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# Analysis and improvement of the fragmentation quality of blasted rock using digital image processing: the case of the Kef Lahmer quarry, N-E Algeria

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**Summary**

The mining industry plays a significant role in the extraction and processing of various ore materials (phosphate, copper, iron, gold, aggregates and others), contributing to industrial and economic development. Rock fragmentation is a fundamental operation and a complex element in mining activities influenced by multiple parameters, including geological and geometric factors, explosive load parameters, and others related to the details of the execution of the blasting plan. The effectiveness of blasting depends on factors such as the geological structure, volume, optimal size of rocks to be blasted, and compliance with safety conditions. To achieve desirable outcomes, it is crucial to make informed decisions regarding the types and quantities of explosives to be used, along with other principal parameters of drilling-blasting design. Continuous evaluation of rock fragmentation is essential for optimizing blasting plans by contributing to the improvement of the quality-price ratio under favorable environmental and safety conditions. This study aims to analyze and enhance the quality of rock fragmentation resulting from blasting activities in the Kef Lahmar-Setif limestone quarry (northeast Algeria), which is characterized by significant rock mass fracturing. This fracturing will be carefully analyzed in order to arrive at an accurate blasting plan for the structure of the studied rock massif. As the aim of the research is to optimize the blasting plan to generate maximum gas pressure and minimize shock pressure due to the existing fractures in the rock mass. in order to test this hypothesis, we conducted several blasting tests by modifying the charge rate of the explosives used (Anfomil and Marmanite III), while maintaining the same parameters in the blasting plan for each test. The goal was to achieve optimal fragmentation. The particle size of the blasted rock pile was analyzed using WipFrag software, which utilizes image analysis techniques.

**Keywords**

blasting • fragmented rock mass • explosives • image analysis • WipFrag

## 1. Introduction

Mining and quarrying industry is considered as an important industry as it provides several key natural resources used for energy, such as coal and uranium, in construction, such as iron ore, aggregates and cement, and in many other sectors [Lacko et al. 2017]. It is important for the economy, particularly in terms of employment, and it has social and environmental consequences, both at global and local level [Rodrigues and Mendes 2018].

Blasting is a critical step in mining operations, as the economic viability of the industry relies on an optimal design of the blasting plan in order to achieve the right fragmentation. The quality of fragmentation has a great influence on subsequent operation, when well-fragmented pieces do not leave secondary debitage [Babaeian et al. 2019, Singh et al. 2019]. The primary objective of blasting engineers is to obtain a pile of cuttings with a size distribution suitable for efficient loading, transportation, and crushing [Bamford et al. 2021]. Blasting has a significant impact on downstream processing in mining. The impact of blasting on the mining productivity is manifested through the rock diggability, the excavator efficiency, the oversize problems and secondary blasting, the crusher throughput and the energy consumption, the plant efficiency, yield, and recovery [Inanloo Arabi Shad et al. 2018]. Rock fragmentation has a significant impact on production costs, drilling and blasting efficiency, as well as the performance of loading, transportation, and crushing subsystems in mining operations. Poor fragmentation can increase costs due to inefficient material handling, decrease equipment efficiency, and lead to lower productivity [Kulatilake et al. 2010]. It allows to measure the size distribution of rock fragments after an explosion and depends on factors such as blasting design, rock strength, natural discontinuities, and thus it is considered a key parameter for evaluating blasting performance [Manzoor et al. 2022, Maerz et al. 2018]. Previous research has shown that the properties of the blasted rock mass (including rock mass and intact rocks) strongly influence blasting outcomes. Good fragmentation is directly related to the rock matrix, when intrinsic properties such as resistance to mechanical stress and hardness serve to keep the fragments in blocks as well as the discontinuous structure, which results in a loss of explosive energy [Akbari et al. 2015, Faramarzi et al. 2013]. Optimal fragmentation by blasting refers to a high percentage of fragments within the desired size range that can be effectively handled by equipment without additional processing [Maerz et al. 1987, Saadoun et al. 2023, Fredj et al. 2015, Fredj et al. 2019]. Various methods, including sieve analysis and digital image analysis, are used to assess fragmentation – each with its advantages and disadvantages. Digital image analysis, provided by software programs like Split-Online, Split-desktop, Gold-Size, and WipFrag, has become the most commonly used indirect approach for evaluating fragmentation in recent years [Nanda et al. 2020, Sudhakar et al. 2006, Shehu et al. 2022, Saadoun et al. 2022]. This study aims to present the results of several blasting tests conducted at the Kef Lahmer aggregate quarry to analyze and improve the quality of fragmented rock using WipFrag image processing software. A final evaluation of this analysis will lead us to an optimization of the blasting plan and subsequently to a simplification of the movement chain for the treatment of fragmented rocks. The effect of different explosives and their charge rates on fragmentation is investigated, particularly due to the presence of substantial cracks in the rock mass, causing a loss of energy through the discontinuities. In order to demonstrate the effect that the seals have on explosive performance, a series of four explosive blasting tests were carried out under the conditions of the Kef Lahmer rock mass. This study was based on varying the percentage of each type of explosive in order to reach an optimal blasting plan. The results obtained were processed by the image analysis technique using a tool designed for this type of problem.

