

# ENGINEERING GEOLOGICAL MODELS IN REMOTE AND DIFFICULT ACCESS TERRAIN: A CASE STUDY FROM BOGONG HIGH PLAINS ROAD

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## ABSTRACT

A significant landslide closed access to Falls Creek via Bogong High Plains Rd in October 2022. An investigation into the potential to open a temporary four-wheel-drive access to Falls Creek via steep terrain adjacent to Lake Guy was completed. The site had difficult access, remote location and limited time for investigation.

For a small project area there was significant variation in slope performance and geology, including colluvium and residual soils overlying exposed granodiorite and metamorphic bedrock. The study considered the rich history of engineering geological studies associated with past hydropower projects to establish broad structural controls on the topography before developing the local engineering geological model. Traditional desktop, geomorphological and field mapping techniques were adopted to characterise the slopes and assign appropriate domains. The domains then directly informed the assessment of landslide hazards and remedial design advice. Landslide hazards were assessed using the Department of Transport and Planning “Roadside Geotechnical Hazard Risk Management” guideline. Domains were validated with a series of test nails/bolts as mobilisation of slope stabilising contractors was imminent.

The case study highlights that meaningful, cost-effective engineering models can be developed without traditional intrusive site investigation methods and that engineering geological models should underpin landslide assessment and remediation.

## 1 INTRODUCTION

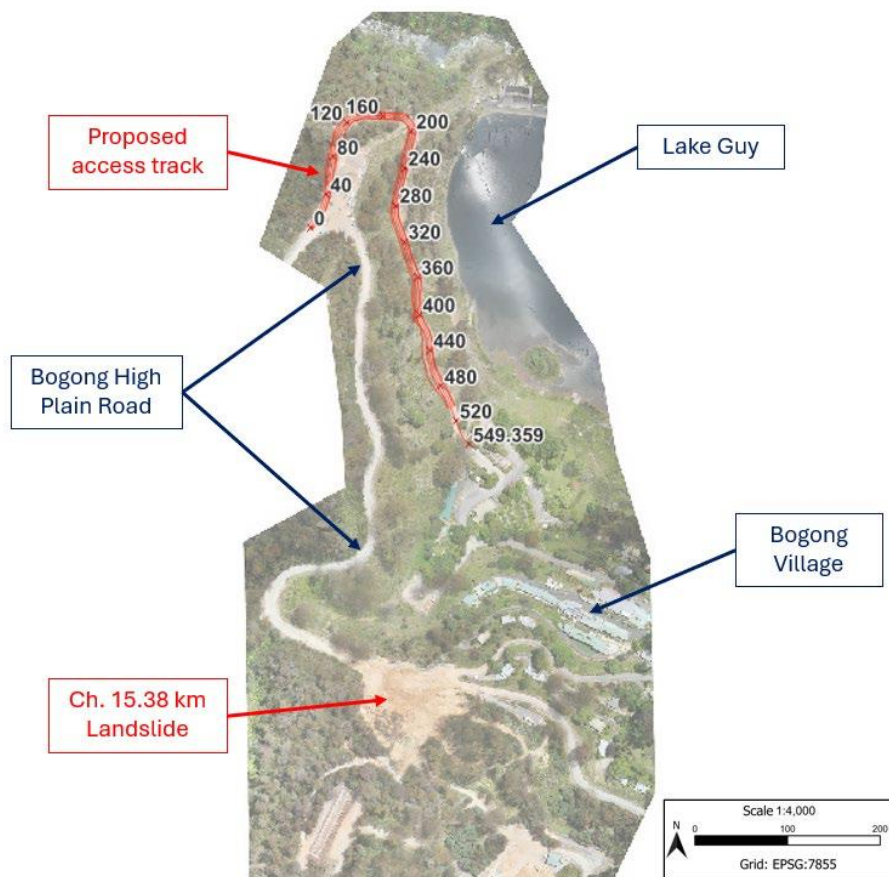
The Bogong High Plains area presents substantial challenges for engineering geological modelling due to its remote location, steep terrain, and landslide-prone slopes. In October 2022, a significant landslide obstructed access to Falls Creek, necessitating a temporary emergency access route to be designed for controlled, four-wheel-drive passage across challenging terrain near Lake Guy, Figure 1. The Department of Transport and Planning (DTP) proposed a 550 m long access track, with slope angles ranging from 30° to 68° and slope heights up to 5.5 m to provide temporary connectivity while minimising impact on the surrounding environment.

Historical studies highlight the complexities in this region, where weathering and structural variability affect slope stability (Beavis, 1949; Kenny, 1937).

Given the challenging terrain and limited access in the Bogong High Plains area, the investigation primarily focused on ground-truthing the LiDAR survey and soil nail/rock dowel boreholes and acceptance tests. The ground-truthing of the LiDAR was focused on geological units, structural features, and slope performance.

This approach is consistent with the guidelines of the International Association for Engineering Geology and the Environment (IAEG) Guidelines (Baynes and Parry, 2022), which recognise that in remote, complex terrain, limited data can be reconciled with observational insights through conceptual domain-based engineering geological models.

