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JASPILITES AND OTHER GEMSTONES OF POST-JASPILITE GENESIS: MINING, TREATMENT, AND ENHANCEMENT

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ДЖЕСПІЛІТИ ТА ІНШІ САМОЦВІТИ ПОСТ-ДЖЕСПІЛІТОВОГО ГЕНЕЗИСУ: ВИДОБУТОК, ОБРОБКА, ОБЛАГОРОДЖЕННЯ

Purpose. To provide an overview of the world jaspilites production technologies and to recommend the optimal technologies for accompanying mining of jaspilites at the ore-mining enterprises of Ukraine.

Methodology. Theoretical and methodological analysis, study and generalization of the world experience for the jaspilites mining on iron-ore deposits.

Findings. The article describes historical names for decorative varieties of jaspilites, trademarks and simultaneously occurring gemstones of jaspilite genesis. The main extraction methods using explosives and sparing technology are analyzed, the best technologies for accompanying mining of jaspilites at iron ore quarries of Ukraine are proved, as well as the further processing and enhancement for gem surfaces.

Originality. For the first time the choice of technologies, machinery and equipment for the jaspilites mining at the iron ore quarries of Ukraine is substantiated.

Practical value. The proposed concurrent production technologies enable the development of ledges containing decorative jaspilite reserves, without affecting the primary production at mining and processing enterprises, developing deposits of ferruginous quartzite.

Keywords: *jaspilite, tiger iron, mining, selective mining, diamond cable sawing, gem surface*

Introduction. Mining and sale of a block stone, including decorative jaspilites, abroad is a profitable business. The obtained blocks are further cut into thin rectangular plates (slabs), which are used as countertops and various decorative elements of interior decoration.

Ukraine can fully realize its potential in this segment of its domestic economy and, more importantly, in the foreign market, where the interest in jaspilites is significantly higher. Competition with the world producers is possible due to the lower production cost of finished products and by creating original design solutions.

Analysis of the recent research. Jaspilites (ferruginous quartzites) are known in many fields of the world. Among them there are varieties which are poor in iron ore; however, they are attractive for their decorative characteristics. They include the following stones.

Actually red-banded jaspilites are positioned abroad as the red-banded jasper, more rarely – as jaspilite. There are many fields of them in the United States, Brazil, Australia, India, and Ukraine [1], and others. The unique geological object is Jaspilite Hill (Jasper Knob), Ishpeming, Michigan State, the United States.

The jaspilite slabs (large plates, about 3 × 1 m) are positioned in the market of decorative stone under the name “iron red granite”.

Jaspilites of Ukraine (their geological position and some theoretical issues of mining) have been studied in the works of the authors [2–4].

However, there are also some other stones known in the market, the genesis of which is somehow connected with jaspilites. Many of them have long been allocated to independent commercial varieties.

Thus, “tiger iron”, which is a red-banded jaspilite with yellow areas, is allocated separately.

“Tiger eye” includes the varieties, fully substituted by chalcedony by crocidolite. Frequently, there also occur other pseudo-morphs by amphibole such as cat and hawk eye. These and other varieties can be considered as semi-precious (gem) stones of post-jaspilite genesis.

The Tiger Eye is one of the great gems that are mined in Western Australia, in Pilbara Region. Currently, several large deposits of rich iron ores are being explored and actively developed there (Marra Mamba iron formation).

The most famous region of tiger-eye mining is located near the Brockman volcano (Brockman Tiger eye mine (Marra Mamba), Mount Brockman, Ashburton Shire, Western Australia, Australia). The ridge of hills with the length about 6 km has given a good quality material from a number of small wells, two of which gave the famous multicolored tiger eve varieties “Marra Mamba” (Fig. 1), a separate variety of tiger eye that differs by multi-color (red, brown, yellow, blue, and black).

Pietersite (Fig. 1) is a kind of fiber-confusedly riebeckite in form of riebeckite breccia, cemented fragments of chalcedonies amphibole in a quartz rock of breccia structure which is extracted at the Prieska deposit, where it received the trade name after the first pioneer Sidney Peters, who discovered this stone in 1962 during exploration of the lands in Namibia to make a farm. Its color grade includes blue-gray, brown, red, and yellow [5].

Only two deposits of pietersite are known in the world, in Namibia and China, as well as isolated findings. Thus, we could find semiprecious stone, like pietersite, in Ukraine on iron ore deposits of Kryvbas and at Poltava mining and beneficiation plant (MBP).

