Rock fragmentation process (Part 03 of 03)

By Bruno Pimentel.

Hello my friends, I hope everyone is well and being brief as always, we leave here the links so you can check our previous articles, as well as register, so that you are automatically notified of each new article we publish.

Portuguese

https://www.linkedin.com/newsletters/desmonte-de-rocha-c-explosivo-6941709482355748864/

English

https://www.linkedin.com/newsletters/rock-blasting-6959820770344595456/

In today's article we will be continuing the theme of the last article, talking about the fragmentation process, mainly about the factors that impact this process.

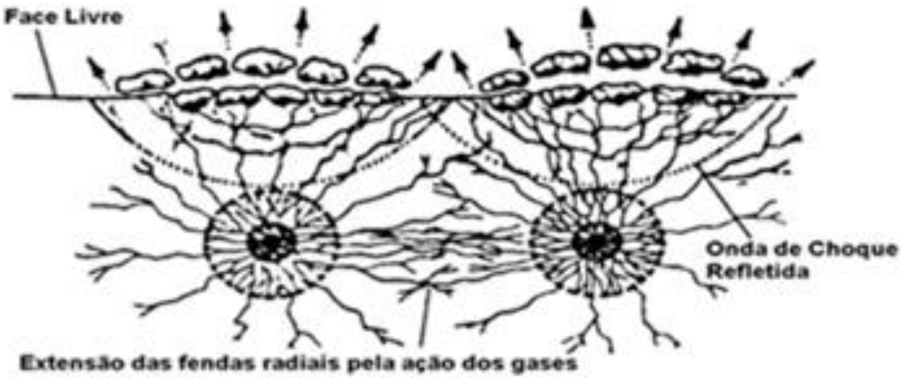
As we have already commented, although there is no universal consensus on how the fragmentation process occurs, as we saw in the previous article, it is believed that several mechanisms act in this process, some simultaneously and others in stages, complementing each other and determining the final fragmentation of our detonation.

Here we have some of these mechanisms, which we believe are the main ones to act in the rock fragmentation process through the detonation of the explosive:

- ✓ Shredding
- ✓ Detachment
- ✓ Fracture extension
- ✓ Creation of fractures
- ✓ Shear along fractures
- ✓ Flexural rupture
- ✓ Relative motion of particles
- ✓ Air and ground fragment collisions

If we more or less follow the phases of the process that we commented on in the previous article, the first mechanism to act in the process would be crushing, caused by the initial impact of the shock wave generated by the detonation of the explosive, being mainly influenced by the characteristics of the explosive, configuration load and rock characteristics.

Afterwards, while the intensity of the shock waves is greater than the resistance to compression of the rock, we will have the creation of an intense fracture zone in the rock, until the waves decrease in intensity, and at this moment, they should find the free face, where part of the waves will be reflected and others refracted, and the interaction between these waves causes the effect we call “spalling”, which is the displacement of pieces of rock on the free face.

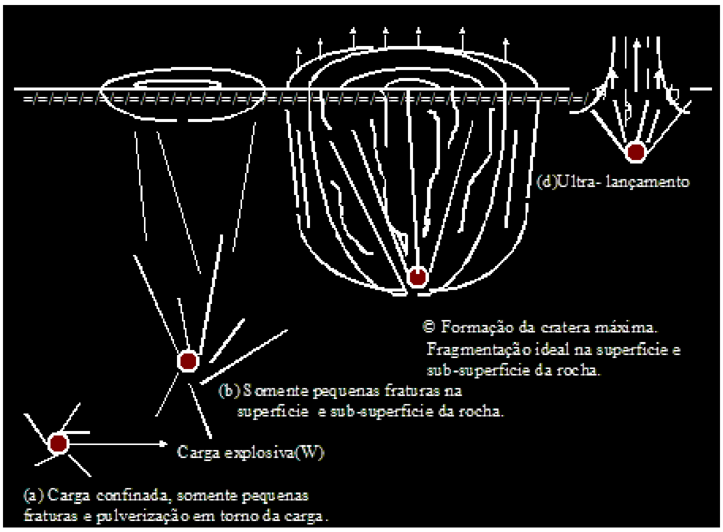


While these mechanisms are already operating in the fragmentation, the gases generated by the explosive are penetrating the fractures, extending these fractures and creating new fractures, and in the same way the shock waves that were reflected in the free face, return causing a traction effort, creating new ones. fractures and extending existing fractures.

As the gases expand, they begin to flex the rock towards the free face, causing flexural rupture, at the same time that the difference in pressure intensity at various points in the rock, as well as variations in this process, causes that the rock breaks by shear and relative movement of the particles, and also, as the rock breaks, and the fragments are released to the free face, these fragments collide, in the air and in the ground, ending the fragmentation process .

We need to remember that the rock's resistance to traction is much smaller than its resistance to compression, so any mechanisms that act causing traction forces, they will have a greater effectiveness in the fragmentation of the rock, and therefore, when designing the parameters of our fire plan, ideally we need to consider the performance of each mechanism, and maximize the performance of those that generate traction efforts, such as the reflection of waves, which create new fractures.

Another theory, whose concept is also applied in several others, is the crater theory, which analyzes the individual behavior of the detonation of a single hole, trying to maximize its performance, and then considers that the result of the detonation will be equal to the sum of the effects of the various individual holes present in the detonation, so the ideal would be to make the effects of the holes overlap, and thus we would maximize the result.

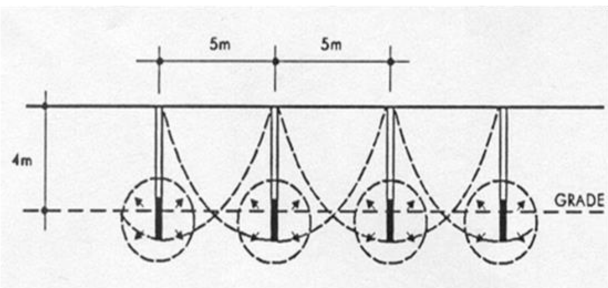


These concepts are widely applied in small loads, since the effect of the interaction between the loads is much smaller.

