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The art and science of ground control: examples from deep hard rock mines

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Abstract

Effective ground control in the uncertain world of complex geology and deep mining is part 'art' and part 'science'. A well-conceived management plan backed by observational data is required to eliminate risk to workers from hazards such as gravity failures or rockbursting. Mine design methodologies are constantly improving, as are technical advances in monitoring. This supports ground control through science, improving the understanding, measurement, and predictability of a mining environment. Data and record keeping, including photographs, are important ground control assets. This paper discusses some of the design assumptions required for ground support and gives several examples of mining tactics used to make the working environment safer.

The need for ground control management plans and a rational ground support design basis is required by legislation in many mining jurisdictions and by most mining company's corporate governance functions. There are many examples of ground support design rationale (Cai & Kaiser 2018; Kaiser & Moss 2022; Hadjigeorgiou & Potvin 2020); however, many assumptions are required before any Factors of Safety or probabilities of failure can be confidently estimated. Several rockburst and fall of ground examples occur where a high percentage of the tendons did not fail, perhaps the bolts' plate was torn off, or the plate punched through the screen/mesh, but the bar itself did not break (Ortlepp et al. 2004 used the term 'naked tendon'). Weak links (Simser 2007), and poor load transfer to the tendon are common problems. Mining ground support systems mix relatively stiff tendons with either brittle shotcrete and/or soft high deformation capacity mesh. There are practical challenges to match the loading stiffness of full areal coverage support to that of the tendon. This complicates the ground support design process. What capacity do you use for the tendons given field observations often show a load transfer problem? How do you add the surface support capacity? How realistic are capacity values from laboratory tests when applied to field conditions? These are examples of where empirical experience or the 'art ' of ground support design come into play and require assumptions in the ground support design process. The science is advancing but still needs to catch up to the art.

Rock support degradation and failure (Hadjigeorgiou 2016) is a well-known problem but not easy to quantify. Rock mass change over time and through extraction impacts the effectiveness of support systems. By design, most permanent infrastructure is placed far from the stoping areas. Stope extraction requires some excavations to be close to major stress changes, especially in deep mining. Part of the 'art' of ground support design is to realise when things have deteriorated beyond a practical limit, and when it is better to purge fractured ground and re-support.

In deep mining, excavations experience repeated seismicity and blasting vibrations. Seismic waves are known to cause reflections/refractions that can amplify the ground motion (Yadav 2024; Alvina & Van Sint 2008) near the opening and can cause a momentary loss of confinement. Examples of using microseismic data to help understand how damaged the rock mass may be are given in the paper.

Keywords: *rockburst, fall of ground, ground support, ground control, mining tactics, mine seismicity*

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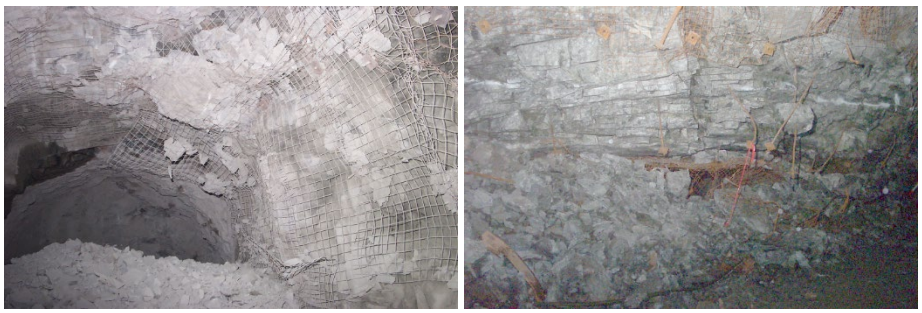
1 Introduction

Effective ground control is both an art and a science. Mining excavations go through a loading cycle that must be accounted for in the ground support design. For example, large span excavations generally require multiple excavation phases, and stoping areas can have dramatic stress change as overall extraction builds. Permanent infrastructure such as shafts, crushers, maintenance facilities and refuge stations by design should be kept outside the long-term influence of the ore extraction areas. There is an economic trade-off between extra development metres to create a conservative offset and being too close, where high mining-induced stress can damage permanent excavations. Mining plans are not necessarily fixed, and changes in metal prices, new geological information, running out of 'easy' ore sometimes trigger the desire to mine more challenging reserves.

Mining steps can be accounted for by both robust first pass support and proactive rehabilitation (installing new ground support, sometimes nicknamed 'prehab'). Kaiser & Moss (2022) deformation-based ground support design calls for the use of deformation monitoring to trigger 'preventative maintenance' (adding new support elements to account for support system capacity loss). This methodology is applied in many cave mining layouts where the development is upfront and cannot be easily re-arranged. Ideally, additional support can be installed prior to the rock mass degrading to a level where the loose material must be removed (purged). Other mining methods, such as sublevel opening stoping, can design ore accesses to be temporary or developed 'just-in-time' to reduce the number of loading cycles.

Engineering judgement ('art') is sometimes required to decide whether to purge or not. Removing dilated fractured ground around a 'tired' opening may be necessary. Removal of this material reduces confinement around the opening, which may trigger more strain bursting or stress fracturing. There is a practical limit where too much dilation has occurred and the ability to reliably re-support a heading is compromised. For example, resin or grout loss in fractured material can make the quality of the newly installed support questionable. There are cases where overzealous rehabilitation purges out too much material, creating larger openings and challenging ground support installation. There are also cases where adding new support over existing support, without substantial purging, was unsuccessful. The rock mass proved to be more dilated/degraded, necessitating complete purge and re-support. Examples of both cases will be presented in this paper.

Ground support capacity gets used up over time, especially when close to stoping areas. Advances in monitoring, such as mobile lidar scanning (Mercer et al. 2023), can quantify the rock mass deformation. However, it is usually only an indirect measure of support capacity lost over time. Rock mass bulking between bolts (Figure 1) is the most common deformation in hard brittle rock at depth, and surface bulking can be the result of a zone of discrete fractures dilating, not necessarily localised on one portion of a bolt. Ground control tactics such as visual limits of screen bagging to trigger rehab or plate bending to signal the need for bolt replacement are used. These can be qualitatively linked to scanning (Counter 2019) especially if there are scans pre-failure and post-failure.