## 2. General setting

The Kef Lahmer quarry represents a large part of the Algerian mining sector with an annual production of 01 million tons for construction and public works. The Kef Lahmer quarry is situated in the Ain Lahdjar municipality, 37 km from the Setif province in northeastern Algeria, on the side of Jebel Youssef. The region's altitude ranges from 1219 m (Jebel Gustar) to 957 m (Oued Sekakene). The region has a well-developed hydrographic network, including the Sekakene valley, the Belkacem valley, and the Kef Lahmer valley.

The study area belongs to the northeastern Algerian Atlas mountain chain. It originates from Triassic to Middle Cretaceous rifting periods related to the opening of the southern Tethyan margin [Guiraud et al. 2005]. Tethyan extensional structures of the Algerian Atlas (South Setefian allochthonous block) were reactivated during the Lower Cretaceous. The litho-stratigraphic context of the region is primarily dominated by Mesozoic terrains, mainly composed of terrigenous carbonate rocks from the Cretaceous and Jurassic. A lower dolomitic Jurassic and a massive calcareous Upper Jurassic outcrop towards the north-east and south-west of the quarry. These formations are known as Djebel Youssef and Mezrat Sekkaken. The Cretaceous layers are mostly carbonate, but calcareous formation are also common, with some dolomitic rock and sandstone with the exception of Neocomian marls. The quarry has an anticlinal structure with compact and well-bedded Upper Jurassic limestone, characterized by extensive fracture systems in the north-west and south-east directions. They feature