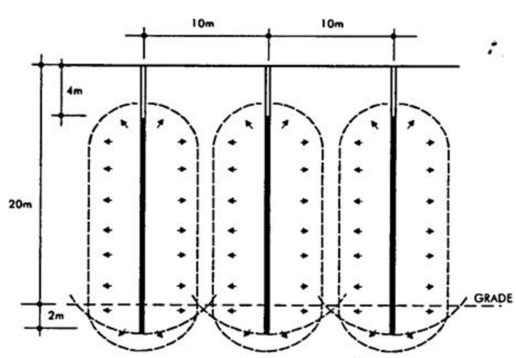
Another point is that on several occasions, we can use the concepts of the crater theory, to carry out tests, which can help us in determining the parameters of our fire plan, such as in the determination of the buffer, where we can do several detonation tests of a single hole, evaluating different configurations, until identifying the configuration that presents a greater retention of gases and the formation of a larger crater, with better fragmentation of the material.

Another example would be carrying out similar tests to determine the best charge configuration, which would be evaluated by the size of the open crater and the intensity of fragmentation, in each detonated hole.

Contrary to the many concepts that involve the crater theory, and even not fully understanding it, it is believed that the result of the detonation, and mainly the effect on the fragmentation process, is not determined by the sum of the work of the holes individually, but , that the various holes in our detonation interact with each other, contributing intensely to the total fragmentation process of our detonation.



CARGAS ESFÉRICAS FORMANDO CRATERAS



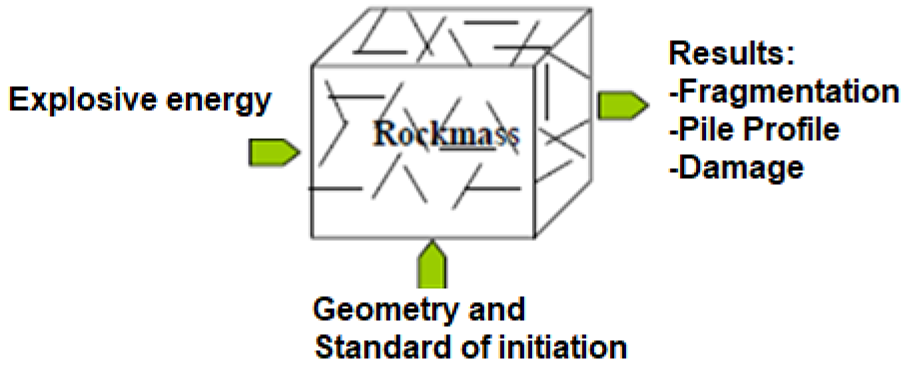
ONDAS DE TENSÕES CILÍNDRICAS

It is believed that this interaction between the different holes plays an even more fundamental role in hard rocks, as their characteristics make the interaction between the waves increase the tensile effort, and thus generate a much more intense fracturing in this type of rock. rock.

A classic example of how this interaction between holes acts is similar to the process of reflection of waves on the free face, where they return and oppose the compression waves, causing the traction effort on the rock, and in the same way, when we have several holes detonating, the waves from these holes overlap each other increasing compression as they approach, and once they pass each other they reverse the effort, causing traction as they move away.

It is important to bear in mind that, despite the various existing theories, it is still unknown how much of the fragmentation process is actually known, and especially how much of it is controllable, and what level of influence we can have in this process.

Therefore, we cannot say with complete certainty what are the impacts caused in the process, as we change some parameter of the fire plan, or even what are the impacts caused by the operational practices that we use in the execution of these parameters.



For example, we know that deviations in drilling will impact the fragmentation process, but we do not know how much this impacts, and they can even have positive and negative impacts at times, where, for example, two holes closer together should generate greater fragmentation, but they they will also be further away from their other neighbors, so fragmentation would be worse at that point.

We know that there are innumerable possibilities for variation, whether due to the features of the plane of fire, the characteristics of the explosive or even the rock, and even the conditions for executing our detonation, and that all of them will influence the fragmentation process, some in a way positive and others negative.

So, from now on, we are going to take the opportunity to comment on some of these variables, and what would be the basic logic of their impacts on the fragmentation process, but we cannot take this as a rule, bearing in mind that in different scenarios, due to changes in other variables, we can have different results, and besides the fact that we will comment on the individual effect of each variable, and in practice, it is practically impossible, to guarantee that the others remain constant.

In short, we have here the main points that are considered to have a more direct impact on the fragmentation process, starting with the characteristics of the rock, and the last one is related to the timing, where the sequence and the delay interval will influence the interaction between the holes:

- Rock characteristics
- Presence of discontinuities
- Characteristics of Explosive
- confinement
- Coupling
- Load configuration
- Drilling Pattern
- Free face
- Hole parameters
- Timing

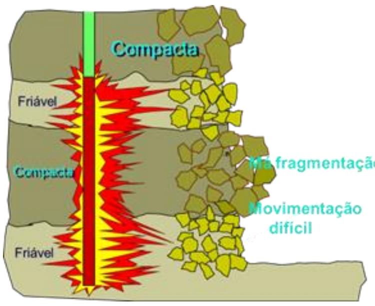
Some of these points or variables are what we consider uncontrollable variables, as we do not control how they vary, but we know that they impact the fragmentation process, so it is important to know them to try to predict what these possible impacts will be, and if we can do something to minimize the negative impacts.

