Посебно издание на
Geologica Macedonica, No3

МАКЕДОНСКО ГЕОЛОШКО ДРУШТВО

ВТОР КОНГРЕС
на
Геолозите на Република Македонија

ЗБОРНИК НА ТРУДОВИ

Уредници:
Јовановски, М. & Боев, Б

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ПРЕДГОВОР

Геолошката наука на територијата на Република Македонија има долга традиција, а е поврзана пред се со рударската активност. Познати се локалитети каде се најдени монети од бакарната и бронзената доба. Сочувани се траги на експлоатација на злато од речниот нанос на Коњска Река-Гевгелиско и на други места, од времето на Александар Македонски. Во источна Македонија рударењето било интензивно за римско време.

Први геолошки податоци на научна основа за територијата на Македонија се јавуваат во првата половина на XIX век, а првите печатени геолошки трудови за нашите простори се среќаваат кај А.Буе (1828-1870) и Виксенел (1842). Од крајот на XIX век па се до денес во зависност од интензитетот на истражувањата напишани се голем број на трудови од сите области на геологијата.

Активностите на стручните лица од областа на геологијата се изведуваат преку Македонското Геолошко Друштво кое е формирано во 1952 година.

Во 2008 година се одржа Првиот Конгрес на Геолозите на Република Македонија од кој излезе зборник со преку 50 научни трудови од кои добар дел беа подготвени од меѓународни тимови.

Во периодот помеѓу 2008 и 2012 година во нашата земја се изведоа голем број на активности во сите полиња на геологијата. Особено важни да се споменат се интензивните истражувања на металични и неметалични минерални суровини, регионалните, геохемиските и инженерско-геолошките, итн.

Вториот Конгрес на Геолозите на Република Македонија претставува сублимат на научните сознанија базирани на споменатите геолошки истражувања и испитувања кои се одвиваа на територијата на нашата земја во периодот од 2008-2012 година. Исто така, на конгресот е презентирана и дел од работата на колеги геолози од соседните земји, така да и овој пат со задоволство може да констатираме дека конгресот има меѓународен карактер.

PREFACE

Geological science on the territory of Republic of Macedonia has long tradition, and is mainly connected to the mining activities. There are numerous localities where coins from copper and bronze age are found. Traces from exploitation of gold in the river Konjska-Gevgelija and other places are known, in the time of Alexander the Great. In eastern Macedonia the mining was very intensive during the Roman period.

First scientific geological data for the territory of Macedonia are found in the first half of XIX century, and the first printed papers for our region are found at A.Bue (1828-1870) and Viksenel (1842). From the end of XIX century until today, depending on the intensity of the investigations numerous publications are presented in all fields of geology.

The activities of geological scientists are performed in the frame of the Macedonian Geological Society which is formed in 1952.

In 2008 the First Congress of Geologists of Macedonia was held. Proceedings with over 50 papers were published. Numerous papers were prepared by international teams.

In the period between 2008 and 2012 investigations in all fields of geology were performed. Especially important to mention are the investigations of metallic and non-metallic mineral resources, regional, geochemical, engineering-geological, etc.

The Second Congress of Geologists of Republic Macedonia presents sublimate of scientific knowledge based on the mentioned geological investigations which were conducted in the period 2008-2012. Also, the congress presents part of the work of colleagues from neighboring countries, so with great pleasure we can once again confirm its international character.

Претседател
на организационен одбор

President
of organizing committee

Проф. д-р Милорад Јовановски

STRUCTURAL RESEARCH ON DOLOMITE MARBLES IN BELOVODICA MINE FROM THE ASPECT OF MARBLE EXPLOIATATION

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Abstract
This paper presents the results and the conclusions of the research on the white dolomitic marbles deposit "Belovodica", which is near the village of Belovodica, at a distance of 21 km to Prilep. The investigative field is an integral part of the Pelagonian tectonic unit. Studies have been made in order to get the real picture of the possibilities and the potential of this terrain for profitable work in the aspect of white dolomite marble exploitation. By analysis and interpretation of the research results, it is confirmed that there is a belt of compact white dolomitic marble that has remained immune to tectonic disruption. By changing the method and the course of mining activities in the direction of exploitation of this layer, the total utilization and cost - effectiveness of "Belovodica" mine can be greatly increased.

Key words: white dolomitic marble; tectonics; fissures systems, blocks, tombolons

INTRODUCTION

White dolomitic marble mine - "Belovodica" is located 15 km east of the town of Prilep, near the village of Belovodica.

Geographically, it belongs to the Dren mountain as a striking orographic unit in this part of the Republic of Macedonia.

