Project No: GEO004025
Report No: G4025/1

SUBJECT: **City of Lithgow.**
SH5 – The Great Western Highway.
Mt Victoria to Lithgow Upgrade.
Geotechnical Desktop Study for Route Options Study.

REFERENCE: **Request from RCS Western Project Management**

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1. INTRODUCTION

The RTA Road Pavement and Geotechnical Engineering Section has carried out a desktop study together with site inspections to provide geotechnical input into the route options study for the Mt Victoria to Lithgow, Great Western Highway Upgrade.

The desktop study has concentrated on the four corridors confirmed in April 2009. From south to north, these corridors are identified as the orange, red, green and purple corridors. The purpose of the desktop study was to identify geotechnically related risks, costs and opportunities within with each of the corridors and each of the route options within those corridors, and to assess design, construction and maintenance aspects, particularly geotechnical constraints and possible design solutions. The risks, costs and opportunities have been discussed with the road designers and, where other constraints permit, route options have been adjusted.

The present report is organised as follows:

- A description of sources of information used to construct the geological and geotechnical models;
- A description of how the geological and geotechnical models were put together;
- Discussion of the geotechnical risks, costs and opportunities identified;
- A tabulated summary of the relationship between the geological units and the geotechnical issues;
- A tabulated summary of the geotechnical issues in each of the corridors and;
- Appendices containing site photographs and details of the information collected and the geotechnical model.

2. SOURCES OF INFORMATION

The sources of desktop data used to build the geotechnical model were as follows:

- Published geological maps
- Geological papers
- Information obtained from residents at public meetings
- Mine plans and coal boreholes from the Deptartment of Primary Industry
- Water bores logs from the Deptartment of Water and Energy
- Aerial photography and surface contours
- RTA slope risk rating reports
- Confirmed corridors
- Preliminary road design long sections along confirmed corridors

The following fieldwork was carried out to complement the desktop study:

- Existing cuttings were photographed and photomosaics prepared
- Broad scale geological mapping of existing cuttings and outcrop was carried out
- Mine entrances and shafts were located on site with GPS
- Broad scale mapping of talus slopes and boulders in selected areas

3. BUILDING THE GEOTECHNICAL MODEL

The interpretation and analysis of the data collected was carried out in the following steps:

- The following layers were obtained or prepared for an Arcgis computer model:
  - Surface contours, creeks, roads, railway, cadastre and confirmed corridors
  - Aerial photography – colour, ortho-corrected, mosaic
  - Outcrop of geological units based on geology maps
  - Locations of coal boreholes and water bores
  - Georeferenced plans of coal and shale mine workings
  - Contours of the boundaries between geological units, based initially on the geology maps and air photomosaics.
  - Interpreted locations of escarpments and possible talus based on the aerial photomosaic, surface contours and slopes
  - Slope risk ratings and locations for existing cutting batters
  - Landowner consent for advising landowners prior to site inspections

- The contoured boundaries of the geological units were refined on the basis of field inspections, coal boreholes and mine maps
- Geological long sections along the center of each corridor were generated, based on the contoured boundaries between units and surface contours
- Coal and shale mines were added to the long sections based on interpreted levels
- Initial proposed boreholes and seismic were added. The proposed investigations are to investigate critical geotechnical features such as rock types and strengths in the possible short tunnel location, depth of talus and levels of oil shale mines
- Corridors and route options were assessed with respect to significant geotechnical considerations such as: Risks from escarpments; Risks from talus; Coal mine voids, oil shale mine voids and potential for subsidence; Viaduct, bridge and retaining wall foundations; Acid sulphate rock; Cut and fill stability; Cut batters; Materials in cuttings; Constructability

4. GEOLOGY

4.1 Stratigraphy and Geological Units

The following rock units are present within the study area (see Figures B3 and B9 in Appendix B). All units, except the granite, outcrop in the existing road cuttings between Mount Victoria and the valley floor, just beyond Victoria Pass:

- The uppermost geological unit, that outcrops on the plateau in hills above the escarpments, is the Banks Wall Sandstone. This is a generally low to very low strength sandstone with occasional claystone interbeds. The road and railway cuttings along the Darling Causeway are in this unit.

- Below the Banks Wall Sandstone is the Burra-Moko Head Sandstone, which is approximately 55 metres thick at Victoria Pass. This unit generally forms the escarpments. The unit comprises a generally medium to coarse grained, medium to high strength sandstone with thin, shaley interbeds in the upper half and occasional red brown claystone beds that are about 2m to 4m thick. One of these claystone beds (the Mount York Claystone) is present at the top of the unit. The Mount York Claystone can be seen in outcrop at the lookout at the top of Victoria Pass.

- Below the Burra-Moko Head Sandstone is the Caley Formation which is approximately 28 metres thick at Victoria Pass. The unit comprises sandstone, claystone and siltstone beds.

- Below the Caley Formation are the Illawarra Coal Measures which are approximately 90 metres thick at Victoria Pass. The Illawarra Coal Measures are mostly buried below talus slopes (loose soils and rock that has fallen from the escarpments above). The unit comprises interbedded claystone, siltstone, sandstone and coal. The unit has numerous, closely spaced rock defects and is mostly deeply weathered in the existing cuttings on Victoria Pass. The Katoomba coal seam (mined under a section of the purple corridor) is at the top of the unit; the Wongawilli seam is also towards the top of the unit and, the Lithgow seam is near the bottom of the unit, as is the oil shale seam mined under a section of the green corridor.
- Below the Illawarra Coal Measures are rocks of the Shoalhaven Group that is in the order of 130m thick. This unit comprises siltstone, sandstone and conglomerate and, based on water bore logs, appears to be weathered to variable depths. Most of the valley floor, except the area around Hartley, is in this unit. Acid sulphate rock, discussed later, has been intersected in a number of existing road cuttings in this unit.
- Below the Shoalhaven Group, are the older, basement rocks of Carboniferous age. In the study area the basement rock is granitic and outcrops in the area around Hartley, the width of the area of outcrop thinning to the north. The top of the basement rocks is sub-parallel to the overlying units described above.

4.2 Route Option Descriptions – Geology

All route options start near Soldiers Pinch in the weak Banks Wall Sandstone, pass a narrow “pinch point” between a corner of the National Park and the railway, then pass under the railway lines to the north of Mount Victoria Station, still in Banks Wall Sandstone. Routes in the orange and red corridors would probably be in a tunnel about 20 metres below the surface, while routes in the green and purple corridors would likely be close to the surface, using a bridge to support the railway lines.

From the western side of the possible railway underpass, routes in the orange and red corridors pass over two valleys (probably on viaduct) before entering a tunnel under Mount York Rd. The tunnel and tunnel portals would be within the weaker Banks Wall Sandstone and / or the stronger Mount York Claystone and Burra-Moko Head Sandstone, depending on the level at which the tunnel is constructed. To the west of the tunnels the routes in the orange and red corridors would run for a short length in a small valley, pass Berghofer’s Pass, run through the end of a north-south running ridge then descend into the valley on a viaduct.

From the western side of the possible railway underpass, routes in the green and purple corridors would follow the Darling Causeway, northwards, in the weak Banks Wall Sandstone. The probable order of construction would be: two lanes constructed adjacent to the western side of the existing road; then traffic moved onto the newly constructed lanes; then the existing road reconstructed with better horizontal and vertical alignments. The new northbound carriageway would pass over three or five valleys (green and purple corridors respectively) where high retaining walls or viaducts would be needed. After leaving the Causeway, routes in the green and purple corridors would pass through undulating bushland before descending into the valley on a viaduct. The viaduct would be constructed down a creek valley or off the end of a ridge, depending on the results of a study into the risks from rock fall from the escarpments and the feasibility of designing to reduce the risk to acceptable levels. The eastern end of a viaduct in the purple corridor would pass over abandoned coal mines. To the west of the possible viaduct in the green corridor, the road would pass over abandoned oil shale mines.

Once in the valley, routes in the four corridors pass over the Shoalhaven Group rocks. Routes in the orange corridor would be close to the existing highway and would pass over about 2.8 km of the granitic basement rocks near Hartley and the River Lett Hill. Routes in the red, green and purple corridors would pass over shorter lengths of the granitic basement rocks.

After coming up out of the valley, routes in all corridors would pass close to the existing highway in the Forty Bends area, along the base of the talus slope. The road would be mainly over Shoalhaven Group rocks, with some sections over talus. The risk of rock fall from the escarpment above (Hassan’s Walls) needs to be addressed in the design.

5. DISCUSSION

5.1 Escarpments and Talus

5.1.1 General Description

The distinctive Blue Mountains topography of escarpments (cliffs), with talus slopes below, is present in all corridors where they descend from the plateau into the valley. The escarpments are in the Burra-Moko Head Sandstone and the Caley Formation that are more resistant to weathering and erosion than the under-lying Illawarra Coal Measures. The Illawarra Coal Measures weather and erode at a greater rate than the overlying, more massive sandstone, resulting in undercutting and loss of support at the base of the escarpment. A common failure mechanism where the escarpment has loss of support at the toe, is collapse or toppling of joint bound pillars, resulting in rock avalanche. Much of the escarpment surface comprises large, planar, joint surfaces that are the release surfaces. The rate of retreat of the escarpment is likely to be higher where coal mining beneath the escarpment cause settlement and cracking of the overlying rock.

The material that falls from the escarpments accumulates on the slopes below as a layer of rock and soil referred to as talus. Some of the rock does not break up and boulders up to 10 meters or more in size are commonly observed on the surface of the talus. The talus slopes decrease in slope away from the escarpment. The material in the steeper slopes, closer to the escarpment, is commonly at or close to its angle of repose (up to approximately 40^o).

All corridors have geotechnical constraints relating to escarpments and talus. The risks and costs associated with escarpments and talus depend very much on the proposed route alignments within the corridors and comparison needs to be made between specific route options rather than broad comparisons between corridors.

5.1.2 Description of the Escarpments

Photo 5 in Appendix A shows a typical escarpment. The escarpments in and adjacent to the green and purple corridors where they descend into the valley are generally between 20m and 30m in height. The escarpments in and adjacent to the red and orange corridors where they descend into the valley are generally between 15m and 25m in height. The escarpments to the north of the red corridor, where it is in the valley, are generally 30m to 40m in height and up to 50m in height in places.

Boulders and avalanches from escarpment failures, have travelled as far as the base of the talus slope and large boulders commonly with a maximum dimension 5m to 8m or more are often present 200m to 300m from the escarpment from which they fell (see Photos 9, 10 and 11 in Appendix A). A boulder on the avalanche debris of a recent failure near Katoomba is about 13m maximum dimension and 230m from the escarpment.

5.1.3 Description of the Talus

Figure D1 in Appendix D shows the interpreted location of talus slopes. The talus slopes, adjacent to the escarpments, are very steep, typically 35^o to 40^o near the top of the talus slope (see Photos 13 and 14 in Appendix A). The steeper parts of the talus slopes are probably at or close to the angle of repose for the materials and are likely to be of marginal stability. Photo 16 in Appendix A shows a gabion retaining wall located on the northern side of the highway at Fourty Bends, that was constructed to remediate a cutting batter in talus that failed in the late 1980s.

At this stage, a significant unknown is the depth of talus at various locations – a shallow, say 5m cover of talus over bedrock has very different design, cost and risk implications to a deep, say 20m layer of talus over bedrock. Future investigation of talus extent and depths is likely to include seismic refraction and drilling. Talus instability may be affected by other factors such as clay content, depth of weathered clayey bedrock beneath the talus, groundwater levels and lateral seepage, so that instability may arise in less steep slopes where these factors are present.

5.1.4 Escarpments – Risks and Design Considerations

The escarpments may pose a significant rock fall and avalanche risk that would need to be addressed in route selection and the design. Achieving an Assessed Risk Level of 4 or better (the desirable level for new works) will require careful investigation and analysis.

Initial assessments of the risk to viaducts located below escarpments indicate an ARL of 3 (Assessed Risk Level in accordance with RTA Guide to Slope Risk Rating V3.1). Similarly, the indicated initial assessment of the risk to road users where the highway may be located close to existing surface level, below escarpments, is ARL 3. These initial assessments are not reliable at this stage and a detailed study is needed to accurately determine the probability and consequences of large boulders impacting viaduct piers and boulders reaching trafficked lanes where the highway formation is close to existing surface level.

5.1.4.1 Risk to viaducts

In the green and purple corridors, there may be a significant risk to a viaduct running down the creek valley from large boulders falling from the adjacent escarpment in a rock avalanche or as individual rock falls and traveling at speed down the talus slopes below.

The level of risk is currently uncertain, however, if necessary the risk could be greatly reduced by moving the road onto the adjacent ridges and starting the viaduct at the end of the ridge. Further studies are needed to assess risks and the road design feasibility of this ridge alternative. Assessment of the urban design and landscape aspects of the options would also be required.

If a viaduct in the green or purple corridors needs to follow the creek, then the risk will to be assessed and quantified and the design include measures to reduce the risk to acceptable levels.

The main risk in the red corridor from rock falls / avalanches would be on the northern side of the corridor for a distance of 3.2km where the corridor runs parallel to Mt York Road below an escarpment that is up to 50m in height. The eastern 2km of this section would be on viaduct and, similar to the green and purple corridors, there may be a significant risk from rock avalanche or rock falls. Similarly, the risk will need to be reliably assessed and quantified and the design include measures to reduce the risk to acceptable levels.

Until further, more detailed studies are undertaken, the effects of these risks on feasibility and cost cannot be assessed to the extent that one or other alternative can be chosen or eliminated. Therefore, route options should include both the creek and ridge options for further investigation. Routes adjacent to the Mount York Road escarpment should include options for increased lateral clearance from the base of the talus slope.

5.1.4.2 Risk to road users where highway is close to existing surface level

In a number of locations, potential routes pass near the base of talus slopes with escarpments above and there is a risk of rock falls and rock avalanches impacting road users. At this stage, the level of risk is uncertain.

The main risk in the red corridor from rock falls / avalanches would be on the northern side of the corridor for the western 1km of the 3.2km where the corridor runs parallel to Mt York Road below the escarpment, and would be close to the existing surface level. If possible, routes in the red corridor should be located to the south of the corridor over this section. If this is not acceptable, then the risk will to be reliably assessed and quantified and the design include measures to reduce the risk to acceptable levels.

The orange and red corridors follow the same corridor where they start to descend from the escarpment. West of the possible western tunnel portal, for approximately 250m, the road would be beneath smaller escarpments that may need treatment. The corridors also intersect smaller escarpments approximately 370m and 530 m from the possible portal location, that could be above portals of a second short tunnel or may be removed by a large cutting. In either case, the risk from rock falls would need to be addressed in the design.

