INVESTIGATION OF THE EFFECT OF BIT GRINDING ON THE COST EFFECTIVE DOWN THE HOLE DRILLING IN OPEN PIT MINES

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ABSTRACT

INVESTIGATION OF THE EFFECT OF BIT GRINDING ON THE COST EFFECTIVE DOWN THE HOLE DRILLING IN OPEN PIT MINES

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The major issue during the life of the mines are to be able to carry out effective and economic operations. Drilling activities comprises the significant amount of the production cost in surface mining and it may be the only controllable one among all other costs. From this point of view, cost effective operations become the main concern in the mines. In this study, effects of bit grinding operation on the cost effective down the hole drilling are analyzed in detail to introduce this concept to the modern mining world. Economic impacts of this operation were investigated in two open pit mines by considering the operational conditions. In these two mines, the trials of the bits in the sample set were performed without grinding operation and then the reground bits were used in the same study area. The mineralogical and petrographical results of the formations helped to interpret the differences in the bit life and drillability when all other operational conditions are the same. Based on the operational costs and the life of the consumables, not only monetary achievements but also achievements in the cost per meter and bit life were determined. As a result,

it is concluded that the bit grinding operation decreases the drilling costs and amount of used bits and increases the effectiveness of the whole operation.
Keywords: Bit Grinding, Drilling, Down the Hole Drilling, Open Pit Mine, Drillability

ÖZ

AÇIK OCAK MADENLERİNDE BİT BİLEMENİN DELİKİÇİ DARBELİ MALİYET-ETKİN DELME ÜZERİNDEKİ ETKİSİNİN ARAŞTIRILMASI

Gürkan Yıldız, Tuğçe
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Madenlerdeki en temel konu, maden ömrü boyunca verimli ve ekonomik bir operasyon yürütebilmektedir. Açık işletmelerde üretim maliyetlerinin önemli bir kısmı delme faaliyetlerinden gelmekte ve delme faaliyetlerinin maliyetleri, diğer maliyetler göz önüne alındığında kontrolü mümkün olabilen belki de tek maliyet kalemi olmaktadır. Buradan yola çıkarak, madenlerde farklı maliyet-etkin operasyonlar ilgi görmektedir. Bu çalışmada, bit bileme operasyonunun etkileri detaylıca araştırılmış olup bu konsept modern madencilik dünyası ile tanıştırılmıştır. Bu operasyonun ekonomik etkileri operasyonel koşullar göz önüne alınarak açık ocak madenciliği ile işletilen iki ayrı madende araştırılmıştır. Bu iki madende, önce örnek kümesinden bilenmeyen bitlerin denemeleri gerçekleştirilmiş ve sonra aynı çalışma alanında bilenmiş bitlerle testler yapılmıştır. Diğer koşullar sabitken, formasyonların mineralojik ve petrografik sonuçları delinebilirlik ve bit ömürleri arasındaki farkları yorumlamaya yardımcı olmuştur. Operasyonel maliyetler ve sarf malzemelerin ömürleri temel alınarak, parasal kazanımlarla sınırlı olmamakla beraber metre başı maliyetlerde ve bit ömürlerindeki kazanımlar

ortaya konulmuştur. Ayrıca bit bileme operasyonunun delme maliyetlerini ve kullanılan bit sayısını düşürürken, bütün operasyonun verimini arttırdığı sonucuna varılmıştır.
Anahtar Kelimeler: Bit Bileme, Delme, Delikiçi Darbeli Delme, Açık Ocak Madeni, Delinebilirlik

To My Family

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CHAPTER 1

INTRODUCTION

1.1 General Remarks

From past to present, mines always were on the focus of humankind. The most primitive hand tools gave their place to modern and effective techniques thereby. In this new and modern era, today's mining methods were crowned with some details to be able to make the operations more effective and economical. In drilling applications, bit grinding operation has started to be an essential part in conjunction with the method itself. The rule of thumb in mining can be summarized as "if the operation is not economical then it is not worth mining". Because of that, in order to decrease the total costs of the operation takes a vital role. However, when it is considered that many costs are fixed or does not depend on an effort, this critical decrease mainly comes from the drilling and blasting operations which are approximately 15% to 25% of the total production costs and the most controllable ones.

In other respects, financial aspects of the operation depend on the efficiency of the operation. Good drilling accuracy as a result of high quality holes increases the productivity and helps to avoid overdrilling or underdrilling or poor blasting problems. If overdrilling takes place, it causes dilution of the ore. If underdrilling occurs, it causes ore loss. Good bit grinding routines and correctly sharpened bits get through these kind of problems. It helps to keep the penetration rate optimal, to achieve good drilling accuracy, to cause less wear on drilling tools, rock drill and even rig and to improve productivity. At last, since the outcome of mining is much more related to the finance, it can be said that proper grinding operation gives the lowest possible cost per drill meter. Grinding is important not only for best possible service life of bits and the hole quality but also total economy of the drilling operation. A proper grinding service set-up is an efficient way to ensure a cost effective drilling operation.

1.2 Statement of the Problem

In percussive drilling two methods are used commonly, top hammer drilling and down the hole drilling. Regardless of the method, the purpose and the desired result are the same. There are some advantages and drawbacks of these two methods compared with each other, however cost effective drilling operation is their common concern. A decrease in the drilling cost means a decrease in the production cost which causes the mine to be more profitable. Both top hammer and down the hole drilling equipment transmit the energy to the rock for fragmentation purpose by means of the buttons on the drill bits. The buttons make the first contact with the rock and because of that, their composition should be highly resistant to wear caused by the rock. The composition and the design of the buttons may be customized however increase of the intended life of the buttons needs different studies. Here, the purpose is to improve the existing situation. To be able to understand the effects of bit grinding operation will help to overcome the bias. In all mines, the question is if grinding operation is whether a costly, time consuming, useless concept or not. For this reason, effects of this operation are tested in two open pit mines using down the hole drilling at Kışladağ Gold Mine and Özdoğu Copper Mine. In this study, economic effects of the grinding operation are investigated and analyzed in detail. Monetary achievements and increment on the life time of the bits was targeted and stated as a problem.

1.3 Objectives and Research Methodology

The main objective of this research is to reveal significant relations between bit grinding operation and economy in rock drilling. In general, the relation between life of a drill bit and strength of the rock; penetration rate and rock strength; life of a drill bit and silica content of the rock are the main parameters investigated.

For this purpose following steps were carried out:

a) The study areas were visited regularly and their drilling activities were observed by considering the geological structures to be able to gather data and make correct comparisons.

b) After detailed geological studies were completed, rocks samples gathered from the mine sites were sent to the Geology-Geophysics Research Center of Middle East Technical University for mineralogical and petrographical analysis.

c) Drilling tests were performed in identified areas without grinding the bits to understand the life of a drill bit under normal circumstances.

d) Based on the observations made, grinding system was introduced and the drilling tests were performed again in the same identified areas by using the bits sharpened by grinding to understand the life of a drill bit while grinding operation is done.

e) The tests were carried out in 2 (two) different mines to be able to make comparisons.

f) The economic impact of the grinding operation was also studied to be able to give a basic understanding of cost per meter concept.

g) Results and recommendations were presented.

1.4 Outline of the Thesis

This thesis comprises of the following parts:

1. The concepts such as cemented carbide, down the hole drilling method, drillability, essentials of grinding were summarized under the Literature Survey in Chapter 2.
2. General information about the study areas and their geologies were mentioned in Chapter 3.

3. The detailed information about the experiments and their assessments are included in Chapter 4.

4. Conclusions and recommendations based on this thesis are submitted in chapter 5.

CHAPTER 2

LITERATURE SURVEY

2.1 Cemented Carbide Concept

Cemented carbide is a metallurgical powder material and it is comprises of the grains of very wear-resistance tungsten carbide and cobalt (Co). The cobalt gets wet and starts to melt at the temperatures of 1400-1600° C. When the cobalt melts, it dissolves the tungsten carbide in the mixture of tungsten carbide and cobalt and it behaves as a cement. The cemented carbide concept comes from this process. Cemented carbide is comprised of hard and wear resistant particles combination (Figure 2.1); it is made up of the grains of tungsten carbide for wear resistance and cobalt for binding (Comstock G.J.,1934). Hard and relatively abrasion resistant this material would be the expedient to the drilling tools in the drilling industry.

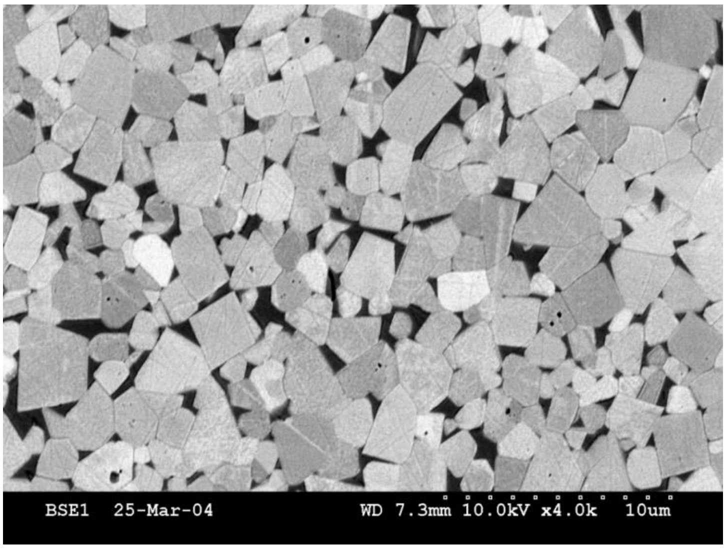


Figure 2.1 Tungsten carbide and cobalt particles, Purdy, 2014

In the drilling industry, pressed and sintered tungsten carbide and cobalt mixture is used in the buttons of rock bits. With special sintering process, toughness and wear resistance of the cemented carbide can be changed by configuring the ratio of tungsten grains in the mixture (Purdy, 2014).

Although some special designs may be available, the most common shape of the buttons are spherical. The spherical shape features the optimum ratio of toughness/wear resistance. When this ratio is not good enough the buttons may not break the rocks as effective as it is. This spherical shape is more suitable for abrasive and hard formations where the rate of penetration has second importance against the life of the bits. The other common shape is called as ballistic. Ballistic inserts are sharper and more aggressive than spherical inserts. This type offers higher penetration rates (Thuro&Spaun, 1996). Its life time is less than the spherical type in the abrasive and hard formations because of its shape; it is more suitable for soft, soft to medium hard and less abrasive formations.

2.2 Down The Hole Basic Drilling Principle

Down the hole drilling is classified as rotary percussive rock drilling method. It is also known as “downhole drill” or “in the hole drill” (Naapuri,1995). In 1940s, down the hole drilling was developed with the idea of drilling bigger, deeper and straighter holes, taking the control of blasting operation a bit more and achieving better fragmentation while charging the holes effortlessly. Today, although Down the Hole Drilling technique is suitable for larger diameters, it is used for the drill holes whose diameter changes between 89 mm to 254 mm with 3 – 10 inch Down The Hole hammers in common (The Little Big Book of Down the Hole Drilling, 2015). Because of the working principle of Down the Hole Drilling, it is more suitable for larger holes unlike Top Hammer Drilling. DTH drills use compressive air more efficiently than the top hammer drills (Naapuri, 1995). Since the location of the drill makes this difference, instead of a drifter assembled in the boom, a drifter which is located right behind the bit ensures a very small leakage in the percussion energy generated in the drifter (Hemphill, 1981). When the piston strikes the bit directly, that created energy passes a very short distance instead of passing a long string of the rods. The down the hole drilling is more advantageous for deeper holes because it offers high penetration rates by keeping the hammer with the bit as going deeper. While the hammer is entering to the hole together with the bit, the rods in the drill string reach large levels in the length. At the same time, the drill rods are not conveying the percussion energy through their body, they are conveying only thrust therefore their life time is getting longer (Hemphill, 1981) In down the hole drilling technique, the drill string is made up of down the hole hammer, bit, drill rod. The main components of a down the hole drilling system (Figure 2.2) of this type of mechanical cutting are as follows:

- Drill rig (source of mechanical energy)
- Drill steel (transmitter of mechanical energy)
- The bit (exercises mechanical energy to the rock)
- Flushing air (cleans out and evacuates the drill cuttings)

(Jimeno et al., 1995)

