ГОДИШНИК НА МИННО-ГЕОЛОЖКИЯ УНИВЕРСИТЕТ "СВ. ИВАН РИЛСКИ", Том 52, Св. I, Геология и геофизика, 2009
ANNUAL OF THE UNIVERSITY OF MINING AND GEOLOGY "ST. IVAN RILSKI", Vol. 52, Part I, Geology and Geophysics, 2009

DRILLING TECHNOLOGY AND USAGE OF POLYMER DRILLING FLUIDS FOR MINERAL EXPLORATION DIAMOND CORE DRILLING APPLICATIONS IN THE CHELOPECH Cu-Au DEPOSIT (BULGARIA)

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ABSTRACT. This paper presents a review of the geology of the Chelopech Cu-Au epithermal deposit (Bulgaria), as well as the drilling technology, chemistry, composition and prepared polymer drilling fluids applicability for mineral exploration diamond core drilling. The present investigation is focused on recommended, mud program selection and application of the polymer drilling fluids and wireline core barrel NQ complex drilling technology from deposits Chelopech, Bulgaria. The key is to provide affordable drilling fluid solutions that will reduce overall drilling costs and drilling problem.

ТЕХНОЛОГИЯ НА СОНДИРАНЕ И ИЗПОЛЗВАНИ ПРОМИВНИ ТЕЧНОСТИ ПРИ ПРОКАРВАНЕ НА ПРОУЧВАТЕЛНО ЯДКОВИ СОНДАЖИ ПО ПРИМЕРА НА НАХОДИЩЕ ЧЕЛОПЕЧ

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РЕЗЮМЕ. В настоящата статия се разглежда актуален проблем, свързан с технологията на прокарване на проучвателно ядкови сондажи на находище Челопеч. Разгледани са геологията на района на Челопеч, технологията на сондиране, състава на използваните полимерни промивни течности приложими при диамантено ядково сондиране. Основната част е фокусирана върху препоръчителната програма за промиване на сондажа, избора и приложението на полимерните промивни течности при диамантено сондиране с изваждаема ядкоприемна тръба – комплекс NQ.

Introduction

The Chelopech volcanic complex is located in the Central Srednogorie magmatic zone (Fig. 1a) and hosts one of the largest Cu-Au deposits in Europe (Stoykov et al., 2003; Stoykov, Pavlishina, 2003).

The Chelopech Mining Ltd is a subsidiary of Dundee Precious Metals Inc. It is a copper-gold mining and processing operation that ultimately produces copper-gold concentrate. The Plans include upgrading of the operation to 1.5 Mt per annum and metal production on the site (*Chelopech Mining;* Haydoutov, 2001).

The Chelopech Deposit is situated near Chelopech village, in the northern part of the Zlatitza valley. The deposit is at the foot of the Balkan Mountains and is on about 700 meters elevation. The geological prospecting of the deposit began as early 1840s. The Chelopech copper-gold mining and processing operation was commissioned in late 1950s with initial capacity of a few thousand tonnes. The mine was expanded and a new concentrator was build in the early 1970s.

Balkan Mineral and Mining EAD company is currently exploring on 10 license areas located throughout Bulgaria. Desire to place the Projects into production by early 2007-2009 and applies the most sophisticated and up-to-date exploration technologies and methods in Bulgaria such as (*Chelopech Mining;* Haydoutov, 2001):

1. Compilation and analysis of geological, geophysical and geochemical data in text format and map materials;
2. Regional methods of preliminary prospecting – primarily stream sediment sampling;
3. Preliminary local-scale research in conjunction with detailed geological mapping;
4. Additional detailed research – petrography, XRD analysis;
5. Local-scale geophysical research;
6. Exploration diamond core and RC drilling;
7. Processing, qualitative and quantitative analysis of samples;
8. Computer processing and development of GIS models utilising specific geological computer software.

