https://doi.org/10.56295/1ACEG29

SCOPING FOR GEOHAZARDS - ENVIRONMENTAL CONTRASTS COMPARING THE ENGINEERING GEOLOGIST'S ROLE BETWEEN MINING, CIVIL ROAD TUNNELS, DAM DESIGN AND PUMPED HYDRO

Helen Baxter-Crawford
SMEC

ABSTRACT

The Engineering Geologist plays a pivotal role, using their geological background to nominate possible geohazards, specifically associated with a project's lithological conditions. An artifice of being a "specialist on everything", the Engineering Geologist is often expected to use their varied project experience to advise on how the nominated hazards are identified in the field, develop health and safety management plans and generate solutions that will allow for project development to continue, through mitigation or elimination for construction and design stages.

This paper explores a series of case studies, comparing the understanding of site specific geohazards associated with 1) iron ore open pit mining in the Pilbara, 2) civil road tunnel construction projects in Sydney, 3) dam foundation design at Mount Bold Dam, and 4) the geohazards already identified and under consideration for the proposed pumped hydro energy storage project, Borumba. It delves into the geohazards associated with each project and discusses what factors influence safety considerations, and which impact design, construction and/or waste management. Specific geohazards discussed are airborne hazards (fibrous and silica minerals); effects of dewatering, including dispersive or dissolvable materials; geomorphology; waste rock and water; and man-induced geohazards. It discusses the Engineering Geologists role in proofing the risk and actions required to enable project development to work around or with the hazard, via engineering control and mitigation.

It explores the factor of project scale, the influence that has on geohazard considerations and in particular the quantum of investigation required.

1 INTRODUCTION

Engineering geology is a dynamic and wide-ranging field. By default or by circumstance, the engineering geologist (EG) needs to be equally as widely versed in all sub-sectors of the discipline, firstly due to the overall shortage of EG's globally and secondly as a means of adjusting to variations in markets. For a fulfilling and lasting career, the EG professional needs flexibility and adaptability to enable a jump from commodity to commodity or sector to sector. As a result, the EG field demonstrates highly skilled individuals with significant cross-pollination of experience, environments, technologies and methodologies in modelling and design.

Identifying geohazards is one area where the EG can greatly support a project to optimise design and safety. Geohazards come in two forms:

1. Natural geohazards are the effects of the ground on a project, independent of the planned ground modifications, like existing landslides and swelling soils, and
2. Activated geohazards which are the effects the ground has on the project, directly influenced by the action of project development, like release of hazardous particulates from excavations, development of ground instabilities due to changes in groundwater regime, and effects of stress on excavations.

The EG is an asset to the design engineer. Engineers are more able to become niche specialists - geotechnical, dams, open-pit mining, and underground mining for example. The primary (geo)hazards that an engineer may focus on for design and construction considerations would be:

- Overall stability relating to natural geohazards
- Local ground instability related to activated geohazards (including stress related), arising during construction,
- Dust and spoil management as a consequence of changes to the form of rocks by the process of excavation.

Within a singular commodity or sector, the amount of rigour required to assess the impact on each may be limited – the data is well understood and can be logically addressed. The lithological and mineralogical properties of rock and soil are direct and indirect inputs into each hazard type and the EG would advise if the properties are typical or outside the norm and direct the degree of further investigation/assessment required.

The EG cements their position in a project when things change or there is a shift to something new, for example:

- Expansion of an open pit below the ground water table,
- Expansion of a city's metro rail network,
- New remote technology may uncover or support previously dismissed geohazards, and
- Intrusive site investigations may suggest the state geological survey mapping requires updating.,

Such case studies are discussed in this paper.

The inclusion of the pure study of mineralogy for any geohazard assessment cannot be understated. A background understanding of the minerals that may be present in any particular rock or soil type will focus the EG for what activated geohazards may form with project development and help shape the site investigation, inputs required for risk assessments and resultant risk profile of the site.

Further, the project scale may, but not always dictate the likelihood of geohazards being present and this must be considered in both the risk assessment and the site investigations. For example:

- A singular mine may be extracting one commodity but depending on the geological environment and mechanism in which mineralisation has occurred, the ore may be contained within one or more lithologies or alteration zones and the background mineralogy and inherent quantum of hazardous minerals may be different – this could be critical for products like gold and copper.
- A tunnel may be over 20 km long and contained within a single stratigraphy or be 2 km long and cover multiple lithological/stratigraphical units.
- A dam may have a 200 m span and have abutments in two totally different rock types or be 700 m long and founded within a singular unit.
- The footprint of a pumped hydro project is much more likely to contain infrastructure in completely different stratigraphic units and depending on the infrastructure being developed in each, the natural and activated geohazards that present may be totally unique for each.

