Blasting 1 Million Tons, 205 Meters from a Town

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Abstract

Blasting at very close proximity to urban areas is typically a situation where both local communities and mining stakeholders get nervous. The context becomes logically even more tensed when the blasting operations have to be performed above an old underground mine. When mitigating subsidence risks requires firing the largest possible shots, the nuisance control (flyrock, vibration, and noise) required by local and national regulations, contrarily urge for being more conservative.

OSISKO Mining Corporation is a Québec-based mining company whose main property, 100% owned, is located in the heart of the prolific Abitibi Gold Belt in Quebec, immediately south of the town of Malartic, approximately 20 kilometers west of the town of Val d'Or. As of January 1, 2013, the open pit Proven & Probable gold reserves stand at 10.1 million ounces. Since the beginning of operations in 2011, the total production amounts to 588,615 ounces of gold. The property includes the former Canadian Malartic underground mine, which produced more than 1 million ounces of gold from 1935 to 1965.

This papers presents the company’s experience in simulating, designing and shooting large to very large-scale blasts that conciliates the company’s commitment to sustainable development, the strict observance of local and national legislation, and the prevention of ground movement that could affect the achievement of the operational objectives.

Particular emphasis will be on integrating innovative blasting digital simulation techniques into the daily operational process, offering the company the opportunity of shooting a 1 million ton (2 billion lb) successful mega-blast, 205 meters (673 feet) from the closest residential area.

Location and Geology of the Malartic Site

The Canadian Malartic gold-bearing deposit is located in Québec, in Canada, just to the south of the town of Malartic, approximately 20 km to the west of the town of Val-d'Or. Its coordinates are 48º 7' 45" latitude N and 78º 7' 00'' longitude W. The deposit overlaps the southern boundary of the eastern part of the Abitibi gold belt that contains many large gold-bearing deposits. The exploration phase began in 2005. The mine was developed in just 6 years. The first gold ingot was cast in April 2011, and commercial production began in May 2011.

The deposit is an archean porphyritic gold-bearing system, consisting of a widespread disseminated ore halo of gold and pyrites, within a dioritic porphyry and altered meta-sediments. Drilling and data collection defined the boundaries of a gold-bearing system measuring 1900 m x 350 m (6200 ft x 1148 ft), with a real thickness varying from between 40 m to 270 m (131ft to 886 ft), to a vertical depth, from the surface, of 320 m (1050 ft). The deposit is composed of 10.1 million ounces of proven and probable reserves (310.6 Mt @ 1.01 g/t Au, according to rule 43-101), 11.70 M oz of overall measured and indicated resources (347.3 Mt @ 1.05 g/t Au), and 1.20 M oz of supposed overall resources (49.6 Mt @ 0.75 g/t Au).

The feasibility study of November 2008, as well as the following updates of reserves in February 2010, March 2011 and February 2013 revealed a potential open-pit production of between 0.5 and 0.6 M oz of gold per year, for a 16-year operation, with a daily processing capacity of 55 000 tons (121M lbs). Ore processing is via a traditional cyanuration process, then the precipitate is extracted by absorption on activated carbon (CIP or "carbon-in-pulp" process). The Canadian Malartic mine required investment in excess of $1 billion.

Specific Site Constraints

The property includes the old Canadian Malartic underground mine that produced over one million ounces of gold from 1935 to 1965, from ore whose content varied from 3 to 6 g/t Au, and over 5 M oz, if we count from 1935 to 1983. The area worked is partly situated above the old galleries of the underground mine, thus creating significant subsidence risks. The presence of these galleries has a direct impact on the operating methods and safety measures implemented to protect persons and property.

The mine (figure 1) reaches as far as the town, half of which has been relocated to the north (figure 2), at a cost of $ 160 million after the exploration phase. Therefore, this is a mine "in a town", with all the associated constraints: flyrock, vibration, noise, dust and blasting fumes.

Figure 1: view of the mine close to Malartic town

Figure 2: the Company's resettlement program for part of the town of Malartic (2008-2009). The relocated southern district, partly closed due to subsidence risk, is outlined on the left-hand side, while the new district appears on the right.

Several measures were taken to reduce the impact of mining on the town of Malartic. The drilling equipment was soundproofed, matting was added to the truck skips, and the position of the plant, crushers and conveyors was optimized to decrease the noise impact of the project.

A huge protective so-called "green wall" (figure 3) separates the pit from the town. A few meters behind the wall there is a park with a children's playground, shops and housing.

Figure 3: Location of the "Green wall" (detail view at left) and of the seismic monitoring points

Site Operating Principles

Traditional open-pit mining methods were chosen for the Canadian Malartic deposit because of its low content and surface proximity. Due to the large quantity of ore with a low content (estimated waste/ore ratio of 2.3:1), a high production rate for the plant of 55 000 t/day, was defined as being profitable from an economic standpoint, and would enable the value of the deposit to be maximized.

