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Evolution of ground support practices at Kittilä mine

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Abstract

Kittilä mine is an underground gold mine owned and operated by Agnico Eagle Finland located in northern Finland. The mining operation started in 2008 from open pits and transitioned to underground production in 2012. The mine consists of 4 separate orebodies, currently producing 2.0 Mt per annum, and requiring over 14 km of development annually.

The primary mining method is longhole stoping using a primary–secondary sequence with delayed backfill. As mining has progressed to greater depths, ground conditions and stress environments have evolved, necessitating changes in ground support strategies. Current ground conditions range from squeezing behaviour during development parallel to foliation to brittle response and rockbursting conditions within massive mafic lithologies.

The early implementation of microseismic monitoring has played a key role in identifying areas of increased seismic hazard, supporting proactive upgrades of ground support systems, and enabling targeted application of enhanced support. Integration of microseismic data with observational monitoring of ground support performance has allowed ongoing calibration and optimisation of ground support design.

Keywords: *ground support, rock mass response, microseismic monitoring*

1 Introduction

Kittilä mine is owned and operated by Agnico Eagle Finland, located 150 km north of the Arctic Circle at 66˚ latitude. Mining started in 2008 as an open pit operation, which operated until 2012 until production transitioned fully underground. The mineralisation is located within a subvertical north-south striking Kiistala shear zone in the Lapland Greenstone belt. Gold is refractory and 95.5% of gold is located within arsenopyrite and pyrite. The mine consists of four separate mining areas (Figure 1), Suuri, Roura, Rimpi and Sisar, currently producing 2.0 Mt and requiring over 14 km of development on yearly basis. The current known strike length of the mineralisation is 3.5 km and the depth extends to at least 1.5 km. The principal mining method is longhole open stoping with cemented paste backfill (CPF) using a transverse primary–secondary sequence and longitudinal mining. Longitudinal mining is utilised in the narrower lenses, usually in fringe zones of the mineralisation.

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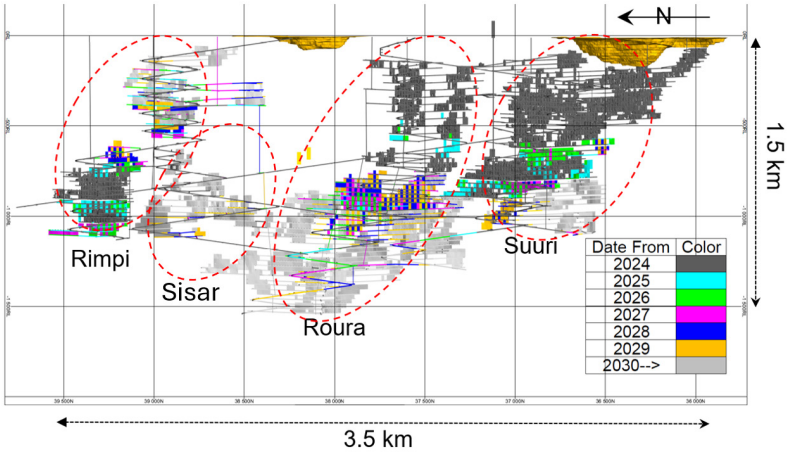


Figure 1 Longitudinal view of the Kittilä mine (Agnico Eagle Mines 2025)

1.1 Ground conditions and in situ stress

Host rock surrounding the mineralisation is competent massive mafic pillow lava. Footwall rock closer to mineralisation is more altered with carbonate vein creating blocky ground in Suuri area. Mineralised lenses within the shear zone are undulating and pinch and swell types. Geotechnical investigation results from Rimpi orebody are summarised in Table 1. Rimpi orebody is located within the same Kiistala shear zone, although the footwall rock mass is less jointed and more massive in comparison to Suuri zone.