Unsolved aspects of the problem. Geological information about the varieties of decorative jaspilites occurring on the iron-ore deposits of Ukraine lacks attention from the companies developing these deposits. Such techniques of concurrent mining of jaspilites, which would not create difficulties for the main production process, and, as a result, could meet interests of an owner, have not been proposed yet.

Objective of the article. The objective of this work is the review of existing jaspilites mining technologies in the world and recommendations of optimal technologies for concurrent mining of decorative jaspilites at the ore-mining enterprises of Ukraine.

Presentation of the main research. Under conditions of the market economy, one of the decisive factors for stone extraction quarries is the high quality of blocks with minimal losses of extracted material.

Today, jaspilites are extracted as the raw material for the steel industry by drilling and blasting method. Along with its known advantages this method has serious disadvantages: increased risk, high costs, high crushability, seismic effect of explosions on the environment, ecological degradation in mining areas (emissions of fine dust and gases into the atmosphere, water pollution by nitrates of explosive components).

Lumps after explosions have irregular shape and often are riddled with cracks, which leads to high energy costs and losses of initial raw material while manufacturing products from them.

The first step of processing natural stone is its mining in form of commodity blocks of rectangular shape, so that the raw material which is fed for processing, can be of high quality and sufficiently precise dimensions.

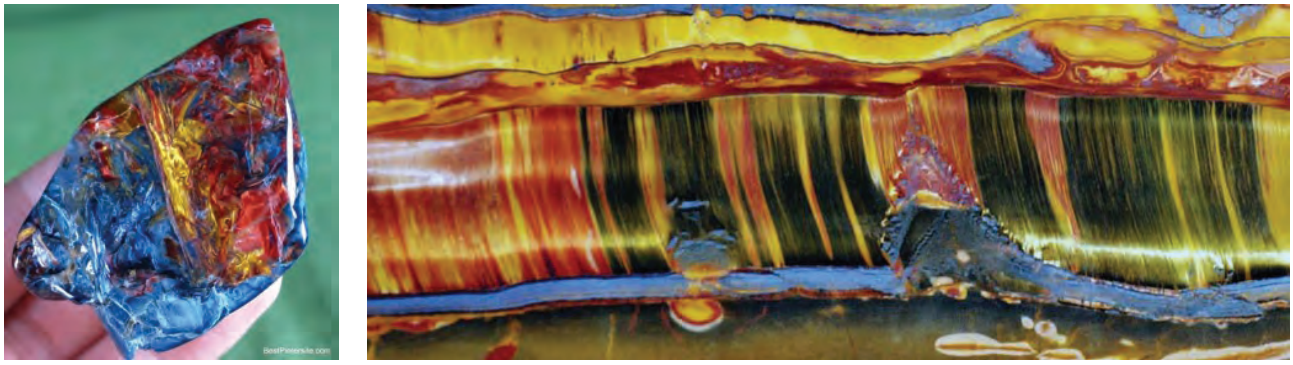
Production of decorative jaspilites can be carried out both: by open mining (in quarries) and underground (in mines). String drilling installations are widely used among the modern methods of extraction block stones. They are designed to prepare stone massif for the further processing and allow drilling a series of horizontal and vertical slots (holes) defining the size and the shape of the future block. Currently, the gentle ways of breaking blocks can be applied for mining jaspilites. The basic methods of mining jaspilites are given below.

Mining and blasting methods. Until the present, the smoky blasting powder (SBP) has been applied during stone blocks mining. Due to its capacity for a slow decomposition in the hole, as compared with other explosive substances (ES) the SBP provides relatively "soft" impact on the stone.

However, this operation mode is carried out only when SMP is initiated with igniters and in small diameter charges. When SMP is initiated with electric detonator or detonating cord (DC), the velocity of decomposition reaction propagation increases from 400 to 2000 m/s, which leads to brisance and appearance of drilling induced fractures and burns of a stone.

At the same time, SBP is hazardous in application: being ignited in the air, it blows even in small quantities. SBP has a high sensitivity to mechanical and thermal effects. Powder dust which is always present in SBP is particularly dangerous.

Usage of DC blocks for breaking in one or two wires is much safer than SBP in terms of storage and handling. However, detonation explosion mode DC has harder impact on the stone, especially in flooded holes. In relation to the latter, the micro-cracking area around the holes exceeds 0.3 m. In addition, the pulse regime of massif loading due to detonation and occurrence of a channel in stemming holes, necessitates reduction in the distance between holes to 0.15–0.2 m to provide a single plane of chipping. This entails an increase in costs associated with drilling operations. When using DC for breaking by the horizontal plane, the height of ledges is limited to 2.5–-3 m, since at higher ledges the DC per-



a *b*

Fig. 1. Pietersite from Namibia (a) and tiger eye of "Marra Mamba" type, [6]

formance is not enough to shift the chipping block. In this case, only a crack can appear with destruction of a stone in a plane of a hole.