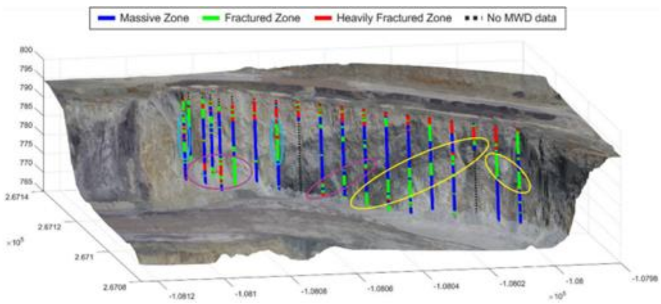
A typical example is the characteristics of rocks, which we do not control, but we know that they change along the rock body, and knowing their variations can help us adjust other parameters.

- **Rock characteristics**

Despite being the most uncontrolled variable we have in our blast, normally the characteristics of the rock are what most impact the detonation process, as these characteristics will determine how the rock will be affected by the effects of the explosive detonation.

Therefore, it is considered that the characteristics of the rock are the initial starting point for determining the parameters of our detonation, so knowing these characteristics is fundamental, both for the design of the fire plan, and for evaluating the impacts that occurred in the fragmentation along our blast





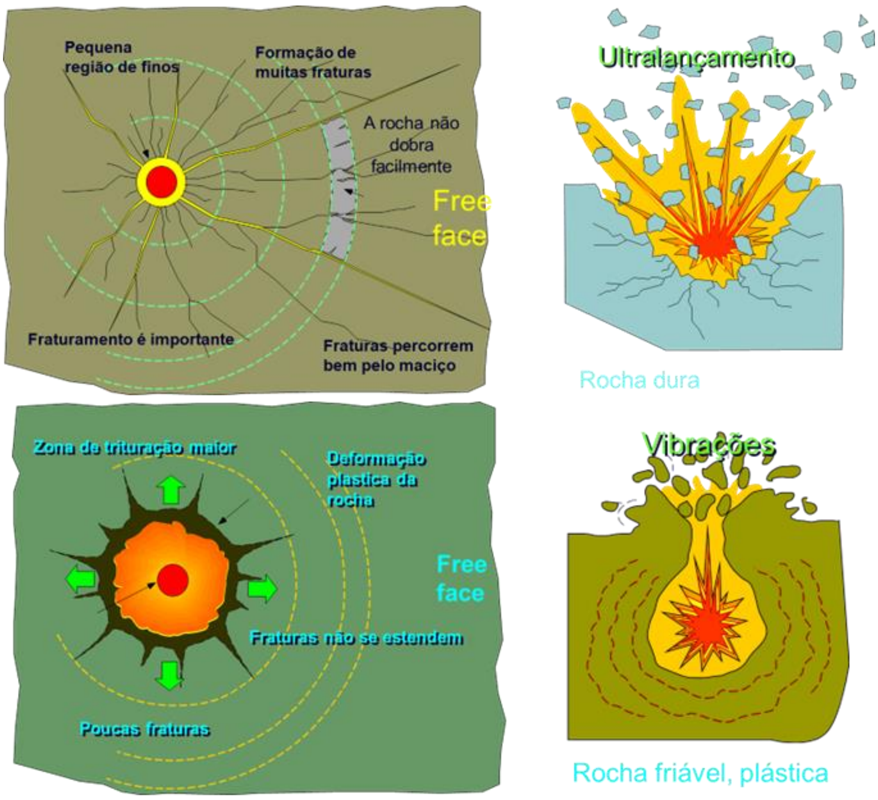
An important detail regarding the characteristics of the rock, is that the fragmentation process is much more efficient in compact and homogeneous rocks, because as we have fractures, discontinuities, or changes in rock properties, we will have a greater interference in the process of fragmentation, usually resulting in lower efficiency.

As with rocks that present more variations in their characteristics, we will have greater difficulty in standardizing and controlling the other parameters, making it difficult both to design and to control the final results of our blast.

Another detail is that with hard rocks, which have a greater resistance to compression, we will have a smaller crushing zone, so that a large part of the fragmentation will be determined by the creation of fractures and the extension of these fractures, both caused by shock waves, as well as the effect of gas expansion, requiring correct sizing of the parameters of our fire plan, as well as ensuring greater confinement, so that we can guarantee better fragmentation.

On the other hand, more friable rocks will undergo greater crushing due to their lower compressive strength, but shock waves will be less effective in creating fractures, due to the greater elasticity of this type of rock, so most of the Fragmentation will be under the responsibility of the expansion of gases, which, when well confined, will cause great flexion in the rock mass, until it ruptures and is thrown towards the free face.

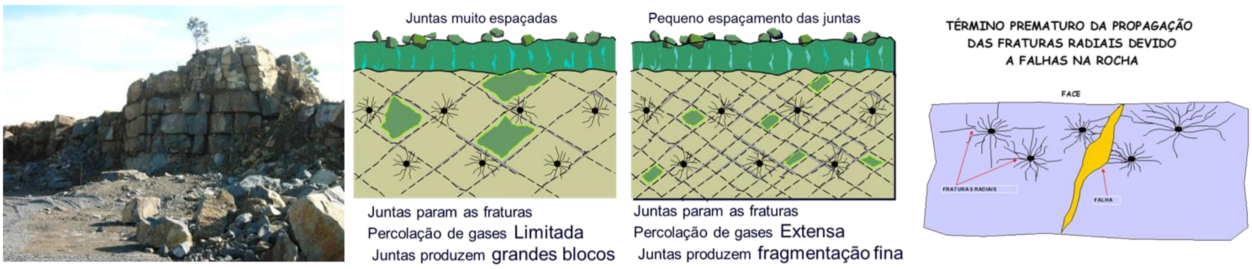
.



That is why normally the basic recommendation is that we use explosives with higher shock energy in hard rocks, and with higher gaseous energy in friable rocks, but as we have already mentioned, this will depend not only on the rock, but also on the other parameters, as well as one of the goals of our blast.

