Geodiversity Values Study

Brooker-Main junction section of Granton to New Norfolk Quaternary Stratigraphic Sites

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1 Introduction

1.1 Project background and scope

In 2021 ERA Planning and Environment (ERA) was engaged to prepare a Geoheritage Impact Assessment to support an application for major project approval for the New Bridgewater Bridge (NBB).

The project has since been granted approval and permit conditions have been issued. The following permit conditions are applicable to geodiversity:

- Condition 42: Prior to the commencement of construction at the Brooker sub-site of the Granton to New Norfolk Quaternary Stratigraphic Sites a study, prepared by a suitably qualified person that details the geodiversity values of that sub-site, must be provided to the Commission.
- Condition 43: Within 1 year after the new Bridgewater Bridge being open to traffic, an addendum to the study of the Brooker sub-site of the Granton to New Norfolk Quaternary Stratigraphic Sites, prepared by a suitably qualified person, that documents the geodiversity values encountered during works and those remaining post construction, must be provided to the Commission.

The purpose of this report is to address the first of these permit conditions (Condition 42), by documenting the suite of sediments that remains un-studied at the Brooker-Main junction section (subsite) of the Granton to New Norfolk Quaternary Stratigraphic Sites. This report describes the lateral and vertical relationships of the various sedimentary units present at the Brooker-Main junction section, hereafter referred to as the 'Brooker sub-site'. This will contribute to an understanding of the paleoenvironmental conditions of the Lower Derwent Valley and determine the significance of the geodiversity values present at the Brooker sub-site.

The second relevant permit condition (Condition 43) will be the focus of follow up investigations and reported as a separate addendum.

1.2 Geodiversity context

Tasmania experienced heavy glaciation multiple times during the Quaternary. These events were characterised by the presence of ice caps, and valley and cirque glacier systems. The glacial events have been identified to be of Middle Pleistocene to Early Pleistocene in age, covering an area of approximately 1000km^2 (Colhoun, 2004; Jennings & Banks, 1958). Many associated deposits (termed relict cold climate deposits), not directly formed by glacial or periglacial processes, also formed during cooler climates than those present today. McIntosh et al (2012) describes relict extraglacial deposits as deposits that show accumulation in cold conditions such as freeze-thaw and snow melt. During the Pleistocene, when lower sea levels and increased continentality led to reduced rainfall and colder conditions, these deposits were found at lower altitudes than the current alpine zone (Colhoun, 2002).

Alluvial fans are depositional landforms which range from individual debris flows to fan deltas, which may be the result of hillslope failure or fluvial geomorphic processes. Alluvial deposits in the Lower Derwent valley have been classified by Wasson (1977) as debris flows or water-laid deposits, where debris flows dominate the proximal parts of fan, and water-laid deposits become more dominant away from the fan apices. Alluvial fans occur on both sides of the Derwent, derived from periglacial slope mantles in higher parts of the catchments, and have been further eroded by stream incision and sea level rise into the Derwent River estuary (Wasson, 1977).

This study considers the landforms and deposits at the Brooker-Main subsite of the Granton to New Norfolk Quaternary Stratigraphic Sites which are thought to be related to colder climates, increasing the effects of mass movement, enhanced alluviation and increased aeolian deposition. Paleoclimatic research is important because studying trends in past climate can increase understanding of future climatic changes and responses to global warming.

1.3 Geoconservation Significance

The Tasmanian Geoconservation Database (TGD) lists sites of geoconservation significance in the state of Tasmania. Geosites are assigned significance as the values context for comparing a geosite with similar or related geosites. Four levels of significance are recognised, namely district, state, national, and global. For example, a feature that is rare in Tasmania and common elsewhere would be considered significant at a state level. Prior to geosites being listed on the TGD, nominations are referred to the Tasmanian Geoconservation Database Reference Group (TGDRG), an expert panel in earth sciences from the University of Tasmania, Tasmanian Minerals Council, government departments and independent consultants.

The TGDRG expert panel provides expert scientific review and significance of sites proposed for listing. The panel advises Department of Natural Resources and Environment whether the proposed site is supported on scientific grounds and ensures that it satisfies the listing criteria. The listing criteria that contribute to geosite significance include the integrity of natural features and processes and the assessment of significance within the hierarchy of levels from global to district. The level of significance is determined by a quorum of the TGDRG.

The Granton to New Norfolk Quaternary Stratigraphic Sites (3278) geosite is listed at a district level of significance for Regolith and Soils and in particular for colluvium, aeolian dune, alluvium depositional environments. The geosite complex (Figure 1) provides a clear exposure of sedimentary sections which preserve evidence of changing environmental conditions in the Lower Derwent Valley over thousands of years. There are six sub sections of the geosite that show a range of sedimentary structures and relationships between facies. A number of publications have referred to the deposits, describing the 'the only loess known in Tasmania' from a cutting (Colhoun, 1977, 2002), debris flow and stream deposits (Wassan, 1977) and aeolian sands overlain by gravelly fan deposits (McIntosh et al., 2012; Mcintosh, 2012). The TGD notes that there are potentially significant but as yet un-studied cuttings at Mason Point and at the Brooker Highway-Main Road junction, and coarse, deeply weathered dolerite-rich alluvium near Sorell Creek (NVA, 2022). This report will document the suite of sediments that remains un-studied at the Brooker-Main junction section that will contribute to the understanding of the geosite values found at the Granton to New Norfolk Quaternary Stratigraphic Sites geosite.

Figure 1: Cuttings on the Lyell Highway and Boyer Road between Granton and New Norfolk expose Quaternary sediments deposited on the margins of the lower Derwent River flood plain, representing the suite of sediments within the Granton to New Norfolk Quaternary Stratigraphic Sites (3278) geosite (NVA, 2022).

1.4 Geology of the region

The geological setting of the area surrounding the Brooker-Main junction section is a large estuarine delta with a low relief river terrace that has formed during periods of deposition, with some older river terraces suggesting higher river base levels and higher flows (Colhoun, 1977). The lower Derwent River was initiated by a down-faulted trough in which clays, sands, and gravels were deposited. These deposits are comprised of Quaternary alluvial gravel, sand, and clay, and Paleogene-Neogene dolerite-based sediments, with limited amounts of Permian carbonaceous siltstone and mudstone interbedded with sandstone (Calver, 2005). On the southern side there are some areas of Jurassic dolerite bedrock along the Brooker highway, which are related to a tectonic event that included the intrusion of a large dolerite sheet seen across the Wellington Range and other parts of Tasmania.

2 Methodology

2.1 Location

The NBB project is approximately 20km north of Hobart, traversing the Derwent River adjacent to the existing bridge between Granton and Bridgewater (Figure 2). The Granton to New Norfolk Quaternary Stratigraphic Sites geosite is a series of road cuttings categorised into six sections, where only three of the sections (Mason Point, Windy Point, and Brooker-Main junction) are within 1km of the project site, and only one section (Brooker-Main junction) is directly in the Extent of Works area (Figure 2). The road cuttings expose Quaternary sediments on the margins of the lower Derwent River flood plain and are described in the Tasmanian Geoconservation Database as showing a considerable variety of facies from different geomorphological processes including mass movement, alluvial, and aeolian processes, and the relationships between them (NVA, 2022).

2.2 Methodology

To describe the lateral and vertical relationships of the various sedimentary units present at the Brooker-subsite, particle size distribution and geochemical analysis was undertaken to understand the textural attributes of grains and relationships between grains, and chemical composition of sediments. The grain or particle size distribution (PSD) of sediments reflects the relative energy and the morphological characteristics associated with landform development. At any site the PSD varies considerably laterally and vertically, representing differences in energy through periods of deposition, demonstrating physical transport and sedimentation processes. To reconstruct paleoenvironments and processes, sampling is required that represents the variety of sedimentary facies of a landform. Particle Size Distribution (PSD) methods that are repeatable, precise, and accurate allow the linking of landform together with physical properties.

Geochemical weathering indices are used to measure the weathering intensity of a stratigraphic sequence and the principle is that elemental composition of the parent material changes based on weathering conditions in the source areas. Various weathering indices have been proposed using major element composition of sediments and sedimentary rocks. For example (Kronborg, 2020) used aluminium(Al)/sodium(Na) based weathering indices as a weathering proxy for loess deposits. During weathering the element composition changes where soluble elements are depleted in contrast to less soluble element which are enriched, and the quantities of the elements can be obtained through X-ray fluorescence (XRF) (Buggle et al., 2011). In this study PSD and XRF analysis were used to determine the energy regime, sorting profile, and climatic changes to reconstruct the paleoenvironment and determine the differences both vertically and laterally across the Brooker sub-site.