This study summarises the geological model that considered slope performance and provides targeted remediation strategies for high-risk areas.



**Figure 1: Proposed access track highlighted in red**

## 2 GEOLOGICAL SETTING

The Geological Map of Feathertop (Geological Survey of Victoria (GSV) Report 125, 2005a) indicates the Site lies within the contact between Lower Silurian aged migmatite (Som) and Cobungra Granite (G549), Figure 2, both from the Omeo Metamorphic Complex (OMC). The “Som” was formed during regional metamorphism, and it is a gneissic rock with thin layers in dark minerals gneiss and schist and it includes small bodies of fine to medium-grained granite. The “G549” is a grey biotite-muscovite granite, coarse to medium grained with K-feldspar phenocrysts. It contains bodies of migmatite, gneiss and quartz and could be foliated.

To the south, the Site is near the boundary of Lower Devonian East Kiewa Granodiorite, a grey, medium grained biotite granodiorite with some muscovite.

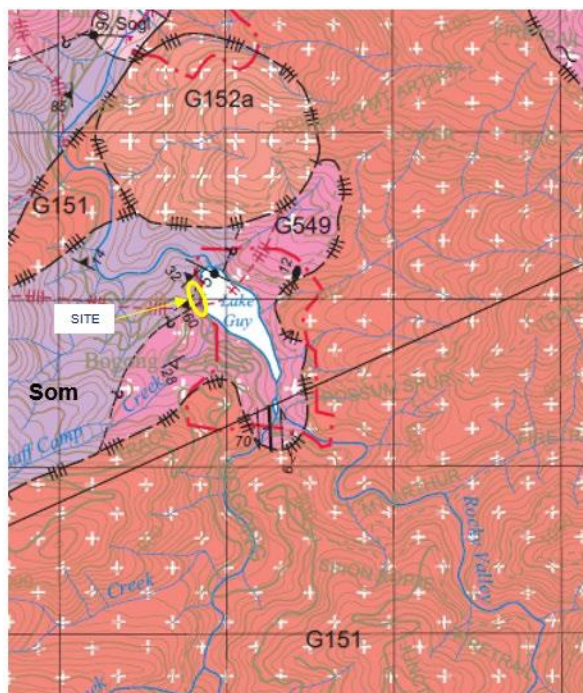
Morand et al. (2005) outlines physiographic setting of Bogong region as follows:

- Much of the Bogong region is mountainous. There are three distinct landforms: plateaus (High Plains), dissected uplands and intermontane valleys.
- The plateaus are interpreted as the remnants of a moderately undulating landscape that preceded the current, more rugged eastern highlands. The plateaus generally lie above 1700 m elevation. The plateaus landform is developed on a variety of different rock types and incorporates the dissected remnant of Cainozoic basalt flows.
- The dissected uplands are the predominant landform and consists of a rugged valley and ridge topography with many hundred metres of relief. Very little geological control, either from rock type or rock structure, is evident in the morphology of this landform. Several straight streams are developed along presumed joints and a few faults, such as the Tawonga Fault. Only minor streams are controlled by the strike of bedding and foliation.
- Amidst the valley and ridge topography of the dissected uplands there are several broader flooded valleys. Most of these intermontane valleys are the result of north-flowing rivers changing from their mountain river track into their downstream valley track.

A more detailed description of the geological unit specific to the Site is presented in Table 1 and Figure 2.

**Table 1: Summary of geological units documented on the Feathertop Geological Map (GSV, 2005a)**

Geological Unit	Description
Cobungra Granite (G549, Figure 2)	<ul style="list-style-type: none"> <li>• Is a medium grained equigranular muscovite–biotite leucogranite. Biotite grains are much smaller than muscovite.</li> <li>• This rock formed as accumulations of melt produced during development of the OMC (William and Wilson, 1999).</li> <li>• In the highest-grade of the complex, melt segregations from the Som were mobilised into intrusive granitic bodies.</li> <li>• Heterogeneous rock unit with an irregular shape, occupying much of the central part of the OMC between Mount Beauty and the Omeo area.</li> <li>• In Bogong the boundary of the pluton is gradational with the surrounding migmatite, but it locally intrudes gneiss and schist.</li> <li>• Area mapped as G549, Figure 2, may contain outcrop of Som.</li> <li>• Even in unfoliated samples, deformation is pronounced.</li> <li>• Biotite is usually more abundant than muscovite.</li> </ul>
OMC migmatite (Som, Figure 2)	<ul style="list-style-type: none"> <li>• Gneissic rock with two components: light coloured granite or pegmatite and darker gneiss rich in biotite.</li> <li>• Most migmatite is layered, with layers of the two components. Leucosomes (melt layers) regularly interlayered with biotite-rich gneiss. A strong gneissosity is parallel to this layering, which can be overprinted by gently plunging, west-verging crenulation folds. This rock is derived from the Pinnak Sandstone, which has been metamorphosed.</li> <li>• Heterogeneous rock that may contain patches of laminated quartz gneiss and various granite such as C549, Figure 2.</li> <li>• Relic bedding may be seen near the boundary with metasedimentary gneiss.</li> <li>• This rock has been folded by upright crenulations folds.</li> </ul>



**Figure 2: Extract from Geological Map of Feathertop (GSV, 2005b)**

### 3 INVESTIGATION METHODS

Observations were conducted on accessible exposed slopes, road cuttings, and the temporary access track, Figure 3. To further understand the geological conditions and assist with developing engineering control measures, subsurface investigations were carried out, involving the following activities:

- Auger and air percussion drilling was completed at five locations along the access track to a maximum depth of 7 m.
- Nineteen slope cuts were excavated and cleaned along the batter of the temporary access track and Bogong High Plains Road using a 6-tonne excavator.

