Drillability and Drilling Bits Lifetime Prediction in Phyllite Quartzite

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Abstract

In extractive industry, especially in mining, the use of drilling bits is essential to facilitate and speed up the exploration process. There are several types of drilling bits, each used in distinct types of work. Over the years, these bits have been optimized to become more durable and increase their efficiency.

Their wear will depend on lithologic, mechanical and human factors. The first factor is mainly conditioned by the type of lithologies where it operates and the spacing between failures and fractures. As far as the second factor is concerned, the type of machine used and its power is very important. And finally, it depends on the operator who controls the drilling jumbo as he is the one who defines the rotation and the percussion to which the jumbo operates. This variable is associated with the operator experience as well as his sensitivity.

It is therefore important to know its lifetime, which translates into the number of meters that can be drilled for each bit (m/bit). By defining this value, a better inventory planning, as well as future investments, will be possible.

So, throughout this dissertation several measurements and laboratory tests were carried out, in order to determinate the lifetime of the drilling bits in a given lithology. It was also compared the data obtained with other data from several biographies.

Key Words: Mining Industry, Drilling Bits, Wear, Drilling Jumbo, Lifetime

1. Introduction

Nowadays, with the increase in consumption of mineral resources, it has become vital to optimize the exploration processes. By developing the mining jumbos, it became more quick and easy to do.

The drill bits are responsible for wearing away the rock, so that can be created the void where the explosive will be placed. These components are installed at the end of the boom of the mining jumbo.

Therefore, it is important to know the way in which bit wear occurs, as well as the processes that lead to its loss of effectiveness and penetration force into the rock so, its useful lifetime can be estimated and economic and stocks predictions can be made.

The objective of this paper is to study the bit average lifetime in a given lithology. So, it is needed to determinate the approximate value of the meters that each bit is able to drill (m/bit) and if the values obtained are similar to the values that are tabulated. These tables relate several indexes obtained by analyzing the physical properties of the rock, with the average number of meters drilled per bit in the same lithology.

So, it is intended to determine the index that presents more accurate results, as well as the one that is easier to implement and that shows a good correlation with the average bit lifetime measured.

2. Drillability

There are different definitions for drillability. Dinis da Gama (1977) considers drillability as "the resistance that the rock offers to the penetration of a drill in standard conditions", conditioned by the nature of the rock and distribution of its mineral components. But, Thuro (1997a) presents a more universal definition. He defines it as the result of the influence that several parameters have, not only on the drilling speed, but also on the wear of the drilling equipment that performs this work.

The three main parameters considered by this author are: r**ock and rock mass, drilling equipment and the working process.**

Since drillability is influenced by multiple parameters, it cannot be measured by a single test or index. Several tests and trials were developed to calculate it. The measurement of the uniaxial compression strength of the rock is universally used, but measurement of parameters such as tensile strength, quartz content, p-wave velocity and porosity of rocks can also be used to predict drillability. There is also a wide range of empirical tests such as the Cerchar Abrasivity Index, Specific Energy and Drilling Rate Index, with which it is also possible to obtain drillability values. (Yarali & Soyer, 2011).

The knowledge about the drillability of a rock mass is very important in order to choose the best method of excavation, drilling equipment and to do a proper prediction of the drilling rate, time life of the tools and to estimate the drilling costs.

However, according to Thuro in 1997b, during the construction of the Altenberg tunnel in Germany, a detailed study that provides the knowledge of the characteristics of the rock mass will facilitate the knowledge of the drilling velocity and of the drilling bits lifetime. So, it will be possible to predict with greater precision the drillability of the rock mass (figure 1).