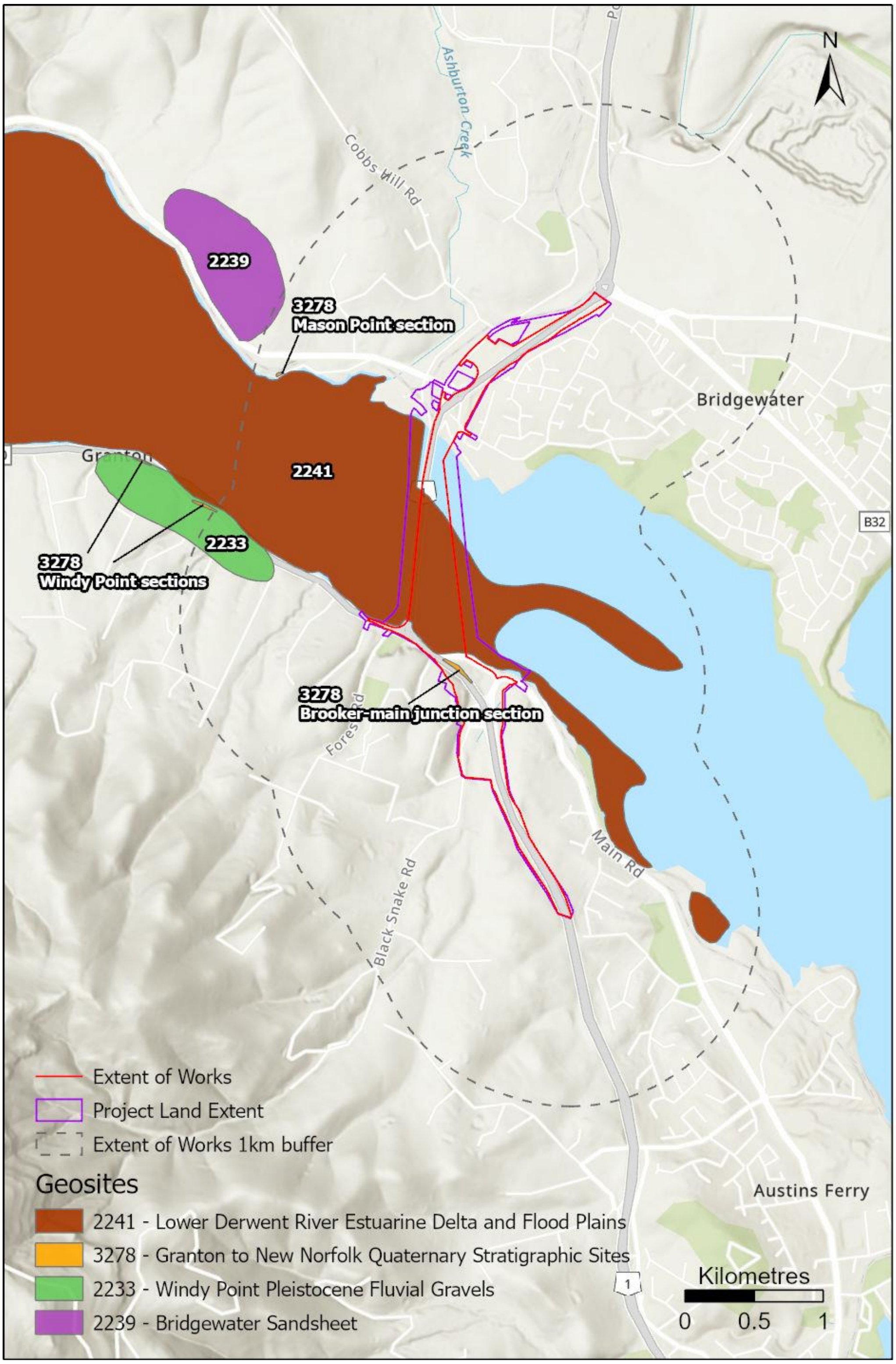


Figure 2: Location of NBB and geosites within 1km of the Extent of Works area

2.2.1 Field survey

To prepare for the field survey a desktop study was undertaken to review the literature related to the geosite and the broad vicinity of the area. Subsequently, the Brooker sub-site was visited on 20th and 21st June 2022. The geosite is located on the north eastern side of the Brooker highway (Figure 3) and is separated by a fault which is inferred to run along this section of the highway (Calver, 2005).

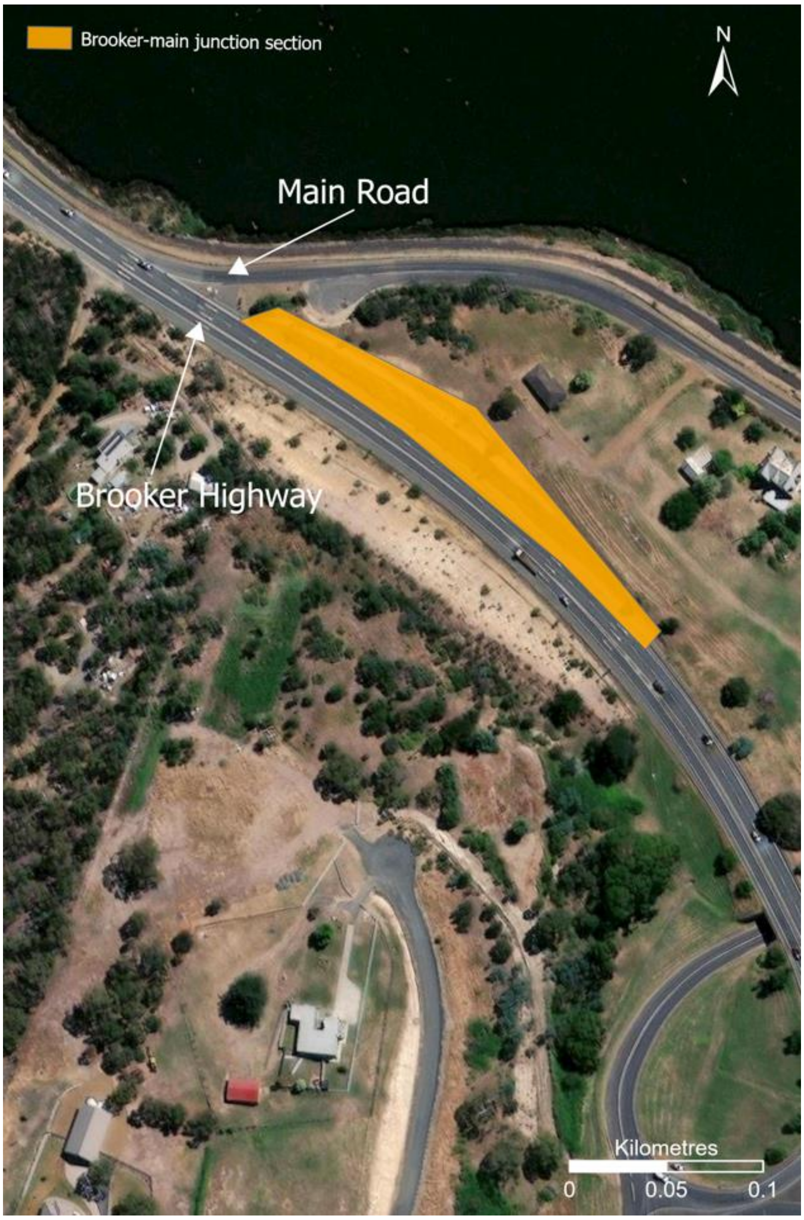


Figure 3: Location of Brooker sub-site at the junction of the Brooker Highway and Main Road, Granton

A sampling strategy was devised using an opportunistic sampling approach where suitable samples were chosen that characterised the range of sediments facies observed. A number of transects were selected on the north eastern side of the Brooker Highway that crossed the vertical extent of sedimentary facies (Figure 4) and representative samples were collected along each transect. Further samples were taken laterally across the middle bench that showed distinct changes in colour, lithology, and texture. The southwestern side was visited, and one transect was sampled to correlate the units between the southwest and northeast sides. Detailed site photographs were taken, sedimentary units were described in the field and locations of each sample was recorded with a handheld GPS. Surface samples were collected using a trowel at a depth of 1-10cm by employing grab sampling techniques, making sure equipment was cleaned between samples avoiding cross contamination. Sediment samples were placed in polyethylene bags to be transported to the lab for analysis.

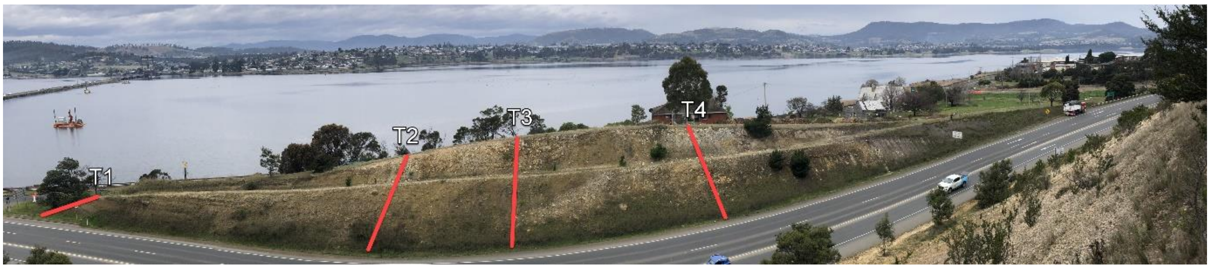


Figure 4: Sampling strategy illustrating transects T1 (northernmost) to T4 (southernmost) chosen on the north-eastern side of the Brooker Highway, characterising the lateral and vertical extent of sedimentary facies

2.2.2 Laboratory analyses

Wet samples were characterised for colour using a Munsell colour chart and a proportion of each sample was prepared for PSD and XRF analyses by air drying in the fume hood for 1 week. Dry samples were ground using a mortar and pestle, and characterised under microscope for roundness to determine the degree of abrasion of particles by the sharpness of its edges and corners. Dominant mineralogy was determined both optically and by conducting a hydrochloric acid test to determine if sediment contained any calcite material. A portion (100g) of the ground samples were sieved for 5 minutes using an automatic shaker fitted with a standard set of sieves using -1 (gravel) and 1 to 4 (coarse sand to silt) of the Wentworth grade scale in Phi units to determine coarse particle distribution (Appendix A). Weights of sediment retained from each sieve were converted into a percentage of total sediment sample sieved (Appendix B).

Fine sediment textural analysis (silt and clay) was undertaken using the Bouyocos (1962) hydrometer method, using Stokes Law of suspension in settling particles. Before starting Bouyoucos-hydrometer method, 100 ml of dispersing agent, 5% sodium hexametaphosphate $Na_6(PO_3)_6$ was mixed with 1 litre of distilled water (Appendix B). Sediment <4 (silt to clay) was agitated in suspension for 30 seconds and left to settle for 2 hours and a reading was taken using a hydrometer, with corrections made for temperature and displacement due to $Na_6(PO_3)_6$. The weight of clay is represented as the corrected 2 hour reading and the difference between the clay weight and original weight is the silt weight. All particle weights were converted into a percentage of total sediment sample. The procedure by Blott & Pye (2001) was used to compute the statistical particle size distribution analysis and determine sedimentary classification of each sample using Folk (1954) classification (Appendix C).