***Usage of non-destructive mixtures* (NDM).** With the help of the NDM-1 and other brands of non-destructive mixtures separation of blocks can be carried out with complete safety for the environment, as NDM-1 is not accompanied by any vibrations, emission of solid or gaseous products. While mixing the NDM-1 powder with water, a working mixture (suspension) is formed, which, being filled into a partially or fully closed cavity (for example, a blasting hole) in any facility, gradually hardens as a result of the powder hydration reaction, increasing in volume at the same time. The increase in volume is accompanied by the development of the pressure on the wall of the cavity (blasting hole), whose size eventually reaches a value of 500 kgf/cm^2 (50 MPa). At the same time, there are voltages developing in the body of a cavity object, the value of which may exceed its ultimate tensile strength, which would lead to the object destruction. The effect of destruction is expressed in form of appearance cracks in the body of the object and their temporal development.

Drilling-hydro-wedging method (Fig. 2). The special hydraulic cylinders with couples of lateral feathers should be inserted into the holes $D = 40–42$ mm, made with the string drilling machine. After feeding pressure from the oil station in cylinders the feathers, under the impact of a piston, diverge in the opposite directions, creating a cracking force of about 300 m. The depth of drill holes is 0.1–0.2 of the height of a block chipped from the monolith.

***Pressure generators*.** GDSh type pressure gas generators allow pyrotechnic components, which are placed in the hole, to burn very quickly, but not to explode. Formed gases have a huge amount of kinetic energy, using this physical phenomenon, the device has a gentle impact on a stone block. When using this method, there is no seismic shock traditional for blasting works, there is no air blast wave, no dangerous separation of fragments.

***Destruction by hydro-hammer*.** Among effective non-blast methods of natural stone destruction there is a method based on the use of mechanical shock. This method provides a number of technological operations: splitting a stone from massif, direct splitting and crushing of large fragments.

The working tool is the hydro-hammer that is installed on a hydraulic excavator. The usage of hydro-hammers on jaspilite massifs of fractured structure is effective. The maximum linear dimension of destroyed fragments along with the main crack can reach 2–3 meters. Hydro-hammers can be applied along with a string-drilling machine for directional split of blocks.

The above mentioned mining methods use low tensile resistance of a stone.

Diamond cable sawing (Fig. 3). Cable machines are designed for cutting stone blocks of rectangular form and plates of different sizes from rock formations. Before working it is necessary to drill mutually perpendicular holes in the massif, through which the working body of the machine is spread – a steel rope with diamond holding cylindrical elements (d = 10–15 mm). The machine with diamond rope is equipped with electronic devices for automatic control of the speed of movement along the guiding rails during the cutting process. The machine can work on inclined surfaces and is equipped with an electromechanical brake, which ensures stopping the mechanism in any position.

Except entire slabs, small samples of jaspilite are also applicable in production process. The companies which are the leaders in the decorative stone market suggest

Fig. 2. Mining jaspilites with the string drilling machine application, Brazil [7]

a *b*

Fig. 3. Mining of Tiger iron (a) in Australia [8] and polished section (b)

a *b*

Fig. 4. Jaspilite slab (a), iron red granite, and standard plane (b) with dimensions of 30.5 × 30.5 × 1 *cm, produced by "gem surface" technology [9]*

different kit mosaics and the so-called "gem surfaces" (Fig. 4) for interior design.

The mining technology with drilling and blasting method allows selecting fractured samples suitable for the future usage. Such samples are to be sawed to get "plywood" with thickness of up to 10 mm, and further, after treatment/decoration of fractures, they can form the basis of unique picture on previously prepared plane (granite or marble slab) and glued with special mixture.

This technology allows obtaining the so-called gem decoration of a surface (gem surface). The products obtained on the basis of the gem decoration (assembled tabletops, water dispensers, bathes, front panels, other large-scale elements of interior decor) are related to the luxury segment. The income from selling these products calculated for 1 kg of gemstone by many times increases the income from selling products as a whole thing produced with ordinary technics (rotating bodies, caskets, landscape cuts and so on) except, may be, mosaic and art carving).