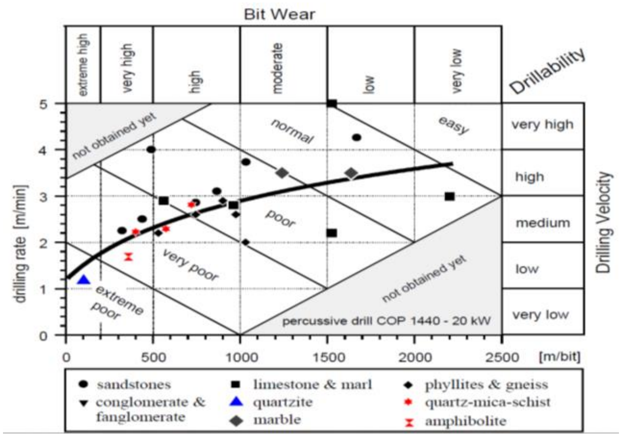

Figure 1 - Drillability classification diagram (Source: Thuro, 1997b).

2.1. Factors that influence wear

The first drilling bits that appeared in the extractive industry were the cross bits. These are still used on a small scale, but have been gradually replaced by button bits (figure 2). Button bits have a much higher degree of efficiency and aggressiveness. They consist of tungsten carbide buttons inserted in an iron body and have flushing holes through which water is expelled. The number of buttons per bit, their composition and geometry may vary according to the type of work they are intended to perform (Plinninger, 2008).

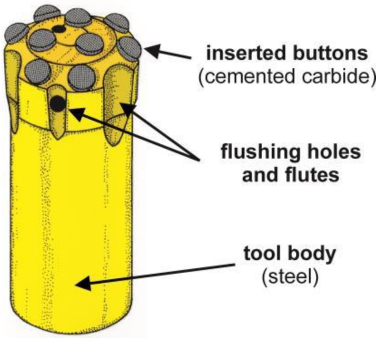

Figure 2 - Drilling bit and it constituents (Source Plinninger, 2008).

Tungsten carbide is a compound created from the combination of tungsten and carbon. This compound has a hardness of 9.0 on the Mohs scale, and a very high melting point. There are four main types of buttons that can be found in bits: **spherical, semi-Ballistic, ballistic and spike.**

The ballistic buttons have a greater penetration in the rock, however as they are being worn, their geometric shape changes to become shallow and their rate of penetration in the rock decreases, and increases the risk of button damage (Plinninger, 2008).

The drilling process, that results from the bit-rock interaction, can be observed through the analysis of figure 3. When the bits contact with the rock, they will induce a new state of tension, which causes its destruction. There can be found four destruction mechanisms, as result of the strong impact of the bit on the rock: an area with a thin layer of powder is formed (number 1); radial fractures are developed, starting from the impact zone (number 2); when the generated fractures are more or less parallel to the surface of the rock, fragments start to release (number 3). A fourth mechanism that relates the frequency and intensity of the impact of the bits on the rock, as well as its rotation and cleaning action of the holes which allows a very high penetration velocity, high compression and shear forces (Thuro & Spaun, 1996).

At the end of this process, the bit is withdrawn from the bore hole and the flushing water removes the loose material that is still in side of it.

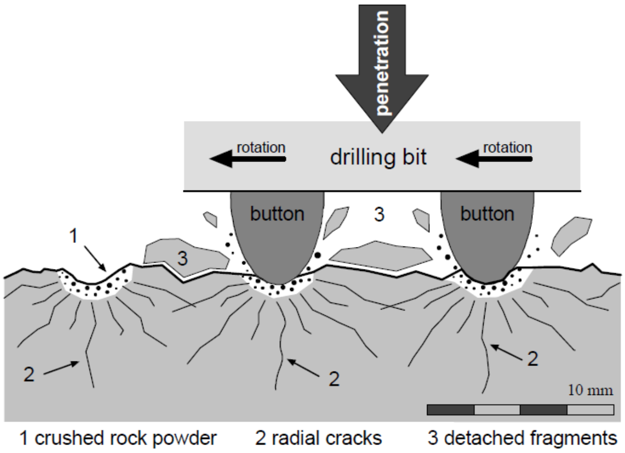

Figure 3 - Drilling Process (Source: Thuro & Spaun, 1996).

In the context of mining industry, wear of drilling materials "can be defined as a process of continuous loss of material from the surface of the drilling bit due to mechanical contact and relative movement of the bit on the rock surface" (Plinninger, 2008).