The result is a very conventional operating process, with stripping, then blasting phases in terraces dropping to the pit. The waste and ore are loaded by three 28 m^3 (989 ft^3) electric hydraulic excavators (O&K RH340-B), three wheeled loading shovel (two LeTourneau L-1850 and one CAT 994). Transport is via CAT 793F - 227 ton (500 000 lbs) - rigid trucks.

General Blasting Constraints

Blasts must be in compliance with the operating constraints (size distribution) but above all with the environmental constraints due the proximity of the town.

- No flyrock beyond the confines of the pit
- Vibration: PPV <12.7 mm/s (0.5 in/s)
- Overpressure: <128 dB
- Blasting fumes (none over the town)

No blasting is carried out when the wind is from the south as to protect the town from blasting fumes. Blasts are scheduled at the least sensitive times of the day, and there is constant communication and information with the authorities and the town's inhabitants. Seven seismographs have been installed in the town of Malartic to measure the overpressure and vibration levels of each blast (figure 3, above).

The authorization of "special blasts", due to their being close to the town, their duration and/or size, are managed individually, directly coordinated with the Ministry of the Environment of Québec and the town of Malartic, and the monitoring committee including the residents. A decree of the Ministry of the Environment enabled the mining company to carry out blasts of up to 15 seconds. This restriction was exceptionally extended to 37 seconds to satisfy the constraints for "special blasts" scheduled for October 2012, also referred to as "mega-blasts" due to their unusual size. For blasts such as these, in addition to the extensive use of blasting mats and sand, evacuation areas from 100 m to 600 m (330 ft -2000 ft) were defined. The authorizations had to be obtained individually with full and accurate documentation. Recourse to digital simulation was proved to be decisive in obtaining the authorizations, particularly thanks to the credibility that their scientific features offer.

General Blasting Design

At the beginning of the project, a traditional design was used. A campaign of test blasts was undertaken with small charges in order to define the seismic behavioral laws (K and alpha), and for the zoning of the site, based on the maximum charges per delay to adhere to the seismic levels. For each area, a diameter was also calculated that was compatible with the charge per delay, taking into account the flyrock risks. After an analysis, a diameter of 225 mm (8 7/8”) was retained for the areas farthest from the town, whilst a diameter of 89 mm (3 1/2") was preferred in the areas closest to the residential areas.

The number of charges recommended per hole after the digital simulations varied from several, close to the town, to one, further afield. The use of electronic detonators (EDD) was generalized at the site to guarantee compliance with the charge per delay, due to the size of the blasts (several hundred holes). The height of the benches was on average 10 m (33 ft).

Specific Blasting Design

In areas close to the town, operations were above the old underground mine. A network of galleries and cavities transformed the solid rock into a "Swiss cheese" whose stability was difficult to assess, particularly when very heavy vehicles drove constantly overhead. For safety reasons, the mine therefore decided to mass blast these areas, in order to limit the risks that would appear when making smaller blasts (decompression of land, uncontrolled subsidence when digging or drilling for instance). This technique is similar to block caving. "It is a special works site. We are above three open works sites that are interconnected. For the safety of our employees, we have to blast in one go, to avoid subsidence,” said Hélène Thibault, company’s Communications Director ("Sautage de 940 000 tonnes", 2012). The company's modeling led to forecast that, during the blast, the rock would fill the voids of the sites below and stabilize the whole area.

Although this option was reassuring for the stability of the ground, it was worrying for the neighboring population, for whom a large-scale blast (e.g. 1 million tons), represented a danger both for people and housing. Therefore, in this configuration, blasting required a specific design and measures in order to guarantee suitable and safe results, especially as far flyrocks, fumes and vibrations are concerned.

Specific Design for Flyrock

Substantial final stemming (from 3.6 m to 5 m (11.8-16.4 ft) with a diameter of 140 mm (5 1/2") was used to contain vertical flyrock. In compliance with the site's practices, particularly in areas closest to the town, the blasts were covered with a layer of inert material (like sand) or matting to limit and contain any stemming ejection or cratering.

Specific Design for Fumes

Blasting fumes (orange fumes) that can sometimes be perceived at a blast are the result of poor detonation of the explosive. This can have several origins; but in the present configuration, it can be specifically due to the effect of time on the explosive. Due to the size of the blasts, loading takes several weeks. Water can alter the explosive or cause some holes to collapse, leading to dilution via the loss of the confinement. The latter can occur during the dynamic phase of the blast via decompression in the former galleries or chambers.

The measures taken to limit the exposure to these harmful blasting fumes consist of only initiating blasts when the prevailing winds are favorable (winds from the north), blowing any potential fumes in the opposite direction to the inhabited areas. These measures are not specific to "mega-blasts", but their criticality increases with the size of the blast and its location above the underground mine.

Specific Design for Vibrations

The first measure, described above, is to limit the charge per delay, according to the different areas of the pit. The method used is a traditional method based on the calculation of an attenuation law (K and alpha parameters). This method leads to using decked charges closest to the town.

