EPIROC MOBILE MINER – HARD ROCK CUTTING IS NOW A REALITY

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Conclusion

Drill and blast has developed to become a very fast, safe and versatile method for mining and tunneling. However, the method has a few shortcomings regarding full automation and other areas, which has reignited interest in mechanical rock cutting systems such as the Mobile Miner. In this paper, we will point out the more pronounced reasons for using these cutting systems and clarify the definition of mobile miner equipment. The young generation may not associate Epiroc (part of the Atlas Copco Group) with mechanical rock cutting, but the fact is that apart from a highly active raise borer business, Epiroc has since the early 1970s always focused on advanced rock cutting machinery. We will give examples from this interesting and ongoing history. Finally, being the main focus of this paper, we will describe the present Mobile Miner projects which Epiroc runs together with customers in different parts of the world.

Drill and blast in drifting and tunneling as a background to Mobile Miner excavation

The tunneling cost aspect

The aim of all tunnelling projects, irrespective of drifting methods, has been to lower costs, ensure a safe and healthy workplace, meet environmental requirements and to deliver an underground opening that will match the expected quality or even strive for improvements.

Improving the tunnelling/drifting speed is an important target for all parties involved in the excavation process – client, designer and contractor – as time is money. There is a direct correlation between cost and time consumption, as is often emphasized, which becomes obvious when splitting the excavation cost into two items. One is related to consumption of material for the building work, wear and spare parts for the equipment as well as consumables. This means that no costs are added to this item when there is no activity in the drift/tunnel. The second item covers all remaining costs which are considered time-related. Rough calculations indicate that the time-related costs in most cases constitute no less than two-thirds of all added costs and in many cases the figure may be three-quarters.

It is not surprising that all parties involved are eager to find means to improve the speed. The slide below shows the development of time consumption for the various activities at the tunnel face over a time span of 25 years, typical for a 60 m^2 tunnel in Europe. It shows that the advance speed has been declining over time, for which there may be more than

one explanation. The most important factor is most probably stricter rules and regulations for safety and working conditions.
The flexibility of the drill and blast excavation technique has always been considered one of the great advantages compared with mechanical rock excavation using the TBM technology. The flexibility covers both size and shape of the underground opening. Curve-taking capacity is another geometric issue where the TBM technology cannot match drill and blast. The so-called "road headers" that provide another form of mechanical excavation can easily match the flexibility of the of drill and blast. However, this excavation method has other drawbacks which makes it less suitable except for special conditions.
Beside the geometric flexibility, the capability of drill and blast to meet variable ground conditions has been considered superior when comparing with mechanical excavation. The TBM technique offers in general terms "one kind of excavation" but when commissioned it is very effective for drifting and tunnelling. The ambition to join the two technologies and combine the best of each is the origin of the Epiroc Mobile Miner.

The quality aspect of excavated underground openings
The quality of the excavation efforts also has a major impact on the costs for a drifting/tunneling project. Striving for a smooth contour with minimized overbreak means that major cost savings can be achieved, particularly when it comes to rock reinforcement measures. Drastic reductions in the input of shotcrete quantities means savings on the material side and less time will be required.
Mechanical excavation offers far better opportunities for getting a smooth contour and less overbreak than the drill and blast technique. The only overbreak that cannot be avoided is the over-excavation needed to ensure that there will be no underbreak. If a deviation of less than 5 cm from the theoretical line can be assured, an average over-break of no more than 6 cm will be the result. The extra centimeter comes from the cutter wear.

Safety and environmental issues
Health and safety issues have made significant progress in recent decades. The Mobile Miner will not offer any major improvements with respect to safety for the workers. Only minor is the environmental advantage of the Mobile Miner as modern blasting causes very little embarrassment.

How can the Mobile Miner outperform the drill and blast and TBM techniques?
The Mobile Miner can be considered a compromise between the drill and blast and TBM techniques. Rock breaking and mucking procedures are the same as in TBM tunnelling, but it offers flexibility that has much in common with drill and blast. The Mobile Miner operates in a non-sequential way which means there are good opportunities for an automated working process. It gives a smooth and undamaged rock surface in roof, walls and invert. By this description it ought to be the ideal machine for most types of underground excavations in both mining and construction but this is not the case. For the shape and size of the opening, the Mobile Miner has a more limited capacity than that of drill rigs. Typically, the excavation speed is slower than the TBM process for similar size tunnels, but it can easily match the advance rate of dril and blast in low-strength rock.