There are several factors that promote bit wear: **geology, tools and logistics** (Plinninger, Spaun e Thuro, 2002).

These factors can cause three main types of wear: adhesion wear, abrasive wear, which includes wear by impact and by thermal effects and, finally, corrosion wear (Efsing & Olsson, 2013).

It is therefore important to determine the number of meters bored by the bits until they are inoperable due to wear. So, a table was created, by Thuro in 1996, for bits with a diameter between 43 mm and 48 mm (table 1) wich classifies the wear rate as function of the bit lifetime (m/bit).

Table 1 – Classification of the wear rate for bits with diameter between 43 mm and 48 mm (Source: Plinninger, 2008).

Wear Rate	Drill Bit Lifetime (m/bit)	Drill Bit Lifetime
Very low	> 2000	Very high
Low	1500 – 2000	High
Moderate	1000 – 1500	Moderate
High	500 – 1000	Low
Very high	200 – 500	Very low
Extremely high	< 200	Extremely low

There are three main reasons for the end of the bit lifetime: when the diameter of the head of the bit is equal or smaller than the diameter of its body; when the bit breaks and when there is excessive wear of the bit head and due to that the buttons break or release from it.

In order to delay the end of the bit lifetime, sharpening of its buttons is carried out. In this way, good levels of rock penetration can be obtained again and so similar initial characteristics of the buttons are kept.

There are several tests to relate the abrasiveness of the rock to the lifetime of the bits:

- **Bit Wear Index (BWI);**
- **Cerchar Abrasivity Index (CAI);**
- **Vickers Hardness Number of the Rock (VHNR);**
- **Equivalent Quartz Content (EQC);**
- **Schimazek Wear Index;**
- **Rock Abrasivity Index (RAI).**

Although reported, no final results will be presented for the BWI and the Schimazek Wear Index, as it was not possible to carry out the laboratory tests to obtain the necessary values for its calculation. Also, no mathematical correlations were found between these indexes and the others that were studied.

3. Case Study

Considering the defined objectives, it will be essential to obtain the number of meters that the bits are capable of drilling in a real situation. So, the progress of the works made in the development of a mining front, that is integrated in the mining area of the Sociedade Mineira de Neves Corvo SA (SOMINCOR), was monitored.

To collect the necessary data, it was followed a mining jumbo owned by Empresa Portuguesa de Obras Subterrâneas (EPOS), which is the contractor responsible for advancing the fronts of the SOMINCOR Development Department. This jumbo was being tested, so it was only working on a single work front. It performs holes with 5,3 meters of depth and has the capacity to store all data related to the drilling.

The work front that was followed is located in the Lombador area, at level 570, approximately 600 meters from the surface. The work place is integrated in the Phyllite-Quartzite Group of the stratigraphic column of Neves-Corvo that dates from the Upper Devonian (Carvalho & Ferreira, 1993; Oliveira, Pereira & Pacheco, 2003).

It is composed mainly by phyllite quartzite. This rock is formed from regional metamorphism and exhibits a low degree of metamorphism. It has gray color, foliation and a very fine granulation.

In a first phase, in SOMINCOR mine, were made several measurements in each phases of the bits lifetime. It was measured the distance drilled by each bit, the variation of its diameters, heights and weights. It was used four drilling bits. It was also adopted the criteria defined in the SOMINCOR mine for the end of the lifetime of the bits. The bits are considered inoperative when: the diameter of the bits head is less than 45 mm; the bit loses two consecutive side buttons; the bit loses two buttons in the middle button set and the bit loses one button on the side and another in the middle when they are in front of each other.

In a second phase, several laboratory tests were performed in the Geomechanics Laboratory of Instituto Superior Técnico, using the rock samples collected in the first phase of the work. Tests were performed to obtain the CAI value, values for the Point Load and Uniaxial Compressive Strength Tests and X Ray Diffraction was also performed.