(a) (b)

Figure 1 (a) Example of screen bagging in the order of decimetres; (b) Stress fracture zone exposed by overhand cut-and-fill mining. Measuring surface displacement is a measurement of the combined dilation of numerous stress fractures

The examples in Figure 1 are not simple to quantify in terms of ground support loss over time. A rigid rebar may only displace a centimetre or two then fail. The cumulative displacement of similar magnitude may occur over multiple locations along the bar and not break it. A typical ground control instrument, such as a multipoint borehole extensometer or a smart cable, will measure displacement between nodes. In hard brittle rock with pervasive stress fracturing, cracking occurs every few centimetres or even millimetres. There are multiple dilating fractures between the ground instruments' measurement points. This may be inconsequential for some bolt types, for example when the deformation occurs between anchors points on a steel stretch style bolt. Other bolt types, such as friction bolts or rebar, would have a different field response versus a pull test that localises displacement. Determining reliable trigger action response plans based on deformation monitoring is not simple: again, art and science.

Figures 2–4 show field observations illustrating the above discussion points.



Figure 2 Mixed of broken and naked tendons after a rockburst. Shotcrete installed after installation of the bolts doesn't help load transfer to the tendon

Figure 2 shows how a relatively rigid support system behaves in a rockburst. Every burst is unique; however, it is common to see a mix of broken tendons, tendons with the plate torn off, and relatively intact bars where the rock unravelled around them. Careful examination of the photos shows all 3 cases and highlights the fact that an outer layer of shotcrete (brittle material) has limited benefit. Bolts and mesh over shotcrete is very beneficial as the shotcrete helps transfer load to both the bolts and the mesh (less unravelling).



(a) (b)

Figure 3 (a) Stress fractures that were ahead of shaft sink bench, now exposed in wall. Timing of the concrete liner requires some thought at great depth, too close might cause deformation onto rigid liner, too far, workers are exposed to a lower capacity support system for longer lengths; (b) Sheared rebar exposed in overhand cut-and-fill stope

Figure 3 illustrates 2 separate points:

- Stress fracturing which is always accompanied by some dilation can occur well ahead of development faces.
- In the shaft sinking scenario, this deformation may impact the final placement of a rigid concrete liner, so some lagging between the liner and the bench face is required.
- The cut-and-fill rebar exposure clearly shows shearing can occur along the stress fractures, most ground support testing is purely axial loading.

Figure 4 shows examples of stripped cablebolts. The twin bulged cables were pumpable resin grouted, and resin can be seen within the bulges. Clean load transfer to tendons can be difficult, the cablebolts were offset and only one plated. Stripping the plate meant the full capacity of the twin cables wasn't solicited during the failure. Some field or in situ factor is required when evaluating the capacity of most tendons, especially when subjected to dynamic loading.



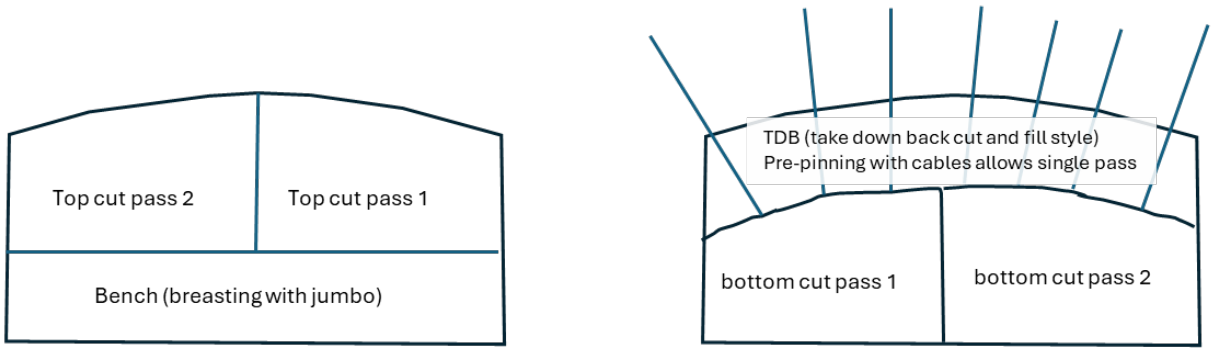
Figure 4 Blast induced fall of ground. An intersection next to a longhole blast collapsed due to blast induced shaking and gases penetrating joints/factures. The area was barricaded off so no personnel were exposed. Most of the cablebolts and tendons were stripped (plates torn off) rather than necked/failed

2 Excavations and ground support

The following section shows several short case histories of excavation and ground support performance from deep brittle rock (Sudbury basin mines).

2.1 Top cut/bench (breasting below the top cut with jumbos) versus bottom cut/take the back down (breasting over top of the bottom cuts)

Large underground excavations generally require multiple stages. As the unsupported span increases, the fall of ground risk increases. Long tendon support (cablebolts) can be installed before opening wider to mitigate the risk. Larger stress changes also increase stored strain energy around openings, which increases the strainburst hazard. Two common methods have been used in the Sudbury mines: most frequently top cut and bench; and occasionally the bottom cut is taken first and then the excavation height increased by coming over the back (Karampinos et al. 2012). Figure 5 illustrates the 2 methods.