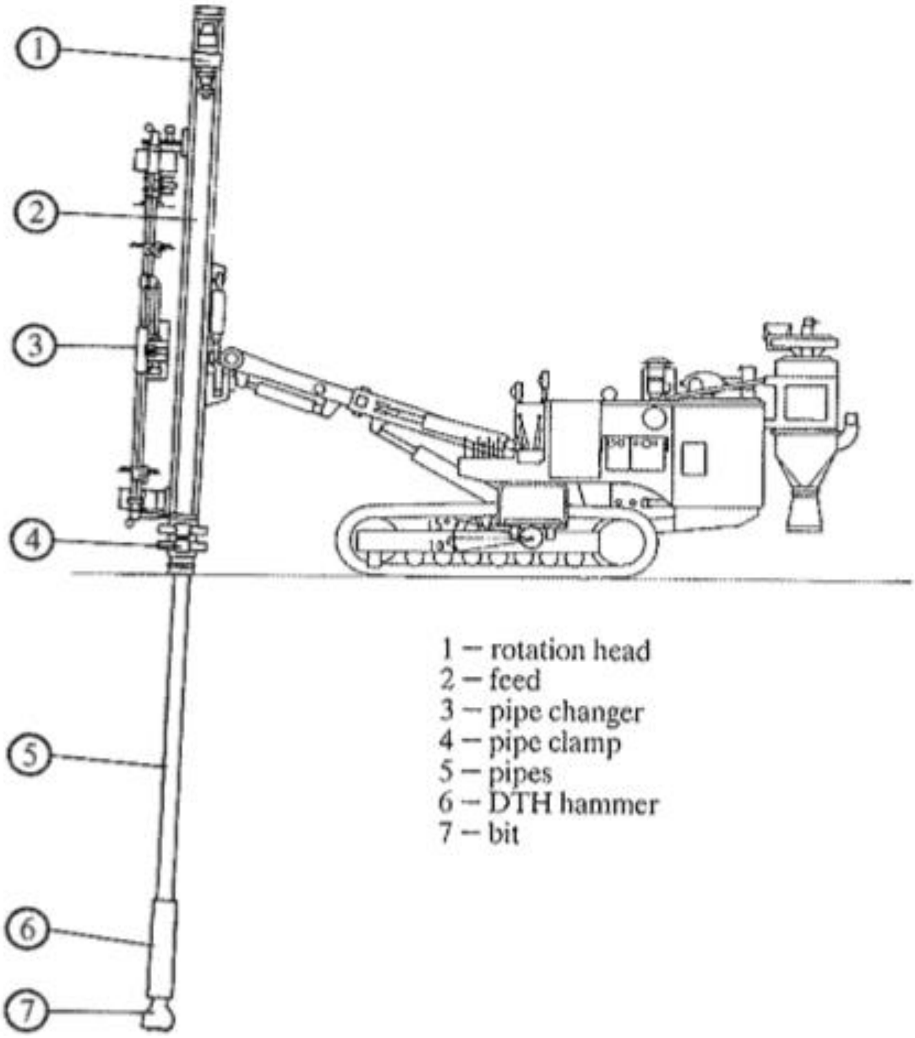


Figure 2.2 The main components of a mechanical cutting drilling system, Boman, 2011

As it is explained, the energy losses are very low in DTH in comparison with other drilling techniques because of its working principle. The key parameter in this energy loss issue is the location of the hammer (Figure 2.2).

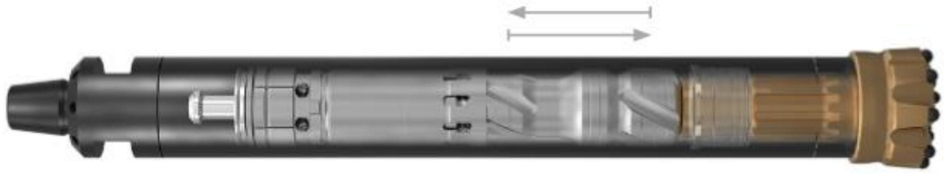


Figure 2.3 DTH Drill Hammer, The Little Big Book of Down the Hole Drilling, 2015

In the drill string, the hammer (Figure 2.3) is located between the drill pipes and the bit with some kind of adapters; the rear of the hammer connected by the top sub to the drill pipe and the front part is connected directly to the drill bit by driver sub. The drill pipes convey the feed force, rotation and a supply of compressed air mixed by means of some kind of grease to the DTH hammer which strikes directly right behind the bit through the hole. The compressed air causes the piston of the DTH hammer to move back and forth very fast and the hammer strikes the bit directly at the end of the strokes and the cutting process starts from here. Rock cuttings transport upward are blown away from the bottom of the hole, by means of the cylindrical motion in the hole (Bergquist, 2016).

As it is mentioned Down the Hole Drilling is more advantageous than other drilling methods but it is valid if the ground conditions and rock type allow the system to work. Because the hammer hits the bit directly, energy loss is very low even the hole gets deeper. This enables to drill stronger species of rocks. Since down the hole method is a kind of percussive drilling, drilling method selection can be done based on rock compressive strength (Figure 2.4).

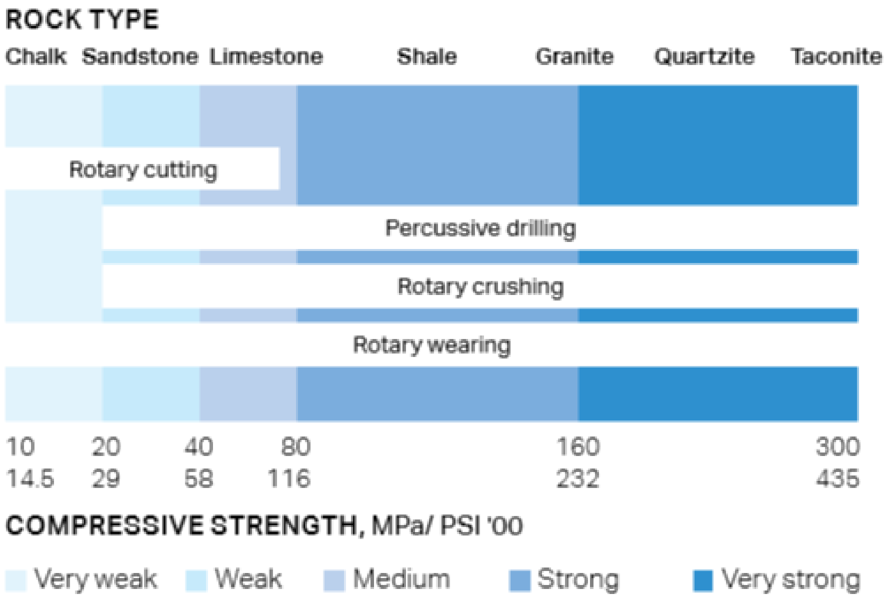


Figure 2.4 Drilling Method Selection Based on Rock Type and Compressive Strength, The Little Big Book of Down the Hole Drilling, 2015

DTH bits have tungsten carbide buttons to create chips. Different shapes of these tungsten carbide buttons are available and these shapes evolve due to the characteristics of the rock which will be drilled (or the material will be extracted). The most common shape is spherical type which is perfect for hard and abrasive rock types (Thuro&Spaun, 1996). In this thesis study, drilling tests are conducted with DTH bits having spherical buttons.

In down the hole drilling, the buttons of the bits expose extreme load because of the blows of the hammer, when the piston of the hammer hits the bit. When this load reaches a point, the rock in contact with the cemented carbide buttons of the bit starts to deform. This deformation causes chips and cracks (Figure 2.5). According to Boman (2011), this whole process related to the rock fragmentation may be divided into four phases:

- Elastic deformation
- Rock Pulverization
- Crack formation
- Chipping

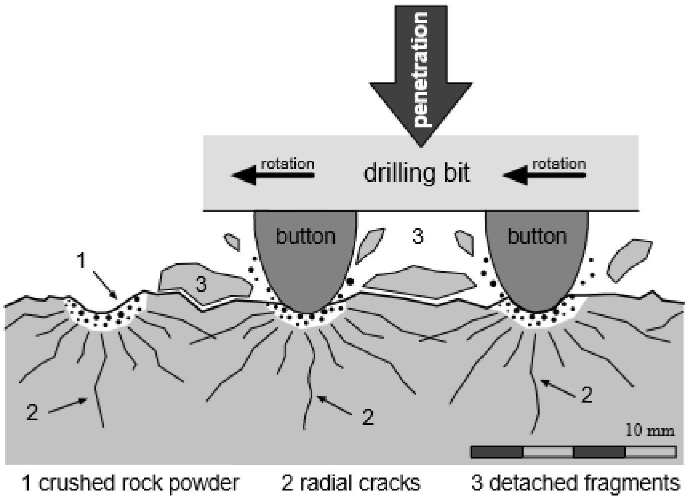


Figure 2.5 crashing process in rotary percussive drilling, (Thuro,1997)

In other words, when the compressive stress-wave passes through the drill-bit and into the cemented-carbide buttons, in contact with the rock, the buttons in turn transmit the stress-wave into the rock. This builds up stress in the rock underneath each button and above 4 phases start to occur respectively. When the stress level is lower than the elastic limit of the rock elastic deformation takes place (Ulusay et al., 2016).

- Elastic Deformation:

The first phase is called an elastic deformation (Figure 2.6). At this point, the rock yields and deforms elastically, allowing the button of the drill bit to penetrate through the rock without dust, crack, or break formation (Han et al., 2009).

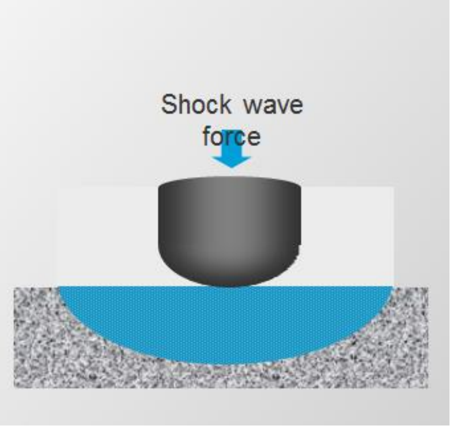


Figure 2.6 Elastic Deformation, Purdy, 2014

- Rock Pulverization

As the button penetrates the rock further, a thin layer of rock directly under the button is crushed to a powder (Figure 2.7). This is a very small area under the button. It is the second phase, rock pulverization, which happens at almost exactly the same time as phase one, elastic deformation (Purdy, 2014).

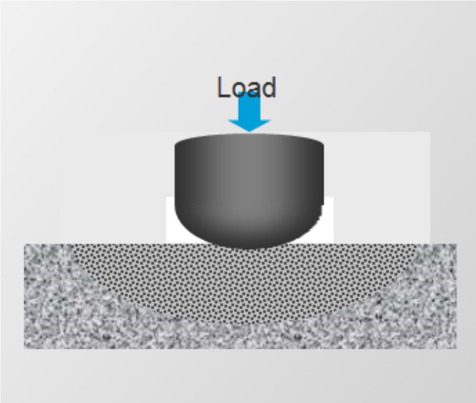


Figure 2.7 Pulverization, Purdy, 2014

- Crack Formation

In this phase, rock fails and cracks are observed (Figure 2.8, Han et al., 2009). Within an instant after pulverization, the stress level overcomes the strength of the rock and cracks begin to form and quickly propagate into the rock. The cracks radiate downward and away from the button (Purdy, 2014).

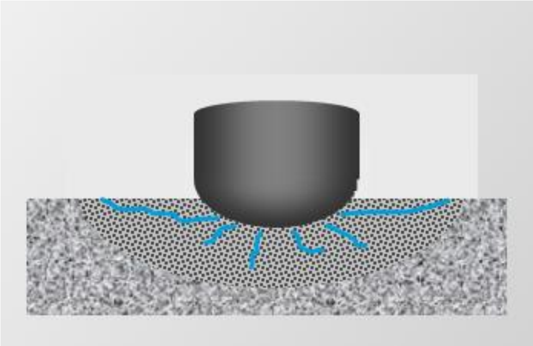


Figure 2.8 Crack Formation, Purdy, 2014

- Chipping

In the final phase, because the rock has deformed beyond its elastic limit, cracks radiates and propagates (Figure 2.9). As it does so, it forces the cracks to go upward towards the free surface of the rock, which causes large chips of rock to break off the bottom of the hole, almost explosively. These are named as the rock cuttings or rock chips or drill cuttings (Purdy, 2014).

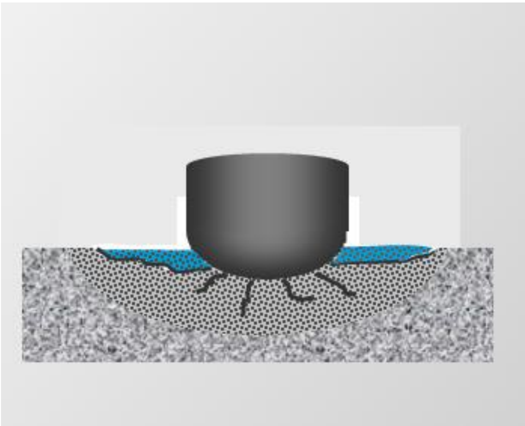


Figure 2.9 Chipping, Purdy, 2014

The four-step rock penetration sequence takes place within a tiny fraction of a second as the hammers strike at a rather high frequency. In DTH works, this frequency is about 1000 to 3000 blows per minute. How much the button penetrates the rock depends on the type of rock and on the shape of the button. Typically, the penetration depth is in the range of 1-2 millimeters per blow from the hammer (Bergquist, 2016).

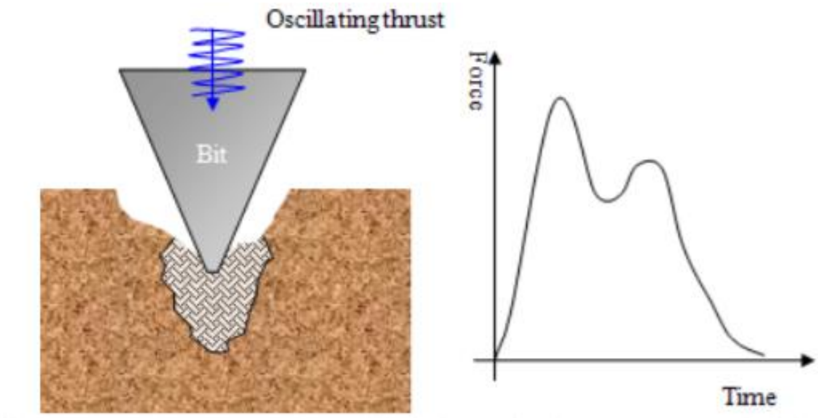


Figure 2.10 Percussive drill and the response of the bit (force), Han et al., 2009)

In percussive type drilling such as DTH, when the impact energy created by the hammer exceeds the strength of the rock, the rock fails against this great energy as it is mentioned above and starts to fracture. The response of this energy in the bit against time can be seen from the Figure 2.10 together with the illustration of the bit-rock contact and the force direction.