The second measure consists of using the "Signature Hole" technique which allows us to oppose the phases of the seismic waves from each of the charges. This technique is based on blasting single holes (one single charge) for which the vibrations are measured at the critical points (housing), and the use of electronic detonators enabling accurate firing at the desired time. Thus, optimized firing sequences are calculated for each blast.

Characteristics of a Typical “Mega-Blast”

In this context, large so-called "mega-blasts" are used. The example below describes the typical characteristics of one of these mega-blasts.

- Number of holes: 1025 (figure 4)
- Number of charges: 1806 (figure 5)
- Diameters: 115 mm (4 9/16") and 140 mm (5 1/2")
- Charge per delay: 70 kg (154 lbs)

- Specific charge: 480 g/m^3 (0.03 lbs/ft^3)
- Minimum Inter hole delay: 6 ms
- Duration of the initiation sequence: 22.5 s (figure 6)
- Average depth of the production holes: 10 m (33 ft)
- Depth of the block caving holes: up to 50 m (164 ft)
- Total quantity of explosive: 110 tons (242 508 lbs)
- Volume of the muck pile: 250 000 m^3 or 500 000 t (8 M ft^3 or 1.1 billion lbs)
- Closest housing: 205 m (673 ft)

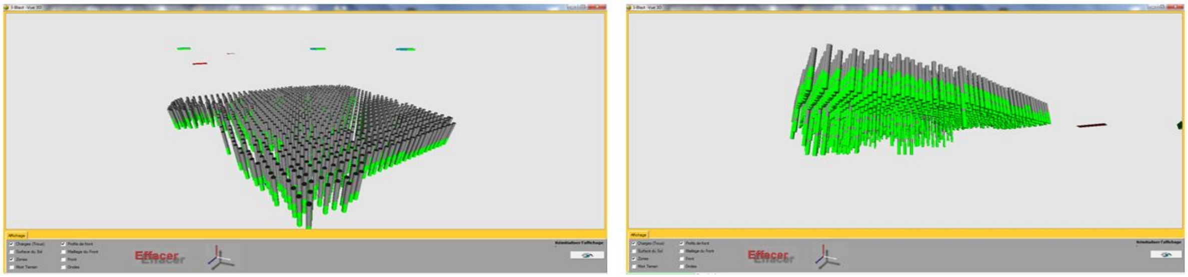


Figure 4: Two 3D views of the 1025 hole blast

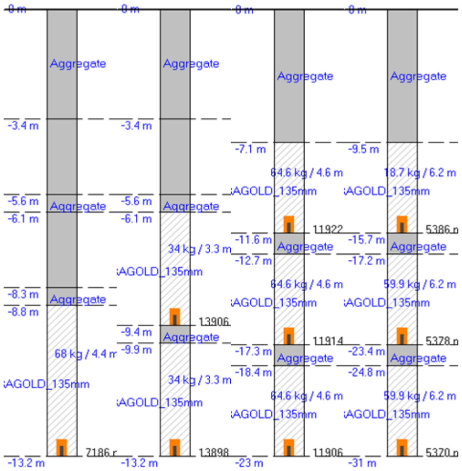


Figure 5: Hole loading from single to multiple decks

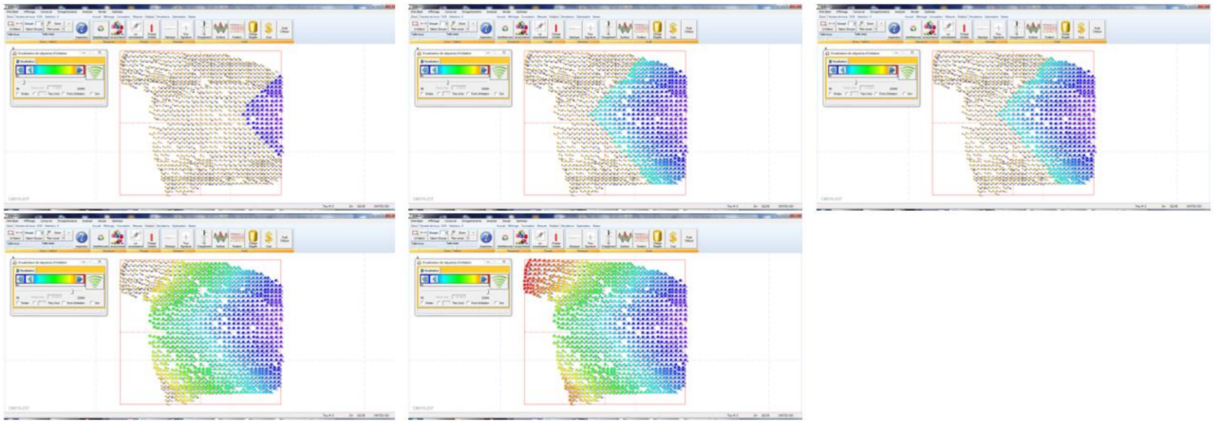


Figure 6: Final sequence for Mega-Blast #2

It is easy to understand that this type of blast could alarm the neighboring population. During one of these operations, on 27 October 2012, the Citoyens du Quartier-Sud de Malartic residential group said they would keep a close eye on this "special blast", as it had been defined by the company. Their spokesperson, Carl-Hugues Leblanc was worried about the proximity of the inhabited area. "Some dynamiting will be only 70 feet from the residence of one of our members. So we are very worried," he told a reporter sent to the site by Radio Canada ("Osisko procédera à un sautage particulier", 2013).