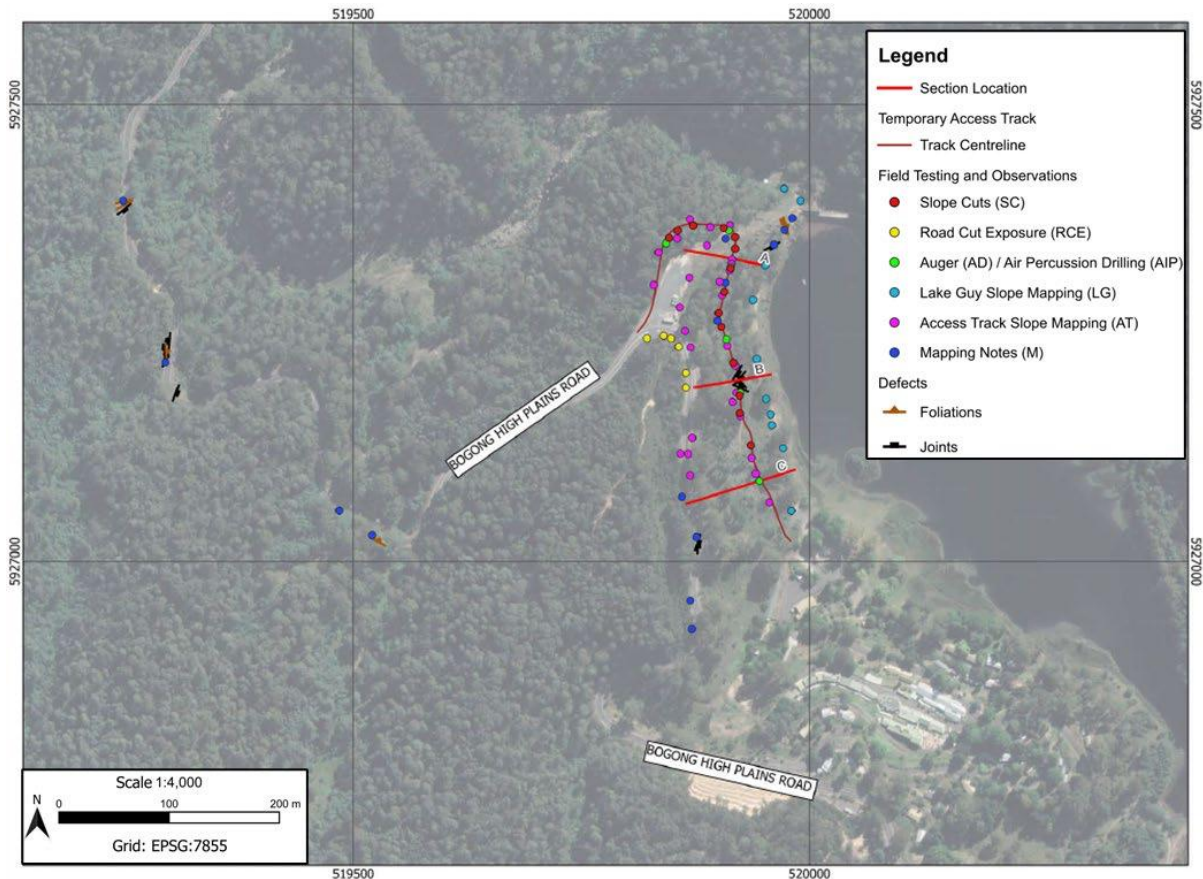


Figure 3: Field testing, observations and section locations

### 4 ENGINEERING GEOLOGICAL MODEL

A preliminary conceptual model was developed prior to fieldwork based on desktop assessment of the Feathertop geological map (GSV, 2005b), historical records from the Kiewa Hydroelectric Scheme (Beavis, 1948; Kenny, 1937), and analysis of high-resolution LiDAR imagery. The site was interpreted to lie within a contact zone between migmatitic gneiss and granodiorite, with topographic and geomorphic features suggesting strong structural control on slope development.

It was anticipated that the slopes would be mantled by variably thick colluvium and residual soils, underlain by either highly weathered bedrock or fresh rock exposures depending on slope aspect and elevation. Structural features such as foliation in the metamorphic units and exfoliation joints in the granodiorite were expected to influence slope stability, particularly where they daylighted on steep slopes. Gully features, slope concavities, and historical landslide scars introduced further uncertainty into the interpretation.

Uncertainties in the preliminary model included:

- The lateral extent and thickness of superficial deposits.
- The depth to competent bedrock across the alignment.
- The condition and orientation of structural defects in fresh and weathered rock.