Table 1 Summary of rock mass classification results for Rimpi (Giroux 2018)

	Domain		
Parameters	**West (footwall)**	**Shear zone**	**East (hanging wall)**
Intact rock strength – uniaxial compressive strength	170 MPa Very strong	90 MPa Strong	200 MPa Very Strong
Rock quality designation	80–85% Good	30–35% Very poor to poor	85% Good
RMR76	70 Good	50 Fair	65 Good
Q`	20–25 Good	0.8–3.0 Very poor to poor	15–25 Good

Early development of the decline showed significant groundwater inflow through the shear zone. Current dewatering quantities exceed 600 m^3/h from the mine. Ground temperature is also relatively low, reaching only 3.5°C at 200 m depth (Martinkauppi & Wiberg 2025) which is likely influenced by the surface-derived cold water seepage through fractures. Groundwater pH is close to neutral and measured salinity is low in the upper part of the mine. Groundwater seepage has been observed to increase through yielded rock mass in the secondary headings after primaries have been mined out (Pyy & Falmagne 2019).

The assumed in situ stress regime within the Fennoscandian shield is listed in Table 2 (Mattila & Valli 2023). Results from the 2 measuring campaigns were affected by fractured rock mass and shear zones and provided inconclusive information of the stress orientation or magnitude. Field observations from stress notching in ventilation raises (Figure 2) and stope slot openings indicate a principal stress azimuth of 150˚ which constrasts with the expected east-west orientation inferred from the orebody geometry.

Table 2 Assumed in situ stress gradient at Fennoscandian Shield

s_H (MPa)	s_h (MPa)	s_V (MPa)
7.4 + (z × 0.041)	4.7+(z × 0.024)	Z × 0.029

z = depth from the surface



Figure 2 Ø4 m raisebored ventilation raise in Roura between 735-1015 showing stress spalling

1.2 Development fleet

The development fleet is listed in Table 3. Four of the six current bolting rigs are owned and operated by the contractor.

Table 3 Current development fleet

Task	Equipment	Quantity
Drilling	Sandvik DT923i	2
	Epiroc Boomer	2
Bolting	Epiroc Boltec E	6
Cable bolting	Epiroc Cabletec	1
Charging	Truck	2
Scaling	Normet Scamec	3
Shotcreting	Normet Spraymec	2

2 Static ground support

2.1 Early development

Initial ground support consisted of (1st pass) wet mix fibre-reinforced shotcrete (FRS), with (2nd pass) resin grouted rebar and Swellex rockbolts with 1.5 × 1.5 m pattern and cable bolting for the larger spans. The development rates were moderate, increasing from 200 to 400 m/month by 2010. Concrete was transported from a batching plant located 60 km from the mine site, making it challenging to maintain the concrete temperature above 15°C during the winter months. Moving the batching plant onto site helped further mix development. The target early strength for shotcrete was set at 3 MPa prior to the rockbolting. Higher early strength facilitated further strength development after the initial effect of the accelerator had subsided. Early strength development was assessed using Hilti method and a penetrometer (European Committee for Standardization 2006) (EN 14488-2, 2006) while temperature was monitored using infrared thermometer and data loggers. The use of modern plasticisers and higher cement content enabled a lower

water-to-cement ratio. Heated storage tank for the alkali free accelerator next to the batching plant and smaller tank on the concrete truck for transferring the accelerator to the spraying unit helped with the logistics and maintaining the temperature. The operator's role in achieving a high-quality final product is important; careful washing of the rock face prior to the spraying, maintaining correct nozzle distance from the wall, pumping speed, correct accelerator dosage and nozzle movement are all important parts of the process. Operator training has been organised together with equipment and chemical suppliers.

2.2 Mesh installation

The implementation of mesh as primary surface support was initially slow. At Suuri S375 level, the footwall drive intersected a shear zone with schistose rock with tight subvertical foliation (Figure 3). Both the thin pillars between and the adjacent wall showed spalling and shotcrete cracks as the stoping front passed through the area. To avoid expanding the intersection span resulting from scaling the pillar nose and to control the deformation, mesh was installed on top of shotcrete with 2.4 m inflatable rockbolts as secondary support. Figure 3 shows the observed buckling of the pillar and outcome of the meshing left too high from the toe. Lower part of the wall that failed was only shotcreted. Although the overall displacement was relatively small, observations provided useful information on the expected rock mass behaviour in future development.



