KIRK ROBERTS
CONSULTING

1st May 2024

Gavin Moore
Client
Silver Creek Limited
s 9(2)(a) (Via Email)

Attention: Gavin Moore

Project Ref: #2355055
Letter Ref: E-LTR-G-005-Rev.A

<u>Silver Creek Geotechnical Letter to Supplement Fast Track Consent</u>

To Gavin,

Kirk Roberts were requested to provide a geotechnical letter to supplement a Fast Track Consenting application for the Silver Creek Subdivision.

Kirk Roberts Consulting provided reporting to assist with Queenstown Lakes District Council's Request for Further Information throughout RM201035 and RM210908 however Ground Consulting Limited provided the Geotechnical feasibility and initial hazard reporting which is further detailed below.

Kirk Roberts Consulting are engaged as the certifying geotechnical engineering consultant to provide the following scope of work throughout Silver Creek subdivision development:

- Provide site investigations for the proposed bulk lots developments to assist with subdivision consent applications.
- Earthworks construction monitoring in accordance with NZS4431:2022 and the Queenstown Lakes District Council Land Development Subdivision Code of Practice.
- On completion of suitable earthworks within each stage prepared, Kirk Roberts Consulting will provide a Geotechnical Completion Report and Schedule 2A certificate.

Previous Geotechnical Reporting

Ground Consulting Limited (GCL) conducted the initial site wide geotechnical feasibility assessment in June 2019 for the proposed future residential development of Silver Creek (Attachment 1). The reporting provides a factual assessment of ground conditions, groundwater conditions, landslide mapping and surface water conditions. Part 2 of the reporting provides Geotechnical Considerations and Analysis such as landslide stability, site development constraints, zoning and stormwater management.

Ground Consulting Limited classified different zones within the development to assess potential future development (Attachment 2 & 3).

- Zone A and B generally indicate traditional NZS3604:2011 developments can be prepared within the specified areas.
- Zone C areas have not been investigated enough to provide a final zoning classification however it is expected that following further investigation, Zone C will be reclassified as Zone A or B. Where areas remain as Zone C, Specific Engineering Design will be required to assist with foundation design due to slope grade or retaining requirements, beyond the limits of NZS3604:2011.
- Zone D is unsuitable for development due to the presence of steep slopes and unsuitable relic landforms however Zone D only covers 6% of the Silver Creek Subdivision.

Summary of Previous Geotechnical Reporting

Kirk Roberts Consulting have reviewed the reporting prepared to date by GCL. The land zoning (Zone A-D) detailed by GCL provides confirmation that the geotechnical investigation works completed to date confirm the Silver Creek subdivision is suitable for residential development.

The GCL reporting considers hazards in accordance with Section 106 of the Resource Management Act (RMA) 1991. Surface water courses and rockfall have been identified as potential hazards however with appropriate mitigation during subdivision development, both hazards are able to be managed. Final commentary and reporting on hazard mitigation will be detailed in the Geotechnical Completion Report of each Silver Creek Subdivision stage completed.

Hazard Maps

Review of the Queenstown Lakes District Council Hazard Map indicates the following hazards identified for the site (Attachment 4):

Queenstown Hill Landslide:

- The GCL reporting prepared provides thorough investigation and reporting in relation to the landslide hazard resulting in the land zoning which indicates development is suitable to progress at the Silver Creek development.

Liquefaction Susceptibility: LIC 1- Nil to Low Risk:

- The classification has been described as nil to low risk. Based on the shallow depth to Haast Schist, the geological conditions on site do not promote liquefaction and therefore, the risk classification is acceptable.

No further hazards are detailed on the maps.

Hazard Maps Summary

The hazards identified on the Queenstown Lakes District Hazard Maps introduce no new hazards that haven't been previously reviewed in existing reporting prepared by GCL for Silver Creek.

Hazard Summary and Geotechnical Suitability for Residential Development

Kirk Roberts Consulting have not completed the Geotechnical Investigations for the proposed stages of Silver Creek at the time of preparing this letter however to provide a high level hazard assessment, have reviewed desk top information and available reporting.

Rockfall hazard mitigation include rock pinning, removal of loose boulders, debris diversion structures, retaining walls and catchment structures. Utilising the measures detailed, the hazard of rockfall risk, if present on site, can be suitably mitigated.

Surface water/inundation is expected to be mitigated through practical civil design such as stormwater run-off from roofs, driveways and hardstand areas should be appropriately managed and discharged appropriately.

Due to the shallow depth of Haast Schist across the site, the nil to low risk of liquefaction on the QLDC maps is acceptable and no further mitigation is required.

As outlined within GCL's zone map (Attachment 3), Zone D outlines the steep slopes located along the central gully and certain areas located within the landslide toe. The current plan indicates there is approximately 18,000 m² of Zone D, which represents 6% of total land within the development.

No proposed lots are made up completely of Zone D land. It is expected that no development zones will be included in the Geotechnical Completion Report as consent notices with appropriate setbacks. Zones A, B & C pending further investigations may provide specific building platforms suitable for SED foundation design. As detailed in Attachment 3, areas of Zone C may also be classed as Zone D following further assessment.

Conclusion

Following review of available geotechnical information prepared for the Silver Creek Subdivision, Kirk Roberts consider that the development is suitable for residential development as illustrated on the Master Plan in Attachment 5. During the earthworks phase of each stage of development, geotechnical hazards identified will be appropriately identified with mitigation measures and final documentation detailed within the relevant Geotechnical Completion Report and Schedule 2A.

Limitations

Whilst every care was taken during our desktop review, there may well be subsoil strata and features that were not detected.

It must be appreciated that the actual characteristics of the subsurface materials may vary significantly between adjacent test locations and sample intervals other than where explorations and investigations have been made.

It should be noted that because of the inherent uncertainties in subsurface evaluations, variations in subsurface conditions may occur that could affect total project cost and/or execution. Kirk Roberts Consulting does not accept responsibility for the consequences of significant variances in the conditions and the requirements for execution of the works.

The letter is suitable only to supplement a Fast Track Consent process however is not suitable to supplement a Resource Consent application.

This report has been prepared at the specific instructions of our client in connection with the above project. No liability is accepted by Kirk Roberts or any of their employees with respect to the use of this report by any other party.

Yours faithfully

Ollie Behrent
Engineering Geologist/Geotechnical Engineer

Attachments

Attachment 1: GCL Geotechnical Feasibility Report

Attachment_E_Geotech_assessment_Rev_B.pdf

Attachment 2: GCL updated Zones Letter

L4726-1E_Updated.pdf

Attachment 3: Subdivision Zones Map

GCL_Subdivision_zones.pdf

Attachment 4: QLDC Hazard Map

QLDC_Hazard_Map.pdf

Attachment 5: Master Plan

350_SK-01A_Masterplan_240426.pdf

Disclaimer

Third Parties:This letter has been prepared for the sole use of our client, for the particular brief and on the terms and conditions agreed with our client. It may not be used or relied on (in whole or part) by anyone else, or for any other purpose, or in any other contexts, without our prior written agreement. We will not be liable for any loss, damage, cost, or expense incurred by such other persons.

Disciplines are limited to those stated: Although we are a multi-disciplinary organisation, we only provide input on each project from the particular disciplines engaged by our client and expressly stated in this document and our obligations are limited to the inputs expected from those specified disciplines. Please let us know if you would like to engage additional services or disciplines for your project.