2.3 Drillability

Drillability can be determined as the ability of the rock to be drilled. However this ability depends on many factors and in fact, the drillability shows up the effects of some parameters summarized in Figure 2.11 on the drilling rate and the wear of the drilling consumables (Thuro&Spaun, 1996). Also, drillabillity shows the improvement of the drill bit through the rock when the rock starts to fail against the energy created by the hammer of the drilling system (Sakız et al., 2017). To sum up, the drillability depends on three main parameters which are discussed in detail below. Some of these parameters cannot be controlled such as the geological properties of the rocks while the others like the face, diameter, button shape of the drill bit and some technical parameters of the hammer and drill rig (Sakız et al., 2017).

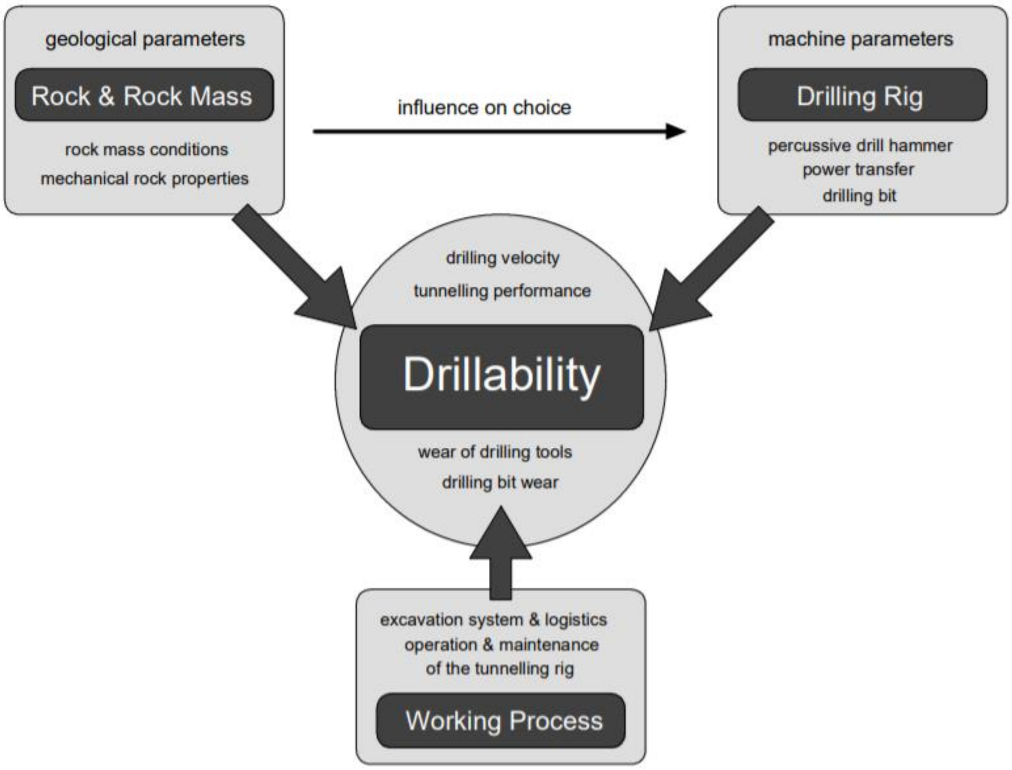


Figure 2.11 Drillability and the factors affecting it, (Thuro&Spaun, 1996)

i) Rock Mass Properties

Geological parameters affect the drilling performance and the wear on the drilling consumables (Figure 2.12). Hardness, abrasiveness, texture, structure and breaking characteristics of the rock affects the drillability in first place. The main influencer among these properties is the abrasiveness of the rock. The abrasiveness is correlated with the quartz content of the rock directly based on an assumption. In this thesis, the quartz contents of two operations are taken into the consideration to be able to interpret the results.

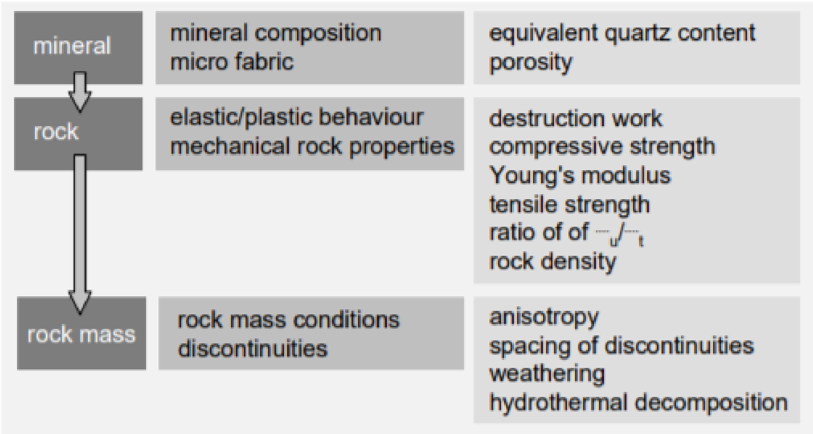


Figure 2.12 Some geological parameters generates the characteristics of the mineral, rock and rock mass, Thuro&Spaun, 1996.

ii) Drill Rig

Although this part is named as drill rig, all the related factors should be taken into the consideration. These parameters can be summarized as the type of the drill rig, the thrust force, bit type, rotation, the quality of flushing, and power transfer (Yaralı, 2011). Apart from the technical properties of the drill rig, every drill rig has its own drifter or hammer. The drilling performance of these drifters or hammers determine the drillability mostly. In this thesis, Sandvik brand heavy duty RH550 (latter RH510) hammers were used during the tests. Hence, the differences coming from the performance of the tools were tried to be eliminated. Also the drill bits have a heavy role in this study hence the same type bits were chosen and used for both operations. Sandvik Brand 165 mm bits which are compatible with RH550 hammers and have a concave face and spherical buttons were used. The button shape (spherical or ballistic) and design of the buttons influence the drilling performance significantly (Thuro&Spaun, 1996). Although it is very difficult (the most difficult one among other face types) to grind the bits with concave face, they drill straighter, and their flushing quality is higher.

iii) Working Process

Working process refers to the operational parameters. Especially if time is the main concern in the operation, this part becomes more important. Drilling method, maintenance conditions, excavation system, human factor (the operator) and logistics affects the performance of the drilling are included in this part (Thuro, 1997).

Besides, drillability can be increased by means of good bit grinding routines and can be measured from the result of the rotation speed. If the systems are working properly, the bit is acting as a new bit and the penetration rate is optimum due to the ground bits, the rock particles around the hole should not be seen as ground (like powder or dust) but fragmented (Figure 2.13) . If some fragmented particles cannot be observed near the collar of the hole, it may mean that the buttons of the bit are blinded and penetration rate is decreasing. Therefore the rock is powdered instead of broken.

Figure 2.13 Correct rotational speed, Kışladağ, Uşak. March 17, 2015.

2.4 Essentials Of Grinding

Drilling applications together with the blasting applications form the backbone of the production in mining. Increasing the efficiency of the drilling work ensures economic and operational advantages. These advantages of the drilling application cannot be considered apart from blasting operations. Achieving good quality holes are very important for good blasting. If the quality of the holes is poor and deviated, amount of the explosives used in the hole will be higher and resulting fragmentation will not be as desired (“Grinding Equipment”, 2016). Because of poor blasting, underbreak or overbreak may be seen in the blasting area and sometimes secondary blasting may be needed. Thus main concern in drilling applications is becoming the hole quality. Good ground bits are the performance key to increase the hole quality. The main goal of the grinding operation is to decrease the cost per meter while increasing the performance of the drilling and blasting operations. Therefore the grinding operation should be an inseparable part of the drilling applications.

In grinding operation, there are some basic and operational rule of thumbs. First of all the amount of the flat worn area is very important in terms of having a good grinding. Excessive over drilling of the bits will cause damage to all drilling consumables and the drill rig. The flat worn area of the button should not exceed 1/3 of its diameter. Worn bits with 100% flat buttons cause button damages Figure 2.14). Although it is possible to grind the drill bits before or after this limit, this limit is the most economic point for grinding based on the experiences. Also, grinding too often is always more economic than grinding too seldom (Olsson, 2014).

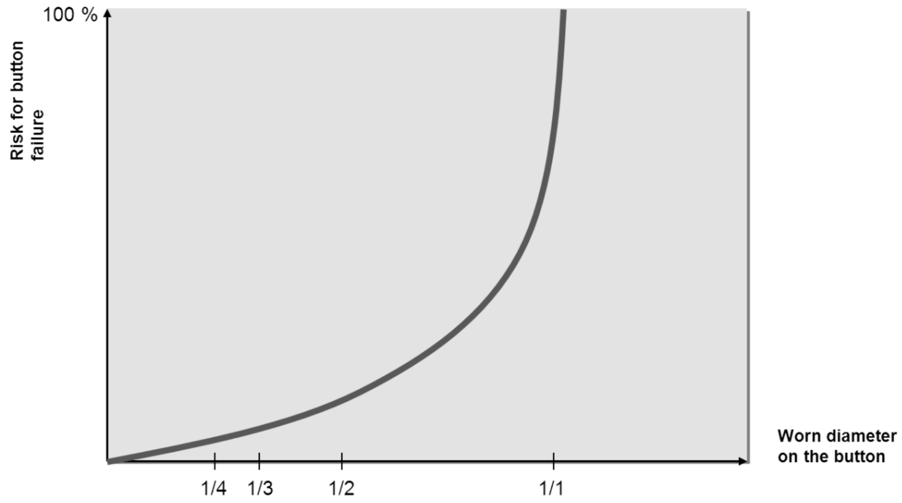


Figure 2.14 Graph of the Button Failure vs Worn Dia. on the Button, Olsson, 2014

A button bit needs regrinding when the penetration rate becomes unacceptably low, or when button damage occurs before the drill bit can be regarded as worn out due to increase in penetration resistance (Figure 2.15). Normally, the penetration rate starts to fall when the size of the wear flat on the button becomes equal to half the diameter of the button (Figure 2.16). Grinding increases the penetration rate and is more economical (Figure 2.16) if the buttons are reground when the size of the wear flat becomes equal to 1/3 of the diameter of the button (Figure 2.17). Purdy (2014) states that it is better to regrind the drill-bits too often than to regrind too seldom. The tests show that the grinding increases the rate of penetration dramatically when the flat worn area is about 1/3 instead of ½ (Figure 2.16).

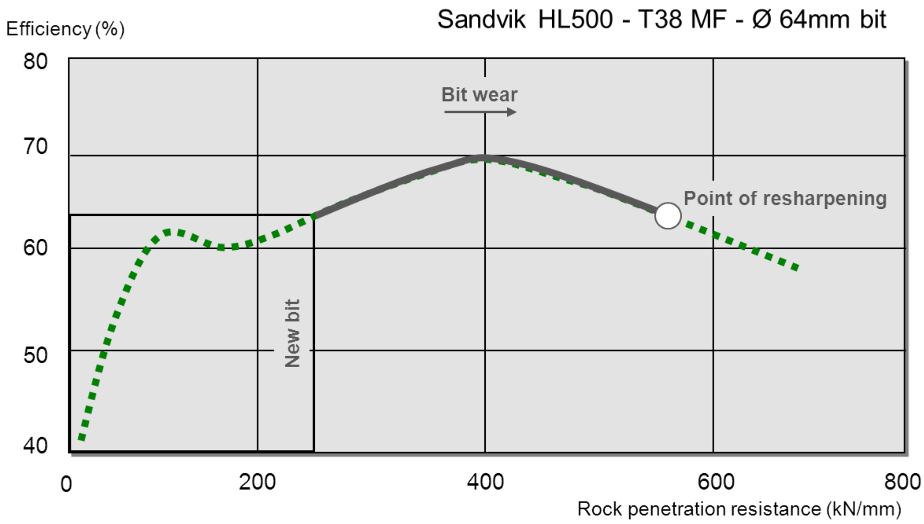


Figure 2.15 Graph of the Efficiency vs Penetration Rate, Olsson, 2014

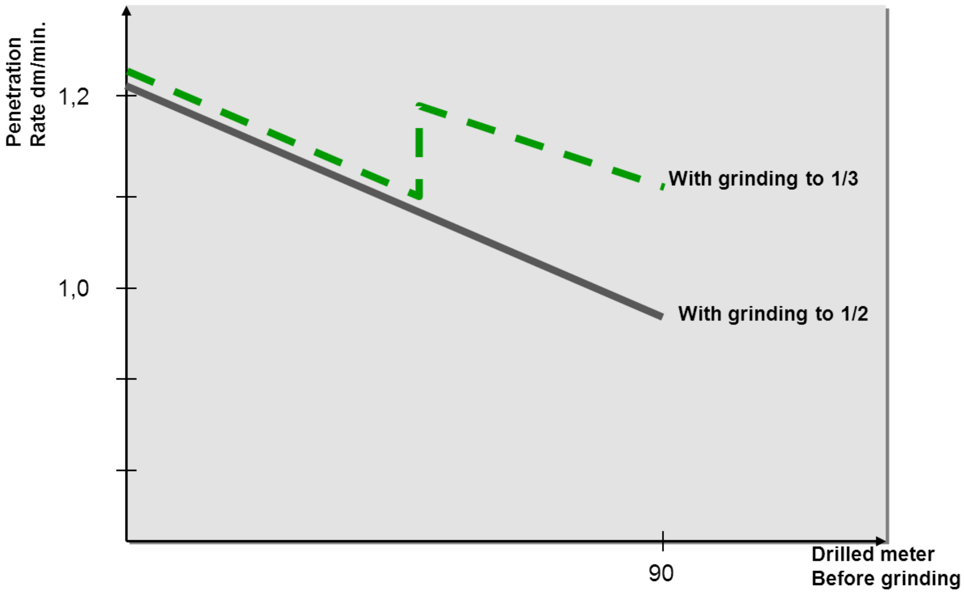


Figure 2.16 Graph of the Penetration Rate vs Drilled Meters, Purdy, 2014

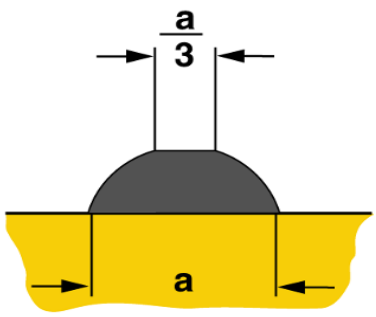


Figure 2.17 Optimum Grinding Rate, Purdy, 2014

Second rule is related to some other observational experiences other than the "1/3 rule" which helps to decide grinding time. According to Purdy (2014), grinding is needed generally under the below circumstances given below:

- Before the wear-flatness develops above recommended limits
- When penetration rate starts dropping off
- Before snakeskin appears on the cemented carbide surface
- When sudden early breakages occur, especially when drilling in non-abrasive rock formations.
- Before anti-taper develops above recommended limits.
- When hole deviation tends to increase.

