tendency to split along these layers if struck with a hammer. Other types of weakness within the schist include joints and faults. Joints are planar fractures or breaks in the rock. Faults are breaks in the rock, along which slipping or shearing movements have occurred, resulting in the crushing or pulverisation of the rock along the fault. Ancient fault zones within the schist may contain seams of crushed rock up to tens of metres wide and which may extend laterally for many hundreds or thousands of metres.

Orientations of these weaknesses in the rock vary from place to place around the Wakatipu Basin, and considerable variation can occur over quite short distances. However, the frequency and orientation of the weaknesses are influential in the development of landsliding within schist slopes. It may be that areas of the basin that have been more deeply and extensively eroded are underlain by schist containing more weaknesses than occur in areas which appear more resistant to erosion.

2.2.2 Tertiary sediments

Between the end of the Rangitata Orogeny, and the middle of the Tertiary Period, about 30 million years ago, the area which is now Otago was gradually worn flat by erosion, forming a broad, low-relief landscape (often referred to as a "peneplain"). Localised subsidence of the Earth's crust in the middle Tertiary Period briefly allowed the sea to extend from the west into what is now the Wakatipu area (Turnbull, Uruski and others, 1993, and references therein). Remnants of marine sandstones, limestones and conglomerate, which were deposited during this incursion of the sea, are preserved at **Bobs Cove**, and as small, isolated strips within the Shotover catchment to the north of the mapped area. More information on these sediments is given by Turnbull and others (1975), and by Turnbull and Forsyth (1988).

In later stages of the Tertiary Period, between about 20 million and 5 million years ago, broad subsidence of the Central Otago region caused streams to build up their beds and lakes to form, resulting in the deposition of layers of quartz gravel, silt, clay and peat (now turned to lignite) across much of the Central Otago peneplain. These deposits are known as the Manuherikia Group. Remnants occur at **Coal Pit Saddle** and near **Crown Saddle**, on the slopes above Gibbston Basin, consisting of poorly cemented layers of sand, mud and lignite. Downslope from the exposures, some of the Tertiary sediments have been incorporated into large landslides, seated on the underlying schist.

2.3 DEVELOPMENT OF THE PRESENT LANDSCAPE

2.3.1 Folding, faulting and uplift

Within the last 5 million years or so, much of New Zealand, including the Otago region, has been deformed and uplifted due to compression of the Earth's crust, an event known as the **Kaikoura Orogeny**. The mountainous areas of the South Island have been formed as a result of this uplift.

In Central Otago, this compression has caused folding and faulting in the Earth's crust. These folds and fault blocks are expressed at the ground surface as ranges and basins (McSaveney and Stirling, 1992). The upfolds and uplifted blocks have formed many of the Otago ranges, whereas the downfolds and downtilted blocks have formed large valleys or basins, such as the Cromwell basin, and the Wanaka-Hawea basin. Erosion has stripped most of the Tertiary sediments off the ranges, but these sediments are still preserved in parts of some basins. The folding and faulting are superimposed on a background of ongoing regional uplift, so that areas which are experiencing downfolding or downtilting may also be rising relative to sea level, but at a much slower rate than adjacent uplifted ranges.

In the Wakatipu Basin, downfolding or infaulting associated with the northeast-southwest trending fault systems (the Moonlight Fault Zone and Nevis-Cardrona Fault System) have been responsible for preserving the remnants of Tertiary sediments at Bobs Cove and at Coal Pit Saddle. Elsewhere in the Wakatipu Basin, absence of a reference datum, such as is provided by the Tertiary sediments, makes the extent of folding and faulting difficult to determine. It is possible that the Queenstown-Arrowtown basin and the valley occupied by Lake Wakatipu are downfolded areas, which have been cut into and modified by glacial action, but not principally formed by erosion. Alternatively, these areas may have been uniformly uplifted during the Kaikoura Orogeny, and these basin and valley areas have been entirely formed by glacial and river erosion, leaving the surrounding ranges standing as remnants of the uplifted land.

2.3.2 Glacial events

During the last 2.5 million years or so, the global climate has undergone a series of fluctuations, resulting in periods of generally cold temperatures (**glacials**) separated by periods of relative warmth (**interglacials**). It is probable that at least 20 separate glacials have occurred during the last 2.5 million years (e.g Fink and Kukla, 1977). Each of the glacial or interglacial periods are believed to have had durations of many tens of thousands of years, although there have been minor fluctuations between relative warmth and coldness within each period. The most recent glacial period (in New Zealand referred to as the Otira Glaciation) is thought to have persisted from about 75 000 years ago until about 14 000 years ago (Suggate, 1990). We are currently in an interglacial period, known in New Zealand as the Aranui Interglacial, although the international term "Holocene" epoch, which refers to the last 10 000 years of geological time, is often used to describe deposits of Aranuian age.

During glacial periods, summer temperatures were so low that winter snow did not melt from the main ranges, and as a result, extensive snowfields accumulated in the high-precipitation areas along the Southern Alps and large glaciers spread down the valleys. As the ranges have risen, glacial action has progressively scoured out the valleys and basins. Away from the Main Divide, permanent snowfields formed above elevations of about 1500 metres on the highest ranges (e.g. The Remarkables) during glacial periods, producing localised cirque glaciers that scoured out basins near the range crest.

Ice was brought down by the Wakatipu Glacier, and where the glacier met The Remarkables, ice spilled northeastwards towards Arrowtown, forming the Wakatipu Basin ice tongue, while the main Wakatipu valley ice tongue continued south towards Kingston. During some glacial periods, the Wakatipu Basin ice tongue extended for some distance down the Kawarau River, and subsidiary ice tongues pushed inland up the Arrow and Shotover valleys, while the Wakatipu valley ice tongue has at times extended south beyond Athol in the Mataura valley. Interpretations of aspects of the glacial history within the Wakatipu Basin area have been given by Mathews (1967), Brockie (1973), Bell (1982, 1992) and Turnbull and Forsyth (1988).

As well as causing erosion, the glaciers have left a variety of deposits within the Wakatipu Basin, as have the streams, rivers and lakes which formed after the glaciers retreated. In areas which have been affected by successive phases of glaciation, such as the Wakatipu Basin, the deposits formed tend to have a complex history. During glacial periods, ice overrode lower-lying parts of the landscape, modifying or removing any existing surficial deposits, and further eroding the schist bedrock.

Around the margins of the Wakatipu Basin, there are indications of glacially eroded benches and spurs at elevations of up to 1500 metres (see Photo 1). These high-level features appear to be relatively old, in comparison to the fresher ice-sculptured schist topography below about 600 metres elevation in the Arrowtown - Lake Hayes area. This may indicate either that earlier glaciers were much larger than more recent glaciers, or that higher-level deposits were formed before the floor of the basin had been eroded to its present depth. It has been postulated that the Crown Terrace is a remnant of an old floor level of the Wakatipu Basin, and that progressive downcutting of the basin floor over time is due to ongoing uplift of the region, where successive phases of glacial erosion have worked to maintain the basin floor at a similar elevation relative to sea level, rather than cutting the basin to deeper levels (Bell, 1982, 1992).

Remnants of glacial deposits, and higher-level stream, river and lake deposits around the margin of the Wakatipu Basin are of considerable geological importance because they provide evidence of older glacial and interglacial events, which help to explain the evolution of the Wakatipu landscape, and provide indications of past climatic changes.

2.3.3 Post-glacial events

Within the Queenstown - Arrowtown part of the basin, most of the surficial deposits are believed to have formed during and after the last (Otira) glaciation. Lake, delta and beach deposits are extensively developed in the vicinity of Lakes Wakatipu and Hayes, below about 400 metres elevation. This provides clear evidence that Lake Wakatipu was formerly much higher than as at present, and formed a continuous body of water through to Lake Hayes, as well as extending north from Lower Shotover into the Dalefield - Speargrass Flat area (see Photos 2 and 3), and also occupying the valley between Frankton and Drift Bay, leaving the Peninsula Hill area as an island. It is probable that the high lake level was due to impoundment by accumulations of glacial deposits at Kingston and near Morven Hill that formed terminal moraines of the last glacial advance.

Brockie (1973) indicates that at the southern end of Lake Wakatipu, a drainage outlet through the Kingston moraine was established at about 400 metres elevation, and progressively became incised through the glacial deposits, eventually reaching schist bedrock at about 355 metres elevation. There was a major stillstand in lake level at this elevation, with the development of prominent beaches. Many of the fan/deltas are graded to the 355 metre lake level, and extensive deposits of lake silt accumulated in the vicinity of the deltas. The

Kingston outlet channel was eventually abandoned as the Kawarau River outlet became incised to lower elevations. As the lake receded to its present level, several poorly defined intermediate-level beaches were cut, and many of the streams and rivers have cut flights of terraces into their fan/delta deposits as they readjusted to maintain grade to the diminishing lake. Lake Hayes became impounded by the deposits of the Shotover fan/delta as lake levels fell.

Colluvium and landslide deposits have accumulated on slopes which were stripped clean by the last ice advance, and new fans have formed, whereas in parts of the basin beyond the limits of the last advance, these deposits have continued to accumulate since earlier glacial times. In places, accumulations of wind-deposited silt and sand (loess and sand dunes) mantle older deposits or are interlayered with coeval deposits. These wind deposits are widespread but are generally thin (less than two metres), and for clarity have not been identified on the map.