SILVER CREEK LTD

GOLDFIELD HEIGHTS,
QUEENSTOWN

GEOTECHNICAL FEASIBILITY ASSESSMENT OF THE MIDDLETON BLOCK FOR FUTURE RESIDENTIAL DEVELOPMENT

REF: R4726-1B
DATE: 26 JANUARY 2021

GCL
Ground Consulting Ltd

REPORT QUALITY CONTROL

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CLIENT		SILVER CREEK LTD			
REV	DATE	REVISION STATUS	AUTHOR	REVIEWER	
A	26 JUNE 2019	ISSUED TO CLIENT	FRASER WALSH	PETER FORREST	
B	26 JANUARY 2021	AMENDMENTS TO SECTION 8 (DEVELOPMENT ZONES) AND DRAWING 005	JAMES WALLIS	PETER FORREST	

APPROVAL			
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EXECUTIVE SUMMARY

Scope of work

General Site Description

Site Investigation and Ground Conditions

Natural Hazards Assessment

Geotechnical Parameters & Recommendations

Stormwater and Effluent Disposal

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APPENDICES

1 INTRODUCTION

1.1 PROJECT BRIEF

A geotechnical feasibility assessment has been undertaken by GCL for the Middleton Block (Lot 2 DP 409336) at Goldfield Heights, Queenstown at the request of the client Silver Creek Ltd. The site location is presented in Drawing 001 and a recent aerial view presented as Drawing 002.

This geotechnical feasibility assessment has been prepared for the purpose of due diligence for future residential development of the block.

The Middleton Block has been studied previously by others including D Stossel (Masters Thesis), Tonkin and Taylor and Bell Geoconsulting Ltd with particular reference to the Queenstown Hill Landslide which has been mapped within the central to upper portions of the property. The previous investigations have been based largely on site mapping and interpretation of historical aerial photographs.

Our recent investigations have added to the previous investigations, including intensive geomorphological mapping, interpretation of LiDAR topographical data and the drilling of four cored boreholes to depths of between 24.5 and 26.5m. In addition, the intact core and shear / crush zones recovered from the boreholes are subject to a testing regime by the University of Canterbury for a Masters Thesis.

This report aims to provide further refinement to the extent and characteristics of the Queenstown Hill Landslide assessed previously and better understand the risks the landslide poses to residential development. In summary this report is split into two parts as follows:

- *Part 1: Factual assessment including:*
    - Ground conditions.
    - Groundwater conditions.
    - Queenstown Hill landslide mapping.
    - Surface water conditions.
- *Part 2: Geotechnical considerations and analysis including:*
    - Queenstown Hill landslide stability and risk of re-activation.
    - Site development constraints.
    - Site development zoning.
    - Stormwater management.
    - Other pertinent constraints and issues identified with the site.

1.2 PROPOSED SITE DEVELOPMENT

The Middleton Block (the "site") comprises 33.7Ha located along the northern fringes of the existing Goldfield Heights and Potters Hill Drive subdivisions. The client wishes to subdivide the property to provide a mix of predominately medium to high density residential development. Limited commercial areas including accommodation is also proposed.

We understand the development will occur over a number of stages, however, specific staging details have not been released to date. The stages will be accessed via a series of new roads which the client has indicated will likely follow a number of existing tracks which traverse the site.

The site is presently accessed by a number of roads which adjoin the southern edge of the property. We are unsure which access-ways will be extended to provide access to the site, however, the existing 4WD track along the northern property boundary, known as the power line inspection track, has been discussed as a main thoroughfare route.

We understand wastewater and stormwater will be piped to the council reticulated network and other services will be extended from the adjoining existing residential areas.

PART 1: FACTUAL ASSESSMENT

2 DESK TOP STUDY

2.1 PREVIOUS INVESTIGATIONS

2.1.1 eDOCS

GCL has reviewed the QLDC eDocs facility which provided limited site investigation documentation for the immediate area. GCL has undertaken recent site investigations within the local district and are therefore familiar with the ground conditions of the area.

2.1.2 D Stossel

University of Canterbury Masters student, D Stossel, has undertaken a thesis on the Engineering Geology of the Frankton Arm (Stossel, 1999). This includes extensive site mapping of the Queenstown Hill Landslide as part of a series of seven schist bedrock landslides studied. The thesis in summary concludes the following in regard to the Queenstown Hill Landslide:

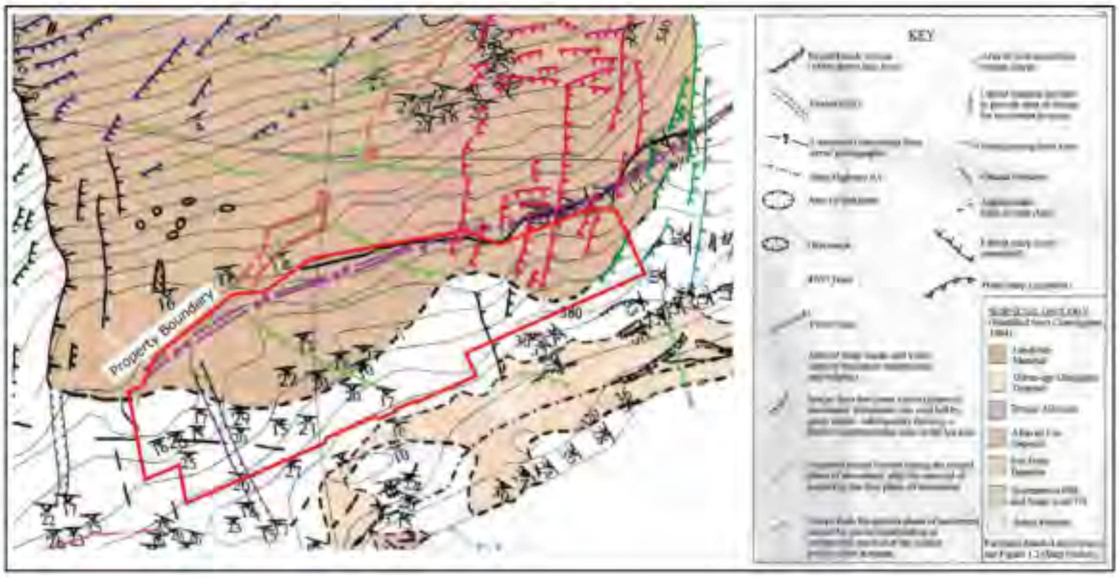
- The schist bedrock of the Frankton Arm consists of Haast Schist Terrane belonging to textural zone IV chlorite schist.
- The bedrock in the Frankton Arm has been subject to at least four major periods of ice advance and retreat (from ~500,000 to 15,000 years ago) with the last ice retreat commencing ~14,000 years ago.
- Stereographic analysis has indicated four major defect sets within the schist bedrock along the Frankton Arm which is considered to contribute to destabilisation of the rock mass.
- The Queenstown Hill Landslide has an estimated volume 240M m^3 and is interpreted as a simple translational slide with the toe forming a shallow compressional bulge. The compression is related to the slow gravitational relaxation into a schist block situated along the slopes of the Queenstown Hill. Three phases of movement are inferred to have taken place, with the earliest stage initiated by ice scouring and undercutting during the final stages of glaciation. The movement of the landslide is classed as

retrogressive over repeated movements whereby the landslide activity propagates up slope.

- A sensitivity analysis using simplified failure models indicates that low friction angles within foliation shear zones (below 20 to 25°) may trigger instability. Failure may be initiated along foliation shears and crushed schist particularly when ground water is at least half the depth of the landslide mass. Elevated ground water levels were feasible following glaciation resulting in increased weathering, alteration and erosion of the platy micaceous minerals contained within the pelitic schist horizons, causing failure along the pre-existing foliation shear zones. Seismic triggers could have been the final initiating failure mechanism.

Figure 1 below shows the mapping of the Queenstown Hill Landslide undertaken by D Stossel.

FIGURE 1: EXCERPT FROM STOSSEL, 1999. QUEENSTOWN HILL LANDSLIDE MAPPING



2.1.3 Bell Geoconsulting Ltd

Bell Geoconsulting Ltd (BGL) has prepared a "high level" review of geological and geotechnical issues at the site (BGL, 2018), and its potential suitability for residential development with particular emphasis on the stability of the Queenstown Hill Landslide. The report is principally based on a review of previous relevant reports / council information for the site, an analysis of historic aerial photographs and the analysis of installed survey marks.