4. Results and discussions

4.1. Field Results

Bit global analysis

From the measurements made, the evolution of the weight, height and diameter of the four bits used in this work was analyzed. In an attempt to find a wear pattern, the average losses of these parameters were calculated (figure 4). The mean of the average velocities in the distinct stages of the bits lifetime was also calculated (figure 5). The trend line that describes this velocity is: $y_m = -0{,}0002x_m + 1{,}6169$.

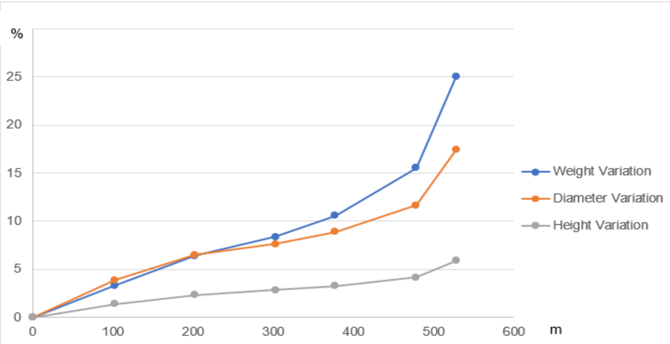

Figure 4 - Percentage variation of average loss of weight, diameter and height of the bits along the drilled meters.

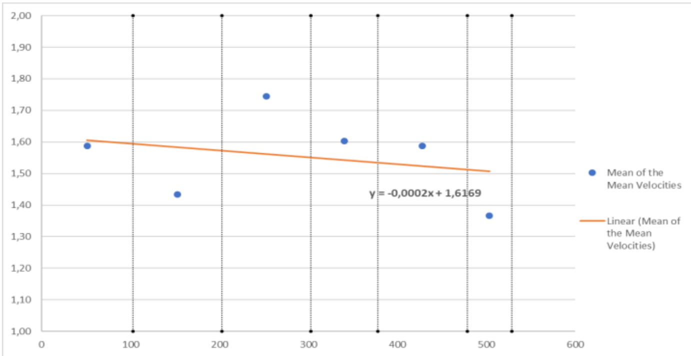

Figure 5 - Mean of the average velocities in each of the drilling stages and respective trend line.

Finally, the average number of meters bored by the bits was **516 m/bit** and the average velocity was **1,55 m/min**.

These values correspond to a low bit lifetime and their wear rate is high.

4.2. Laboratorial results

Cerchar Abrasivity Index

The value obtained for the CAI was approximately **4,0**, which corresponds to an extreme abrasiveness.

Point Load Test

This test was performed to correlate the average value obtained from the Point Load Test with the Uniaxial Compressive Strength value from the formula developed by Singh and Singh in 1993. This formula consists of multiplying the $I_{s(50)}$ by the constant 23,4, which was developed to obtain the value of the Uniaxial Compressive Strength of quartzites (Rezende, 2016).

The average value obtained for $I_{s(50)}$ was **2,15** and by applying this formula it is obtained a value of **50,2 MPa** for the Uniaxial Compressive Strength.

This test was only possible to do by applying the force in the direction of the shales schistosity, because when a force was applied in the specimen with perpendicular schistosity, it did not rupture, but it fell apart, releasing flakes corresponding to the layers of the shale.

Uniaxial Compressive Strength Test

This test was attempted to do by applying a force according to the plane of the schistosity (figure 6) and another force perpendicular to this plane (figure 7). However, when the specimens with the perpendicular schistosity were being prepared they broke. The only test pieces that were obtained were the ones in which the force could be applied trough the direction of its schistosity.

Figure 6 - Force applied trough the plane of the schistosity.

Figure 7 - Force applied perpendicular to the plane of schistosity.

Also with these specimens problems arose: when applying the force, a splitting type brake occurred, instead of breaking, the rock separated according to its planes of schistosity. So, the values obtained correspond to the resistance of these planes and not to the value of the Uniaxial Compressive Strength of the rock. Consequently, the Uniaxial Compression values obtained are relatively low for this type of lithology, considering that they are not representative of the studied phyllite quartzite.