Geology of the Chelopech deposit

The basement of the volcanic rocks consists of high-grade metamorphic rocks (two-mica migmatites with thin intercalations of amphibolites, amphibole-biotite and biotite gneisses), and low metamorphic phyllites and diabases of the Berkovitsa group (Early Paleozoic island-arc volcanic complex, Haydoutov, 2001). The base of the Chelopech volcanic rocks is partly exposed on the surface, although it has been intersected in the underground mine. The Upper Cretaceous succession in the Chelopech region starts with conglomerates and coarse grained sandstones intercalated with coal-bearing interbeds (coal-bearing formation, Moev, Antonov, 1978) covered by polymictic, argilleous and arkose sandstones to siltstones (sandstone formation). Collectively, these units have a thickness of less than 500 m. Pollen data suggests that both formations are Turonian (Stoykov, Pavlishina, 2003). The sedimentary rocks are cut by volcanic bodies and overlain by sedimentary and volcanic rocks of the Chelopech Formation (Moev, Antonov, 1978). It comprises the products of the Chelopech volcanic complex, epiclastics, as well as the Vozdol sandstones (Fig. 1b-c). The latter are recently paleontologically dated as Turonian in age (Stoykov, Pavlishina, 2003). These formations have been partly eroded and transgressively covered by sedimentary rocks reddish limestones and marls, which are in turn overlain by flysch of the Chugovo Formation (sandstones, aleurolites, argilites and marls with clear turbidite marks) Campanian-Maastrichtian in age (Fig. 1b-c).