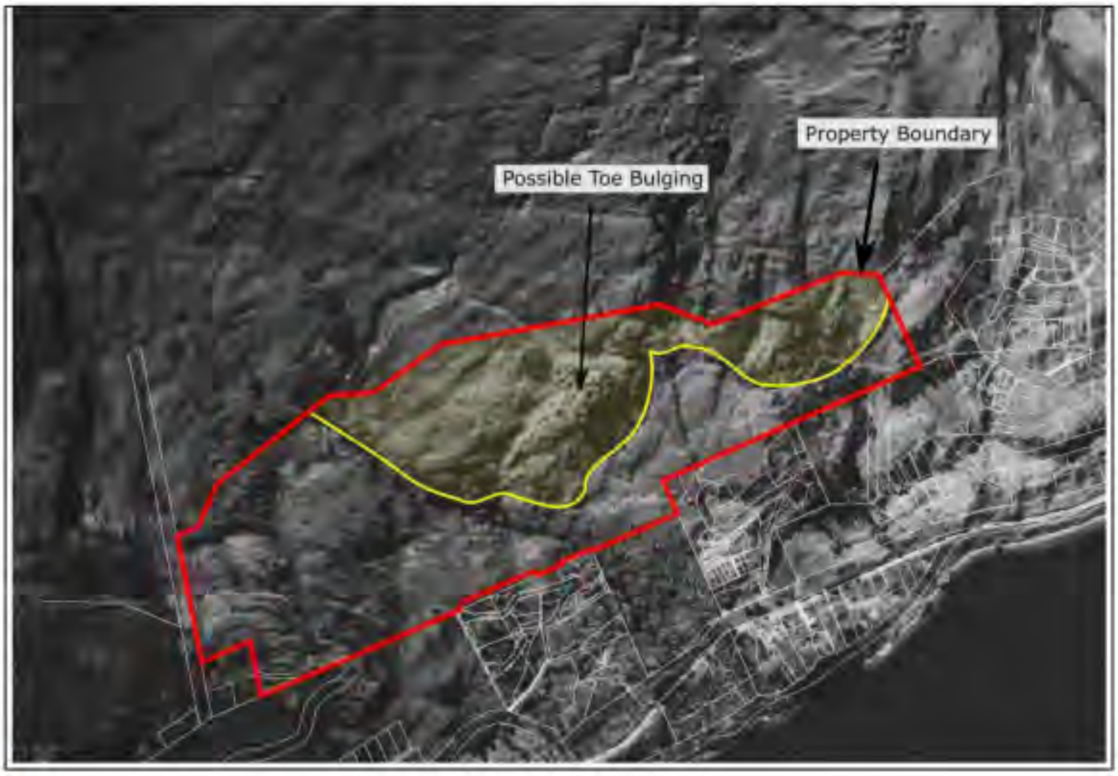
The BGL report in summary concludes the following:

- The site is located on the lower reaches of the Queenstown Hill Landslide. The landslide is approximately 10,000 to 14,000 years old and formed due to glacial over-steepening of slopes and subsequent failure during glacial retreat by removal of slope buttressing.
- The landslide appears to be stable from an analysis of historical aerial photographs since 1954 and levelling of eight survey marks over the past 10 years which have indicated no movement outside a 50mm error bar.
- Two development zones have been identified, one which shows evidence of ground deformation and the other which is considered suitably stable for development. The

"low development priority" zone comprises the lower reaches and toe of the Queenstown Hill Landslide with the remainder of the site classed as "suitably stable".

Figure 2 below shows the extent of the Queenstown Hill Landslide provided by BGL.

FIGURE 2: EXCERPT FROM BGL, 2018. EXTENT OF QUEENSTOWN HILL LANDSLIDE



2.1.4 Tonkin and Taylor

The BGL report refers to a Tonkin and Taylor preliminary geotechnical assessment of the site in 2005 which is not publicly available and has not been viewed by GCL. BGL indicate that Tonkin and Taylor divide the site into three stability zones. A large portion of the upper section of the site is described as "actively creeping landslide", due to the presence of scarps on the historical aerial photographs. A second portion of the site is described as "marginally stable land" due to the localised occurrence of ground cracks and possible block sliding. The remainder of the site is described as "land suitable for residential development".

2.2 NEW ZEALAND GEOTECHNICAL DATABASE

The New Zealand Geotechnical Database has been viewed and no geotechnical investigations have been identified in the immediate vicinity of the site.

2.3 HISTORICAL AERIAL PHOTOGRAPHS

Aerial photographs available from Google Earth Images and Retrolens dating from 1954 to 2016 were studied to observe the site over time and assess the geomorphological setting. We were unable to observe any additional features to that reported previously and concur with the previous authors that no movement or changes in shape can be observed in the vicinity of the Queenstown Hill Landslide.

We note the historical aerial photographs do not show the recent Middleton Road subdivision which has recently been completed to the east of the site.

2.4 GIS HAZARD MAPPING

2.4.1 General

With reference to the ORC and QLDC GIS hazard mapping, the site has the following characteristics:

- The site is not mapped in a flood hazard zone.
- The site is not mapped in an area associated with active fault zones.
- The site area is mapped as having a low to nil risk of the development of liquefaction due to proximity to rockhead and the lack of fine-grained sediments.
- A 1:2500-year seismic event will cause significant shaking and damage to inappropriately designed structures.
- The seismic soil classification for the area is mapped as Class B (shallow rock head).

2.4.2 Queenstown Hill Landslide

The ORC and QLDC GIS hazard mapping shows the Queenstown Hill Landslide. The mapped extent of the landslide differs between the hazard maps, with QLDC indicating a landslide toe which approximately matches D Stossel (1999) and BGL (2018) and ORC providing a significantly larger footprint comprising both smaller and larger landslides. The landslide hazard mapping is presented below.