The place is located at an altitude of about 1000 meters, one of which can be defined as a slightly flattened slope inclined towards the west –southwest, and it turns in a relatively steep department eastwards. The mine can be placed on the northern slopes of Dren mountain of about 1,5 km away from the village of Belovodica.

In the close vicinity of the marble exploitation mine of "Belovodica", White River passes, which has water throughout the year. And right above the village of Belovodica, because of the series of marbles, there is an appearance of numerous periodic flows and lower aquifers that build the occasional flow of the river Drenska. The results of detailed geological investigations on this field can be found in the works of Boev (2005) and Patchanagis (2010).

The colour, and the results of the physical–chemical and the mineralogical research show, that this is white dolomitic marble with a good quality. But the tectonic damage in the marble mass appears as the biggest problem in the process of exploitation. For particular definition of potentiality of this mine, in terms of profitability, summarizing the results of experimental exploitation with the results of geological investigations, is required.

Figure 1. Geographical position of the investigated area

GEOLOGICAL COMPOSITION OF THE WIDER REGION

Marbles of the deposit of "Belovodica" belong to the marble mass of the southern part of Pelagon. This marble mass is located in the edge part of Pelagonian metamorphic complex to the west and Vardar Zone to the east.

It is a relatively narrow zone that is presented as two types of marbles, such as: calcite in eastern contact part with Vardar Zone and white dolomitic in the western part, in direct contact with series of gneisses from Pelagonian metamorphic complex.

The basic structural features of the metamorphic phase of Pelagon are a result of syngenetic processes at high regional metamorphism and crimping by a mechanism on plastic-flow with simultaneous granitoide intrusion of the first phase, which formed major fold structures. (M. Arsovski 1997)

It should be noted that second granite stage played the significant role during Grenville orogeny which manifests itself as a major magmatic activity whose products, besides metasomatic processes and homogenization of metamorphic rocks in certain parts of Pelagon, effectuated recent crimping and forming new large folds, whereupon a completed destruction of older fold structures is made. It is important for marble mass of Belovodica that homogenization, whitening and dolomitization of marbles is performed in its lower parts. These processes are associated with the intrusion of granite rocks in Dren anticline. At lower levels this marble mass is represented by massive, saccharoses white dolomitic marbles, in which traces of foliation, micro-folds, can be seen but only locally, as well as some low occurrence of calcite veins.

Eastwards, dolomitic marbles gradually convert into foliated calcite – dolomitic marbles.

The geological terrain includes geological units that are an integral part of southern metamorphic complex of Pelagon including: granite, gneiss, granite -gneisses and marbles. The first geological studies of the ground are connected with the first geological surveys of the areas of Pelagon performed in the early XX century.

(Detailed geological data obtained from the basic map of Yugoslavia in the M = 1:100000, sheet Vitoliste 1980 edition of the Federal Geological Institute, Belgrade).

The investigated terrain has different types of rocks of different geological age. The oldest rocks in this terrain are Precambrian metamorphic rocks, and then the rocks of Cretaceous age, rocks of Pliocene and the youngest ones are the rocks of Quarter.

- **Precambrian:** The oldest rocks of this terrain are represented by rnuscovitic gneisses, white dolomitic marbles and calcite marbles. Series of marbles are represented in two super-positioning horizons. White dolomitic marbles and dolomites dominate in the lower part and calcite marbles dominate in the upper part.

Foliated rnuscovitic gneisses (Gm): These gneisses have the largest spread in the gneiss series. The parties, in which a striped texture is quite expressed, are noted among them, but also there are parties in which the texture is very vague, in this way they could represent normal coarse-grained gneiss. The colored compounds are differentiated from the uncolored ones in a form of thin strips. The color of the gneiss is yellowish grey to light green. The size of the grains varies from 0.5 to 6mm, it is usually 2 mm. They are built from felspad, quartz, and coloured minerals that are represented by muskovit, fengit, rare shells of biotit and tiny grains of epidot. Accessorily, sfen, garnet, apatite, zircon, pyrite, magnetite occur and secondary minerals are kaolinite, sericite and limonite.

Grey to grey-white white dolomitic marbles (Md): Dolomite marbles are developed in the lower part of the marble series. Starting with plate cipoline, they mainly occur as bank form marbles and they rarely convert into massive ones. The whole mass is relatively homogeneous and it is mainly built of white dolomitic marbles. They are fine-grained white saccharoses dolomitic marble, quite cracked, with granoblastic structure. The grain size is from 0,05 to 0,5 mm.