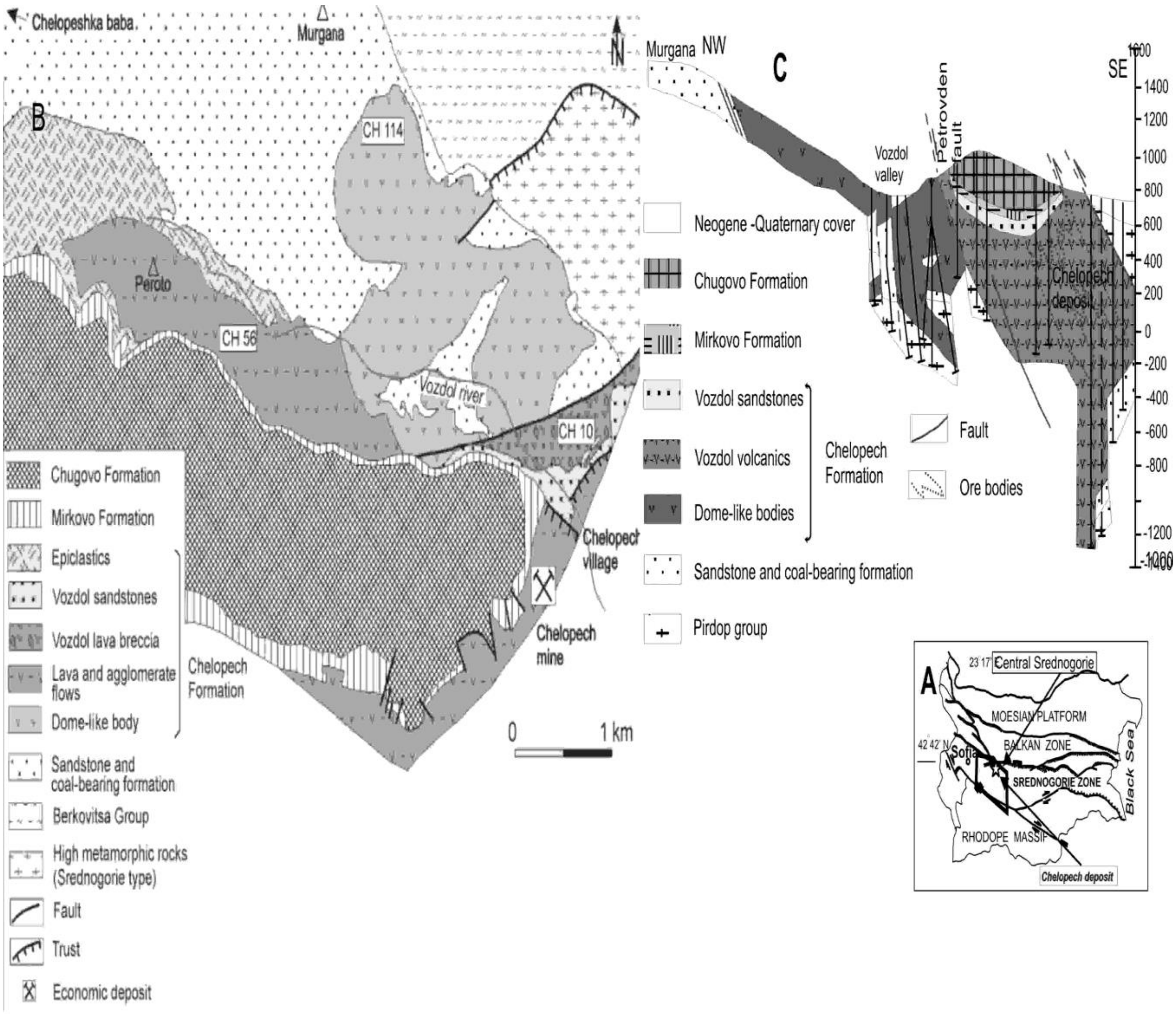

Fig. 1. (a) Major tectonic zones in Bulgaria with the location of the Srednogorie zone and Chelopech deposit; (b) Geological map of the Chelopech region (modified after Stoykov et al., 2002); (c) Geological section of the Chelopech region after Stoykov et al. (2002)

Field observations and sedimentary relationships allow to distinguish three units of the volcanic complex: (I) dome-like bodies, (II) lava to agglomerate flows, and (III) the Vozdol lava breccias and volcanites (Stoykov et al., 2004). The volcanic rocks are porphyritic with plagioclase and amphibole phenocrysts, quartz and biotite are rare. The lava flows contain fully crystallised, fine-grained enclaves of more basic composition.

Selecting drilling fluids for mineral exploration – diamond core drilling and planning the mud program

The economic importance of the information to be gained through diamond coring is well known to mining geologists (Heinz, 1994; Papp, 2001; http://www.dpm-group.com/internal/bmmAbout.html?l=bg). The enormous capital investment required developing a low-grade ore body demands a reliable evaluation of the prospect based on adequate core rock samples. Incomplete core recovery may require additional drilling and even then results may not be sufficiently reliable to justify major development costs. The cost of the core depends on the time and materials expended to get it; its value depends on the extent of recovery, and both are strongly influenced by the drilling fluid. Consequently, the drilling fluid deserves consideration in a well-planned exploratory drilling program. The purpose of exploratory drilling is to gain information. However, there are times when preoccupation with current operating details appears to obscure the true objective. The attempt by drilling contractors to manage with inadequate equipment, their insistence on the use of water only as the drilling fluid, the reluctance of the driller to accept new technologies, and the refusal of the purchasing agent to buy on quality rather than price, can be cited as examples of failure to keep the subject clearly in focus. The drilling fluid should be regarded as one of the tools in the planned program to *secure maximum results at the minimum cost.*

The cost of the drilling fluid can be evaluated only in terms of the total cost of drilling and not just on the price of the additives alone. Numerous inter-related factors affect the results of a drilling operation consideration should be given to the following significant factors:
1) The primary purpose of the drilling program: requirements for core, depth, time allotted;
2) The nature and properties of the rocks to be drilled: type and thickness of formation, and structural conditions as related to hole stability;
3) The site, in relation to the layout of the rig, sumps and working environment, disposal of wastes and the availability of and access to supplies of mud products;
4) Water: source, quality, and quantity;
5) The capabilities and limitations of the drilling equipment;
6) The skill, experience, training and attitudes of the crew.

Product selection and application

There is no uniformity in the formations that will be drilled there can not be uniformity in the formulation of the drilling fluid to be used. In each individual case the fluid must be formulated to meet the objectives at hand. In cases where the mud engineer does not have any information on the area to be drilled then he will have to formulate a generic mud. The mud formulations have to be used until the problems are identified.

The drilling mud engineer can then adjust the mud formulation to make certain that the objectives are met. In areas, which have been drilled previously, the engineer has been able to look at a core. By looking at the core he can determine the problem areas and to formulate mud to overcome problems. The drilling contractor may also be consulted as to common problems that have been encountered in the previous drilling program. Another vital piece of information is to determine what type of drilling fluid and products were used in the previous drilling program.