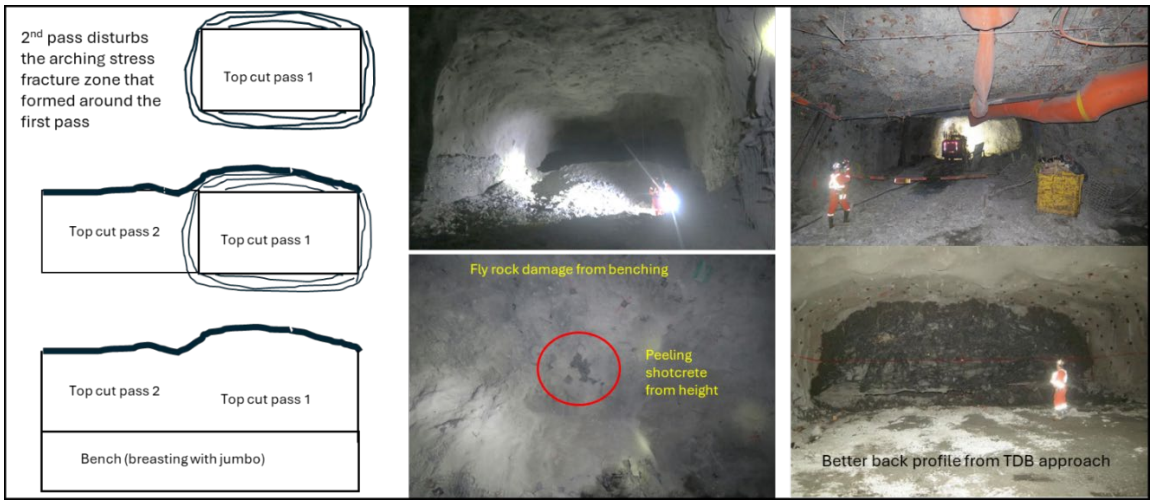
(a) (b)

Figure 5 (a) Sketch of 3 staged excavation, 2 top cut passes, and one bottom cut or bench pass; (b) Two bottom cuts with a third pass of coming over the back. The pre-pinning from the bottom cuts allows a wider span final pass. TDB = take the back down

In a relatively shallow environment without much stress fracturing around the openings, the top cut bench method is usually preferred as the back/roof ground support only goes in once. The take the back down (TDB) approach means the first 2 passes have the back/roof support removed and new final back support is installed from the wider final pass. At depth, with relatively deep stress fracturing, the TDB approach improves overall ground conditions. Both methods can be safely done, but for deep mining conditions the pros and cons of both methods should be considered (Table 1 and Figure 6).

Table 1 Pros and cons of 2 different multi-staged excavation approaches

Top cut/bench (breasting with jumbo)	Bottom cut/take the back down
Pros	**Pros**
Benching stage is relatively fast. Only wall support required	Final back/roof ground support does not undergo the benching loading cycle
Only top cut passes require back/roof support	Protection from fly rock damage is not required, eliminating the peeling shotcrete problem
Cons	Final back profile is relatively easy to get good arch shape, drill and blast controls the profile (pre-pinning bottom cut allows wide single final pass)
Benching/breasting laterally along the bottom cut always has significant fly rock damage to the top cut ground support	Back/roof mounted equipment (e.g. lights, cranes) is easy to do without high lift equipment
Blasting mats can be used but are awkward in large mining excavations	Drill/blast profile for floor, less overbreak, which may = less floor concrete
Shotcrete over mesh does a nice job of eliminating the fly rock damage	**Cons**
Peeling/spalling shotcrete from height is a hazard. The stress change and seismicity from benching often causes shotcrete cracking when developing in hard brittle rock at depth	The TDB phase must mine through the bottom cuts' back support (steel in the material handling systems), especially cablebolts (they need to be cut/grinded off or folded over)
The back profile is ugly. The second pass on the top cut undermines the stress fractures from the first pass. Final profile is a scaled out back, not the drill/blast shape	Each stage requires back/roof support
Floor overbreak is inevitable when blast gases from benching get into stress fracture zone. Lots of overbreak occurs, which may mean extra floor concrete required	Large accumulation of blasted muck that needs to be removed in one big batch



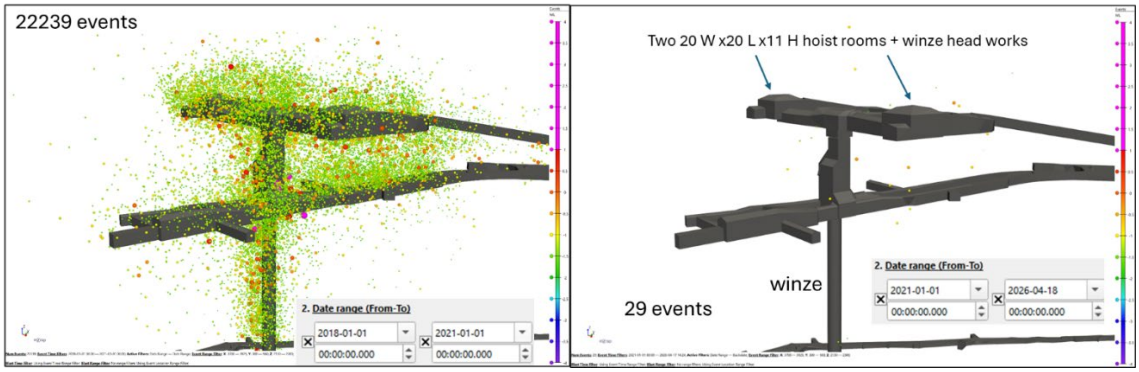
(a) (b)

Figure 6 (a) Top cut/bench excavations; (b) Two bottom cuts with a third pass of coming over the back. TDB = take the back down

Effective shotcrete application in permanent openings is critical. By design, large excavations are kept far from stoping induced stress, so after the excavation is complete, brittle shotcrete on the outside may be acceptable. The multistage approach does mean there is both stress change after each excavation increment and blast fly rock damage. The fly rock damage can be controlled by shotcreting over the mesh prior to the next stage of the excavation. At depth, the stress change from the next increment of excavation creates seismic activity and new fracturing. The dilemma becomes exposure to the outer layer of shotcrete spalling versus unprotected mesh being damaged by blast fly rock (neither is desirable).

Taking the back down via the bottom cut/TDB approach has its' cons (Table1), but in general breasting downward from the top cut pass has very limited blast fly rock damage. Shotcrete if required can be applied at the end of the exaction process, thus reducing the potential for brittle spalling.

Figure 7 shows the recorded seismicity from excavating twin hoist rooms and a winze at 1,200 m below surface. During the excavation process (2018–2020), a lot of small and moderate magnitude seismicity was recorded. Several incidents of shotcrete spalling occurred during this period, generally at blast time when there was no worker exposure (fortunately). Between 2021 and early 2026, minimal seismicity was recorded. Once the excavation process is complete, in high-quality, hard/brittle rock, then the seismicity stops or drops off dramatically. Shotcrete as a final pass worked exceptionally well and has not had any observed change since the excavations were completed.