- **Presence of discontinuities**

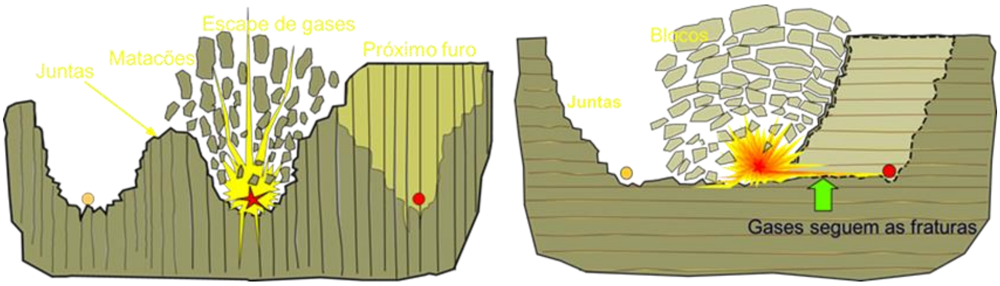
In addition to rock hardness, another key point is the presence of discontinuities, as they directly affect the fragmentation process, interfering both with shock waves and gas expansion..



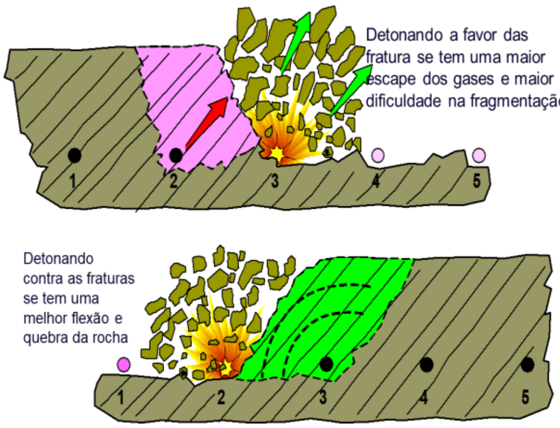
Usually the discontinuities will negatively impact the process, limiting the propagation of fractures, causing disturbances in the interactions between waves, and also decreasing the pressure of the gases, due to the greater empty space available, in the same way as they can create points of weakness, which allow the gases escape, further decreasing its efficiency.

Very fractured rocks, regardless of their hardness, will increase the difficulty of controlling the fragmentation process, where normally they will require special treatment, where we will need to adapt the fire plane to the rock conditions, which can be extremely variable, and including, in many situations, we will not have complete knowledge of what internal conditions the rock presents.

Another point that is affected by discontinuities is the determination of the sequencing of the holes, as the sequencing of the holes will determine the direction of gas release, so that if the exit of the holes is towards the openings of the discontinuities, the gases will easily find an escape route during its expansion, decreasing the pressure on the rock, and thus decreasing fragmentation.



When the fractures are in the same alignment as the holes, they can direct the energy of the hole that is detonated first to the other hole, and thus it can initiate it out of sympathy, or even desensitize that hole, and this will impact the result of our blast.



So, in cases with a large number of discontinuities, normally the standard recommendation is to sequence the holes in such a way that they detonate against the direction of the fractures, causing greater bending of the rock. Also, when necessary, increase the burden to hinder the escape of gases, and decrease the spacing to increase the interaction between the holes..

- **Characteristics of Explosive**

After the characteristics of the rock, the characteristics of the explosive are the ones that most impact the fragmentation process, as these characteristics will determine how much energy will be released and how this release will be.

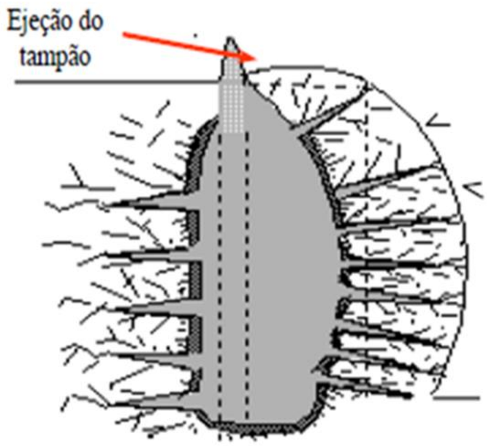
So, in order for us to have a good performance from our blast, we normally adapt the characteristics of the explosive to the type of rock we need to detonate, because in this way we can try to maximize the fragmentation process.

An example of this is the basic recommendation, in which we must use explosives with greater shock energy and high blast speed, in hard and compact rocks, while in friable or fractured rocks, we need explosives that release a greater amount of gases.

Of course, this is not that simple, and in practice, we start with a basic configuration, listing the known characteristics to determine an initial scenario, and as we detonate, when possible, we can change the type of explosive, or the characteristics of application, such as explosive density, charge configuration, coupling factor, confinement, and other variables that interfere with the reaction of the explosive during the blast.

- Confinement

As we mentioned in the last class, a key factor in the fragmentation process is confinement, as it will be primarily responsible for determining the time in which the energy released by the blast, mainly the gases, will act on the rock.



In the ideal scenario, in order to maximize fragmentation, we need the shock waves to travel through the rock, compressing it, and after finding the free face, it returns, generating the tensile effort, to maximize the generation of fractures, while the gases they continue expanding, penetrating the created fractures, and complementing the fragmentation, without the rock breaking, as we see the example in the figure here on the right side.

That is, we need the maximum of the energy of the explosive to be spent on breaking the rock internally, before the rest of the energy escapes, or is spent on other effects, such as material release or vibrations.

To achieve this, we need all the parameters of our fire plan to be balanced, as well as being suitable for the rock we are blasting.