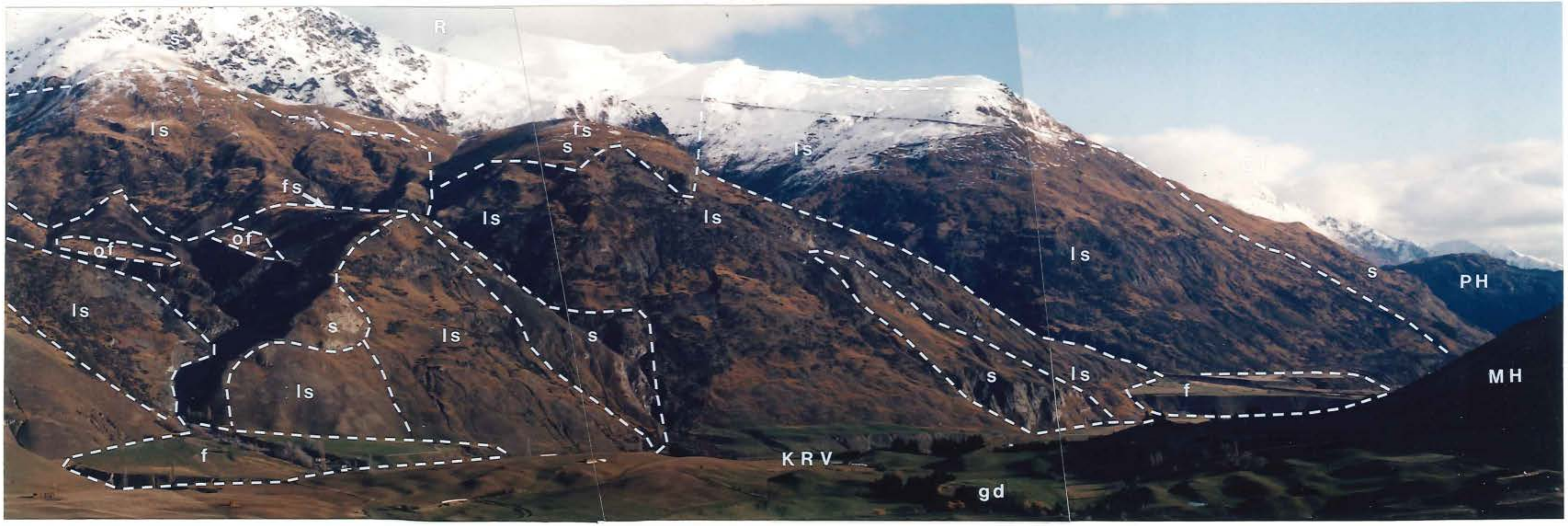

Photo 1. Panorama looking southwest from Crown Terrace towards northern end of The Remarkables range (R). The incised valley of the Kawarau River (KRV) runs from right to left along the foot of the range, although the river bed is obscured from view. The shaded slope of Morven Hill (MH) lies at the far left, and Peninsula Hill (PH) and Cecil Peak (CP) can be seen in the distance. The road to Remarkables Ski Field can be seen near the skyline of the range.

The steep front of the range have been formed by the erosive action of glaciers, and the flattened spurs (fs, arrowed) may also be of glacial origin. The low-lying hummocky terrain in the foreground near Morven Hill indicates the presence of glacial deposits (gd). Very extensive landslides (ls), formed since the retreat of ice, are characterised by hummocky and broken topography, and the underlying schist bedrock (s) is exposed in only a few places on the lower slopes. Large fans (f) have developed where the gullies of Owen Creek (left) and Rastus Burn (right) exit from the foot of the range. The lower end of each fan has been subsequently cliffed due to erosion by the Kawarau River. Remnants of older fan deposits (of) are preserved at higher levels up Owen Creek.

3. SURFICIAL DEPOSITS

3.1 GLACIAL DEPOSITS

All of the glacial deposits have been grouped together and are shown on the map as a single unit, due to their complexity and variability from place to place. Definitions of the terms which are used in this report to describe the different types of glacial deposits are given in Appendix A.

The glacial deposits include **tills**, which have been deposited directly by glacier ice, and what are referred to as **ice-margin sediments**, which have been deposited by water, adjacent to or beneath the ice. Tills are typically poorly layered or homogeneous, and may be either loose materials (ablation till) or compact materials (basal till). Ice-margin sediments are typically layered, and although they may be of a very similar nature to the stream, river and lake deposits identified on the map, they may be distinguished by their occurrence in proximity to till, and by their typically disrupted or deformed layering. All these deposits characteristically contain a significant proportion (up to 30%) of Caples Terrane greywacke gravel. The term **moraine** is used here to refer only to the characteristic landform which has developed on the deposits of till and/or ice-margin sediments (see Photo 1). On the map, much of the area shown as glacial deposits has been mapped principally by the presence of moraine landforms, as there is little exposure to indicate the nature or thickness of the underlying deposits.

Glacial deposits are widely distributed throughout the Wakatipu Basin, and are inferred to extensively underlie the younger post-glacial deposits of the basin (see cross sections). The glacial deposits probably include remnants of at least two separate glaciations, and the following paragraphs outline their general distribution and nature.

Crown Terrace area. The highest deposits lie about 4 kilometres eastnortheast of Arrowtown, at about 900 metres elevation, in an area known as Brackens Gully. They comprise lateral moraine remnants which locally rest on terrace alluvium, and typically consist of unweathered to slightly weathered, variable sands and gravels with disrupted layering, interpreted to be ice-margin sediments and ablation till. Along the western margin of the Crown Terrace, at elevations of between 600 and 670 metres, there are variably dissected moraines composed of slightly weathered, compact basal till and loose ablation till.

Across the Kawarau River from the southern end of the Crown Terrace, near Cowcliff Hill, till and ice-margin sediments occur at elevations of between 470 and 510 metres (grid reference F41 864 690), overlain by lake sediments and terrace alluvium (Bell, 1977; pers.comm., 1994).

***Gibbston Basin*.** Although the broad U-shaped profile of the basin suggests that it owes its origin to the scouring action of ice, glacial deposits within the basin are rare. In Camp Creek (grid reference F41 900 680), at about 460 metres elevation, there is exposure of slightly to moderately weathered, intermixed till and ice-margin sediments, overlain by fan deposits. About 2 kilometres north of the Camp Creek exposure, Bell (1976, 1977) identified a moraine-style hummocky topography on an extensive bench centred at F41 890 680, between 500 and 540 metres elevation (Gibbston Moraine of Bell, 1977, 1982, 1992, and of Turnbull, 1988). However, evidence presented by Thomson (1994) suggests that this topography may be better attributed to the occurrence of a large schist landslide (the Resta Road Slide), and accordingly it is shown on the map as a landslide deposit.

***Crest of The Remarkables*.** Within basins on The Remarkables, at elevations above about 1500 metres, there are glacial deposits formed by localised cirque glaciers. Lake Alta is ponded within some of these deposits.

***Western flank of The Remarkables*.** At elevations ranging from about 350 metres on the valley floor, up to about 900 metres on the range, the Wakatipu Glacier has deposited homogenous to coarsely bedded, sandy gravel and gravelly silt, with inclusions of till (Watts, 1988). Lateral changes from fine grained to coarse grained material occur over short distances, and they appear to be a mixture of ice-marginal fluvial sediments, deposited as kame terraces, and till deposited from melting ice. The deposits overlie higher-level fan deposits, and thickness of the glacial deposits varies from a few metres on higher slopes to more than ten metres on lower slopes. They have been extensively dissected by streams draining from the Remarkables, and are partially overlain by younger fan deposits.

***Crest of Queenstown Hill*.** Glacial deposits form a discontinuous mantle on the broad crest of the hill, between about 700 and 900 metres elevation. The moraine morphology suggests that at least two phases of deposition are preserved here.

***Main part of the Wakatipu Basin*.** This area includes the Queenstown-Kelvin Heights, Arthurs Point, Arrowtown and Arrow Junction areas. The schist rock which forms the floor of the basin has a distinctive ice-carved morphology (Photo 2), and in many places there is a mantle of glacial deposits, at elevations ranging from about 300 to 470 metres (Photo 1). In addition, on the northern flank of Morven Hill, near Lake Hayes, there is an isolated area of moraine at between 500 and 600 metres elevation.

The glacial deposits are of variable composition and texture, and include basal till, ablation till and ice-margin sediments. At many locations throughout the basin, large boulders of schist or greywacke lie on the ground surface, and are interpreted to be "glacial erratics", which were carried by the glacier and left stranded when the ice melted. Good examples are seen at the Kelvin Heights golf course and in the Queenstown Gardens.

Examples of presumed basal till are exposed in cliffs along the Shotover River between F41 736 722 and F41 744 726 (see Photos 2 and 3). This material comprises compact, homogeneous, silty coarse gravelly sand or silty, sandy coarse gravel, containing up to 20% greywacke clasts. It has sufficient strength to form a free-standing cliff face. Materials of similar appearance are exposed in cliffs bordering Lake Wakatipu in the Kelvin Heights area, where they overlie layered sandy gravels. Another example of basal till is seen in the Kawarau River cliffs southeast of Morven Hill (F41 827 703), comprising compact, angular gravelly sand/silt.

Ablation till ranges from relatively fine-grained to relatively coarse-grained materials. Examples include loose, poorly layered sand and silty sand with some gravel, exposed along Lower Shotover Road (F41 763 717) and along Arrowtown-Lake Hayes Road (F41 802 754), and loose, poorly layered sandy coarse gravel (F41 835 712).

West of Queenstown. In the area between Queenstown and Bobs Cove, there are localised patches of glacial deposits at a variety of elevations. Apart from small deposits at 900 metres on the southwest flank of Ben Lomond (shown by Turnbull, 1969) and a thin veneer of till at about 730 metres elevation on the north side of Bobs Peak, the deposits lie between about 300 and 700 metres elevation. They comprise a variety of ablation till, basal till and ice-margin sediments.

3.2 STREAM, RIVER AND LAKE DEPOSITS

3.2.1 Terrace alluvium

This unit incorporates a variety of river-laid deposits at a variety of elevations. The deposits, which include various combinations of gravel, sand and silt, underlie a discontinuous suite of terraces which extend around the northern and eastern margin of the Arrowtown end of the Wakatipu basin, and into the Gibbston Basin. Also included within this unit are the flight of terraces which flank the Shotover River, and localised deposits to the west of The Remarkables. The beds of the modern rivers contain similar deposits, but these have been mapped separately under the "Recent floodplain" unit.

Northern and eastern margin of the main part of the Wakatipu Basin. Near Arthurs Point, several closely spaced levels of terraces (not differentiated on the map) extend northeast from an area of glacial moraine at F41 713 733. The terraces descend from a maximum of about 460 metres elevation adjacent to the moraine, through the Arrowtown area, reaching the vicinity of the Arrow-Kawarau confluence at an elevation of about 350 metres. Details of the continuity or correlation of particular terraces through this area have not been investigated as part of this project, although preliminary observations suggest that dissected higher-level terraces extend for about 3 kilometres northeast of the moraine and are probably outwash aggradation gravels, whereas the terraces beyond this point are probably degradation features eroded into outwash gravel.