Calcite marbles (M): In the upper part of the marble series, plate to bank form calcite marbles appears gradually from dolomite marbles. They represent the final part of these series and they are discovered in the area of the villages of Belovodica, Veprchani and Labnica, while the rest is covered with young formations. Calcite marbles are fine to medium- grained, white to grey – white color.

Massive, medium to coarse-grained granodiorite (δγ): It occurs in rocks of several meters to large masses of several square kilometers. During the intrusion, the magma mainly used the course of foliation and of the

older anticlinal and vertical structures; it conducted intensive magmatism in surrounding rocks. Massive granodiorite are grey to dark grey, medium to large grains.
They have a hypidiomorphic-grain structure and a massive texture. They contain important minerals such as: plagioklas, K-feldspar, quartz and biotite, and they also contain secondary minerals such as: apatite, titanite, amphibole, zircon, garnet, magnetite and ortite.

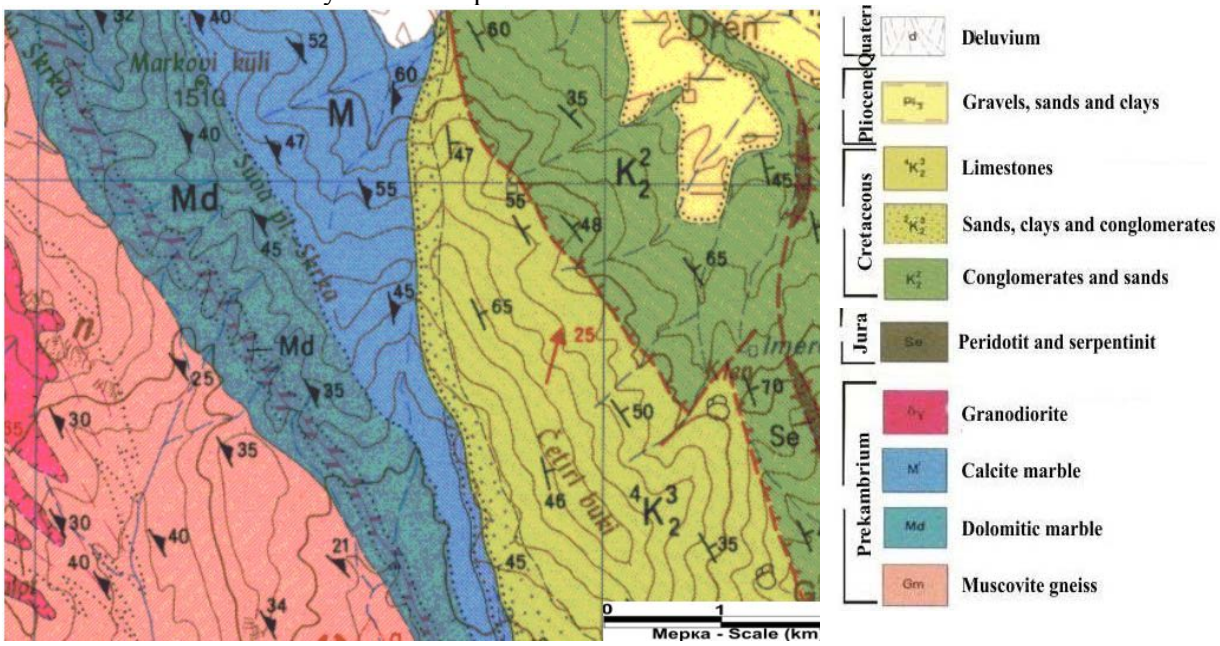


Figure 2. Geological map of the investigated area

- Jurassic: Rocks of Jurassic age in this terrain are: serpentinites and peridotites. They extend in the zone of Dren village, south through Gudjakovo, Vitolište, Polchishte villages to Crna Tumba and they continue along Greek territory.

Peridotites and serpentinites (Se): Serpentinites strongly dominate over other ophiolitic rocks. They have light to dark green color, they are made of serpentine with relics of pyroxene and olivine. Secondary they contain talc, chlorite, magnetite and chromite.

- Cretaceous: The rocks that appear in the Lower Cretaceous are conglomerates and sandstones of Turonian age; tile clays, conglomerates and tile and bank – type limestone of Senon age.

Conglomerates and sandstone (K ² 2): Conglomerates participate in more than 60% and they are developed in layers that are up to 3 m. thick. They are highly compositionally heterogeneous and built of well rounded pieces, maximum 20 cm in diameter, of quartz, quartzite, gneiss, rarely sandstone, shale and clay.