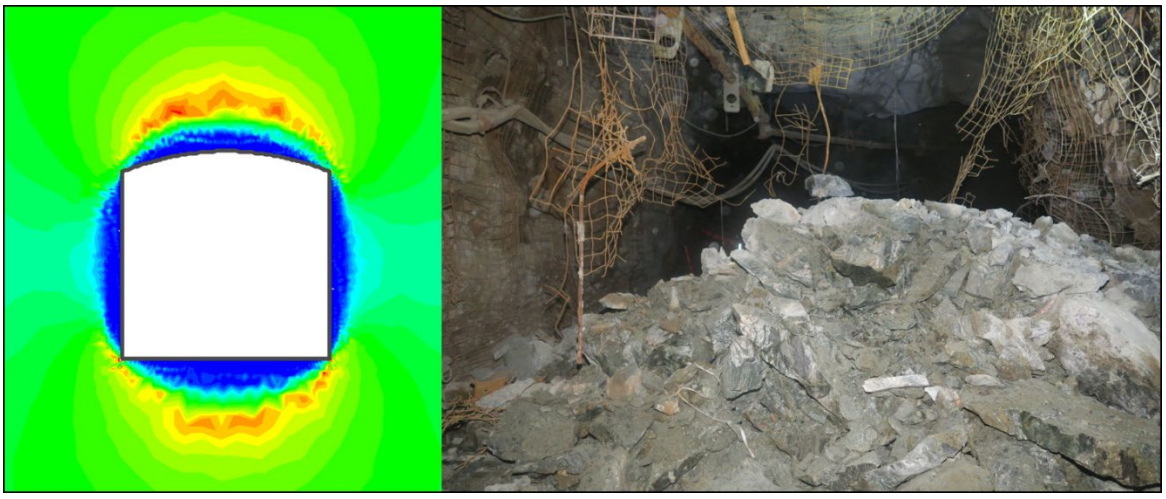
(a) (b)

Figure 7 (a) Recorded seismicity during active development of a headworks/hoist room area 1,200 m below surface in high-quality rock; (b) Minimal seismicity since the excavation process was completed and no nearby mining is occurring (by design)

2.2 Re-establishing safe access over top of a heavily mined abutment

The next example is a case of where a decision was required to either rehabilitate an existing stope access or TDB over it (removing fractured/dilated material and installing new ground support). Figure 8 shows a case of 2 extremes. Removing fractured material (purging) removes confinement and may re-initiate the stress fracturing/spalling process which, in some cases, possibly triggers strainbursting. Support through the fractured ground and pinning it into the solid beyond may be preferable. Difficulties with resin/grout loss into dilated fractures can occur; however, new ground support practises such as pumpable resin can mitigate this issue. Typical pumpable resin products start to set relatively quickly and won't migrate too far from the drillhole. Fixed volume cartridge resin is vulnerable to resin loss in the fractures, creating a poor bond with the bolt in the hole. Pumpable products still fill up the hole, and the resin loss into fractured ground just equates to higher costs as more resin is pumped in Knox & Hadjigeorgiou (2023).

At the other extreme, as fracturing deepens, it becomes prone to shake down (from nearby blasting or seismic activity) making it difficult to safely install long enough anchors through the dilated material. Blasting or purging the worst of it down and starting with a fresh back may be preferable. The right side of Figure 8 shows a 40 tonne fall of ground triggered by the rehabilitation process. The work moved from 'good' ground towards the poorer ground requiring re-support. The failure was ahead of the operating equipment, which safely 'scaled' it out by simply drilling into it. In other words, it was ready to fall out under mostly gravity loading alone, and the decision to take it out proved to be a good one.



(a) (b)

Figure 8 (a) Profile of deep tunnel. The low stress (blue contours) represents failed/stress fractured material. The high stress beyond it gets exposed if the failed material is scaled out; (b) Fall of ground caused by scaling. The material was close to falling out on its own due to gravity and was much safer to proactively remove rather than try to re-support it

Part of the 'art' of ground control is to know when re-supporting is the right option or re-establishing a new back is the better choice. Seismic history, numerical modelling, underground observations, and test holes are some of the scientific tools that can be used to help guide the decision.

Figure 9 shows a late-stage mining area that required safe access to the last stope in the area. A better mining plan would have been to high lift the 'light blue' material into the stope below. For various planning reasons, it was left behind as the last stope. A long flat abutment had been created (5 × 15 m wide stopes) and the original 5 × 5 m profile crosscut would have required extensive re-support to safely re-use. The seismic history was examined, and the decision to TDB over it was made. The wide abutment had significant stress fractured material above it, deep enough that removing a few metres of it did not get back into high stress (Figure 8a scenario) but safely removed 'tired' dilated material to avoid the scenario of Figure 8b.