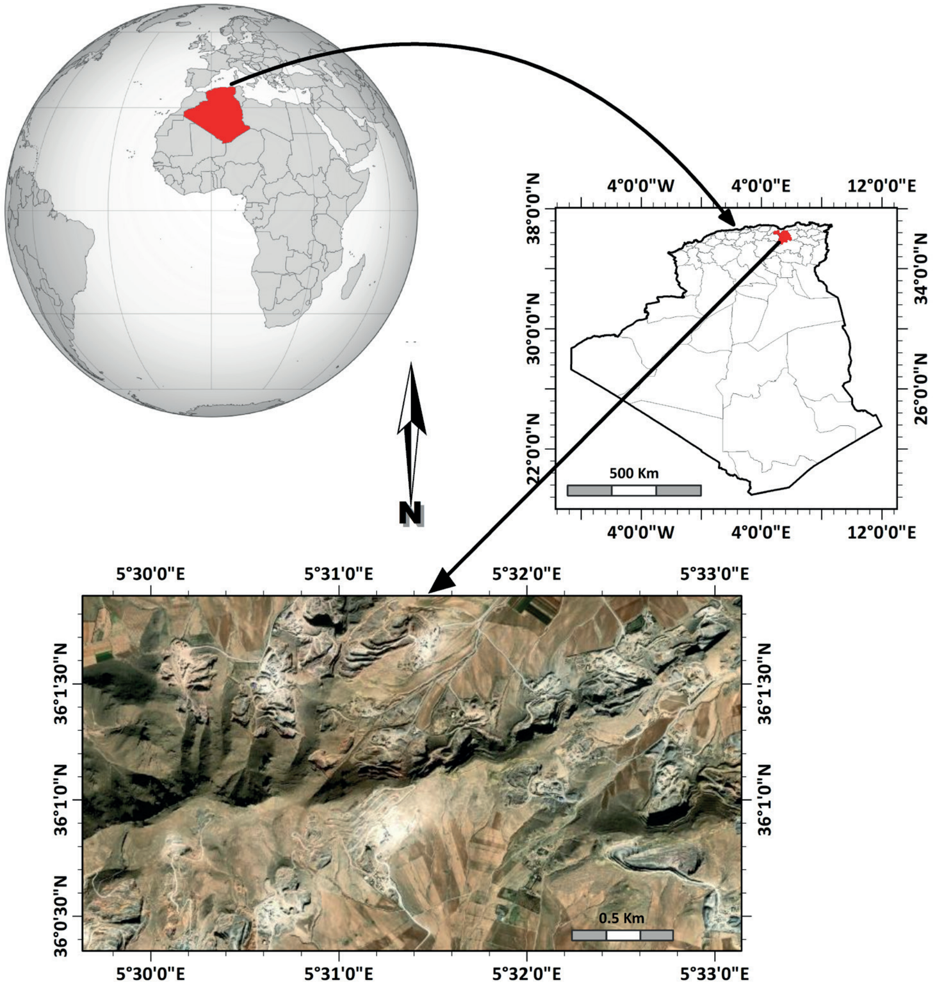


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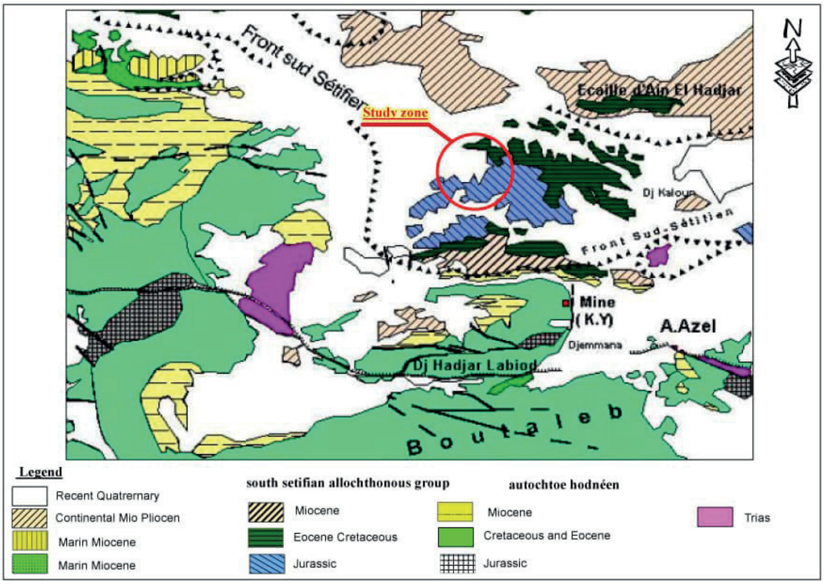
**Fig. 1.** Location map of the study area

an intense grinding with striated planar and calcite mineralization. The oldest fractures are composed of joints/veins strike, which are related to an early Cretaceous tectonic event that affected North Africa. The vast fracture systems of this rock massif stretching in their directions are natural discontinuities in the rock that result from the formation of the massif. They have a very important influence on the mining processes. In particular, on the output of mining operations, they determine first of all the size of the blocks, the execution of the blasting, the dynamics of the explosive energy and its transmission to the massif.

**Table 1.** Main characteristics of the limestone rock in the case study

| Characteristic | Unit | Value |
|---|---|---|
| Density | t/m$^3$ | 2.6 |
| Water content | % | 0.83 |
| Absorption | % | 1.54 |
| Porosity | % | 3 |
| Micro Deval | % | 13 |
| Los Angelos | % | 24 |
| Hardness | – | 07 |
| Resistance to compression | Kgf/cm2 | 700 |