FIGURE 3: QLDC LANDSLIDE HAZARD MAPPING

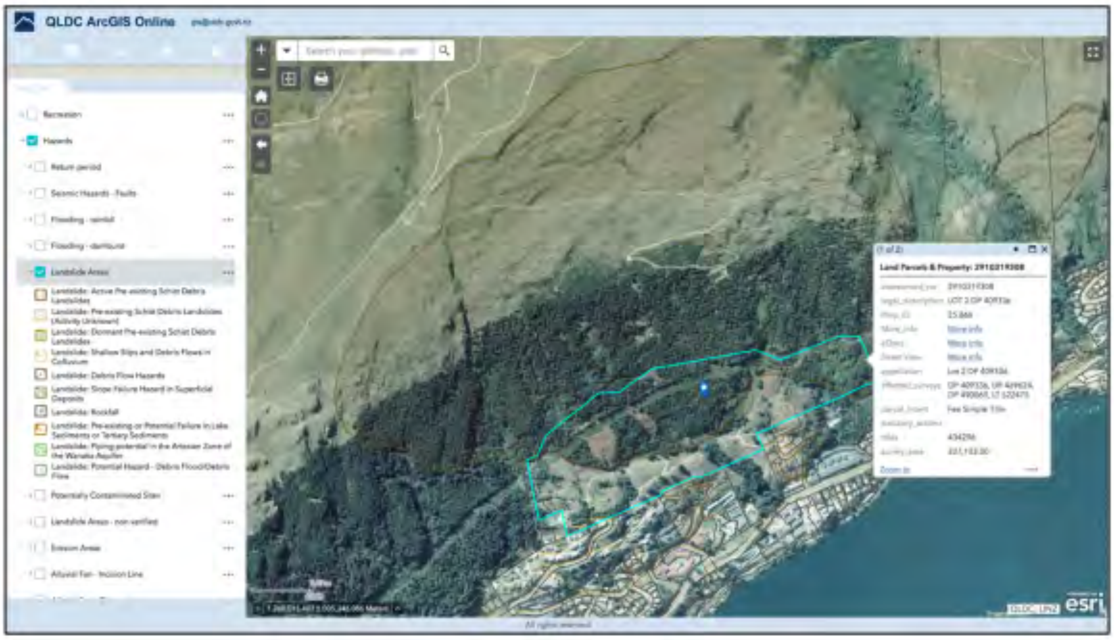


FIGURE 4: ORC LANDSLIDE HAZARD MAPPING

2.4.3 Tonkin & Taylor (T&T) Liquefaction Hazard Assessment for QLDC

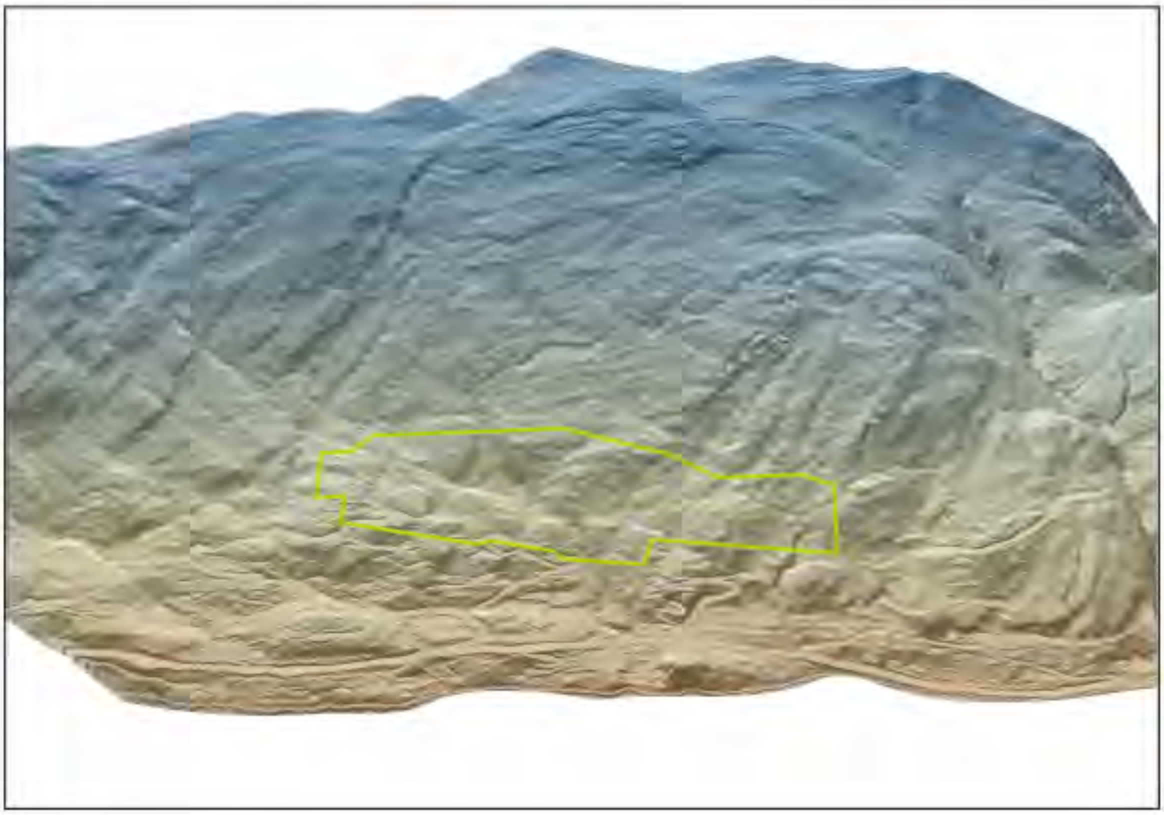
In 2012, T&T published their Queenstown Lakes District Liquefaction Hazard Assessment Report, a summary of which is usually attached to the LIM for any property. The report indicates that the site lies in an area zoned as "nil to low" for the potential development of liquefaction. This is consistent with the relatively shallow schist rock head identified across the site.

2.5 LIDAR TOPOGRAPHICAL DATA

LiDAR data of the site and local area is made available by Land Information New Zealand and Queenstown Lakes District Council. The data has been down-loaded and processed using qGIS and is utilised in Drawings 003 to 005.

LiDAR data provides accurate topographical information and removes the effect of vegetation and structure cover such as dwellings. The LiDAR data has been utilised to accurately map geomorphological features and in particular scarps, lineations, disturbed ground, bluffs / rock lines, overland flow paths, gullies and existing site development features. Site mapping has been utilized in conjunction with LiDAR data to effectively ground truth the analysis undertaken. An excerpt from the LiDAR data is shown below.

FIGURE 5: LIDAR DATA SHOWING 3D VIEW OF SITE AND SURROUNDS



2.6 PUBLISHED GEOLOGY

The Geological Map of New Zealand, Sheet 18 (Wakatipu), at a scale of 1:250,000 maps the site as being underlain by undifferentiated Caples terrane schist. The Caples terrane schist consists of well foliated psammitic and pelitic schist with incipient segregation; minor greenschist and metachert and quartz veins are not uncommon.

2.7 SITE SERVICES

GCL has not undertaken any specific searches of the site utilities and services for the purpose of this report. However, at the time of our site investigation, there was no evidence of any buried services within the site.

With reference to the Queenstown Lakes District Council GIS viewer, the adjoining subdivisions are serviced by reticulated sewer and stormwater systems. Power, telecom and water is provided via underground service mains.

A set of high-tension overhead power lines traverse the upper portion of the site in a general west to east direction.

3 SITE CONDITIONS

3.1 SITE DETAILS

The site comprises Lot 2 DP 409336 at Goldfield Heights, Queenstown, with an area of approximately 34Ha located along the northern fringes of the existing Goldfield Heights and Potters Hill Drive subdivisions. The site is presently accessed by a number of roads which adjoin the southern edge of the property.

The site is presently undeveloped and covered in a mix of wilding pines, exotics, scrub and grass.

3.2 EXISTING SITE DEVELOPMENT FEATURES

The site contains a number of existing site development features as follows:

- A series of tracks traverse the site. The tracks are in various states with a number of overgrown tracks recently cleared to allow access through the site. A 4WD vehicle access track extends off Goldfield Heights / Tree Tops Rise and progresses up the site slopes and along a cleared portion of the site provided for high tension power lines.
- High tension power lines traverse in an east to west direction close to the northern edge of the subdivision. The pines have been cleared along the lines providing a tract of mainly overgrown grass and shrubs.
- A small pond has been dammed close to the central and southern site boundary. We are unsure on the purpose of the pond which may have been provided for stock watering purposes.

3.3 SITE TOPOGRAPHY

3.3.1 Site Topographic Setting

The site is located near the base of extensive southerly facing slopes which extend down the southern flanks of Queenstown Hill. Queenstown Hill forms a high point of 907m asl.

The site presents as largely gently to moderately steep with more confined areas of steep to very steep slopes associated largely with bluffs and gullies.

The highest point is located on the northern property boundary with the lowest point ~50m lower on the southern property boundary.

3.3.2 Site Topographic Features

The site contains a number of topographic features which we wish to summarise as follows:

3.3.2.1 Central Lobe

A significant lobe protrudes from the slopes within the central portion of the site. The lobe forms an approximate V shape on the lower edge and is readily identifiable on Figure 3 (Section 2.4 of this report). The southern edge of the lobe provides steep to very steep slopes and rock bluffs up to 10m high in places. The slopes are disturbed and disjointed and contain a number of large open cracks and displaced schist blocks as discussed later in this report.

The lobe is covered in dense wilding pines and scrub and as such is difficult to observe by remote methods and requires close inspection to delineate a lot of these features.