The curve taking capability is better than in TBM tunneling, but not as good as in drill and blast operations.
So, which are the best applications for Mobile Miners? Generally small to mid-size openings where flexibility is important and changes in tunnel size and shape are moderate, and where there is no need for long tunnels and drifts. Deploying the Mobile Miner is a much less demanding activity overall and its performance is often superior to drill and blast in low strength rock. As the name implies, the Mobile Miner is primarily suitable for small-scale mining operations – and here it can be very competitive. In addition, there are many civil engineering projects that have factors in common with mining such as storage of spent nuclear fuel, underground defence systems and supplementary communication systems under major hospitals and other industrial installations. In other words, there is a promising but somewhat limited market for the Mobile Miner technology.

What is a Mobile Miner?

We all have our own ideas about what mobile miners really are. As there are many available variants, we would like to briefly give a common definition. As the name implies, mobile miners give high priority to mobility. They also go by another common name – "part face cutting machines", and there have been attempts to classify these machines as "boom mounted rock cutting machines" (Prof G. Almgren). Well-known members in this family are Road Headers.
So which features do we normally associate with "a mobile miner"? To make it mobile, it needs some means of self-propelling capacity using wheels, crawler tracks etc. To qualify as highly mobile equipment it should also be able to travel at speeds greater than just a few km/h, it should be able to handle tight curves and to travel backwards in drifts that it has produced.
Though these machines could be able to cut a circular drift, it is commonly understood that they normally cut other profiles like flat bottoms. Mobile miners have a working range from the smallest possible height and width, defined by the machine's own size, to the maximum, defined by how far "the boom" can reach. A common interpretation is also that that the machine can pick up rock cuttings and deliver them to the rear where a different solution, such as load-haul-dumping (LHD) vehicles or a conveyor system, can take over. It can be argued to what extent the excavation machine should be able to consolidate the rock in the drift. If the rock is extremely poor this type of machine may not be the first choice. If the rock is of "medium" quality, methods where a stepwise advance, a few meters at a time as safety allows, could be considered. The machine is then backed out and set to work in a nearby drift. Meanwhile, the drift is consolidated with special separate rock reinforcement measures. For safety reasons, it is normally assumed that the machine has at least one or a pair of rock bolters attached to provide temporary support. Adding too many features on the machine will increase its size without increasing the max cutting size. This would also make the machine longer and reduce mobility. Having trailing support systems may also mean that rock consolidation is carried out far away from the face, which is not ideal.

The actual cutting

Based on our definition above, Mobile Miners have a cutting system mounted on a boom which can be moved in at least one direction – vertical or both vertical and sideways. In "hard rock" (UCS 80 MPa and more) the industry's focus is on "TBM" type disc cutting concepts. Rock UCS is clearly not the only determining factor. Tensile strength, brittleness and fracturing can all play equally important roles when discussing which methods works best in given situation. This paper will not elaborate on the topic, more than to say that pic cutting has its limitations in "tough" rock. It's also important to differentiate between the practical viability of and doing so at reasonable cost.

As we limit this presentation to cutting using TBM cutters, there are two different available types: systems that use a true TBM technique, which implies cutters rolling perpendicular to the rock face, and various types of "Undercutting Machines", meaning machines that penetrate the face a rip out the rock.

There is a common misunderstanding that Undercutting Machines are much more energy efficient than the true TBM type. The reason is that the undercutting principle works against the much lower tensile/shear strength, whilst the TBM works against the UCS. But in fact, 80-90% of the rock fracturing using TBM cutters in the TBM mode, is also due to tensile forces. While the rock is to some extent crushed in the groove under the cutter, the rock fracturing between and in the grooves occurs due to large tensile forces that produce cracks and result in chipping.