5.1.5 Talus Slopes – Risks and Design Considerations

All route options appear to need a viaduct or bridge to descend from the plateau. Viaduct options would require one or more piers to be founded on talus slopes. A cable-stayed bridge option would allow large spans and piers that are on the valley floor, away from talus slopes.

It appears feasible to construct a pier on the talus where the talus slope is approximately 2:1 or flatter. The construction pad would need to include a retaining wall and be designed to ensure global stability. An access track would need to be constructed on the talus slope to provide access for construction purposes.

The stability of cuttings or fill embankments constructed on the steeper talus would need to be assessed. It is likely that retaining and stabilisation measures designed to ensure the global stability of the road would be required. Creep movement is also likely in the steeper talus slopes and the curved shape of occasional tree trunks indicate that creep movement has occurred. Viaduct piers on talus slopes would need to be isolated from such creep movement by having them within oversized, cased holes with sufficient open space to accommodate at least 100 years of creep movement.

The risk to viaduct piers from avalanches and large boulders is greater on the talus slopes compared to the more gently sloping, valley floor beyond the talus slope. Earth mounds or structural barriers could be designed to deflect boulders from piers. It is likely to be more difficult to design a structure that would deflect a large avalanche. In addition, large earth mounds on talus, upslope of viaduct piers, would need considerable engineering to maintain a reasonable factor of safety against global slope failure and to reduce creep at viaduct piers to acceptable rates.

Large diameter and deep bored piles are anticipated to be required to support the bridge structure in view of low and or variable rock strength in the areas. Spread footings may be feasible for the eastern abutments. For pier foundations in the talus areas, the piles are likely to be sleeved to cater for potential down slope movement of the talus (eg. Mittagong viaduct refers). Subject to engineering feasibility and cost studies, a long span bridge (say >100m?) may be considered (e.g. a cable stayed bridge.) to be used so as to minimise or eliminate the number of foundation piers within talus slopes.

On all corridors, for all route options other than those that follow creek valleys, the eastern 200m to 300m of viaduct will be over talus and it is likely that one pier at least will need to be constructed on the steeper talus slope - for a conventional balanced, cantilever bridge. Rigid barriers, rock ditches, earth mounds or deflection walls would be required to protect foundation piers. The size of these structures is anticipated to be quite substantial in view of steepness of escarpments and potential large rock size.

An alternative to constructing a pier on the talus slope is to design a cable stayed bridge. The tower would be approximately 100m in height above deck level. The first pier would be located on or near the valley floor, avoiding the environmental and engineering problems associated with constructing a pier on the steep talus slope.

5.2 Bridge and Viaduct Foundations

5.2.1 Viaduct for Escarpment Descent

Except possibly at the eastern abutments, piles for the various viaduct options would be founded in the Illawarra coal measures or the Shoalhaven Group rocks. At this stage the depth of weathering in these units at potential viaduct sites is not known, however, existing cuttings along the Great Western Highway and driller’s logs for water bores indicate that depths of weathering are very variable between only a few metres and up to 40 metres. With the available information it is not possible to say in which corridor the foundation conditions may be better or worse. Nevertheless the weathered rock in both geological units is likely to be poor with respect to foundation conditions and the foundation costs for viaduct options will probably be significant.

5.2.2 Bridges for Railway and Creek Crossings

Foundations for bridges would likely be bored piles, spread footings or possibly driven piles depending on the depths and properties of soil and rock materials present at bridge sites. Foundations in the Shoalhaven Group rocks may need to be designed to withstand attack from acid sulphate rock.

As mentioned previously, routes in the green and purple corridors would pass under the railway, with the rail lines supported on a bridge. The bridge would be founded in the relatively weak Banks Wall Sandstone, probably on bored piles designed to transfer the bridge loads to the weak rock through shaft adhesion and end bearing.

5.3 Acid Sulphate Rock

There are a number of existing cuttings on the Great Western Highway in acid sulphate rocks within the Shoalhaven Group (see Photos 17 and 18 in Appendix A). These rocks occur in the central and western parts of the study area. They contain iron sulphides that oxidise when exposed in cuttings, producing iron oxides, sulphates and sulphuric acid that represents an environmental hazard through effects on soil fertility, scalding of vegetation and pollution of water courses. The oxidised sulphate minerals generated are of greater volume than the iron sulphides and break the rock up, causing fretting of the cut batter faces. The iron oxides cause staining and the sulphuric acid released can damage concrete and steel in structures and cause environmental damage.

Remedial measures include:

- encapsulating acid sulphate rock fill within low permeability fill to minimise the water and air reaching the rock;
- running acid leachate over limestone drains to neutralise the acid;
- cutting batter faces flatter to accommodate fretting and;
- using concrete and reinforcing designed to withstand acidic leachate conditions.

With respect to the latter and where required, viaduct piles founded in the Shoalhaven Group rocks will need to be designed to resist attack from acid groundwater.

The risk from acid sulphate rock is considered similar for all corridors and is unlikely to be a significant input to route selection. It is recommended that where possible, large cuttings in the Shoalhaven group rocks be avoided and that during investigation of route options, any proposed large cuttings in rocks of the Shoalhaven Group be drilled and assessed to determine whether or not acid sulphate rock is present.

Acid sulphate rock may impact on the structural integrity of foundation piles and other concrete and steel road elements. Durability of concrete and steel in acid rock environments will need to be assessed during the design stage. Measures such as the use of heavier steel, allowance for a greater thickness of steel corrosion and use of sulphate resistant concrete would be considered.

5.4 Tunnel Support and Portals

Route options in the red and orange corridors include a tunnel option under Mt York Road. Route options in the green and purple corridors may include a short tunnel under the railway in the design.

In the vicinity of the possible tunnel under Mt York Rd, the base of the Banks Wall Sandstone is at approximately RL 1030m at the eastern end to RL 1040m at the western end. The geological unit(s) that the tunnel would be excavated through and the tunnel length would depend on the level at which the road is constructed. Sections of tunnel in the Banks Wall Sandstone, would likely need heavy support, such as closely spaced rockbolts or steel sets. For sections of tunnel in the Burra-Moko Head Sandstone, below the Banks Wall Sandstone, patterned roof bolting would probably provide adequate roof support. Treatment schemes for a tunnel would be determined during more detailed investigation and design phases, and there would be provision for more intensive treatments for weaker zones such as faults, dykes and fractured zones.

Due to the geometry of the ground surface and the rock units, it is difficult to locate a shorter (say 300m to 500m) tunnel in the Burra-Moko Head Sandstone. If the base of the Banks Wall Sandstone is close to the level estimated, then a shorter tunnel with reasonable depth portal cuttings (say 20m deep) would be largely in the Banks Wall Sandstone. A longer tunnel would be needed if the tunnel was in the stronger Burra-Moko Head Sandstone, unless very deep portal cuttings are included in the design. The footprint of deep portal cuttings intersecting the Banks Wall Sandstone would depend on whether the cuttings are retained or not.

A tunnel under Mt York Road would probably be excavated using a road header. Blasting in the stronger rock would also be an option provided that vibration levels at nearby residences could be limited to acceptable levels. A tunnel beneath the railway is expected to be in Banks Wall Sandstone.

5.5 Widening the Darling Causeway

Route options in the green and purple corridors would almost certainly require widening and re-alignment of the Darling Causeway. The orange and red corridors do not follow the Darling Causeway and widening considerations do not apply. In some locations there are steep slopes adjacent to the Darling Causeway where the road would need to be widened (see Photo 8 in Appendix A). The steeper slopes, measured from the ground surface contours are 21^{o} to 31^{o}. A preliminary assessment of the constructability of reinforced soil walls (RSWs) on these slopes indicates that they are feasible on a 21^{o} slope, provided that suitable founding rock is present at shallow depth, but may not be the best design solution on a 31^o slope where retained temporary excavations would likely be needed to construct the RSWs.

Due to the engineering characteristics of the sandstone, heavy retaining structures may be required to ensure long term stability – bored pile walls or L-shape cast insitu walls.

Widening of the Darling Causeway would also necessitate realignment and deepening of the existing cuttings in the generally weak and erodible Banks Wall Sandstone. As discussed in Section 4.9 "Batter Design", low, vertical cut faces with an overall batter slope of 1.5H:1V would probably be appropriate for un-retained cut batters. Where steeper overall cut batters are needed, the sandstone may need to be retained using soil nails.

5.6 Coal Mines

Abandoned coal mines are present under the purple corridor where potential routes descend into the valley.   Abandoned coal mines are unlikely to be present under the orange, red and green corridors (see Figure C1).

The mines are at a level of approximately RL 890m, a level that will be refined in the near future by surveying the mine entrances. Mining at this location ended in the 1960s. The workings on plans run in a north-south zone and underlie the full width of the corridor.

The mine plans also show an "old tunnel" intersecting the surface on the western side of Hartley Vale Road (see Figure C2). The collapsed tunnel opening can be seen from Hartley Vale Road, however, the extent of any workings associated with this "old tunnel" are not known.

If the route follows the creek valley on the southern side of the corridor, it would pass over 320m of workings, then run sub-parallel to 580m of escarpment that will be potentially de-stabilised by the mine voids beneath it (see Figure C2). All feasible route options in the purple corridor are likely to be on viaduct over this 580m section and the risk to the viaduct from avalanches and rock falls would need to be analysed. Possible measures to reduce these risks include filling of mine voids, stabilization of escarpments, increased thickness of viaduct piers and construction of mounds etc to deflect falling material away from viaduct piers. The viaduct eastern abutment would likely be founded over mine voids 30m to 50m below.

Route options that pass along the ridge in the north of the purple corridor would pass over at least 520m of workings (see Figure C2).

Other abandoned mine working are present under the hills to the north of Forty Bends, near Lithgow, and are present in the northern 100m of a short section of all corridors where they merge to the east of Forty Bends. In this location the mines are under a talus slope and it is unlikely that any feasible routes would pass over the workings.

The RTA has plans of the coal mines that probably indicate the minimum extent of extraction. It is understood that it is likely that not all workings are shown on these plans and that other, un-mapped mine voids are likely to be present.

5.7 Oil Shale Mines

Oil shale mines dating from the late 1800s are present under a section of the green corridor (see Figures C1 to C3 in Appendix C). Three shafts were inspected in the northeast corner of the purple corridor and there is a possibility that oil shale mines may also be present in the vicinity of these shafts (see Figure C1). Oil shale mines are unlikely to be present under the orange and red corridors.

As with the coal mines, it is unlikely that the plans of workings show the full extent of mining and other un-mapped mine voids are likely to be present. Route options are likely to be close to existing surface level over the mine voids, being in minor cut and/or on low fill embankment.

The mines appear to be at two different levels, probably between RL 785m and RL 792m under the valley floor and probably between RL 810 and RL 815m in the hills to either side of the valley. On a geological section prepared by the Department of Mines and Agriculture in 1901, the shale beds in the valley floor are shown in a down-thrusted, fault bounded block. The vertical displacement is approximately 80ft or 25m. The shale seam on the down-thrust block is shown 50ft (15m) below the valley floor. Another source suggests that the faults were located by J. E. Carne, Assistant Geologist with the then Mines Department in 1903, who recorded them in a Memoir on the Oil Shales of NSW c. 1903, noting that the displacement was 8m or thereabouts. At this stage the mine levels are uncertain and need to be checked by drilling.

Depending on route location, between 160m and 600m of the alignment could be over oil shale mines and be at risk of damage due to subsidence. Depending on the mine depths below the road level, treatment to prevent subsidence might include filling the voids or excavating to the base of the voids and then filling with engineered fill. The possible impact of subsidence on cutting batters would need to be addressed in the design.

Grouting of mine voids may be required if found present underneath the foundation piles at the western end of a viaduct. Alternatively the foundation piles would have to be founded well below the mine voids.

5.8 Batter Design

Cut batter design has a significant impact on the road footprint where deep cuttings are needed. The road footprint may be a constraint where it impacts heritage items or environmentally sensitive areas, or where it is undesirable for aesthetic and urban design reasons. The location, depth and footprint of cuttings depends on the detailed horizontal and vertical alignments of route options, the nature of rock and soils intersected and measures to support and steepen batters. Therefore, the following preliminary cut batter designs are intended for the initial comparison of specific route options and are of very limited use for broad comparison of the four corridors.

Fill embankments are generally battered at 2H:1V, unless reinforced or retained, with a general design standard factor of safety of 1.5. Cut batters are generally designed to achieve an assessed risk level (ARL) of minimum 4, with factor of safety checks where deemed necessary, usually to minimum 1.5. The following preliminary cut batter designs are suggested for route option studies. The final batter designs would be based on geotechnical investigation of the individual cuttings.

The Banks Wall Sandstone is commonly of low to extremely low strength, friable and highly erodible. The cut batters need to be designed to minimise erosion and achieve an adequate factor of safety against instability, considering associated risks. Small vertical faces are recommended to reduce erosion and to provide adequate stability for individual faces. For preliminary purposes, an overall batter slope of 1:1 with low vertical faces and benches can be adopted to provide a generally adequate global stability. Where appropriate low height benching of batters is not possible due to other constraints, cut batters in Banks Wall Sandstone may require soil nailing and/or shotcreting to ensure long term stability due to friable and weak rock properties. Where faces higher than 3m are needed, cost estimates should include an estimate for soil nailing at 1.5m centers, with soil nail lengths 0.6 times the face height. Higher, steep to vertical un-reinforced batters may be adopted on a risk basis.

The Burra-Moko Head Sandstone is generally of medium strength and an appropriate preliminary batter slope for route selection would be 7m high faces cut at 0.5H:1V with 4.5m wide benches. Where faces are orientated parallel to the main NNW or NE joints sets, an allowance for rock bolting would need to be included in cost estimates.

The Illawarra Coal Mesaures and Shoalhaven Group mostly comprise thinly bedded shale, siltstone and sandstone, are generally closely jointed and are commonly deeply weathered. An appropriate preliminary batter slope for route selection would be 7m high faces cut at 1.5H:1V with 4.5m wide benches. The final batter slopes are likely to vary between 2H:1V and 0.75H:1V depending on the rock types, rock strength, defect spacing and weathering.

In the case of the granite (see Photo 15 in Appendix A), it is more difficult to suggest an appropriate preliminary batter slope for route selection. The granite appears to be variably weathered, in some locations having fresh granite close to the surface and elsewhere being weathered to a depth of at least 8m. It is suggested that a preliminary batter design of a 7m high face at 2H:1V in assumed weathered granite and then 7m high faces at 0.25H:1V in assumed fresh granite, with 4.5m benches, be used for route option assessment until borehole data becomes available.