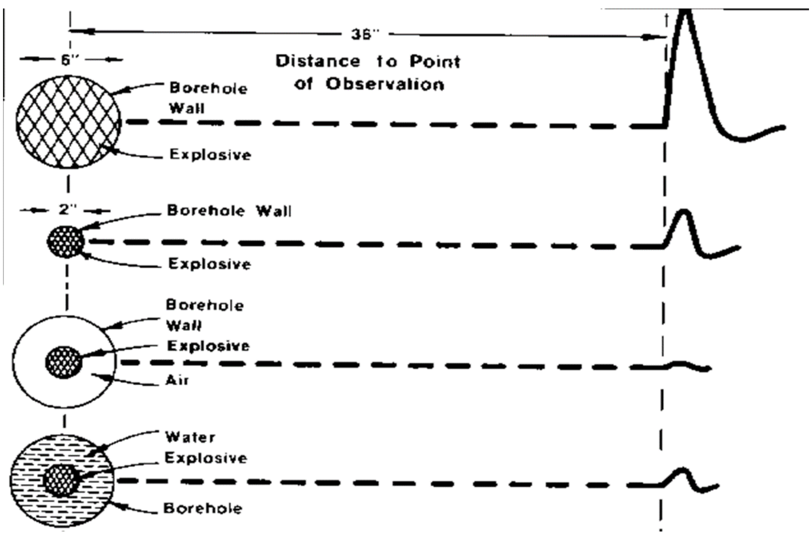
A variable that plays a fundamental role in this process is the plug, as it is responsible for closing and ensuring confinement at the weakest point, which is the opening of the hole, so we need to guarantee its quality, both in terms of sizing and dimensioning, as well as its execution.

- **Coupling**

Another factor that directly impacts the effect of the energy of the explosive on the rock is the coupling, which refers to the degree of filling of the hole with explosive, and the contact that the explosive has with the internal walls of the hole, that is, with the rock.

When the explosive has a low coupling factor, that is, it does not have full contact with the rock, the shock wave pressure transfer drops exponentially, as does the initial expansion pressure of the gases, because the gases must first fill the empty volume inside the hole, to then start exerting pressure on the rock.

We see an illustration of this effect in this comparative figure below, where initially we have a larger diameter hole, with the explosive completely coupled, and we see here on the right that we have a high pressure peak at the moment of its blast.



Then we have a small diameter hole, but still completely engaged, and we see that the decrease in the peak pressure is directly due to the reduction of the explosive charge.

When we take the explosive charge from the smaller diameter hole, and put it in the larger diameter, and thus have an uncoupled charge, that is, with a low coupling factor, we see that the peak pressure on the rock drops to almost zero , due to the lack of contact between the explosive and the rock, causing the initial impact to be in the air.

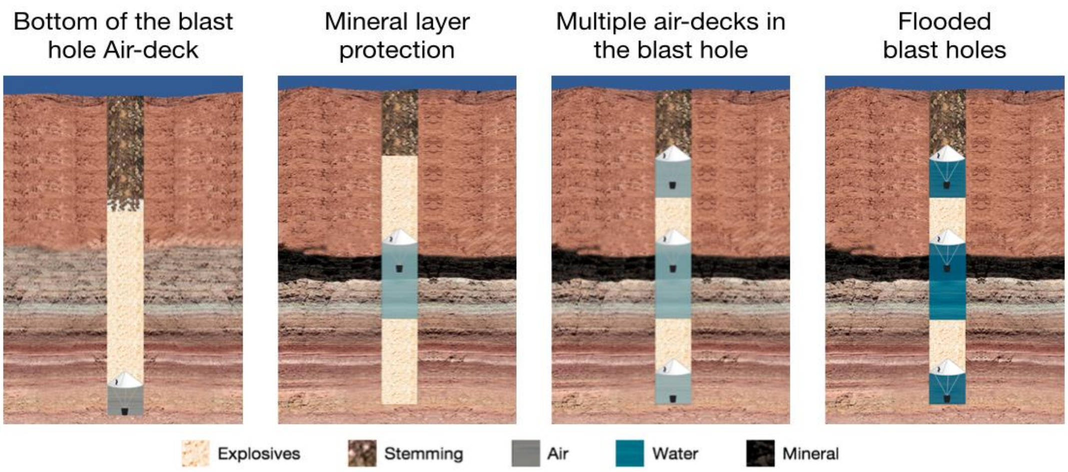
Finally, we have an example, with filling the void with water, and we see that we already have a slightly higher pressure, as the pressure transfer is greater, due to the greater filling of the hole.

Thus, the greater the contact of the explosive with the rock, that is, the greater the filling of the hole with explosive, the better the transfer of the initial pressure, increasing the effect of the shock wave on the rock.

Therefore, when we want to increase fragmentation, it is usually better to use a smaller diameter hole with a well-coupled and confined explosive charge than to use a larger diameter hole with a low coupling factor..

- **Load configuration**

Another important point in the fragmentation process is the distribution of the explosive along the rock and inside the hole, as this will directly affect the distribution of energy along the rock at the time of the blast.



The ideal would be to have the energy of the explosive acting perfectly and the same at all points of the rock, but this does not happen, because the distribution of the explosive, and of the energy generated in its blast, is not uniform within the rock mass, and will directly depend on the configuration of our explosive charge, as well as the operational quality in carrying out the proposed charge configuration.

Therefore, it is important to bear in mind that the same amount of explosive can be distributed in different ways throughout the rock mass, and even inside the hole, and this difference in distribution will present a difference in the action of energy on the rock, and in turn, in the manufacturing process.

So, during the elaboration of our fire plan, we need to be attentive, in order to carry out the best possible distribution of the explosive, as well as guarantee the operational quality when executing this distribution, so that we do not have direct impacts on the fragmentation process.