Accompanying mining of jaspilites on the quarries of Ukraine. The provided methods for mining block stones are prospective at the development of a single quarry. The extraction of jaspilites at one separate quarry is not efficient due to their small content there. Jaspilites can often be found on iron-ore quarries which are developed by the general method, transferring them into the dumps as a waste rock mass. The selective development of areas containing jaspilites is the prospective direction in mining activities. The selective mining provides a significant economy effect. Selective mining on the iron-ore quarries should be carried out using different special methods of drilling and excavation-loading works: combination of blasting and selective loading; separate blasting and separate loading. In case of the joint blasting it is important to save initial structure of the block mass.

It requires application of the special methods of blasting, generally at the development of complex-structured deposits, represented by jaspilites and other

rock mass. Practically, the joint blasting of the complex-structured blocks is mostly carried out with single-rowed and multi-rowed location of wells. In case of the single-rowed blasting of wells it is necessary to make separate development of ore and mineral (jaspilite) areas of blasted rock mass breakdown and its separate loading in a vehicle.

Selective mining can be simple and complicated. The simple selective mining assumes an isolated loading of different types, ore grades and rock mass by ledge length without selection in a vertical plane. The simple separate development is made with narrow stopes, ordinary stopes and by a selective method (ore areas are developed first and areas with minerals are developed second).

Mining of jaspilites is related to the complicated selective mining which is itself the excavator sorting by the large height, is made by different methods: selective loading, screening rock pieces by fractions, controlled rock collapse, combines loading. The selective loading is applied on the deposit areas where jaspilites and other rocks have clear edging. The controlled collapse methods of a deposit include various collapses of jaspilite areas of a deposit into the tray-formed cavities preliminary prepared by an excavator in the bottom-part of the blasted rock mass breakdown for the further loading into the dumper trucks. It is also possible to use some options of jaspilite mass collapses for their further loading into the dumper trucks and transportation to the screening site. The controlled collapse can be carried out with the eccentric ripper type Xcentric RIPPER without preliminary blasting destruction with enough stable slopes of the rock mass slaughter. It is necessary to carry out the inner-slaughter sorting on areas where it is possible to extract jaspilites by grades with placing into preliminary prepared sited near the slaughters (for their further loading into vehicles). In slaughters divided by their height on ore and jaspilite areas it is necessary to apply the vertical excavator selective mining with eccentric rippers type Xcentric RIPPER. The areas are developed in a certain order with selective loading of the ore and jaspilites. The horizontal excavator selective mining is carried out in the slaughters with clearly allocated ore and jaspilite areas by the bounder of the breakdown of the blasted rock mass. The areas are mined by the transverse and longitudinal excavation stopes of variable width in accordance to configuration and parameters of an area.

Selective blasting includes: under-ledge ripping (different time blasting of the ledge massif by horizontal layers); explosion of inclined well charges; selective blasting of the separate ledge areas; split blasting; direct blasting. Selective blasting of the ore and jaspilite areas is performed when it is possible to allocate areas by the blasting block bounder, represented by conditioning ore or jaspilites.

With selective mining on the quarries it is mostly relevant to apply automobile transport which provides separate transportation of different grades of ore and jaspilites from complicated slaughters. The special place during selective mining should be taken by the single-bucket loaders on a pneumatic wheel course, hydraulic excavators and eccentric rippers type Xcentric RIPPER.

Usage of selective (separate) mining leads to the increase in mining costs by 10–30 % compared to the general mining and requires technical and economical comparison of the different variants. However, selling finished products from the empty rock mass (jaspilites) will cover these costs and allow having an additional profit.

It is necessary to pay attention to such unique varieties as pietersite, tiger iron and other stones containing pseudomorphisms of chalcedony by amphiboles at the currently operating quarries. Their detection will allow evaluating the present stocks of decorative jaspilites significantly higher.

Conclusions and recommendations for further research. Mining and geological production conditions of Ukraine allow conducting concurrently the selective mining of decorative jaspilites obtaining different sizes of blocks. It will provide additional raw material for the gem processing industry. The decorative jaspilite products are most popular in the world markets and try to conquer Ukrainian market. Combining the famous methods to mine block stones and selective mining of the rock mass will allow optimizing jaspilite mining and reducing the production cost of the finished products.

The following technologies of concurrent mining are recommended for Ukrainian conditions:

1. For iron-ore quarries developed by the general method:

- separate blasting and vertical excavator selective mining with eccentric rippers;
- joint blasting and selective loading.

2. For development of small quarries:

- application of diamond cable sawing;
- application of string drilling machines.