- The degree to which geomorphology had reworked or obscured in situ geological structures.

The conceptual model was refined using field observations obtained during the investigation program described in Section 3. Slope cuts, temporary track exposures, and mapped features were assessed to characterise lithology, structural fabric, and soil–rock transitions, which informed the delineation of engineering geological units.

#### 4.1 GEOLOGICAL UNITS

The geological units identified during the fieldwork are summarised in Table 2. The depth below surface of the geotechnical units is difficult to differentiate, and three representative cross-sections are presented in Figure 4.

**Table 2: Detailed summary of geological units**

Unit	Description
Colluvium (COL1 & COL2)	<ul style="list-style-type: none"> <li>• Derived from ancient debris flow and more recent Bogong High Plains Road construction</li> <li>• Highly variable but often defined by: <ul style="list-style-type: none"> <li>– COL1: Matrix supported. Matrix is SAND trace silt to SAND with silt and gravel: fine to coarse grained, light brown, orange, gravel is sub-angular up to 10 mm. Boulders up to 800 mm of highly to slightly weathered (HW to SW) granodiorite, medium to very high strength, dry to moist, loose to medium dense.</li> <li>– COL2: Matrix supported. Matrix is SAND trace silt: fine to coarse grained, dark brown, orange. HW gravels and cobbles, moist, medium dense to dense.</li> </ul> </li> <li>• Boulders and cobbles are commonly present from Ch. 0 m to Ch. 400 m along the temporary access track slopes with the following properties: <ul style="list-style-type: none"> <li>– Highly to moderately weathered</li> <li>– High to very high strength.</li> </ul> </li> <li>• Thickness of colluvium is variable across the Site and controlled by slope angle. Colluvium thickness is inferred from Slope Cuts, and it varies from 0.5 m to 2.5 m.</li> </ul>
Residual (RES)	<ul style="list-style-type: none"> <li>• Derived from rocks of BEDROCK1 and BEDROCK2</li> <li>• Mostly dominated by: <ul style="list-style-type: none"> <li>– SAND with silt and gravel: fine to coarse grained, brown to orange, gravel is sub-angular up to 10 mm, moist, medium dense, typically weakly cemented</li> </ul> </li> <li>• Thickness of RES is variable across the Site and controlled by subsurface weathering.</li> </ul>
Bedrock (BEDROCK1)	<ul style="list-style-type: none"> <li>• Observed on the Temporary Access Track between Ch. 210 m and Ch. 290 m, and between Ch. 350 m and Ch 370 m.</li> <li>• Observed along Bogong High Plains Road between CH. 13.58 km and CH. 14.28 km.</li> <li>• Observed along Lake Guy Access track and near the Lake guy Dam outlet.</li> <li>• Mostly defined by: <ul style="list-style-type: none"> <li>– BEDROCK1: Heterogenous metamorphic rock, MIGMATITE, fine to coarse grained, dark grey colour, crenulation folds and lamination, boulders subcrop and outcrop with dimension varying from 1.5 m to &gt; 10m, very high strength, moderately weathered to fresh</li> <li>– BEDROCK2: Heterogenous igneous rock, GRANITE/GRANODIORITE, medium grained equigranular muscovite-biotite, dark grey to pale grey colour, evidence of contact metamorphism, boulders subcrop and outcrop with dimension varying from 1.5 m to &gt; 10m, very high strength, moderately weathered to fresh.</li> </ul> </li> <li>• Dark mineral, biotite, and hornblende (50 – 60 %) and white mineral, feldspar, muscovite, and quartz (40 – 50 %).</li> <li>• Bedrock is typically observed as sub cropping boulders with dimensions varying from 1.5 m to &gt; 10 m.</li> </ul>