2 ENVIRONMENT 1 – OPEN PIT MINING IN THE PILBARA

The author worked for over a decade at various mining operations in the Pilbara iron ore region of Western Australia. During this time, the author developed a rich understanding on the local geological units, namely the ore bearing units of the Dales Gorge and Marra Mamba Banded Iron Formations and the overlying Tertiary Detrital sequences, Figure 1.

The focus of projects the author was involved with was geotechnical – expanding and/or optimising existing mines in the folded and faulted bedrock environment and designing new green fields operations.

The banded iron formations (BIF) of the Dales Gorge and Marra Mamba Formations consist of inter bedded cherts, shales and iron bearing laminated sequences. The shales form discrete, distinct and continuous marker horizons with a clear, repeatable gamma downhole geophysical signature. The units are stratigraphically continuous (other than where folded or faulted) for thousands of kilometres. Where folding has resulted in dip slopes, the continuity, waviness and friction angle of the beds are critical inputs for slope design. Undercutting of the beds, may result in planar slide at bench and inter-ramp scale.

With respect to the geohazard focus of engineers outlined above, the following commentary is made with regards to iron ore mining in the Pilbara:

1. Overall stability relating to original landforms and geomorphology – within the bedrock units, the overall stability is typically governed by the dip slopes; ancient landslide surfaces are rare, limited to localised block falls.
2. Local ground instabilities that result during pit excavation are usually related to the kinematic relationship between the dip of the beds, slope angle and bed friction angle. Some allowance for small scale planar slide or wedge formation is expected with the unstable material captured on catch berms.
3. Dust is a common issue within most mining operations and dust suppression mechanisms are used during normal day to day activities by means of water carts and exclusion zones. The minerals present in the "dust" generated by mining activities are not considered high-risk, so the requirement to wear dust masks is typically a case-by-case site requirement or related to daily assessment of wind conditions.
4. Spoil rock – The beauty of the Pilbara's iron ore deposits is the majority of excavated material is ore. Spoil rock is typically limited to areas of required excavation to fit the pit design in units like the West Angela Shale, Whaleback Shale and the Mt McRae Shale. The Mt McRae shale is a known reactive shale and therefore considered a hazardous material – the unit contains nodules of pyrite, benign due to oxidation when weathered, but when unweathered, pose an acid drainage problem as well as a potential for spontaneous combustion,

especially when stored inappropriately in waste dumps, (Waters & O'Kane, 2003). The unit underlies the Dales Gorge Iron Formation and as such typically forms the footwall of Dales Gorge deposits. The issues with pyritic shale management are so well understood, that standard operating procedures are in place at most sites that intersect this unit.

5. Spoil water: During the early 2000s very few of the Pilbara iron ore sites had developed below water table, so water spoil management wasn't a significant consideration, at least from a geotechnical perspective.