The project geologist can be contacted to learn about the rocks and the stratigraphy that will be drilled. With all this information, the engineer can develop a cost-effective formulation that will provide an optimum drilling fluid.

Certainly no rules can be laid down that will serve to fit each drilling condition with the drilling fluid of optimum composition and properties. Some generalizations can be made, however, that may be used as a first approximation. The following formulations are based on average requirements and normal emphasis placed on several factors that have been discussed. These drilling fluids should be considered as examples that have been found to be satisfactory under general conditions. Supplementary materials may be needed to furnish certain properties for specific applications. The formulations are keyed to different formations that will be drilled.

The selection of the composition of the drilling fluid may be influenced by several factors. Obviously certain compromises must be made and requirements sometimes are contradictory. The planned mud program requires consideration not only of the water supply and the additives but also of the facilities for mud mixing and separating cuttings.

Drilling techniques, technology and usage of drilling fluid for applications in the Chelopech Cu-Au deposit

The tool complex for drilling with a wireline core barrel NQ of the company "Board Longyear" (Table 1) is used for drilling of boreholes with reception and extraction of the core on a surface without wireline rising, and also for work on rise and descent of a column for rock cutting tool change.

Table 1
Technical parameters wireline core barrel NQ of the company "Board Longyear"

System	NQ
External diameter of reamer, mm	75.82
External diameter of core bit, mm	75.44
Internal diameter of core bit, mm	47.6
Diameters of drill rods (string)	
External,mm	69.9
Internal, mm	60.3
Length of drill rods, m	1.5; 3.0
Weight of drill rods, kg	11.7; 23
Length of core barrel, m	1.52; 3.05
Borehole deviation, degree	90-45

Elements of the Complex NQ (Table 2; Fig. 2) of the company "Board Longyear": rock core bit; core wireline barrel; drill rods (string); lifting equipment, auxiliary and emergency tool; cable hoist for rising of a retrievable core receiver. Core sets are intended for reception and preservation of a core during the process of drilling, and also for extraction of a core on a surface without rise of a drilling string.

Table 2. *Technical features of core barrel NQ of the company "Board Longyear"*

Diameter of core barrel, mm	
External	73.2
Internal	60.5
Diameter of wireline core , mm	
External	55.6
Internal	50.0
Weight of core set, kg	
Weight of core lifter, length – 1.525 m	43.0
Weight of core lifter, length – 3.05 m	62.9
Weight of retrievable core receiver, kg	
Weight of core lifter, length – 1.525 m	17.1
Weight of core lifter, length – 3.5 m	21.4