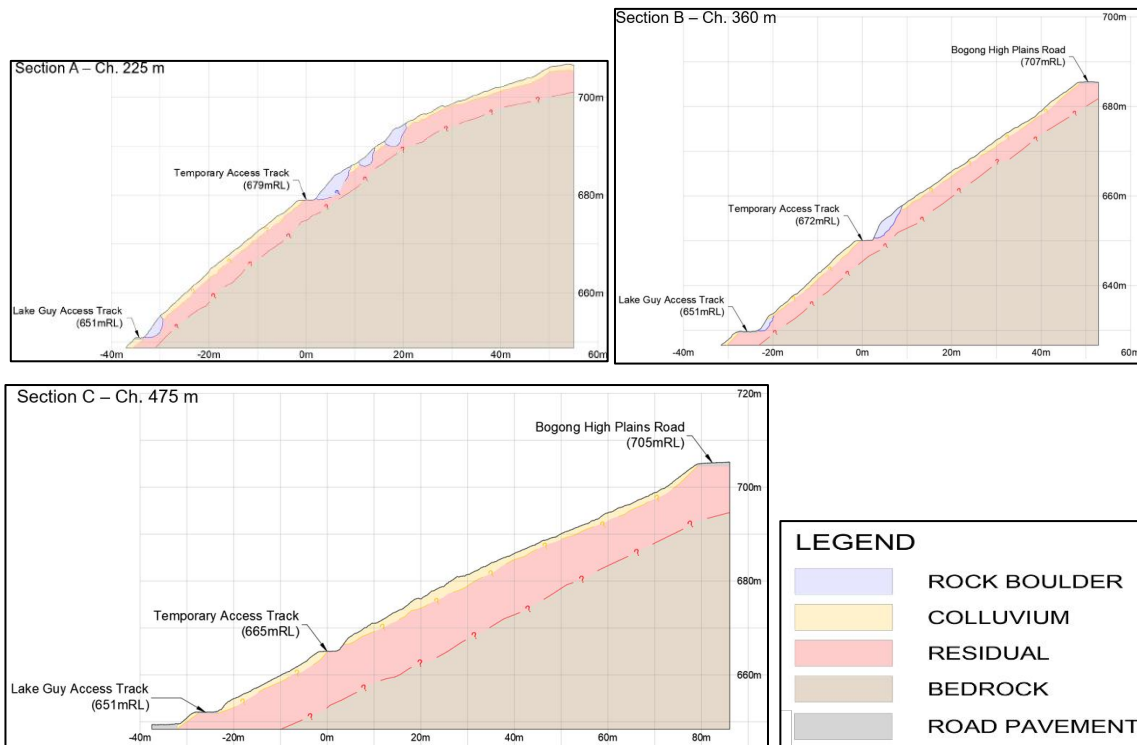


Figure 4: Representative cross-sections

## 4.2 GEOLOGICAL STRUCTURE

One aim of the investigation is to understand whether stress relief joints in the BEDROCK2 and foliation in BEDROCK1 control slope stability. The development of a site wide engineering geological model allows for a comprehensive assessment of potential mechanisms to be undertaken.

### 4.2.1 Field mapping

Bedrock exposures of BEDROCK1 and BEDROCK2 units along Bogong High Plains Road present as a moderately to extremely weathered foliated and massive rock mass respectively. Geotechnical face mapping from available exposures is presented on a stereonet in Figure 5.

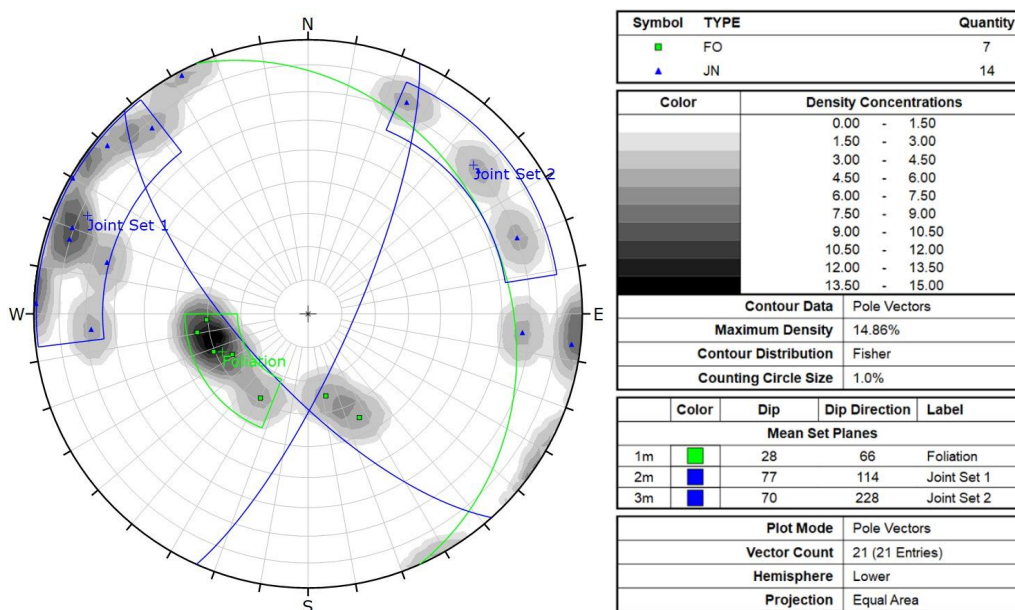


Figure 5: Stereographic projection of BEDROCK1 and BEDROCK2 defects.

#### 4.2.2 Cleavage and Foliation

Some outcrops have a mineral lineation that is parallel to regional folds, with the mineral lineation, Figure 6, usually dipping a low to moderate angle to the southeast.



**Figure 6: Sample taken from road cut in BEDROCK1 on Bogong High Plains Road, showing an example of mineral lineation and crenulation folds following the black minerals**

The observed foliation had a dip of  $25^{\circ}$  to  $35^{\circ}$  towards  $030^{\circ}$  to  $090^{\circ}$ . PSM notes that there is uncertainty about the validity of defect measurements due the potential for disturbance and rotation from landslide activity. Nonetheless, it was anticipated that foliation could have unfavourable orientations at the Site where BEDROCK1 was exposed in cuttings and slope aspect was towards the east/northeast (e.g. CH. 100 m to 200 m, Figure 1). Between these Chainages, cuttings were dominated by colluvium and residual soils without relict foliation observed.