Given the difficulties found in the accomplishment of these last two tests (Point Load Test and Uniaxial Compressive Strength Teste), it was decided to adopt the value of **85 MPa** of Uniaxial Compressive Strength, proposed by the Laboratório Nacional de Engenharia Civil, in 1987, calculated for the phyllite quartzite of the Neves - Corvo mine (Torres & Gama, 2005).

X Ray Diffraction

According to the study carried out by Pereira, 2017, three mineral species were identified: chlorite, ilite and quartz.

Other necessary values for the calculation of several indexes are the percentage of the constituent minerals of the rock where this study was developed. Professor Manuel Francisco, through analysis of several sample photographs, inferred that the composition of this phyllite quartzite is about 50% to 60% quartz and about 40% to 50% of chlorite and illite together (clayey constituents). In the present work, the values of 60% of quartz and 40% of illite and chlorite were considered.

Combination of the results

Data obtained through the field work and the indexes calculated in the laboratory will be correlated. Therefore, these values were recorded in the graphs developed by several authors that evaluate the drilling bits lifetime.

Indexes corelated with the drill bit lifetime:

- CAI – The obtained point matches with the reference results (figure 8).
- VHNR - The point lies between the lines corresponding to the diameters of 45 mm and 64 mm of the bits (figure 9).
- EQC - Applying the formula that calculates the EQC, it is observed that the obtained point is very close to the main curve of the graph (figure 10); Applying the formula that correlates the EQC with the CAI, the obtained point does not match with the lines of the graph, however it is not far from the main line (figure 11).
- RAI – Applying the RAI formula, the obtained point is close to the main curve of the graph (figure 12); Applying the formula that correlates the RAI with the CAI, the obtained point does not match with the curve of the graph, however, it is also close (figure 13).
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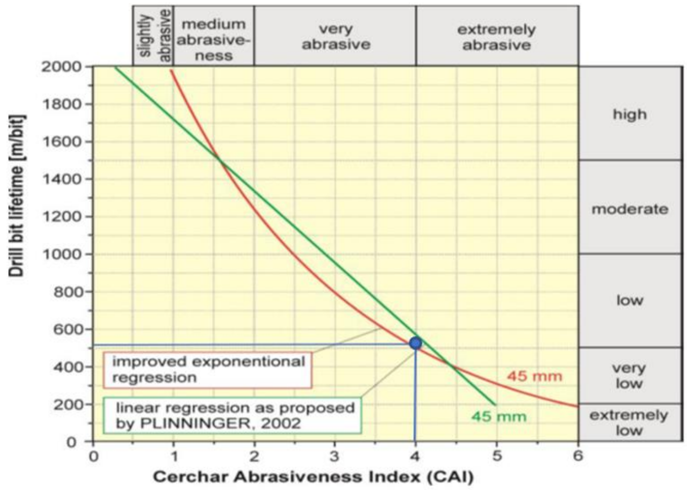

Figure 8 - Correlation between CAI and the average bit lifetime.

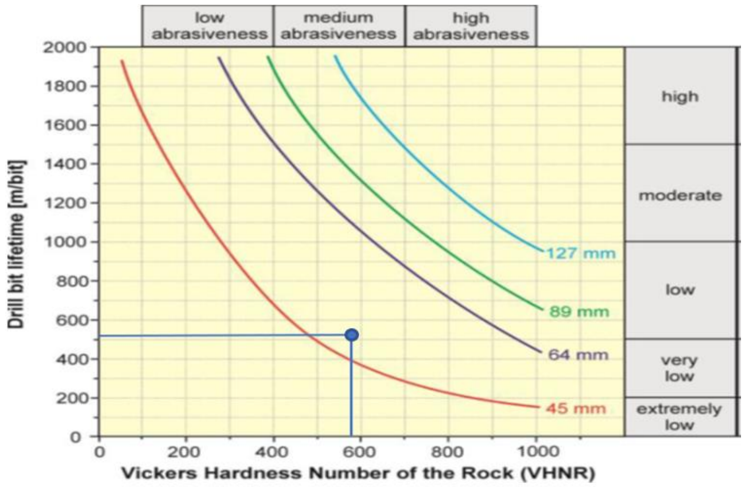

Figure 9 - Correlation between VHNR, calculated from its correlation with CAI, and the average bit lifetime.