If "undercutting" enables reduced energy consumption at any level, it is due to the fact that rock fragmentation is coarser. The tool(s) rips out smaller or larger pieces of the rock. This principle of fracturing can also be a weakness if the machine is not capable of handling large blocks from rock fall. Epiroc has vast experience from both these methods, but is currently focusing on the TBM cutting process. There are several reasons for this. We want a reasonable large cutting head helping to support the face, which ensures that the machine can handle fallen rock on the invert if needed.

As part-face machines are used, blocks will always occur from time to time, regardless of method, and will need to be dealt with efficiently. This is a much smaller problem for traditional "full face" machines like TBM, but even here blocks can present difficulties in mucking out operations etc.

In conclusion, this paper will after the upcoming historical part, limit itself to Mobile Miners as defined above, using TBM disc cutters for rock fragmentation.

Epiroc past experience with Mobile Miners

Since the early 1970s, Epiroc has been heavily involved with conventional TBM cutting full face machines and, over the years, a number of Mobile Miners have been developed and built. The RBM business has been active since 1990.

A short historical overview:

- 1964-1980 Atlas Copco Tunnelbohrmaschinen Ag Thun
- 1980-1985 Atlas Copco Jarva Inc Solon Ohio
- 1983-1988 JV with Eickhoff GmbH Road headers. Very heavy road headers for civil construction
- 1985-1989 Webster UK small Roadheader/loader for mining
- 1985- 1988 JV with Kvaerner Brug Norway FORO later Jarva TBM Machines

- 1988-1992 JV med Ilbau Jarva type TBMs
- 1993-1998 Atlas Copco owns Robbins Company, Jarva Robbins RBM mobile miners
- 1998-Today RBMs at Epiroc, Sweden

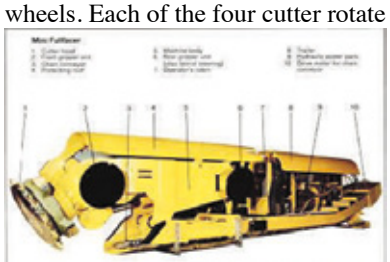
Pioneering machines that paved the way for the Mobile Miner:

A number of important product milestones precluded the development of the Mobile Miner system as we know it today. These include:
– The Mini Midi machines built by Atlas Copco Tunnel-Bohr Maschinen in Thun SCH.
– The Robbins 3 different Mobile miners, partly built before Atlas Copco's ownership. The MM120, The MM130 and the Taisei tunnelling system.
– The large Tunnelling Boring system developed together with Rio Tinto 2011-2014.

Roadheaders

Road Headers such as displayed in above image were built together with Eickhof.

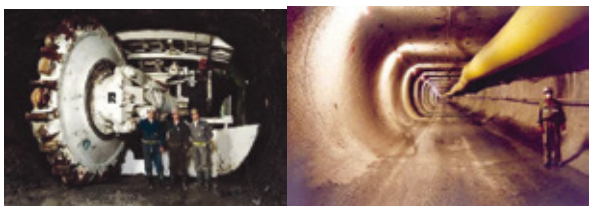
The famous Mini and Midi TBMs
TBMs from Atlas Copco Thun 1970-1980. It was basically an undercutting machine equipped with giant TC bits, low revolution and very high forces. Several were built and became very popular in urban water and sewer system applications. Based on the Mini design, a Midi machine for White Pine USA was also developed featuring four cutter wheels. Each of the four cutter rotate simultaneously as the whole face is rotating.



The Midi machine achieved a clean cut with a very large radius invert and a smooth horse shoe roof.

The Robbins Mobile Miners, later owned by Atlas Copco, now known as Epiroc
In the early 1990s, The Robbins Company started to develop Mobile Miners, the first of which was MM120 tried in Mount Isa. While there were some design issues, it was

followed up by MM120 was built and then tried with Pasminco. At both locations the rock was extremely strong, at UCS 300+, but the MM130 made great progress. Reports have made clear the importance of recognizing that these machines should only be used in their own environment. The MM130 was at standstill for extended shift time while waiting for drill and blast activities.



A classical picture of the MM130, and an excavated drift using the MM130.
The cutter head is very narrow, which allows for few cutters in action. As this presentation will later show, we have widened the cutter heads significantly.