2.4.1 Wear Types

2.4.1.1 Over-Drilled

Excessive over-drilling of bits will cause damage, not only to all drilling consumables, but also to rock drill (drifter)/hammer and rig. The maintenance costs of the drifters/hammers and rig itself are higher and downtimes of the rigs causes money loss since the production is stopped.

Figure 2.18 Over-drilled Bits, Purdy, 2014

As it can be seen from the Figure 2.18, these two bits are over-drilled. They should have been reground a long time ago, now it is almost impossible to restore the shape of the buttons. Besides low penetration rate, these bits have also caused wear and damage to the rock-drill and the rig. Drilling with blunt buttons will cause a lot of the energy that is sent from the piston to the bit to turn around and cause increased wear on tools and equipment instead of breaking the rock. Also it should be taken into consideration that increased maintenance costs on rock-drill and rig may originate from drilling with blunt drill-bits (Purdy, 2014).

2.4.1.2 Snake Skin

Snake skin wear occurs in rock formations which cause very little wear to cemented carbide (Figure 2.19). The surface of the button becomes fatigued and a pattern of micro cracks develops. The initial micro cracks must be removed by grinding before they spread deeper into the cemented carbide. Even if there are no visible signs of micro cracking, the cemented carbide should be ground every 300 (three hundred) drill meters in the case of button bits, when drilling in nonabrasive rock formations (Purdy, 2015).

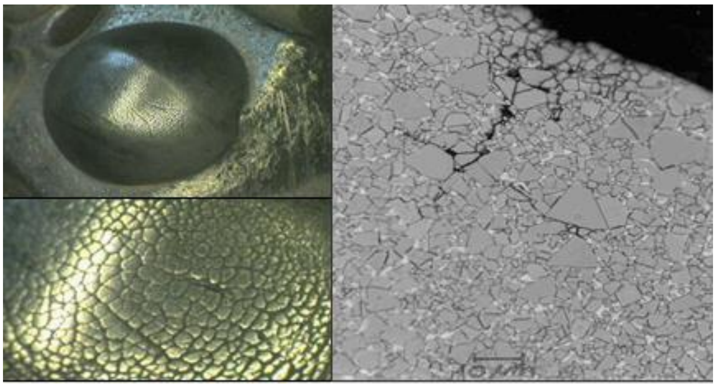


Figure 2.19 Snake Skin Wear, Purdy, 2014

2.4.1.3 Anti Taper

Anti-taper occurs when the gauge buttons are worn down so there is no or less clearance between the bit body and the hole. There is an increased risk that the bit will jam in the hole if drilling continues. It will also increase the load on the rotation motor on the rig.

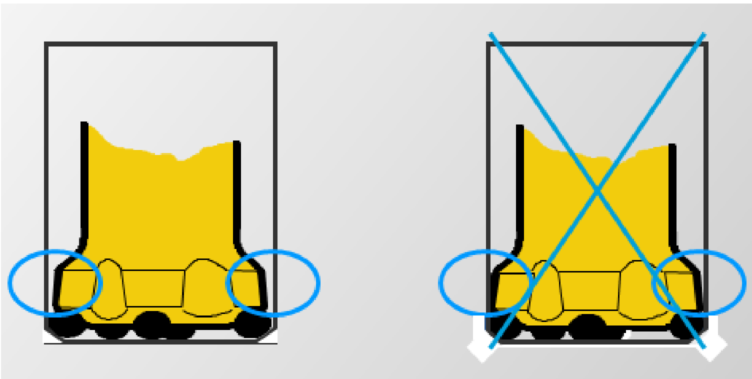


Figure 2.20 Anti Taper, Purdy, 2014

To avoid anti-taper there should be a clearance of at least 0.5 mm between button protrusion and the bit body. If necessary, steel on the side of bit body has to be removed to create enough clearance (Purdy, 2014).

The bits are designed for axial load on the buttons. In an anti-taper situation, the load will be more of shear load than axial, and that can break the button. In Figure 2.21, the gauge buttons of a new drill bit are exposed to axial forces. In Figure 2.22, when the bit wears, the load angle changes and the risk for button breakage increases.

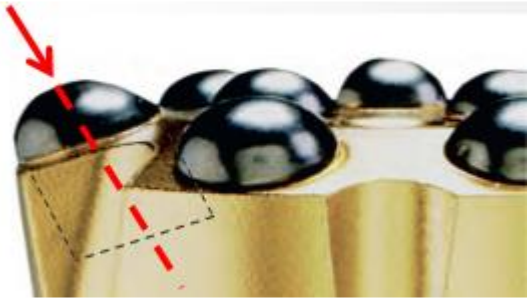


Figure 2.21: Axial Loads on a New Bit, Purdy, 2014

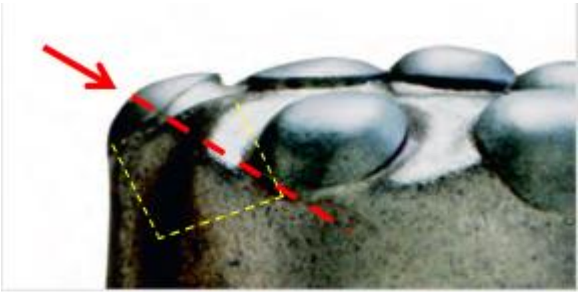


Figure 2.22: Axial Loads on a Worn Bit, Purdy, 2014

2.4.1.4 Button Protrusion

Sometimes the steel in the bit body is not worn away at the same rate as the cemented carbide buttons (Figure 2.23). When this happens, the steel must be ground away to maintain same button protrusion as on a new bit (Purdy, 2015). In this type of problem, using a hand-held grinder to remove steel from around the buttons will be a solution.

Figure 2.23 Button Protrusion, Purdy, 2014

As it can be seen from Figure 2.23, excessive button protrusion is another problem. Sometimes the steel in the bit body is worn away faster than the cemented carbide in the buttons. The buttons must be ground to maintain same button protrusion as on a new bit. If not, there is an increased risk of button breakage (Purdy, 2014).

Figure 2.24 Excessive Button Protrusion, Purdy, 2014

2.4.2 GRINDING OF THE BUTTON BITS

In this study, the effect of grinding of the button bits are fitted with cemented-carbide buttons which are highly resistant to wear is analyzed. Although cemented carbide buttons are very resistant to wear, they also wear down and need to be ground at regular intervals to restore them to their original shape.

As it is mentioned before, the button bits should be ground when

- The penetration rate drops, owing the wear flats having formed across the tops of the buttons.
- Before anti-tapered develops
- Hole deviation tends to increase
- The wear-flat is equal to 1/3 of the button diameter. This is generally the most economical point to regrind (Purdy, 2014).

The grinding operation can be carried out in different ways. According to its idea, each button should be redressed to its original shape. The grinding ways can be listed as below:

- Hand-held grinder (Figure 2.25)

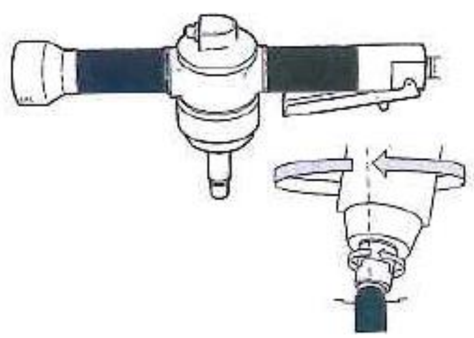


Figure 2.25 Hand-held grinder, Olsson, 2014

To grind a button correctly, the grinder is oscillated in an orbital motion around the axis of the button insert. It uses a diamond impregnated grinding cup (Olsson, 2014).

- Semi-automatic grinding (Figure 2.26)

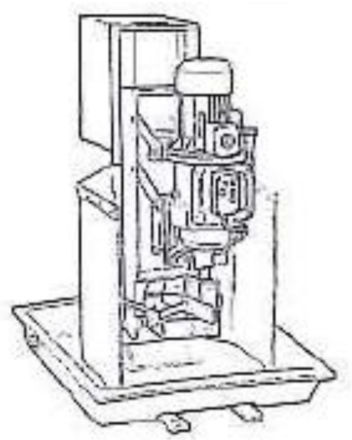


Figure 2.26: Semi-Automatic Grinding Machine, Olsson, 2014

It is suitable for larger work sites or permanent grinding station. It uses a diamond impregnated grinding cup (Olsson, 2014).

- Hand-held grinder fitted with a small silicon carbide grinding wheel (Figure 2.27)

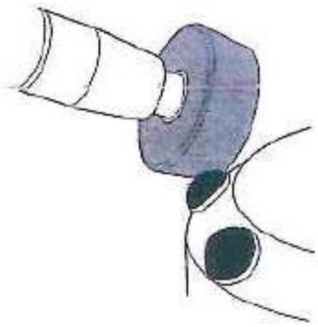


Figure 2.27 Another type of Hand-held Grinder, Olsson, 2014

This method is suitable when need of removing steel body to make buttons protrude. The button protrusion should be no less than half of the button diameter. This method is relatively cheaper than others.

However, the height of the bits should not be ground down excessively. Always, at the top of the button there should be a few millimeters (approximately 2mm) of the old wear-flat (Figure 2.28). Overgrind is an issue that should be considered well. If any anti-tapers occur on the buttons, they should be removed through grinding but the diameter of the bits should not be reduced too much.

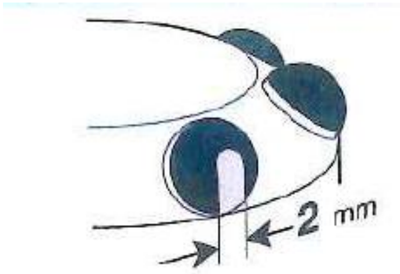


Figure 2.28 Optimum Old Wear-Flat, Olsson, 2014

Apart from its operational advantages, grinding is also more advantageous from the economics point of view. At this point, one should be consider as all the grinding costs are related to its usage and this analysis will be explained in Chapter 4. But it can be said that the only consumable in this operation is the grinding cups therefore total grinding cost apart from the machine itself, heavily depends on the wear flat size on buttons. As it is stated in the literature, 1/3 wear flat is the optimum time for grinding since cup cost index is the lowest for this state (Figure 2.29). According to Purdy (2014), all related studies shows that grinding too often is more economical than grinding too seldom.

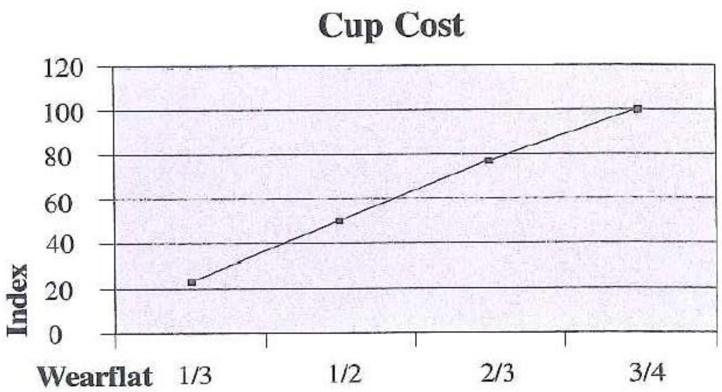


Figure 2.29 Cup Cost Graph, Purdy, 2014

CHAPTER 3

STUDY AREA AND GEOLOGY

This thesis comprises of 2 (two) sections. In the first section, general aspects of Kışladağ Gold Mine and the studies related to the effects of bit grinding operation will be discussed. After that the same process will be applied to Özdoğu Copper Mine (Kuzey Ege Copper Enterprises Inc.). Finally, the comparisons between these 2 (two) mines will be figured out. Briefly, Kışladağ Gold Mine is a low grade open pit operation and it is the biggest gold mine in Turkey and in Europe. The operation belongs to a Canadian company named as Eldorado Gold Corp. On the other hand Özdoğu Copper Mine produces Copper and Molibdenum and it is the first producer of Molibdenum concentrate in Turkey (retrieved from http://www.ozdogu.net/v2/?sayfa=kebi). The operation belongs to a Turkish company named as Özdoğu İnşaat A.Ş.