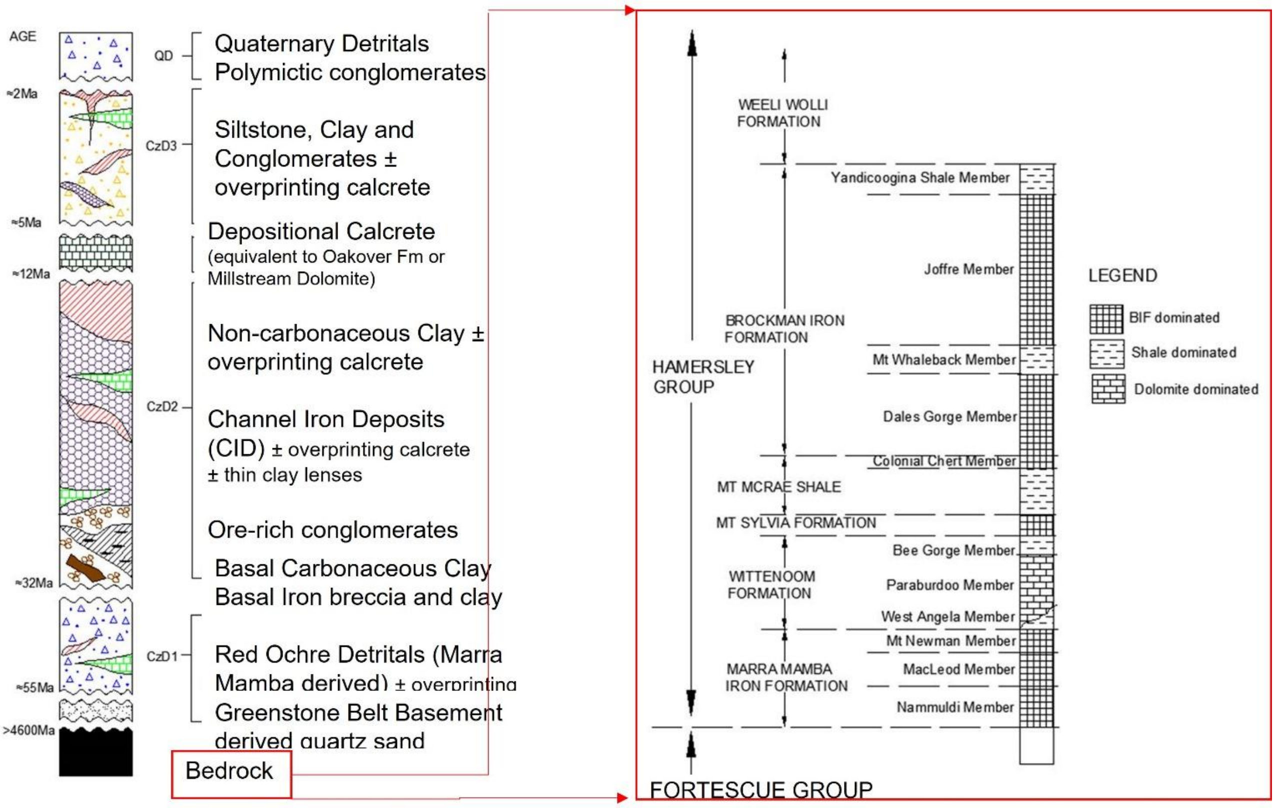

Figure 1: Stratigraphic Column for the Pilbara Iron Ore sequences and overlying Tertiary Detritals, after Baxter 2016 in (Eggers, Griffiths, Parry , & Culshaw, 2016).

A key additional geohazard, directly related to mineralogy of the Banded Iron Formations (BIF) that forms the bedrock is the potential presence of naturally occurring asbestos (NOA). For the mineralised zone of the deposits, any NOA is typically altered (to tiger iron) and regarded as non-hazardous, and so is not a considered factor in dust mitigation and safety. Only in unweathered and unaltered BIF would NOA be expected. As such, many of the mining operations develop their ore body delineation through the use of low expense reverse circulation drilling, with assay geochemical testing and gamma geophysical survey under the strict control of a risk management plan that dictates the holes are terminated 3m below (or one drill run) the base of mineralisation so as to avoid exposure of NOA during the exploration process.

At one particular site where the author led a geotechnical site investigation of drilling and mapping to optimise and expand existing operations, the initial pit configurations, already under development had been designed based on a rudimentary ore body model with correlations of major beds made purely by interpreting between 50 x 50m spaced holes with geophysics.

The orebody was located in the Marra Mamba Iron Formation, specifically the Newman Member, with the unmineralized optimised pit slope to be developed in the lower-most portion of Newman and the underlying McLeod Member. The ore was centred within a synclinal fold hinge. The inter-ramp slope of the pit followed the approximate dip slope, but benching had been poorly achieved. Use of blasting and digging without presplits had effectively resulted in a 120 m high slope with bench face angles parallel to bedding (essentially parallel to the planned inter-ramp angle) and limited to zero catch berm capacity.

As part of the optimization site investigation, diamond drilling was introduced with the intent to penetrate 50 m behind the pit slope and allow development of a design with suitable bench face angles and catch berm capacity, and ultimately expansion of the mine. Use of the diamond rig brought new risk management documentation requirements to the project - the operations staff had been averse to geotechnical core drilling due firstly to the potential for NOA intersection, but secondly as they were unfamiliar with diamond drilling. Despite diamond drilling being commonplace in the early 2000s it had never been observed at this site so substantial, safe work method statements had to be developed to ensure that diamond drilling was actioned as safely as possible. The proposed drilling of unweathered and unmineralized BIF meant the risk of encountering NOA increased and so further risk management systems had to be implemented, including development of a substantial risk management plan in order to gain permits for the drilling to take place. Put simply, the risk management plan detailed the use of wet drilling to minimise NOA fibres becoming airborne and inspection of all rock core for fibres. Were any found, a sampling and testing protocol was implemented to allow for laboratory testing to confirm the intersections. Had any intersections been found, these zones would have been demarcated in the geological model for the mine.

The geotechnical program completed at the site resulted in two key outcomes for geohazard assessment:

1. No asbestos was encountered, but risk management plans were developed and the work paved the way for further geotechnical investigations at other deposits within this operation.
2. The synclinal shape of the fold that formed the pit became much better understood. The diamond drilling and mapping indicated that the ore body did not uniformly parallel the bedding and further, bedding was not uniform in dip – with the new deeper penetrating data, the model was updated, resulting in a shift of the fold hinge by some 200 m, compared to the ore-body drilled model, Figure 2. The laboratory testing and mapped data allowed for an improved understanding on design friction angles and resulted in a suitable and constructable bench-berm configuration.

For this project, the value-add of the engineering geologist being engaged to identify and develop work systems that would allow geological assessment beyond the ore zone to be completed were:

1. The development of safety protocols and risk management plans that were informed and useful,
2. A revised model that allowed for safer but also more economical pit development.