Current Projects

The Rio Tinto Epiroc TBS

Around 2010 Rio Tinto was planning to open up several very large copper block caving mines including Resolution, Oyu Tolgoi and others. Block caving mines supposedly enable very low operational costs, but the block caving method has severe drawbacks.
For example, mine development can extend to 7 years or more at very large costs and, typically, there will be no ore output until all development is completed. Over the life of a large block caving mine, more than 100 km of tunnels will be needed.
Rio Tinto invited a number of equipment suppliers to propose mechanical rock cutting machines for this extensive development. The prime objective was speed and not, for instance, cost per meter or cubic meter. The reasoning for this was that if the development time could be cut in half, enormous savings would be made on the total costs. After a long evaluation period, two manufacturers were selected to deliver one solution each.

Epiroc (Atlas Copco at the time) was one of these equipment suppliers. The machine and its specifications were discussed extensively, multiple simulations and calculations were performed before the mechanical design started. The machine was then detail-designed and assembled in Finland with testing carried out on the factory floor. However, no actual rock cutting was done and during approximately five years the market changed. Copper demand did not grow as expected, metal prices plummeted and Rio Tinto finally decided to postpone the planned block caving mines.
The machine which had been built was disassembled and put into storage, waiting for new application areas, which have now materialized. The Swedish contractor Bergteamet AB has purchased the machine to develop a research tunnel at SKB's test facility at Äspö, Sweden. According to the plan, boring operations will start up during the second quarter of 2018. We expect that this project will be covered in various upcoming reports during the year.

It could be argued that the machine is more a tunnel factory than a "Mobile Miner". As shown in the image below, several back up units containing two different rock bolting stations are on site: a shotcrete station, a wire-mesh station, rescue chambers and all relevant gear including emergency power generators, compressor and more. The rock conditions at these proposed block caving mines differ slightly, but the rock is generally not considered difficult to excavate (UCS in the 40-160 MPa range).
Instead, other tougher challenges at these depths include extremely high temperatures and 70-80 °C is not uncommon. In situ stresses are also similar to the rock's UCS. The machine has a cutter head with 4.5 m diameter and 1.65 m width. It has 52 cutters, with two in each position (kerf) 180 degrees apart. Cutter head power is 650 kW at 12 RPM (variable speed drive) Total weight 700-1000 ton. Drift sizes extend up to 5.5 (H) x 4.5 (m) without moving the machine sideways.

The Anglo American – Epiroc RMDS project

Introduction

Anglo American is a leading producer of Platinum with several mines (shafts) in operation in southern Africa (and elsewhere). Platinum orebodies are typically relatively flat thin lenses ranging from almost "nothing" to, in some few places, 1.5 meter in thickness. Orientation is basically horizontal or with slopes up to 20-30 degrees. These mines will often have several reefs, some 30-50 meters vertically apart, called The Merensky, The UG2 etc. The red lines on the map point out the more significant locations of platinum mines in South Africa.

Still today, more than 90% of Platinum ore is excavated in the conventional way using pusher leg drilling for panels (modified roof-and-pillar), hoisted scrapers and so on. Needless to say, being a miner in these conditions with roof heights of 60 cm or less, is not just extremely demanding but at times dangerous.

For this and other reasons, the Platinum industry has over the past 10-15 years looked for "trackless" solutions meaning rig-based drills, LHDs etc. Different generations have since been developed starting with LP rigs (Low Profile) operating below 1.6-1.8 m, through XLP (lower) to ULP (Ultra Low Profile) with machine heights less 80 cm. As mentioned in the introduction, even if high performance machines are employed that are individually automated, it will be a difficult task to automate the whole chain of operations. And that is partly why the industry is now looking at mechanical rock cutting for these mines.
In this process, mine operators are looking at one category of machines for rock excavation and ore extraction, and a different range of machines more suitable for development work. Typical development consists of a number of parallel drifts following the ore's dip. These drifts are intended for different purposes such as hosting the main muck haulage conveyor or other machines, and other drifts are strictly for personnel. In what is known as an "assembly barrel" consisting of 5-7 parallel drifts, drifts are typically located 20 m apart and are cut perpendicular to the barrel. From these, the actual excavation is carried out. Epiroc is engaged in this development with both a machine for ore excavation and another for development. A number of other manufacturers are also involved deploying different machines for the ore excavation.
The joint development between Anglo American and Epiroc has progressed over a few years. The first "out-of-the-mine" development machine is now undergoing testing in one of Anglo's mines, Twickenham. The other machine for ore extraction is being started up for field trials.
In this paper we will limit ourselves to the machine used for mine development.