3.1 Kışladağ Gold Mine, UŞAK

Kışladağ Gold Mine is settled 180 kilometers east of Izmir and 350 kilometers southwest of Ankara and located in Uşak province (Figure 3.1).

Figure 3.1 Kışladağ Gold Mine, Google Maps, 2018

3.1.1 Topography, Climate, Flora and Fauna

Kışladağ mine lies on the western edge of the Anatolian Plateau, at an altitude of approximately 1,000 meters. According to Sutherland D., Juras S., Skayman P., Nilsson J. (2018), Kışladağ is a porphyry gold deposit and the region is affected by Miocene Beydağı strata volcano. The mine is in the mid-late Tertiary volcanic complexes of Turkey and these volcanic rocks erupted onto a basement schist of Menderes Massif. There are no many water resources in the area, the potable water is provided from approximately 5 km away from the Kışla village. Due to ephemeral streams and seasonal ponds and lack of permanent water bodies, the water supply is very limited. The topography of the area comprises of valley bottoms which are 700 meters and hills which are 1.300 meters above the sea level. The climate is arid (waterless), hot in the summer and cold in the winter. So, it displays the typical properties of the continental climate. Temperatures change between -15°C which is the minimum temperature in January and 40°C as a maximum temperature in August. In addition, annual rainfall is about 450 millimeters which occurs mainly in winter, from November to March.

The flora in the area is variable. Both the coastal Aegean type and the more continental Anatolian regions can be observed. Small oak and pine trees, shrubs, and meadow grasses can be seem in the area (Hatch, 2003).

3.1.2 Geology

Sutherland et al., (2018) states that Kışladağ is a porphyry gold deposit. The rocks in Kışladağ Gold Mine are made up of 2 rock types, the extrusive and intrusive rocks together with these stratovolcanos which are formed by the erosion of the rocks of Beydağı Volcanic sequences and the Menderes metamorphic rocks which are the base rock of the region. The gold mineralization is observed within the intrusive rocks at most. A vertical geological section is shown in the figure 3.2.

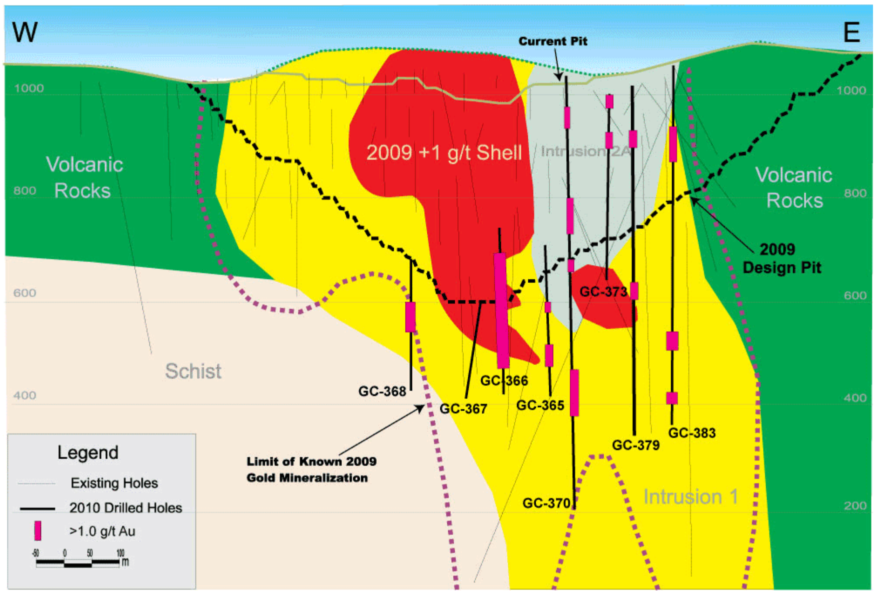


Figure 3.2 Geology Map, Juras S., Miller R., Skayman P., 2010

3.1.2.1 Physical Geology and Mineralogy

The porphyry layered gold mineralization is the core on a series of overlapping sub-volcanic intrusive of quartz-syenite to quartz-monzonite compound at Kışladağ sediment.

The Kışladağ deposit rests in the eroded core of Miocene strata-volcano composite. In spite of the lack of major faults, the Kışladağ deposit and neighboring rocks hold a high density of low-displacement brittle fractures. Joints and low-displacement faults are the most common or in other words they can be recognized easily with respect to other geological structures.

Gold mineralization with signs of molybdenum, zinc, lead and copper surrounds the Kışladağ deposit. Higher grade gold mineralization is joined with the oldest and best mineralized porphyritic intrusive phase. The higher gold grades link with multiphase quartz sulphide stock-work permeative silicification. The mineralized districts plunge exterior in a bell-shaped body (sub-parallel to the contact of the stock). The paramount sulphide mineral is pyrite and it presents with ocular approximations about 4% in the earliest mineralized zone.

The effect of oxidation causes the Kışladağ deposit being deeper on the southern side with respect to the northern side. In the area, the most abundant oxide mineral is limonite (Juras et al., 2010).

3.1.2.2 Petrology

The host succession for the Kışladağ gold mine embodies volcanic, volcano-sedimentary rocks. In the area there are three types of intrusions named as Intrusion#1, Intrusion#2, Intrusion#2A and Intrusion#3. In this thesis the studies were carried out in Instrusion#1 which is the oldest among them and it is rich in K-feldspar (Sutherland,2018). Kışladağ lies within one of several mid to late-tertiary volcanic complexes in western Turkey. In the Kışladağ region, the volcanic complexes erupted onto a basement of schist at the northeast margin of an uplifted terrain known as the Menderes Massif. Mainly, there are two rock types at the Kışladağ deposit:

- ➢ The Basement Metamorphic Rock (Menderes Massif)
- ➢ Beydağı Volcanic Sequence

There are six subcategories to this sequence:

- ▪ Latite Flows
- ▪ Quartz Latite Flows
- ▪ Monolithologic Breccias
- ▪ Stratified Tuffaceous and Epiclastic Rocks
- ▪ Volcanic Conglomerate
- ▪ Intrusive Rocks

➢ The Basement Metamorphic Rock

The north side of the property includes uncovered pre-cretaceous basement schists and gneisses via erosional windows. This rock type is detached from the volcanic complex by a gently sloping and uneven unconformity.

➢ Beydağı Volcanic Sequence

● Latite Flows: Embodied massive flow banded porphyritic rocks with porphyritic clasts (plagioclase, K-feldspar, biotite, hornblende, quartz), and composes discontinuous, tabular units adequate to tens of meters in thickness. Phenocrysts may form adequate to 40% of the rock volume, and most outcrops carry flow banding, weak or strong.

● Quartz Latite Flows: It is similar to latite flow in terms of texture however contains approximately 3% quartz phenocrysts. This type of rock is only found out on the southern part of the offered waste dump, and made up of a layer of 10-20 m in thickness.

● Monolithologic Breccias: Interfingering and overlying the latite flows, the breccias are several tens of meters thick and form much of the Beydagi volcanic sequence. Breccia fragments are tightly packed and are no more than 10 cm in length. Though they lack visible strata on the outcrop scale, they are in fact layered on the tens of meters scale. They are similar in texture with the latite flows and they can be easily differentiate on outcrops as they form a rubbly surface texture.

● Stratified Tuffaceous and Epiclastic Rocks: With critical alteration of lithologic mark, this rock type outcrops along the margins of the deposit and with limited exposure, so subunits of this sequence is not identifiable. In the map area this rock type usually overlies the Breccia and Latite flows. This type concerns rocks ranging from coarse monolithologic, to slightly heterolithic breccias and conglomerates, to welded lapilli tuffs, to fine crystal tuffs or tuffaceous siltstone. Pebble breccia is dominant on the southern and eastern side of the deposit, near the leach pad area.

●Volcanic Conglomerate: These are similar to the monolithologic volcanic breccias with one distinction: they hold sub-rounded clasts, mega clasts (+1m), and are matrix supported.

● Intrusive Rocks: These gold host rocks are situated at the southern side of the deposit, and a smaller peripheral intrusion to the northern part of the deposit. There are three sub-units of intrusions which are only determined by phenocryst size, abundance, intensity of alteration and gold grade. It is not possible to detect them by outcropping. The intrusions all contain plagioclase, K-feldspar, hornblende, biotite, and some quartz. The three sub-units are called as phase 1 (containing the highest grade gold), phase 2 (intermediate gold grade), and phase 3 (very poor gold grade). (Tüprag Database, 2010). These phases can be seen in the Figure 3.3.

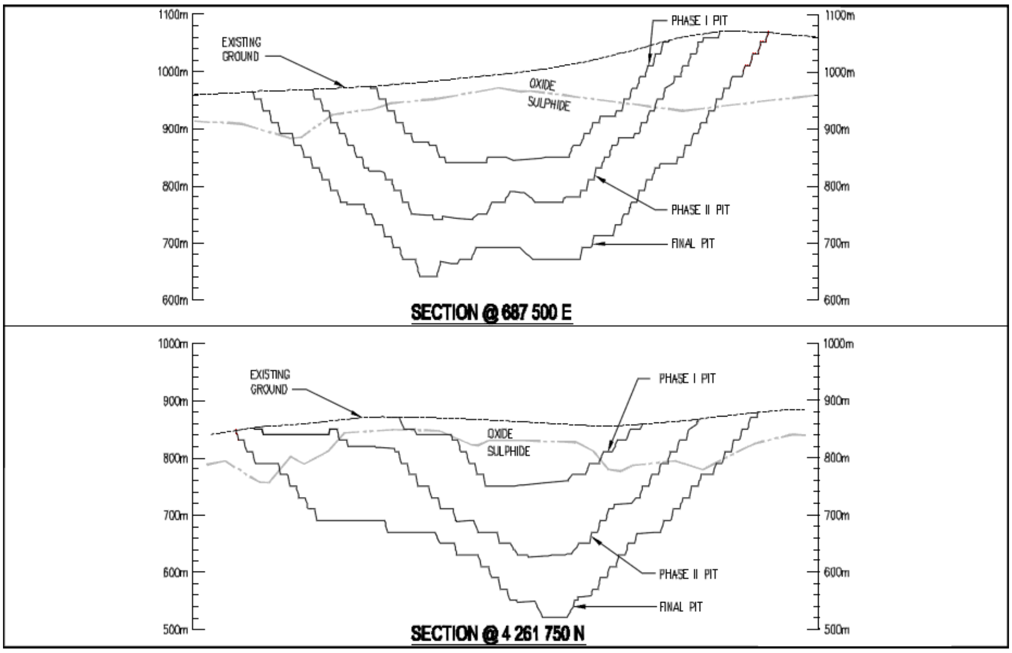


Figure 3.3 PHASE 1/2/3, Kışladağ Project Feasibility Study, 2009

3.2 Özdoğu Copper Mine

Özdoğu Copper Mine (Figure 3.4) is located 10 km north of Havran in Balıkesir province.

Figure 3.4 Özdoğu Copper Mine, Google Maps, 2018

3.2.1 Topography, Climate, Flora and Fauna

The mine site lies on the southern part of Biga peninsula. The climate is typical Mediterranean climate, the summers are hot and arid while the winters are warm and rainy. Average temperature of the area is 15°C and the annual rainfall is 650 mm approximately. The main water resources Kumluca stream and Beşgere stream flow into the Havran stream (Küçükefe et al., 2006).

The flora in the area is variable. Approximately 45% of the region is forest land. Both the coastal Aegean type and the more continental Anatolian regions can be observed. Black pine, Turkish pine, Hornbeam, Oak and Olive trees are very common in the area. The area is located in one of the important migration route of the birds, therefore more than 3millions of birds appear in the area. Also, the area has coastal to both Marmara and Aegean Sea and host to a very large marine life (retrieved from http://www.balikesirkulturturizm.gov.tr/TR,65838/flora-ve-fauna.html).

3.2.2 Geology

Mineralization of Cu-Mo-Au in Tepeoba is located approximately 10 km North of Havran city, in Balıkesir province.

According to Küçükefe et al. (2006), triassic age metasedimentary and metabasic rocks (Karakaya formation) and oligo-miocene aged granitoid (Eybek) formed Tepeoba field. The granitoid part is made up of granite, acidic dykes and basic dykes while the metasedimentary and metabasic rocks are exposed to contact metamorfism. Generally, the heat which comes from the magma causes contact metamorphism and rock alterations are observed especially in the country rocks close to the magma. Ore minerals are found in contact metamorphic rocks, namely hornfels and scarn (Figure 3.5). Hornfels are hard, compact and highly metamorphosed contact rocks which generally contain silicate and oxide minerals (Callegari, E., 207).

Cu-Mo-Au mineralization is seen as brecciated, stockwork vessel-vein and dissemintaed in the contact metamorphic rocks and granite. In the area, there is a brecciated mineral zone which is 800 meters long and 150 meters wide in the North East – South West (NE-SW) extent. There are many fault zones in the area especially near the mineral zone. 4 of them are East-West strike dip-slip normal faults that are sloping to South 70° while the other two distinct faults are East-West strike dip-slip thrust faults that are sloping to West 70° (Küçükefe et al., 2006).