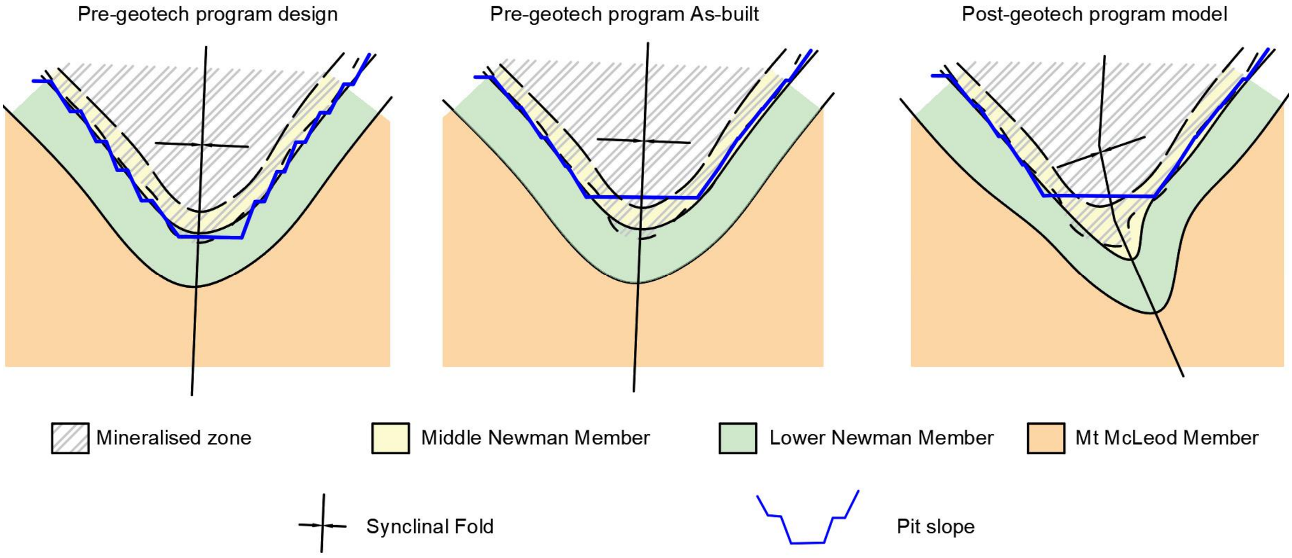

Figure 2: Schematic of the modifications to the model resulting from the geotechnical drilling. Not to scale

By 2007, several operations had begun exploring the feasibility of extending below the water table to extract ore. The author had significant involvement in the early stages of below water table expansion site investigations and design for the Marandoo deposit, with ore contained in the Marra Mamba Iron Formation, and expansion below Tertiary Detrital soil and rock sequences.

Beyond the aforementioned geohazards, the introduction of pit excavation below the water table introduced a new geohazard system, whereby the change in groundwater regime had the potential to destabilise the carbonate balance which could lead to a potential for sinkhole formation from the dissolution of calcium carbonate in the form of calcrete.

Additionally, as the footwall of the pit expansion was contained within the Marra Mamba Iron Formation, a similar risk-based approach to the potential for NOA intersection in the BIF units was implemented.

Calcrete, formed from precipitation of calcium carbonate at the top of an ancient groundwater table, was observed about 30 m below the ground surface throughout the detrital sequences, though with very limited penetration into the ore body.

Critically, the thickest and most well-developed calcrete concentrations (with assay records indicating CaCO3 in abundance of 20%) occurred behind the proposed pit slope adjacent to the main ore transport rail line. The act of dewatering the pit posed a risk that it could destabilise the delicate balance where the CaCO3 remained as rock and could cause dissolution (Baxter, 2012). This could be the catalyst for unravelling of the overlying clastic low strength rock (with zones of soil strength material) and promote the formation of sinkholes.

The diamond-RC twins and geochemical relationships were used to characterise the calcrete mass condition (Baxter, Eggers, Muhairini, & Smith, 2015), Figure 3, and extrapolate the signature patterns between boreholes to develop a model of calcrete development intensity and thereby define potential areas of higher risk for sinkhole development where preventative remediation treatment could actioned if required.

The geotechnical program completed at the site resulted in two key outcomes for geohazard assessment:

1. No asbestos was encountered, but risk management plans were developed and used.
2. The calcrete study and model allowed for identification of high-risk areas to be monitored and further assessed in event remediation was required prior to dewatering.

For this project, the value-add of the engineering geologist being engaged to identify and develop work systems that would allow the appropriate geological assessments to be undertaken were:

1. Refinement of safety protocols and risk management plans that were informed and useful,
2. Accurate modelling of high-risk areas, to inform ground monitoring systems to be used during the mine development.