Gibbston Basin. At the western margin of the Gibbston basin, there is an extensive high-level deposit of sandy gravel between elevations of about 490 and 650 metres, centred at F41 867 687. Localised exposures indicate that these terrace alluvium deposits overlie lake sediments and glacial deposits (Bell, 1977, 1982, 1992). The terrace alluvium is interpreted to be predominantly outwash gravel, overlain by fan deposits.

Within the main part of the Gibbston basin, alluvium has been mapped at several different levels ranging in elevation from about 300 metres, adjacent to the Kawarau River, up to about 530 metres (F41 910 668) on the southwestern flank of the basin. These deposits are known from a number of exposures, and are predominantly well-bedded fine gravels and sands. Terrace surfaces are well preserved at lower levels, but at higher levels, they have been dissected by streams and extensively buried beneath fan deposits.

Shotover River. Along the Shotover River downstream from Arthurs Point, the river has cut numerous and locally extensive degradation terraces into earlier fan/delta deposits, glacial deposits or schist. The terraces are generally underlain by sandy gravel, typically no more than a few metres thick (see cross sections). Terrace alluvium has been mapped along the Kawarau River between the Shotover and Arrow River confluences, below about 350 metres elevation, and these terraces are probably downstream correlatives of the Shotover terraces.

Western flank of The Remarkables. In this area, two deposits of sandy gravel have been mapped as terrace alluvium. One small area east of Peninsula Hill, at F41 760 648, occurs in close proximity to fan/delta and glacial deposits, and its significance is uncertain. The other exposures lie at elevations of less than 360 metres, southeast of Jacks Point.

3.2.2 Fan alluvium

Alluvial fans are extensively developed on the lower slopes of the Wakatipu Basin. They have been formed by streams where they exit from confined channels. In places, fans from adjacent streams have overlapped or coalesced to form what is often referred to as a piedmont fan. The character of deposits underlying fan surfaces varies from place to place, and is influenced by stream size and the geology of the stream catchment. Phases of fan-building appear to have occurred at different times in different places, and may be a function of episodic increases of erosion rates in the stream catchment, rather than necessarily being due to changes in climate. Hence some fans, such as those on the western side of The Remarkables, have been active during recent floods, but others, such as those at the foot of Coronet Peak, have not shown signs of recent activity.

Crown Terrace. Extensive fan deposits mantle the eastern side of the Crown Terrace, between about 650 and 800 metres elevation. The fans have coalesced to form a piedmont fan, relatively undissected by erosion.

Gibbston Basin. On the southern side of the Kawarau River, a complex sequence of fans is developed between about 400 and 600 metres elevation. Younger fans tend to be "nested" within older fans, indicating an ongoing interplay between erosion and deposition. Below about 400 metres elevation, on both sides of the Kawarau River, the fans have spread over river terraces, and are relatively undissected. Deposits beneath the fan surfaces are predominantly sandy coarse gravel, and are described in more detail by Thomson (1994).

Main part of the Wakatipu Basin. Near the shore of Lake Wakatipu and throughout the main part of the Wakatipu Basin, small fans are developed at the mouths of most gullies, formed by both permanent and ephemeral streams. They include a large piedmont fan developed at the foot of Coronet Peak. The fans overlie a variety of older deposits, including terraces, fan/deltas and older fans, and many may be potentially active. Adjacent to the present lakeshore, the young fans grade into fan/deltas.

Western flank of The Remarkables. Below about 700 metres elevation, old fan deposits are locally exposed where stream channels have incised through overlying glacial deposits. At lower elevations, younger fans extend downslope to about 400 metres elevation, where they grade into fan/delta deposits, built into an enlarged Lake Wakatipu. Even younger fans, which are locally active, have in places built over the older fans, fan/deltas and lake deposits. The older, higher-level fan deposits comprise locally derived angular schist gravel with some sand, dipping downslope at between about 15° and 25°, and the material appears to be greater than 10 metres thick. The younger fans contain sandy, fine to coarse angular gravel, originating both from reworked glacial deposits and from locally derived schist. The deposits tend to be coarser near the flank of the range, and become progressively finer towards the lake.

Moke Lake area. In the valleys south of Moke Lake, fans are extensively developed, and some have coalesced to form piedmonts. Moke Lake and Lake Kirkpatrick (1 km WNW of Bobs Peak) were formed by blocking of drainage due to fan build-up. For the most part, the fans are relatively undissected.

3.2.3 Fan/delta sediments

Deltas form where rivers and streams build sediment out into bodies of standing water, such as lakes. Typically, delta deposits overlie lake sediments which are deposited in deeper water in front of the developing delta. In high-country lakes such as Wakatipu, delta sediments are generally bedded sandy gravels, with layers which dip lake-ward at between 10° and 30° from horizontal (see Photos 2, 3 and 4). As deltas progressively build out into lakes, the inclined layers tend to be overlain by subhorizontally layered river or stream deposits. This complex inter-relationship between the stream and delta sediments is the reason the term "fan/delta" has been used to describe these deposits.

Extensive fan/deltas formed when Lake Wakatipu was at high levels following the last glacial retreat. Many of the fan/deltas may have started forming when the lake was at its initial level of about 400 metres, but most were subsequently graded to 355 metres elevation, during a long stillstand in lake level.

Shotover area. The Shotover River built an extremely large fan/delta into the enlarged Lake Wakatipu. A tongue of this fan/delta is thought to have extended through to the northern end of Lake Hayes. The Shotover fan/delta isolated the Lake Hayes basin from Lake Wakatipu, and fan/delta deposits have left Lake Hayes impounded at some 20 metres higher than the present level of Lake Wakatipu. The sediments generally consist of bedded sandy gravel near the main areas of river inflow to the former lake, such as the area north of Lower Shotover (see Photos 2, 3 and 4). Some river cliff exposures (e.g. F41 738 726) indicate that the upper part of the fan/delta deposit consists of fine to medium sandy gravel with sandy interbeds, laid down by river action following migration of the delta front further into the lake. More distal areas of the fan/delta complex, where the majority of sedimentation occurred in shallow lake conditions (e.g. southwest of Lake Hayes) predominantly comprise fine-grained silty sands and silty gravel.

Information from water bores drilled into the Shotover fan/delta north of Ferry Hill, and between Lower Shotover and Lake Hayes, suggests that lake deposits occur extensively beneath the Shotover fan/delta deposits (see cross sections).

West of Frankton. Fan/deltas graded to the 355 metre lake level are developed at the mouths of most major stream gullies between Frankton and Bobs Cove. Deposits are generally well bedded sandy gravel with minor layers of sand and silt. Accumulations of finer grained distal sediments are rarely seen. As this section of the lake margin is quite steeply shelving, the fine-grained sediments were probably deposited in deeper parts of the former lake, beyond the present shoreline.

Photo 2. Westward view up the Shotover River from Domain Road, west of Slope Hill, looking towards Bowen Peak (BP) and Shotover Gorge (SG) near Arthurs Point. Tucker Beach (TB) is part of the recent floodplain of the river. River-eroded cliffs comprise fan/delta deposits (fd) overlain by glacial till (ti). Photo 3 (3) shows these deposits in more detail. Hummocky slopes (hs) behind are formed on ice-sculptured schist bedrock overlain by a veneer of glacial deposits.

Photo 3. Detail of fan/delta and glacial deposits seen in Photo 2, in a 15 to 20 m high exposure. Well bedded sandy gravels (fd), with inclined layers indicating deposition at a lake margin. Formed by the Shotover River during initial glacial retreat. Overlain by poorly stratified silty till (ti), believed to have formed during a minor glacial readvance. Photo 4 (4) details the gravels.

Investigation holes drilled at the site of the THC Hotel on the Queenstown waterfront encountered a sequence of sands and gravels, interbedded with silt containing carbonaceous layers and wood fragments (Pocknall and others, 1989). The silt intervals appear to be typical lake sediments, whereas the origin of sands and gravels is less certain. Some of the layers have textures and strengths suggestive of glacial till, but pollen analyses do not indicate a correspondingly cool climate (Pocknall and others, 1989). A possible explanation is that the sequence represents influxes of sandy and gravelly fan/delta sediments from Horn Creek which interfinger with "quiet water" silty lake sediments.

South of Frankton. Fan/deltas from the flanks of The Remarkables became isolated from the lake margin when the lake dropped to its present level. These deposits grade into the lake sediments which line the valley bottom. The Wye Creek fan/delta was built into a more steeply shelving part of the lake, and still lies adjacent to the lake margin.

3.2.4 Lake sediments

This unit incorporates fine-grained sediments which have accumulated in standing water, such as lakes and ponds. The sediments typically consist of thinly bedded (i.e. less than 60 mm) micaceous silt, locally with interbedded thin layers of fine sand. They are known from exposures around Lake Hayes, and exposure and drillholes have found extensive lake sediments beneath the valley which extends south from Frankton to Drift Bay. These deposits are mostly found below about 355 metres elevation, and are believed to have formed within the enlarged Lake Wakatipu.

Lake deposits also occur at a variety of elevations east of Morven Hill and in the Gibbston Basin, and are regarded as being older than deposits in the Lake Hayes and Frankton to Drift Bay areas.

Frankton to Drift Bay area. The sediments are characterised by grey, horizontally thinly bedded or laminated silt, commonly with interbeds of fine sand, and locally containing fine to coarse gravel. They are inferred to grade laterally into fan/delta deposits. The lake sediments are well exposed along the banks of the Kawarau River (Photo 5), and in cut batters along State Highway 6 for about 2 kilometres south from the Kawarau Falls bridge (e.g. F41 745 662). To the northeast of Frankton, the deposits are either overlain or replaced by coarser grained fan/delta sediments.