Rock conditions at the Twickenham mine site

Geology

The rock formations at the mine site are very old. The current consensus is that the rock was formed some two billion years ago. The intrusive rock has a very wide lateral extent and the thicknesses of the various layers is fairly constant. Randomly larger bodies can be found that are called pot holes. The intrusive rocks have a mineral composition typical for mafic rocks. There are various forms of pyroxenite and norite in the layers where the ore body is located. The ore is chromite and the parent rocks are various forms of pyroxenite (feldspathic, pegmatoid). The chromite reef is only half a meter thick and the other layers vary considerably in thickness from centimeters to meters. As the orebody is only 0.5 m thick/high large sections of parent rocks have to be mined out for practical reasons. A typical stratigraphic column is given in Figure 1.

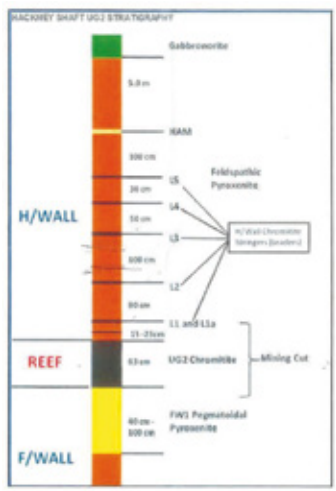


Figure 1 Stratigraphic column at section around the orebody

Rock mechanical properties

Extensive testing of rock mechanical properties in the orebody and surrounding parent rock has been conducted. This comprises uniaxial compressive strength, brittleness and wear properties. In table 1 below the results of the UCS tests are exhibited. As can be seen, more than one testing campaign has been performed and the varying test results are also shown. Figures on tensile strengths are provided by the mine company and are most likely not derived from testing of defined rock samples. This is likely an assumption that the typical tensile strength is 1/10 of the UCS, which could have been confirmed in previous testing. This means that the typical strength should be quite high, 16 to 20 MPa. These high figures, if they are correct, will hamper good penetration of disc cutters.

Lithology	Old UCS Value (*As stated in the TSD*)	*New UCS Value*	Variance
Footwall Pyroxenite	182 MPa	*155 MPa*	-27 MPa
Footwall Anorthosite	- *	*212 MPa*	0 MPa
Hangingwall Pyroxenite	182 MPa	*195 MPa*	+13 MPa
Footwall Norite	220 MPa	*220 MPa**	0 MPa
UG2 Chrome	89 MPa	*84 MPa*	-5 MPa

** Values not tested in the 2017 tests.*

Table 1 UCS test results from Twickenham mine. Please note that results from two test campaigns are shown.

Brittleness of the rock material has also been established by use of the Swedish brittleness test (S20). The typical value for the pyroxenite given by the mining company is 30. This is a low value which means that the material will not break as easily as in granitic rock. As a consequence, more energy will be needed to produce cracks in the rock when exposed to the load of a disc cutter. In other words, it will have a negative effect on the penetration of the cutters.

The abrasivity of the rock has great impact on the cutter consumption. For pyroxenite which is the dominating rock material to be mined out, the CAI value is 3.5. This means that the abrasivity is far less than for granitic rock but considerably higher than for e.g. limestone. The Twickenham mafic rocks have high densities and the figures shown below indicate a density slightly higher than what is the general assumption for mafic rocks. This is probably a consequence of the large pyroxene content. The density will have a very limited effect on the excavation performance of the disc cutters.

Generally, jointing the rock mass will have a positive effect on the penetration of the disc cutters. At the Twickenham mine, documented results on jointing are only available for vertical core drilling. It can be concluded that jointing is not intense. The spacing between the joints is so large that the boosting effect on the cutter penetration is limited. Spacing of joints found when drilling horizontal holes can only be speculated on. Here they are assumed to be similar as for the vertical holes as condition are verbally described by site personnel at the mine.