#### 4.2.3 Joints

The joints are mostly relict joints in BEDROCK2 or overturned joints in BEDROCK1, Figure 7. The joints in BEDROCK1 may have formed from lineation or foliation overturned by folds documented in the area. Two joint sets were mapped within the temporary access track:

- Joint Set 1: sub-vertical set dipping from  $75^{\circ}$  to  $85^{\circ}$  towards the east
- Joint Set 2: sub-vertical set dipping from  $60^{\circ}$  to  $75^{\circ}$  towards the west – southwest

Note that stress relief joints were not observed however, evidence of planar slide was documented in areas of BEDROCK2. Basal landslide angles ranged from  $25^{\circ}$  to  $40^{\circ}$ .



**Figure 7: View of a jointed BEDROCK1 on Bogong High Plains Road Ch. 13.88 km.**

#### 4.2.4 Faults

Faults were not observed on site. However, with regards to published information on faults in the project area:

- The Nelse Shear Zone strikes northwest through the broader project area.
- During construction of Lake Guy Dam (originally called Junction Dam) and the Number 2 Tail Race Tunnel minor faults and shears were mapped, Figures 8 (State Electricity Commission (SEC), 1950) and 7 (Beavis, 1949).
- Approximately 300 m from the No. 2 Power Station in the Number 2 Tail Race Tunnel, Figure 9, the tunnel alignment intersected a basic porphyrite dyke, which was intruded along a fault line. The dyke itself was sheared, indicating both pre- and post-dyke shearing, Figure 9 (Beavis, 1948, 1949)

Given that the proposed access track was predominantly in surficial soils and with some bedrock exposures, it was considered unlikely that the faults would directly control stability.

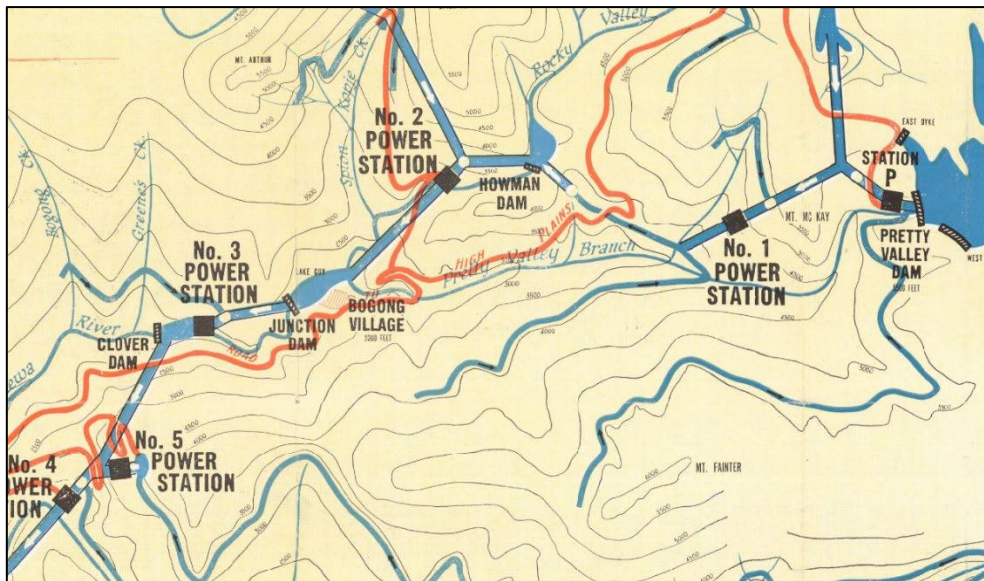


Figure 8: Plan of Kiewa hydroelectric project (SEC, 1950)

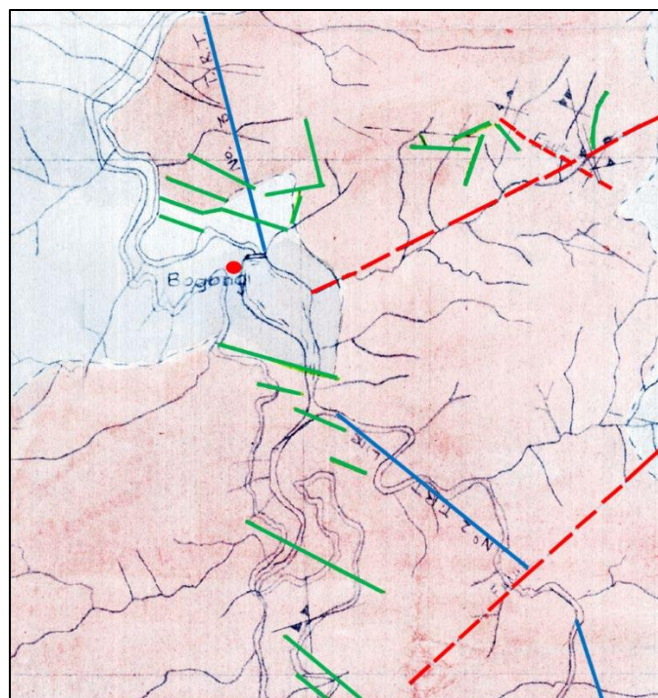


Figure 9: Extract from the geological plan of the Kiewa Scheme (Beavis, 1948). Faults are marked with dashed red lines, dykes with a green line, Tail Race Tunnels with a blue line, and the Site location with a red circle.