In the area, the principal ore minerals are chalcopyrite, molybdenite, gold, pyrite, aikinite, emplectite, magnetite, ilmenite, ilmeno-magnetite, rutile, limonite, sphene, siderite, pyrrhotite, anatase, leucoxene, malachite, azurite, gangue minerals, quartz, feldspar, biotite, tourmaline, chlorite, muscovite, epidote, calcite as it is determined by Küçükefe et al. (2006).

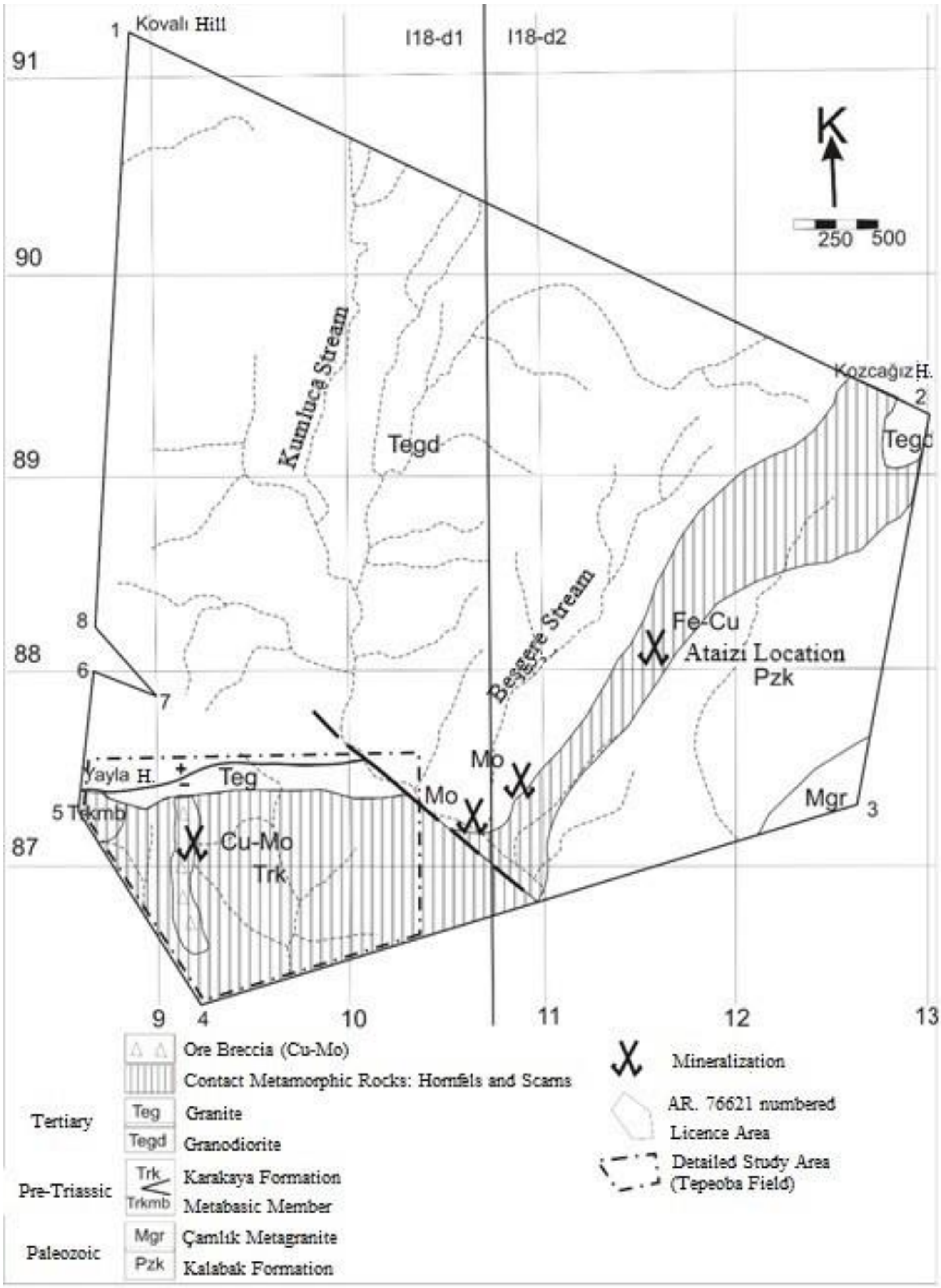


Figure 3.5 Geology Map, Özdoğu Copper Mine Database

3.2.3 Petrology

Before Jurassic period, the basement of the region was known as Triassic age Karakaya Formation which is made up of metasedimentary and metabasic rocks. Granite- Granodiorite composition named Eybek Granitoid and its acidic and basic dykes are tertiary aged rocks. Eybek Granitoid metamorphismed the metasedimentary and metabasic rocks of Karakaya formation and transformed them to andalusite- biotite feldspars (Küçükefe et al., 2006). Location of the study area is shown in the terrane map of Turkey in figure 3.6.

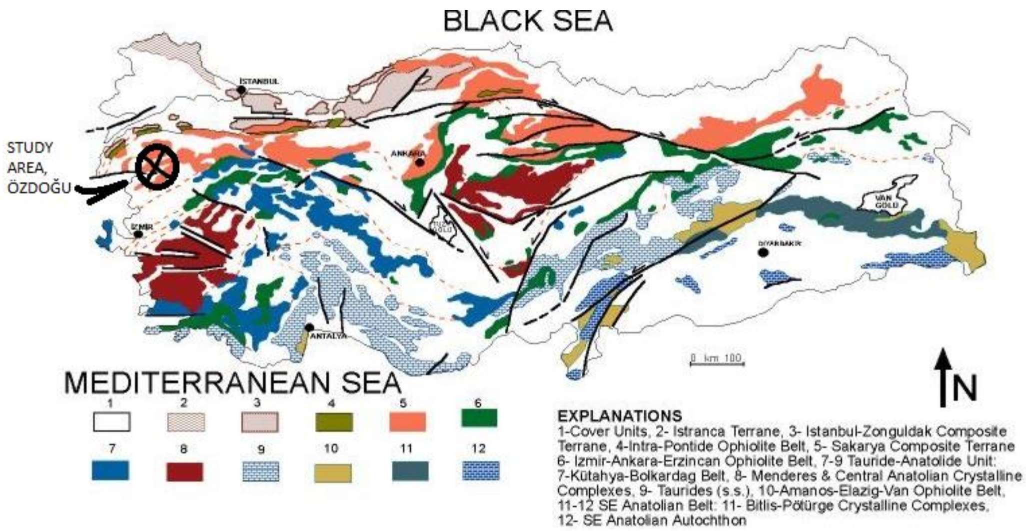


Figure 3.6 The Study Area (Özdoğu) in the Terrane Map of Turkey, Göncüoğlu, Kuwahara, Tekin & Turhan , 2004)

3.2.3.1 Karakaya Formation (Trk)

The formation is under the effect of tectonics. The samples taken from the metasedimentary rocks are determined as cataclastic andalusite hornfels, mylonite, mylonitic hornfels. Also, the same rocks are named as andalusite schist, andalusite-muscovite schist, muscovite-andalusite schist, muscovite-andalusite- biotite schist. The samples taken from the drilling shows that the same rocks are classified as silicified biotized altered rock, contact metamorphised schist, pelitic hornfels and phyllite (Küçükefe et al., 2006; Göncüoğlu et al., 2004).

3.2.3.1.1 Metabazit Member (Trkmb)

Based on the study of Küçükefe et al., (2006), the metabasic rocks which are included in contact metamorphised rocks, amphibolite-amphibolite schist as a mineralization in the intrusion contact. Hence they resembles the metabasics in the Paleozoic age Kalabak Schists. However, the metamorphism effect in the metabasic rocks decreases when going from the intrusion contact towards Tepeoba Village and the rocks are observed as basalt and metabasalt. Metabasic rocks are observed as massive and black and greenish black colors in the field.

3.2.3.2 Eybek Granodiorite (Teg, Tegd, Tega, Tegb)

According to Krushensky’s study, intrusive mass is composition of granodiorite-quartz monzonite and made up of porphyritic rocks. It is light coloured and contains coarse crystallines. Eybek Granitoid is granite in the side zones with wall rocks in the study area. Through the inner zones, it becomes a compostion of granodiarite and granite-granodiortie contact is partly transitional or tectonics (Küçükefe et al., 2006).

3.2.3.2.1 Granite (Teg)

It is outcropped among the granodiorite metasedimentary rocks. It is named as granite because of the abundance of felsic minerals and absence of mafic minerals. It is observed as micrQgranite or apliticgranite and its sides are fine grained. From the core samples, the rock is named as Leucocratic Granite and this name is used for explanations of the core logging. The core samples taken from the rock named as leucocratic granite comprise of quartz, alkaline feldspar (orthoclase) and plagioclase minerals. It is dirty-pink coloured (Küçükefe et al., 2003; Küçükefe et al., 2006).

3.2.3.2.2 Granodiorites (Tegd)

It is located in the Northern part of the study area and extents East-West. It has almost the same properties with granite but it contains more mafic minerals. Quartz, k-feldspar, plagioclase, hornblend, biotite, sphene, apatite, carbonate and opaque minerals are seen in its petrographic analysis (Küçükefe et al., 2003; Küçükefe et al., 2006).

3.2.3.2.3 Acidic Dykes (Tega)

The rocks are fine grained, white-pinkish white coloured and they made instrusion to the metamorphised rocks and based on studies of Küçükefe et al., (2006) they are named as acidic dykes. They are seen commonly in the northern intrusion contact. The rocks contains ore are oxidized such as malachitization, limonitization etc. According to samples taken from the drilling disseminated, vein and vessel type pyrite, chalcopyrite and molibdenium mineralizations exist.

3.2.3.2.4 Basic Dykes (Tegb)

They are the youngest sections and Küçükefe et al., (2006) named them as basic dykes. Generally they extension in North-South although in some places the extension is East-West direction. According to samples taken from the drilling, they are named as micro quartz-diorite, quartz-diorite and basic lava flow. Disseminated and vessel type pyrite is found in the rock, the rock is epidotic and calcitic.

3.2.3.2.5 Contact Metamorphic Rocks (Kmk)

Eybek Granodiorite contact metamorphised the Karakaya Formation which is made up of metasedimantary and metabasic rocks. Andalusite, biotite, muscovite, corundum and silimanite has formed in the metasedimantary rocks while tremolite, actinolite, plagioclase and garnet has formed in the metabasic rocks by means of the effect of intrusion. According to samples taken from the drilling, they are named as phyllite, contact metamorphised rock, pelitic hornfels.

CHAPTER 4

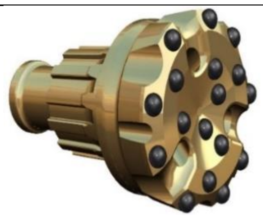
EXPERIMENTS AND ASSESSMENT

4.1 Experiments

The main objective of this thesis is to investigate significant relations, if any, between rock abrasiveness, bit grinding operation and the bit life. In order to achieve this objective, some in situ drilling tests were performed to assess the bit grinding requirement and bit life in Kışladağ Gold Mine and Özdoğu Copper Mine. The intersection set of these tests is the diameter and brand of the bit while the formations are in the non-intersection clusters. Although the differences in the skills of the operators and the drill rig may create major differences in the mine sites, these effects were kept out of the scope of this study.

Technical specifications of the tested bits are presented in Table 4.1

Table 4.1 Technical specifications of the tested bits

Brand	Sandvik
Diameter	165 mm
Button type	Spherical
# of Buttons	17 (8 face buttons; 9 gauge buttons)
Number of the buttons per bit	17
Face type	Concave
Illustration	

The rock specimens taken from Özdoğu Copper Mine and Kışladağ Gold Mine are shown in Figure 4.1 and 4.2 respectively. The Uniaxial Compressive Strength (UCS) value of the rock in Kışladağ is measured as 90-100 MPa. In general, UCS values of granite changes between 100- 200 MPa (Afrouz, 1992). The UCS value of a very similar leucocratic granite which has almost the same mineralogical composition with Özdoğu is around 120 Mpa. (Leith et al., 1991). Therefore, this value may give an idea about the UCS value of the rock in Özdoğu since it was not possible to test it due to lack of appropriate rock sample within the scope of this study.

Figure 4.1 Rock sample taken from Özdoğu Copper Mine in Balıkesir

Figure 4.2 Rock sample taken from Kışladağ Gold Mine in Uşak

Based on the laboratory tests carried out at the mineralogy laboratory by the Department of Geological Engineering of Middle East Technical University (METU) on the samples taken from the mines, the mineralogical and petrograhic properties were determined. The mineralogical compositions of the rocks taken from Özdoğu Copper Mine and Kışladağ Gold Mine, as determined in mineralogy laboratory are presented in Table 4.2 and 4.3 respectively.

The name of the rock taken from Özdoğu Copper Mine is determined as Leucocratic Granite and its hardness is 5,5 to 7 according to the Mohs scale.

Table 4.2 Mineralogical composition of the specimen taken from Özdoğu Copper Mine

Minerals	***Percentage, %***
Orthoclase	60
Quartz	30
Muscovite and Chlorite	<1,5
Chlorite	<0,5
Chalcopyrite Pyrite	8
Pyrite	0,5

The name of the rock taken from Kışladağ Gold Mine is determined as Potassic Alteration Rock and its hardness is 5,5 to 6 according to the Mohs scale.