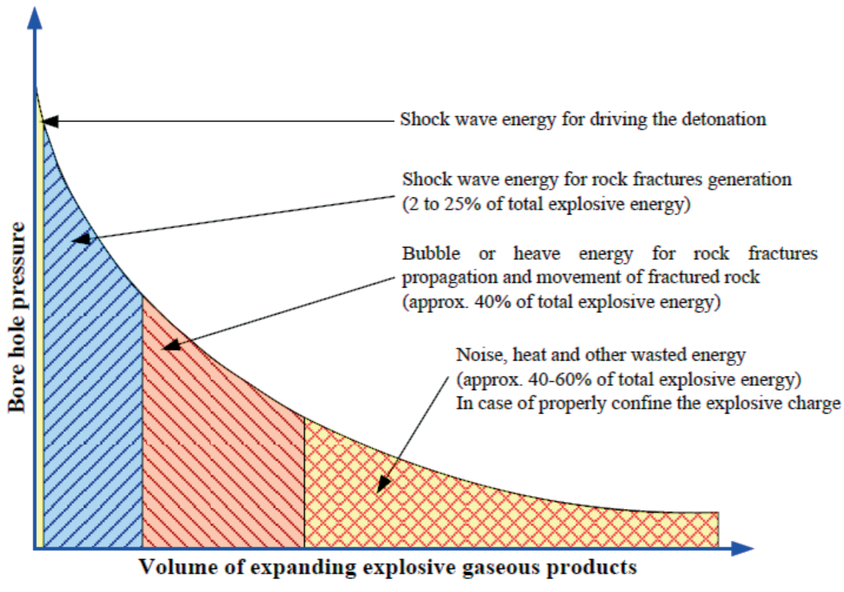

Source: Authors' own study

**Fig. 2.** Simplified geological map of the study area

## 3. Process of rock fragmentation using explosives

Explosives are the most effective means of fragmenting hard rock in various rock-engineering disciplines [Saadatmand Hashemi and Katsabanis 2020, Wang et al. 2021, Zhang et al. 2020, Shirani Faradonbeh et al. 2016, Baranowski et al. 2020, Khandelwal and Monjezi 2013].

Blasting is a very rapid chemical energy release process that has a strong impact on the surrounding medium and generates a large amount of blasting gas [Yang et al. 2018]. Fragmenting rock with explosives involves the decomposition of explosive material into gas at high pressure and temperature, the propagation of stress waves in the rock mass, the fracturing or damaging of the rock, the expansion of gas through created fragile zones, the opening of cracks, and eventually the movement and ejection of material fragments [Mouloud 2017]. The efficiency of a blasting operation is highly dependent on the mechanical parameters of the rock mass (the strength of rock) that govern the responses to blast waves, the geometrical parameters of the blast design that affect the distribution of the blast energy in space (borehole bottom and column energy), and the temporal factors (delays between holes/rows) that control the release and transfer of the explosive energy to the surrounding rock mass, in real time and during the blast [Salmi and Sellers 2021]. The practice of rock blasting remains largely undefined in terms of the explosive energy transferred to the rock and the fraction converted into effective work [Sanchidrián et al. 2007]. Figure 3 shows the contribution of explosive energy to useful work.




Source: Authors' own study

**Fig. 3.** Distribution of explosive energy during rock blasting [Kılıç 2009]

ONEX (National Office for Explosive Substances) provides various quarries with a wide range of explosives and shooting accessories manufactured in Algeria. The following table presents the two types of explosives used in our study case and their characteristics.

**Table 2.** Types and characteristics of explosives used in the study [ONEX]

| Types of explosives | Resistance to water | Density (g/cm$^3$) | Detonation velocity (m/s) | Volume of gas released (l/kg) | Practical use factor (CUP) |
|---|---|---|---|---|---|
| Anfomil (gas creator) | Mediocre | 0.90 | 3000 | 975 | 1.15 |
| Marmanite III (shattering) | Mediocre | 0.95 | 3800 | 907 | 1.18 |

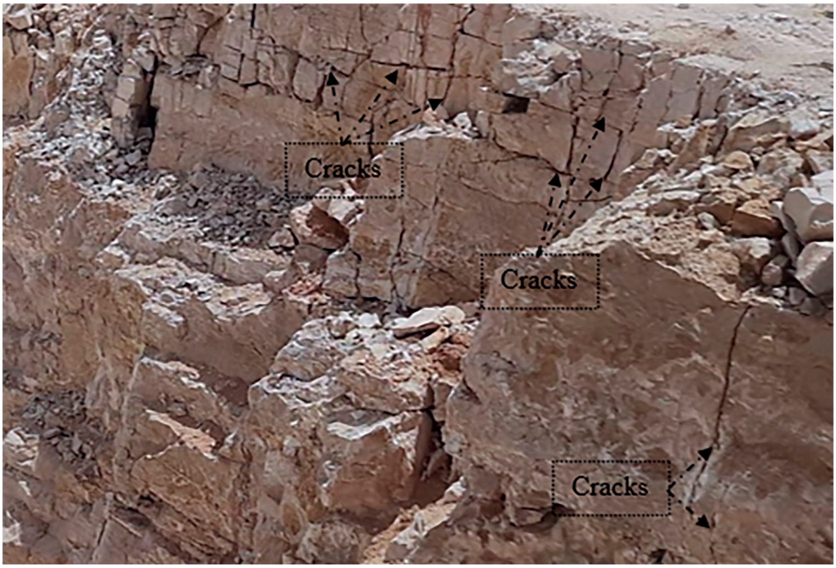
## 4. Evaluation of the particle size of blasted rock using image analysis