#### 4.2.5 Groundwater conditions

While no groundwater was encountered directly in the cut slopes or test pits, signs of wet soils were observed in select areas, and seepage was observed in two minor gullies.

The Visualising Victoria's Groundwater (VVG, 2023) database confirms that regional groundwater depth generally exceeds 20 metres and reduces to less than 5 m (essentially at the surface) in proximity to Lake Guy.

## 5 SLOPE PERFORMANCE, HAZARDS AND REMEDIATION

### 5.1 LANDFORM DOMAINS AND SLOPE OBSERVATIONS

Based on soil type, rock mass characterisation and terrain evaluation, the Site was divided into five domains (D1-D5), each exhibiting distinct slope characteristics, Figure 10 and Table 3.

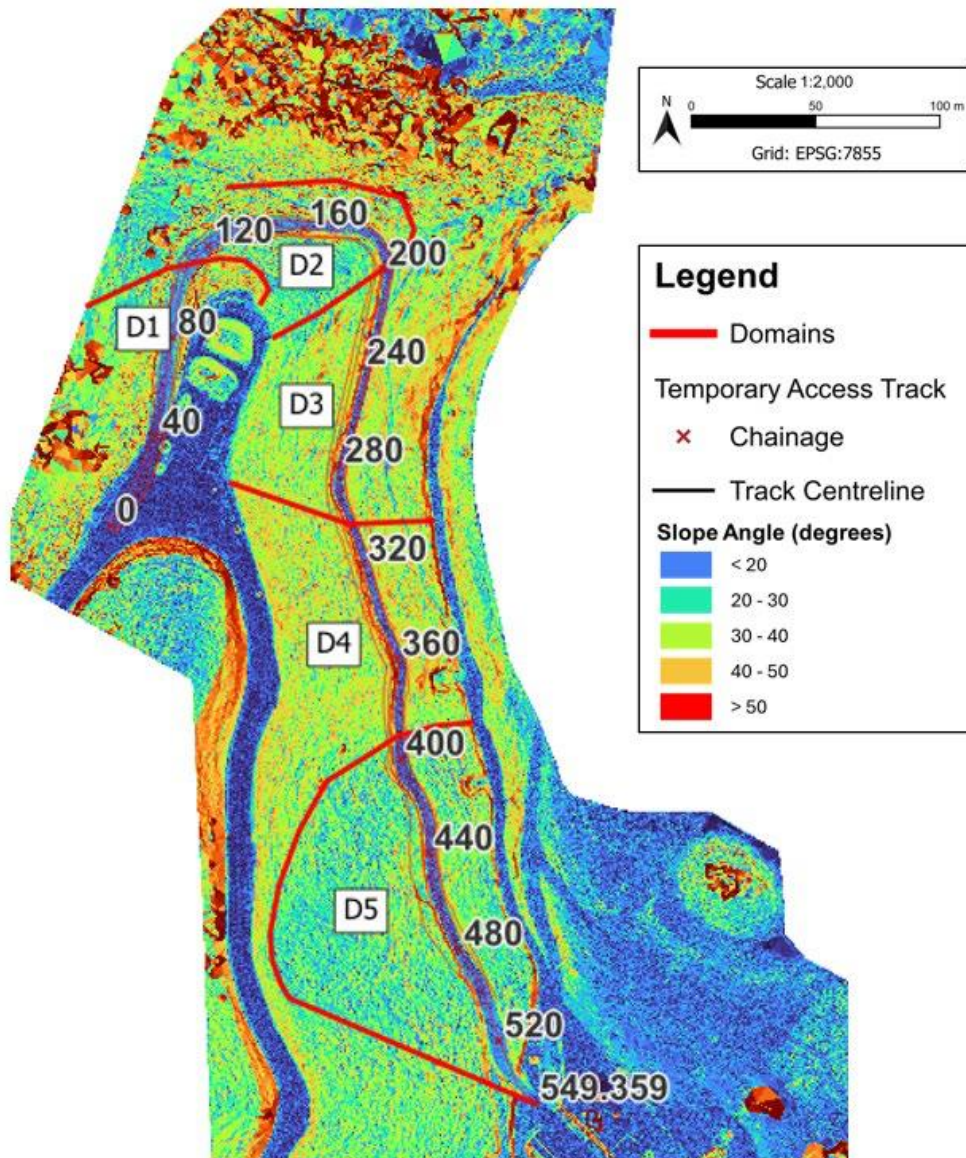


Figure 10: Slope map with two inferred planar slides marked by black ovals

**Table 3: Site Domains**

Domain	Chainage	Rock mass and soil characterisation	Slope observation	Slope performance
D1	Ch. 0 m to 110 m	COL1 and RES	Downslope 40° Upslope 25° - 35°	No sign of instability observed
D2	Ch. 110 m to 200 m	COL1 and RES Scattered boulders	Downslope 40° Upslope 25° - 35°	Minor slip in COL1 recorded. The upslope angle controls stability of the area
D3	Ch. 200 m to 305 m	COL1, RES and BEDROCK1	Downslope 45° Upslope 40° - 45°	Minor slips observed in COL1, and RES caused by recent construction.
D4	Ch. 305 m to 390 m	COL1, COL2, RES and BEDROCK2	Downslope 40° Upslope ~ 45° From Ch. 385 m ~ 35°	One inferred planar slide observed in COL2, RES and BEDROCK2, and one minor slip in COL1, COL2 and RES along Lake Guy Access track
D5	Ch. 390 m to 550 m	COL2 and RES Scattered boulders of BEDROCK2	Downslope 25° - 35° Upslope 30°	One inferred planar failure in COL2 and BEDROCK2 observed along Lake Guy Access track