Cut batters in talus are likely to be retained by rigid structures if they can not be laid relatively flat at between 2H:1V and 3H:1V. If cuttings are needed in talus, it is suggested that an appropriate preliminary batter slope for route selection would be 7m high faces cut at 3:1 with 4.5m wide benches.

5.9 Excavation Conditions and Blasting

Excavation of cuttings in the sedimentary rock units could probably be achieved without the need for blasting. Some blasting may be needed in stronger sandstone (high strength or higher). Where cuttings are in granite, some blasting is likely to be required. Blasting of granite and granite boulders is most likely to be needed in the area around the River Lett. Blasting may be a constraint where it is needed close to historic buildings that would require low vibration limits; where the highway needs closing while blasting is carried out; where airblast and vibration limits need to be met at houses and; where fly rock is a risk.

Much of excavation is likely to require ripping with medium to heavy weight bulldozers. Blasting may also be required for pre-split formation of batter faces steeper than 1:1.

5.10 Materials

The earthworks materials likely to be available from the various geological units are as follows:

General fill would be available from all of the geological units, however, some of the rock from the Shoalhaven Group contains iron sulphides and will need to be placed and treated as acid sulphate rock. Coal from the Illawarra Coal Measures could be spoiled, sold or placed mixed with other materials in fill cores.

Material for the Upper Zones of Formation is likely to be available from all of the geological units except that:

- Acid sulphate rock from the Shoalhaven Group would not be suitable;
- the Banks Wall Sandstone has been used for the Selected Material Zone on previous projects but requires stabilisation with cement and fly ash to achieve the compaction required;
- shale from the Shoalhaven Group and Illawarra Coal Measures may not be suitable for the Upper Zones of Formation.

The best sources of material for the Selected Material Zone are likely to be the Burra-Moko Head Sandstone and weathered granite.

The best sources of material for reinforced soil wall (RSW) fill are likely to be the Burra-Moko Head Sandstone and weathered granite. Some of the Banks Wall Sandstone may be suitable for RSW fill, however, experience from previous Blue Mountains projects has been that some of the sandstone produces fill which exceeds the 15% passing 75 micron upper limit of the RTA R57 Design of Reinforced Soil Walls specification.

Sources of sound, durable rock for drainage blankets, gabions, armour rock etc are likely to be limited to fresh granite, if it is available from cuttings.

Material suitable for use in bridging layers is likely to be available from most of the geological units.

Routes that follow the existing Great Western Highway or Darling Causeway would involve excavation of existing road pavement materials. These materials would probably be suitable for blending and incorporation in the Upper Zones of Formation beneath the pavement if needed or could be used in general fill if sources of Upper Zone are plentiful.

Topsoil is more likely to be available from cuttings and fill foundations in the valley than on the plateau.

The valley is the most likely area to produce unsuitable material where the road passes over weak, boggy ground, where fill embankments are not of sufficient height to allow a bridging layer to be constructed, or where shallow cuttings are used. Unsuitable material may also be present in gullies and swamps on the plateau. In order to minimise the quantities of unsuitable and "difficult" material produced, it is recommended that design options adopt a target minimum fill height of 2m and a target minimum cutting depth of 2m.

6. SUMMARY COMPARISON OF GEOLOGICAL UNITS

Table 1 – Summary comparison of the Geological Units with respect to Geotechnical Considerations

	Banks Wall Sandstone – Sandstone with minor interbedded claystone	**Burra–Moko Head Sandstone –** Sandstone with thin claystone interbeds, and **Caley Formation –** Sandstone, claystone, shale and conglomerate.	**Illawarra Coal Measures –** Shale, sandstone, conglomerate and chert with coal and torbanite (oil shale) seams	**Shoalhaven Group –** Shale, conglomerate and sandstone including lenticular development of the Megalong Conglomerate	**Lower Carboniferous –** Ademellite, granite and granodiorite	**Talus**
Age	Triassic	Triassic and Permian	Permian	Permian	Carboniferous	Quaternary
Geotechnical description	Commonly low to very low strength and erodible. Generally 2% to 10% high to very high strength ironstone zones, generally less than 100m thick but can be up to 1m thick.	Generally medium strength sandstone with shallow weathering. The claystone and shale beds are generally 2m to 4m thick and erode somewhat faster than the sandstone. The escarpments are generally in this unit with talus on the slopes below.	The unit contains a high proportion of thinly bedded shale and claystone and is commonly deeply weathered in existing cuttings. Mine voids are present in coal and torbanite seams in some locations.	The unit contains a high proportion of thinly bedded shale and claystone and is commonly deeply weathered in existing cuttings. Acid sulphate rock is likely to be present in some locations.	The granitic rocks are likely to be weathered to varying depths and contain varying proportions of very high strength boulders in the weathering profile. The fresh rock is likely to be of high to extremely high strength and the weathered rock of low to very low strength.	Located on slopes below escarpments. Slopes up to 36 degrees or more from horizontal. Loose soil and rock with boulders up to 10m in size. Steep slopes are of marginal stability and creep movement would be expected. Generally overlies the Illawarra Coal Measures that are likely to have a high permeability beds and introduce groundwater into the talus.

Table 1 – Summary comparison of the Geological Units with respect to Geotechnical Considerations (Cont.)

	Banks Wall Sandstone	**Burra–Moko Head Sandstone** and **Caley Formation**	**Illawarra Coal Measures**	**Shoalhaven Group**	**Lower Carboniferous Granite**	**Talus**
Possible cut batter designs for batters that are not retained	Weak and erodible. For preliminary design assume overall batter slope of 1:1 and vertical faces. Relatively wide footprint	7m high, 0.5H:1V faces with 4.5m benches. Relatively narrow footprint	Average 7m high, 1.5H:1V faces with 4.5m benches. (0.75:1 to 2:1 may be appropriate depending on rock strengths and defects) Shales, claystone – possible planar slides on residual shear strength. Relatively wide footprint	Average 7m high, 1.5H:1V faces with 4.5m benches. (0.75:1 to 2:1 may be appropriate depending on rock strengths and defects) Relatively wide footprint	Weathered granite: 7m high, 2H:1V faces with 4.5m benches. Fresh granite: 7m high, 0.25H:1V faces with 4.5m benches.	Probably stable if cut at 3H:1V. Cut batters steeper than 2H:1V would generally need to be retained.
Bridge and viaduct foundations	Assume equivalent to Class V sandstone. Likely deep bored pile foundations.	Assume equivalent to Class III sandstone.	Assume equivalent to Class III shale or Class IV sandstone. Likely deep bored pile foundations.	Assume equivalent to Class III shale or Class IV sandstone. Likely deep bored pile foundations.	Boulders may add to cost of pile excavation. Likely bored pile founded on fresh bedrock.	Found in underlying bedrock. Creep movement would need to be considered in the design. Construction may not be possible on the steeper slopes.

Table 1 – Summary comparison of the Geological Units with respect to Geotechnical Considerations (Cont.)

	Banks Wall Sandstone	**Burra–Moko Head Sandstone** and **Caley Formation**	**Illawarra Coal Measures**	**Shoalhaven Group**	**Lower Carboniferous Granite**	**Talus**
Retaining wall foundations	Global stability a consideration on steep slopes. Piled wall may be required		Consider water seepage and claystone / shale beds on side slopes.	Consider water seepage and claystone / shale beds on side slopes.	Consider global stability on steep slopes where granite is deeply weathered and weakened.	Global stability on steeper slopes is a major consideration. Piled wall founded in underlying rock may be required
Rockfall and rock avalanche risk	Low	High below escarpments, particularly where subsidence may occur over coal mines in the green corridor.	High below escarpments, particularly where subsidence may occur over coal mines in the green corridor.	Low	Low	High below escarpments, particularly where subsidence may occur over coal mines in the green corridor.
Acid sulphate rock	None	None	Possible	Likely	Unlikely	None
Mine voids	None	None	Coal mines present in the green corridor may cause escarpment instability and subsidence under viaduct abutment and adjacent road. Oil shale mines present in the blue corridor where route options are likely to be close to ESL.	None	Lead mine in the red corridor needs to be checked at concept stage.	Oil shale mines below talus in the green corridor.

Table 1 – Summary comparison of the Geological Units with respect to Geotechnical Considerations (Cont.)

	Banks Wall Sandstone	**Burra–Moko Head Sandstone** and **Caley Formation**	**Illawarra Coal Measures**	**Shoalhaven Group**	**Lower Carboniferous Granite**	**Talus**
Excavation	Mostly easy	Some blasting may be required	Blasting unlikely or very limited	Blasting unlikely or very limited	Some blasting of fresh granite likely to be required. Likely difficult excavation where there are a high percentage of boulders in a weathered matrix.	Temporary and permanent excavations on steeper slopes are likely to need retaining. Localised blasting of large, high strength boulders may be needed.
Tunneling	Tunnel likely to need heavy support such as closely spaced sets and/or closely spaced pattern bolting and shotcreting.	Pattern bolting likely to provide adequate roof support.	Tunnel may need heavy support such as closely spaced sets or reinforced shotcrete with closely spaced bolts.	Not applicable	Not applicable	Very difficult tunneling conditions. Cut and cover may be an option.
Environmental considerations	The weak sandstone, where present, is highly erodible in cut faces, fills and stock piles	Possible blasting	Acid sulphate rock may be present.	Acid sulphate rock likely to be present. Impact on groundwater and associated flora.	Likely blasting	

Table 1 – Summary comparison of the Geological Units with respect to Geotechnical Considerations (Cont.)

	Banks Wall Sandstone	**Burra–Moko Head Sandstone** and **Caley Formation**	**Illawarra Coal Measures**	**Shoalhaven Group**	**Lower Carboniferous Granite**	**Talus**
Materials	On previous mountain projects the sandstone has been marginal with respect to use in SMZ and RSWs	Sandstone is a likely source of RSW backfill and selected material.	Coal may need to be spoiled or possibly sold.	Acid sulphate rock would need to be encapsulated in fills and an acid rock management plan used.	Weathered rock is a possible source of SMZ Possible source of hard, durable rock in deeper cuts if proposed	
Constructability	Constructability of RSWs adjacent to and down slope of existing roads in steep terrain needs to be considered. Temporary cut batter support.	Cutting at edge of scarp may require special construction methods.	High water flows from coal seams may affect construction.		Trafficability and use of bridging layers when the residual soils are saturated.	Slope stability during construction – access tracks, temporary excavations, excavation of very large boulders.
Major rock defects	Two major joint sets are present in the eastern half of the study area. The major joints are near vertical. One set strikes mainly NNW and the other set strikes NE to ENE. Where steeper cut faces are used, for example in the Burra – Moko Head Sandstone, slabs and columns in the face, created by these joints will need to be removed or stabilised with rock bolts. The geometry of slabs and columns created by the joints will depend on the orientation of each cutting face relative to the major joint sets. Many of the rock faces in the escarpments are joint surfaces and the orientation and spacing of major joints will be an important input to the assessment of rock avalanche and rock fall risk from escarpments adjacent to route options. The roof support design for the proposed tunnel would need to address blocks bounded by joints and bedding defects and sub-horizontal defects causing delamination..					
Insitu stress						
Impact on groundwater						

7. SUMMARY COMPARISON OF CORRIDORS

Table 2 – Summary Comparison of the Four Corridors with respect to Geotechnical Considerations

Geotechnical Considerations	Orange Corridor	Red Corridor	Green Corridor	Purple Corridor
Rock fall and rock avalanche risk	The risk of rock fall / avalanche impact on viaduct piers exists in all corridors but is higher in the green and purple corridors if either of the routes follows the creek with escarpments on either side. Routes that come off the end of ridges have a lower risk from avalanches and rock fall, particularly if some of the escarpment has been removed by a cutting at the end of the ridge. Rigid barriers, rock ditches or deflection walls may be required to protect foundation piers. The size of these structures is anticipated to be quite substantial in view of steepness and height of escarpments and talus slopes, and potential large rock size. The likelihood of rock fall / avalanche is likely to be higher where coal mines are present beneath the escarpments on the purple corridor and at Hassan's Wall.			
Mine voids	Unlikely – low risk	Unlikely – low risk	150m to 400m (depending on the route alignment) would be over oil shale mines at roughly 15m depth. Road level likely to be close to existing surface level. Grouting of mine voids may be required if found present underneath the foundation piles. Alternatively the foundation piles would have to be founded well below the mine voids	A minimum of 360m of any route in the corridor would be over coal mine voids at depths of between 50m and 20m below existing surface level. Possible viaduct abutment likely to be over coal mines.

Table 2 – Summary Comparison of the Four Corridors with respect to Geotechnical Considerations (Cont.)

Geotechnical Considerations	Orange Corridor	Red Corridor	Green Corridor	Purple Corridor
Mine Voids (Cont.)			Grouting may also be required if the risk of collapse or settlement under the road is unacceptable. A detailed assessment of the natures, risk and treatment of oil shale and coal mine voids will be required.	
Acid sulphate rock	The possibility of intersecting acid sulphate rock in cuttings is similar for all corridors. May impact on the structural integrity of foundation piles and other concrete and steel road elements – concrete and steel and therefore should be appropriately looked at during the design stage, e.g. the use of heavier steel and allowance of thicker steel corrosion and use of higher concrete grade. Potential environmental impacts from acid leachate – can be managed by encapsulation of fill materials, treatment of batter faces and treatment of runoff water. Environmental treatments may require increased land take, suitable deep fill sites and long term monitoring.			
Environmental considerations	Blasting is more likely to be needed in the orange and red corridors because a greater length of these corridors are in granite.		More ersosion and sedimentation controls are likely to be needed both during and after construction for the green and purple corridors because of the greater lengths in the commonly highly erodible Banks Wall Sandstone. Contaminated ground associated with oil shale mining may be present in the green corridor.	
	The risk of intersecting acid sulphate rock in the Shoalhaven Group rocks is similar in all corridors			
Bridge and viaduct foundations	All corridors are likely to need a viaduct to make the descent from the plateau into the valley. The number of piers likely to require piling through talus is likely to be greater in the green and purple corridors. Large diameter and deep bored piles are anticipated to be required to support the bridge structure in view of low and or variable rock strength in the areas. For pier foundations in the talus areas, the piles are likely to be sleeved to cater for potential/possible down slope movement of the talus. Large span bridge structures, possibly together with a descent off the end of a ridge, may avoid piers in talus.			

Table 2 – Summary Comparison of the Four Corridors with respect to Geotechnical Considerations (Cont.)