Indeed, the mining company was preparing to blow up **940 000 metric tons of waste and ore (2.1 billion lbs).** Months of preparation were necessary. The importance of the communication and information plan managed by the company was in the case in point of primary importance.

A safety zone was set up and thirty or so company's employees were positioned to prevent people accessing the safety areas, should any flyrock be cast. The residents closest to the blasting area were evacuated as necessary as a precautionary measure. As early as mid-September, the company sent out a letter to each resident in the town informing them that larger, and above all, longer blasts than those usually made would take place "shortly."

Blast mats were positioned and a thick layer of sand was spread over the surface bench. The sequence initially scheduled to last 37 seconds was divided into two separate operations in the end: one lasting 15 s, shortly followed by another of 22 s. The usual length of a blast at Malartic was 4 to 6 s.

The Dispensatory Nature of "Mega-Blasts"

The Minister of the Environment of Québec, Daniel Breton, had given his consent for a 37-second blast subject to conditions; in particular requiring the setting up of a safety zone to protect the site's employees, but also the formal request of an independent study, with an expert's report to be submitted to the ministry. Thus, the authorization was granted via a dispensation from the Ministry of the Environment of Quebec to whom the company had to provide a report on the simulation of flyrock for the blasts, a plan of the safety zone implemented and a plan of the safety measures implemented to protect persons and property

This operation was in the media limelight, in particular due to the unusual immediate proximity of housing to this mega-blast, and the political context surrounding the dispensatory procedure.

How to Guarantee the Results of Such a Blast

An explanation of all the technical measures (state of the art) taken by a team of professionals to carry out a blast such as this correctly, was not sufficient to convince people of their being well founded. The size of the blast (in terms of the rock blasted, the quantity of explosive), and the proximity are frightening!

"We informed the residents to avoid them being surprised, but we carried out tests and simulations in order to comply with the vibration and overpressure figures", Thibault asserted a few days before the blast ("Sautage de 940 000 tonnes", 2012). Digital simulation was at the core of the arrangements in order to provide the necessary guarantees. This technique that consists of virtually reproducing the effects of a blast to make sure that the result will be conform to the objectives, be they for risks and nuisances (flyrock, vibration, noise) or the size distribution of the blast, enabled the company to obtain the administrative authorizations, whilst providing the different stakeholders with an additional degree of confidence.

A Model Based on Physical Equations

To simulate is to forecast. In this respect, two types of model are in direct opposition. Models based on statistics allow inputting different configurations and results, and the model can interpolate for other configurations. This type of model is limited in that it is only capable of simulating within the scope of the reference cases.

Now in our "mega-blast" situation, we are confronted with new relatively unique situations (the first blast takes place without there being a comparable operation to serve as a reference). Therefore, we have to turn to the second type of models: models based on physical principles. The advantage is that they only require one reference case to be operational (calibration). The universality of the physical principles allows all types of configurations to be calculated, with an excellent degree of reliability (Bernard, 2009), even if they are far-removed from the reference case. This is the case of the DNA-Blast model and its I-Blast software. Therefore, this is the model (figure 7) that was chosen and used to simulate the effects of these mega-blasts.

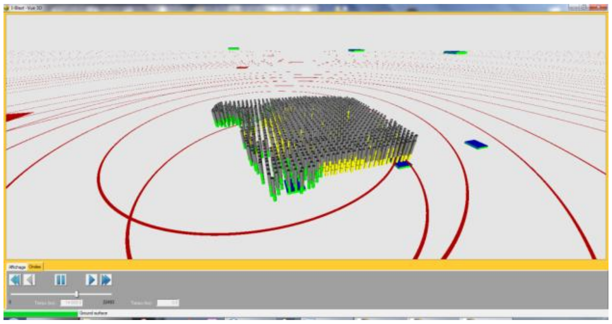


Figure 7: Vibration simulations on a 3D view of the blast: seismic waves in red

Signature Holes and Digital Simulation of Vibration

The Signature Hole principle was used, as previously mentioned. In this configuration, the use of physical principles for digital simulation is very relevant (Bernard, 2012). The model must be capable of simulating the seismic signal, its maximum level of vibration and its frequency content, for more than 1800 spaced out charges. The presence of decked charges also requires the simulation technology to take into account the 3 dimensions in its representation, and more importantly in its calculations.

With 1806 charges and 1025 holes, the hypothesis that the signal of a signature hole would be representative of all the holes in the volley can appear to be risky. This is why six signature holes (figure 8) were made, separated by 1 second and located as close as possible to the area to be mined. Six of the single holes gave a workable waveform.