Sandstones, clays and conglomerates (2K ³ 2): Sandstones, can be fine-grained, medium-grained and coarse-grained. They are composed of arkoze and quartz and the cement is clay- carbonate. Conglomerate occurs in thicker bank form, mostly with sand, while clays occur as rare constituents.

Plate and bank form limestone (4K ³ 2): These rocks make up the uppermost level of Senon sediments. They appear grey and white, rarely pink, usually flat and in some case bank form.

- Pliocene. Rocks of Pliocene age in this terrain are gravels, sands and clays.

Gravel, sands, clays (Pl3): Sediments are represented by yellow gravel, gravel sands, sands and clays.

- Quarter: The youngest rocks of the examined terrain are rocks of Quarter and it is deluvium (d).

Deluvium (d) : Deluvium deposits are grouse material from granodiorites and metamorphic rocks.

TECTONICS OF THE WIDER AREA

Rupture tectonics occupies a significant place in the structural construction of this marble mass and it is represented by faults, cracked zones and fault zones. General occurrence of the marble mass is karstification, predominantly expressed in the main rupture directions (NW – SE and NE - SW) and large prominent surface damage of marbles under the influence of
atmospheric impacts.

This neotectonic damage of the marbles in the western part, reaches a depth of ten meters, and eastwards, where the terrain morphologically rises, the impairments grow up to several ten meters. It is primarily about the abrasive activity of the former Pleistocene – Pliocene Pelagonian lake.

But the major damage to the blocks of marble mass is associated with rupture tectonics of convergent movements, represented by faults and crack that belong to multiple systems. Rupture structures are of diverse age, but the main rupture tectonics is mainly young and it is formed by a process of formation of the neotectonic graben of Pelagonia valley in Pliocene, as well as the processes of young and crimping faults during Alpine orogeny (Boev 2005).

Regionally, this terrain is under the influence of the convergent movements between two major geotectonic units: the Vardar zone and Pelagonian Horst antiklinorium.

The predisposition stems from the upper Eocene marine transgression, conditioned by the development of large elongated graben under the direction of faults, inherited from Laramian orogen stage. With the process of block tectonics, i.e. the dominant vertical movements of rising and sinking, between Helvet and Thornton (Styrian orogeny phase), the valley area with faults is broken and lowered again. The present primary (main) tectonic form is obtained with this (A. Killias, 2010).

Also in "Belovodica" mine, cracks of smaller intensity and different orientation are developed.

Some of them are probably before Neotectonic, they are difficult to be deciphered from Neotetonic and some of them are secondary ruptures, obtained as reflexive impulse, or manifestation of stabilization of the mountain massif, after the tectonic movements.

Mainly, in “Belovodica” mine cracks systems into direction (NW – SE and NE - SW) dominate and the impact of these cracks networks, manifests as extremely inconvenient for the blocks of dolomitic marbles.

EVALUATION OF THE OBTAINED RESULTS AND A COMMENT

In the entire process of geological examinations, it is necessary to summarize the results of exploration with geological drilling and tectonic elements of the wider area. Because, the biggest problem in the exploitation and cost effective operation of the mine, is the tectonic damage of the marble; special attention is given to the proper marking of the larger ruptures, their correlation with productive horizons and finding some new reserves of compact marble mass in the mine - Belovodica.

Petrographic and mineralogical features

In order to research petrographic – mineralogical features of marble, in mine “Belovodica”, several samples with different types of marble are selected. Massive white dolomitic marbles build up the southwestern part of the marble mass and in the north-eastern parts marbles with increased amounts of calcite, appear. With the microscopic studies of samples of white marble grain, it is posited, that they have fine grained - granoblastic structure, shifting to a mosaic, and in some places there is an appearance of porphyroblastic structure.

In the crushed zone, the existence of cataclastic structures and on some places up to mylonitic, is posited. The size of dolomite grains ranges from 0,07 up to 1 mm.

Dolomite grains are partially rounded and they have an expressed cleavage. On some parts, they have elliptical cross sections and they are poorly elongated in the direction of the foliation. Dolomite grains are rarely irregular and they are often polygonal in shape. Besides dolomite, calcite occurs as well as some smaller amounts of muscovite. Rarely there is some appearance of quartz, fluorite, rutile and phlogopite.