X-ray fluorescence (XRF) analyses were performed on bulk samples and were prepared using the same drying and grinding method used for PSD and then were sieved through -1 (gravel) sieve. These steps are required to increase homogenisation and to reduce the effects of large clusters of grain on the XRF results (Kronborg, 2020). The ground samples were put in small plastic cups with mylar film on top (Appendix B) and placed in a radiation shielded housing. An Olympus DELTA Professional XRF analyser was setup in a fixed position attached to the housing. The results were controlled by measuring reference samples at the beginning and end of the XRF analysis, to ensure that the analyser was measuring samples with small relative deviation and error. Each sample was measured three times, in a central position and then 5mm to the right and left of the central position.

3 Findings

3.1 Clast characteristics and sorting

The observed and sampled sediment characteristics of the Brooker sub-site are reviewed hereafter, first as separate transects, and then as climatic/geomorphological events.

Refer to Table 5 and Table 6 for descriptions of parent material and Folks class abbreviations used in the tables in the following sections.

3.1.1 Transect 1 (518555E, 5266848N) - 9m

The sediments in the first, smaller profile that terminated the landform to the north, ranged in clast[1] size and maturity in a range of largely unconsolidated strata (Figure 5, Table 1). Notably, the most 'well-arranged' clasts were found within sample 1.5, which were still 'poorly', but just not 'very poorly', sorted. Clasts were sub-angular in shape, with the notable exception being the sample taken in the uppermost part of the profile. The latter was sub-rounded, implying more transport than the clasts in other layers. There were notable differences in the colour of samples, which related to their observed lithology.

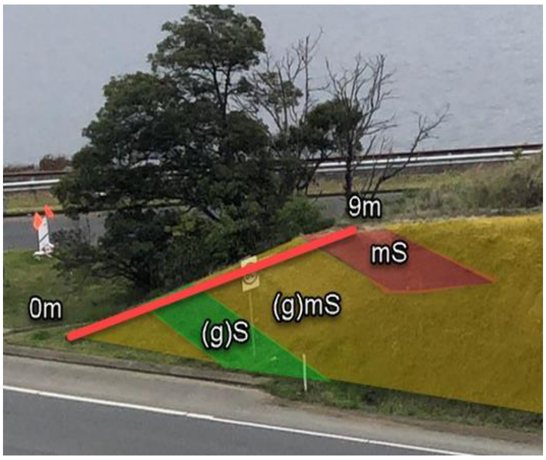


Figure 5: Transect 1 annotated with Folks classes. Note: not to scale

Table 1: Sediment and lithological descriptions for transect 1

Sample	Length (m)	Folks class	Description	Parent material	Sample photo
1.1	9-6.8	mS	Yellowish brown (10YR 5/6) muddy-sand with minor sandstones and siltstones. Very poorly sorted, subrounded and very fine skewed, leptokurtic distribution.	Pua/Rqp	

[1] A clast is a fragment of rock.

Sample	Length (m)	Folks class	Description	Parent material	Sample photo
1.2	6.8-6.2	(g)mS	Yellowish brown (10YR 5/6) slightly gravelly muddy sand with minor sandstones and siltstones. Very poorly sorted, sub angular and very fine skewed, leptokurtic distribution.	Pum/Rqp/ Pua	
1.3	6.2-5.5	(g)mS	Yellowish brown (10YR 5/6) slightly gravelly muddy sand with minor sandstones and siltstones. Very poorly-sorted, sub angular and very fine skewed, leptokurtic distribution.	Pum/Rqp/ Pua	
1.4	5.5-5.1	(g)mS	Dusky red (10YR 3/4) slightly gravelly muddy micaceous quartz-dominant sand. Very poorly sorted, sub angular and very fine skewed, mesokurtic distribution.	Pum/Rqp/ Pua	
1.5	5.1-4.8	(g)S	Yellowish brown (10YR 5/6) slightly gravelly micaceous sand. Poorly sorted, subangular and symmetrical, mesokurtic distribution.	Pum/Rqp	
1.6	4.8-0	(g)mS	Yellowish brown (10YR 5/6) quartz-derived, slightly gravelly, muddy sand. Very poorly sorted, sub angular and fine skewed, very leptokurtic distribution.	Pum/Rqp	

3.1.2 Transect 2 (518591E, 5266823N) - 14m

The second transect faced west, to the south of T1. Here, upper strata were somewhat rounded, whereas strata and sediments less than 5.8 m above the road were sub-angular, indicating less transport/time (Figure 6, Table 2). The colour and lithology indicated consistency throughout this part of the strata, with a notable possibility of the inclusion of Jurassic dolerite clasts around 4-5 m along the transect. Each of these samples were observed to contain substantial clay content and other fine sediments, as indicated by the skewedness of the samples, although the dominant measured mineralogy as determined by particle size analyses was comprised of sand and quartz sands.

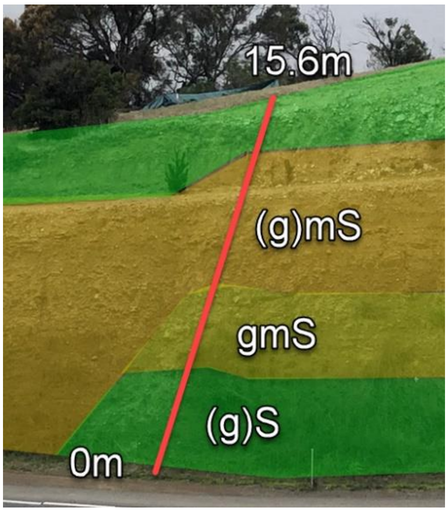


Figure 6: Transect 2 annotated with Folks classes. Note: not to scale

Table 2: Sediment and lithological descriptions for transect 2

Sample	Length (m)	Folks class	Description	Parent material	Sample photo
2.1	14-12.6	(g)S	Dark yellowish brown (10YR 3/4) slightly gravelly siliceous quartz dominant sand. Poorly sorted, sub rounded, very fine skewed, mesokurtic distribution.	Pua/Rqp	
2.2	12.6-7.1	(g)mS	Dark yellowish brown (10YR 4/4) slightly gravelly muddy siliceous quartz dominant sand. Poorly sorted, sub rounded, very fine skewed, mesokurtic distribution.	Pum/Rqp	
2.3	7.1-5.8	gmS	Dark yellowish brown (10YR 4/4) slightly gravelly muddy clay dominant siliceous sand. Very poorly sorted, sub rounded, fine skewed, leptokurtic distribution.	Pum/Rqp	
2.4	5.8-4.2	gmS	Dark yellowish brown (10YR 4/4) slightly gravelly muddy siliceous quartz dominant sand with large mafic grains. Very poorly sorted, sub angular, very fine skewed, leptokurtic distribution.	Pum/Rqp/Jd	
2.5	4.2-0	gmS	Dark yellowish brown (10YR 4/4) slightly gravelly muddy siliceous clay dominant sand. Very poorly sorted, sub rounded, very fine skewed, leptokurtic distribution.	Pum/Rqp	

3.1.3 Transect 3 (518609E, 5266814N) - 15.6m

The third transect faced west, to the south of T2. This transect had a range of different sediment types, contexts, and facies. Colouring, sorting, shape, and type were variable, and included a notable inclusion of Jurassic dolerite in debris and associated weathering (Figure 7, Table 3). Apparent lenses and facies were geomorphologically indistinguishable from the remaining strata, despite their apparently conspicuous variation from the surrounding materials.

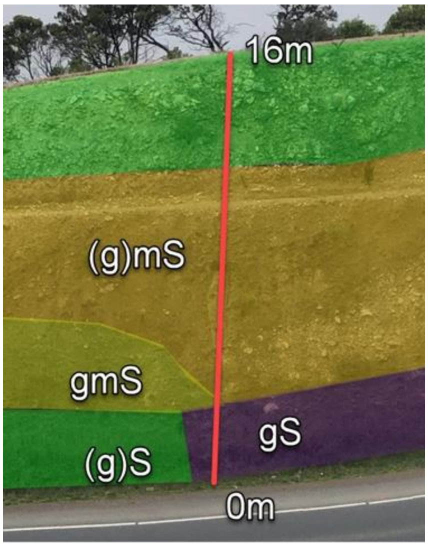


Figure 7: Transect 3 annotated with Folks classes (not to scale)

Table 3: Sediment and lithological descriptions for transect 3

Sample	Length (m)	Folks class	Description	Parent material	Sample photo
3.1	15.6-12.9	(g)S	Yellowish brown (10YR 5/4) gravelly muddy siliceous quartz dominant sand. Poorly sorted, sub angular, very fine skewed, leptokurtic distribution.	Pum/Rqp	
3.2	12.9-8.2	(g)mS	Olive (5YR 5/3) slightly gravelly muddy clay rich sand with iron weathering. Poorly sorted, sub rounded, very fine skewed, mesokurtic distribution.	Pum/Rqp/ Jd	
3.3	8.2-7.3	gmS	Dark reddish gray (2.5Y 3/1) gravelly muddy sand with unconsolidated clays. Very poorly sorted, subrounded, fine skewed, leptokurtic distribution.	Pum/Rqp	
3.4	7.3-5.5	(g)mS	Yellowish brown (10YR 5/6) gravelly muddy siliceous clay dominant sand. Very poorly sorted, subrounded, fine skewed, leptokurtic distribution.	Pum/Rqp	

Sample	Length (m)	Folks class	Description	Parent material	Sample photo
3.5	5.5-4.1	gS	Yellowish brown (10YR 5/8) gravelly siliceous clay dominant sand. Poorly sorted, subrounded, symmetrical, mesokurtic distribution.	Pum/Rqp	
3.6	4.1-0	(g)S	Light reddish gray (2.5YR 7/1) siliceous quartz dominant gravelly sand, Poorly sorted, sub angular, fine skewed, platykurtic distribution.	Pum/Rqp	

3.1.4 Transect 4 (518629E, 5266803N) - 16m

The fourth transect faced west, to the south of T3, and was the southernmost set of vertical observations. This transect had a range of different sediment types, contexts, and facies. Colouring, sorting, shape, and type were variable, and included a notable inclusion of Jurassic dolerite alluvium and associated weathering (Figure 8, Table 4). Most samples observed clay minerals, although were classified as gravelly sands and finely skewed with variable sphericity, demonstrated different transport processes. Notably, at 7.7m, a gravelly sand with large cobbles was observed, principally derived from doleritic materials.