The evaluation of rock fragmentation has always been one of the main interests of mining engineers [Roy et al. 2016]. Such evaluation is aimed at understanding the parameters related to the operations in the production process (blasting, crushing, grinding, transportation, etc.), including explosive energy, blast design. Understanding these parameters will reduce operating costs and improve the size distribution obtained by fragmentation (mainly the reduction of fine particles) [Outal 2006].

The use of digital image analysis (processing) technique can be very useful in analyzing the different fragment size types. It has been widely adopted in the industry, as it is very fast and can process multiple images with low percentage of error [Bharath et al. 2020]. This technique can be performed using images of the pile of debris taken with portable cameras [Afeni and Okeleye 2020]. One of the advantages of the image analysis technique is that there is no limit to the mass size and volume. Samples (images) are prepared quickly and do not disrupt the production process. Moreover, the results can be analyzed quickly, which can be used to optimize the parameters of the blast pattern. Considering how easy it is to take samples, a large number of images can be prepared to reduce analysis error [Tavakol Elahi and Hosseini 2017]. WipFrag is an auto-generated image based granulometry software that uses digital images to evaluate size distributions of fragments [Shehu et al. 2022].

WipFrag images can be digitized, whether they are imported from fixed video cameras in the field or from roving camcorders. Photographic images can be digitized from slides, prints or negatives, by using a desktop copy stand. Digital images can come in a variety of formats, delivered on a disc or transferred through electronic networks. WipFrag uses powerful image analysis techniques to isolate the individual fragment boundaries. WipFrag has the capabilities for zoom-merge analysis, in which a combined analysis of images takes place at different scales of observation and can be used to overcome the size limitations inherent to a single image. Alternatively, an empirical calibration mode is available [Maerz et al. 2018].

In our case study, four blasting tests have been conducted with varying rate of explosive charge used (Anfomil and Marmanite III) in order to gain a better understanding of the effect of the type and quantity of explosive on the quality of fragmentation obtained from a rock mass. Figure 4 demonstrates the rock structure of the study area.




Source: Authors' own study

**Fig. 4.** State of the rock mass of the quarry

The proportions of explosive charges have been used as shown in Table 3.

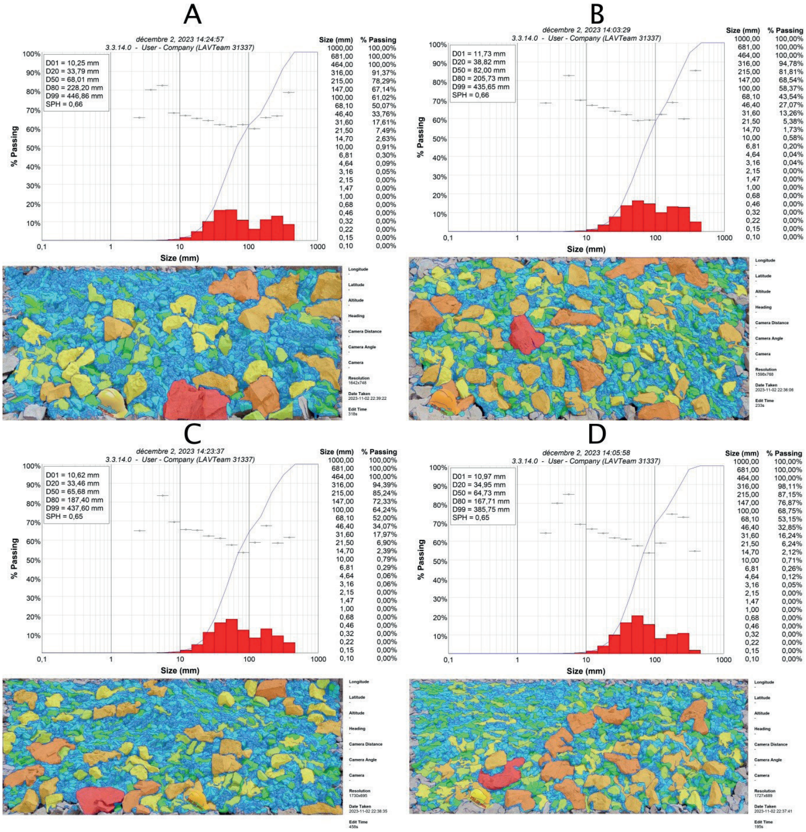
**Table 3.** Proportions of explosive charges used in each blasting test