Updated technologies allow getting different elements of interior decoration. Using jaspilites will allow an owner to diversify their business, what, along with mining of other types of gemstone raw materials and decorative stones, will give a new opinion of Ukraine as the country, which can mine gemstones and offer new technology solutions in the field of the gemstone processing and construction decor.

References.

1. Baranov, P. N. ed. Jaspilites. In: *Gemstones of Ukraine*. V. 2 [online] Available at <http://gem.nmu.org.ua/index.php/uk/nauka/publikatsii.html>.

2. Baranov, P., Shevchenko, S., Heflik, W., Dumanska-Slowik, M., and Natkaniec-Nowak, L. *Jaspilite – the gemstone of Ukraine.* [online] Available at: <http://www.academia.edu/11464256/Jaspilite_the_gemstone_of_Ukraine>.

3. Khomenko, O. Ye., 2012. Implementation of energy method in study of zonal disintegration of rocks. *Visnyk Natsionalnoho Hirnychoho Universytetu,* 4, pp. 44–54.

4. Kononenko, M. and Khomenko, O. *Technology of support of workings near to extraction chambers / School of*

Underground Mining: New techniques and technologies in mining. [online] Available at: <http://www.crcnetbase.com/doi/abs/10.1201/b11329-32>.
5. Kaifan Hu and Peter J. Heaney, 2010. A microstructural study of pietersite from Namibia and China. *Gems & Gemmology,* 46 (4), pp. 280–286.
6. Pseudomorphs of quartz on amphibole asbestos. [online] Available at: <www.mindraw.web.ru/cristall15.Tigers-eye.htm>.
7. The Brazilian quarry of Iron red, [online] Available at: <www.brunozanet.com/en/quarries/iron-red-quarry>.
8. Tiger Iron mining in Australia, [online] Available at: <www.floatingstones.com.au/mining.html>
9. Sharjah Gemstone Overlay Materials, [online] Available at: <www.agapetile.com/products/>.

Мета. Виконати огляд існуючих у світі технологій видобутку джеспілітів та рекомендувати оптимальні технології для попутного видобутку джеспілітів на гірничорудних підприємствах України

Методика. Теоретико-методологічний аналіз, дослідження та узагальнення світового досвіду розробки запасів декоративних джеспілітів на залізорудних родовищах.

Результати. Описані історично сформовані назви для декоративних різновидів джеспілітів, існуючі торгові марки та самоцвіти, що зустрічаються попутно. Проаналізовані основні способи видобутку із застосуванням вибухових речовин і щадні технології, обґрунтовано вибір оптимальних технологій для попутного видобутку джеспілітів на залізорудних кар'єрах України, а також технологій подальшої обробки та облагородження для отримання декорованих поверхонь.

Наукова новизна. Уперше обґрунтовано вибір технологій, машин і устаткування для попутного видобутку джеспілітів на залізорудних кар'єрах України.

Практична значимість. Запропоновані технології попутного видобутку дозволяють розробляти уступи, що містять запаси декоративних джеспілітів, без впливу на основне виробництво на гірничозбагачувальних комбінатах, що розробляють родовища залізистих кварцитів.

Ключові слова: *джеспіліт, тигрове залізо, видобуток, селективна виїмка, алмазно-канатне розпилювання, декорировка поверхні*

Цель. Выполнить обзор существующих в мире технологий добычи джеспилитов и рекомендовать оптимальные технологии для попутной добычи джеспилитов на горнорудных предприятиях Украины.

Методика. Теоретико-методологический анализ, исследование и обобщение мирового опыта разработки запасов декоративных джеспилитов на железорудных месторождениях.

Результаты. Описаны исторически сложившиеся названия для декоративных разновидностей джеспилитов, существующие торговые марки и самоцветы, встречающиеся попутно. Проанализированы основные способы добычи с применением взрывчатых веществ и щадящие технологии, обоснован выбор оптимальных технологий для попутной добычи джеспилитов на железорудных карьерах Украины, а также технологий последующей обработки и облагораживания для получения декорированных поверхностей.

Научная новизна. Впервые обоснован выбор технологий, машин и оборудования для попутной добычи джеспилитов на железорудных карьерах Украины.

Практическая значимость. Предложенные технологии попутной добычи позволяют разрабатывать уступы, содержащие запасы декоративных джеспилитов, без влияния на основное производство на горно-обогатительных комбинатах, разрабатывающих месторождения железистых кварцитов.

Ключевые слова: *джеспилит, тигровое железо, добыча, селективная выемка, алмазно-канатная распиловка, декорировка поверхности*

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