Geotechnical Considerations	Orange Corridor	Red Corridor	Green Corridor	Purple Corridor
Retaining wall foundations			Realignment and widening of the Causeway in the green and purple corridors is likely to require a number of retaining walls that would probably be founded on low strength Banks Wall Sandstone on steep slopes. Heavy retaining structures may be required to ensure long term stability – RSWs or L-shape cast insitu walls, anchored bored pile walls.	
	Retaining walls in talus, if required, are expected to be founded in talus unless bored piles are used.			
Tunneling	If tunneling is in Bankswall sandstone, closely spaced rockbolts or steel sets are anticipated to be required. The Burra-Moko Head Sandstone would provide relatively good conditions for tunneling. The level of the base of the low strength Banks Wall sandstone needs to be determined by drilling to check the above. Subject to the final road alignment, very high cuttings, (up to say 50m), may be needed at tunnel portals, requiring substantial retaining structures if the road footprint needs to be reduced.		Not applicable	Not applicable
Batter designs for batters that are not retained	Similar for all corridors except that there would be more cuttings in granite in the orange corridor and more cuttings in Banks Wall Sandstone in the green and purple corridors. Where cut batters cannot be laid back to achieve ARL 4 or better and, where required, an adequate factor of safety (generally 1.5) then the batters may need to be retained – this would most likely involve soil nailing and/or shotcreting in the Banks Wall sandstone and rigid retaining structures in the steeper talus slopes. In the flatter talus slopes, 2:1 or 3:1 batters may be acceptable subject to global stability checks.			

Table 2 – Summary Comparison of the Four Corridors with respect to Geotechnical Considerations (Cont.)

Geotechnical Considerations	Orange Corridor	Red Corridor	Green Corridor	Purple Corridor
Constructability	In all corridors one or more viaduct piers may need to be constructed on a steep, marginally stable, talus slope.			
			Construction of reinforced soil walls on steep slopes adjacent to the Darling Causeway may require temporary retaining of the existing road in some locations.	
Excavation conditions	Excavation conditions are similar for all corridors except that fresh granite in the orange and red corridors is likely to need blasting and granite boulders in a weak matrix produces difficult excavation conditions.			
Materials	All corridors are similar with respect to materials, including sources of material for the upper zones of formation, general fill, bridging layer material and reinforced soil wall fill.			
	The orange and red corridors pass over a greater length of granite that is may be a good source of material for the selected material zone and RSW fill. The granite may also be a good source of sound, durable, hard rock for drainage blankets, gabions, armour rock etc.			

8. PROPOSED INVESTIGATION

In the short term, the high priority geotechnical investigation needed for input to route option comparisons comprises:

- A cored borehole on Mt York Road to investigate the level of the base of Banks Wall Sandstone and the rock types, strengths and defects to a level below the likely, maximum tunnel depth in order to estimate likely tunnel roof support and portal options;
- Seismic refraction surveys and boreholes to establish depths of talus and foundation conditions where viaducts or bridges are likely to be located in each of the corridors;
- Detailed inspection of escarpments in all corridors and assessment of the risk to potential route options;
- Two cored boreholes to determine the levels of oil shale mine voids beneath the green corridor;
- Accurate survey of coal mine entrances in the purple corridor;
- Core drilling in any deep cuttings proposed in Shoalhaven Group rocks to test for acid sulphate rock;
- Investigation (one or more of surface mapping, boreholes and seismic) for any large cuttings proposed in the granite to determine excavation conditions, batter design and materials.

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APPENDIX A

SITE PHOTOGRAPHS

Photo 1 - Location of proposed railway underpass – Mount Victoria

Photo 2 - Cutting in Banks Wall Sandstone at location of proposed railway underpass

Photo 3 - Railway cutting in Banks Wall Sandstone - east of Mt Victoria Station

Photo 4 - Railway cutting in Banks Wall Sandstone - east of Mt Victoria Station

Photo 5 – Escarpment in Burra-Moko Head Sandstone from the lookout at the top of Victoria Pass

Photo 6 - Mt York Claystone at lookout at top of Victoria Pass

Photo 7 - View of the valley from Mt York Lookout

Photo 8 - Retaining wall on the Darling Causeway - example of location where a retaining wall or viaduct would be needed to widen the Causeway

Photo 9 - 8m and 11m boulders near bottom of valley off Hartley Vale Rd

Photo 10 – Rock avalanche in Hassan's Walls

Photo 11 - Boulders in valley down hill from Victoria Pass - photograph taken from Berghofer's Pass

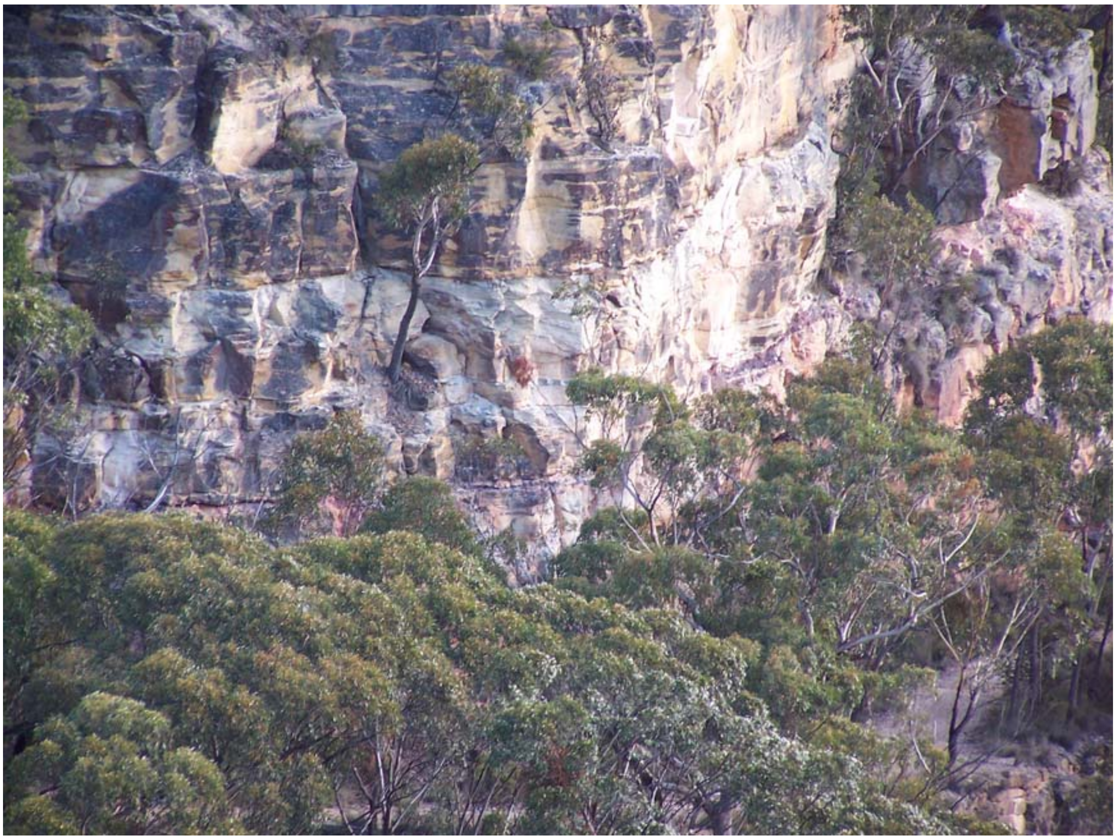


Photo 12 – Escarpment in the orange / red corridors above Berghofer's Pass to be removed in cut or tunneled under. Photographed from Berghofer’s Pass

Photo 13 - Talus slope down hill of Berghofer's Pass near Mount Victoria

Photo 14 - Talus slope down hill of Berghofer's Pass near Mount Victoria

Photo 15 – Hard granite in Great Western Highway cutting near Hartley

Photo 16 - Gabion retaining wall on Great Western Highway at Forty Bends near Lithgow retaining a cutting in a talus slope that failed

Photo 17 - Acid sulphate rock in Great Western Highway cutting at Mudgee turnoff, northwest of Lithgow

Photo 18 - Acid sulphate rock in cutting on GWH between Lithgow and Bathurst

APPENDIX B

CONTOURING OF GEOLOGICAL UNITS

The geotechnical aspects that need to be considered route option development are largely associated with the different geological units in the project area. In order that these geological units could be shown on the road design long sections and cross sections, the levels of the boundaries between the geological units was estimated from a number of sources of information and then each boundary was contoured - see Figures B5 to B8 in this Appendix. The location of the geological units in at the surface is shown in Figure B3. The following sources of information were used:

Available geological maps (Figure B2):

- Katoomba 1:50,000 Geological Series sheet 8930-I
- 1:100,000 Western Coalfield (Southern Part) comprising Geological Series Sheet 8931 and part of 8830, 8831, 8832, 8930 and 8932

Base of Banks Wall sandstone based on:

- Katoomba 1:50,000 Geological Series sheet 8930-I
- Outcrop of Mt York Claystone (the unit immediately beneath the Banks Wall Sandstone) at:
  - The lookout at the top of Victoria Pass (E 243,892 N 6,280,584 RL 1045) (see Appendix A Photo 6)
  - Mt York Road (E 244,002 N 6,281,306 RL 1040)
  - Berghofer's Pass (E 244202 N 6281228 RL 1045)
- Location of the transition in slope between the top of escarpments in the stronger Burra-Moko Head Sandstone and the flat lying, weak, erodible Banks Wall Sandstone interpreted from the contours and air photos.

Top of the Illawarra Coal Measures based on:

- Both geological maps
- Level of coal mines (at the top of the Illawarra Coal measures)
- Level of the top of the Katoomba Seam in coal boreholes (See Table B1)

Base of the Illawarra Coal Mesaures

- Both geological maps
- Level of oil shale mines (assumed to be near the base of the Illawarra Coal Measures)

Top of Granite

- Outcrop locations on the 1:100,000 Western Coalfield Sheet
- Levels recorded in driller's logs for water bores (see Table B2 and Figure B1)

Major joint sets

- Traced from the air photos near escarpments (see Figure B4). The creeks also show preferential orientation to the main joint orientations.

Table B1: Summary of Levels of the Katoomba Seam from Boreholes Drilled for Coal Investigations

BOREHOLE	EASTING	NORTHING	COLLAR RL (m)	DEPTH (m)	Top of Katoomba Seam RL(m)	Bottom of Katoomba Seam RL(m)
Grose Valley DDH2	246988.3	6286241.8	1004.9	166.7	843.4	842.0
Grose Valley DDH3	250028.0	6286662.7	1027.5	417.7	762.7	760.8
Grose Valley DDH4	249471.2	6287310.3	1010.7	230.3	784.2	782.4
Grose Valley DDH5	247497.6	6288837.2	1061.4	235.1	833.1	830.7
Grose Valley DDH6	245906.9	6291059.8	1092.6	260.2	840.0	838.5
Grose Valley DDH7	246736.2	6287535.7	1039.5	194.3	851.6	849.7
Grose Valley DDH8	246973.6	6289701.6	1073.4	251.6	827.0	824.3
Grose Valley DDH9	246550.9	6288428.7	1015.6	176.3	845.4	843.1
Grose Valley DDH10	244987.1	6290551.8	1086.2	360.3	865.4	863.8
Grose Valley DDH11	247054.6	6288147.3	1049.1	215.3	844.7	842.0
Grose Valley DDH12	245844.9	6289030.5	1037.3	190.4	855.4	853.3
Grose Valley DDH13	245821.3	6289732.3	1045.6	197.4	854.5	852.9
Grose Valley DDH14	246538.6	6289066.8	1015.5	184.0	837.7	835.4
Grose Valley DDH15	245317.5	6288202.8	992.8	128.2	869.2	868.1
Grose Valley DDH16	246091.3	6288084.6	988.9	135.7	857.9	855.5
Grose Valley DDH17	247055.1	6288694.6	1066.1	239.0	834.3	831.8
Grose Valley DDH18	245466.2	6288690.9	1020.9	160.8	864.7	863.4
Grose Valley DDH19	246676.6	6287980.8	1034.1	189.9	849.2	847.1
Grose Valley DDH20	245976.1	6287517.0	998.7	141.7	861.4	860.5
Grose Valley DDH21a	246400.4	6288138.6	1021.2	176.0	850.7	848.8
Grose Valley DDH22	246436.0	6287593.0	997.4	141.7	859.4	858.2
Grose Valley DDH23	246407.6	6290204.0	1082.5	249.0	837.3	835.0
Grose Valley DDH24	246268.0	6288837.509	956.0	111.5	847.7	845.7
Grose Valley DDH25	246869.6	6288089.7	1038.7	200.2	842.5	841.3
Grose Valley DDH26	248266.7	6288753.0	1067.0	252.3	822.1	820.2
Grose Valley DDH27	244828.7	6290047.4	1088.4	217.4	871.2	869.8
Grose Valley DDH28	244789.4	6291258.3	1055.9	198.4	863.2	861.4

Table B2 : Summary of Materials Recorded on Drillers' Logs for Water Bores (Note: Rock names changed to standardise descriptions)