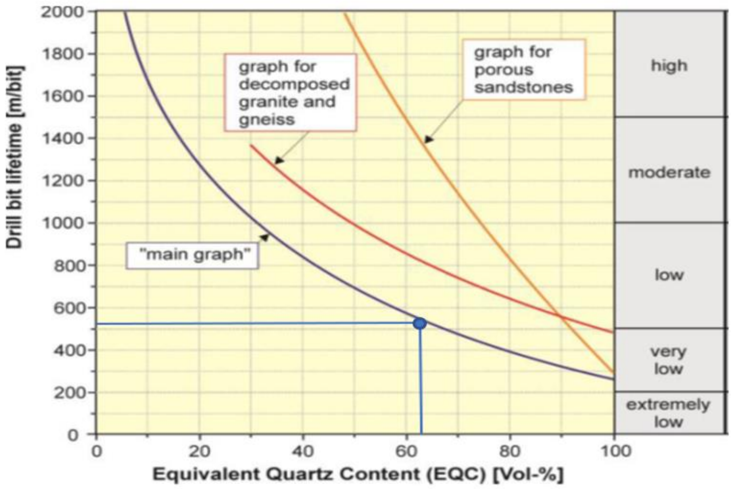

Figure 10 - Correlation between EQC and the average bit lifetime.

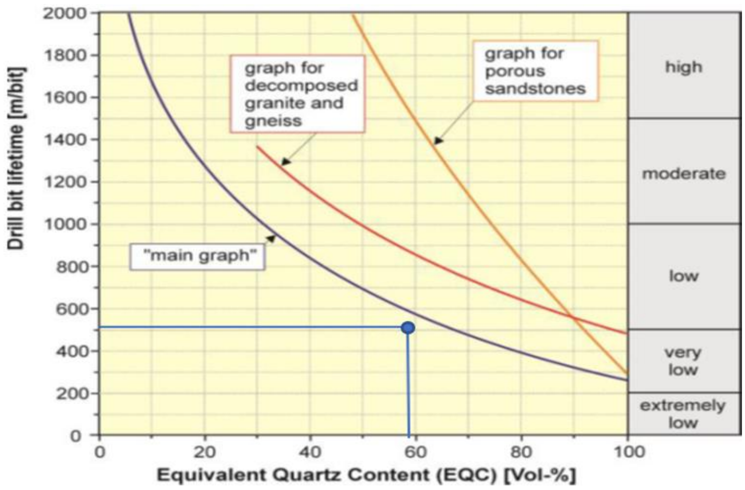

Figure 11 - Correlation between EQC, calculated from its correlation with CAI, and the average bit lifetime