- **Drilling Pattern**

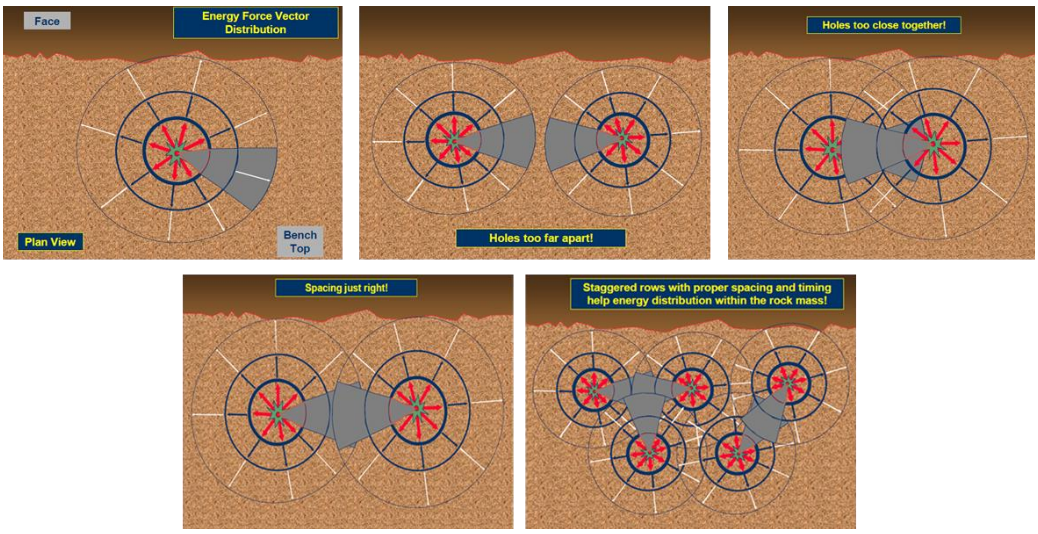
As we said, the distribution of the explosive along the rock body will directly influence the fragmentation process, so the mesh has a fundamental role in this distribution.

That's why we need to pay attention both to their geometry and to the balance between burden and spacing, so that they can allow a good distribution of the explosive, as well as maximize the interaction between the holes.

When we have an adequate grid, we have good fragmentation, release of material, and definition of the remaining rock cut, and this goes well with good distribution of the explosive and adequate interaction between the holes.

When we have distances less than the ideal, we will have several impacts on the safety and preservation of the remaining rock, as well as we may have the risk of one hole damaging the other during the blast, and when we have the opposite situation, with greater distances, we may have the phenomenon of craterization in the holes, the generation of oversizes, as well as problems in the breakage of the bottom part material.

Here below we see some illustrations that show us the circle of influence of each hole, and what we want is for them to interact on the rock, maximizing the fragmentation between them, but without harming each other in the process.



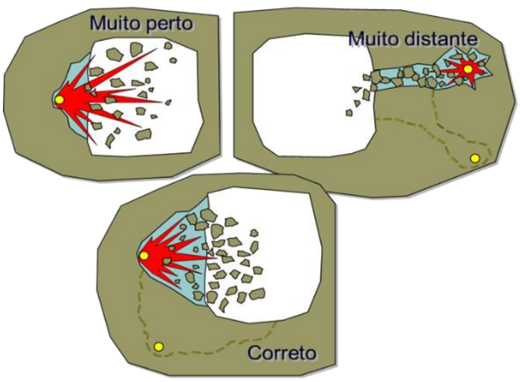
Still with regard to the mesh, the spacing between the holes in the same line will influence the level of interaction between the holes, while the spacing will interfere more with the reflection of the waves.

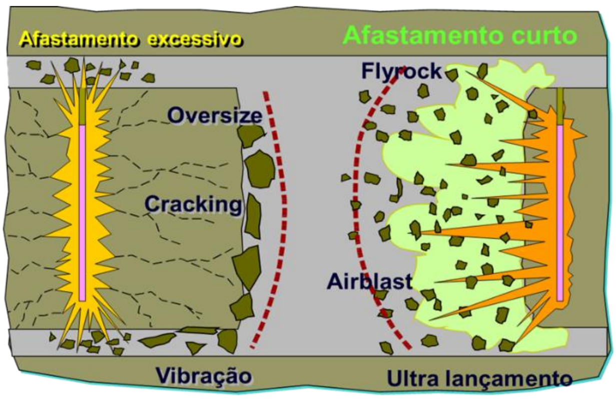
So when we have very small spacings, we run the risk of the holes damaging their neighbors, or detonating them out of sympathy, while very large spacings will reduce the interaction between the holes, causing less fragmentation between them.

In the same way, when we have a small gap, we will have a premature loss of gases, since the fractures created by the compression caused by the shock wave quickly reach the free face, and when we have the opposite case, with a burden greater than the ideal , we will have a smaller reflection of the shock waves, decreasing the fragmentation and release of the material, as well as increasing the level of vibration, due to the excessive weight of the rock.

Just remembering that everything we are talking about normally applies in the same way to open-air and underground detonations, as we are talking about the response of the rock to the action of the explosive, and thus, regardless of the type of blast, the responses are the same, of course related to each setting.

As soon as these theoretical concepts, and possible impacts on the performance of the fragmentation process, apply both to an opening of a pylon, in a blast of a tunnel, or to production detonations, in underground mines, in the same way that it applies in different types of open pit blast.