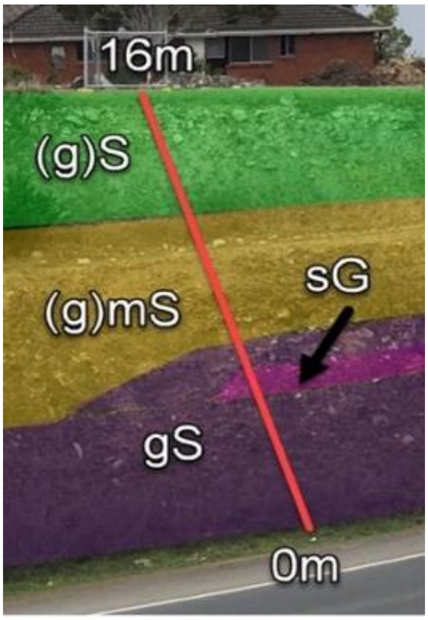


Figure 8: Transect 4 annotated with Folks classes (not to scale)

Table 4: Sediment and lithological descriptions for profile 4 (16m length)

Sample	Length (m)	Folks class	Description	Parent material	Sample photo
4.1	16-14.8	(g)S	Olive brown (2.5Y 4/6) slightly gravelly siliceous clay dominant sand. Poorly sorted, sub rounded, very fine skewed, very mesokurtic.	Pum/Rqp	
4.2	14.8-7.7	gS	Light reddish gray (2.5YR 7/1) slightly gravelly siliceous clay dominant sand. Very poorly sorted, sub rounded, very fine skewed, very leptokurtic.	Pum/Rqp	
4.3	7.7-6.8	sG	Light olive brown (2.5Y 5/4) sandy gravel, derived from weathered dolerite and associated minerals. Poorly sorted, angular, symmetrical, mesokurtic distribution.	Pum/Rqp/ Jd	
4.4	6.8-0	gS	Yellowish brown (10YR 5/6) gravelly quartz dominant sand. Poorly sorted, sub angular, fine skewed, mesokurtic distribution.	Pum/Rqp	

3.1.5 Additional samples (Appendix D)

Additional samples were used to identify and contextualise the horizontal extent of hypothesised landform and stratigraphic units. These provided some novel observations, including white, slightly gravelly muddy sand with consolidated mudstone (A3), darkish gray slightly gravelly clay dominant sand with mafic minerals (A8), and dark siltstone/mudstone with deep red mottling (M1). Most samples observed were slightly gravelly sands or gravelly sands, angular, and finely skewed. Notable differences were found with A1 observed to be moderately sorted and A8 observed to be subrounded indicative of further transport from parent material. A transect on the east-facing side of the Brooker Highway (E1-E7) texturally varied from gravelly muddy sands to unconsolidated cobbles. A thin paleosol was observed at the top of the transect (E1). The mid-section (E2-E6) varied from slightly gravelly muddy sands to sandy gravels, with some clay and silica minerals. A notable sample, at 6-12m (E Debris Flow), was characterised as well-rounded quartz, mudstone pebbles, and large dolerite cobbles indicative of an alluvial debris flow.

3.2 Landform and stratigraphic context

The oldest exposed rocks units in the region are of Permian age comprised of a siltstone-mudstone sequence, overlain by Triassic sandstones and mudstones, and Jurassic dolerite have intruded the Permo-Triassic rocks as a series of dykes and sheet that are partially exposed (Leaman, 1976). These rocks units (Table 5) were evaluated as the source of parent material for sediments found at the Brooker subsite by comparing the minerology, and clast characteristics between the rock unit descriptions and the PSD results of samples. Rock units that were potential parent material were mapped across the landform surface of the Brooker subsite to understand the likely sources of the sediments (Figure 10). Sediments at the lower levels of the landform were likely sourced from sandstones, siltstones, and mudstone parent materials (Pum, Pua, Rqp). The middle section contained a thin layer of dolerite and sandstone, siltstone, mudstone-derived sediments (Pum, Pua, Rqp, Jd). The upper section contained sediments derived from sandstone, siltstone, and mudstone (Rqp, Pua).

Table 5: Parent materials units based on New Norfolk 1:25 000 Geological Map (Calver et al., 2011)

Unit	Period	Description summary
Pum	Permian	Glaciomarine fine-grained sandstone, siltstone, mudstone with common lonestones and pebble-rich patches
Pua	Permian	Glaciomarine interbedded mudstone, siltstone, minor poorly sorted pebbly sandstone
Rqp	Triassic	Freshwater, cross-bedded quartzose to feldspathic sandstone, subordinate micaceous siltstone
Jd	Jurassic	Dolerite

Ternary diagrams revealed that the substantive grain sizes were sands, some of which contained silts consistent with alluviation from fluvial sources (Figure 9). Finer classification of particle sizes revealed occasional gravels and gravelly sands, more frequently associated with muds, and some exclusively sand-sized clasts.

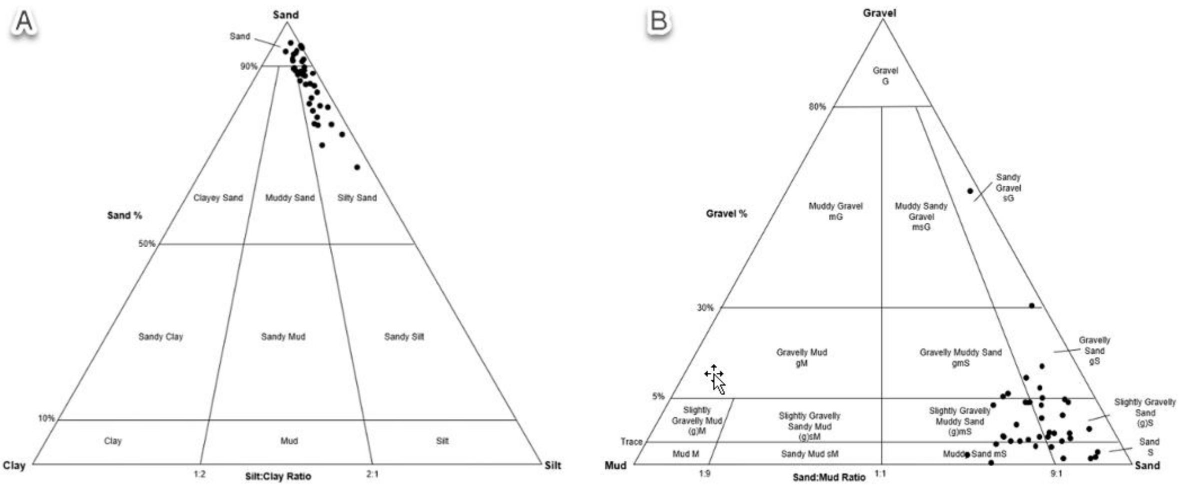


Figure 9: Folks classification ternary diagrams classifying proportion of sand, silt clay (A), and gravel, sand, mud (B)

Based on the Folks classification, six stratigraphic units were identified from muddy sand (mS) to sandy gravel (sG) (Table 6, Figure 11). Sediments at the lower level were dominantly slightly gravelly muddy sands to gravelly sands. The middle section mainly contained slightly gravelly sands and some gravelly sands to sandy gravels. The upper section was dominated by slightly gravelly sands.

Table 6: Sediment stratigraphic units based on Folks classification and sediment analysis

Unit	Description
mS	Muddy sand with minor sandstones and siltstones. Very poorly sorted, subrounded and very fine skewed, leptokurtic distribution.
(g)mS	Slightly gravelly muddy siliceous dominant sand with some iron weathering. Poorly to very poorly sorted, sub angular to subrounded, fine to very fine skewed, varying distributions
gmS	Gravelly muddy siliceous dominant sand with unconsolidated clays. Very poorly sorted, subrounded to subangular, very finely skewed, leptokurtic distribution.
(g)S	Slightly gravelly siliceous quartz dominant sand. Poorly sorted, subangular to subrounded, very fine skewed, varied distribution.
gS	Gravelly sand derived from quartz and clays. Very poorly to poorly sorted, sub angular to subrounded, very fine to fine skewed, varied distribution.
sG	Sandy doleritic gravel. Poorly sorted, angular, symmetrical, mesokurtic distribution.

3.3 Weathering indices and climatic context

The novel parent material combination Pua/Rqp was only observed once in the samples collected and hence the key weathering mineral indicators – potassium (K), strontium (Sr) and Rubidium (Rb) – detected in this sample arise from a singular measurement (Table 7). Nonetheless, this sample contained the highest concentrations of the relatively more immobile (when compared with strontium) elements Rb (most immobile) and K (second-most immobile), and the lowest concentration of Sr.

The Pum/Rqp/Jd combination had the lowest K, highest Sr, and lowest Rb concentration. The inclusion of Jd in this combination introduces the possibility that the lowest mean Rb/Sr ratio observed for the combination is due to differences in mineralisation rate due to lithology, and not the actions of weathering. More compellingly, the concentrations of more mobile Sr were similar in parent material combinations that lacked conspicuous substantive inclusion of igneous Jd, and lent support to the possibility that (a) potentially similar weathering and climate controls could have acted on these two sediment-dominated groupings and (b) that particle composition is a more important classification to use when examining potential climatic context and weathering rates of strata of potentially different ages.

With respect to the particle composition, there was a clear trend from coarsest to finest particle classifications (with the notable exception of the gmS combination, which contained Jd source materials) (Table 8). The coarsest sediments had the lowest concentrations of K and the highest concentration of Sr relative to Rb, which therefore suggests that coarser sediments have been deposited in a drier climate, or not otherwise subject to the same relative exposure to water. By comparison, finer particulate samples contain muds and clays, which have been subject to either more water for transport and/or movement in wetter times. This is further evidenced by the relatively more rounded clasts in the finer sediment categories and strata than in the coarser ones, in this study, and the distinct clusters of particle sizes by relative frequency and classification (Figure 12, Figure 13).