Figure 3: Variation in calcrete overprinting texture (After Baxter, 2012)

3 ENVIRONMENT 2 – TUNNELLING IN SYDNEY

The author has worked numerous tunnel projects across Australia and the Asia-Pacific over the last 20 years. The Sydney Basin experience has involved road header, drill and blast and Tunnel Boring Machine (TBM) tunnels ranging from 1 km to 14 kms length, crossing a maximum of three stratigraphic units with a typical drill ratio of one borehole per 100 to 200 m, and higher ratio at caverns/station boxes or where tunnels overlapped. This drill ratio reflects the relative simplicity of Sydney's stratigraphy. By contrast, the 7 km Brisbane Airport Link crossed three stratigraphic units with a drillhole to tunnel length spacing of 30 to a maximum of 200 m.

With respect to the geohazard focus of engineers, the following commentary is made about tunnelling in Sydney:

1. The geomorphology of Sydney is such that existing landslides within the natural surfaces are very localised and while the tunnel alignment should be reviewed, and portal areas mapped, landslides would rarely be a key focus for the investigations.
2. Tunnelling in Australia is controlled through the use and implementation of controlled, well-practised international methods for construction so the risk of instability related activated geohazards should be engineered for in the design. Small scale wedge fallout is usually addressed through the use of spot bolts or a change to the support class from the predicted. Recent occurrences of ground movements through to surface have human factors as the primary contributors. Stress issues are very localised and generally situation specific. The Sydney trains, roads and metro networks are relatively shallow (maximum around 80 m depth) and the strength of the Sydney stress regime is low. Exceptions are where other stress factors occur like valley bulge as indicated from the Northside Storage Tunnel.
3. Consideration as to the impacts of silica dust released from excavation processes has on tunnellers has been a focus of recent years, however, at the authors first tunnelling project in 2003, the supply and use of disposable P2 dust masks was optional, with most choosing not to wear and not being appropriately educated to understand why they should. By 2008, they were expected to be carried and used on an as needs basis. Self-rescuers were considered a more important piece of safety equipment, with detailed training sessions on use and reporting mechanisms in place to report those not carrying one underground. By 2016, P2 was the minimum requirement with most sites moving to fit-tested personal options. Legislation is following suit, with guidelines for the minimum number of times annually any staff member is allowed to be exposed, before mandatory health surveillance testing is required. Silica exposure is a very real activated hazard from excavations in the quartzose Hawksbury Sandstone.
4. Spoil rock from Sydney's Hawkesbury Sandstone is like gold - its readily able to be sold off as a reuse product as engineered fill. The Ashfield Shale is not as valuable and often is repurposed within a site. Neither are considered hazardous.
5. Waste-water management and groundwater seepage control is a project within a project for road and transit tunnels. While the maximum groundwater inflows at a single location (for example flowing from a bed or joint) in Hawkesbury Sandstone that the author has observed is in the order of 10L per minute (more than what is delivered by a standard shower head), Figure 4a. When this occurs, the total lugeon value for a 1 km segment of tunnel may be higher than designed, particularly if the zone is structurally affected (fault zones) or forms a gravitational low. The deepest point of the M8 tunnel at Arncliffe is an example where both increased structure and flow direction coalesce to form a zone of significant groundwater inflow and ongoing management.

Other geohazards the engineering geologist may need to identify within the Sydney tunnelling environment are:

- Shrink-swell potential for Ashfield Shale. This characteristic of the unit is well known and actively monitored for during construction as a risk mitigation measure, but this natural geohazard could become more of an issue as tunnelling pushes to the west of Parramatta with continued urban development.
- Beyond simple management of waste-water, continued maintenance of the sumps and drainage systems is needed in the Hawkesbury Sandstone to keep the drainage clear of bacterial iron precipitate sludge, Figure 4b. This activated geohazard “sludge” doesn't always appear to develop, but where observed, begins to form within weeks to months of excavation. It effectively forms a geohazard as if the drainage systems are not adequately maintained, groundwater seepage becomes an ongoing issue for tunnel users.
- Over the last 20 years there have been several cases of significant ground instability occasioning serious damage and in one situation, death in Sydney. A direct result of these incidents has been a change to the immediacy of ground support requirements with the inclusion of shotcrete application almost immediately upon excavation. This limits the amount of time geologists have to collect the factual mapping data to groundtruth the design and provide updates to the assumptions made for the subsequent tunnelling section. Use of shotcrete as a support medium has been adopted in civil tunnel conventional (roadheader and drill and blast) rock tunnels throughout Australia. The key activated geohazard risk is that the observational method adopted as part of the construction methodology is substantially time-constrained and unable to be verified. Features that could be telling of changes

to stress and groundwater conditions are not readily observable and key geological structures may not be identified.

Figure 4: a) flow of water from structure in M8 tunnel with iron precipitation beginning to develop. b) bacterial sludge beginning to develop in association with flowing water in M8 tunnel.

The value-add of the engineering geologist being engaged to identify geohazards and develop work systems that would allow the appropriate geological assessments to be undertaken in Sydney tunnels are:

1. Refinement of safety protocols and risk management plans that were informed and useful,
2. Identification of high risk areas (for shrink-swell response, for excessive groundwater inflows) and provision of advice for drainage and treatment requirements.