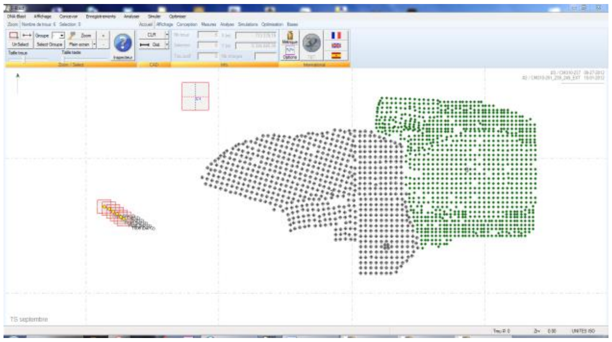
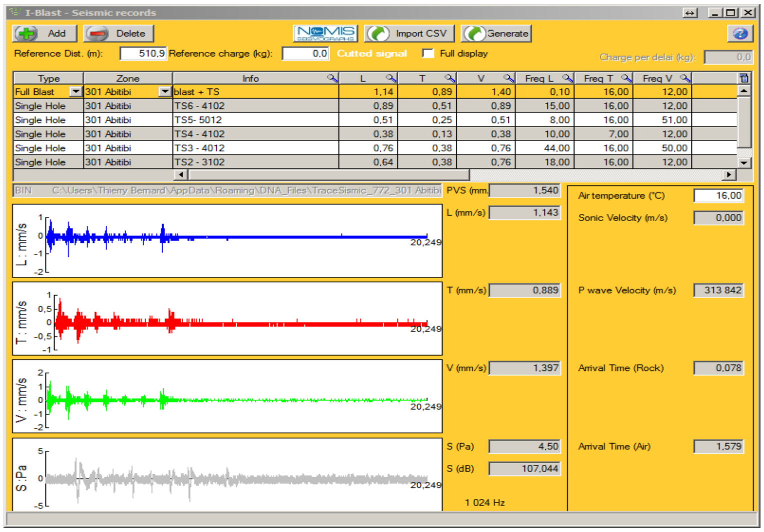


Figure 8: Location of the 6 signature holes (red squares), at left to the Mega-Blast

The results showed different amplitudes (figure 9) and wave shapes, but a relatively similar frequency content (figure 11). Six simulations corresponding to the six signature holes were carried out, which enabled the confinement differences to be taken into account and provided an estimated range of the vibration levels.



Reference Dist. (m): 510,9
Reference charge (kg): 0,0
☐ Full display
Charge per delai (kg): 0,0

Type	Zone	Info	L	T	V	Freq L	Freq T	Freq V
Full Blast	301 Abitibi	blast + TS	1,14	0,89	1,40	0,10	16,00	12,00
Single Hole	301 Abitibi	TS6 - 4102	0,89	0,51	0,89	15,00	16,00	12,00
Single Hole	301 Abitibi	TS5- 5012	0,51	0,25	0,51	8,00	16,00	51,00
Single Hole	301 Abitibi	TS4 - 4102	0,38	0,13	0,38	10,00	7,00	12,00
Single Hole	301 Abitibi	TS3 - 4012	0,76	0,38	0,76	44,00	16,00	50,00
Single Hole	301 Abitibi	TS2 - 3102	0,64	0,38	0,76	18,00	16,00	12,00

BIN C:\Users\Thierry Bernard\AppData\Roaming\DNA_Files\TraceSismic_772_301 Abitibi

PVS (mm. 1,540
L (mm/s) 1,143
T (mm/s) 0,889
V (mm/s) 1,397
S (Pa) 4,50
S (dB) 107,044
1 024 Hz

Air temperature (°C) 16,00
Sonic Velocity (m/s) 0,000
P wave Velocity (m/s) 313 842
Arrival Time (Rock) 0,078
Arrival Time (Air) 1,579

Figure 9: Seismic traces of the 6 signature holes

An attenuation law (figure 10) was performed on the signature hole PPVs recorded at various distances (figure 11) in order to feed the simulation model. Results were very consistent, building confidence in the simulation results.