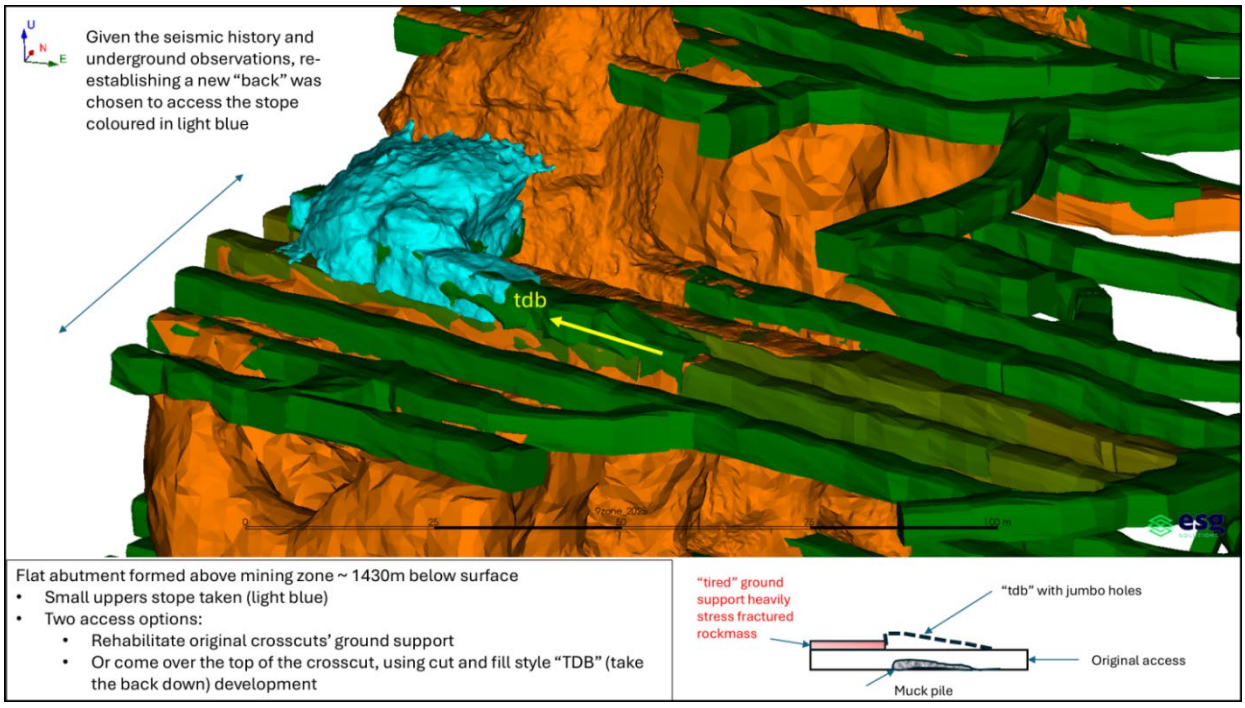


Figure 9 Late-stage mining layout that required safe access to a small stope highlighted in light blue. In this case, the decision was to re-establish access by TDB over the original crosscut

Figure 10 shows some photographs of the access after the fractured back had been blasted down and supported. The working floor was the broken rock form the TDB process, and this was later remotely removed after the stope was completed as most of it was ore grade.



Figure 10 Photos of the take the back down access shown in Figure 9. Right side shows a full face of fractured material in what was originally a high-quality rock mass

Figure 11 shows the local seismic history in the area. A strong indication of yielded rock is when is goes from high seismic activity to low/no activity. Location scatter (location errors in the order of 10 m) can make it difficult to determine the extent of yield which is also in the order of 5 to 10 m. Figure 12 shows a seismic data analysis technique based on recorded development blasts that strongly suggests yielded ground.

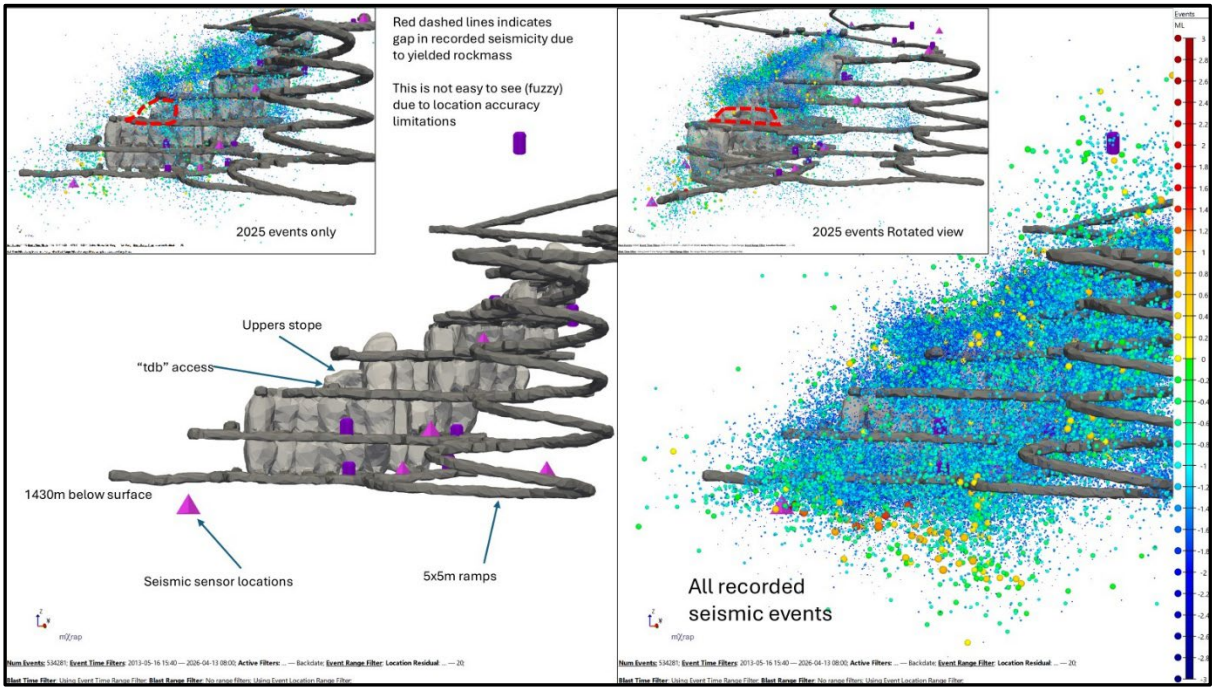


Figure 11 Seismic records from the take the back down (TDB) area. The long flat abutment that the TDB traversed had seen a significant amount of mining-induced seismicity over a period of 12 years

The frequency content of the seismograms can be represented by the source radius, a seismic parameter inversely proportional to the corner frequency. In theory, the source parameter characteristics of development blasts should be the same, same number of holes, same charge per hole. In practice, if the source region of the development blast is yielded/fractured ground, as per the TDB concept (Figures 9–12), then the high frequency content of the seismic waves gets attenuated. Blast records in fractured rock show higher source radius than blasting in solid/intact rock.