3.3.2.2 Central Gully

A prominent gully extends in a north-west to south-east direction through the central and western portions of the site. The gully is generally steep sided and forms the lower western edge of the aforementioned lobe. The gully continues to the south of the site between Goldfield Heights and Potters Hill Drive. A small pond has been formed within the gully close to "BH 2" (see Drawing 003).

3.3.2.3 Eastern Steep Slopes

The eastern and north-eastern portions of the site contain steep slopes which are incised by a series of confined gullies and bluffs forming an irregular topographic profile. The slopes extend down to the southern property boundary and lower lying existing residential development.

3.3.2.4 Western and Southern Moderate Slopes

The remainder of the site is characterised by broad gently to moderately steep undulating slopes which extend down to the southern property boundary. The slopes contain some irregularities including confined gullies and bluffs. These are generally isolated features within the slopes. Drawing 003 shows these areas as containing the more topographically featureless (less shading changes) portions of the site.

3.4 SITE SURFACE WATER FEATURES

The site is drained via. a series of gullies and small channels which drain down to the southern property boundary. The more significant "central" gully contained flows on inspection and appears to provide a local low point for a number of overland flow paths which feed into this feature.

The water features are generally delineated by linear indentations observed within the slopes in Drawing 003.

Outside of the surface water features, surface drainage is characterised by sheet flow following the general southerly sloping topography.

4 QUEENSTOWN HILL LANDSLIDE

4.1 GENERAL

The slopes in the vicinity of the site are dominated by large scarp features, significant tension cracking and lobes which form what has previously been described as the "Queenstown Hill Landslide". Significant geomorphological mapping, site sampling, aerial photography analysis and LiDAR analysis has been undertaken previously by others and GCL to define the extent and characteristics of this feature.

The Queenstown Hill Landslide is defined as a large translational planar slide controlled by schistosity / foliation and defects within the schist bedrock. The slide forms part of a series of similar landslides which are located along the southerly facing slopes above the Frankton Arm of Lake Wakatipu.

The landslide is approximately 1.6km wide by 1.5km long and has an estimated volume of 240M m^3 (D Stossel, 1999). The upper extent of the landslide is defined by a series of large-scale scarps and tension cracks, as shown on Drawing 004.

The western and eastern lateral extent of the landslide is defined by significant north to south trending scarps forming a series of prominent rock bluffs.

The toe of the landslide is marked by a series of lobes which likely represent compression and associated bulging at the toe. Toe bulging features are located within the subdivision in part as shown on Drawing 003.

4.2 HEAD SCARPS

The head of the landslide is marked by set of clear tension cracks and scarps. These features repeat themselves down-slope marking a series of head scarps which step down the hillside. Mapping of the head scarps has identified near vertical schist faces up to 10m high with the faces moderately to slightly weathered and partially in-filled with slope wash and vegetation. No sign of any recent movement was observed.

Further significant scarps are located within the central and lower portions of the landslide as shown on Drawings 004 & 005. The scarps are indicative of a landslide complex, whereby movement likely occurs at various rates and intervals. D Stossel (1999) indicates the movement is likely retrogressive whereby the lower portion of the landslide moves which releases further sections of the complex up-slope over time.

The scarps typically trend in a south-west to north-east direction and are noticeably larger within the lower portion of the landslide likely indicating greater magnitude of movement.

4.3 TOE BULGING

The toe of the landslide is marked by a series of compression failures forming toe bulges to varying degrees. These can be clearly seen in the LiDAR data and aerial photographs.

BGL (2018) shows the large lobe feature within the central portion of the site to consist of landslide "toe bulging". This is also in agreement with D Stossel (1999) and QLDC landslide hazard mapping. ORC shows a much larger landslide extent; however, we are unsure on how this was derived, but is unlikely to have been based on detailed site specific data produced by recent authors.

GCL has undertaken geological and geomorphological mapping of this feature given its prominence within the property and identified the following:

- The lobe face consists of a series of steep rock bluffs up to 10m high. The bluffs are highly irregular, disjointed and display large cracks and displaced schist blocks.
- A number of the cracks and scarps which have developed within the lobe appear to be younger features given the lack of significant weathering of the exposed rock faces and little vegetation / slope wash in-fill.
- Some cracks can be traced up-hill to the upper northern track with the majority terminating less than 50m from the top of the steep bluff line.
- Thick wilding pines cover the majority of the lobe. The thick carpet of pine needles has in many cases partially obscured deep cracks observed which have been probed to measure up to 5m deep. It is possible that the cracks propagate 10s of metres into the slopes.
- The lobe bluffs contain a number of large schist blocks, some of which appear only marginally stable and in some cases appear to have moved, for example leaning against trees.
- Drawings 003 to 004 show some of the prominent scarps and cracks within the toe bulge.

Photographs of some of these features are shown below.

FIGURE 6: LOBE PHOTOGRAPHS

Figure 6a: Large crack partially filled with vegetation

Figure 6b: Large crack > 5.0m deep

Figure 6c: Displaced schist blocks

Figure 6d: Displaced schist blocks up to 35m wide (background block)

4.4 FOLIATION MAPPING

Detailed mapping of the Queenstown Hill landslide across the site has been undertaken. As part of this mapping, over 220 strike and dips of foliation have been recorded with a hand-held device. This was achieved by the use of a 20 tonne excavator which cleared soil from extensive shallow rock head exposing typically clean / unweathered to slightly weathered foliation. The strike and dips of foliation are shown on Drawings 003 to 005.

Plots of the foliation poles measured from site show differing degrees of variability depending on their geographical location within the wider slope. Our interpretation of this variability, in combination with field observation, has allowed us to define three distinct zones, namely green, orange and red.

The green zone represents largely undisturbed areas. The red zone is predominantly around the area of the bluffs and toe bulge, while the orange zone is defined as areas showing some level of disturbance or a lack of data available to interpret.

The stereographic plots taken from these zones are shown in Figure 7 to Figure 9.