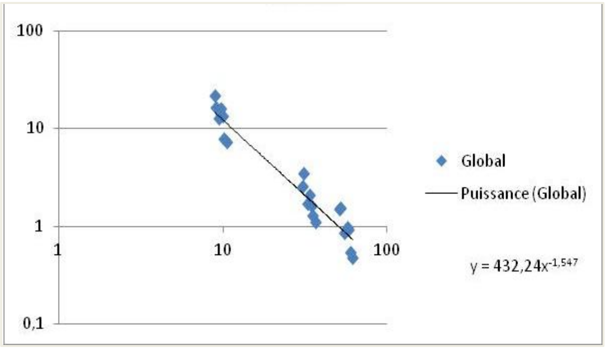


Figure 10 : Attenuation law based on signature holes

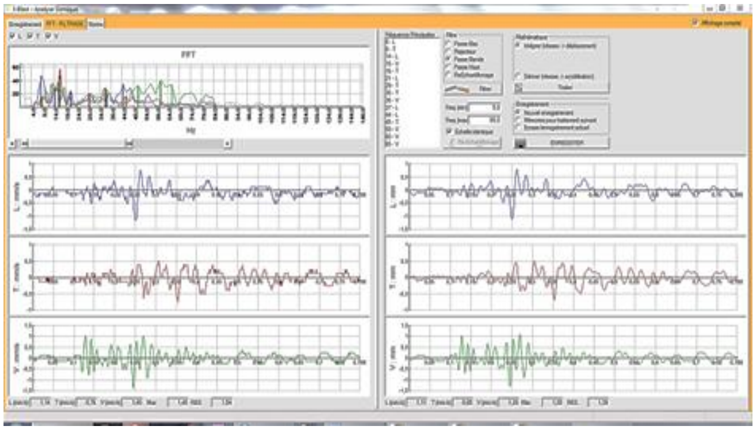
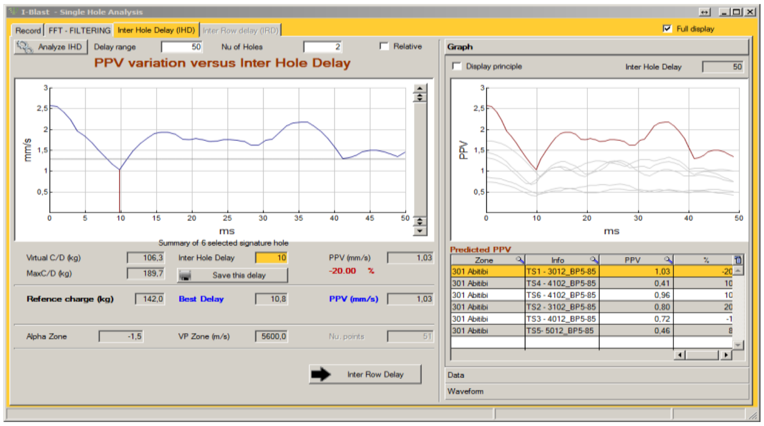


Figure 11 : Typical frequency content of a Signature Hole

For reasonably sized blasts, the firing sequence was optimized using the Signature Hole method (figure 12).



Delay range 50

Nu of Holes 2

☐ Relative

☐ Display principle

Inter Hole Delay 50

Summary of 6 selected signature hole

Virtual C/D (kg) 106,3

MaxC/D (kg) 189,7

Inter Hole Delay 10

PPV (mm/s) 1,03

-20.00 %

Refence charge (kg) 142,0

Best Delay 10,8

PPV (mm/s) 1,03

Alpha Zone -1,5

VP Zone (m/s) 5600,0

Nu. points 51

Predicted PPV

Zone	Info	PPV	%
301 Abitibi	TS1 - 3012_BP5-85	1,03	-20
301 Abitibi	TS4 - 4102_BP5-85	0,41	10
301 Abitibi	TS6 - 4102_BP5-85	0,96	10
301 Abitibi	TS2 - 3102_BP5-85	0,80	20
301 Abitibi	TS3 - 4012_BP5-85	0,72	-1
301 Abitibi	TS5- 5012_BP5-85	0,46	8

Figure 12 : Optimum delay as a result of processing 6 Signature Hole for one location

However, in the case of a mega-blast, the sequence was constrained, firstly by the configuration of the blast itself, and the limit of the programmable delay range of electronic detonators (EDD). In the case in point, EDD enabled us to have 22 000 ms delay available. Consequently the mega blast was split into two mega-blasts respectively of 1025 and 790 holes. For mega blast #1, as an example, 1025 holes represent 1806 charges: this provided a maximum of 12 ms between charges. The firing order of the charges was defined by the practitioner (expert) according to his knowledge of the underlying ground. The first simulation (figure 13, left) was then carried out with a 8 ms inter charge delay and showed a peak particle velocity (PPV) of 19.5 mm/s (0.77 in/s) that was not compatible with the vibratory limit of 12.7 mm/s (0.5 in/s).

A virtual trial and error process was then applied thanks to the digital simulation software in order to discover, via the iterations, the deviation between charges that would be compatible both with the structural limit of the blasting accessories, and that would satisfy the limit in terms of PPV. For final design, delays between charges of 10 and 12 ms were used (figure 13, right). The simulated PPV was 5.9 mm/s (0.23 in/s).