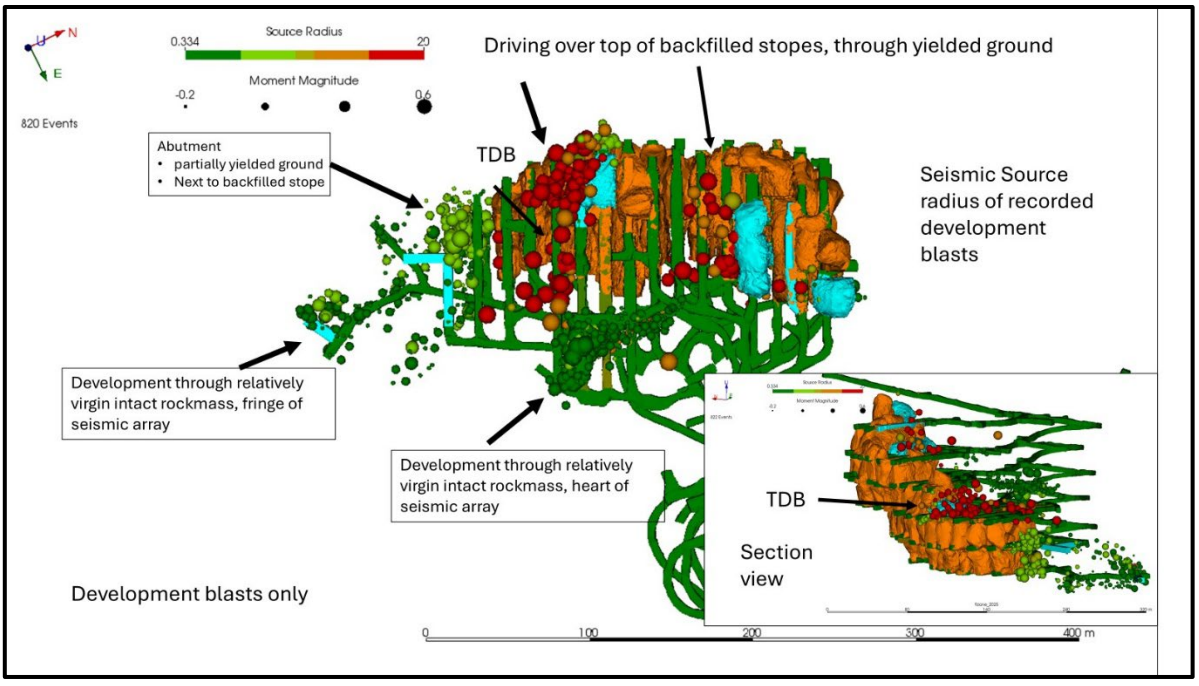


Figure 12 Seismic records of development blasts in the region of the take the back down (TDB). High source radius blasts are indicative of high frequency stripping of the waveforms due to blasting in fractured ground

The general area had occasional larger events (up to moment magnitude 2) in the abutment zone above the mining. Re-supporting the crosscut may have worked, but it was felt that the 5+ m zone of fractured material above the crosscut would be vulnerable to seismic shake down (seismically induced fall of ground) and it was better to remove the material. Although removing the confinement and cushioning of the fracture zone has its drawbacks, in this case there was still some fractured material above the new back. Very little seismic activity accompanied the TDB process indicating the high stress zone above it wasn't directly perturbed. The stope was safely extracted without any incidents.

2.3 To purge or not to purge (example of keeping material in place)

While bolting through heavily fractured ground is difficult, that approach can be advantageous. Figure 13 shows an example where purging damaged rock after a large seismic event would have increased the local span of the opening in an already high stress abutment, next to an existing intersection. The decision was to attempt to pin the failed material back deeper into the rock mass with cablebolts. As mentioned above this has the big advantage of maintaining confinement and a 'cushion' for future seismic loading.