Physical – mechanical characteristics

Strength of pressure in dry condition:
P max = 125 N/mm²
P min = 85 N/mm²
P av = 100 N/mm²
Strength of pressure in water-saturated condition:
P max = 110 N/mm²
P min = 65 N/mm²
P av = 78 N/mm²

Strength of pressure after 25 freeze-thaw cycles:
P max = 85 N/mm²
P min = 68 N/mm²
P av = 82 N/mm²
Water absorption: σ = 0.15 %
Volume weight: γ = 2800 kg/m³
Abrasion resistance:
A = 46.6 sm³ / 50 sm³

Structural – tectonic elements

The structural - tectonic elements in the mine of "Belovodica" are represented by faults and fissures. A1 and A2 are primary faults (fig. 3) created as products of a genetic discontinuity in the process of formation. B -1 and B – 2 are the oldest faults from secondary faults, which are reverse (thrust) faults, filled with brecha sediments. Convergent movement is observed on these faults but not longer than one meter.
Other faults are Neotetonic, equivalent with the main tectonic activity. Characteristically, in Belovodica mine, there is a rapid change of compactness of the marble mass before and after the rupture structures.

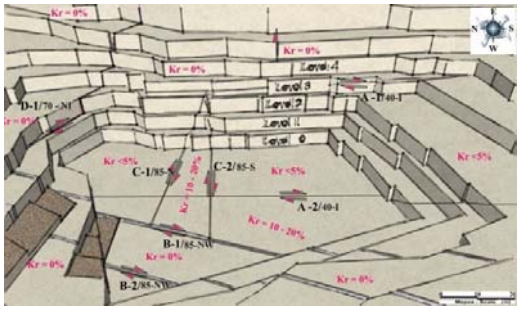


Figure 3. 3D image of mine Belovodica with delimitation of larger ruptures and utilization of individual parts

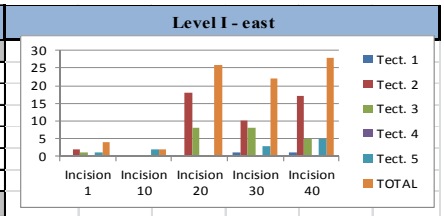
Fissures and fissures systems

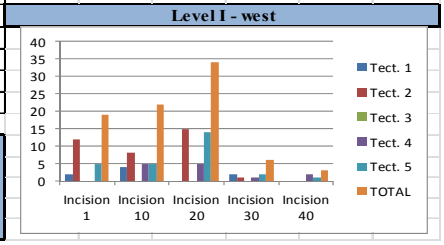
The measurement of fissures was performed in the open parts of the mine, from its eastern and western side in the Level - 1 and level - 0. In order to connect the results of the exploration, measurement points are placed on sectors, cellos of incisions that are obtained in the process of exploitation. In Belovodica- mine for white dolomitic marbles, five fissures systems have been observed, three of which are more intensive. Those are fissures systems with (1. NW - SE, 2. NE – SW and 3. I - W) direction. In the inter-relationship of these fissures systems, it can be seen that the older system is a system with NW – SE direction, which occurs in the western part and the younger one is the NE-SW system, which occurs in the eastern part of the mine. Besides these, another damage on stratification is observed in some places, that was obtained as a product of genetic discontinuity in the origin.

Table 1.

MEASUREMENT OF CRACKS AND CRACKS SYSTEMS								
Level I - east								
No.	Location	Tect. 1	Tect. 2	Tect. 3	Tect. 4	Tect. 5	TOTAL	Category
1	Incision 1	0	2	1	0	1	4	II
2	Incision 10	0	0	0	0	2	2	I
3	Incision 20	0	18	8	0	0	26	IV
4	Incision 30	1	10	8	0	3	22	IV
5	Incision 40	1	17	5	0	5	28	IV
Level I - west								
No.	Location	Tect. 1	Tect. 2	Tect. 3	Tect. 4	Tect. 5	TOTAL	Category
1	Incision 1	2	12	0	0	5	19	IV
2	Incision 10	4	8	0	5	5	22	IV
3	Incision 20	0	15	0	5	14	34	IV
4	Incision 30	2	1	0	1	2	6	II
5	Incision 40	0	0	0	2	1	3	I

Legend		
	Tect. 1 = vein crack	α= 40 ° / I - Dip angle
	Tect. 2 = Crack system SI - NW	α= 80 ° / SW - Dip angle
	Tect. 3 = Crack system I - W	α= 85 ° / N - Dip angle
	Tect. 4 = Crack system SW-NI	α= 70 ° / NW - Dip angle
	Tect. 5 = Cracks that are different from the familiar cracks systems	