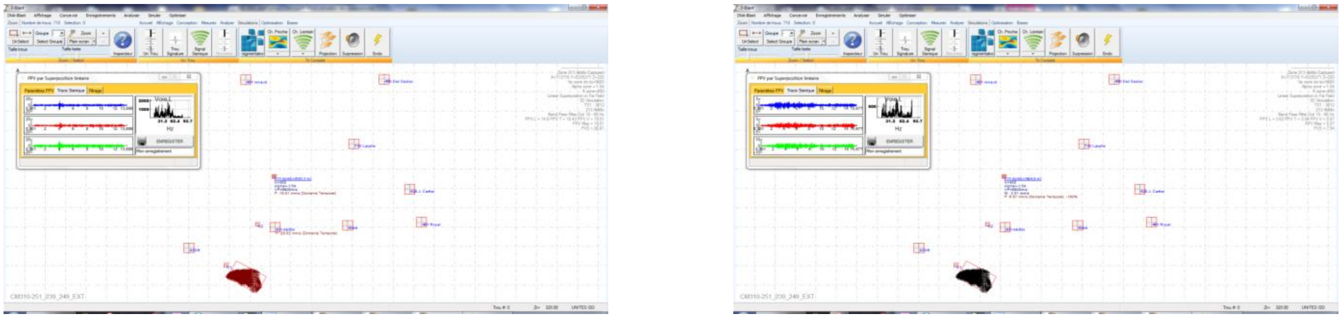


Figure 13 : Vibration simulations with 8 ms (right) and 10-12 ms (left) Inter Charge delay

Flyrock Simulation

A flyrock simulation was also undertaken for each of the holes with a free face, in order to predict the maximum horizontal projection distance. A simulation of the other blast holes was carried out to analyses the location and magnitude of any vertical flyrock, particularly caused by stemming. Each hole was accurately recorded (final stemming, depth of cover (figure 14), so the simulation (figure 15) underlined the boundary conditions that were then corrected on site.

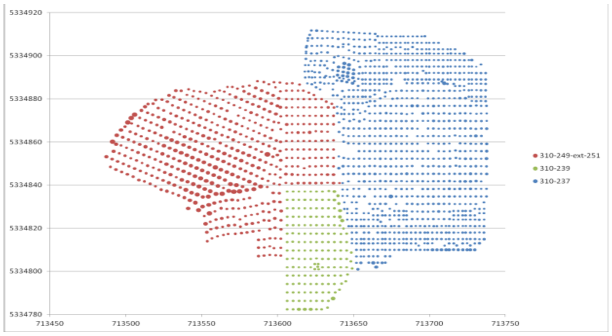
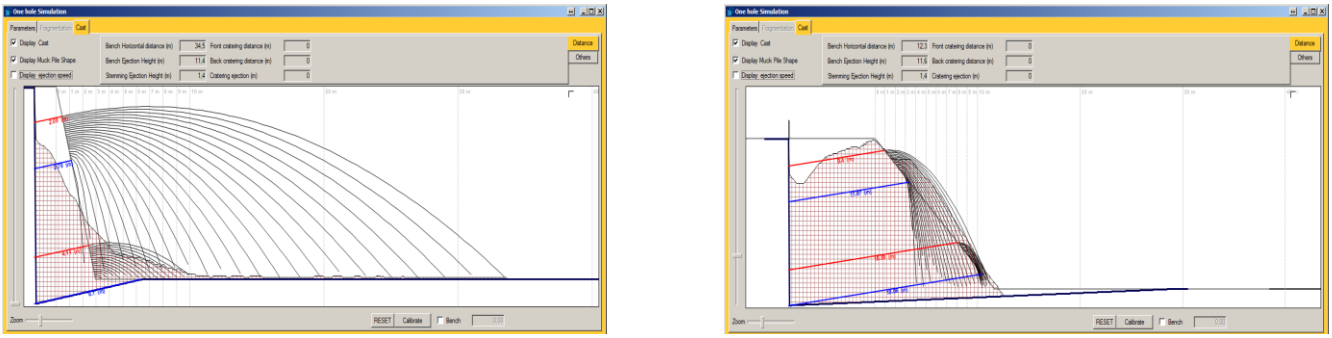


Figure 14 : Stemming length reporting for each hole



☑ Display Cast
☑ Display Muck Pile Shape
☐ Display ejection speed
Bench Horizontal distance (m) 34,5
Bench Ejection Height (m) 11,4
Stemming Ejection Height (m) 1,4
Front cratering distance (m) 0
Back cratering distance (m) 0
Cratering ejection (m) 0

☑ Display Cast
☑ Display Muck Pile Shape
☐ Display ejection speed
Bench Horizontal distance (m) 12,3
Bench Ejection Height (m) 11,6
Stemming Ejection Height (m) 1,4
Front cratering distance (m) 0
Back cratering distance (m) 0
Cratering ejection (m) 0

Figure 15 : Flyrock simulations depending burden

Presentation of the Simulation Results

In the case in point, communication and information were crucial, as we saw. The presentation of the results in the form of graphs showing the ranges of incertitude enabled a better account to be taken of the simulation results to implement the relevant recommendations and safety measures.

Both from the standpoint of administrative authorizations as well as the debate with the political world, or residents groups, the clear and exhaustive presentation of credible simulations, based on physical principles enabled a certain degree of serenity to be maintained and helped with a favorable outcome for this operation.