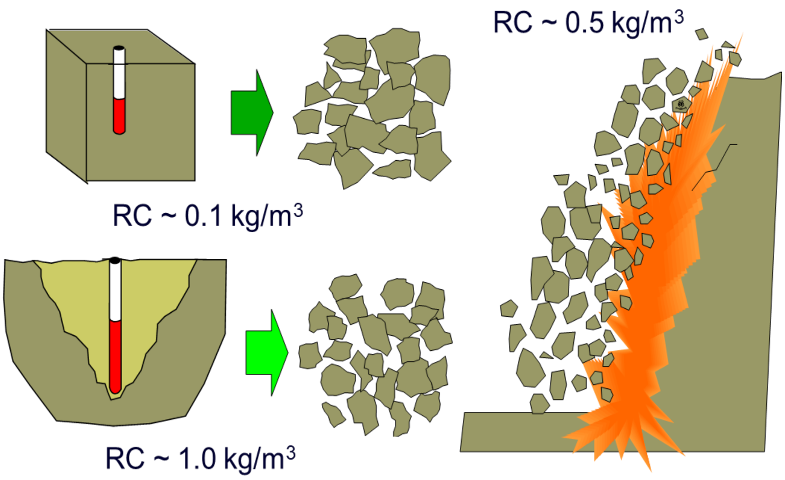




- **Free face**

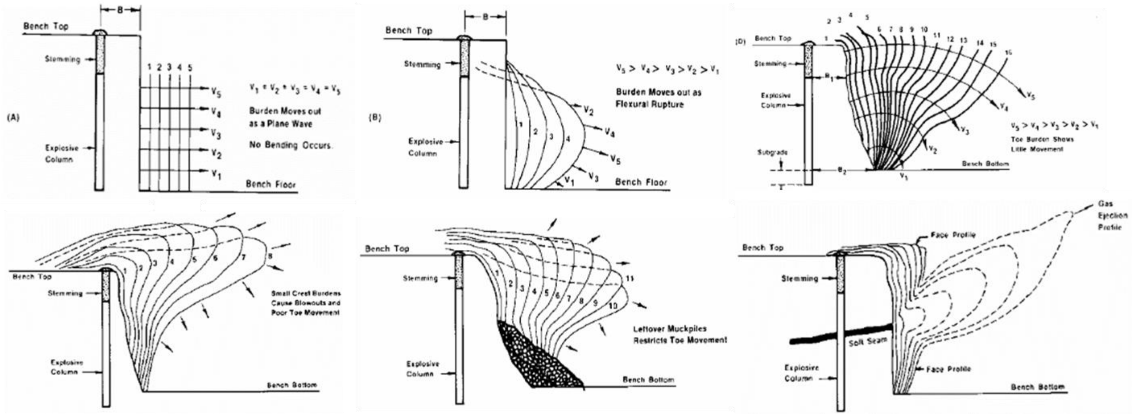
As we saw in the last class, the free face plays a fundamental role, mainly with regard to the process of reflection of the shock waves, and likewise the generation of free face, or relief, along the blast of each hole, it is essential to continue creating the appropriate free face for each hole.

The presence of the Rock-Air interface, created by the free face, allows the reflection of the shock wave, which returns continuing the fragmentation process, so if the free face is insufficient or non-existent, this will cause the compression waves to travel freely, without being reflected, which is what happens with the waves that are towards the remaining rock mass, generating only the propagation of seismic waves.



That's why most of the overbreaks we have are caused by the compressive force of the shock wave, which damages the rock as long as its intensity is greater than the compressive strength of the rock, and then just continues to generate vibrations.

Here in the figure below we have some very interesting illustrations, which help us to visualize the response of the release of the material, depending on the free face, which directly implies the way in which the gases will act on the rock, in the fragmentation process.

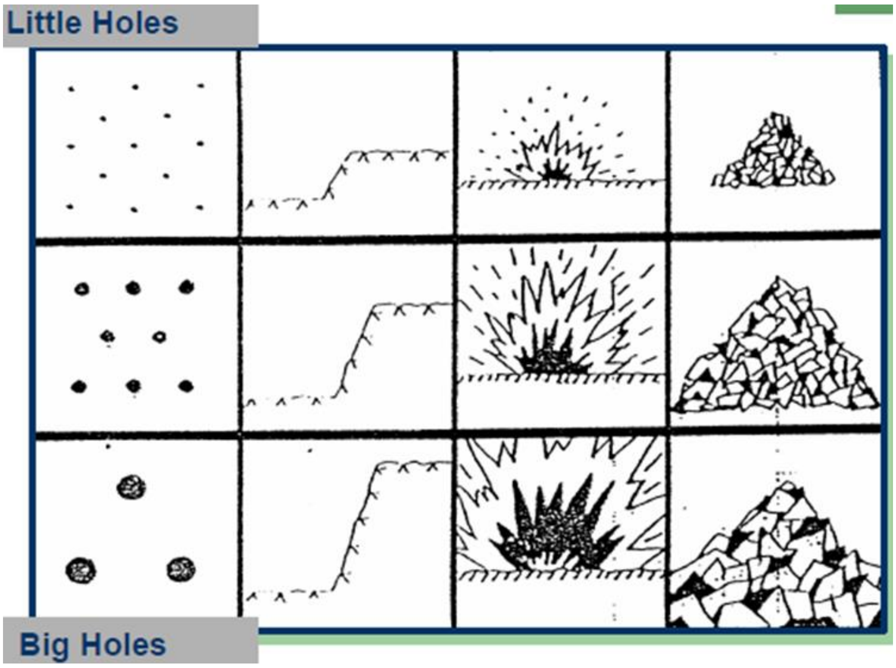


We can see in each example, that as we have anomalies on the free face, whether in a punctual way, or along the face, we will have a disturbance in the expansion of gases, and this will affect the release of the material, and in the same way, the process of fragmentation.

- **Hole parameters**

The Hole parameters and their balance with the other parameters of our fire plan are also factors that will directly impact the fragmentation process.

The diameter of the hole deserves to be highlighted, as it is a variable that is often uncontrollable, but which is decisive in the dimensioning of several other parameters of our fire plane, in the same way that it directly influences the distribution of the explosive charge along the rock, where small diameters can allow a better distribution of the explosive charge, but the intensity of each shock wave generated will be smaller, while large diameters, generate a smaller distribution, but generate shock waves of high intensity, normally increasing the amount of fines and fractures caused by the compression wave.

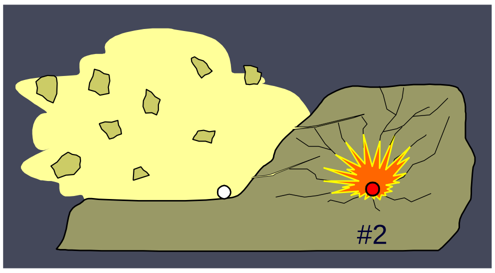


The other parameters of the hole, such as depth, inclination and sub-drilling also influence the fragmentation process, mainly with regard to the effect of rock bending and the interaction between the holes.