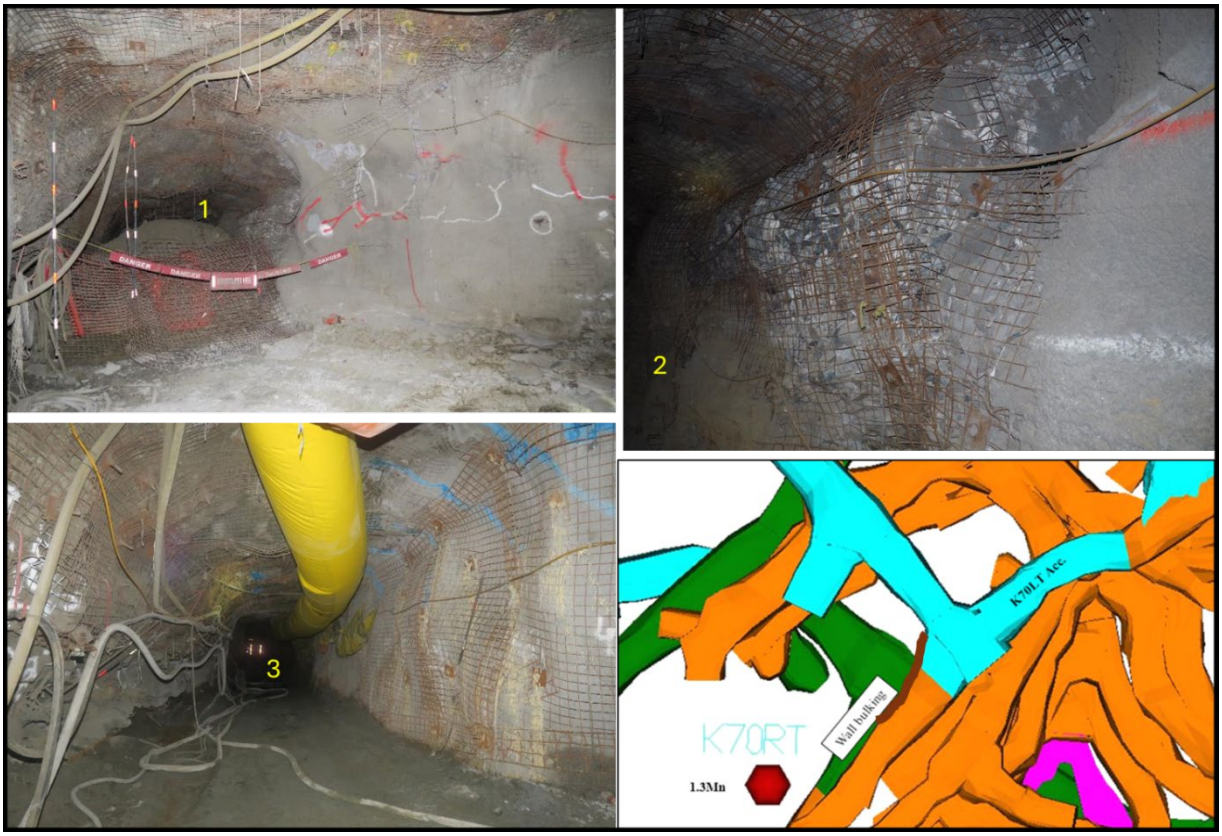


Figure 13 Example of repairing a damaged wall rather than purging and re-supporting it. Lower right – a moment magnitude 1.3 seismic event caused severe wall bulking in a narrow vein 3 × 3 m heading

The upper left portion of Figure 13 shows a waste filled heading that had significant wall damage after a large seismic event. The heading was re-accessed to mine a narrow copper vein with longhole methods. The support system held after the seismic event but most of its' deformation capacity had been used up. Although time consuming, operators were able to shotcrete over the damage and pin it back with 5 m long cablebolts and pumpable resin filled splitsets. The ground control tactics were successful in preserving the wall and keeping the local span manageable. The narrow vein longhole stope was mined afterwards without incident.

3 Discussion

Considerable improvements to ground support design rationale are occurring (Kaiser & Moss 2022; Hadjigeorgiou & Potvin 2020). However, there are still a few areas where the 'art' of ground control, or an

observational approach needs to back-up the science behind the design rationale. The concept of monitoring rock mass displacement and how it consumes ground support capacity over time is important, but in practise limited in its resolution. Figure 14 shows examples from deep mining in brittle rock to help explain this point.



(a) (b)

Figure 14 (a) Heavily stress fractured floor exposed by breasting the floor of a top cut/bench excavation; (b) Heavy bulking (screen bagging) between bolts after a seismic event

Laser based scanning is gaining popularity in underground mines and has been proven to be a useful tool for monitoring rock mass deformation. The scans can accurately (within centimetres or even a few millimetres) detect surface displacements. Counter (2019) developed a solid empirical relationship to trigger the need for rehabilitation. 'X' amount of tunnel convergence, meant it was time to replace lost support capacity. The relationship was empirical, based on scans of ground failures before and after. Figure 14 left shows a zone of heavy stress fracturing after being exposed by benching. The dilation that could be measured on the surface by scanning is the cumulative effect of multiple fractures dilating. The further into the rock mass from the excavation, the less the dilation. Even a stiff rebar might survive the displacement because the movement occurs over multiple discrete fractures. The rebar might stretch a total of 10% across a dozen different places along the bar (although its plate has probably been overloaded or the nut may fly off due to stored strain energy).

The design value (capacity) for the bolt likely comes from an axial pull test, or dynamic drop test. This represents localised displacement across one discontinuity. The fracture zone also tends to shear, and offset along the fractures, meaning bolts won't always be purely axially loaded. Figure 14b shows mesh bagging. A few bolts seem to have gone along for the ride, but most of the displacement is in-between the tendons. The effectiveness of the load transfer to the bolts is also compromised as the rock mass degrades (Figures 2, 4, 8 and 15). Shotcrete under mesh can help by reducing dilation and giving a more uniform load distribution to the surface support.

Even instrumented bolts or multipoint extensometers are indirect indications of how much deformation a bolt 'sees'. The multiple fracture scenario means that the displacement measured between MPBX nodes is a cumulative number of multiple fractures displacing. It may or may not equate to a pull test depending on the type of bolt being used.

In hard, brittle rock, surrounding mining increases the depth of fracturing around excavations. The new fractures dilate, using up some of the deformation and energy absorption capacity of the bolt. Joints and stress induced fractures also slip, deform, and shear. Axial pull tests or laboratory drop tests are good for comparative evaluation but are not directly applicable to all underground loading conditions. The clean load transfer in particular likely gives an optimistic scenario for the bolts' potential capacity. Observations of ground failures often show unravelling failures where the bolt capacity was not fully utilised, or bending and shearing of the tendons meant a lower deformation limit occurred in the field.

Recent work by Knox & Hadjigeorgiou (2025) shows multiple tests of different bolts in shear. Although in the field there is usually a combination of axial and shear loading of bolts, this type of testing may provide a

practical and conservative design limit for the maximum displacement capacity of different bolt types. The bolts' energy absorption capacity determined by pull tests or drop testing changes dramatically if the deformation capacity of the tendons gets pinched off by shearing. The deformation capacity is also contingent on eliminating weak links in the ground support system and good load transfer to the tendon (Figure 15). Some decision must be made on how a near perfect tensile lab test result needs to be downgraded to an appropriate field value for support design.



Figure 15 No bolt failures! However, multiple weak links failed, and the support system was not successful

Numerical models offer a potential path forward. In principle, both ground support system characteristics and complex loading conditions could be simulated (Garza-Cruz et al. 2019). At present, mine scale models are required to estimate the loading conditions of mining excavations, which, when close to stoping, can change dramatically as extraction builds. More detailed tunnel scale models are required to capture effects such as stress fracturing, jointing, geological complexities and ground support. Coupling the 2 together is possible but can be computationally challenging (Beck et al. 2010). No doubt instrumentation, field observations and experience will be required to 'calibrate' models. Advances in lidar scanning, borehole measurements (optical and acoustic televiewers), fibre optic instrumentation and seismic monitoring all help geotechnical engineers to make better decisions and slowly turn the art into more of a scientific approach.