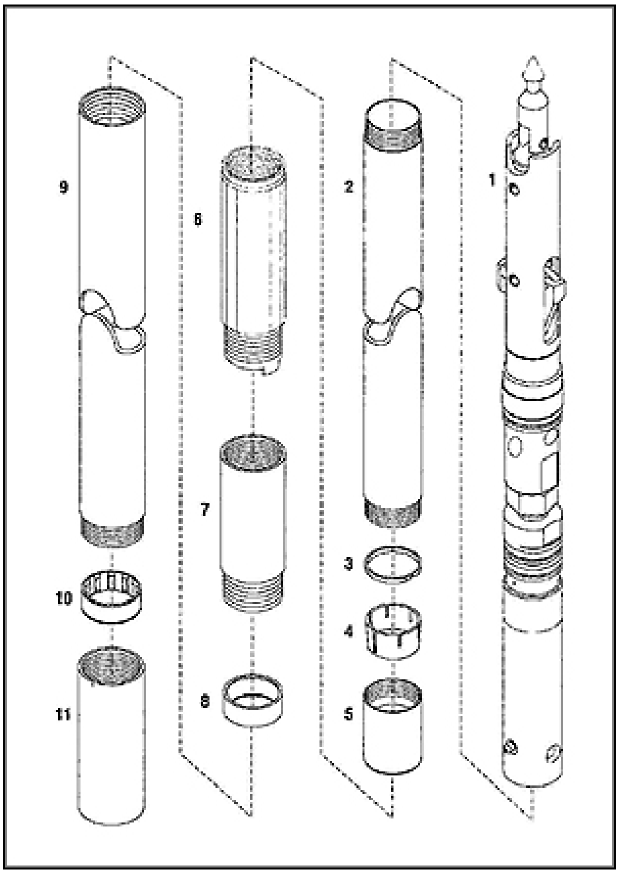

Fig. 2. 1 – bearing unit; 2 – internal core barrel; 3 – locking ring of core breaker; 4 – core breaker ring; 5 – core-catcher adapter; 6 – special passage; 7 – reducing coupling; 8 – supporting ring; 9 – outside pipe; 10 – stabilizer of internal pipe; 11 – core bit

Recommendations on impregnated bit application in the Chelopech Mining Ltd. of various series depending on hardness, abrasivity, grinding and fracturing of rocks and power of drilling rigs:
- *Series 4* is for half-hard, abrasive and dense rocks. It is recommended only for low-power drilling tools, in particular for drilling from underground excavation. The increase of load on bit will considerably reduce its lifetime.
- *Series 6* is for half-hard, hard and very hard, abrasive and grinded rocks. Also it can be used in dense nonabrasive rocks. It works very good in the rocks alternating on hardness and abrasivity. It is a bit of wide application, which has a long lifetime and high mechanical speed of drilling.
- *Series 7* is for hard and very hard, moderately abrasive and fracturing rocks. Such strong, rather easily cutting bit has a good speed of borehole making.

The recommended fluid application for drilling in difficult geological conditions by the wireline core barrel complexes NQ of the company "Board Longyear" should meet the following basic requirements:
- to create a thin and strong polymeric or polymeric-clay layer on borehole and core walls for increase of stability of borehole walls and core output;
- to possess a good greasing ability for maintenance of high speeds of bullet rotation and decrease of core friction in a core lifter;
- to give all the sludge to a sediment in circulating system (about 7 kg/m^3 of a borehole), leaving only thin sludge particles of solution (on the level of clay particles). It allows to carry out drilling on high speeds of bullet rotation without sludge crust formation on an internal surface of boring pipes.

The long-term experience in the Chelopech Mining Ltd. and laboratory experimental program in the Department of Drilling, Oil and Gas Production, Laboratory of Drilling Fluids and Cement Slurry at the University of Mining and Geology "St. Ivan Rilski" – Sofia, has development a series of laboratory experiments to quantify drilling fluids performance and has shown that the drilling solution prepared on the basis of basic polymeric reagents: PAC, PA and PHPA meets these requirements. Polymer muds incorporating generally long-chain, high-molecular-weight polymers are utilized to either encapsulate drill solids to prevent dispersion and coat shales for inhibition, or for increasing viscosity and reducing fluid loss. Various types of polymers are available for these purposes, including acrylamide, cellulose and natural gum-based products. Frequently, inhibiting salts such as KCl or NaCl are used to provide greater shale stability. These systems normally contain a minimum amount of bentonite and may be sensitive to divalent cations such as calcium and magnesium. Most polymers have temperature limits below 300 [degrees] F, but under certain conditions may be used in wells with appreciably higher BHTs (drilling fluids for mineral exploration).

1. *PAC polymer* reagent is a high-molecular cellulose polymer. This reagent is nontoxical and it is not exposed to fermentation
The basic function of PAC polymers:
- viscosity increase of drilling solutions with small content of the firm phase, prepared on fresh, salty and sated with salts water; decrease in solution filtration;
- covering of slate surfaces to avoid swelling and destruction;
- formation of thin impenetrable filtration crust, preventing from water penetration into a layer.
2. *PHPA ("Fibrospan" – Bulgarian trade mark) reagent* is a highly active (> 69%) partly hydrolized polyacrylamide with a big molecular weight (10-15 million). This reagent is ecologically safe at the use in recommended concentration.
3. *PA ("Geolin K-D" – Bulgarian trade mark) reagent* modified water – soluble polymer of acrilonitril. Non-toxic, fire-proof. "Geolin K-D" is also used as a stabilizer of wash liquid in geological drilling operation.