To sum up the consequences for the advance rate/penetration of cutters, the rock material is not ideal for mechanical excavation by disc cutters. However, the cutter consumption will most likely be moderate. Although the geology has disadvantages, the mechanical excavation is considered to improve the economy of the mining activity.

The Epiroc Mobile Miner machine

The machine has a cutter head rotating around a vertical axle. The head has a diameter of 3.5 m and a height of 1,1m. Built into the head is a single radial piston hydraulic motor rotating at the same speed as the head. (Direct drive). Installed power is 500 kW at 12 RPM (VSD). The cutter head is equipped with 32 17" HD TBM type cutters arranged as two opposites in each kerf, which is why the number of kerfs is 16. Hydraulic linkage can move the head sideways and vertical. The sideways movement can be done while cutting, while vertical movement is done by backing the head the full 0.7 m stroke, moving the head up or down and the sump in again. Muck is removed with a system comprised of two star wheels on an apron loading the muck onto a chain conveyor, followed by a normal conveyor midway in the machine. This ends up at the rear, high enough for trucks and other equipment to get in under. Grippers hold the machine stable while cutting, but are retracted when moving the machine on the crawler bands. Between the cutting part of the machine and the rear part, the backup with all pumps and so on, is where the cabins are located. Here, two bolting booms are also mounted for systematic bolting of the roof and crown while boring.

Epiroc's experiences so far

The machine was first tested at an old, closed-down mine called Kvarntorp in Örebro, Sweden. The mine is currently used for storage of documents etc., but also for advanced testing of Epiroc prototypes and new drill rigs. The rock is a pure sandstone UCS 130-150 MPa, tensile strength approximately 5 MPa, and is very abrasive.

A 70 meter-long tunnel measuring 2.5-2.6 m high and 5.5 m wide was bored with an average rate of penetration recorded at 1.3 m/h. Cutter wear was surprisingly low.

Typical drift at Kvarntorp, 2.4 m (H) 5.5m (W)

Tests in Twickenham

Based on the geological description above, it is clear that boring at Twickenham is a completely different challenge. The rock is very strong, has a high tensile strength, and is very ductile. Add to this the mixed face, with the (ore) reef relatively soft and the waste rock very tough. Rolling in and out from soft to hard and vice versa is always an added difficulty for TBM cutters. The initial trials showed good penetration rates but an unacceptable high cutter consumption rate. High cutter consumption can be devastating for the production cost and, in addition, changing cutters takes time which reduces the daily advance rate.

Following a series of tests and improvements, new procedures were established that have brought cutter wear into control. An average 40-50 m^3 per disc ring is recorded which is normal or good for a standard TBM in this type of rock. Since the drift area is not constant the target for performance is set at m^3/hour at instantaneous rate and m^3/ day continuous performance. We have not yet reached Anglo American's expectations for cubic meters per hour but are getting very close on the daily performance rate. The discrepancy between the two is due to the high availability, which is positive in itself. Tests will continue this spring and we see no reasons why we should not be able to reach the desired targets.

Hecla Mining Company and Epiroc Mobile Miner

Introduction

The mine is located in northern Idaho close to the Montana border. It was discovered late 1800 and has been in operation over nearly eight decades, as one of the major silver producers in the U.S. The mine is also very deep with current operations at more than 2000 m below the surface. The narrow vein mine produces 725 tons of ore per day that contains lead, zinc and silver. The applied mining method is cut and fill of the steep narrow vein. Ore has been identified down to a depth of at least 3000 m.

Geology and in situ stresses

The host rock mass is an extremely thick sedimentary sequence (the Belt Series) that has been tilted vertically by mountain building. The rock mass in the current section of the mine consists of weak, heavily foliated argillites and stronger, bedded silty-argillites termed siltite. The vertical veins (80° to 85° dip) are parallel to the foliation with an approximate width of around 3 m (10 ft).