Figure 3 Buckling of the foliated footwall drive pillar between crosscuts due to the vertical loading. Footwall drive visible on the right side of the pillar, view towards south

Damaged shotcrete was observed more frequently below 800 level and pieces of loose shotcrete and rock, although small, comprised fall of ground risk. Rehabilitation consisting of first mechanical scaling and followed by shotcreting caused also delays for the production. The use of welded wire mesh with 2.4 m Swellex bolts was first introduced in crosscuts to reduce rehabilitation requirements associated with damaged shotcrete and to improve containment of small loose rock fragments, 1.3 × 1.1 m square pattern of the bolting with Ø5.5 mm welded wire mesh, 75 × 75 mm wire spacing.

2.3 Development through cemented paste backfill

Backfill quality is checked every shift by slump testing and taking cylinder samples for compressive testing in the backfill plant. Samples are tested in the onsite laboratory. The 28-day uniaxial compressive strength (UCS) design target for the CPF at the sill level target is 1.0 MPa or higher. The standard strength requirement outside the sill area for primary stope CPF UCS is 0.5 MPa.

First sill pillar stopes were excavated when panel from Suuri S500 level connected to S300-level sill. CPF quality was variable and it was investigated with diamond drilling through the fill (Pyy & Falmagne 2019). In 2025, 890 m of development was completed through CPF, and 640 m is planned for 2026. The application of the modified cutterhead to excavator has enabled high-quality excavation through the CPF. To help the operator align the heading, the surveyor marks the centreline and height of the profile on the back (Figure 4a). Figure 4b highlights the horseshoe profile of the heading. Careful cleaning of the lower part of

the wall and application of shotcrete from floor to floor are important aspects of the support system, enabling arching of the support and backfill material. Drill and blast is only used in CPF if the excavator is not available.

Two adjacent backfill development headings (minimum distance 30 m) improve productivity as a wheel loader can clean the heading while the other face is being excavated and machines can switch faces. Two adjacent headings, both either primary or secondary, can each be advanced by 4 m in a single shift while maintaining the operator cabin within supported area at all times. The wheeled excavator facilitates rapid moving in the mine.



(a) (b)

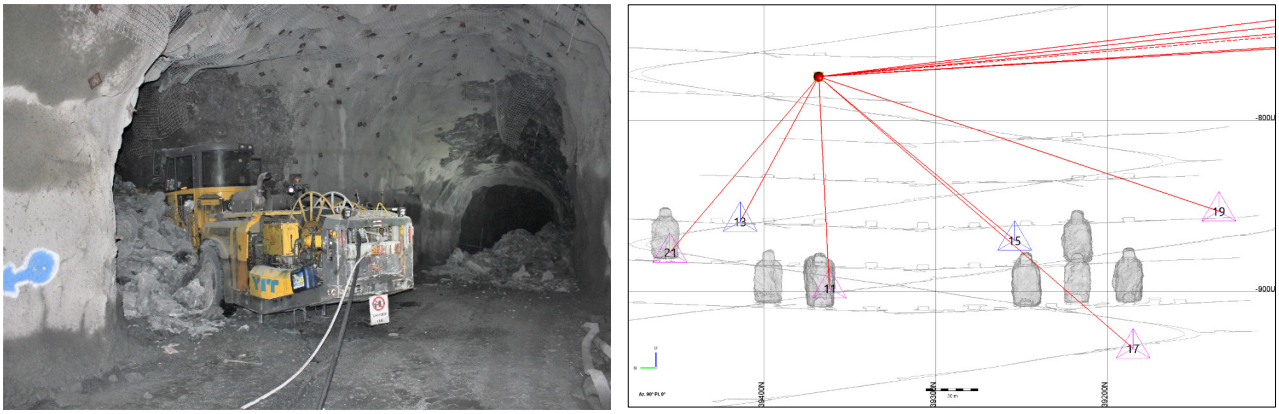
Figure 4 Cemented paste backfill development. (a) Excavating with cutterhead; (b) Excavated profile, support ongoing

3 Dynamic ground support

Seismic monitoring was tested early in the mine between level S625-500 and later installed before stoping commenced in the Rimpi X900 pyramid (Pyy et al. 2022). During early development, a rockburst associated with an M_W1.6 event was observed during bolting of the heading (Figure 5). The event magnitude was larger than expected and understanding the reason for the event was important. Investigations showed that the event source mechanism was reverse slip that triggered 2 strainbursts in the proximity of the shear zone intersecting the area.