4 ENVIRONMENT 3 – DAMS

The author is relatively new to the dams' sector, working on various projects over the last four years, though observes similar geohazard issues arise as observed within mines or tunnels, but with a higher potential consequence should the geohazard result in failure.

Many dams within the Australian portfolio are presently undergoing either 20-year risk reviews and full dam risk assessments, some as the first phase into upgrades; others to simply ensure they are compliant with current ANCOLD regulations.

One such dam looking for potential upgrade is Mount Bold Dam in the Adelaide Hills, straddling the Onkaparinga River. The main dam is founded on a phyllitic rock mass belonging to the Woolshed Flat Shale.

With respect to the geohazard focus of engineers outlined above, the following commentary is made about the dam:

1. Excavation of the existing dam was completed to slightly weathered rock. Historic photos demonstrate vertical to near vertical temporary faces prior to dam concrete pouring and back filling.
2. Stress is related to regional scale earthquake loading with the dam and reservoir within the neotectonic zone associated with the Willunga Fault.
3. Local ground instabilities during construction of any upgrade are considered possible with the right abutment forming a dip slope and sub-vertical joint release planes present. Such small (<10 m3) scale slide and wedge derived instabilities have been observed along access roads to date so are known to be possible. This is expected to be controllable by means of bench scale slope design and use of catch berms, or if the available space is not conducive to a benched approached, then through the use of short-term face support, like bolting. Long term, any new excavation would likely be covered with dam concrete or fill and thereby be stabilised. The rock mass strength of the less weathered and unweathered foundation rocks would suggest piping is unlikely. Larger scale ground movements are discussed following.
4. Dust is expected to only be an issue during construction of any dam upgrade and would likely be mitigated using conventional methods like water trucks. The mineralogy is being tested to assess the risk of airborne silica, though this is unlikely to be an issue with the anticipated excavation methods.
5. Spoil rock and water would need to be controlled during any excavation for the upgrade, to avoid contamination downstream. Substantial fill already exists on the lower downstream slopes that may need removal for the upgrade. These aspects are yet to be properly considered at this time with no design in place.

Previous workers at the site have suggested zones of inferred colluvium present on the right abutment downstream slope may be of landslide origin. The area of concern has been repeatedly identified as a risk, mapped (and drilled), discounted and raised again over many years of study.

Several phases of LiDAR (Light detection and ranging) have been imaged over the last 20 years, with the most recent incorporating cleaning of the digital data to remove vegetation from the imagery and at the highest resolution available to date. This latest data set expresses the character of the upper slope of the right abutment far better than any mapping of the highly vegetated slope would allow, Figure 5. Further work is ongoing in this space but the improvements in LiDAR technology in recent years are such that the author encourages all sites with inconclusive landslide understanding to recapture their local data.

The value-add of the engineering geologist being engaged to identify geohazards and develop work systems that would allow the appropriate geological assessments to be undertaken for this dam are:

1. Review of the dam foundation rock mineralogy to assess the risk to personnel from excavation practises, should the dam upgrade proceed. The last excavations for the dam were completed nearly 100 years ago, and as such, so such systems were in place,
2. Identification of high-risk areas for ground movement using the latest technological tools and supported by traditional ground-truthing techniques.