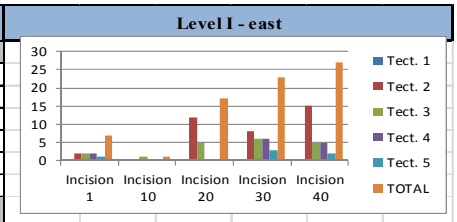


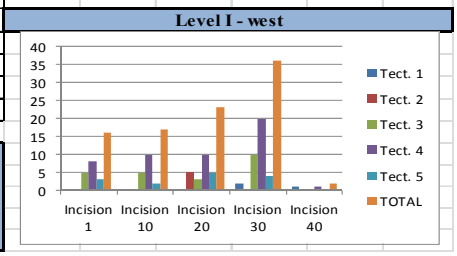
Cracks that can not be attributed to any of the previous systems, are the fifth system. These cracks are often the result of the damage to the marble, caused by blasting, that is an integral part of the process of exploitation. The results of measurements of the damage to the marble mass in certain sectors of the mine, are given in table 1 and table 2.

Table 2.

MEASUREMENT OF CRACKS AND CRACKS SYSTEMS								
Level 0 - east								
No.	Location	Tect. 1	Tect. 2	Tect. 3	Tect. 4	Tect. 5	TOTAL	Category
1	Incision 1	0	2	2	2	1	7	II
2	Incision 10	0	0	1	0	0	1	I
3	Incision 20	0	12	5	0	0	17	IV
4	Incision 30	0	8	6	6	3	23	IV
5	Incision 40	0	15	5	5	2	27	IV
Level 0 - west								
No.	Location	Tect. 1	Tect. 2	Tect. 3	Tect. 4	Tect. 5	TOTAL	Category
1	Incision 1	0	0	5	8	3	16	IV
2	Incision 10	0	0	5	10	2	17	IV
3	Incision 20	0	5	3	10	5	23	IV
4	Incision 30	2	0	10	20	4	36	IV
5	Incision 40	1	0	0	1	0	2	I

Legend		
	Tect. 1 = vein crack	α= 40 ° / I - Dip angle
	Tect. 2 = Crack system SI - NW	α= 80 ° / SW - Dip angle
	Tect. 3 = Crack system I - W	α= 85 ° / N - Dip angle
	Tect. 4 = Crack system SW-NI	α= 70 ° / NW - Dip angle
	Tect. 5 = Cracks that are different from the familiar cracks systems	





Investigative drilling

In the first phase of geological drilling, investigative boreholes were placed in 12-meters square grid, which most of mining field is covered with. By summarizing the results of these investigations, it was concluded that the section of marble mass of Belovodica mine which does not fit in the contours of previously located positive horizon, is decomposed and sterile, in terms of getting the marble blocks.

In the second phase of the investigative drilling, the placement of the boreholes is in a linear direction, that follows the previously located productive horizon. This drilling is done in order to obtain more specific information about the depth of the productive horizon and to confirm the previously obtained findings. In this part, the marble mass shows greater compactness. Rarely, in some places, fissure from systems (NW - SE and NE - SW) characteristical of the other part of mine, do not generally appear.