FIGURE 7: PLOT OF FOLIATION POLES – GREEN ZONE

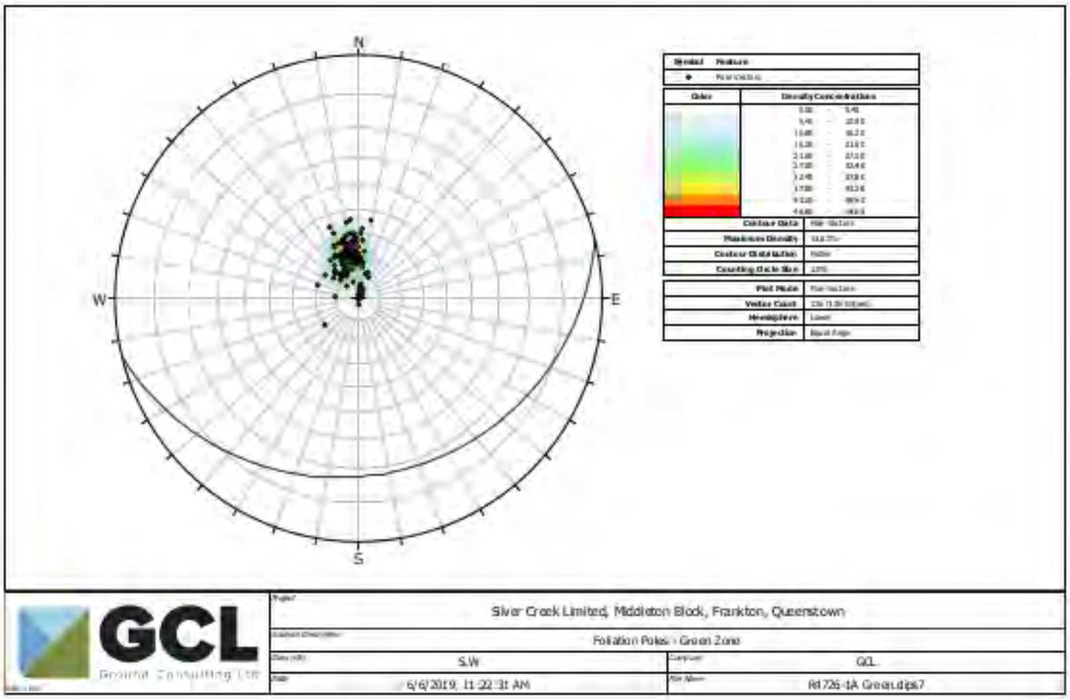


FIGURE 8: PLOT OF FOLIATION POLES – ORANGE ZONE

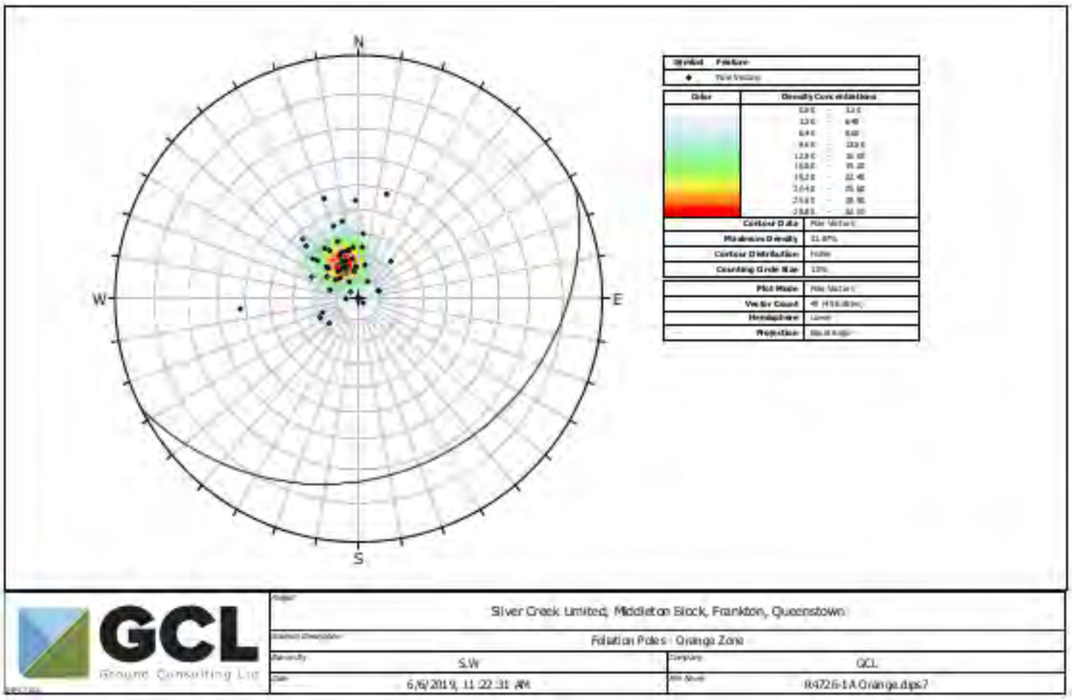
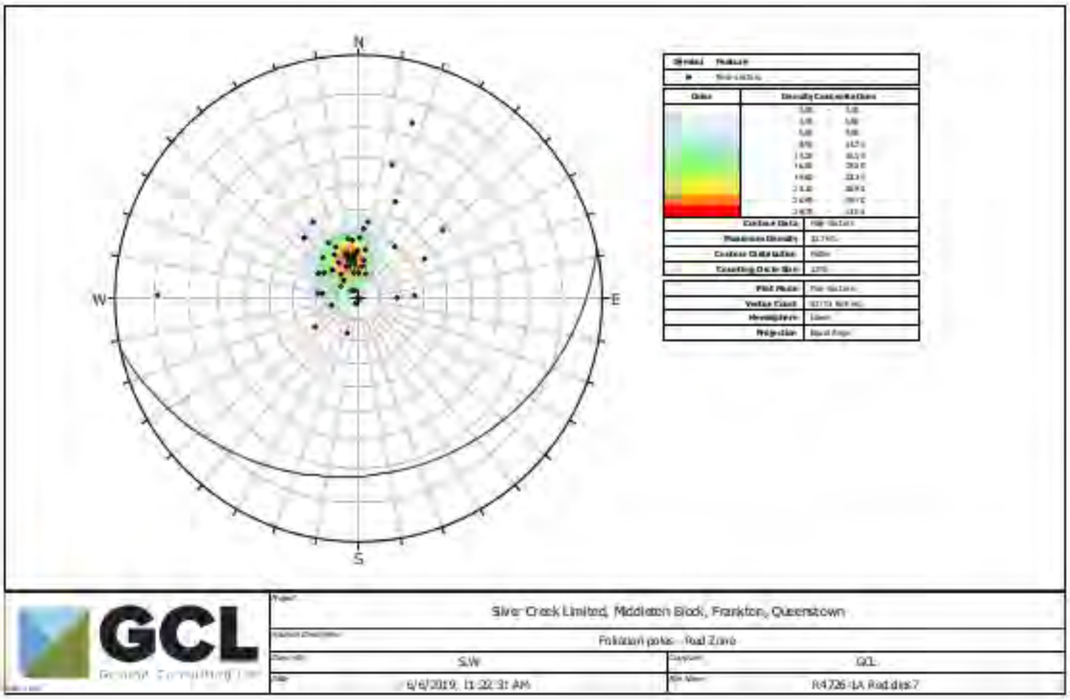


FIGURE 9: PLOT FOLIATION POLES – RED ZONE



The plots show the following features of note:

- All three plots show a general grouping of foliation poles with an associated average dip to the S to SSW at 18°. This is consistent with the local foliation strike and dip measured by D Stossel (1999) and others within the undisturbed Goldfield Heights and Potters Hill Drive subdivisions.
- The undisturbed "green zone" provides a much tighter cluster of poles than the orange and red zones. The red zone located in the vicinity of the toe bulge provides the largest scatter of foliation poles. This is consistent with the disturbed rock profile in this zone where a number of large schist blocks have partially rotated.

4.5 MONITORING

4.5.1 Survey Monitoring

BGL indicate that eight survey marks have been placed within the site and in particular including survey marks on the landslide toe bulge. Monitoring of the survey marks by Aurum have indicated no appreciable movement with a survey error of 50mm. Given the 10 year period of surveying, any creep in the landslide over this period has been <50mm (ie <5mm/year).

4.5.2 Observation

Features such as the power poles that run through the upper part of the project site show no signs of distortion or rotation. As these are believed to be at least 25 years old the lack of movement supports survey data showing that less than 50mm of movement has occurred in this part of the hillside in recent times.

4.6 OTHER PROMINENT LINEATIONS / BLUFFS

Other lineations and features have been identified in the process of field mapping and examining LiDAR data as follows:

- A prominent series of west to east trending lineations can be observed from the LiDAR data and aerial photographs. These features run approximately along the strike of foliation and are likely associated with differential erosion resulting from variations in the pelitic and psammitic schist. These features are not considered to be associated with slope instability.
- A prominent series of north to south trending rock bluffs form within the site and in the local area. These features appear to be associated with a common fracture orientation observed by D Stossel (1999) and in part run parallel to the Queenstown Hill Landslide lateral scarps. The fracture orientation likely provides a wedge type failure component to the translational type Queenstown Hill Landslide. These features may also represent glaciation plucking along the prominent fracture orientation.

5 SUB SURFACE CONDITIONS

5.1 FIELD INVESTIGATIONS

Sub-surface investigations have been undertaken within the project site. The investigations were undertaken by a suitably qualified engineering geologist from GCL, with locations determined with a hand-held GPS device and the use of QLDC GIS viewer and Google Maps.

The sub-surface investigations have comprised:

- Four fully cored boreholes to a depth of between 24.5 and 26.5m.
- Over 220 measurements of foliation strike/dip, fracture strike/dip and other rock defects. The majority of points were uncovered with the use of test-pits excavated down to rock level (typically less than 1.0m deep) by a 20 tonne excavator with a rock bucket.