Lake Hayes area and north of Lower Shotover. Silts of presumed lake origin are extensively exposed at the southern end of Lake Hayes and along Hayes Creek (F41 789 707). Isolated exposures of silt are also found at the northern end of the lake, at elevations of up to about

380 metres. The silts are locally calcareous and have in the past been quarried for fertiliser (F41 792 707). The deposits are thought to grade westward into coarser sandy sediments of the Shotover fan/delta. Deposits of silt and fine sand are exposed locally in the banks of the Shotover River valley (e.g. F41 761 714), and are considered to be lake deposits.

East of Morven Hill. In this area, there are isolated occurrences of lake sediments which are thought to pre-date the deposits of post-glacial enlarged Lake Wakatipu, described above. They may be a key to understanding the evolution of the Wakatipu Basin, because they may provide evidence for older glacial advances or the formation of landslide dams in the Kawarau River. Lake sediments have been identified at the following locations.

- At about 360 to 370 metres elevation, on the south bank of the Kawarau River, above the Arrow confluence (F41 850 695). The deposit comprises thickly bedded silts (i.e. bed thickness up to about 1 m).
- At about 420 metres elevation, on the north bank of the Kawarau, above the Arrow confluence (F41 857 699), comprising thinly bedded (i.e. beds less than 60 mm thick) micaceous silt.
- At the southern end of the Crown Terrace, between about 530 and 600 metres elevation, patchy exposures of silt, calcareous mud and freshwater limestone are present ("Lake Eastburn" deposits of Bell, 1977; Bell and Swanson, 1977; Bell, 1982, 1992).
- Above the south bank of the Kawarau near Cowcliff Hill, at an elevation of about 500 metres (F41 867 692), an 8 metre thick sequence of lake sediments has been described by Bell (1977; 1982, 1992).
- In the Gibbston basin on the western side of Resta Road (F41 898 685), there is a deposit of thinly bedded micaceous silt, at an elevation of between about 370 and 390 metres (Thomson, 1994).

3.2.5 Beach sediments

Beaches were extensively developed around the margins of the enlarged Lake Wakatipu, and were stranded as the lake fell to its present level. There is patchy evidence for stranded beaches at a variety of elevations, ranging from about 400 metres elevation down to below present lake level. Apart from the modern beach deposits, beach sediments are principally concentrated at about 355 metres elevation, attesting to a long stand of the lake at this level. At this elevation, a wave-cut bench, up to several tens of metres wide, can be traced discontinuously around the enlarged lake basin. The bench is generally widest where it has been cut into surficial deposits, but in many places there is a recognisable though somewhat irregular wave-cut bench eroded into schist bedrock.

Photo 4. Detail of moderately to thinly bedded sandy gravel and gravelly sand shown in Photo 3, with scale indicated by the 35 cm long hammer. These sediments are believed to have been deposited underwater on the sloping face of the Shotover River fan/delta, built into deep water of enlarged Lake Wakatipu, as the glacier front began retreating back towards Frankton Arm area.

Photo 5. Lake deposits exposed in north bank of the Kawarau River, 1.4 km downstream from Kawarau Falls bridge at Frankton. The sediments comprise thinly bedded silt, in an exposure about 3 m high, and are believed to have been deposited at a time when Lake Wakatipu was enlarged, and stood at about 355 m elevation (45 m higher than at present).

The stranded deposits comprise layered sandy gravels, ranging from veneers a few tens of centimetres thick, to accumulations a few metres thick. Locally, linear ridges of gravel were constructed by wave action, and examples of these stranded beach ridges are seen at the northern end of Lake Hayes (F41 802 745), at Closeburn (E41 611 627) and at Bobs Cove (E41 578 614). In places, including Closeburn and Bobs Cove, there are bedded silt deposits on the landward side of the beach ridges, and these are inferred to be sediments that accumulated in lagoons isolated from the lake by the ridges. At several places, including Queenstown, Frankton and Bobs Cove, beach deposits extend from the 355 metre level down to present lake level, indicating continuous deposition, or redistribution of beach deposits, as the lake dropped to present levels.

At Frankton, there is evidence for a submerged beach ridge, about 3.5 metres lower in elevation than the beach ridge of the modern lakeshore (Thomson, 1985). The submerged ridge lies about 400 metres lakeward from the Frankton beachfront, and indicates that the lake outlet was formerly cut to a deeper level, and has subsequently become impeded, causing a minor rise in the average level of the lake. Disrupted sediments within the south bank of the outlet indicate a landslide, which appears to have failed into the former axis of the outlet channel. This appears to have forced all the lake outflow to pass across a resistant schist bench, at a slightly higher level (Kawarau Falls).

There are modern beach deposits along the Lake Wakatipu shoreline, but in most cases, these are not of sufficient extent to show on the map.

3.2.6 Recent floodplain sediments

In plan form, the exposed alluvial deposits of the present riverbeds occur as bars, aprons and lenses (see Photo 2). They comprise sandy gravels, with subordinate areas of sand and/or mud. The materials are unconsolidated, and are predominantly composed of schist, with minor greywacke and associated rocks, and are unweathered, except for occasional clasts of moderately weathered schist.

3.3 SLOPE DEPOSITS

3.3.1 Landslides

Landslides are extensively developed on schist slopes within and around the Wakatipu Basin. At a few locations, they are also developed within other deposits, particularly glacial deposits. They may be identified by the presence of disrupted materials, but in many cases, their identification is principally based on certain geomorphic characteristics, including hummocky topography, the presence of arcuate steps or escarpments, and backtilted benches. Some examples of landslides can be seen in Photo 1.

In the case of some old landslides, or slides which have only moved a short distance, many of the diagnostic features are poorly expressed or lacking, and the slides may remain undetected. An example is the relatively small landslide which is postulated to have impeded the Lake Wakatipu outlet (Section 3.2.5 above), which was only identified during investigations to find an explanation for the apparently anomalous drowned shorelines within the lake (Thomson, 1985).

The current work has not attempted to differentiate types of landslide, but general observations suggest that styles of movement (based on the terminology of Varnes, 1978) include translational slides, rotational slumps, rock flows, debris flows, and combinations thereof. General observations of exposed landslide materials indicate that the landslide deposits range in composition from large transported blocks of schist to highly disrupted chaotic debris.

There is little information on depths of landslide movement, but depths are likely to vary from a few metres for shallow landslides, to many tens of metres for deeper-seated landslides. The thickness of landslides does not necessarily depend on the areal extent of the slide. Geomorphic features can provide a guide to thickness of landslides, and judged on this basis, the landslide which occupies the south face of Coronet Peak is a good example of a deep-seated landslide which may be many tens of metres thick.

The principal factors influencing location, depth and nature of landslides are likely to be the nature, orientation and spacing of weaknesses (foliation, joints and faults) within the schist rock, and the depth and extent to which the schist is weathered. It is probable that much of the landsliding has resulted from the influence of glaciation, whereby glacial erosion of the basin floors and margins has tended to steepen the overall slopes, promoting instability, and frost/permafrost activity may have contributed to the opening and loosening of fractures within the rock. In addition, slopes adjacent to glaciers may have been supported by the mass of ice, and the loss of support due to glacial retreat may have triggered landslides.

With regard to their degree of activity, most landslides appear to be either dormant or creeping slowly (i.e. moving less than about 10 centimetres per year). There are landslides which, judged by surface morphology, are probably moving at faster (although not quantified) rates. Examples of these are seen at Arthurs Point (E41 691 704), on the slopes of Ferry Hill (F41 743 705) and on Sugar Loaf Hill (F41 717 707).

3.3.2 Colluvium

Colluvium characteristically forms a mantle or apron on steeper slopes which range in angle from about 25° to 50° or more. Colluvium as described here includes a variety of materials, including scree and rockfall debris, which is predominantly angular coarse to bouldery gravel, and a variety of slope wash debris which typically comprises layered silty gravel, with some beds of wind-deposited silt (loess). The layering is generally subparallel to the slope.

Colluvium is usually thickest towards the base of the slope. The materials may have a similar appearance to fan alluvium, although geomorphically, accumulations of colluvium tend to have apron-like or cone-like form as opposed to a fan shape.

Colluvium forms by downslope gravitational sedimentation. Colluvial processes involve progressive accumulation of discrete layers of sediment, whereas landslides are regarded as involving downward and outward movement of a mass of slope-forming materials. In some publications (e.g. Varnes, 1978), rockfall is classified as a type of landslide, but for the purposes of this report, association of rockfall deposits with the colluvium unit is preferred. Colluvial deposition may be assisted by rainwater and sheet flooding (i.e. slope wash), and a continuum exists between colluvium and fan deposits; colluvium grades into fan alluvium where fluvial processes become dominant over subaerial gravity processes.

3.4 DISCUSSION

The information presented above has outlined the general nature and distribution of the different types of surficial deposits within the Wakatipu Basin. It is emphasised that this study has been of a reconnaissance nature, and illustrates that there are many complex geological relationships within the basin. While the map presents a framework of information that will be of benefit for development of the region, it is also apparent that significant details of the surficial geology are yet to be resolved. The following discussion is separated into two parts, one of which addresses the unresolved geological issues, and the other addresses issues directly relevant to regional development.

3.4.1 Further geological studies

The objective of the project has been to produce a map which shows the general distribution of surficial geological deposits within the Wakatipu Basin. It is considered to be a first step towards identifying aspects which require more detailed study. The eventual goal of future study should be to improve understanding of the geological and geomorphological evolution of the Wakatipu area, which will also assist future development and land-use planning.

Radiometric dating of surficial deposits in the Upper Clutha valley (McSaveney and others, 1991) indicates that glacial deposits in the Clutha area span a greater length of time (more than half a million years) than has previously been generally postulated for the South Island glacial record (e.g. Suggate, 1990). As a result, the glacial sequences of other catchments would benefit from reassessment, to establish whether existing published interpretations of glacial chronology and rates of landscape development are appropriate. The Wakatipu Basin is of primary importance for reconsideration, because of its link to the Clutha catchment via the Kawarau River. Any reinterpretation of the Wakatipu Basin deposits should take account of deposits elsewhere within the catchment (e.g. the Kingston area to the south and the Von/Mavora areas to the west), and also take account of glaciological factors (e.g . Mathews, 1967) and appropriate depositional models.