The arrangement of the particle sizes within the strata, and their change with height, appears to suggest three depositional events:

1. The deposition of slightly muddy sands through to gravelly sands is apparent in the bottom 6 metres of the strata. These tended to be very poorly sorted, to poorly sorted, with a range of sphericity. These tend to be more quartz-dominated with some clay.
2. Between 6-10 meters from the bottom of the observed strata, there are a range of textures and particle sizes, indicative of small boulder flows, gravelly debris, and possible inclusion of Jd in flow materials.
3. A third 'event' has incorporated the uppermost strata in the Brooker subsite, as well as the strata sampled on the east-facing side of the road ('E' samples, Appendix D). Here, depositional strata are comprised primarily of coarser sediments, some gravels, and a thin paleosol.

Table 7: Concentrations of key elements used for weathering proxies for samples grouped by potential parent materials

Potential parent material	K (ppm)	Rb (ppm)	Sr (ppm)	K/Sr	Rb/Sr
Pua/Rqp	21568.67 (*n* = 1)	226.00 (*n* = 1)	62.67 (*n* = 1)	95.4 (*n* = 1)	3.6 (*n* = 1)
Pum/Rqp	15466.13 ± 77.86	132.70 ± 6.81	65.70 ± 5.36	115.4 ± 4.1	2.4 ± 1.2
Pum/Rqp/Jd	11075.38 ± 81.22	108.05 ± 7.37	69.09 ± 4.80	99.8 ± 4.6	1.8 ± 1.2
Pum/Rqp/Pua	21303.93 ± 77.49	182.00 ± 8.63	65.00 ± 5.16	124.3 ± 4.8	3.5 ± 1.5

Table 8: Concentrations of key elements used for weathering proxies for samples grouped by Folks classifications

Unit	K (ppm)	Sr (ppm)	K/Sr	Rb (ppm)	Rb/Sr
sG	5515.16 ± 1193.5	89.83 ± 3.0	61	74.66 ± 26.2	0.8
gS	9622.27 ± 933.4	68.88 ± 6.2	139	95.00 ± 12.6	1.4
(g)S	12721.41 ± 1818.5	72.94 ± 13.1	174	105.64 ± 6.8	1.5
gmS	18945.93 ± 1529.9	51.73 ± 20.1	366	159.46 ± 3.2	3.1

Unit	K (ppm)	Sr (ppm)	K/Sr	Rb (ppm)	Rb/Sr
(g)mS	18634.61 ± 1627.5	54.56 ± 18.5	341	152.76 ± 5.8	2.8
mS	21568.66 (*n* = 1)	62.66 (*n* = 1)	344 (*n* = 1)	226.00 (*n* = 1)	3.6

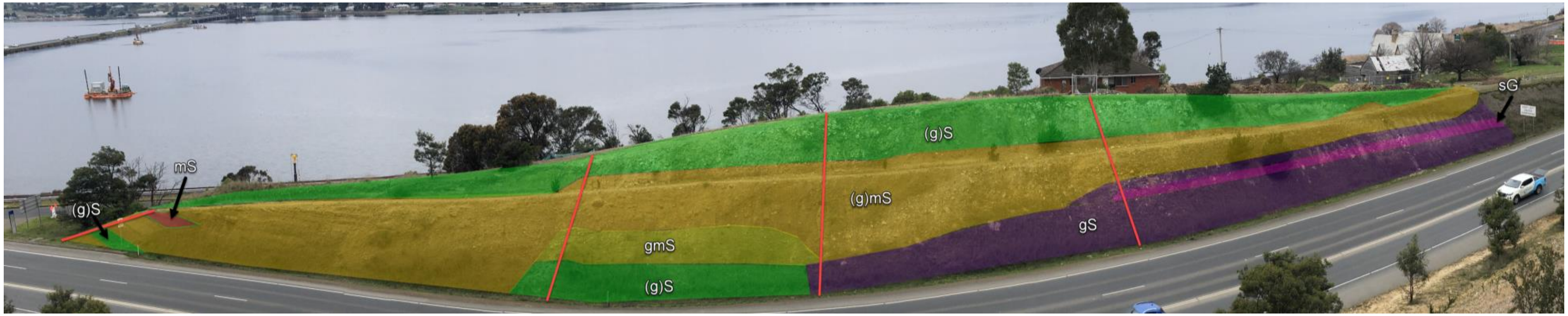


Figure 10: Landform stratigraphic classification based on Folks particle size characterisation

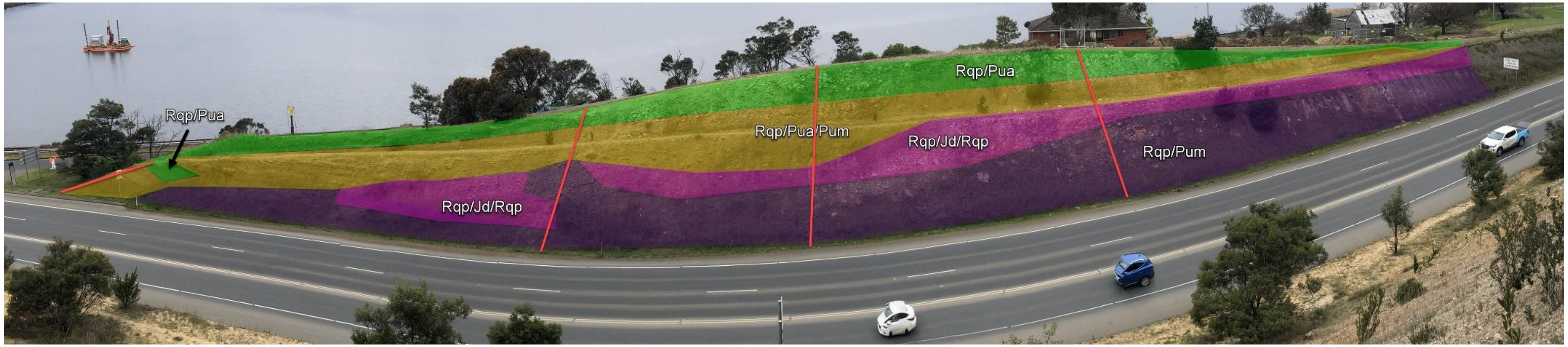


Figure 11: Landform stratigraphic classification based on potential parent material

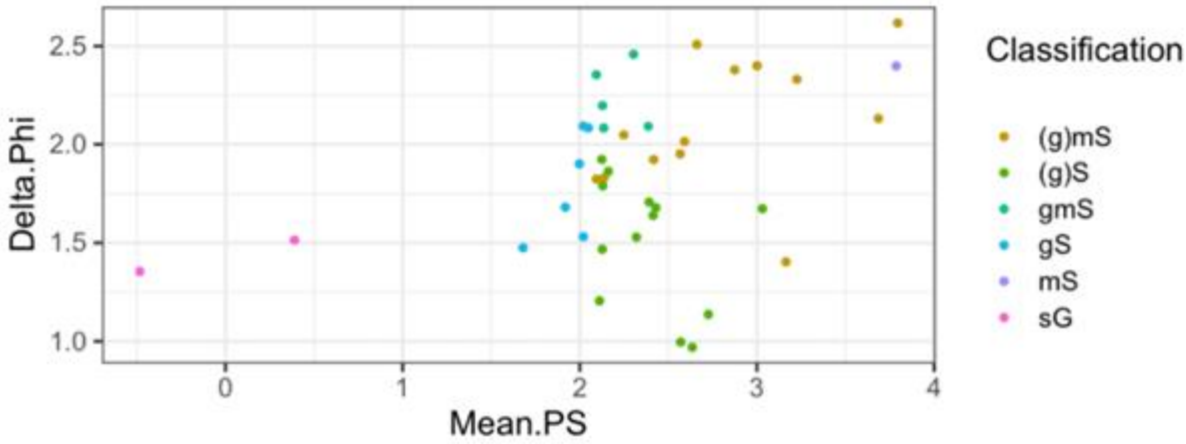


Figure 12: Scatterplot of mean particle size and sorting using Folks classification