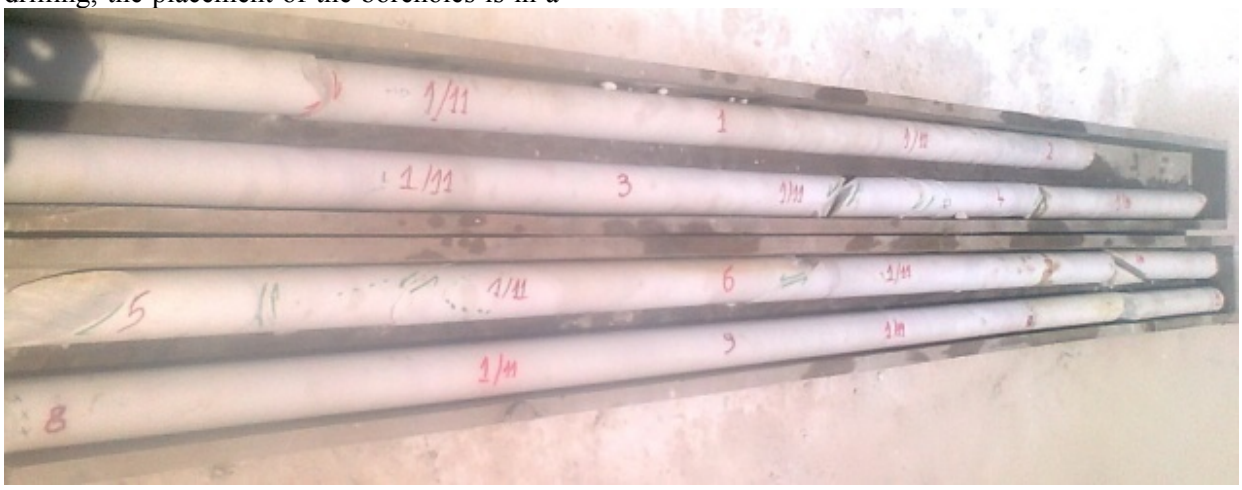


Figure 4. Positive borehole B 1/11

At certain parts, a minimum occurrence of sub – vertical fissures of fissure system (I - W) and some open fissures that follow the stratification, are noted. In the upper parts, near the exploitation field, we have the appearance of damage that is not consistent with the known fissure systems and probably it is damage to the marble due to blasting operations, which are often used in the process of exploitation. With this drilling, it is concluded that in this part of the mine, a compact part of the marble mass is located, which is marked and limited as a positive horizon. (fig.5).

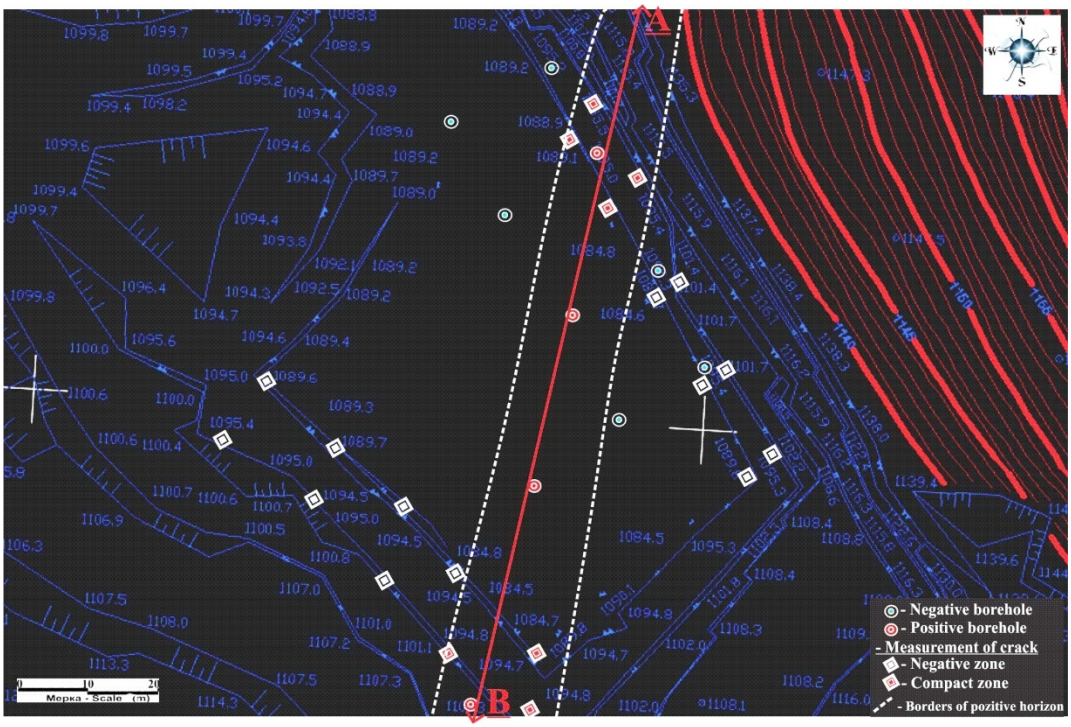


Figure 5. Spatial position of points of investigations in mine – Belovodica

With summarizing the results of exploitation and geological investigations, geological profile (AB) is produced, which is placed in the center of the compact horizon (Fig. 6).