Table 4.3 Mineralogical composition of the specimen taken from Kışladağ Gold Mine

Minerals	***Percentage, %***
K-Feldspar	42
Biotite	39
Pyrite	16
Chlorite and Actinolite	3

The abrasiveness of the rocks depends on their silica content in a broad sense. Quartz percentage indicates this content directly while other minerals may contain free silica and indicate it indirectly. The covalent bonds and their lengths take a significant role to be able to understand the silica content of the minerals.

Mineralogical compositions determined at the Department of Geological Engineering of METU indicate that quartz (silica) content is 30% for the rock sample from Özdoğu Mine (Table 4.2) and zero percent for the rock sample from Kışladağ Mine (Table 4.3).

The X-Ray Fluorescence (XRF) may be helpful to determine the minerals in a rock very roughly. XRF technology uses the emission energies of the elements while they are exposed to high energy x-rays or electrons (Mazurkiewicz, P., 2005). The modern XRF spectrometers which are known as XRF guns are used to determine elements in rock samples in situ as shown in Figure 4.3 below.

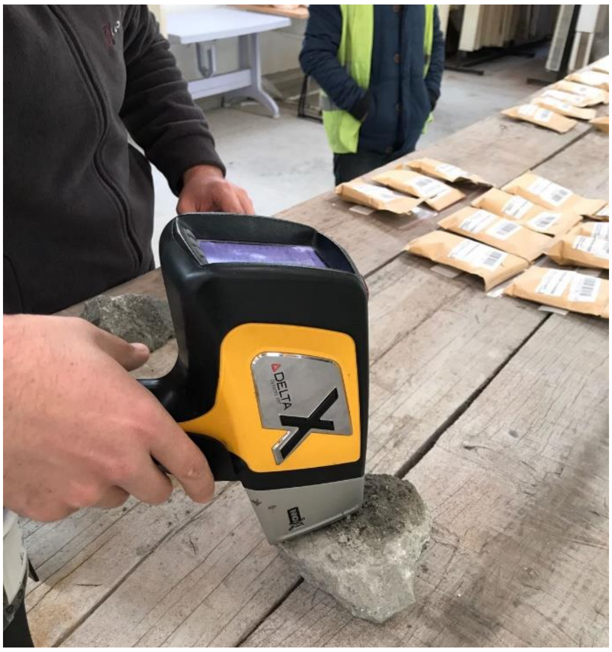


Figure 4.3 XRF Gun Test at Kışladağ Gold Mine, in Uşak. November 23, 2017.

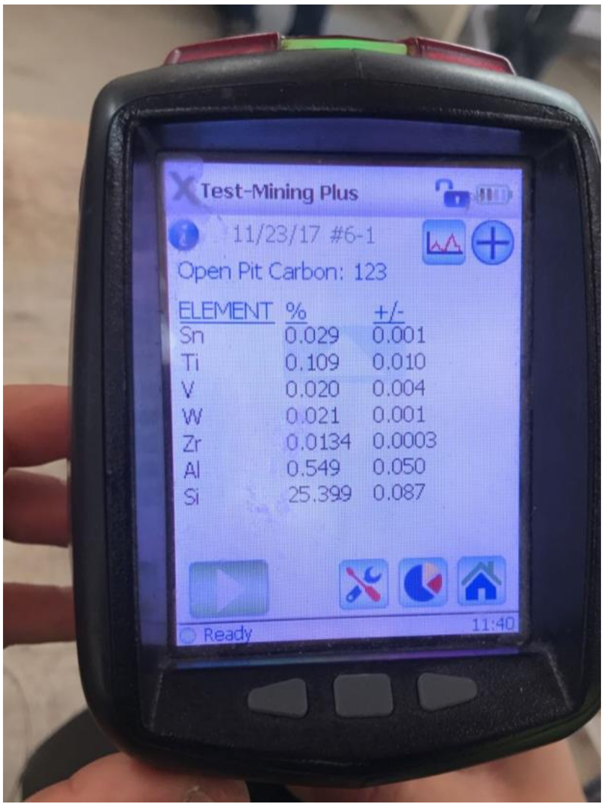


Figure 4.4 XRF Gun test result at Kışladağ Gold Mine, in Uşak. Nov. 23, 2017.

As it is seen clearly from the XRF screen (Figure 4.4), although the rock has no quartz content as determined by mineralogy laboratory of METU, it still has free silica element at an amount of 25% approximately. This information is important because when a laboratory report shows no quartz in a sample, it does not mean that there is no silica in it. In order words, the rock is still abrasive. However, the quartz content will be focused on by taking into consideration the existence of the free silica elements for interpretation in this thesis.

The assessment will be based on the quartz content and the bit life. It is more realistic to test actual number of consumed bits in a month. However, the sample set is limited due to unexpected slowing down of operations in Kışladağ Gold Mine.

Hence, based on the monthly production amounts and the drilled meters, some assumptions were done for interpretation of drill bit test results.

In Kışladağ, 4 bits and in Özdoğu 15 bits were analyzed during the drilling tests (Table 4.4). The average bit life without grinding in Kışladağ Mine was 1,267.00 meters while it was 552.00 meters in Özdoğu Mine (Table 4.4).

Table 4.4 Sample Data Set Details from the Mines

	Özdoğu	***Kışladağ***
Mining and Drilling Methods	Open Pit, Down the Hole	Open Pit, Down the Hole
Bit Diameters, mm	165	165
Quartz Content, %	30	0
Number of Tested Bits, pcs	15	4
Monthly Bit Consumption, pcs	12	37
Average Bit Life (without grinding), m	552	1,267

Average bit life is 552.0 meters in case of 30% quartz content at Özdoğu Mine, and 1,267.0 meters in case of zero quartz content at Kışladağ Mine (Table 4.4). From this point of view, the only variable that is affecting the results directly, is the quartz content of the rock samples. Although some human errors and machine downtimes may affect the results, they were kept out of the scope of this thesis.

4.2 Calculations and Assessment for Özdoğu Copper Mine

The targeted monthly production in Özdoğu Mine is approximately 200,000.00 metric tons. Since the influence area of one hole is 15 m^2 and the bench height (effective hole length) is 6 meters, it makes 90 m^3 material per blasthole. Taking the density of the material into account, 90 m^3 material makes 225 metric tons (assuming the density as 2,5 ton/m^3). Without grinding operation, 889 holes (by considering total drilled meter is 6,223 meters and hole length is 7 meters) were drilled on average monthly. In this case, 889 holes provides the monthly production (for the tested month) which is 200.025,00 metric tons.

4.2.1 Calculations for the operation without grinding for Özdoğu Mine

Table 4.5 Test data and calculations for drilling without bit grinding in Özdoğu

COSTS, €	
Cost per bit	450
NECESSARY INFORMATION	
Monthly bit consumption, pcs (6223m/552m=11.3 bits)	11.3
Bit life, m	552
RESULT	
Cost per meter (cpm), €/m	0.82
Total bit cost per month, € (11.3 bits x 450 ***€***= 5,085 ***€*)**	5,085.00

4.2.2 Calculations for the operation with grinding for Özdoğu Mine

In Özdoğu Mine, Sandvik RG460 grinding machine was used (Figure 4.5).

Figure 4.5 Sandvik RG460 Grinding Machine in Özdoğu, Balıkesir. April 18, 2017.

Table 4.6 Test data and calculations for drilling with bit grinding in Özdoğu

NECESSARY INFORMATION	
Bit life after grinding, m	668
# of monthly ground bits for target production, pcs	9.3
Number of grindings per bit	1
# of buttons on a bit, pcs	17
Average life time of grinding cups (# of buttons), pcs	350
# of bits a grinding cup will last (lifetime of a grinding cup in terms of bit number), pcs	20.59
# of required grinding cups for 9.3 bits, pcs	0.45
COSTS, €	
Grinding machine purchase cost	15,000
Depreciation cost of the grinding machine per month*	125
Unit cost of grinding cup	120
Grinding cup cost for monthly operation (based on bit consumption)	54
Maintenance cost for grinding machine (1%)**	1.25
Total monthly grinding cost***	180.25
Total grinding cost per bit	19.38
Bit cost	450
RESULT	
Cost per meter (cpm), €/m****	0.70
Total cost of bit consumption and grinding, €	4,365.25

*Depreciation time is assumed as 10 years (10yrsx12=120 months) based on the literature (retrieved from https://www.depreciationrates.net.au/grinding).

**Maintenance cost is assumed as 1% of the monthly depreciation cost.

***Total monthly grinding cost is the sum of depreciation cost, maintenance cost and grinding cup cost. It is calculated on monthly basis.

****Cost per meter is the ratio between the total bit consumption and grinding cost and the total monthly drilling meters.

Table 4.7 Comparison of two cases for Özdoğu Mine

COMPARISON BETWEEN THE CASES	
Achievement in cost per meter (cpm), %	14.63
Achievement in bit life, %	21.01
Monetary achievement for bits, %	14.15

4.3 Calculations and Assessment for Kışladağ Gold Mine

The annual production in Kışladağ is approximately 2,500,000 metric tons. They are drilling 46,000 meters per month to be able to reach this target. Without grinding operation, approximately 37 bits were used for this purpose.

4.3.1 Calculations for the operation without grinding for Kışladağ Mine

Table 4.8 Test data and calculations for drilling without bit grinding in Kışladağ

NECESSARY INFORMATION	
Monthly bit consumption, pcs	36.30
Bit life, m*	1,267
COSTS, €	
Bit cost	450
RESULT	
Cost per meter (cpm), €/m	0.36
Total bit cost per month, €	16,335

**Bit life refers to average bit life in the study area.*

4.3.2 Calculations for the operation with grinding for Kışladağ Mine

In Kışladağ, Atlas Copco Secoroc BQ3-DTH grinding machine was used (Figure 4.6).

Figure 4.6 Atlas Copco Secoroc Grinding Machine in Kışladağ, Uşak. November 21, 2017.

Table 4.9 Test data and calculations for drilling with bit grinding in Kışladağ

NECESSARY INFORMATION	
Bit life after grinding, m	1,593
# of Monthly ground bits, pcs	28.88
Number of grindings per bit	1
# of buttons on a bit, pcs:	17
Average life time of grinding cups (# of buttons), pcs	350
# of bits a grinding cup will last (lifetime of a grinding cup in terms of bit number), pcs	20.59
# of required cups for 28.88 bits, pcs	1.40
COSTS, €	
Grinding machine purchase cost	15,000
Depreciation cost of the grinding machine per month*	125
Unit cost of grinding cup	120
Grinding cup cost for monthly operation (based on bit consumption)	168
Maintenance cost for grinding machine (1%)**	1.25
Total monthly grinding cost***	294.25
Total grinding cost per bit	10.19
Bit cost	450
RESULT	
Cost per meter (cpm), €/m****	0.29
Total cost of bit consumption and grinding, €	13,290.25

*Depreciation time is assumed as 10 years (10yrsx12=120 months) based on the literature (retrieved from https://www.depreciationrates.net.au/grinding).

**Maintenance cost is assumed as 1% of the monthly depreciation cost.

***Total Monthly Grinding Cost is the sum of depreciation cost, maintenance cost and grinding cup cost. It is calculated on monthly basis.

**** Cost per meter is the ratio between the total bit consumption and grinding cost and the total monthly drilling meters.

Table 4.10 Comparison of two cases for Kışladağ Mine

COMPARISON BETWEEN THE CASES	
Achievement in cost per meter (cpm), %	19.44
Achievement in bit life, %	25.73
Monetary achievement, %	18.64

In Kışladağ Mine, the grinding machine was tested before internally. According to the study of Takmak (2010), average life time of the ground bits was 1,850 meters while the average life time of the bits which were not ground was 1,232 meters. At that time, 12 pcs ground bits drilled 22,195 meters in total in 662 hours, while 21 pcs not ground bits drilled 25,875 meters in total in 760 working hours. Also, Takmak (2010) states that grinding a bit takes approximately 15 minutes minimum and 60 minutes maximum. However it may be concluded that a button on a bit needs 1 minute to be ground completely and the total grinding time for a bit may be estimated based on the number of buttons on it accordingly.

4.4 Assessment

Effects of bit grinding operation may be discussed here by explaining the drilling cost changes per meter. Decrease in cost per meter is 0.07 €/m, from 0.36 € to 0.29 € per meter in Kışladağ Mine. Since they drill 46,000 meters monthly, this decline in cost per meter affects the budget of the operation at a saving of 3,220 € per month (0.07 €/m x 46,000 m/month =3,220 €/month) for the benefit of the mine. This decrease in the costs may be distributed to the grinding operation costs on monthly basis as it is seen from below calculation.

- Grinding machine purchase cost when divided by monthly saving (15,000/3,220 = 4.66 months) means 5 months for amortization.
- If one considers other cost items, such as grinding machine operator salary etc., amortization period may be extended to 6 or 7 months.

Hence, approximately after 7 months, the costs of grinding operation will compensate itself and start to yield profit to the mine in the long run.

Likewise, the decrease in cost per drilled meter is from 0.82 € to 0.70 € in Özdoğu Mine. The saving per drilled meter is 0.82-0.70=0.12 €. Since, they drill 6,223 meters per month and this decline in cost per meter affects the budget of the operation at a saving of 746 € per month (0.12 €/m x 6,223 m/month =746.76 €/month) in favor of the mine. This decrease in the costs may be distributed to the grinding operation costs on monthly basis as it is seen from below calculation.

- Grinding machine purchase cost when divided by monthly saving (15,000/746 = 20.10 months) means 21 months for amortization.
- If one considers other cost items, such as grinding machine operator salary etc., amortization period may be extended to 24 months.