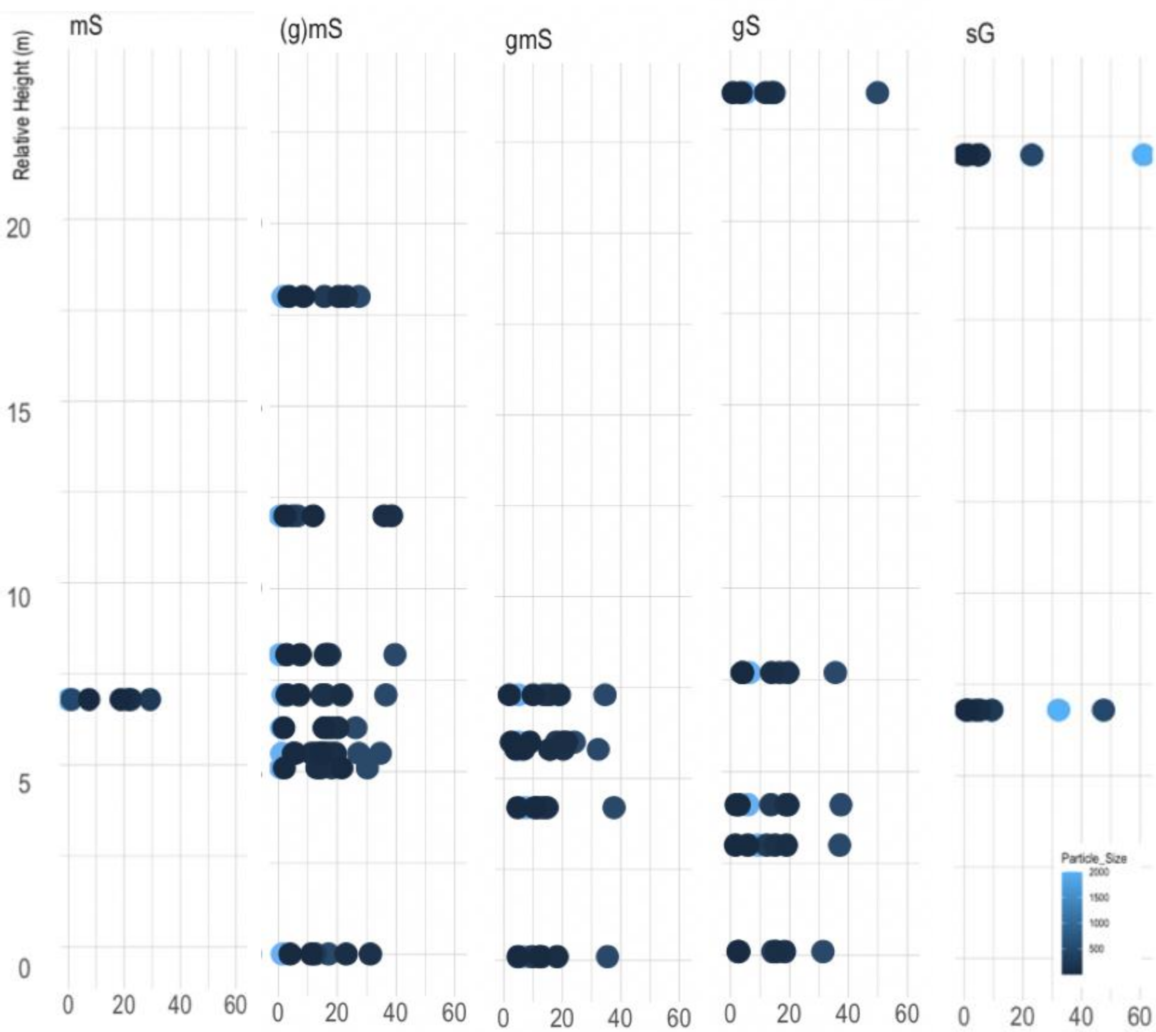


Figure 13: Particle size (µm) distribution correlated with height across all transects

4 Conclusion and Recommendations

The sediments studied within the Brooker sub-site are related to other deposits on the margins of the lower Derwent River flood plain. On both sides of the Derwent Estuary many of the tributary streams have deposited poorly sorted angular to poorly sorted rounded alluvial gravels of local rock types in thick fans. Deposits on the northern side of estuary contain abundant dolerite cobbles, and deposits on the southern side are predominantly composed of Permian/Triassic sandstone/siltstone and mudstone in a sand and silt matrix (Colhoun, 1977). Some sections of fan gravels at Limekiln point are separated by a thick aeolian sand deposit and a paleosol and fan gravels tend to be poorly stratified gently dipping to the northeast (Colhoun, 1977, 2002).

These deposits have conservation significance associated with climate and depositional conditions. A number of publications have referred to the deposits, describing the 'the only loess known in Tasmania' from a cutting (Colhoun, 1977, 2002), debris flow and stream deposits (Wassan, 1977) and aeolian sands overlain by gravelly fan deposits (McIntosh et al., 2012; Mcintosh, 2012). Suggested dates of fan deposits at Granton span the Last Glacial and Penultimate Glacial periods (McIntosh et al., 2012), a proposition supported by the deposition events described in this study.

Similar sites are found nearby, namely the Windy Point Pleistocene Fluvial Gravels (de-listed 2015), the Lower Derwent River Estuarine Delta and Floodplain and the Boyer Road Dune and Fan Deposits (Table 9).

Table 9: Geosites of significance that are related to Granton to New Norfolk Quaternary Stratigraphic Sites - 3278

Site name	Relevance	Significance level	Values
Windy Point Pleistocene Fluvial Gravels: 2233	Indicative of a prior stage of landscape development.	District	Fluvial, Alluvial and Lacustrine processes
Lower Derwent River Estuarine Delta and Flood Plains: 2241	One of the best developed estuarine sedimentary sequences and landform complexes in Tasmania.	State	Coastal and Estuarine processes
Boyer Road Dune and Fan Deposits: 2242	Older dune-sands, palaeosol, younger dune-sand, and angular fan deposits that may date to the LGM.	State	Polythematic Landscape processes

This report has documented the suite of sediments found at the Brooker subsite that will be impacted by the NBB. The analysis appears to suggest three depositional events of alluvial fan gravels. The deposition of slightly muddy sands through to gravelly sands in the bottom 6 metres of the strata, overlain by 6-10m of small boulder flows and gravelly debris, and the uppermost strata are comprised primarily of coarser sediments, some gravels, and a thin paleosol.

The recommendation arising from this report are for the TGDRG to review the significance of the Granton to New Norfolk Quaternary Stratigraphic Sites (3278) based on these findings in the context of the other sections of this geosite, and other related geosites, that may exhibit similar values. The listing status, values, significance level, boundary, and description of the Granton to New Norfolk Quaternary Stratigraphic Sites (3278) may need alteration upon review from the TGDRG. Further opportunities arise to utilise the data derived from this study for a further scientific study to link this to surrounding climates. Additionally, the data could be used for another geosite nomination that displays similar values that capture important climatic and depositional environments related to the landscape evolution of the Lower Derwent Valley. This report could be complimented through the development of new geoheritage and geodiversity educational and interpretation resources for the public to raise awareness and understanding about the changing environmental conditions that have occurred in the Lower Derwent Valley over thousands of years.

References

Blott, S. J., & Pye, K. (2001). Gradistat: A grain size distribution and statistics package for the analysis of unconsolidated sediments. *Earth Surface Processes and Landforms*, *26*(11), 1237–1248. https://doi.org/10.1002/esp.261

Buggle, B., Glaser, B., Hambach, U., Gerasimenko, N., & Marković, S. (2011). An evaluation of geochemical weathering indices in loess–paleosol studies. *Quaternary International*, *240*(1–2), 12–21.

Calver, C. (2005). *Digital Geological Atlas 1:25 000 Series. Sheet 5026 New Norfolk*.

Calver, S. ., Forsyth, S. ., Clark, M. ., & Latinovic, M. (2011). *Digital Geological Atlas 1:25,000 Scale Series*. http://www.mrt.tas.gov.au/portal/digital-geological-atlas-1-25000-scale-series

Colhoun, E. A. (1977). Tasm. Dept. Mines 1 mile series Explan. Rep. Sheet 8312N. In *Leaman 1977 Brighton, Tasmania* (pp. 19–24).

Colhoun, E. A. (2002). Periglacial landforms and deposits of Tasmania. *South African Journal of Science*, *98*(1–2), 55–63.

Colhoun, E. A. (2004). Quaternary glaciations of Tasmania and their ages. In *Developments in Quaternary Sciences* (Vol. 2, pp. 353–360). Elsevier.

Folk, R. L. (1954). The distinction between grain size and mineral composition in sedimentary-rock nomenclature. *The Journal of Geology*, *62*(4), 344–359.

Jennings, J. N., & Banks, M. R. (1958). The Pleistocene Glacial History of Tasmania. *Journal of Glaciology*, *3*(24), 298–303. https://doi.org/DOI: 10.3189/S0022143000023960

Kronborg, P. (2020). Identifying Quaternary Climate Change with XRF Analysis on Loess From South-Western England Identifikation av kvartära klimatförändringar med. *Independent Project at the Department of Earth Sciences*.

Leaman, D. E. (1976). Geological atlas 1:50000 series. Sheet 82 (83125) Hobart Explanatory Report. Department of Mines Tasmania.

Mcintosh, P. D. (2012). Dates Geoconservation Sites in the Forest Estate in Tasmania. In *Forest Practices Authority*.

McIntosh, P. D., Eberhard, R., Slee, A., Moss, P., Price, D. M., Donaldson, P., Doyle, R., & Martins, J. (2012). Late Quaternary extraglacial cold-climate deposits in low and mid-altitude Tasmania and their climatic implications. *Geomorphology*, *179*, 21–39. https://doi.org/10.1016/j.geomorph.2012.08.009

Natural Values Atlas (NVA). (2022). *Tasmanian Geoconservation Database*. https://www.naturalvaluesatlas.tas.gov.au/

Wassan, R. J. (1977). Last-glacial alluvial fan sedimentation in the Lower Derwent Valley, Tasmania. *Sedimentology*, *24*(6), 781–799. https://doi.org/10.1111/j.1365-3091.1977.tb01915.x

Wentworth, C. K. (1922). A scale of grade and class terms for clastic sediments. *The Journal of Geology*, *30*(5), 377–392.

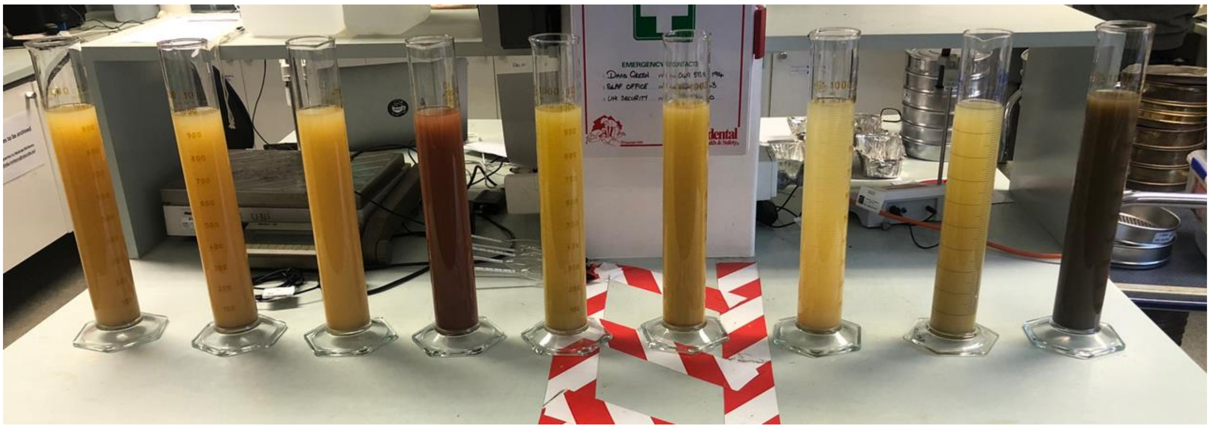
Appendix A Wentworth particle size classification