Lower corporate and regulatory risk tolerance will force engineers to rely less on experience or the 'art of ground control' especially given the context of deeper mining in more challenging environments. In the meantime, the gaps that exist in our understanding, ability to measure, and forecast/predict are still being met by the observational approach. Good record keeping – even if the ground failure isn't perfectly understood – is essential. A photograph is still worth one thousand words, and as you get more experienced, your understanding improves. One of our most valuable ground control 'assets' is the collection of named/dated photographs going back to early digital cameras in the 1990s. It is perhaps surprising how revisiting the old records, with a more experienced view, leads to a better understanding of how to manage challenging ground control environments.

4 Conclusion

Although there are some "inconvenient truths about ground support in deep and high stress mines" (Hadjigeorgiou 2024), anchoring ground control techniques and support design with observational data has made mining safer. Some of the current design methodologies (Kaiser & Moss 2022) provide a solid framework, albeit with a few gaps and assumptions required to operationalise the approach. Advances in

monitoring (mobile lidar scanning, optical and acoustic televiewer surveys, better denser more accurate seismic arrays, fibre optic sensors, etc.) are helping to quantify observations and take some of the subjectivity out of decisions that need to be made on a regular basis in deep mining environments.

Current and future research projects, such as the Australian Centre for Geomechanics' Ground Support Systems Optimisation, are helping improve some of the fundamental understanding of how ground support interacts with complex underground loading. This type of research will help inform the numerical modelling community and may eventually lead to better forecasting of ground support system performance. In the meantime, artists at the operational level are required to help keep deep mining safe.

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References

Alvina, N & Van Sint, J 2008. 'Ground movement amplification around underground excavations' *Australian Centre for Geomechanics Newsletter*, vol. 31, no. 21e22.

Beck, D, Stacey, K & Gilbert, D 2010, 'Mine to tunnel scale discontinuum simulation of repeated dynamic loading of mine excavations', *Second Ground Control In Mining Conference,* Australasian Institute of Mining and Metallurgy, Melbourne.

Cai, M & Kaiser, PK 2018, 'Rockburst phenomena and support characteristics', *Rockburst Support Reference Book*, Laurentian University, Sudbury.

Counter, DB 2019, 'Laser-based scanning to manage geotechnical risk in deep mines', in J Hadjigeorgiou & M Hudyma (eds), *Ground Support 2019: Proceedings of the Ninth International Symposium on Ground Support in Mining and Underground Construction*, Australian Centre for Geomechanics, Perth, pp. 43–58, https://doi.org/10.36487/ACG_rep/1925_01_Counter

Garza-Cruz, T, Bouzeran, L, Pierce, M, Jalbout, A & Ruest, M 2019, 'Evaluation of ground support design at Eleonore Mine via bonded block modelling', in J Hadjigeorgiou & M Hudyma (eds), *Ground Support 2019: Proceedings of the Ninth International Symposium on Ground Support in Mining and Underground Construction*, Australian Centre for Geomechanics, Perth, pp. 341–356, https://doi.org/10.36487/ACG_rep/1925_23_Garza-Cruz

Hadjigeorgiou, J 2024, 'Inconvenient truths about ground support in deep and high-stress mines', in P Andrieux & D Cumming-Potvin (eds), *Deep Mining 2024: Proceedings of the 10th International Conference on Deep and High Stress Mining*, Australian Centre for Geomechanics, Perth, pp. 23–60, https://doi.org/10.36487/ACG_repo/2465_0.02

Hadjigeorgiou, J 2016, 'Rock support: degradation and failure', in E Nordlund, TH Jones & A Eitzenberger (eds), *Ground Support 2016: Eighth International Symposium on Ground Support in Mining and Underground Construction*, Luleå University of Technology, Luleå.

Hadjigeorgiou, J & Potvin, Y 2020, *Ground Support for underground mines,* Australian Centre for Geomechanics, Perth.

Kaiser, PK & Moss, A 2022, 'Deformation-based support design for highly stressed ground with a focus on rockburst damage mitigation', *Journal of Rock Mechanics and Geotechnical Engineering*, vol. 14, issue 1, pp. 50–66.

Karampinos, E, Simser, B & Hadjigeorgiou, J 2012, 'Determination of rock mass failure and rock mass damage criteria for the felsic norites at Nickel Rim South Mine', in Y Potvin (ed.), *Deep Mining 2012: Proceedings of the Sixth International Seminar on Deep and High Stress Mining*, Australian Centre for Geomechanics, Perth, pp. 401–413, https://doi.org/10.36487/ACG_rep/1201_29_karampinos

Knox, G & Hadjigeorgiou, J 2023, 'Performance of conventional and energy-absorbing self-drilling hollow core rockbolts under controlled laboratory conditions', *Rock Mechanics and Rock Engineering*, vol. 56, no. 1, pp. 1–16.

Knox, G & Hadjigeorgiou, J 2025, 'Rockbolts in shear', *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 125, no. 11, pp. 621–628.

Mercer, S, Morgenroth, J & Simser, B 2023, 'High-resolution ground-deformation and support monitoring using a portable handheld LiDAR approach', in J Wesseloo (ed.), *Ground Support 2023: Proceedings of the 10th International Conference on Ground Support in Mining*, Australian Centre for Geomechanics, Perth, pp. 51–60, https://doi.org/10.36487/ACG_repo/2325_02

Ortlepp, WD, Murphy, S & van Aswegen, G 2004, 'The mechanism of a rockburst – an informative study', *Second International Seminar on Deep and High Stress Mining*, The South African Institute of Mining and Metallurgy, Johannesburg, pp. 23–40.

Simser, BP 2007, 'The weakest link - ground support observations at some Canadian Shield hard rock mines', in Y Potvin (ed.), *Deep Mining 2007: Proceedings of the Fourth International Seminar on Deep and High Stress Mining*, Australian Centre for Geomechanics, Perth, pp. 335–348, https://doi.org/10.36487/ACG_repo/711_25

Yadav, P 2024, 'Geomechanical evolution of the Nickel Rim South Mine', in P Andrieux & D Cumming-Potvin (eds), *Deep Mining 2024: Proceedings of the 10th International Conference on Deep and High Stress Mining*, Australian Centre for Geomechanics, Perth, pp. 61–84, https://doi.org/10.36487/ACG_repo/2465_0.03