- **Timing**

One last point that we could not fail to mention is the timing, because the sequencing and the time interval, which we use between the holes in our detonation, are what will dictate the rhythm of the music, which the other parameters of our fire plan go dancing.

Through timing we determine the direction and generation of free face throughout our blast, and this will directly impact the fragmentation process.



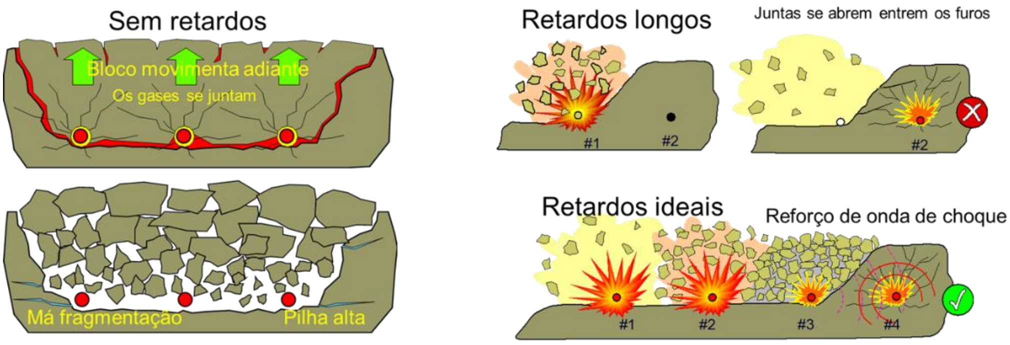
In summary, we can say that when we detonate several holes instantly, or with a very short interval of time between them, we will have a very strong initial performance of the pressure, but it is quickly relieved, generating a strong frontal launch, but the performance quick release of pressure, does not cause effective fragmentation.

While when we have the opposite, with very long time intervals, each hole acts individually, eliminating the interaction between the holes, and thus also reducing the level of fragmentation.

Therefore, seeking a balance between sequencing and time interval is important, as they will allow each hole to have the best free face conditions and time for pressure to act, and at the same time, will allow the holes to add up their forces, without damaging or interfering with the work of its neighbors´ holes.

In a simple way, we can say that the ideal delay time should be the one that allows the first hole to start expanding the rock, but still full of tensions, that is, before starting the breakage of the rock and the escape of gases, for the next hole to start, and thus, the waves interact, helping to finalize the fragmentation process of the first hole, while their waves help in starting the next one.

Comparing with the phases of the previous article, we can say that the first hole must be in phase 3 of the fragmentation process, where the gases are already acting intensely on the rock, but which has not yet started the process of breaking and releasing the material. , so when the next hole detonates, it will already be receiving the shock waves from the first one, and its shock waves will help in finishing the fragmentation of the first hole.



Another point of view, which is also widely accepted, and which the time intervals practically coincide, is to consider that the second hole must detonate when the shock waves from the first hole reach it, so that, when detonating, the shock waves will have a maximum interaction in the area of the second hole.

Normally, this criterion is used to carry out tests, which aim to determine the ideal time interval between holes with electronic detonators, where a pressure sensor is placed in the second hole, and the time is measured, between the detonation of the first hole and the receipt of the peak pressure in the second hole, and thus this would be an adequate time interval to use, aiming at increasing the interaction between the waves.

It is always important to consider that there are several variables that will impact the fragmentation process, in the same way that there are countless combinations between these variables, and what we have seen and commented on here was just a punctual analysis of how some variables will influence the detonation process and fragmentation, and in turn, will influence the results of our detonation.

Therefore, it is important to keep in mind that there is no magic formula, but a good understanding of the process and how the variables work, give us indications of what may be happening in each detonation, or what will happen according to the changes that we do.

For this, we need to control the design and execution of the fire plan well, controlling the quality throughout the entire process, as normally the greatest impacts come from operational errors in the execution, or else from the imbalance between the variables, which is caused when we don't apply one correctly or when we change, without balancing the others.

Another important point is that it is necessary to pay attention to uncontrollable factors, such as the characteristics of the rock, which can directly affect the blasting performance, so the more we know about the uncontrollable variables, the better we adjust the other parameters, to maintain balance in the process. .

Finally, we could not fail to comment that in the last phase of the fragmentation process, which we call phase 4, we have together the movement of rock fragments that will form our pile of detonated material.

We won't go into details, but as with fragmentation, there are a number of variables that will determine the shape, height, spread, and distance from the remaining wall of our pile of material. So, depending on the objectives of our detonation, we may have situations where we need to analyze these variables in detail in order to have greater control over this process, and have battery results that are more adequate to our needs.

In summary, we can say that the four main points, which we need to take into account for the format of our fragment stack, are:

1. the volume of gases generated by the explosive
2. the pressure of these gases
3. the blasting sequence of the holes
4. the blast plan geometry, mainly the effective burden and the characteristics of the hole.

Where the amount and pressure of the gases will influence the force of launching the material, the sequencing in the direction of the launch and the characteristics in the plane of fire, will give greater or lesser resistance to this launch.

But that's all for today, the story continues and it's very long, so we're going to stop here, because we've gone on longer than we intended, and although the topic is long and we could still continue with it, we'll look for other topics for the next ones articles to not get so tiring.

As always, we ask that you please comment and share, so that we have safer and quality detonations!!!

Blasting Trainings wants to help you shape the world with safety and quality.

Rock Blasting Courses:

Português -> https://hotmart.com/pt-br/marketplace/produtos/curso-completo-de-desmonte-de-rochas-com-explosivo-2022/B61107994S

English -> https://hotmart.com/en/marketplace/products/blastingtraining/U66086910H

www.blastingtreinamentos.com

blastingtreinamentos@gmail.com