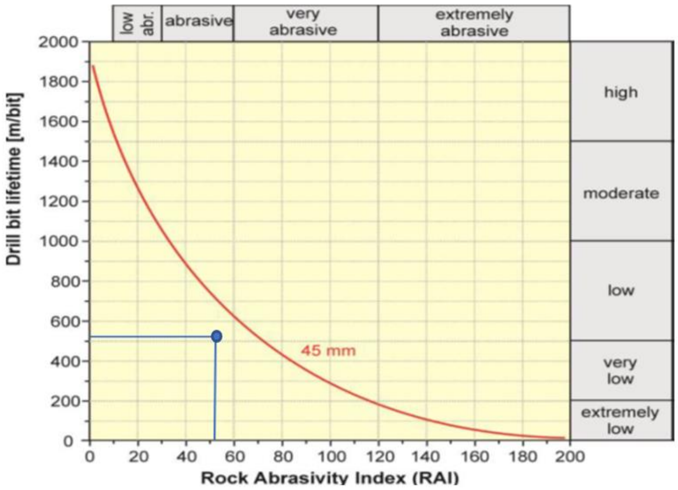

Figure 12 - Correlation between RAI and the average bit lifetime

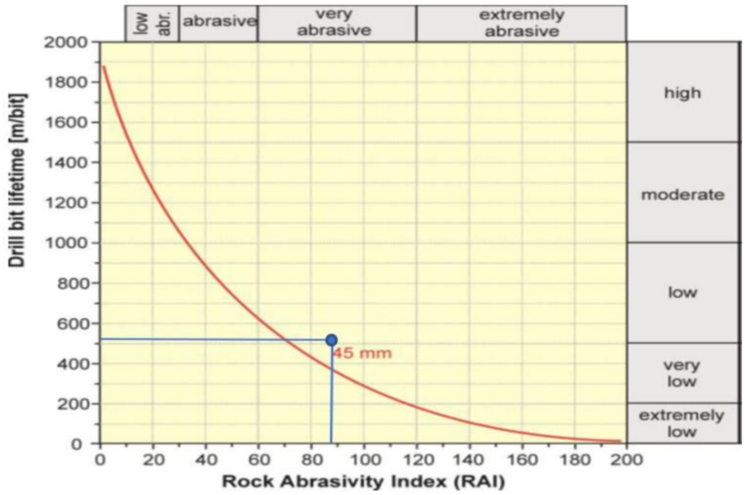

Figure 13 - Correlation between RAI, calculated from its correlation with CAI, and the average bit lifetime

Finally, by relating the average drilling velocity and the average bit lifetime and recording it in the respective diagram, it was found that the rock drillability is very low (figure 14).

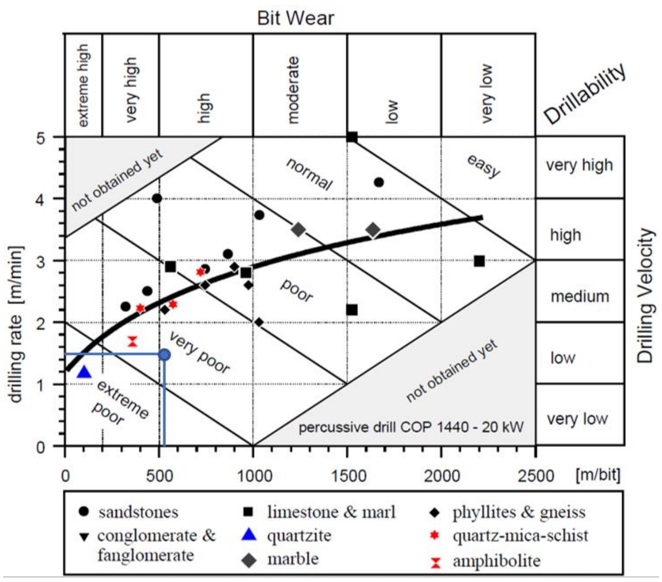

Figure 14 - Point obtained in the drilabillity classification diagram.

5. Conclusions

It is possible to conclude that the phyllite quartzite studied is a very abrasive rock, which leads to a high wear rate of the bits and consequently a to short lifetime of it; the drilling speed and the bit mass will decrease throughout the process due to the wear to which the bits are subjected. In the drillability diagram, it is possible to conclude that the phyllite quartzite has a very poor drillability.

The average lifetime of the bits was 516 m/bit in the lithology where this work was carried out. This value can be considered quite satisfactory because correlating it with the different indexes that evaluate the abrasiveness of the rock, it was verified that the obtained points adjust to the lines of the theoretical models illustrated in the graphs.

It was also concluded that the methodology followed for obtaining the CAI was the one that had the easiest application and the results that were obtained are convergent with those calculated using other methodologies. Another favorable aspect is that this index is easily correlated with other three indexes (VHNR, EQC and RAI) and the results of those mathematical correlations are close to the values calculated from the formulas of the respective indexes. It can also be inferred that the final results that were reached through the applied methodologies and the collected data are in agreement with the bibliography researched.

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