Re-evaluation of the geological and geomorphological history of the Wakatipu area has not been attempted here, as it is considered more appropriate that this study be used as a framework for focusing future work. Previous geological studies have presented some valuable descriptive information on specific aspects of the deposits, but there is a need for more **detailed geological mapping in particular areas**. Such work is a prerequisite for testing the interpretations presented in previous studies, and will enable models for the glacial history and landscape evolution in the Wakatipu Basin to be refined and expounded with more confidence.

Key areas for more detailed mapping are (i) Gibbston Basin, (ii) Crown Terrace area, (iii) Queenstown-Arrowtown basin, and (iv) the western flank of The Remarkables. Each of these areas could be suitable topics for short-term self-contained studies. Once details of the geology have been documented, there should be an **overview study** which reviews the findings, and re-evaluates the geological and geomorphological models.

Mapping studies should focus on detailed description of the geological materials and their distribution. The nature and weathering characteristics of the glacial deposits and terrace alluvium may aid the correlation and relative chronology of deposits around the basin. Identification of materials suitable for dating is of particular interest, and would assist correlation with dated glacial deposits in the Clutha catchment (McSaveney and others, 1991).

There is considerable subsurface information from water bores which should be collated as part of future work.

As a result of our reconnaissance mapping, it appears probable that the lake and fan/delta sediments related to the higher-level Lake Wakatipu may be more extensive than have so far been identified. These deposits provide a key to understanding the post-glacial development of the Wakatipu Basin. More detailed investigations between 355 and 400 metres elevation, particularly in the Queenstown-Arrowtown basin, may significantly aid our understanding of the development of the Kawarau River outlet from Lake Wakatipu.

3.4.2 Development applications

In outlining the nature and distribution of surficial deposits within the Wakatipu Basin, this study provides a framework of information which could form the basis for future assessment of geological resources and hazards. Geological aspects which are relevant to planning and development include:

- erosion and deposition;
- slope instability;
- foundation conditions;
- groundwater availability;
- effluent disposal;
- aggregate resources;
- earthquake hazards.

The information presented in this study could be utilised in a general assessment of geological hazards in the area, and complements information previously provided by Otago Catchment Board (1988) and Riddolls Consultants Ltd (1993).

Assessment of aspects of the seismotectonic (earthquake) hazards along known fault lines in the area is provided by Hancox and others (1985), and Hancox and Salt (1990). Smith and Berryman (1986) have presented assessment of probable return periods for different intensities of earthquake ground-shaking in the Queenstown area. This seismotectonic information could be used in conjunction with the geological data presented here, to evaluate the likely seismic behaviour of the different surficial deposits.

In the future, as a more detailed understanding of the deposits is developed, knowledge of the surficial geology should be of greater benefit to planning and development than has previously been possible.

4. CONCLUSIONS

(a) Surficial deposits in the Wakatipu Basin are varied and widespread, and they extend discontinuously from the crests of the ranges to the beds of the rivers and lakes. Their general distribution has been established, but details of the nature, boundaries and thicknesses of the deposits are not well known. In many cases, the information presented here is tentative.

(b) Complex relationships exist between different types of surficial deposits, and in places the deposits form multiple layers. All of the deposits are predominantly schist-derived. For the purposes of mapping and description, they have been subdivided into three major groups.

(i) Slope deposits.
(ii) Stream, river and lake deposits.
(iii) Glacial deposits.

(c) Assessment of the relative and absolute ages of the deposits has not been included in this study, but some general comments can be made. The age relationships of the deposits appear to be complex. Landslides high on the slopes may have developed gradually over a long period of time (e.g. hundreds of thousands of years), whereas some glacial deposits and stream, river and lake deposits may have developed during relatively short intervals of time (e.g. less than a few thousand years). Other deposits, such as alluvial fans, may have had a history of intermittent development over time.

(d) On higher slopes, landslide deposits predominate. They are mostly on schist and many have surface characteristics suggesting that they are either dormant or undergoing generally slow movement. Fan alluvium, along with minor terrace alluvium and glacial deposits are also found at high levels, and are mostly thought to be remnants of relatively old, formerly more extensive deposits. The glacial deposits in basins high on The Remarkables appear to be relatively younger, having been deposited or modified by localised cirque glaciers formed during the last glaciation.

(e) On the mid to lower slopes, there is a wide range of different deposits which mantle the underlying schist. Successive glacial advances have removed or modified the surficial deposits. In effect, the landscape in the lower parts of the basin has been "reset" following each glacial advance. Most of the deposits on the basin floor have formed since the climax of the last glaciation.

(f) Post-glacial deposits, formed during the last 14 000 years or so since the last glaciers began to retreat, are laterally and vertically complex. There is a predominance of lake silts/sands and fan/deltaic sediments, which were formed within and marginal to Lake Wakatipu, which initially stood at a high level following evacuation of glacial ice. Beach deposits overlie distinctive wave-cut benches which formed around the fringe of the lake as it progressively dropped to present levels.

(g) The surficial deposits and landscape have had a significant influence on human development in the Wakatipu Basin and environs, and will continue to do so in the future. Of particular importance are the scenic and recreational values of the landforms, the geological materials which form foundations and provide construction resources, as well as the geological hazards posed by active processes such as landsliding, earthquakes, flooding, sedimentation and erosion.

(h) Groundwater occurs within the surficial deposits, and effective utilisation and protection of this resource depends upon an understanding of the deposits which contain the resource.

(i) The information presented in this report is a step forward in our understanding of the nature of the surficial deposits. It provides a guide for resource utilisation and development planning, bearing in mind that it represents a "first-step". More detailed and specific investigations need to be undertaken to resolve particular geological problems.

5. ACKNOWLEDGEMENTS

This study has benefited from discussions and information provided by Ginny Cunningham and David Bell, both of the University of Canterbury. Discussions with Trevor Chinn, Institute of Geological & Nuclear Sciences Ltd, have assisted in refining terminology for glacial deposits, and reviews by Mauri McSaveney and Ian Turnbull, Institute of Geological & Nuclear Sciences Ltd, have resulted in improvements to the content and presentation of the map and text. The cooperation of landowners in the Wakatipu Basin for allowing us to gain access to their land is gratefully acknowledged. This project has been financed through Non-Specific Output Funding provided by the Foundation for Research, Science and Technology, and administered under the direction of Richard De Luca, Institute of Geological & Nuclear Sciences Ltd.

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APPENDIX A: Terminology of glacial deposits

Till: Accumulated glacial materials, typically unsorted and unstratified, composed of various mixtures of boulders, gravel, sand, silt or clay, deposited directly from or by glacier ice. May be differentiated into:

(i) *basal till*, which has been deposited beneath a glacier, and is typically a dense and compacted material, (also known as *lodgement till*, or *drift*);

(ii) *ablation till*, which comprises debris carried within and on top of the glacier, deposited when the ice melted. It is typically a loose, homogeneous material.

Moraine: The landform developed on accumulations of till or ice-margin sediments, characterised by hummocky topography and poorly drained ground. Different types of moraine are recognised on the basis of environment of deposition:

(i) *terminal moraine* may be formed at the down-valley end of a glacier. It marks the position of the glacial terminus during a long period of glacier equilibrium, and may be associated with the maximum of a glacial advance. Terminal moraines may not be preserved, due to erosive action of meltwater streams. Terminal moraine is developed predominantly on ice-margin sediments and ablation till;

(ii) *lateral moraine* may be developed along the margins of a valley that was occupied by a glacier, and is developed predominantly on ice-margin sediments and ablation till;

(iii) *ground moraine* may be developed on accumulations of basal till and ice-margin sediments on the floor of a valley which was occupied by a glacier. It may be overlain or obscured by recessional moraine;

(iv) *recessional moraine* comprises minor ridges or accumulations of ablation till and ice-margin sediments on the floor of a glacial valley, deposited during glacial recession. A common glacial landform, being the last glacial sediments deposited as glaciers receded.

Note that elsewhere, the term *moraine* is sometimes used in a different sense to refer to the rock debris carried within and on top of present-day glacial ice.

Ice-margin sediments: Comprise a variety of gravelly, sandy, silty or clayey sediments deposited from ponded or flowing water adjacent to, or beneath, a glacier. Deposits typically are layered, and layers may be deformed or contorted as a result of ice movement or slumping/subsidence of the deposits.

Includes deposits described elsewhere as *kame terraces*, *glaciofluvial sediments*, and *ice-contact sediments*.

Outwash: Gravel-dominated deposits laid down by meltwater streams which extended down-valley from glacier termini. Characteristically associated with terrace landforms, and here, the deposits have been included within the "terrace alluvium" map unit. The term *fluvioglacial* is synonymous with outwash.

GEOLOGICAL UNITS

SLOPE DEPOSITS

Landslide — Gravitationally displaced materials, typically characterised by the presence of hummocky topography. Predominantly comprise schist debris and schist-derived materials. Thickness may range from a few metres to many tens of metres. May include an extensive cover of colluvium.

Colluvium — Accumulations of debris on steep (>25°) slopes. Includes scree and bouldery rockfall deposits. Nature of materials variable, but typically consists of layered gravelly and silty deposits.

STREAM, RIVER AND LAKE DEPOSITS

Recent floodplain — Unvegetated or poorly vegetated, low-lying areas adjacent to major rivers. Comprise generally loose sands and gravels. Prone to inundation during large floods.

Fan — Identified by the presence of fan-shaped landforms. The slope of the fan surfaces range from less than 10° to about 25°. Typically, the deposits are layered sandy gravels with some silt. The coarse component ranges in size from fine gravel to boulders, and ranges in shape from angular to subrounded. The inclination of the layers is broadly subparallel to the slope of the fan surface.

Fan/Delta — Formed where fans have built out into lakes. Principally developed at a time when Lake Wakatipu was at levels up to 80 metres higher than at present. The deposits are typically dominated by well layered sandy gravel, in proximity to the head of the fan/delta, generally fining to layered sand and silt with increasing distance from the ancient shoreline.

Lake — Found extensively near Lake Hayes and to the south and east of Peninsula Hill. Predominantly consist of subhorizontally layered, thinly to thickly bedded, micaceous silt, locally containing significant amounts of calcium carbonate.