The main reagents features are:
- slate stabilizer, strengthening the borehole walls;
- effective intensity decrease of dispersion of clay and slate particles in water by the attachment to particles that reduces the water penetration to the minimum;
- effective viscosity increase of drilling solutions on the water basis; polymer is dispersed in water and as a result of electrostatic and chemical interactions it forms a grid of polymeric chains, and it leads to the viscosity increase of drilling solution;
- flocculation of rock particles (sedimentation in circulating system); greasing ability increase of drilling solution (the content of reagent in water is 0.7 kg/m^3, solution greasing ability raises on 31% in comparison with pure water.

The slippery and strong polymeric layer appears during the usage of reagents PA, PHPA and PAC on a column of drilling pipes and it allows to work on the high speeds of bullet rotation, decrease the deterioration of boring pipes on external diameter and the tightening of threaded connections. In the solution there is no sludge, it is completely besieged in the circulating system and it also stimulates the deterioration decrease of boring pipes.

At work with the wireline core barrel NQ complexes the following borehole construction is usually used. The drilling works are carried out with the help of a conductor (112 mm) and casings (108 mm). The further drilling up to thick root rocks is made by drilling core bits (93 mm) and a borehole is settled by the casing (89 mm). After that the complex NQ can be used.

The clay solutions are used for drilling works on the friable deposits and the clayless polymeric solutions are used for root rock drilling. The preparation of clay solutions from the lumpy clay is carried out in a usual clay mixer, and the addition of soda ash (0.5-1.0 kg/m^3 of solution) is necessary for clay mixing improvement. The solution viscosity (as well as the clay quantity) depends on the geological section complexity and it should be not less than 32-38 sec on the Marsh funnel viscosimeter.

The clayless polymeric solution is made in a high-speed propeller mixer, allowing dismissing the polymeric clots quickly. It is possible to prepare a clay solution from the bentonite drilling powder in this mixer.

Depending on complexity of geological conditions at borehole drilling the following kinds of drilling solutions can be used:

- clayless solution on the basis of polyacrylamide (PHPA – *"Fibrospan"*) with some reagent in water (1.0-1.5 kg/m^3) is used for drilling in rather favorable conditions (good stability of walls).
- clayless solution on the basis of two reagents (PAC and polyacrylamide – *"Geolin K-D"*) is used for drilling in rather difficult geological conditions, but the same quantity of reagents should be in the water (0.75-1.0 kg/m^3 of PAC and 1.0-1.25 kg/m^3 of polyacrylamide – *"Geolin K-D"*).
- polymeric clay solutions are used for drilling in very difficult geological conditions. Such solutions are made of highly colloidal montmorillonite bentonitic powder. The same quantity of reagents should be added into the prepared solution (0.7-1.0 kg/m^3 of PAC and 0.7-1.0 kg/m^3 of polyacrylamide – *"Geolin K-D"*). The viscosity of prepared polymeric clay solution should be within the limits of 32-48 sec on the Marsh funnel.

When such solutions are used the circulating system should have two sludge pits (1-2 m^3 and 3-5 m^3). The slime sedimentation is to go in the first pit. Drilling with junk solution is inadmissible, as it leads to crust formation on internal surface of drilling pipes that impedes the descending of overshot and the rise of retrievable core receiver with overshot, because of the gland formations.

It is necessary to apply the solutions of high viscosity with increased content of reagents and clay to overcome the caving. It is possible to use a rolling cutter bit (76 mm) for borehole cleaning to avoid a steep slope. The special adapter (from a rolling cutter bit on the boring pipes) can be made.

The particular fillers, added in the drilling solution, are used for the control of drilling fluid absorption. After retrievable core receiver extraction on the open end of drilling column a swage is settled, it is used for the solution with a filler. In case of substantial increase of pressure on a manometer of the pump to include. The rotation of drilling string can be switched on in case of pressure increase on the pump manometer. It is possible to use this operation several times to clean any borehole from drilling fluid. The drilling of boreholes with washing using the pure water is carried out only in steady rocks, and Rod Grease is used for increase of rotation speed and wastage decrease of drilling pipes.

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