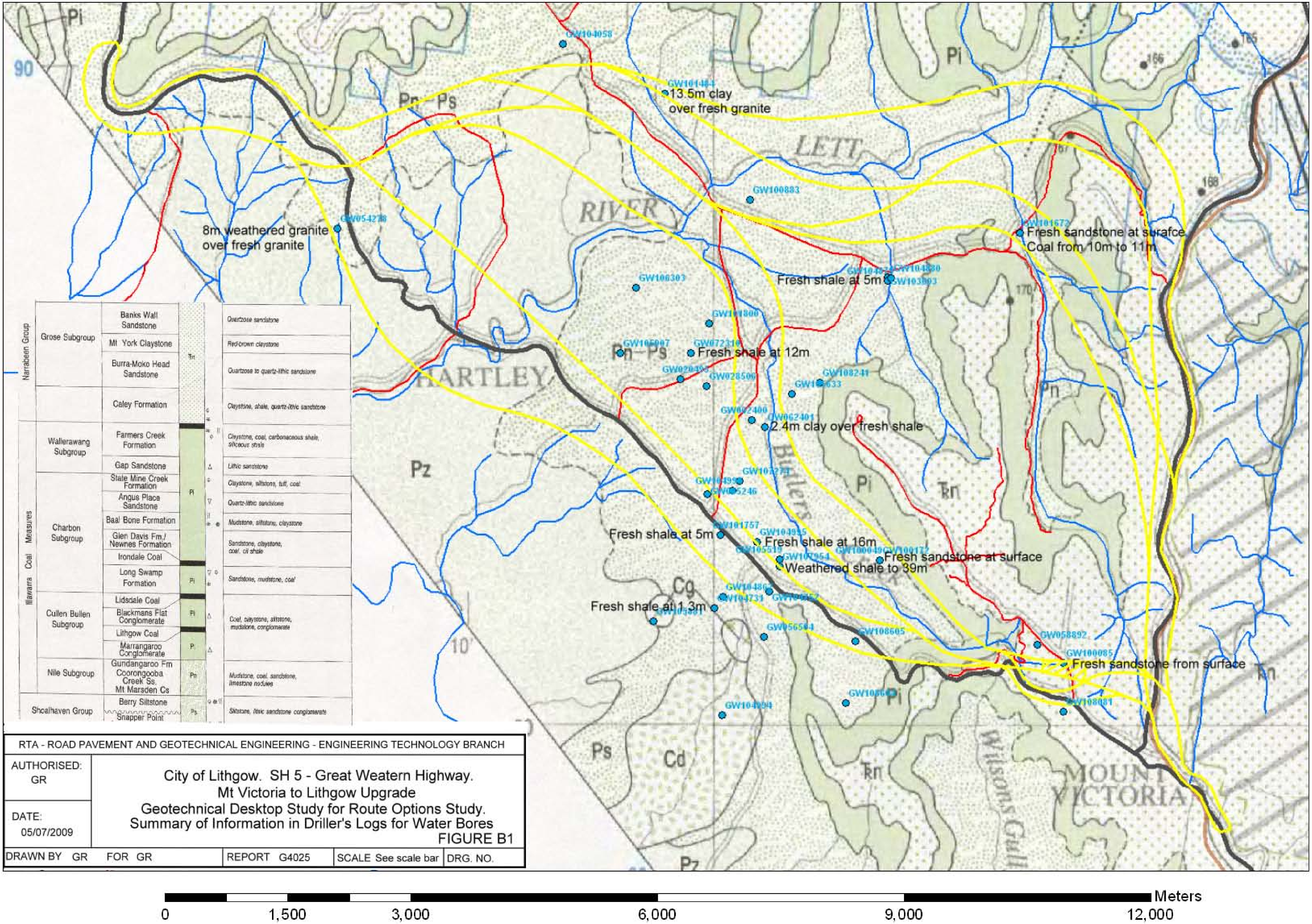
Water Bore	Depth From (m)	Depth To (m)	Material	E	N
GW028506	0	9.14	Clay	240006	6284336
	9.14	9.15	Rock		
GW054278	0	7.9	Weathered granite	235513	6286249
	7.9	70.7	Fresh granite		
GW055246	0	6.1	Clay	240016	6283011
	6.1	33.5	Shale		
	33.5	38.1	Granite		
GW056504	0	5.4	Shale	240709	6281272
	5.4	60.9	Granite		
GW058892	0	0.6	Weathered sandstone	244041	6281176
	0.6	83.8	Fresh sandstone		
GW062400	0	10.1	Clay	240560	6283920
	10.1	19.5	Shale		
	19.5	32	Fresh sandstone		
	32	36.6	Clay		
	36.6	38.4	Weathered granite		
	38.4	56.7	Fresh sandstone		
GW062401	0	2.4	Clay	240717	6283831
	2.4	30.5	Fresh shale		
GW069012	0	4	Clay	237269	6289452
	4	12	Weathered sandstone		
	12	31	Fresh sandstone		
GW072310	0	5.5	Clay	239813	6284732
	5.5	12.2	Weathered shale		
	12.2	27.4	Fresh shale		
	27.4	83.8	Fresh granite		
GW100049	0	10.2	Fresh sandstone	242116	6282213
GW100085	0	12.5	Fresh sandstone	244357	6280955
	12.5	20.3	Fresh sandstone		
	20.3	93.7	Fresh sandstone		
GW100172	0	1.5	Clay	242117	6282213
	1.5	100.6	Fresh sandstone		

Table B2 : Summary of Materials Recorded on Drillers' Logs for Water Bores (Cont.)

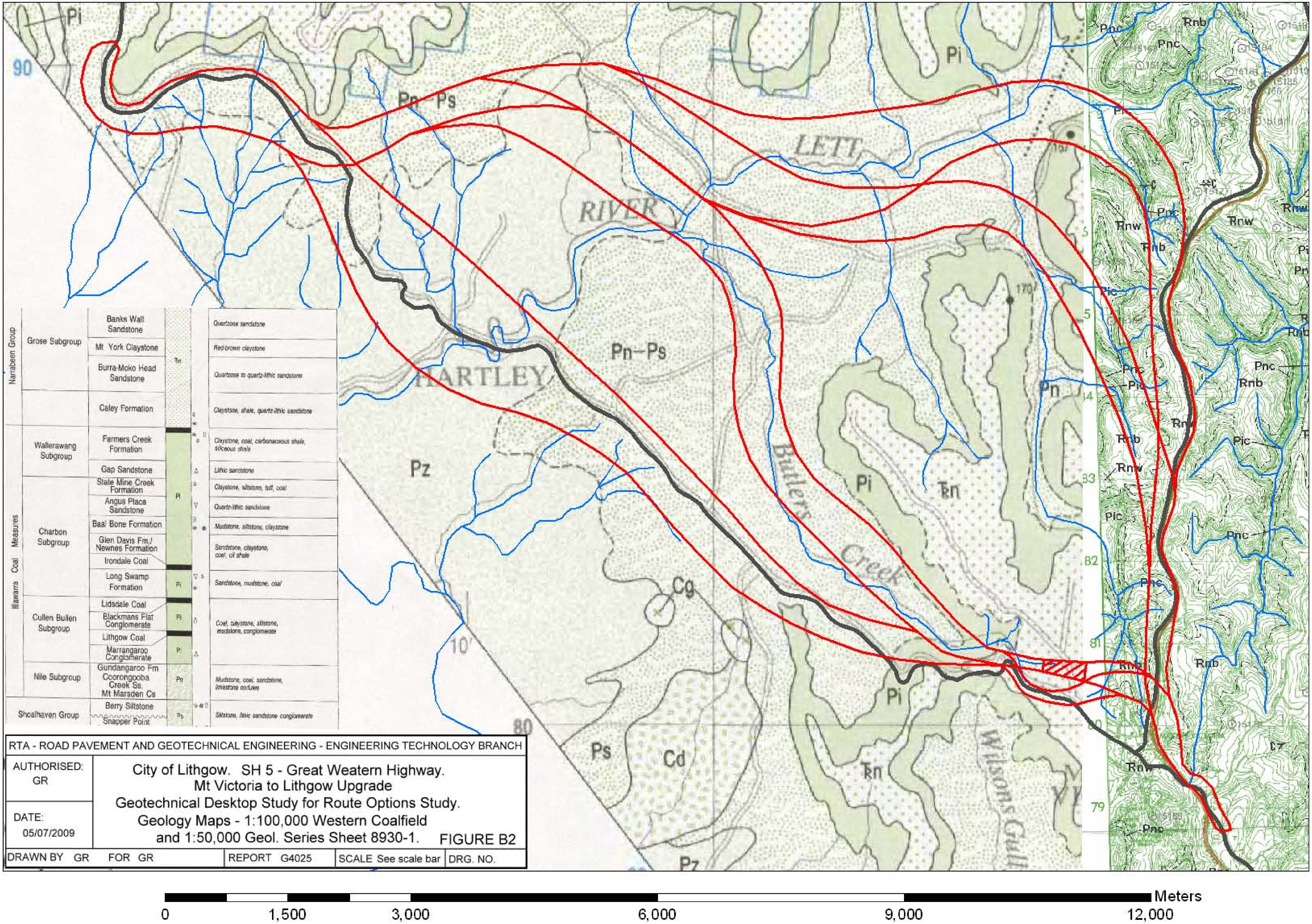
Water Bore	Depth From (m)	Depth To (m)	Material	E	N
GW100897	0	16.8	Weathered granite	240540	6286606
	16.8	61	Fresh granite		
GW101484	0	13.5	Clay	239497	6287899
	13.5	60	Fresh granite		
GW101672	0	10	Fresh sandstone	243834	6286201
	10	11	Coal		
	11	62	Fresh sandstone		
GW101757	0	2	Clay	240175	6282514
	2	5	Sand		
	5	36	Fresh shale		
GW101800	0	4.76	Clay	240043	6285091
	4.76	37.2	Fresh sandstone		
GW103693	0	5	Clay	242217	6285660
	5	76	Fresh shale		
GW104731	0	1.3	Clay	240109	6281627
	1.3	42	Fresh shale		
GW104752	0	45	Fresh sandstone	240770	6281826
	45	46	Fresh granite		
GW104879	0	6	Fresh sandstone	242219	6285616
	6	90			
GW104880	0	6	Fresh sandstone	242256	6285650
	6	61	Weathered shale		
	61	184	Fresh Shale		
	184	200	Fresh granite		
GW104994	0	7.5	Clay	240201	6280324
	7.5	16	Weathered shale		
	16	62	Fresh granite		
GW104995	0	3	Clay	240625	6282429
	3	16	Weathered shale		
	16	64	Fresh shale		
GW104996	0	7	Clay	240328	6283055
	7	34	Fresh shale		
	34	37	Fresh granite		

Table B2 : Summary of Materials Recorded on Drillers' Logs for Water Bores (Cont.)

Water Bore	Depth From (m)	Depth To (m)	Material	E	N
GW105519	0	4	Clay	240901	6282218
	4	39	Weathered shale		
GW108241	0	9	Clay	241392	6284374
	9	36	Fresh shale		
	36	89	Fresh sandstone		



RTA - ROAD PAVEMENT AND GEOTECHNICAL ENGINEERING - ENGINEERING TECHNOLOGY BRANCH			
AUTHORISED: GR	City of Lithgow. SH 5 - Great Weatern Highway. Mt Victoria to Lithgow Upgrade Geotechnical Desktop Study for Route Options Study. Summary of Information in Driller's Logs for Water Bores FIGURE B1		
DATE: 05/07/2009			
DRAWN BY GR FOR GR	REPORT G4025	SCALE See scale bar	DRG. NO.



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AUTHORISED: GR	City of Lithgow. SH 5 - Great Western Highway. Mt Victoria to Lithgow Upgrade Geotechnical Desktop Study for Route Options Study. Geology Maps - 1:100,000 Western Coalfield and 1:50,000 Geol. Series Sheet 8930-1. FIGURE B2
DATE: 05/07/2009	