Prior to the M_W1.6 event, a M_W0.4 seismic event occurred in the intersection following a development blast. The event prompted an upgrade of the intersection support, including the installation of mesh and cable bolts. Although the mechanism of the M_W0.4 event was not fully understood at the time, the subsequent performance of the excavation suggests that the upgraded support likely prevented more extensive damage during the M_W1.6 event.

Following the event, a proactive upgrade of the footwall drive ground support system was initiated. Installing resin (cartridge) grouted rockbolts with meshing was inefficient and the results were variable with partial encapsulation of the bolts and slow progress. Two-pass support was implemented; first pinning the mesh with Swellex bolts followed by mesh straps (Ø7.8 mm wire) and grouted yielding rockbolts (Ø22 mm, 2.4 m D-Bolts and PAR1 Bolts). A major portion of the ground support in the Rimpi X900 pyramid footwall drives was upgraded, new footwall-drive development was supported directly with enhanced support.



(a) (b)

Figure 5 (a) M_W = 1.6 rockburst damage at Rimpi X775-level during bolting; (b) Event location in longitudinal view, initial seismic system sensors and cavity monitoring system models of mined stopes (Pyy et al. 2022)

Resin installation of the bolts was replaced with cement grouted bolts with mechanical anchor (Kiruna wedge) to facilitate faster installation. Both standard rebars and yielding dynamic bolts are installed using the Kiruna wedge. Cement grouted bolts are not used in areas with significant water inflow; these areas are first supported with Swellex bolts and resin grouted bolts are added as second-pass.

Grouting process of the Kiruna bolt:

- Pushing the grout tube in the toe of the drilled borehole.
- Grout (water/cement = 0.3) is pumped in the hole while retracting the tube.
- Bolt is pushed into the hole, grout leaking from the collar indicates that the hole is fully filled.
- Bolt is hammered to activate the mechanical anchor after it reaches the toe, and the nut is torqued tightening the plate against the mesh.

The change was justified by the observation that seismic activity following development blasting decays rapidly, typically within 1 hour. Bolters have long booms and the operator is protected by the cabin, work is never conducted under unsupported back. In addition, all headings are mechanically scaled, and development sequencing allows sufficient curing time for the cement grout. FRS is no longer systematically applied to every heading but only planned when developing longer term accesses, footwall drive development parallel to shear zone and development intersecting identified shear zones/faults.

After the changes, productivity has increased. This is also due to the improved maintenance of the bolting equipment and logistics of the supplies. Bolts, plates and mesh are transported to the heading with flatbed truck. Equipment waiting times and downtime have decreased, resulting in improved cycle times.

3.1 Reasoning for planning

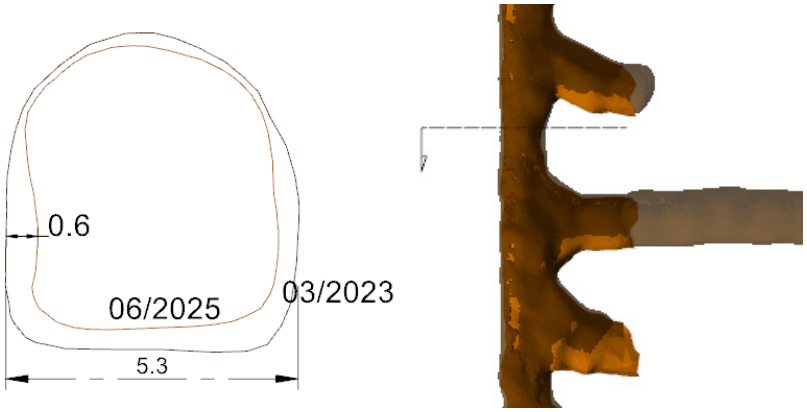
Seismic monitoring enabled the identification and tracking of active structures intersecting the footwall drives, improving hazard assessment and providing justification for both enhanced support and post-blast exclusion protocols (Pyy et al. 2024, 2025). Initial assumption of several subparallel structures has been confirmed. Some of these planar discontinuities intersect footwall development creating seismic hazard that is mitigated both with dynamic ground support and non-entry protocols after blasting. Basic elastic modelling of the faults has provided further information on behaviour of structures. Moment tensor analysis of the larger events (Pyy et al. 2022) has provided insight of the event mechanism.