Hence, approximately after 2 years, the costs of grinding operation will compensate itself and start to yield profit to the mine in the long run.

These periods can be decreased by,

- Increasing the production,
- Increasing the frequency of the bit grinding interval,
- Increasing the quality of the drilling work by minimizing the human errors in the operations.

It is understood that the grinding operation reduces the cost of the total operation. In these two cases investigated, it is seen clearly that the bit lives in the mines increased at least 20% which reduces the drilling cost per meter (Table 4.11).

Table 4.11 Comparison of two cases in two different test mines

	Kışladağ	***Özdoğu***
Cost per meter for without grinding (cpm), €/m	0.36	0.82
Cost per meter for with grinding (cpm), €/m	0.29	0.70
Achievement in cost per meter (cpm), %	19.44	14.63
Achievement in bit life, %	25.73	21.01
Monetary achievement, %	18.64	14.15
Quartz content	0%*	30%

*Does not show the free silica content, shows only quartz content.

Comparison of the results from Kışladağ and Özdoğu mines reveals that the life of the same bit is much lower in Özdoğu Mine. This dramatic decrease is attributed to the significantly higher quartz content in Özdoğu Mine with respect to Kışladağ Mine. Although there are silica minerals other than quartz in the rock specimen of Kışladağ Mine, in general quartz is considered as the most abrasive mineral which affects bit life. Here, the difference between the silica and the quartz should be underlined. The chemical composition of Silica is SiO_2 and it exist in many different forms in the nature. The most common crystalline silica form is known as Quartz. Hence quartz is a special form of silica, SiO_2. Crystalline silica is very hard and abrasive mineral. The decrease in the lifetime of the same bit depends on the 30% quartz content, crystalline form of silica, in Özdoğu Mine.

The information on bit life without and with grinding from different mines of the world are summarized in Table 4.12. To interpret the table with limited information is not suggested however it gives a general understanding about the grinding operation and its economic effects.

Table 4.12 Information on bit life without and with grinding from the world

	Bit Life (without grinding), m	***Bit Life (with grinding), m***	***Rock Type***	***Abrasiveness based on quartz content***
Boliden, Sweden	50	300	Lower Carboniferous limestones	Not known
La Arena, Peru	400	1,000	Mesozoic sedimentary rocks (dacitic and andesitic feldspar porphyries)	<20%
Udupi, India	160	365	Granite	<10%
Efemçukuru, Turkey	350	700	silicified to hornfels	55%<;<70%
Kışladağ, Turkey	1,267	1,593	Potassic Alteration Rock	0%
Özdoğu, Turkey	552	668	Leucocratic Granite	<30%

The increment in the bit life after bit grinding in Boliden, La Arena, Udupi and Efemçukuru is relatively more than Kışladağ and Özdoğu projects. The reasons behind this table may be related to the automation levels of the mines, the skills of the operators and drill rigs. These effects should be investigated and these claims need to be supported by further studies.

Independent of the rock type, the drilling cost per meter savings due to the increment in the life of the bit with grinding from different mines abroad and in Turkey are summarized in Table 4.13.

Table 4.13 Achievements in cost per meter according to the mines

Mine	***Achievement in cost per meter (cpm), %***
Boliden, Sweden	66%
La Arena, Peru	51%
Udupi, India	49%
Efemçukuru, Turkey	45%
Kışladağ, Turkey	19.4%
Özdoğu, Turkey	14.6%

Although making direct comparisons on percentages does not seem suitable due to factors such as grinding interval and quartz content, it is obvious that the grinding operation always yields positive results. It is thought that the main difference in the cost per meter achievement in Kışladağ Mine and Özdoğu Mine compared to other mines comes from the grinding intervals. For example, the grinding intervals at La Arena Mine is very frequent. Grinding too often is always more economical than grinding too seldom. On the other hand, one bit can be ground 3 or 4 times generally. La Arena Mine example is an extreme case, since they grind the same bit

10 times. This variation creates huge differences in results. For example, if the bits ground 3 times in Kışladağ Mine, life of one bit may reach 2,500 meters and it may cause to consume 18 bits monthly in this mine. In such a case, the cost per meter achievement would be 50% instead of 19.44%. Likewise, in Özdoğu Mine, if the bits are ground 3 times, the achievement would reach 38%. However, to track the bits and their grinding intervals precisely may not be possible and easy in the mine sites, especially in large open pit mines. Besides, a general outlook on the issue of the bit consumption in open pit mines and underground mines are really different. For example, Efemçukuru is an underground mine and in Efemçukuru the annual bit consumption was decreased from 2,361 to 1,489 pcs between the years 2013 and 2014 due to grinding operation even though the production increased (Dönmez, 2015). Efemçukuru Mine is strict in this issue and grinding the bits 3 or 4 times precisely. Because the profit gained from the grinding operation is nearly equal to the cost of the bits consumed during the year. The open pit operations are relatively huge operations in comparison with the small scale underground operations. The total bit cost forms a small amount of the total operation cost in open pit mines, especially working with down the hole principle. Nevertheless, these achievements are incontrovertible. Also, bit grinding operation not only ensures economic benefits, but also increase the quality of the drilling operation which will enhance the fragmentation by blasting.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This thesis is intended to create a basic understanding about the drill bit grinding operation and its effects on the economy of mining operation. The relation between the bit life and the grinding operation is tried to be found out pertinaciously. In brief, the economic plus effects of the grinding operation are much dependent on the consumption and life time of the bits. The total cost of the bits has incontrovertible amount in the drilling costs and among all other costs, these costs are the most controllable ones. The decrease on cost per meter values and increase on the life time of the consumables (bits) are clearly seen from the results of the field tests. The grinding operation will help to make savings in drilling costs within a rational period of time. A few years for amortization of grinding machine is needed until making the grinding operation profitable during the long mine life. Besides the apparent economic savings due to the grinding operation, other advantages of it, makes drilling operation much efficient. Grinding operation ensures optimal penetration rate, good drilling accuracy, lowest possible cost per drill meter, less wear on drilling tools, rock drill, hammer and the rig and improved productivity. If the bit is not working properly, quality holes cannot be developed hence the hole deviation is observed. Also, the lifetimes of all other equipment reduce while their maintenance costs increase. Grinding operation helps to prevent hole deviation and helps to achieve good blasting. Good drilling accuracy prevents the underbreak or overbreak and keeps the grade of the ore at the desired level. The main concern in drilling activities is to achieve a quality hole. A bit with good grinding routines will behave as a new bit at every turn. Hence, it will protect the drill rig and the rock drill or hammer from overloads. Also, sharpened buttons will not let the penetration rate to decrease during the operation. In drilling applications, the whole process depends on the basis of the correct transmission of the energy.

When the energy created by means of the hammer is transmitted to the rock properly, less amount of energy comes back from this compressive stress wave to uncouple the threads and/or to force and damage the drill string. Therefore, maintenance costs of the rig and/or drilling tools including the hammers are reduced while the life time of the drill string is increased in the total drilling operation. Also, good drilling results in a good blasting and good fragmentation and prevent to use unnecessarily more explosives and time. The savings from this kind of claims should be taken into the consideration. As a final comment, it can be said that the bit grinding concept is open to new investigations, such as the effect of bit grinding on decreasing the hole deviations, increasing the penetration rate, enhancing the fragmentation, etc.

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APPENDIX A

ANALYSIS REPORT FOR ÖZDOĞU COPPER MINE (THE ANALYSIS NUMBER 17.03.09.508) IN GEOLOGY-GEOPHYSICS RESEARCH CENTER OF MIDDLE EAST TECHNICAL UNIVERSITY

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ORTA DOĞU TEKNİK ÜNİVERSİTESİ
JEOLOJİ-JEOFİZİK ARAŞTIRMA MERKEZİ

02.05.2017

Jeoloji-Jeofizik Araştıma Merkezi'ne 21.04.2017 tarihinde teslim edilen bir adet örneğin mineralojik-petrografik analiz sonucu ektedir.

Bilgilerinize sunulur.

Saygılarımla,

Yrd. Doç. Dr. Fatma (Toksoy) Köksal

Ek: Deney raporu

Analiz No: 17.03.09.508

Kaya adı: Lökokratik granit

Makroskopik olarak örnek grimsi ve dumanlı gri, açık pembemsi gri, koyu gri, grimsi ve hatta yeşilimsi metalik sarı kısımlar içermektedir. Farklı renkli kısımların dağılımı heterojen olup yer yer birbirine geçişlidir. Yüzey ağırlıklı olarak alterasyona bağlı killeşme nedeniyle toprağımsı mat görüntü sergilemekle birlikte temiz yüzeyler camsı ve metallik sarı kısımlar ise metalik parlaklık göstermektedir. Taze kısımlardan gözlendiği üzere kristal boyutları >1 mm olup yer yer 1 cmm'ye varmaktadır. El numunesinden belirlendiği kadarıyla örnekte ortoklaz en youğun mineral iken bunu kuvarz takip etmektedir. Çok az miktarda (<1.5%) mika ve klorit minerali bulunmaktadır. 8% civarında ise sülfit minerallerinden kalkopirit ve %0.5 civarında pirit vardır. Örnek yüzeyinde alterasyona bağlı killeşme (kaolinleşme) vardır. İnce kuvarz damarları ağ şeklinde düzensiz olarak dağılım göstermektedir. Bunun yanısıra, sülfit mienrallerinin yoğunluk gösterdiği kısımlarda kuvarz oranında artış vardır. Kayaç lökokratik granittir.

Mikroskop altında örnek, 60% civarında ortoklaz, 30% civarında kuvarz, <2.0 % muskovit ve klorit, 8.5% civarı sülfit mineralleri kalkopirit ve piritin varlığı tespit edilmiştir. Örnekte en baskın mineral ortoklaz yarı-özşekilli kristallerden oluşmaktadır. Kuvarz yer yer ortoklaz kristal aralarında öz-şekilsiz kristal öbekler ya da ortoklaz kristalleri içinde büyümeler halinde grafik dokulu olarak bulunmaktadır. Kuvarz bunun yanısıra damar dolgusu olarak bulunmaktadır. Kuvarz opak sülfit minerallerinin bulunduğu kısımlarda daha yoğundur. Kuvarz magmatik ve hidrotermal alterasyon kökenli olmak üzere iki tiptir. Ortoklazda yoğun olarak kaolinleşme ve az miktarda serisitleşme vardır. Bunun yanısıra yine alterasyona bağlı kloritleşme vardır.

Sertlik

Örneğin sertliği Mohs skalasına göre 5.5-7 arasındadır.

Bilgilerinize sunulur.

FKöksal

Yrd. Doç. Dr. Fatma (Toksoy) Köksal

APPENDIX B

ANALYSIS REPORT FOR KIŞLADAĞ GOLD MINE (THE ANALYSIS NUMBER 18.03.09.502) IN GEOLOGY-GEOPHYSICS RESEARCH CENTER OF MIDDLE EAST TECHNICAL UNIVERSITY

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ORTA DOĞU TEKNİK ÜNİVERSİTESİ
JEOLOJİ-JEOFİZİK ARAŞTIRMA MERKEZİ

17.01.2018

İlgi yazınız ekinde Jeoloji-Jeofizik Araştıma Merkezi'ne 04.01.2018 tarihinde teslim edilen 1 adet örneğin mineraloji-petrografi ve sertlik deney sonuçları ektedir.

Bilgilerinize sunulur.

Saygılarımla,

Yrd. Doç. Dr. Fatma (Toksoy) Köksal

Ek: Deney raporu

ANALİZ RAPORU

Analiz No: 18.03.09.502

Mineraloji-Petrografi

Kaya adı: Potasik alterasyon kayası

Makroskopik olarak örnek koyu gri siyahımsıdır. El numunesinde kristallerinin bir kısmı çıplak gözle zorlukla görülebilirken bir kısmı görülemeyen örnek genel olarak orta ince tanelidir. Yer yer sarımsı metalik yansımalar olup sülfit minerali pirittir.

Örnek mikroskobik olarak ana mineraller %42 K-feldispat, %39 biyotit ve %16 pirit içermektedir. Ayrıca numune %3 civarında klorit ile aktinolit ve aksesuvar miktarda zirkon ile apatit içermektedir. Ana minerallerden biyotit soluk sarıdan kahverengiye değişen çift kırılım vermekte ve mikron boyutundan 1-2 mm'e varan değişken boyutlarda gözlenmektedir. Biyotit yamalı görüntü veren agregalar halinde bulunmakta ve bunlardan bazıları radyal yelpaze biçimlidir. Klorit açık-koyu yeşil renkte değişen çift kırılım vermekte olup anormal, mavi, kahverengi veya mor girişim renkleri göstermektedir. Klorit çoğunlukla radyal agregalar halindedir. Aktinolit ise açık yeşilimsi pleyokroyik olup iğnesimsi kristallerin oluşturduğu radyal agregalar halindedir bulunmkatadır. Sülfit minerali pirit, yarı öz-şekilliden öz-şekilliye küçük kübik kristallerin oluşturduğu agregalar halinde olup örneğin içinde dağılım göstermektedir.

Örnekteki mineral oluşumları ikincil olup örnek porfirik Cu-Mo-Au cevher oluşum yan kayasında potasik alterasyonu temsil etmektedir.

Sertlik

Örneğin sertliği Mohs skalasına göre 5-6'dır.

Bilgilerinize sunulur.

Yrd.Dr. Fatma (Toksoy) Köksal