## 5.2 HAZARD ASSESSMENT AND CONCEPTUAL REMEDIAL OPTIONS

The risk assessment framework was based on the Department of Transport and Planning (DTP) “*Roadside Geotechnical Hazard Risk Management*” guideline (2018). This guideline states that DTP “*undertakes risk management of roadside geotechnical hazards in accordance with the Australian Geomechanics Society (AGS) Practice Note Guidelines for Landslide Risk Management 2007*”. It is important to note that the DTP guideline was developed “*specifically for the risk assessment of roadside geotechnical hazards*” and that the guideline has specific definitions regarding risk tolerance criteria that do not directly translate to AGS (2007) suggested criteria. The differences in the guidelines are not the subject of this paper.

While the AGS Landslide Risk Management Framework (AGS, 2007) provides a robust methodology for formal risk assessment, the project adopted the DTP guidelines. Nevertheless, the first principles technical process required for delineation of landform domains and identification of slope hazards is relatively consistent between the two guidelines. This is particularly the case when recognising hazard types, slope performance indicators, and consequence pathways.

Hazards and consequences of failure for each landform domain were developed, Table 4. Similarly, conceptual remediation options were developed per domain, Table 4.

**Table 4: Hazard assessment and conceptual remedial options**

Domain	Chainage	Hazard	Consequence	Conceptual Remediation
D1	Ch. 0 m to 110 m	<ul style="list-style-type: none"> <li>Metastable cut slopes</li> <li>Debris flows.</li> </ul>	<ul style="list-style-type: none"> <li>Temporary closure of road</li> <li>High maintenance.</li> </ul>	<ul style="list-style-type: none"> <li>Appropriate permanent batter angle.</li> </ul>
D2	Ch. 110 m to 200 m	<ul style="list-style-type: none"> <li>Metastable cut slope</li> <li>Small changes in stress could result in slumping soil.</li> <li>Debris flows and rock fall: 300 to 600 mm boulders in sand matrix.</li> </ul>	<ul style="list-style-type: none"> <li>As per D1 and,</li> <li>Over excavation</li> <li>Need for strengthening.</li> <li>Impact vehicles at low speed.</li> </ul>	<ul style="list-style-type: none"> <li>Soil nailing</li> <li>Appropriate permanent batter angle.</li> </ul>
D3	Ch. 200 m to 305 m	<ul style="list-style-type: none"> <li>Very high strength boulders with undefined dimension – mobilised by earthworks</li> <li>Rockfall</li> <li>Slips between boulders.</li> </ul>	<ul style="list-style-type: none"> <li>As per D2 and</li> <li>Over and under excavation.</li> </ul>	<ul style="list-style-type: none"> <li>Soil nailing</li> <li>Rock meshing.</li> <li>Loose boulders removal.</li> </ul>

D4	Ch. 305 m to 390 m	<ul style="list-style-type: none"> <li>• Very steep upslope but dense soil and less boulders, more cobbles</li> <li>• Wet area with gullies</li> <li>• Debris flows.</li> </ul>	<ul style="list-style-type: none"> <li>• As per D2.</li> </ul>	<ul style="list-style-type: none"> <li>• Combination of surface and sub-surface drainage</li> <li>• Appropriate permanent batter angle</li> <li>• Soil nailing.</li> </ul>
D5	Ch. 390 m to 550 m	<ul style="list-style-type: none"> <li>• No or scattered boulders, loose soil. But slope flatten</li> <li>• Metastable cut slopes</li> <li>• Debris flows.</li> </ul>	<ul style="list-style-type: none"> <li>• As per D2.</li> </ul>	<ul style="list-style-type: none"> <li>• Appropriate permanent batter angle.</li> </ul>

## 6 SUMMARY

The landform domains provided a systematic approach to identifying hazards and develop appropriate conceptual remediation. The observed variability in geological conditions across the Site highlighted the importance of site-specific stabilisation measures tailored to each domain.

The study demonstrates that simple, proven field methods should always be considered when developing a site-wide engineering geological model. This is particularly the case in difficult access and remote terrain. Fortunately, the difficult access to the Site was well supported by readily available historical records associated with the Kiewa Valley Hydro Scheme (Kenny, 1937; Beavis, 1948, 1949; GSV, 2005a). This reinforces the importance of the historical catalogue provided by the Geological Survey of Victoria that can be accessed under Creative Commons Licence.

## 7 ACKNOWLEDGEMENTS

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