The Mega-Blast Design and Implementation

The implementation of the Mega-Blast ran through particularly challenging constraints, starting from ground instability due to the already mentioned old galleries. Drilling and loading operations were particularly affected as shown in figures 16.

Figure 16 : Drilling (right) and loading hole (left) safely over an instable area

The high number of charges created a dense network on the surface, requiring extensive craning to proceed with the sand-covering stage without damaging the electronic detonators cables (Figure 17).

Figure 17: Covering the blast area with sand, craning to avoid damaging EDD cables

Similarly, the areas situated at the closest distance between the mega-blast and the residential area, were covered with a very large number of blast mats, as shown in figure 18.

Figure 18 : Mat covering on closest holes to the town

Finally, a specific evacuation area was defined and implemented (Figure 19)

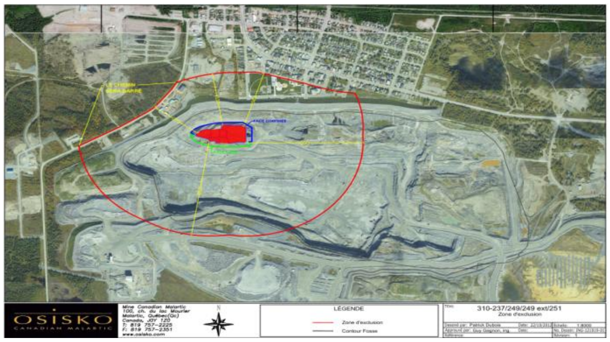


Figure 19 : Evacuation area

The Mega-Blast: the Results

The seismic results were conforming to the forecasts of 4.4 mm/s (0.17 in/s) for a simulated range of between 3 and 5.5 mm/s (0.12 – 0.21 in/s) (figure 20).

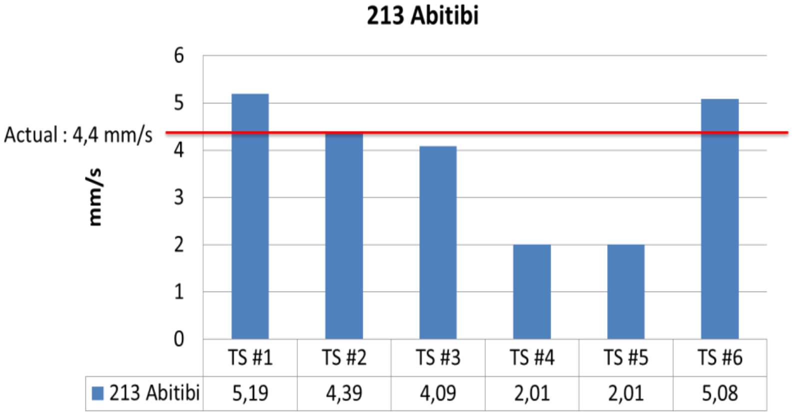


Figure 20 : PPV simulated versus actual for the “213 Abitibi” monitoring point

The frequency content and the seismic trace were also in line with the forecasts (figure 21)

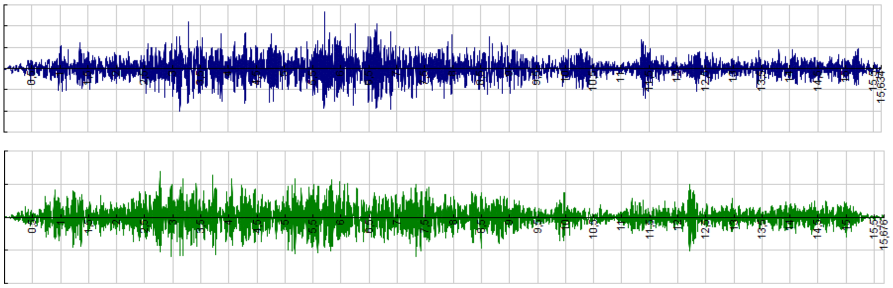


Figure 21 : Comparing predicted (blue) and measured (green) waveform

All the face flyrock was very close to forecasts as well as the ejection of the stemming. Only one area seriously decompressed into a cavity and created a vertical ejection (figure 22) causing a few fragments to fall within the confines of the safety zone. Today, this type of unforeseen circumstance is difficult to take into account and represents the limit of the simulation exercise.

Figure 22 : View from the town of the exceptional blast carried out on October 27 at Malartic mine Photo: Daniel Rompré / Ville de Malartic

Conclusion

Mega-blasting at Malartic mine was possible at such a short distance to the town and adhering to the various constraints be they, seismic, flyrock, or blasting fumes, thanks to the perfect control of the blasting parameters and the use of modern technology such as electronic detonators and digital simulation.

Digital simulation based on physical principles offers:

- The possibility of finding the best set of parameters thanks to virtual trial and error
- An additional degree of confidence, in the choice of the blasting parameters when the blast is very complicated or exceptional

However, we must remain humble and take all the necessary precautions and protection with regard to persons and property, because unforeseen circumstances, chiefly linked to the geology, can never be reduced to zero.

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