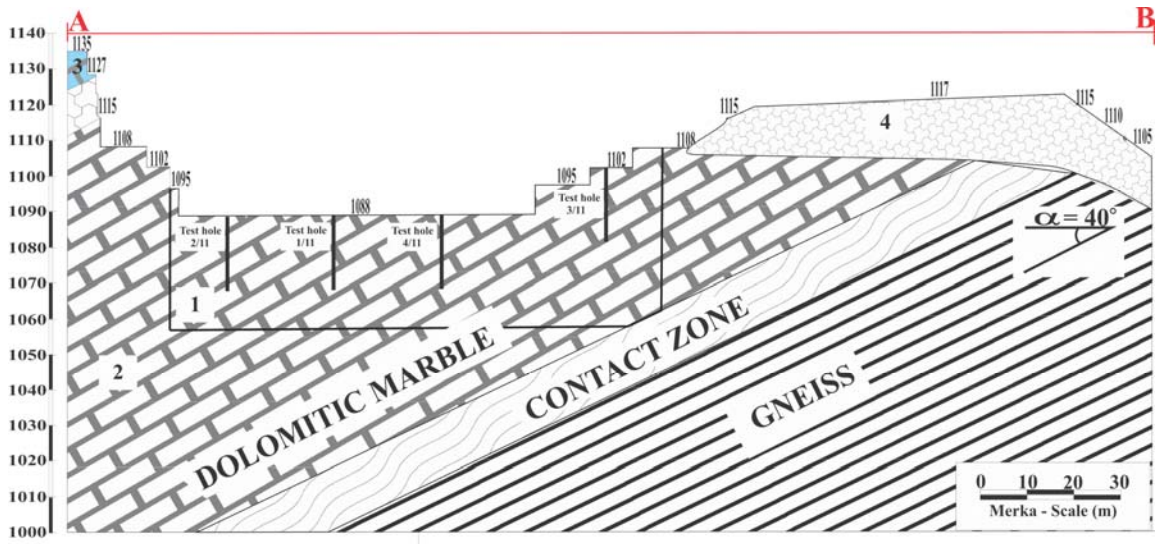


Figure 6. Longitudinal profile (A-B) of the positive horizon. 1 - Confirmed reserves, 2 - Potential reserves, 3 - Calcite marble, 4- Surface, waste material.

Reserves of white dolomitic marble

Calculation of the reserves is made using 3 – D software and CAD software package. The total amount of material in place, Qt = (L2 x P) is designed, in correlation with the current method of exploitation and the needs for sufficient space for effective and safe operation.

The coefficient of utilization (R1) in the productive horizon is obtained as a product of the results from exploitation and geological investigations.

Because of the rapid change in the compactness of marble mass, the reserves of compact white dolomitic marble are classified into two groups: confirmed and potential.

Table 3.

RESERVE CALCULATION										
Levels	P (m²)	L1(m)	R1 (%)	Q1 (m³)	Comercial material (m³)	Block (m³)	Tombolons (m³)	L2 (m)	Qt (m³)	Rt (%)
1108	1000	0	0	0	0	0	0	110	110000	0,0
1102	720	5	10	3600	360	216	144	100	72000	0,5
1095	600	15	20	9000	1800	1080	720	90	54000	3,3
1088	1100	15	20	16500	3300	1980	1320	80	88000	3,8
1082	1400	15	20	21000	4200	2520	1680	70	98000	4,3
1076	1200	15	20	18000	3600	2160	1440	60	72000	5,0
1070	1100	15	20	16500	3300	1980	1320	50	55000	6,0
1062	1000	15	20	15000	3000	1800	1200	45	45000	6,7
1056	900	15	20	13500	2700	1620	1080	40	36000	7,5
1050	800	15	20	12000	2400	1440	960	40	32000	7,5
1044	700	15	20	10500	2100	1260	840	40	28000	7,5
1038	600	15	20	9000	1800	1080	720	40	24000	7,5
1032	500	15	20	7500	1500	900	600	40	20000	7,5
TOTAL			**19,8**	**152100**	**30060**	**18036**	**12024**		**734000**	**4,1**
Confirmed reserves (m³)					**13000**	7800	4680			
Potential reserves (m³)					**17060**	10236	7344			

* P – the surface area of the productive layer, L1 - the width of the productive layer , Q1 – the volume of the productive layer, L2 –- the width of the work surface, Qt - the amount of the demolished volume on-site , R – coefficient of usage.

Reserves in "Belovodica" mine are estimated at 30 000 m³ compact white dolomitic marble, 13 000 m³ of them are confirmed by the results of explotation and geological research and 17 000 m³ are assumed.

The coefficient of utilization, R (t) in the total process of work, is obtained from the ratio of commercial material and overall mass on site (Qt), would move about 4%.

CONCLUSION

In the process of geological research, the obtained results indicate that in "Belovodica" mine, is exploited quality white dolomitic marble with excellent physical – mechanical characteristics. The main problem is the tectonic damage to the marble, mainly caused by a network of the cracks from the systems (NW - SE and NE - SW).

With analysis and interpretation of the research results, it is found that there is a belt of compact white dolomitic marble that remained immune to tectonic disruption. In this section reserves of 30000 m³ compact white dolomitic marble are located, 13 000 m³ of them are confirmed by geological research and 17 000 m³ are assumed.

The rest of the mine is tectonically damaged, sterile and unproductive in terms of getting marble blocks.

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