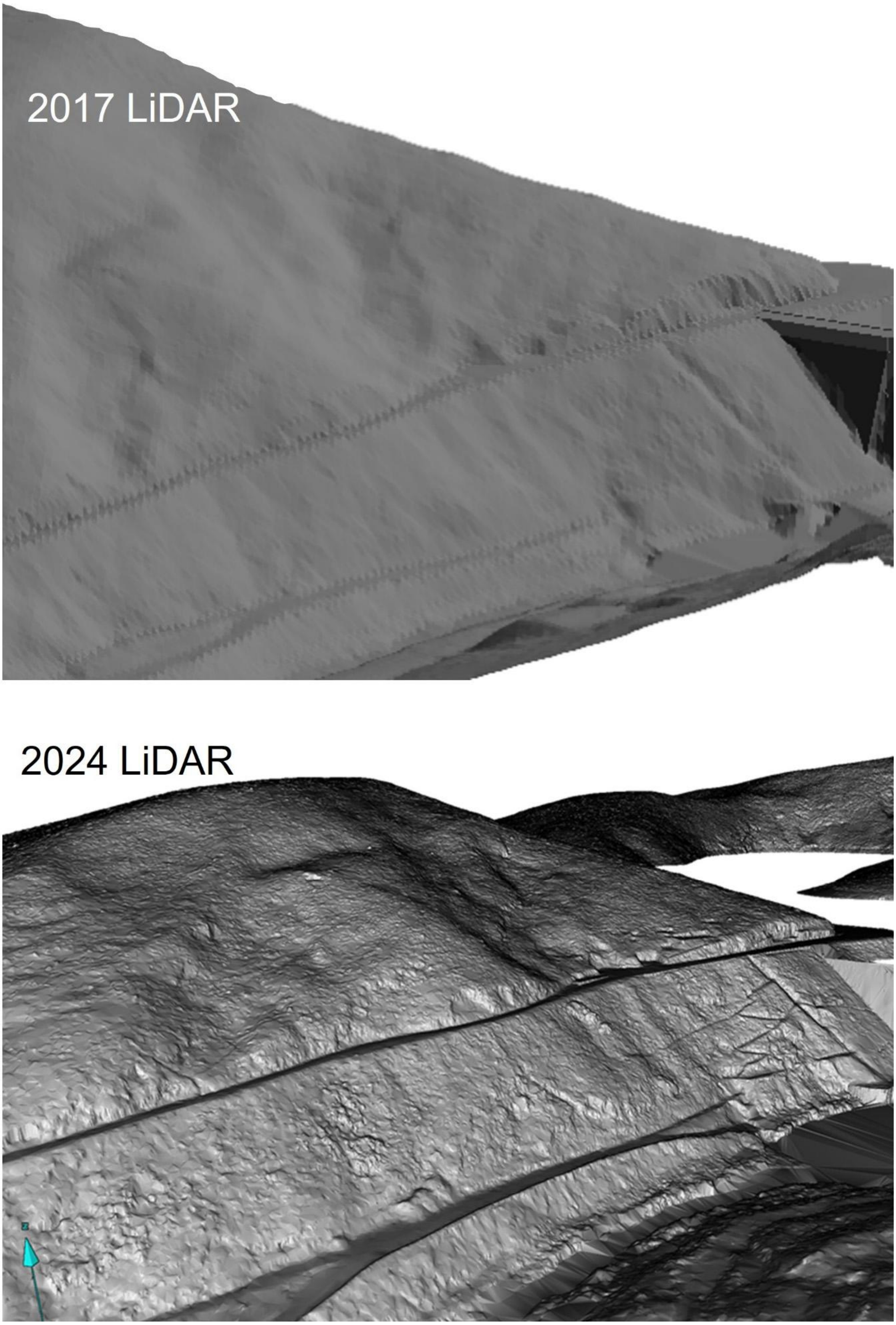

Figure 5: Comparison in LiDAR quality between 2017 and 2024

5 ENVIRONMENT 4 – PUMPED HYDRO

The scale of pumped hydro projects is such that multiple stratigraphic sequences can be contained within one project footprint. The author has been working as Qwners Engineer for the Borumba Pumped Hydro Energy Storage (PHES) project, assisting in recognising potential geohazards for the early investigation stages and assisting in developing risk management plans to allow work to progress. The geohazard predictions are proactive, used to pre-emptively action safe work processes and advocacy for the sustainability goals of the project. The site covers tunnels and caverns within a meta-sediment laminated rock mass, with portal in a granitic intrusion; upper reservoir dams in the same meta-sediment unit and in a granodiorite intrusion; and a lower reservoir dam within a sequence of metavolcanics, not seen in the upper reservoir; as well as other excavations for camp and road developments crossing a variety of rock and soil units. The Mt Mia Serpentinite is inferred as present on the Queensland geological survey map within the site bounds, though the key infrastructure sites do not intersect. This unit and its inferred fibrous minerals habit has been considered and incorporated within a risk management plan for geotechnical drilling with key safeguards active until sufficient data has been captured to identify any high risk or known occurrence areas. Despite the very low expectation of fibrous mineral intersection, until all areas are proofed as clear, every drilling/mapping intersection on the project is being marked on a GIS-portal based map indicating:

- Not observed
- Fibrous minerals observed (not tested)
- Fibrous minerals observed (tested negative)
- Fibrous minerals observed (tested positive).

The area is very remote, green fields with some areas of dense vegetation, and others (the granitic zones) used for cattle grazing. The Queensland geological survey mapping is showing low reliability with differences observed during initial field work. The inferred boundaries of granitic intrusions don't match observations and the main unit targeted for cavern development is lithologically different to the inferred stratigraphy of the survey map, with site workers considering it to belong to a different sequence. As such, the early drilling has been very important in delineating which lithologies (and minerals) are expected and both the natural and activated geohazard considerations required, both at site investigation stages, for sustainability and disposal considerations in design with reuse of excavated material within the project bounds being a key sustainability goal, and for construction health and safety.

To further remotely define the unit boundaries, a closely spaced airborne geophysics survey has been completed using helicopter which has proven highly favourable in identifying unit boundaries and particularly the Mt Mia Serpentinite.