Beach — Overlie gently-sloping benches cut by wave action when Lake Wakatipu was at higher levels. Deposits comprise layered sandy, gravelly, and locally silty, sediments, ranging in thickness from a few tens of centimetres to a few metres. Linear storm beach ridges are locally present.

Terrace alluvium — Typically consist of subhorizontally layered sandy gravel with minor layers of sand and silt. Generally underlie gently-sloping (<5°) terrace surfaces. Includes outwash gravels developed downstream from glacial moraines (aggradation deposits), and gravelly deposits underlying lower-level terraces incised into outwash gravels or older deposits (degradation deposits). Aggradation deposits may be up to tens of metres thick, whereas degradation deposits may be as thin as one or two metres.

GLACIAL DEPOSITS

Undifferentiated unit which incorporates a variety of materials including till (deposited by glacier ice) and ice-margin sediments (laid down by water beside or beneath the ice). Tills are generally unstratified and comprise either compact, gravelly, sandy, silt-clay, deposited at the base of the glacier (basal till), or loose clayey and sandy gravel, deposited from melting ice (ablation till). Ice-margin sediments include layered sandy gravel, sand and silt, typically with contorted or deformed layers.

BASEMENT GEOLOGY

Tertiary sediments — Deposited during the Oligocene and Miocene/Pliocene epochs (between 30 and 5 million years ago), and preserved as isolated remnants. They comprise limestone, sandstone and conglomerate near Bobs Cove, and sand, mud, lignite at Coal Pit Saddle and near Crown Saddle.

Schist — The predominant underlying rock type, formed by metamorphism during the Jurassic Period (about 200 million years ago). Typically comprises laminated rock composed of alternating light-coloured (quartz and feldspar-rich) and dark-coloured (mica-rich) layers.

Note: All structural and lithological details within the basement rocks (including all faults) have been deliberately omitted from the map. Refer to Turnbull (1988), Turnbull and Forsyth (1988) and Mortimer (1993) for structural and lithological information.

RECOMMENDED BIBLIOGRAPHIC REFERENCE

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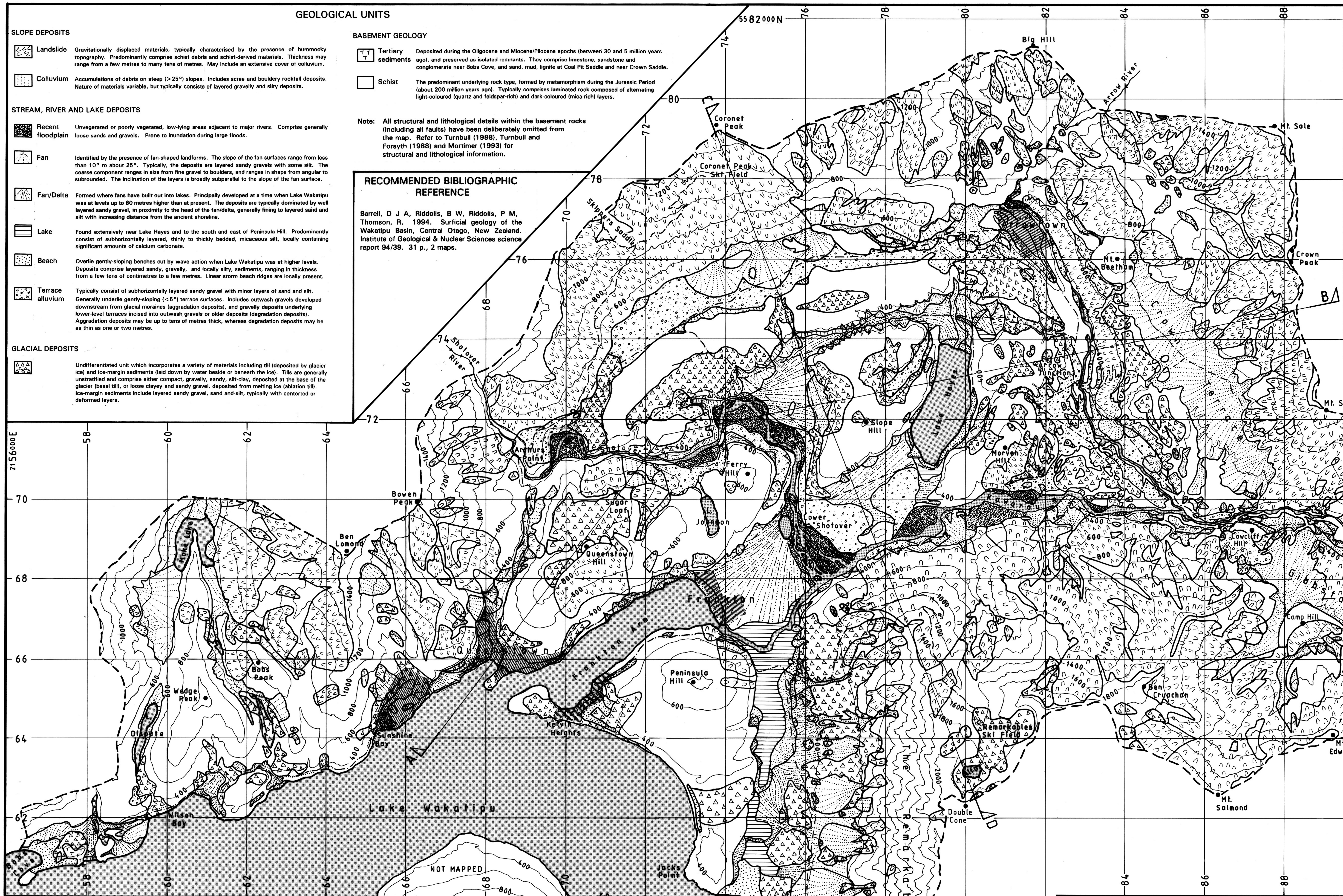

LOCATION DIAGRAM

(with index to published geological maps which relate to the area)

This map

Geological Map of New Zealand, 1:250 000. Sheet 22 - Wakatipu. Wood, B.L., (1962), 1st Edition, reprinted 1985.

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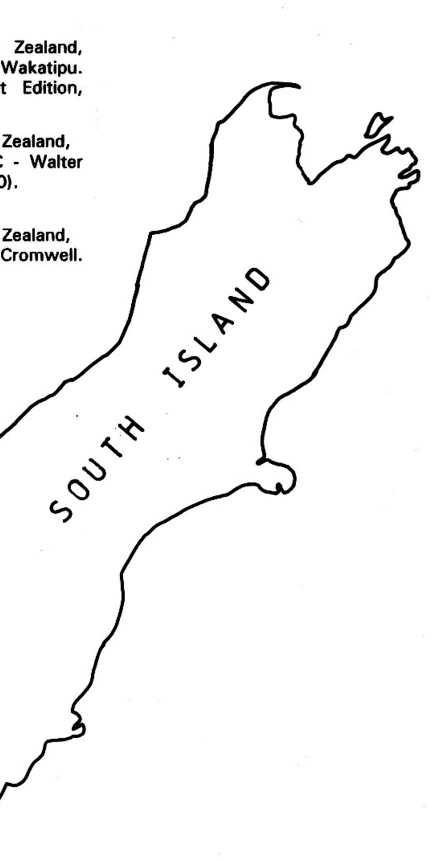
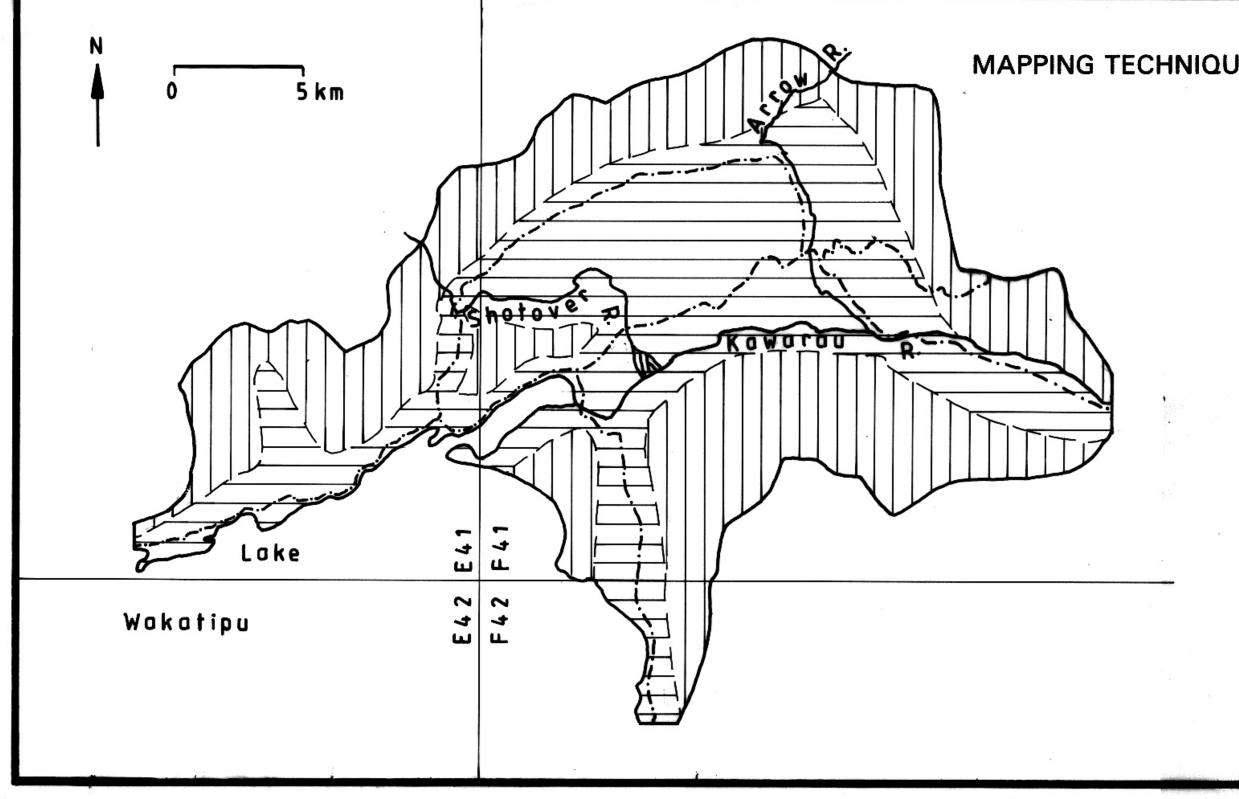


MAPPING TECHNIQUES AND TOPOGRAPHIC MAP REFERENCE



E41/F41 — Boundary between NZMS 260 series map sheets.