Grain size		Descriptive terminology			
phi	mm/µm	Udden (1914) and Wentworth (1922)	Friedman and Sanders (1978)	GRADISTAT program	
			Very large boulders		
−11	2048 mm				
			Large boulders	Very large	
−10	1024				
			Medium boulders	Large	
−9	512	Cobbles			
			Small boulders	Medium	Boulders
−8	256				
			Large cobbles	Small	
−7	128				
			Small cobbles	Very small	
−6	64				
			Very coarse pebbles	Very coarse	
−5	32				
			Coarse pebbles	Coarse	
−4	16	Pebbles			
			Medium pebbles	Medium	Gravel
−3	8				
			Fine pebbles	Fine	
−2	4				
		Granules	Very fine pebbles	Very fine	
−1	2				
		Very coarse sand	Very coarse sand	Very coarse	
0	1				
		Coarse sand	Coarse sand	Coarse	
1	500 µm				
		Medium sand	Medium sand	Medium	Sand
2	250				
		Fine sand	Fine sand	Fine	
3	125				
		Very fine sand	Very fine sand	Very fine	
4	63				
			Very coarse silt	Very coarse	
5	31				
			Coarse silt	Coarse	
6	16	Silt			
			Medium silt	Medium	Silt
7	8				
			Fine silt	Fine	
8	4				
			Very fine silt	Very fine	
9	2	Clay			
			Clay	Clay	

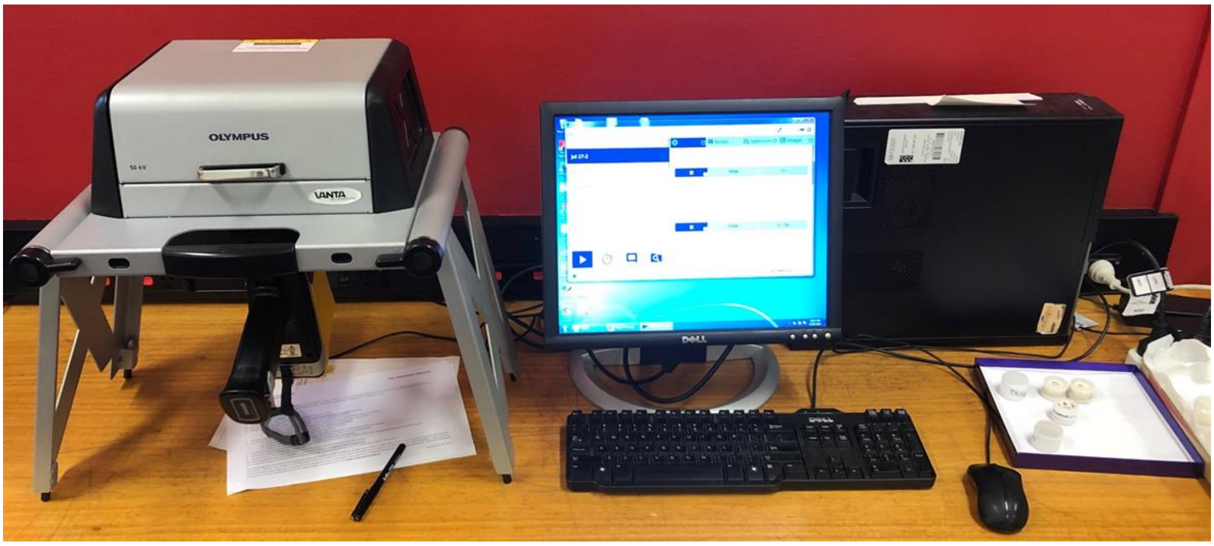
Correlation between phi sizes, millimetre diameters and Wentworth (1922) size classifications (Blott & Pye, 2001)

Appendix B Lab analysis methods

Standard set of sieves using -1f (gravel) and 1f to 4f (coarse sand to silt) and sediment retained was weighed.

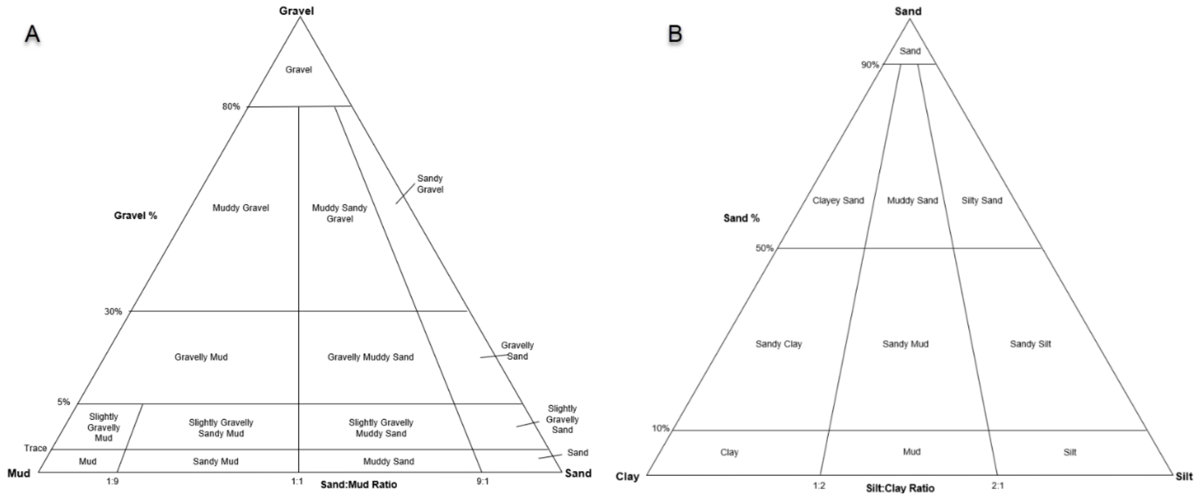


Bouyocos (1962) hydrometer method for determining fine sediment proportions for T1 samples and some opportunistic samples on the northernmost end of the Brooker- subsite.



Olympus DELTA Professional XRF analyser was setup in a fixed position attached to the housing used to analyse samples prepare in plastic cups with mylar film

Appendix C Folks particle size classification



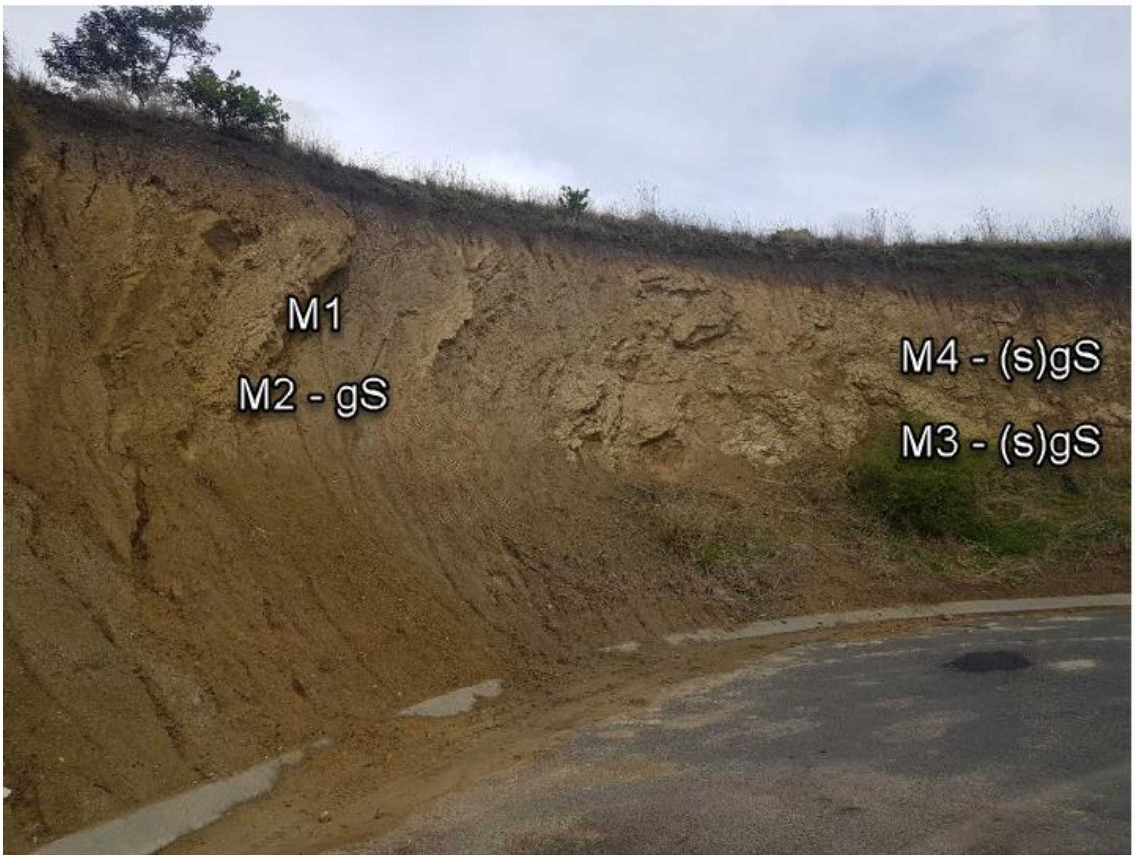
Folk sedimentary class as a function of percentage of gravel, sand, and mud (A), and percentage of sand, silt, and clay (B)

Appendix D Sediment and lithological descriptions for selective samples

Sample	GPS coordinate (GDA2020 UTM Zone 55)	Folks class	Description	Parent material	Sample photo
A1	518891E, 5266836N	(g)S	Yellowish brown (10YR 5/6) slightly gravelly silica/quartz dominant sand. Moderately sorted, sub angular, symmetrical, leptokurtic distribution.	Pum/Rqp	
A2	518591E, 5266834N	(g)S	Brownish yellow (10YR 6/6) slightly gravelly silica/quartz dominant sand. Poorly sorted, sub angular, fine skewed, leptokurtic distribution.	Pum/Rqp	
A3	518623E, 5266808N	(g)mS	Yellowish brown (10YR 5/6) slightly gravelly muddy siliceous clay dominant sand. Very poorly sorted, sub angular and very fine skewed, leptokurtic distribution.	Pum/ Rqp/Pua	
A4	518643E, 5266806N	(g)mS	White (2.5Y 8/1) slightly gravelly muddy sand with consolidated clay mudstone. Very poorly sorted, sub angular, very poorly sorted, fine skewed, very leptokurtic distribution.	Pum/Rqp /Pua	
A5	518645E, 5266794N		Micaceous, quartz dominant mudstone.	Pum/Rqp /Pua	