With respect to the geohazard focus of engineers outlined above, the following commentary is made about the project:

1. Excavation of the dam foundations are expected to be developed by digging methods. Tunnelling for the caverns is proposed to be drill and blast - the rock mass is tending high to very high strength based on early drilling data, so this is a suitable, economical method.
2. Stress increases would predictably be expected at the depth of the cavern, proposed some 500 m below ground surface. Testing is underway to identify the dominant stress direction and develop a cavern orientation best suited for conditions to de-risk the excavation.
3. Data is being collected to capture the blockiness characteristics of the rock masses being tunnelled such that local ground instabilities are considered and captured in the design. To further de-risk the construction stage, a permit to tunnel (PTT) system is planned to inform and permit construction of the exploratory tunnel in defined segments, with a detailed forward probing plan to collect data and inform design. The PTT process allows the designer to review forward probing data and confirm the early support predictions are suitable or require modification, with the PTT discussions advising which areas are approved for excavation and the support systems and monitoring requirements that are required. With respect to ground instabilities on the surface, any areas of slope excavation, including portals are being mapped to capture the understanding of existing historic landslides, with data collected input into models for stability analyses. Access roads are subject to inspection protocols to assess for indicators of changes in slope behaviours following rainfall with these protocols updated as and when changes to the road usage (including vehicle quantity) occurs.
4. Mapping is progressing to assess the geomorphological character of the site and generate a landslide risk map.
5. Tunnelling to access the cavern locations is expected in the moderate silica meta-sediments and high silica granitic rock masses. Excavation in these units would follow standard dust suppression and mandatory dust mask health requirements used elsewhere in the country. Health and safety regulations are being followed with respect to health monitoring of employees.
6. The mineralogy of tunnel spoil is being assessed for reuse purposes, stockpiling and to inform health and safety understanding. Pyrite has been observed in the granitic rock mass from the proposed tunnel and is presently being assessed to understand the form and quantity of the mineral such that its effects can be appropriately

controlled/mitigated. Geochemistry of groundwater is also being assessed as there are strict controls on the mineralogical make-up of reservoir water and contamination.

As new lithologies are being encountered, the mineralogy is being assessed for fibrous mineral potential, influence on stability, and other characteristics via petrographic assessment and various suites of geochemical laboratory testing. Reuse and/or permanent storage of excavated materials on site is a key sustainability goal for the project.

The value-add of the engineering geologist being engaged to identify geohazards and develop work systems that would allow the appropriate geological assessments to be undertaken at Borumba are:

1. Pro-active identification of potential hazardous minerals across the entire project,
2. Pro-active mapping and remote survey controls to inform natural geomorphological geohazards allowing variations to design to be considered at early project stages,
3. Pro-active development of risk management plans that are informed and useful, and constantly updated,
4. Identification of high-risk areas across each facility area of the project, to be further informed by ground-truthing.

6 DISCUSSION ON ENGINEERING GEOLOGIST'S ROLE

The Engineering Geologist plays a pivotal role on any project, using their geological background to nominate possible geohazards, specifically associated with a projects lithological conditions. The EG needs to develop sufficient familiarity with the stratigraphy, lithology and mineralogy of a site to be able to advise on the potential issues that may be encountered and be able to communicate how to identify and manage risk and provide solutions to assist the engineers with their design through to construction.

The case studies presented in this paper demonstrate that while the infrastructure environment changes, and the stratigraphic and lithological environments changes, the author is repeatedly faced with similar geohazards, particularly those related to airborne dust and lung health. All require proofing, but the stratigraphic and lithological understanding (and associated mineralogical understanding) were the basis for suggesting the geohazard presence and nominating controls and investigation methods to define the risk to the project. Only stress and surface ground instabilities were dictated by topographic variations more than being distinctly related to geology/mineralogy.

The safe work practises and mitigation measures to contain airborne dust particles during construction is a common theme for all work environments. The engineering geologist has been at the forefront of firstly identifying the high-risk minerals, then assisting health and safety teams in developing risk management plans that allow work to continue while managing the health and safety of employees.

Overall, the Engineering Geologists role never changes when it comes to geohazard (natural and activated) identification. Just the environment does.

7 ACKNOWLEDGEMENTS

The Author would like to thank Queensland Hydro and SA Water for permission to publish this paper.

8 REFERENCES

Baxter, H. (2012). Pilara Cenozoic Detrital Sequences and Associated Geohazards. *AGS Symposium.* Perth.

Baxter, H., Eggers, M., Muhairini, A., & Smith, J. (2015). The effect of carbonate alteration on Detrital mass strength and implications for geotechnical slope design. *Iron Ore Conference 2015*, (pp. 429 - 435). Perth.

Eggers, M. J., Griffiths, J. S., Parry , S., & Culshaw, M. G. (2016). *Developments in Engineering Geology.* London: The Geological Society of London.

Waters, P., & O'Kane, M. (2003). Mining and Storage of Reactive Shale at BHPBilliton's Mt Whaleback Mine. *6th International Conference on Acid Rock Drainage*, (pp. 155-161). Cairns.