Ground-based reconnaissance mapping of available subsurface exposure, with positions of geological boundaries largely based upon interpretation of landforms. Assisted by examination of aerial photographs.

Interpretation of the nature and position of geological units largely based on examination of aerial photographs, and information from previous studies.

TO OBTAIN A GRID REFERENCE ON THE MAP (to the nearest 100 metres)			
EXAMPLE POINT: ● Peninsula Hill			
EAST Locate the first VERTICAL grid line to LEFT of point and read the figures labelling the grid line at top or bottom of sheet	72	NORTH Locate the first HORIZONTAL grid line BELOW point and read the figures labelling the grid line at left margin of sheet	64
Estimate twentieths eastward from grid line to point	12	Estimate twentieths northward from grid line to point	14
	732		654
EXAMPLE REFERENCE (including topographic sheet number) F41 732 654			

SYMBOLS

TOPOGRAPHICAL REFERENCE

- Principal road
- Major river
- Lake
- 400 — Topographic contour (metres above sea level)
- Town
- Named hill or peak

GEOLOGICAL REFERENCE

- Boundary of mapped area
- Boundary between geological units
- D — Position of cross section end-point

SURFICIAL GEOLOGY OF THE WAKATIPU BASIN

Map to accompany Science Report 94/39 of the Institute of Geological & Nuclear Sciences Limited

SCALE 1:50 000 **DATE: October 1994**

0 0.5 1 1.5 2 km

ACKNOWLEDGEMENTS: Geological information obtained by R. Thomson, V.J. Cunningham, B.W. and P.M. Riddolls, and D. Barrell, from published and unpublished maps and reports, field surveys and aerial photograph interpretation. Final map compiled and assembled by D. Barrell, draughted by B. Smith Lyttle. Topographic information taken from DOSLI INFOMAP 260 series (1:50 000), Sheets E41, F41 and F42, Department of Survey and Land Information Map Authority PL098817/20: Crown Copyright Reserved.

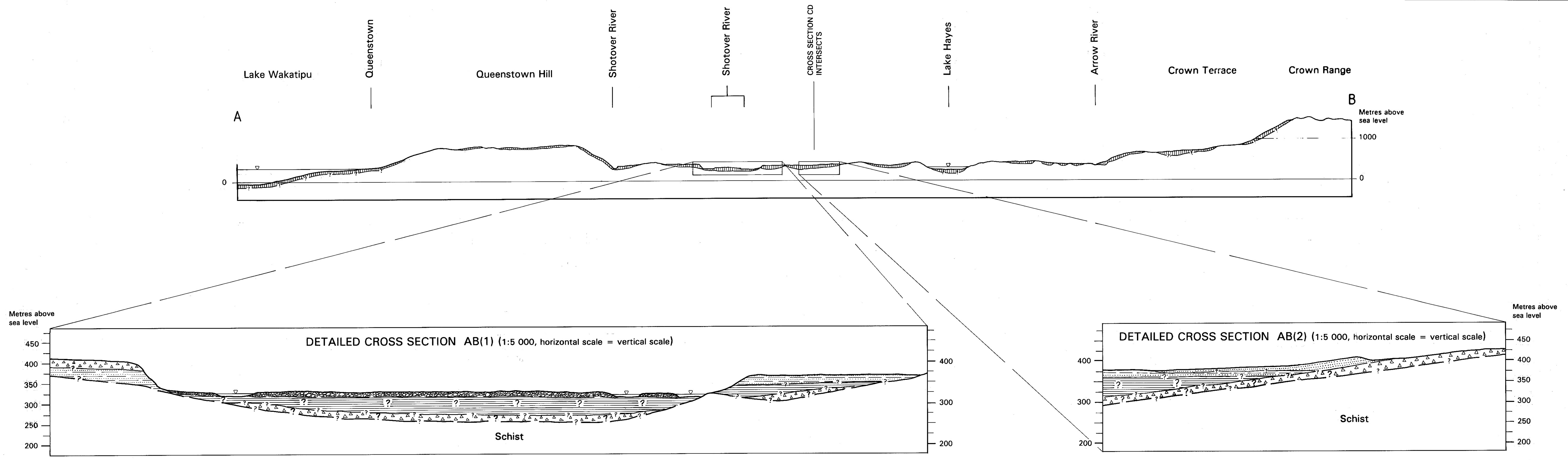
NOTE: This map is a general compilation and boundaries shown are approximate. **It should not to be used for any project requiring site specific investigations.**

RECOMMENDED BIBLIOGRAPHIC REFERENCE

Barrell, D J A, Riddolls, B W, Riddolls, P M, Thomson, R, 1994. Surficial geology of the Wakatipu Basin, Central Otago, New Zealand. Institute of Geological & Nuclear Sciences science report 94/39. 31 p., 2 maps.

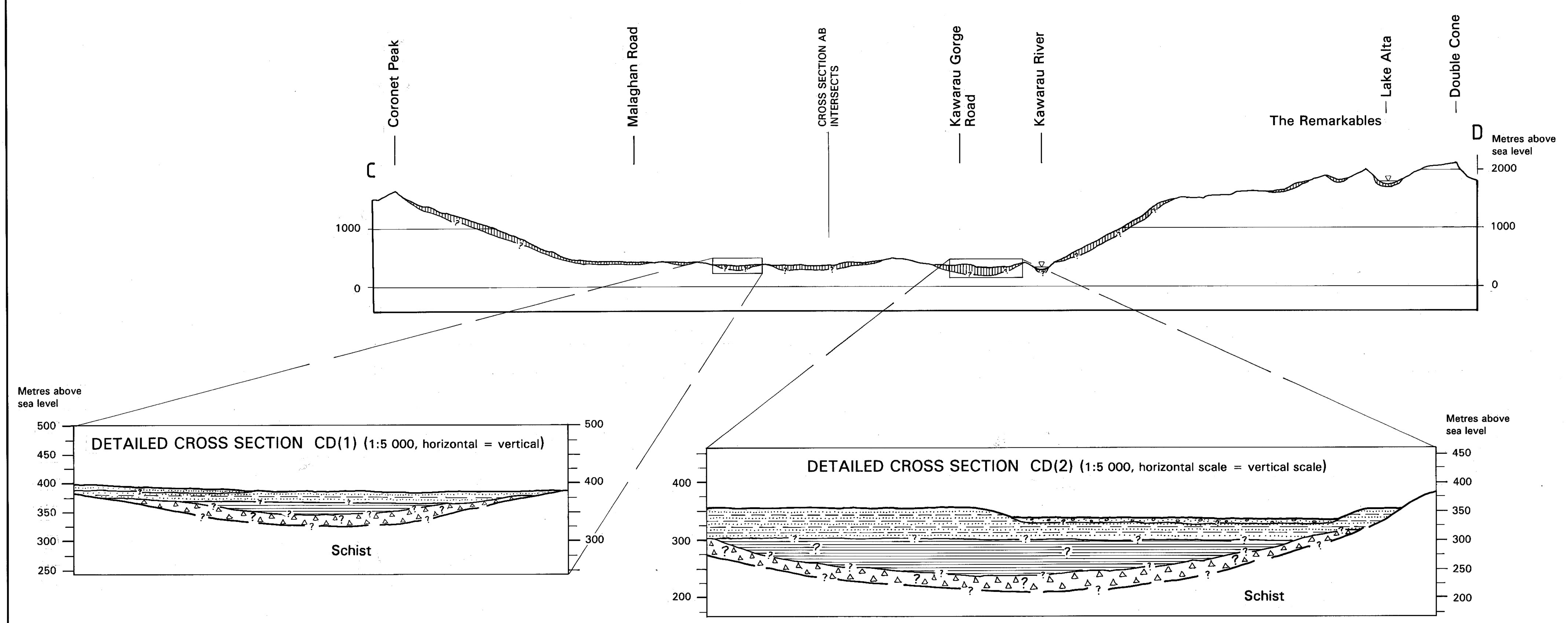
MAIN CROSS SECTION AB (1:50 000, horizontal scale = vertical scale)

(thickness of surficial deposits in some places exaggerated for clarity)



MAIN CROSS SECTION CD (1:50 000, horizontal scale = vertical scale)

(thickness of surficial deposits in some places exaggerated for clarity)



GEOLOGICAL UNITS AND SYMBOLS

MAIN CROSS SECTIONS (1:50 000)

- Surficial deposits (undifferentiated: includes all slope, river, stream, lake and glacial deposits)
- Schist (Note: no Tertiary sediments are present along the cross section lines)
- Ground surface / lake bottom
- Typical river level / lake level
- Inferred position of surficial deposit / schist contact

DETAILED CROSS SECTIONS (1:5 000) - refer to accompanying geological map for description of units

- Recent floodplain
- Fan deposits
- Fan/delta deposits
- Lake sediments
- Terrace alluvium
- Glacial deposits
- Schist
- Inferred schist / surficial deposit contact
- Inferred contact within surficial deposits
- ? Presence of unit uncertain

SURFICIAL GEOLOGY OF THE WAKATIPU BASIN

Geological Cross Sections to accompany Science Report 94/39 of the Institute of Geological & Nuclear Sciences Limited

SCALE 1:50 000 and 1:5 000 **DATE: October 1994**

Refer to accompanying geological map for location of cross sections

ACKNOWLEDGEMENTS: Prepared by R. Thomson, based on information presented on accompanying 1:50 000 geological map and limited water bore information. Compiled and assembled by D. Barrell, draughted by B. Smith Lyttle. Bottom profile of Lakes Wakatipu and Hayes adapted from Irwin, J., 1972: Lake Wakatipu, Bathymetry. NZ Oceanographic Institute Chart, Lake Series, 1:63 360.