| Tests | Explosive types | |
|---|---|---|
| | **Anfomil (%)** | **Marmanite III (%)** |
| **1** | 50 | 50 |
| **2** | 60 | 40 |
| **3** | 70 | 30 |
| **4** | 80 | 20 |

After each blasting test, WipFrag software has been used for measuring the size distribution of blasted rock in order to evaluate the fragmentation quality of the fractured rock.

## 5. Discussion of the results

The visual observation of each test, the results of the blasting, and the analysis of the particle size of the fragments (Fig. 5) demonstrate that changing the percentages of explosives has an effect on (Marmanite III and Anfomil) on the quality of the fragmentation of rock. There is a noticeable improvement, when the Anfomil rate increases and the Marmanite decreases. This improvement is represented by a reduction in the dimensions (sizes) of the fragments of the blasted rock pile, limiting the output of large blocks, as shown in Table 4.




Source: Authors' own study

**Fig. 5.** Results of blasting A: test 1; B: test 2; C: test 3; D: test 4

**Table 4.** Dimensions of fragments of the blasted rock pile in each test

| Tests | Fragments dimensions (mm) | |
|---|---|---|
| | D50 | D80 |
| 1 | 68.01 | 228.20 |
| 2 | 82 | 205.73 |
| 3 | 65.68 | 187.40 |
| 4 | 64.73 | 167.71 |

**Table 5.** Main parameters of a blasting plan used

| Parameter | Unit | Value |
|---|---|---|
| Hole Diameter | mm | 76 |
| Face Dip Direction | Degree | 80 |
| Burden (B) | m | 3 |
| Spacing (S) | m | 3 |
| Sub-drilling | m | 1 |
| Hole depth | m | 13 |
| Powder Factor (Specific charge) | kg/m$^3$ | 0.41 |
| Charge weight per hole | kg/hole | 40 |
| Bench Height | m | 12 |
| Charge Length | m | 10.5 |
| Stemming height | m | 2.5 |

These results are based on the fissured structure of the rock mass, which requires a certain type of explosive based on gas energy (Anfomil) rather than a shattering explosive, given that the discussed rock massif is already cracked. Finally, it is concluded from the tests carried out that it is preferable to rely on the effect of the gas wave for blasting in fissured rock masses.

## 6. Conclusions

In this study, the quality of fragmentation of four blasting tests of the Kef-Lahmer limestone quarry located in Setif (North-East Algeria) was analyzed using the digital image processing software (i.e., WipFrag). The results were obtained from digital image processing. Of the tests carried out in our case study, the fourth trial showed the best fragmentation result, with 80% Anfomil and 20% Marmanite charge applied, which is illustrated by an image analysis by the WipFrag tool. Meanwhile, Figure D shows the distribution of particle size of the fragments.

The results from rock blasting show differences in the quality of the fragmentation depending on the percentage of the explosive type used.

When blasting in fractured rock masses, a gas wave rather than a shock wave is favorable to obtain the intended blockometry; the rocks are already dislocated and do not need to be subjected to further rupture forces. Thus, to get a good quality of fragmentation and, subsequently, good management of a mining unit whether in the technical, organizational, environmental, safety, or economic terms, the following recommendations should be followed:

- The design of the blasting plan must be carried out carefully.
- The decision on the charges must consider the type of the explosive and the nature of the rock.
- The right choice of the types of explosive for each charge is essential.

This work allowed us to explore other avenues of research to contribute to the improvement of the fragmentation quality in fractured rock massifs, such as the revision of controllable parameters, and/or the adoption of unlikely parameters. It also encourages the search for other more suitable explosive substances or more favorable deflagration techniques that are appropriate to the conditions in the field.

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