There are two regional, vertical faults that parallel the vein; one forming the hanging wall of the orebody and one approximately 90 m (300 ft) in the footwall. Additionally, there are several thin, rough North-dipping faults that occur in the footwall of the vein which terminate on the major vertical faults. Both the argillite and vein package rock have moderate strength, with uniaxial compressive strength averaging about 100 MPa (14,700 psi with a range from about 70 to 125 MPa), and are moderately abrasive, with CERCHAR abrasivity index of 2 to 3. The major in situ stress is horizontal and oriented in a northwest direction with magnitude about 1.5 times the vertical stress. Consequently, the Lucky Friday stress magnitude at depth is comparable to significantly deeper South African gold operations.

The present mining method and the transition to mechanical mining

In this cut and fill mining operation, the drill and blast method is employed to extract the ore. As operations have progressed deeper, the mining approach has been altered to handle stress-related problems. The present method is called “Lucky Friday Underhand

Longwall", which implies long wall mining to the full width of the vein. The width and height are roughly 3 x 3.5 meters. When the full length has been mined out it is backfilled with a cement paste which is given vertically installed rock bolts at defined spacing. When the paste has achieved adequate strength, the next longwall cut starts and the paste will then form the roof.
As mining goes deeper, stress related problems become more and more pronounced. Exhaust fumes from the diesel-powered mining equipment and the exposure of personnel to high ambient temperatures and seismic events like rock burst, that to some extent is triggered by the blasting, creates tough conditions. For this reason, the mine management initiated a study on the possibility of using mechanical excavation instead of the drill and blast technique. Furthermore, the haulage equipment that generated the majority of the combustion exhaust fumes were to be changed to electrically powered units. Apart from air pollution the combustion engines also generated a lot of heat in the mine. By cutting down on the number of these engines, it would be possible to reduce fresh air supply. The number of mine personnel was also foreseen to be reduced.
Discussions were held with suppliers of mechanized mining equipment and a decision was taken to work with Atlas Copco, now known as Epiroc, on the task of creating a Mobile Miner suitable for the Lucky Friday mining operations. But before the final decision, an extensive analysis of cutting capacity of the Mobile Miner was presented. This work included a full-scale test at the Colorado School mines that have a test rig in their laboratory. Penetration and required drag-forces were monitored and the test results were positive. The decision was finalized to start the design and build of the mining machine, which is planned to be delivered to the mine in early 2020.

A set of design and operational criteria were developed for the Mobile Miner based on:
• Advance rate (ft/day/machine) • Mining width and height • Manoeuvrability (turning radius) and negotiable grade • Operation within the constraints of the current underhand mining system with engineered paste-fill roof • Teleremote (non-tethered) operation and automated face-cutting operations • Onboard bolter for wall bolting and meshing (roof pre-supported) with goal of eventual automation • Wall collision detection and guidance assist • High definition cameras for face viewing

A few words on the "Mobile Miner" machine
The Mobile Miner developed for Hecla Mining is a machine for mechanical rock excavation of tunnels in hard rock. It uses standard steel disc ring-rolling cutters on the circumference of a wheel, or cutter-head, to crack and fracture the rock so it can be transported via a conveyor to the back of the machine. The cutter-head is suspended on a boom with a horizontal rotating axis so the cutters can roll with vertical kerfs. The Mobile Miner is a partial-face machine, which requires the cutter-head to be repositioned to be able to excavate the entire tunnel face. The machine is demonstrated in the image below.

Some of the key benefits of Mobile Miner include:
-high mobility -a productivity that is expected to far outperform drill and blast - less demand for fresh air -less damage to rock-walls, and more precise cutting resulting in less overbreak.

Some technical data
Tunnel / drift size to be excavated: width: 3.0 to 4.5 m, height: 3.6 to 4.5 m
Slope: +- 20 percent
Cutter head diameter 3.5 m, width: 1.15m
Cutters: 17 inch
Machine size: width 2.5m, height 3.5m, length 20m

Final remarks
In this paper we have presented a historical panorama of advanced rock excavation technology followed by a review of a recent innovation, the Mobile Miner, which is expected to take center stage in mining challenges around the world.
The Mobile Miner is a small, flexible and customizable machine that makes mining projects more productive, predictable and easier to schedule. During 2018, Epiroc will focus on the trial of three new concepts at various stages of development that will add further value and increased safety in mining.

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