NOTE: These cross sections are a general compilation. The nature of materials below the ground surface and the positions of boundaries shown are inferred and are of lesser reliability. **These cross sections should not to be used for any project requiring subsurface investigations.**

Annexure lll
ECON207: Intermediate Microeconomics – Households and Government

There has been publicity in the media recently about house prices in Auckland being some of the most unaffordable in the world. Some people suggest land prices are higher in NZ because of council restrictions such as zoning and other regulations that restrict what can be built on land.

This essay asks you to use your knowledge of externalities to present the arguments for and against council restrictions on building and land use in a major city like Auckland. As part of your answer state whether restrictions on building and land use to reduce externalities are worth the cost of higher land prices in a city like Auckland (1200 words).

The primary contention of academic literature considered in this work is that zoning as a regulatory tool places restrictions on the supply of land or houses which cause high land prices. Underpinning that is neo-institutional economic and transaction cost planning theories informed by Ronald H. Coase (Lai, 2006) (Evenson, 2003)(Fischel, 2015). In the New Zealand context it is argued that existing resource management planning appears to respond poorly to urban development challenges related to competition for resources and urban externalities, resulting in the under development of residential capacity required to meet long term demands of a major city like Auckland. Since 2001 there has been a surge in average house prices and rent across all regions of New Zealand, but most noticeably in Auckland where tight land regulation makes it one of the most expensive cities in the world to live in (NZIER, 2014 and 2015).[1]

Externalities are defined in Palgrave Economics Dictionary as the "indirect effects of consumption or production activity, that is, effects on agents other than the originator of such activity which do not work through the price system" (Laffont, 2008). Indirect effects are both positive and negative. Negative externalities of a restriction on the supply of housing can be classified by type: population externalities such as congestion or noise, lack of sunshine amenity due to the height of a new building, landscape deterioration, pollution activities, or other societal malevolence such as racial tensions (Kono, 2010). Acts of benevolence and knowledge spillovers are examples of positive externalities that tend to follow urban growth linked to the process of urbanization, agglomeration, and income distribution in the labour market (Durlauf, 2008). Congestion – a negative externality – is said to follow urban conglomeration – a positive externality. However, it is also linked to city sprawl. The size of urban agglomeration therefore is a tradeoff between forces of congestion and agglomeration (Jones, 1999). Because evaluation of the costs and benefits of government policy objectives is a legislative planning requirement, land values must be considered in this context together with other related factors such as the labour market, transportation, and economic growth.[2] The academic literature discussed in this essay provides evidence that a constraint on housing supply causing high property prices is not worth the trade off to urban growth opportunities within a city like Auckland in the absence of good spatial planning and significant upward adjustment to urban density.

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[1] Auckland house prices have increased at an annual rate of 26.6% exceeding 9 times the gross income in Auckland (Reserve Bank, 2015).
[2] Section 32(2) of the Resource Management Act 1991 requires that an economic evaluation accompany any policy plan or statement, evaluating costs and benefits of the objectives of the plan or statement including the proposed national policy statement on urban development capacity, which in the authors opinion should be a positive statement for the benefit of New Zealand and reach beyond the self interest of local communities (Pellegrino, 1993).

Resource Management is the main regulatory tool for land planning in New Zealand. It is a complex system of national and municipal rules combined with legal enforcement powers arising out of statute and the common law. The Auckland Housing Accord (2013) is an interim measure designed to facilitate a perceived failure of the regulatory process and response to market failure in dealing with externalities of the urban housing market. Economic theory is increasingly viewing urban economics within a broad framework of academic disciplines to meet the challenges posed by Coasian problems (Inostroza, 2014).[3] That broad approach is consistent with the complex rules of the resource management regime in which community preservation groups remain a powerful lobby group in the planning process (Glaeser, 2005).[4] Good intentions and good planning do not always win community approval. Specific regulatory tools commonly used in an urban spatial planning context both in New Zealand and other major global cities, are intended to reduce or internalize externalities within 'zones' that take account of social and economic goals through the use of common planning rules regulating such things as urban boundaries, employment and community well being, open space, views, noise and emissions, building height, density, and use of space (Bertaud, 2005). Methods of reducing regulatory restrictions include expanding the metropolitan urban limit (MUL) or providing for greater housing density and fewer restrictions on height limits. Both options incur both positive and negative externalities (Lai, 2014 and Glaeser, 2008) and remain open to challenge through the adversarial process.[5]

Gyourko (2006) argues and provides evidence that income growth and patterns of spatial dispersion in house prices are inextricably linked and are caused by a scarcity of land combined with a growing number of high income families choosing to live in those metropolitan areas referred to as 'superstar' cities (Evenson, 2003). These cities accommodate families with high incomes and do not have close substitute locations. Regulation and geographical limitations do not permit incursion of their superstar status through increases in density or expansion. The result is an acceleration of house prices in those cities, skewed over and above national averages. Arthur Grimes (2007) asks whether Auckland's MUL has an effect on land prices.[6] He notes that growth limits as well as other regulatory restrictions like building codes and zoning govern the nature of a city's development. Zheng (2013) relies on data from Grimes and Liang (2009) and advises that the price of land just inside the MUL is approximately 9-10 times higher than land just outside Auckland's MUL. Grimes and Lang (2009) suggest that urban growth limits are effected by multiple factors that also include infrastructure services and new transport routes (Brueckner, 2012)(Grimes, 2010). Accessibility to markets and transport is seen as a significant factor impacting on rents as well as land values (Whipple, 1995).

It is argued that internalizing congestion externalities of growth requires upward adjustment to market density (Wheaton, 1997). Although height restrictions may be used to achieve

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[3] The 3D linkages discussed in this work discussing the city of Bogotá, seek to find methodological approaches to modeling that link with urban economics, urban design, engineering and architecture. Limitations with the type of spatial data required to build technomass are estimations of underground structures including all services and transportation where applicable which would normally be information dispersed amongst numerous organizations and held in different formats. It is suggested that a better understanding of these relationships would lead to better policy making as useful planning indicators in the urban ecosystem.

[4] *Cockburn and Oriental Bay Parade (Clyde Quay) Planning Society Inc. v Wellington City* (1999) W001/99 and W63/05 for discussion of design guidelines, planning height limits and densities along Oriental Parade as part of a plan change appealed by local resident/building owners in comparison with the Carneigie Hill Battle.

[5] Refer *Tram Lease Ltd v Auckland Council* [2015] NZEnvC 133; *Landco Mt Wellington Ltd v Auckland City Council* [2008] W042/08 as examples of the use of the adversarial process to protect view shafts.

[6] The Productivity Commission (Zheng, 2013) defines the MUL as "a zoning restriction that defines the boundary of the urban area with the rural part of the region".

aesthetic considerations, it is also argued that some externalities may be sufficiently large to warrant a regulatory tax as not all social costs are internalized by developers through development contributions (Glaeser, 2005). Social costs include the fact that new apartments may eliminate views from existing apartments, which makes lifting height limits difficult. Glaeser identifies the economic theory that new development could be taxed to the extent that there are negative externalities generated through congestion and possible pure wage depression effects. In contrast it is suggested that any effects are limited, offset by positive externality effects such as significantly increased land values and benefits to the economy of urban growth. Glaeser's research indicates that high-density buildings generally internalize congestion, as transport requirements are reduced through the need for less cars and trips. It has even been suggested that on these grounds, development of tall urban residential buildings should be subsidized not taxed, suggesting a congestion amenity rather than a negative externality or 'disamenity'.[7]

Urban growth is defined in Palgrave and explained as the growth rate of an economy being proportional to the level of research within that economy (Jones, 1999). Urban growth literature underscores knowledge spillovers, labour market pooling, and non transportable input sharing within and between cities as the main reason for growth of agglomeration economies which result in benefits to urban amenity services such as employment opportunities, entertainment, shopping and healthcare facilities (Rosenthal, 2001) (Jofre-Monseny, 2011) (Ding, 2012). This model suggests the best policy for urban growth embraces increased density and supports a national policy growth agenda supporting supply side city living thus reducing congestion externalities. Good urban design also promotes the use of open space, balconies and greenness that can reduce stress. Academic studies prove the importance of safe large green areas in metropolitan areas for the welfare and health of residents and quality of urban living (Sugiyama 2015).

It is suggested in urban planning literature that height restrictions are used to achieve other goals such as restricting job and population densities (Brueckner, 2012). Indian studies suggest that excessive density results in negative externalities - traffic congestion and reduced environmental quality which place demands on infrastructure that Indian cities are technologically and financially not well equipped to support at the necessary levels. The New Zealand Institute of Economic Research (NZIER, 2014) provides an argument for expanding the city spatially arguing that improving land supply reduces rising house prices and improves welfare. That theory suggests it may be optimal for cities to increase their sprawl to deal with other negative externalities such as traffic congestion. In contrast, the theoretical basis behind the analysis of economists such as Bertaud and Brueckner is that building height restrictions reducing city density cause a city to expand spatially and that expanding the city spatially causes congestion associated with greater commuting costs, loss of welfare and higher land values (Bertaud, 2005).

If real demand is driving a genuine housing boom as a contributor to urban growth rather than pure speculative forces (Lin, 2004 and Wang, 2016) (Ciccone, 2008) the risk of an Auckland housing bubble in response to escalating housing demand would be minimized (Glaeser, 2008) (Du, 2011) (Cai, 2013). To focus exclusively on escalating land value ignores the relationship between land values and labour markets, which are a significant factor in New Zealand's economic growth. The World Bank suggests that spatial equilibrium generated as a result of profit maximizing firms and utility maximizing workers in the

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[7] While San Francisco compares better to Auckland than Boston or New York in terms of geographical constraints such as underground transport networks, existing concentration of building densities and green space, the general theory remains applicable.

presence of externalities requires forward thinking policy solutions to generate the optimal solution for urban growth and welfare (Goswami, 2015). Significantly increasing the form, density and height inside Auckland's MUL would lower house prices and could achieve the possibility of a vibrant cityscape that maintains the health and welfare of its residents.

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