Seismic monitoring has provided timely and accurate information of the rock mass response to mining. Early monitoring in Rimpi orebody improved understanding of the rock mass response and provided justification for revising the ground support strategy.

4 Squeezing ground

Development parallel to foliated ground has been well documented in earlier work, e.g. Hadjigeorgiou et al. (2013). At Suuri local footwall drives were developed further to hanging wall and within ultramafic and talc schist lithologies at S675 and S700-levels. Subvertical tightly foliated rock striking parallel to development was observed. Development ground support strategy was modified due to the observations. Tight pattern of bolting (3-2-3-staggered pattern, 1.8 bolts/m^2) was required with horizontal straps with 1 m vertical spacing (4 lines on 5 m high sidewall with 1 m spacing) was installed. Frequent follow-up of the area during extraction of the nearby stopes was required. Inspections were conducted weekly to identify failed tendons and restore support capacity through the installation of replacement bolts.

Figure 6 shows a comparison of the heading profile after mostly wall deformation and floor heave.



(a) (b)

Figure 6 (a) Scan of the footwall drive between 2 years; (b) Plan view, location of the profile in between the crosscuts

Ground support installation was conducted in the following sequence:

- FRS
- Meshing with Swellex (square 3-3-3 pattern, 1.3 × 1.1 m)
- Adding after every 15 m of development (keeping also 15 m distance from the face)
  - square pattern of D-Bolts inside the initial pattern (3-2-3)
  - mesh straps with 1 m spacing of D-Bolts and de-bonded cables.

De-bonded 6–8 m long cables grouted 3 m from the toe added displacement capacity as fully grouted cable bolts sank in through the mesh soon after the installation. A disadvantage to this was that the barrel and wedge assemblies on plates slipped in several cables, even with double locks. Timely development of the heading and fast stoping cycle would further improved heading stability. All but the last 2 of the stopes were mined as planned, and these secondary stopes were mined as 50 m high-lift stopes. Figure 7 shows the deformation of the side walls during late stage. Further use of high-definition LiDAR data to quantify support capacity consumption would enable more accurate and justified support replacement.



Figure 7 Visible deformation of the footwall drive, with most of the stoping already completed at the time the image was taken

5 Quality assurance and control

Ground support products are periodically evaluated through pull testing of installed bolts. Task observation encourages open discussion with the operators and enables misguided practice prevention.

New ground support items are tested externally prior to installation. Canada Centre for Mineral and Energy Technology (CANMET) laboratory testing is normally required for dynamic rockbolts. Split tube drop testing gives comparable results of the products.

Further third-party testing is also conducted, and basic steel quality laboratory testing is compared to manufacturer specifications. Steel tensile testing is conducted across the yielding straight parts and across the paddles. Steel between the anchor/paddle set of the yielding bolt should be strain hardened by the forging process enabling load transfer to the straight section of the bolt. Figure 8a shows the expected failure of the bar outside the anchor section and Figure 8b shows failure in between the central anchors. (Metsäjoki & Sirkiä 2021; Metsäjoki 2022) This type of failure could possibly cause bolt pre-mature failure in actual loading.

Bolt plates have been tested both in drop tests and tensile testing. Plate hole dimensions have been changed together with suppliers to better match the washer.