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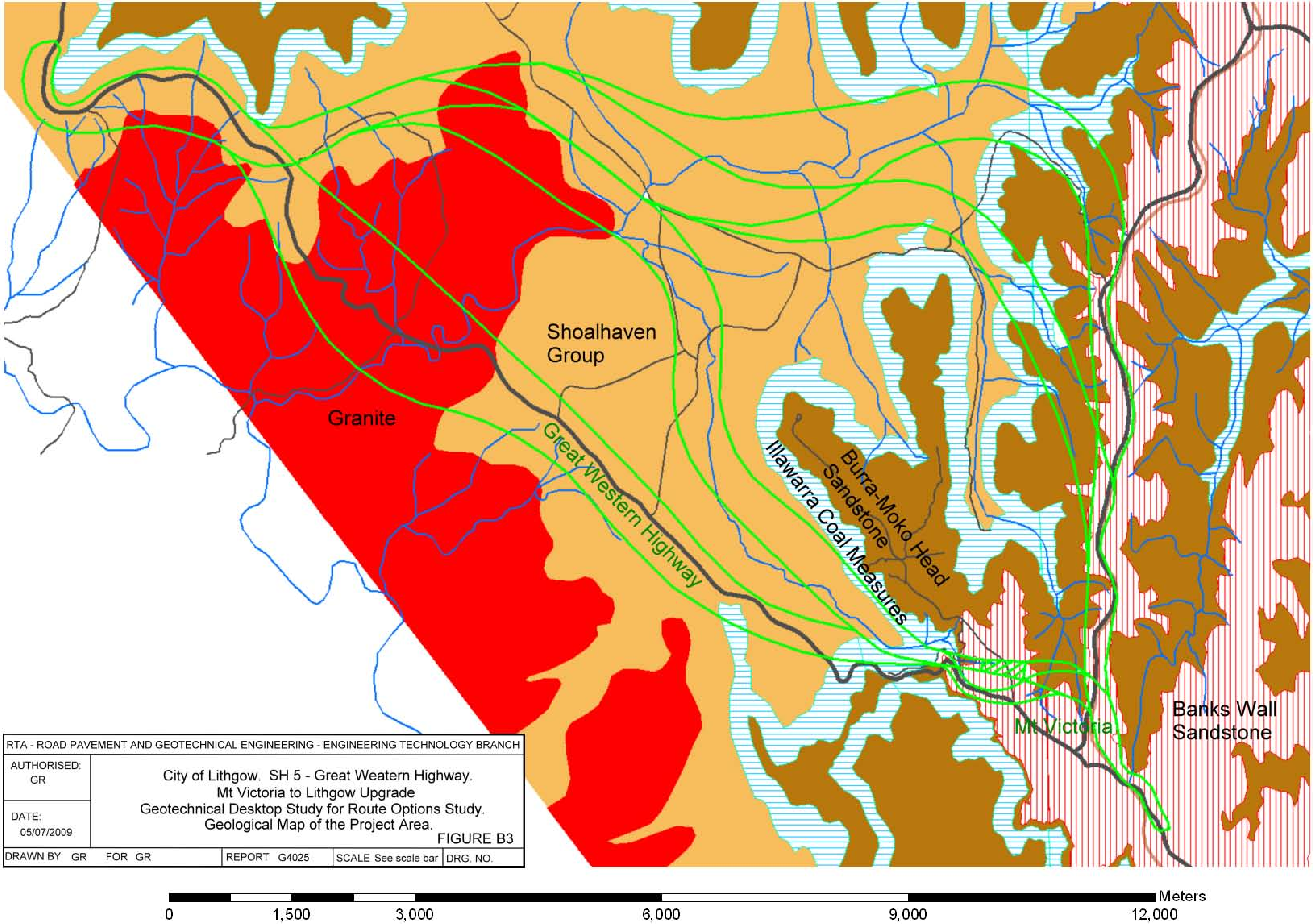
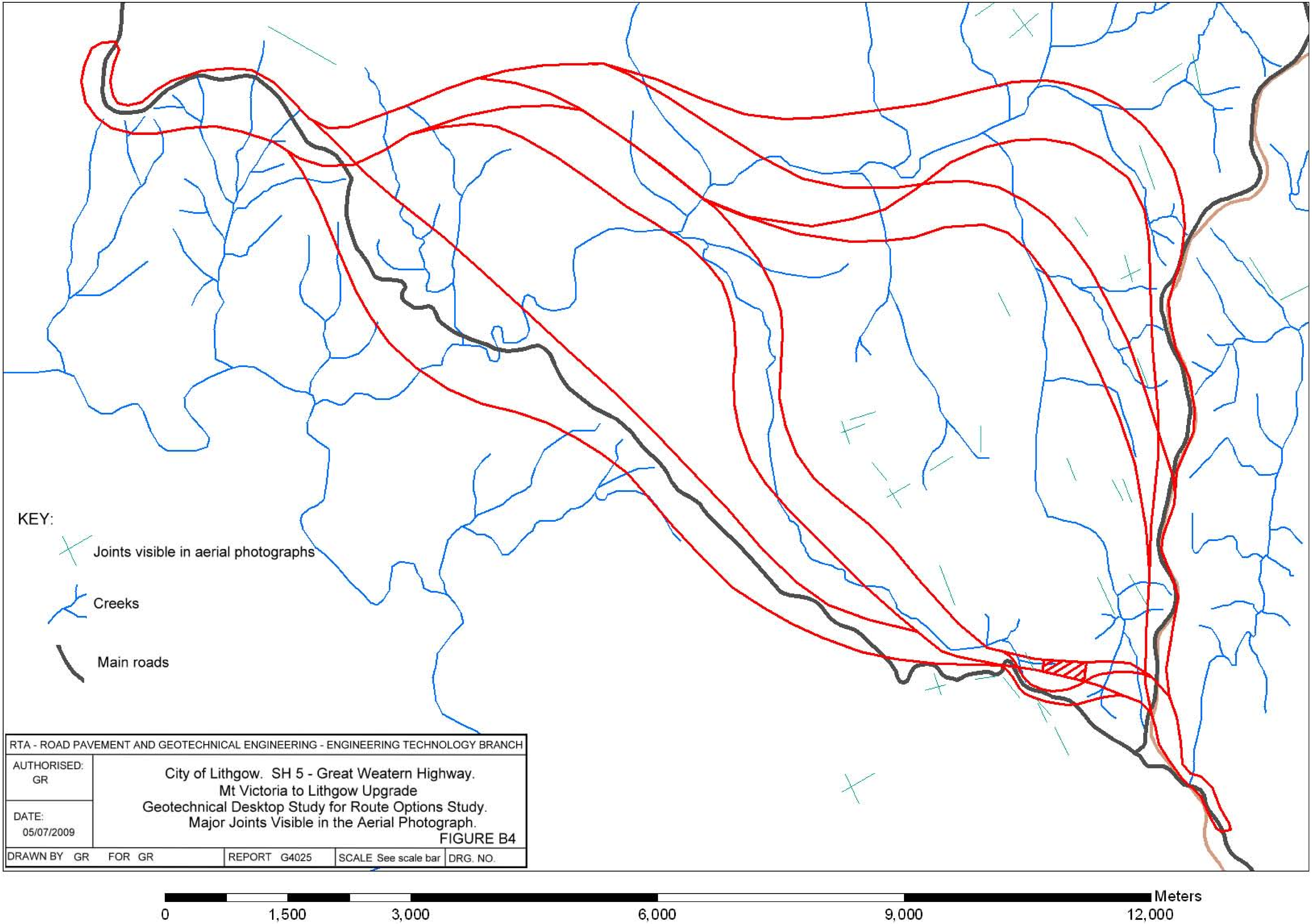
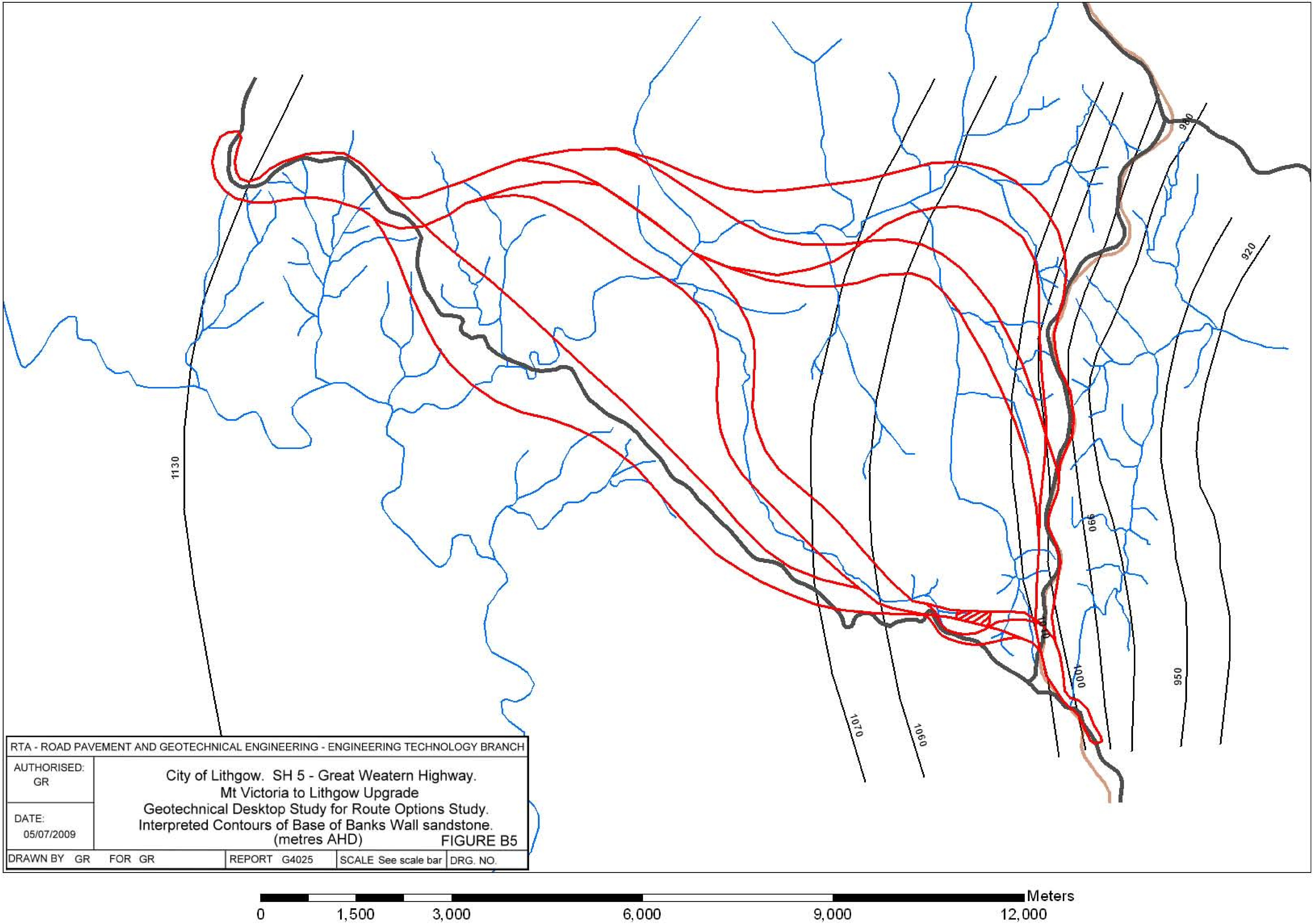
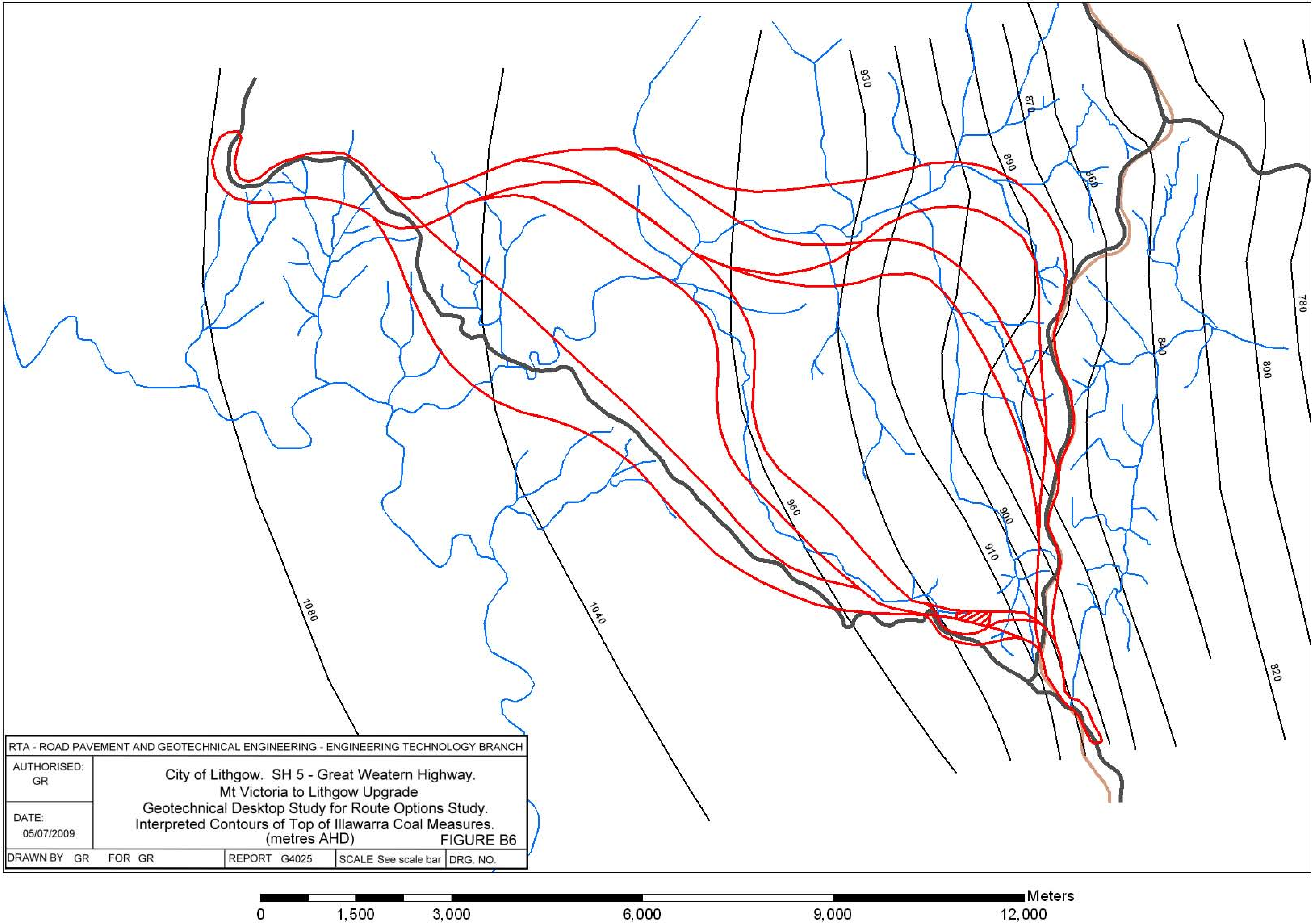


RTA - ROAD PAVEMENT AND GEOTECHNICAL ENGINEERING - ENGINEERING TECHNOLOGY BRANCH			
AUTHORISED: GR	City of Lithgow. SH 5 - Great Weatern Highway. Mt Victoria to Lithgow Upgrade Geotechnical Desktop Study for Route Options Study. Geological Map of the Project Area. FIGURE B3		
DATE: 05/07/2009			
DRAWN BY GR FOR GR	REPORT G4025	SCALE See scale bar	DRG. NO.


KEY:
Joints visible in aerial photographs
Creeks
Main roads
RTA - ROAD PAVEMENT AND GEOTECHNICAL ENGINEERING - ENGINEERING TECHNOLOGY BRANCH
AUTHORISED: GR
DATE: 05/07/2009
City of Lithgow. SH 5 - Great Weatern Highway.
Mt Victoria to Lithgow Upgrade
Geotechnical Desktop Study for Route Options Study.
Major Joints Visible in the Aerial Photograph.
FIGURE B4
DRAWN BY GR FOR GR
REPORT G4025
SCALE See scale bar
DRG. NO.
0
1,500
3,000
6,000
9,000
12,000
Meters



RTA - ROAD PAVEMENT AND GEOTECHNICAL ENGINEERING - ENGINEERING TECHNOLOGY BRANCH			
AUTHORISED: GR	City of Lithgow. SH 5 - Great Weateern Highway. Mt Victoria to Lithgow Upgrade Geotechnical Desktop Study for Route Options Study. Interpreted Contours of Base of Banks Wall sandstone. (metres AHD) FIGURE B5		
DATE: 05/07/2009			
DRAWN BY GR FOR GR	REPORT G4025	SCALE See scale bar	DRG. NO.



RTA - ROAD PAVEMENT AND GEOTECHNICAL ENGINEERING - ENGINEERING TECHNOLOGY BRANCH

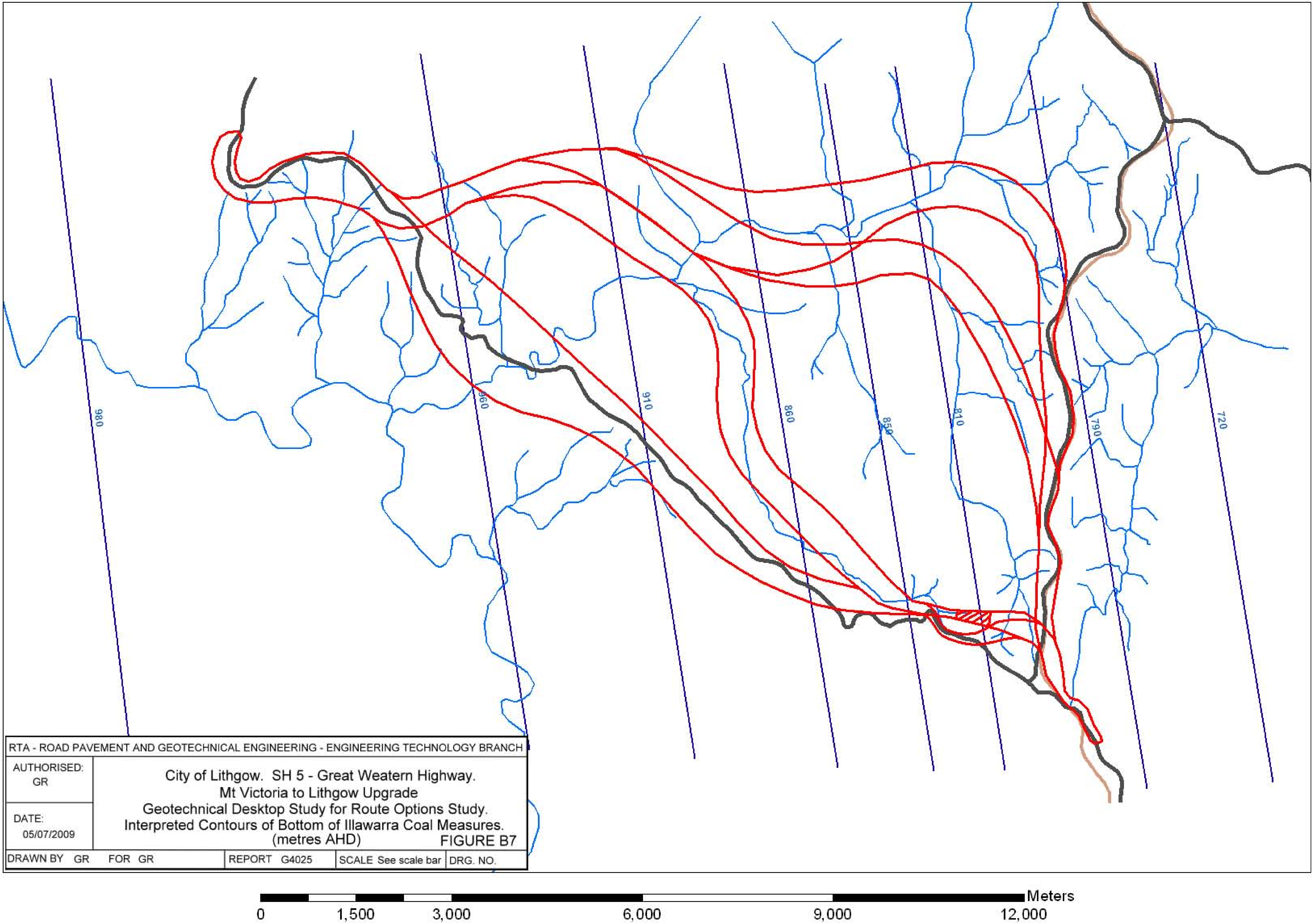
AUTHORISED: GR

DATE: 05/07/2009

City of Lithgow. SH 5 - Great Weatern Highway.
Mt Victoria to Lithgow Upgrade
Geotechnical Desktop Study for Route Options Study.
Interpreted Contours of Top of Illawarra Coal Measures.
(metres AHD)