A6	518645E, 5266794N	(g)mS	Olive brown (2.5Y 4/3) slightly gravelly muddy sand with siliceous mudstone. Very poorly sorted, sub rounded, symmetrical, mesokurtic distribution.	Pum/Rqp /Pua	
A7	518645E, 5266794N	(g)mS	Olive brown (2.5Y 4/4) slightly gravelly muddy sand with siliceous mudstone. Very poorly sorted, sub rounded, very fine skewed, mesokurtic distribution.	Pum/Rqp /Pua	
A8	518651E, 5266783N	(g)S	Dark grayish brown (2.5Y 4/2) slightly gravelly clay dominant sand with mafic minerals. Poorly sorted, sub rounded, symmetrical, platykurtic distribution.	Pum/Rqp /Jd	
A9	518648E, 5266782N	gS	Dark gray (10YR 4/1) gravelly clay dominant sand with mafic minerals. Very poorly sorted, subrounded, fine skewed, leptokurtic distribution.	Pum/Rqp /Jd	
A10	518644E, 5266788N	(g)S	Very dark grayish brown (2.5Y 3/2) slightly gravelly silica/quartz dominant sand. Poorly sorted, sub angular, symmetrical mesokurtic distribution.	Pum/Rqp	
M1	518583E, 5266842N		Dark siltstone/mudstone with deep red to brown mottling	Jd/Pua	
M2	518583E, 5266842N	gS	Pale brown (2.5Y 7/3) gravelly sand with siliceous clay dominant mudstone. Poorly sorted, sub rounded, fine skewed, mesokurtic.	Pum/Rqp	

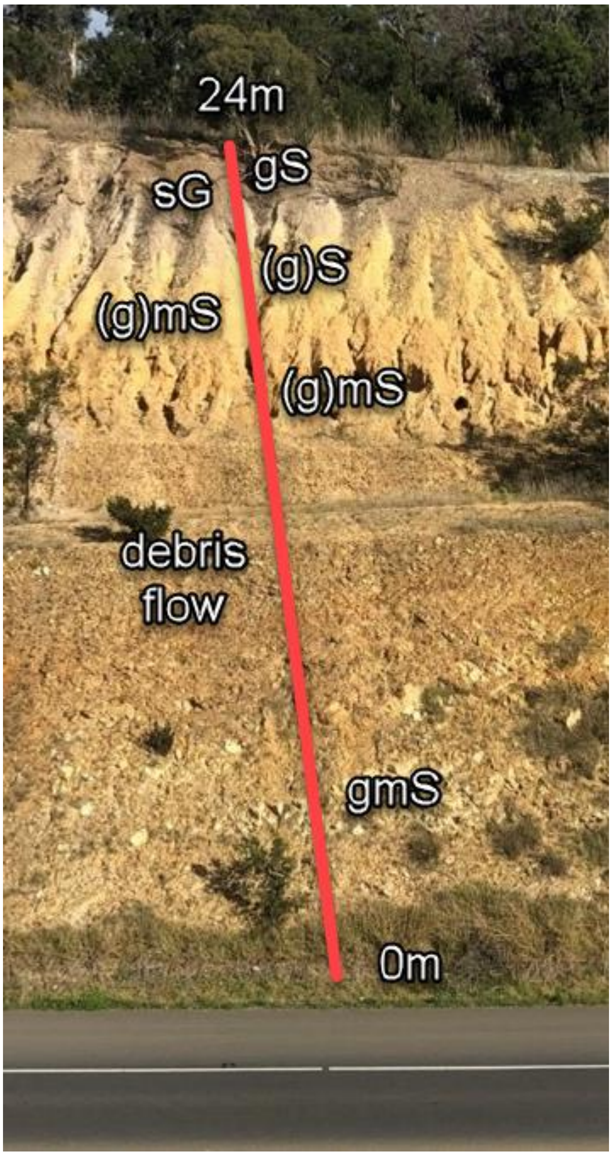
M3	518573E, 5266847N	(g)S	Pale brown (2.5Y 7/3) slightly gravelly sand with siliceous clay dominant mudstone. Poorly sorted, sub rounded, symmetrical, platykurtic.	Pum/Rqp /Pua	
M4	518573E, 5266847N	(g)S	Pale brown (2.5Y 7/3) slightly gravelly silica/quartz dominant sand. Poorly sorted, sub rounded, symmetrical, mesokurtic.	Pum/Rqp	



Main road select samples annotated with Folks classes. Note: not to scale

Sediment and lithological descriptions for eastern landform profile (24m length) 518581E, 5266791N

Sample	Depth	Folks class	Description	Parent material	Sample photo
E1	**24-23.5**	gS	Dark yellowish brown (10YR 3/4) gravelly sand paleosol with clay and quartz. Poorly sorted, sub rounded, poorly sorted, very fine skewed, mesokurtic distribution.	Pum/Rqp	
E2	**23.5-22**	sG	Yellowish brown (10YR 5/4) sandy gravel with siliceous clay mudstone and oxidated iron rich clasts. Poorly sorted, sub angular, very fine skewed, mesokurtic distribution.	Pum/Rqp /Jd	
E3	**22-19**	(g)S	Grayish brown (10YR 5/2) slightly gravelly sand with silica/quartz clay and oxidated iron rich clasts. Poorly sorted, sub rounded, symmetrical, platykurtic distribution.	Pum/Rqp /Jd	
E4	**19-18**	(g)mS	Yellowish brown (10YR 5/6) slightly gravelly muddy silica/clay dominant sand. Poorly sorted, sub rounded, fine skewed, leptokurtic distribution.	Pum/Rqp /Pua	
E5	**18-16.5**	(g)S	Strong brown (7.5YR 4/6) slightly gravelly sand derived from dolerite weathering. Poorly sorted, sub rounded, coarse skewed, very leptokurtic.	Pum/Rqp /Jd	
E6	**16.5-12**	(g)mS	Yellowish brown (10YR 5/6) slightly gravelly muddy sand derived from dolerite weathering. Poorly sorted, sub angular, very fine skewed, leptokurtic.	Pum/Rqp /Jd	
E Debris Flow	12-6		Mix of well-rounded dolerite, quartz and siliceous mudstone alluvial pebbles and cobbles.	Jd/Pua	
E7	**6-0**	gmS	Dark yellowish brown (10YR 5/6) gravelly muddy silica/quartz dominant sand. Very poorly sorted, sub angular, symmetrical, leptokurtic.	Pum/Rqp	



East facing transect annotated with Folks classes. Note: not to scale

Appendix E Particle size distribution using Folks classification

Sample	%Gravel (2000)	%Coarse Sand (500)	%Medium Sand (250)	%Fine Sand (125)	%Very Fine Sand (63)	%Silt (3.9)	%Clay (<3.9)
1.1	0.00	1.05	29.21	22.37	21.32	18.68	7.37
1.2	1.08	26.28	18.31	16.93	20.18	15.45	1.77
1.3	4.74	34.62	16.05	12.86	11.22	14.89	5.61
1.4	0.76	30.21	18.10	14.39	13.09	21.48	1.96
1.5	1.93	25.58	14.11	23.76	25.18	8.63	0.81
1.6	1.24	17.01	12.47	31.24	22.99	11.13	3.92
A1	2.32	8.17	33.89	36.53	15.67	3.42	0.00
A2	0.39	26.59	24.47	29.67	15.03	3.85	0.00
A3	0.32	15.92	3.66	9.24	39.81	28.18	2.87
2.1	3.41	34.92	15.60	16.74	19.73	5.68	3.93
2.2	1.51	36.53	15.84	14.83	21.39	7.06	2.83
2.3	5.11	32.26	15.77	20.29	15.77	6.72	4.09
2.4	7.50	37.67	11.44	13.31	14.79	10.55	4.73
2.5	6.83	35.44	9.64	12.85	18.27	12.15	4.82
3.1	4.77	31.43	16.18	20.23	18.67	5.81	2.90
3.2	0.49	39.59	17.40	15.84	16.52	7.43	2.74
3.3	5.06	34.60	13.82	15.61	18.99	10.02	1.90
3.4	1.06	27.31	15.09	17.75	19.34	14.35	5.10
3.5	5.97	37.42	13.63	18.76	19.50	2.83	1.89
3.6	3.74	31.63	16.56	20.92	20.92	5.23	1.00
4.1	1.03	34.57	15.89	17.03	23.22	4.33	3.92
4.2	6.42	35.54	16.68	19.48	13.89	4.04	3.94
4.3	32.16	47.51	9.36	3.80	5.41	0.58	1.17
4.4	15.27	31.33	14.29	18.33	15.47	2.56	2.76
A4	1.52	2.78	19.37	18.48	36.96	14.43	6.46

A5 (rock only)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
A6	1.57	24.25	11.27	10.41	31.53	17.97	3.00
A7	2.79	36.35	14.24	15.04	15.04	13.45	3.09
A8	1.91	25.21	15.04	23.52	27.75	3.28	3.28
A9	12.13	31.33	10.32	20.06	17.57	5.64	2.96
A10	1.86	25.16	16.36	28.36	19.46	6.63	2.17
E1	5.19	49.85	14.75	13.94	11.90	0.81	3.56
E2	61.15	23.05	4.83	4.65	5.02	1.30	0.00
E3	1.34	30.24	18.06	24.77	18.78	5.26	1.55
E4	1.51	27.36	15.59	23.04	20.52	8.45	3.52
E5	0.23	11.62	13.81	18.99	46.26	5.06	4.03
E6	0.57	6.39	4.69	38.49	35.94	11.79	2.13
E7	5.02	24.05	17.91	20.06	21.49	8.90	2.56
E Debris Flow (cobbles/rock only)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
M1 (rock only)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
M2	9.25	37.01	12.24	15.07	18.96	5.82	1.64
M3	0.23	12.87	16.78	34.02	30.80	2.76	2.53
M4	0.26	6.75	30.46	41.59	16.42	3.05	1.46