(a) (b)

Figure 8 Yielding rockbolt tensile testing results across the anchor points. (a) Expected failure outside the anchor points; (b) Failure in between the central paddle set

6 Development of the ground support practices

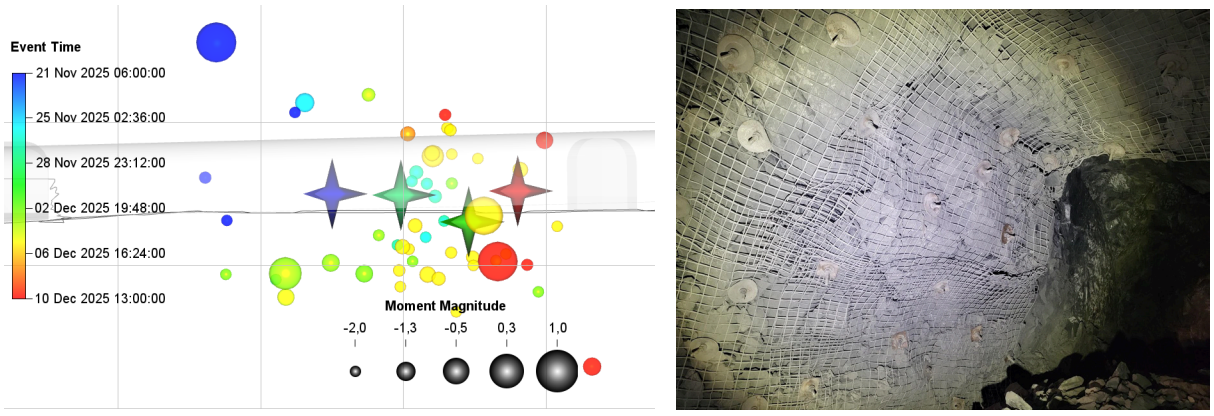
Ground support practices at Kittilä mine have evolved in response to changing underground conditions and increasing mining depth. Larger faceplates to dynamic rockbolts have been introduced to prevent punch through damage through the mesh. Mesh straps are currently installed manually, and mechanising this process would further reduce personnel exposure. The inclusion of central bolts to standard square pattern (0.6 m ring spacing, 1.3 m bolt spacing) has been introduced for high-stress development with seismic response after development blasting to increase bolt density and prevent punch through damage.

Table 4 summarises ground support evolution over time and changing ground conditions. The transition between support systems is governed by observed ground conditions rather than by fixed depth limits. Fully grouted cable bolts used as second-pass support in intersection backs are a critical component of the ground support system and have proven effective in both dynamically loaded and destressed ground conditions.

Table 4 Summary of the ground support evolution

Period	Ground conditions	Primary support
Early mining	Low to moderate stress	Fibre-reinforced shotcrete (FRS) Pattern bolting
Increasing depth (+800 m)	Moderate stress (shotcrete damage)	FRS+rebar Mesh+swellex
Squeezing ground	Foliated ground	Dense yielding support FRS+straps+cables
Seismic areas	Dynamic loading (fault interaction)	Mesh+yielding bolts straps
Increased seismicity (+1,000 m)	High-stress (massive, brittle ground)	Dense dynamic support straps

Figure 9 shows recorded seismicity after the development blasting, with $M_W > 0$ events taking place during the blast sequence and activity decreasing to background rate within 2 hours after the blast.



(a) (b)

Figure 9 (a) Longitudinal view of seismicity around development. Located adjacent blasts are drawn with stars and events with spheres; (b) Picture of the heading after the blast

Future work will focus on quantifying ground support system capacity and its consumption under seismic loading. The results will support the continued optimisation of the support design and risk management in seismically active mining areas. Seismic monitoring system is being expanded into the new development areas to improve coverage.

7 Conclusion

The evolution of ground support at Kittilä mine demonstrates the importance of adapting reinforcement system to changing rock mass response as mining depth increases. Early adaptation of microseismic monitoring enabled support modifications to be implemented proactively rather than reactively, contributing to improved safety and operational performance.

Ground support practices at Kittilä mine have evolved in response to changing underground conditions and increasing mining depth. One of the most significant changes in recent years has been the transition from extensive shotcrete use to wire mesh-based surface support. Higher-than-expected seismic response between the 700 and 900 levels initiated a transition to yielding ground support and a proactive upgrade of the support system.

Ground support productivity has improved through faster installation cycles and reduced rehabilitation work. Overall, bolting efficiency, measured as installed bolts/rig, has more than doubled over the past 3 years. These changes and optimisations have enabled more efficient installation of the required ground support system while maintaining a high standard of safety for underground personnel.

Acknowledgement

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