FIGURE B6

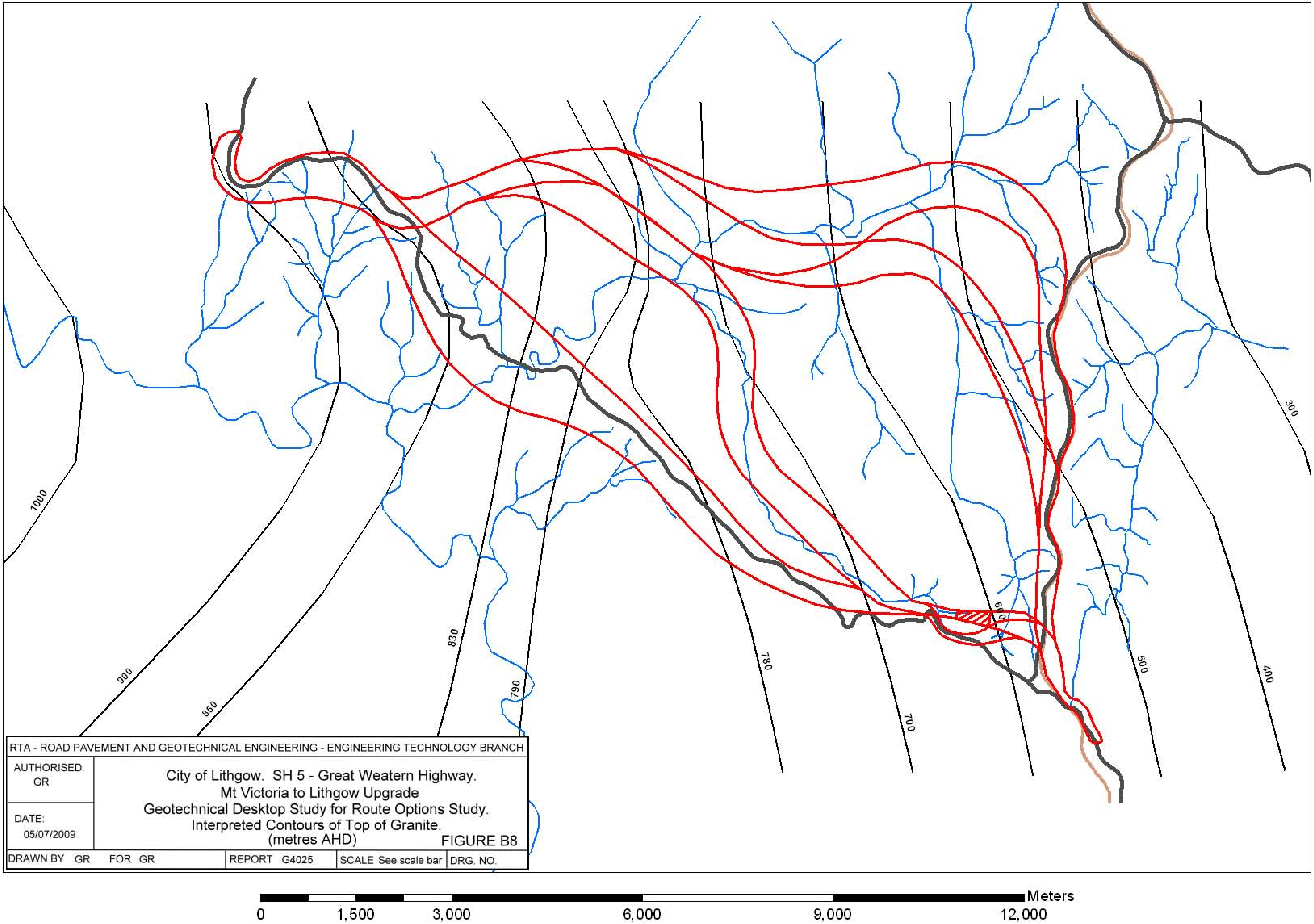
DRAWN BY GR FOR GR	REPORT G4025	SCALE See scale bar	DRG. NO.



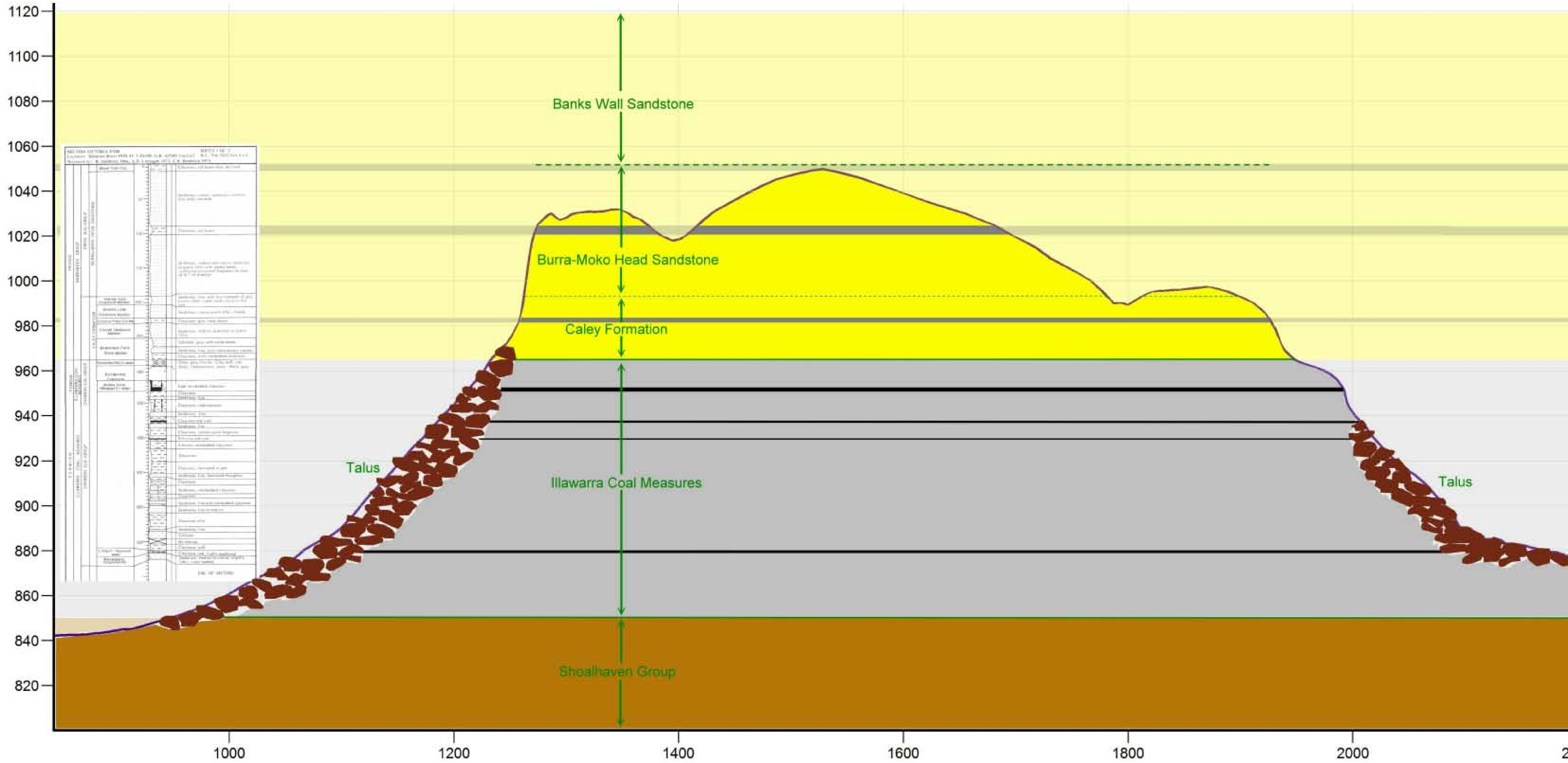
RTA - ROAD PAVEMENT AND GEOTECHNICAL ENGINEERING - ENGINEERING TECHNOLOGY BRANCH

AUTHORISED: GR	City of Lithgow. SH 5 - Great Weatern Highway. Mt Victoria to Lithgow Upgrade Geotechnical Desktop Study for Route Options Study. Interpreted Contours of Bottom of Illawarra Coal Measures. (metres AHD) FIGURE B7
DATE: 05/07/2009	

DRAWN BY GR FOR GR	REPORT G4025	SCALE See scale bar	DRG. NO.



RTA - ROAD PAVEMENT AND GEOTECHNICAL ENGINEERING - ENGINEERING TECHNOLOGY BRANCH			
AUTHORISED: GR	City of Lithgow. SH 5 - Great Weatern Highway. Mt Victoria to Lithgow Upgrade Geotechnical Desktop Study for Route Options Study. Interpreted Contours of Top of Granite. (metres AHD) FIGURE B8		
DATE: 05/07/2009			
DRAWN BY GR FOR GR	REPORT G4025	SCALE See scale bar	DRG. NO.



RTA - ROAD PAVEMENT AND GEOTECHNICAL ENGINEERING - ENGINEERING TECHNOLOGY BRANCH			
AUTHORISED: GR	City of Lithgow. SH 5 - Great Weatern Highway. Mt Victoria to Lithgow Upgrade Geotechnical Desktop Study for Route Options Study. Schematic Cross Section Illustrating the Stratigraphy FIGURE B9		
DATE: 07/08/2009			
DRAWN BY GR FOR GR	REPORT G4025	SCALE See scale bar	DRG. NO.

APPENDIX C

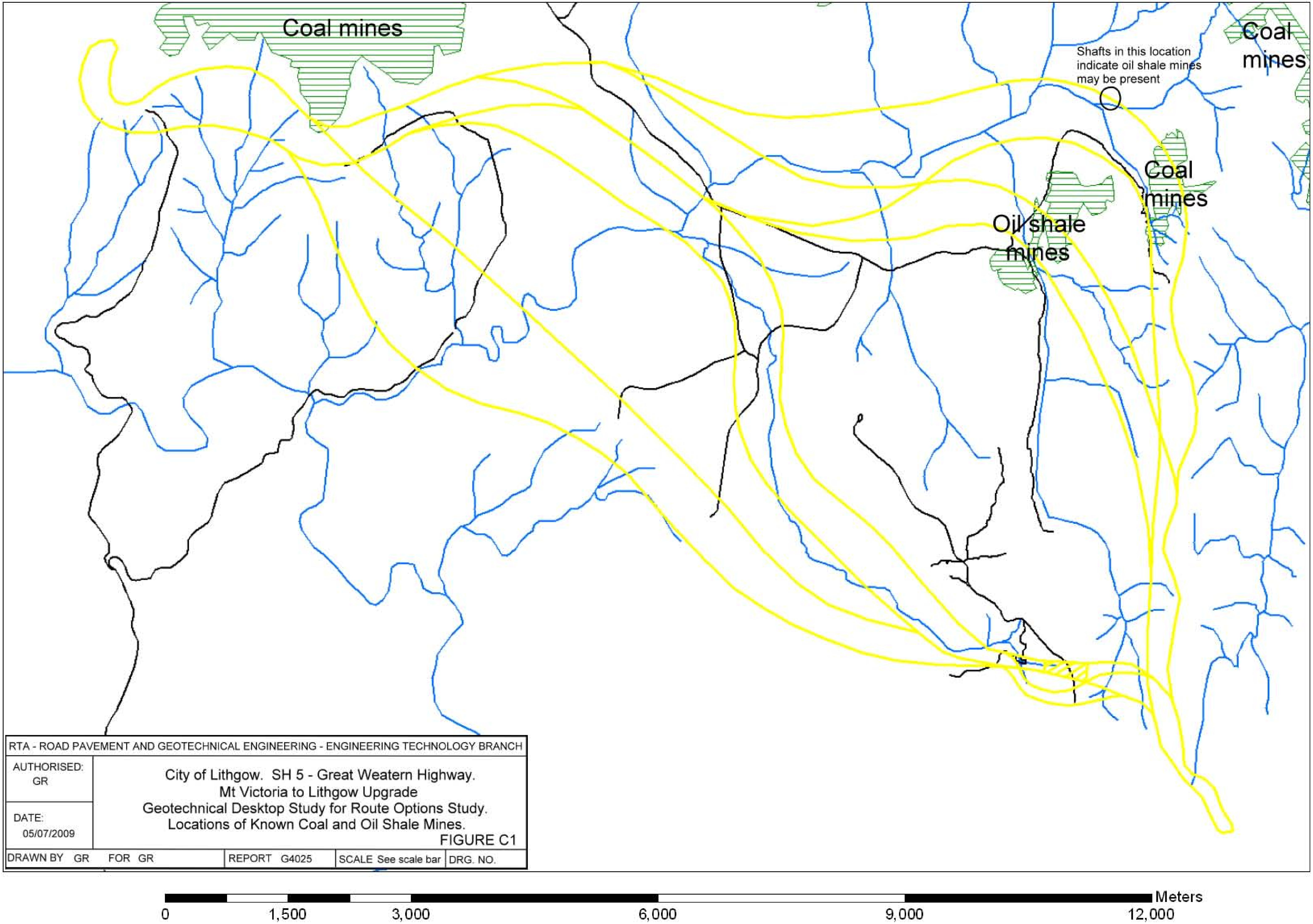
COAL AND SHALE MINES

Coal Mines

- Mine plans from Dept. of Primary Industry georeferenced based on cadastre information
- Mine entrances located by GPS on site