The location of each test point is shown on Drawings 003 to 005 with plots of the foliation poles presented on Figure 7 to Figure 9.

5.2 INVESTIGATION LOGGING AND TESTING

Rock recovered from the boreholes has been logged and is presented in Appendix A. Logging of the recovered core has been undertaken in accordance with NZ Geotechnical Society Guidelines for the Field Classification and Description of Soil and Rock for Engineering Purposes.

Determination of rock strength has been undertaken in accordance with NZ Geotechnical Society Guidelines for the Field Classification and Description of Soil and Rock for Engineering Purposes.

As part of the University of Canterbury thesis being undertaken in the general area, rock strength measurements in the form of uniaxial compressive strength and point load testing has been undertaken, which will allow the derivation of a suite of geotechnical parameters.

5.3 GROUND CONDITIONS

A summary of the sub-surface conditions identified in the investigations undertaken is presented below in order of depth from the ground surface. The sub-surface conditions have been extrapolated between the investigations undertaken. Whilst care has been taken to provide sufficient sub-surface information following best practice for the purposes of due diligence, no guarantee can be given on the validity of the inference made. As such, it should be appreciated that ground conditions may vary between the investigations undertaken.

5.3.1 Topsoil

A topsoil layer mantles the vegetated portions of the site to a depth of typically between 0.1 and 0.4m.

5.3.2 Colluvium Deposits

Alluvial deposits, consisting largely of slope wash, mantle the shallow rock head to a depth of typically less than 1.0m but may be thicker within topographic low points and along drainage paths.

This granular material is best described as gravelly SAND, silty SAND and sandy GRAVEL with occasional cobbles.

Strength testing of this layer was not undertaken but the colluvium deposits are expected be in a loose to dense condition.

5.3.3 Schist Bedrock

5.3.3.1 General

Schist bedrock underlies the site at or close to the surface over significant portions of the property. The schist presents itself where in-tact as weathered to unweathered, dark grey (pelitic) to light grey (psammitic), thinly laminated, foliated, and weak to moderately strong.

5.3.3.2 Foliation

The schist foliation has been mapped as described in Section 4.4 of this report. In summary, the undisturbed schist foliation dips to the south at typically between 15 and 25° with a mean dip of 18°.

5.3.3.3 Discontinuities and Rock Defects

While a number of defects and discontinuities exist within the rockmass at various scales, these are insignificant in the context of the wider landslide, where the macro features of scarps, tension cracks and toe bulge will be the main features that dictate stability.

The schist contains prominent fracture orientations which have been mapped extensively by D Stossel (1999).

In addition, the schist bedrock contains highly fractured shear zones which have been consistently identified in the borehole investigations undertaken. D Stossel (1999) also describes the common shear zones in the local area. It is likely that the fractures and shear zones provided pre-existing weaknesses for the development of the large-scale landslide features on Queenstown Hill.

5.3.3.4 Boreholes

Four fully cored boreholes have been constructed within the site to a depth of between 24.5 and 26.5m. The location of the boreholes is shown on Drawings 003 to 005 with the logs presented in Appendix A.

The logs in terms of engineering geology features have identified the following:

BH1: BH1 is located near the north-western corner of the site and has been constructed to a depth of 25.0m. The borehole is considered to be outside of the Queenstown Hill Landslide zone. The recovered core is largely in-tact with significant sections providing no rock defects. A significant shear zone consisting of crushed schist was identified at a depth of between 13.4 and 15.6m with three minor shear zones encountered at a depth of less than 8.0m. The shear zones generally present as gravel sized fragments of schist, with the finer fractions likely washed out by the drilling process. Circulation losses where noted by the drillers in the shear zones. Foliation dip where measured is consistent down the rock profile at an angle of between ~30° and 35°.

BH2: BH2 is located near the base of the landslide lobe within the central portion of the site and has been constructed to a depth of 26.5m. The recovered core contains extensive shear zones. The largest shear zone was identified at a depth of between 10.3 and 16.2m with a number of other shear zones up to 1.0m thick encountered at regular intervals to the base of the borehole. Circulation losses where noted by the drillers in the shear zones. Foliation dip where measured has some variability at an angle of between ~30° and 45°.

BH3: BH3 is located within the upper northern portion of the site and has been constructed to a depth of 24.5m. The borehole is considered to be located within the Queenstown Hill Landslide zone. The recovered core is largely in-tact with significant sections providing no defects. A significant shear zone was identified at a depth of between 18.1 and 19.5m with five other minor shear zones encountered at regular intervals. Foliation dip where measured is reasonably variable at an angle of between 25° and 40°.

BH4: BH4 is located near the lower eastern portion of the site and has been constructed to a depth of 25.0m. The borehole is considered to be outside of the Queenstown Hill Landslide zone. The recovered core is largely in-tact with only two minor shear zones encountered. Foliation dip where measured is consistent at an angle of ~20°.

5.4 GROUNDWATER CONDITIONS

Groundwater was not encountered within any of the shallow investigations consisting largely of test-pits to rock head level.

Borehole groundwater levels were not measured, however, from discussions with the drillers, a coherent groundwater table was not encountered in any of the boreholes. This is consistent with the elevated aspect of the site.

PART 2: GEOTECHNICAL CONSIDERATIONS

6 QUEENSTOWN HILL LANDSLIDE

6.1 GENERAL

The geotechnical constraints for residential development within the site are principally controlled by the Queenstown Hill Landslide. The Queenstown Hill Landslide is best described as a translational complex failure which was induced from the undercutting and subsequent removal of support provided by retreating glaciation. Failure was likely along pre-existing discontinuities such as shear zones, fractures and foliation.

The investigations undertaken by GCL, in addition to those carried out by others previously, has been undertaken to address the following issues:

- The extent / depth of the landslide within the site.
- Any evidence of recent movement and the risk of re-activation.

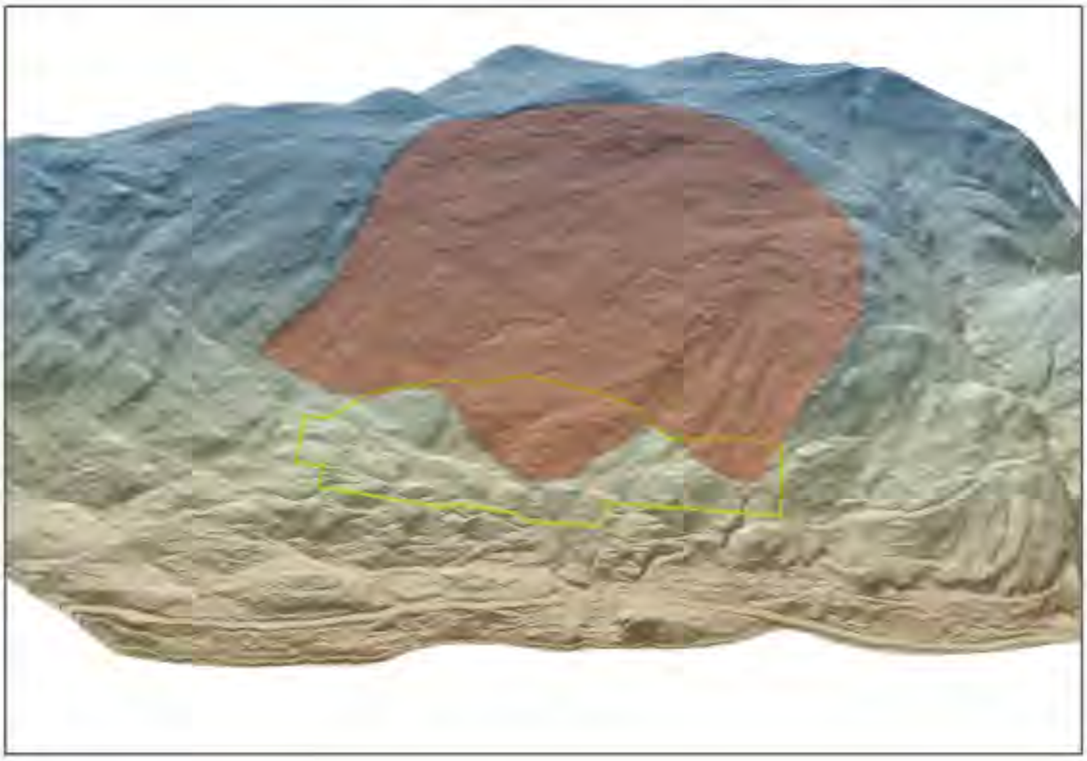
- The competency of ground conditions within the landslide zone.