Oil Shale Mines

- Mine plans from Dept. of Primary Industry georeferenced based o cadastre information
- Levels based on:
    - Surface levels in the valley (RL802 to 805) – and assuming that the mines are at least 10m below the surface – say RL 792m
    - Surface levels on the hills and the extent of mapped workings that are assumed to have stopped when the cover became too thin near the sides of the hills
    - The faults were located by J. E. Carne, Assistant Geologist with the then Mines Department in 1903. He has recorded them in a Memoir on the Oil Shales of NSW c. 1903 and that the displacement was 8m or thereabouts.
    - Geological section prepared by the Department of Mines and Agriculture in 1901 - the vertical displacement is approximately 80ft or 25m.
    - Best estimate RL800 or 815?? and RL792



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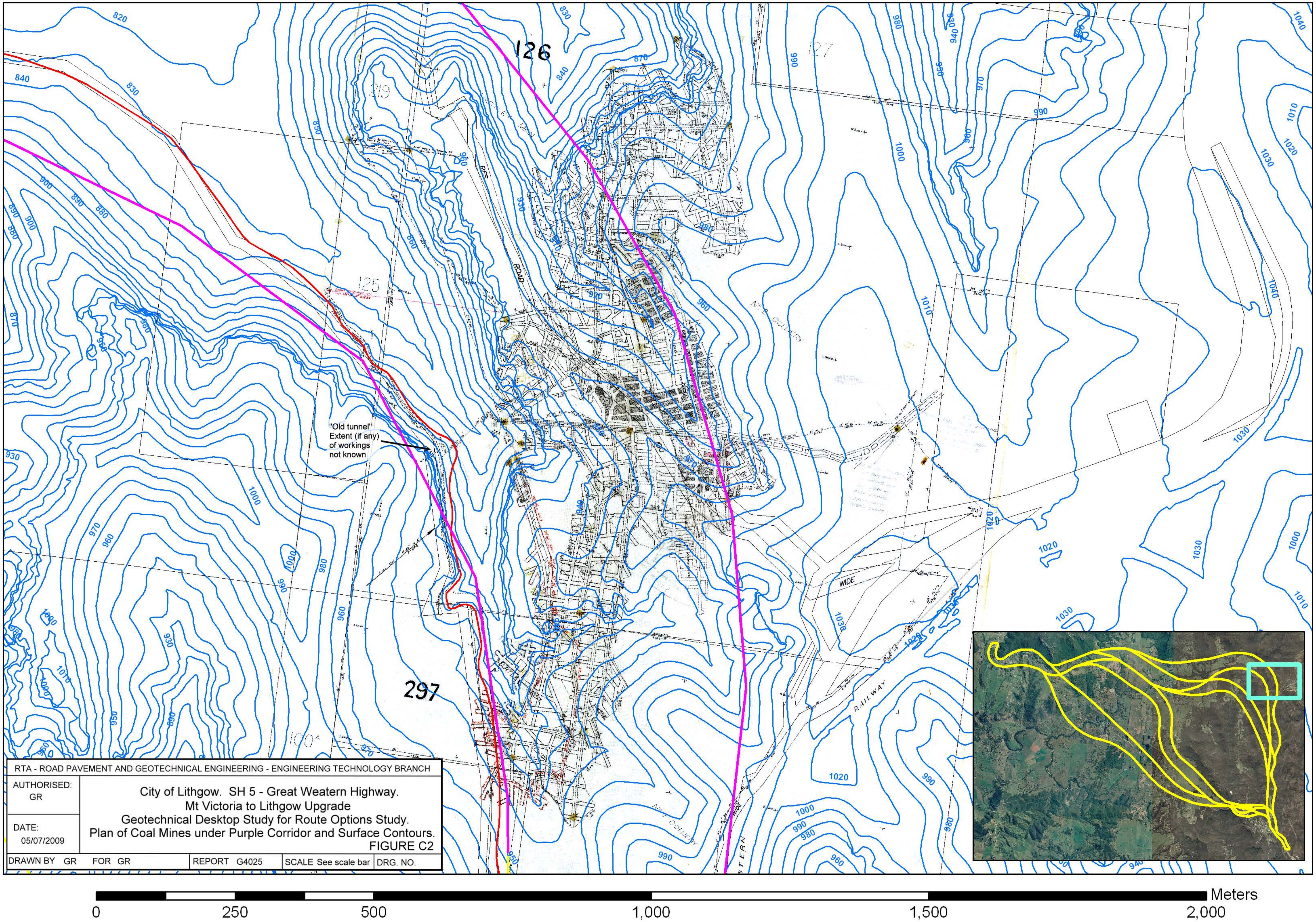
AUTHORISED: GR

DATE: 05/07/2009

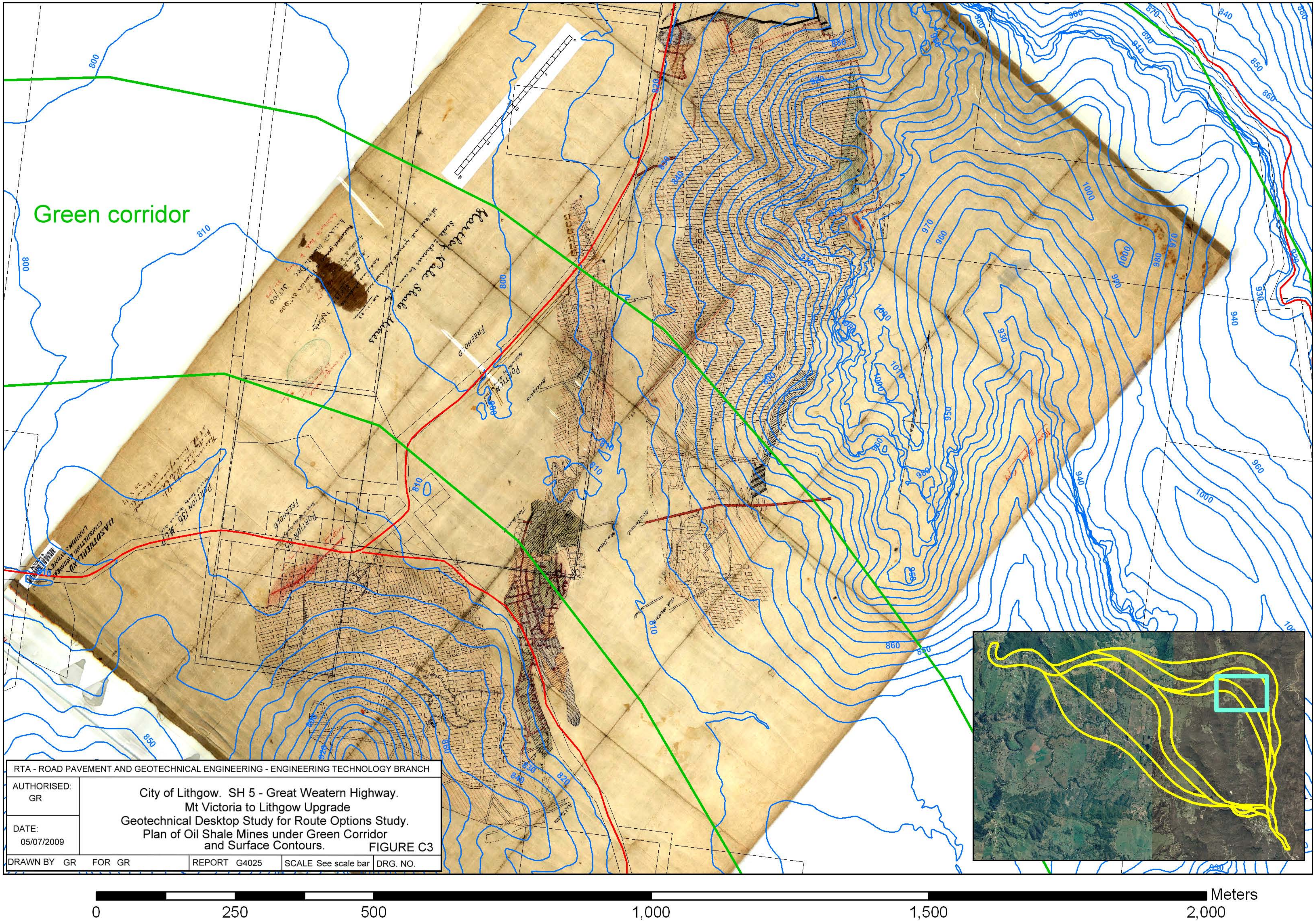
City of Lithgow. SH 5 - Great Weatern Highway.
Mt Victoria to Lithgow Upgrade
Geotechnical Desktop Study for Route Options Study.
Locations of Known Coal and Oil Shale Mines.

FIGURE C1

DRAWN BY GR | FOR GR | REPORT G4025 | SCALE See scale bar | DRG. NO.



RTA - ROAD PAVEMENT AND GEOTECHNICAL ENGINEERING - ENGINEERING TECHNOLOGY BRANCH			
AUTHORISED: GR	City of Lithgow. SH 5 - Great Weatern Highway. Mt Victoria to Lithgow Upgrade Geotechnical Desktop Study for Route Options Study. Plan of Coal Mines under Purple Corridor and Surface Contours. FIGURE C2		
DATE: 05/07/2009			
DRAWN BY GR FOR GR	REPORT G4025	SCALE See scale bar	DRG. NO.



RTA - ROAD PAVEMENT AND GEOTECHNICAL ENGINEERING - ENGINEERING TECHNOLOGY BRANCH

AUTHORISED: GR

DATE: 05/07/2009

City of Lithgow. SH 5 - Great Weatern Highway.
Mt Victoria to Lithgow Upgrade
Geotechnical Desktop Study for Route Options Study.
Plan of Oil Shale Mines under Green Corridor
and Surface Contours.

FIGURE C3

DRAWN BY GR | FOR GR | REPORT G4025 | SCALE See scale bar | DRG. NO.

APPENDIX D

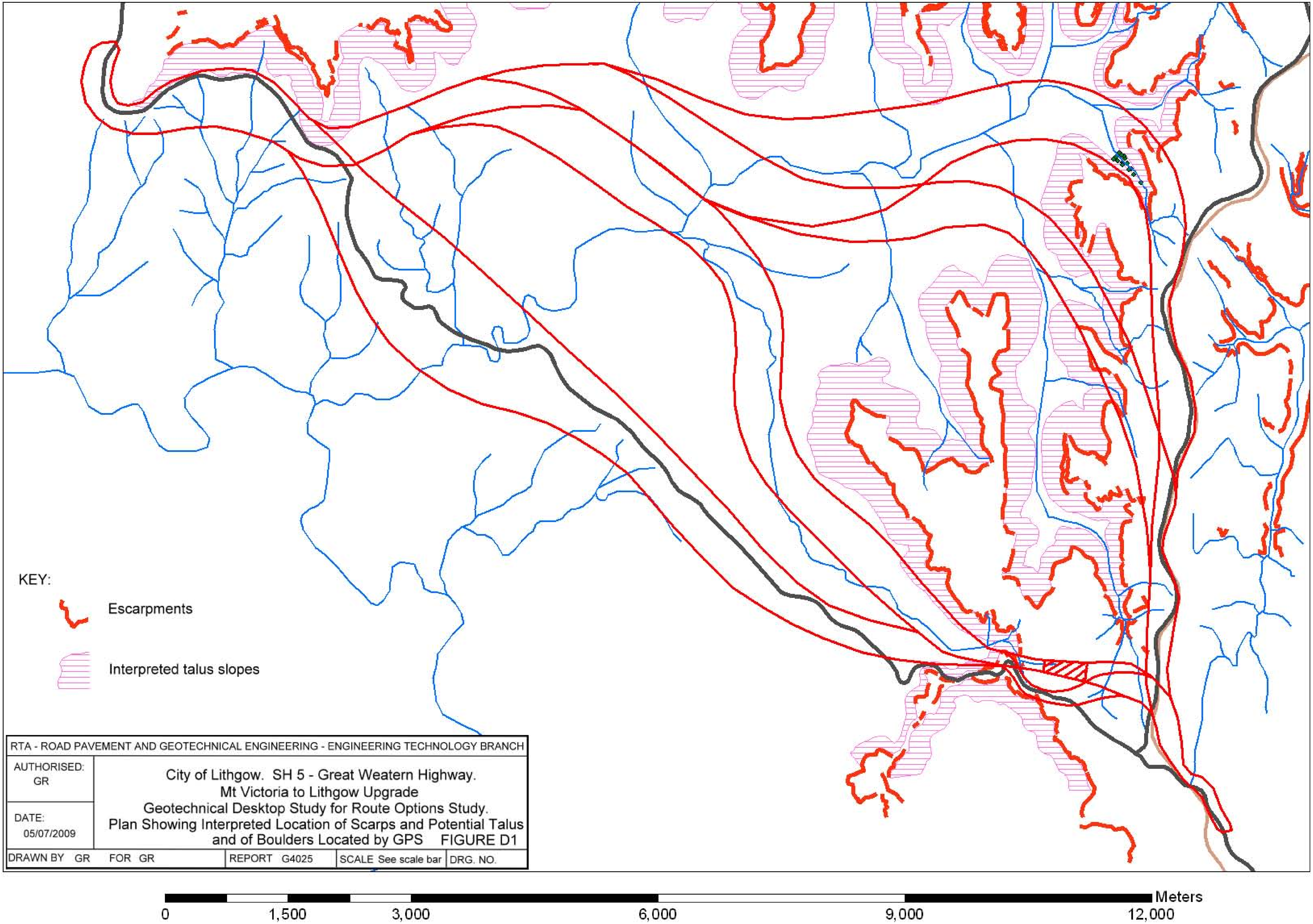
ESCARPMENTS AND TALUS

Talus slopes

- Location of boulders located on site
- Surface slopes as indicated by surface contours

Escarpments

- Air photos and surface contours



RTA - ROAD PAVEMENT AND GEOTECHNICAL ENGINEERING - ENGINEERING TECHNOLOGY BRANCH

AUTHORISED: GR	City of Lithgow. SH 5 - Great Weatern Highway. Mt Victoria to Lithgow Upgrade Geotechnical Desktop Study for Route Options Study. Plan Showing Interpreted Location of Scarps and Potential Talus and of Boulders Located by GPS FIGURE D1
DATE: 05/07/2009	

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