6.2 LANDSLIDE EXTENT

The Queenstown Hill Landslide has been mapped extensively by GCL and others. Our best assessment of the landslide extent is shown on Figure 10 below, which is in general agreement to Stossel (1999) and BGL (2018) and is based on the following factors:

- Landform evidence: the landslide presents in the LiDAR data, aerial photographs and site mapping as disturbed ground, irregular topography, scarps, tension cracks, displaced schist blocks and bulging as shown on Drawings 003 to 005.
- Schist Foliation: Over 220 foliation strike/dips have been recorded and show a correlation between the landslide zone (irregular / disturbed schist blocks) and the scatter of foliation strike /dips as shown on Figure 7 to Figure 9.
- Boreholes: The correlation with disturbed foliation and the landslide zone is also evident in the recovered borehole core which show larger variance with foliation dip within the landslide zone. The boreholes also show less shearing down-slope of the landslide and this zone of schist appears to have provided a "dam" to the landslide toe resulting in prominent compressional bulges along the toe of the landslide.

FIGURE 10: MAPPED EXTENT OF QUEENSTOWN HILL LANDSLIDE (RED SHADING)



6.3 LANDSLIDE DEPTH

D Stossel (1999) estimates the landslide depth to between 50 and 150m. Given the translational nature of the landslide a relatively shallow depth of movement compared to aerial extent is expected.

The borehole investigations undertaken within the landslide to a depth of ~25m did not conclusively show a landslide base.

6.4 HISTORIC LANDSLIDE MOVEMENT

The historic landslide movement has been assessed in two parts:

6.4.1 Survey Marks

BGL indicate that eight survey marks have been placed within the site and in particular including survey marks on the landslide toe bulge. Monitoring of the survey marks by Aurum have indicated no appreciable movement with a survey error of 50mm. Given the 10 year period of surveying, any creep in the landslide over this period has been <50mm (ie <5mm/year).

As such, the survey data likely indicates the landslide is presently not active. We recommend that surveying of the marks is continued, especially following a significant seismic event.

6.4.2 Site Observations

6.4.2.1 Landslide Zone

Extensive mapping of the landslide zone has been undertaken. As part of the mapping we have inspected the large scarp features and tension cracks which generally present as weathered faces where exposed. No unweathered / recently exposed rock was observed within these areas indicating movement is not recent and likely ancient. The only exception to this was in the vicinity of the toe bulge face which is described below.

6.4.2.2 Lobe Face

The toe of the landslide has been mapped and only signs of recent surficial movement were evident. This included sharp, angular, and unweathered cracks, large schist blocks with fresh faces and minor in-fill of deep cracks. The more recent movement is typically confined to within 50m of the steep lobe face and likely represents relaxation of the steep face (tensional forces) rather than movement of the landslide toe (compressional forces). The relaxation of the lobe face has likely been exacerbated by significant seismic events. Potential rock-fall hazard associated with the lobe is discussed later in this report.

6.4.2.3 Degree of Landslide Movement

Given the aerial size of the landslide, the associated degree of movement appears to be relatively small. This is evidenced by:

- The size of the head scarps and tension crack zones.
- The size of the landslide toe bulge.
- The relatively coherent nature of the schist bedrock within the landslide zone (apart from the toe bulge area).
- The lack of completely disturbed schist debris as compared with other similar translational slides within the Queenstown region.

6.4.2.4 Conclusions

Given the relatively small degree of landslide displacement observed, we agree with others that the landslide trigger was likely associated with undercutting and removal of the buttress support provided by the glacier at the end of the last glaciation period (~14,000 years ago). After initial mobilisation, the landslide has reached a point of equilibrium which has not been disturbed for a significant period of time given site observations.

More recent movement identified in the toe area is considered to be associated with the steep slopes in the toe rather than re-activation of the landslide per se.

6.5 RISK OF LANDSLIDE RE-ACTIVATION

Following from 6.3 of this report, it is difficult to provide a quantitative assessment of landslide reactivation based on the investigations undertaken to date. The residual risk with this type of landslide is the propensity to creep and gross movement (especially following a significant seismic event). However, based on the investigations undertaken to date we note the following:

- Survey data has shown no appreciable landslide movement.
- The Alpine Fault has been subject to some 30+ ruptures since the last glaciation period without any apparent effect on the landslide.
- The landslide movement appears to be relatively confined and equilibrium was likely reached early on.

Further investigations are required to quantify this risk and presently testing of the recovered borehole core is being undertaken as part of a Masters thesis from the University of Canterbury.

6.6 COMPETENCY OF GROUND CONDITIONS WITHIN LANDSLIDE ZONE

As discussed previously, much of the site is underlain by competent schist rock at a shallow depth. Some zones contain disrupted areas as follows:

6.6.1 Landslide zone

Much of the landslide zone contains some disruption to the schist bedrock, however, for standard NZS 3604 type residential dwellings, a number of measures can be employed to provide a suitable building platform. This is separate to the issue of potential landslide movement which has been discussed previously.

6.6.2 Landslide Toe Lobe

This zone is highly disrupted and unlikely to provide suitable conditions for residential development without major engineering and ground control works

6.6.3 Slopes in Close Vicinity of the Landslide Lobe

BH2 indicates there is significant disturbance of the schist rock immediately down-slope of the landslide toe. This is to be expected given the significant compressional forces acting on the down-slope coherent schist block. Furthermore, the central gully formed near the toe of the landslide appears to have formed as a result of the weak schist which has eroded easily.

The extent of the disturbed toe zone appears to be relatively confined given the down-slope Goldfield Heights subdivision provides a series of intact road rock cuttings. This will require further investigation if utilised for residential development.

7 OTHER CONSTRAINING FEATURES

From the investigations undertaken to date the site contains other constraining features which may provide some constraints to residential development as follows:

7.1 SURFACE WATER COURSES

The site contains a series of overland flow paths, water courses and channels which direct water typically to the central portion of the site and into a main gully water course which extends to the south of the site.

Development of the site should be mindful of the watercourses which may require re-direction if developed. This has the likely beneficial consequence of increased local stability.

7.2 ROCK FALL

The steep faces within the site, especially in the vicinity of the landslide toe, contain significant loose or partially detached schist blocks. These blocks may fall / roll down the steep slopes, particularly in the event of a significant seismic event.

Rock fall can be managed via a number methods including rock pinning, removal of loose boulders, slope planting, debris diversion structures, benches, retaining walls and catchment structures.

7.3 SCHIST EXCAVATION

Competent schist rock underlies large portions of the site at a relatively shallow depth. Whilst this provides competent conditions for residential development, significant excavation of schist rock may be required to form access-ways and individual building platforms depending on the slope shape. This can be costly and time consuming for both the developer and lot owners.

This can be managed to a degree by adopting single lane roads, passing bays, off-street parking, and cognizance of slope geometry during master planning.

8 DEVELOPMENT ZONES

8.1 GENERAL

We have identified three development zones based on the investigations and ground model developed for the site. The development zones provide a traffic light type system as follows: