UDC 55 CODEN - GEOME 2

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SIVEC TYPE OF MARBLE
(MINERALOGICAL, WHITENESS AND PHYSICO-MECHANICAL FEATURES)

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A b s t r a c t: The marbles in Republic of Macedonia are widely spread, especially in the Pelagon metamorphic complex where two types of marble can be found – dolomite and calcite. The SIVEC type of marble is unique in its own characteristics which are result of the specific of mineral composition, the structural-texture properties, the physical-mechanical characteristics, color, chemical composition and esthetical features.

Key words: Sivec; marble; dolomite

INTRODUCTION

The marbles of the marble mass Sivec are part of the Precambrian Pelagonian marble series, which is preserved along the east peripheral part of the Pelagonian crystal mass. It enters into the tectonically segmented marble zone Belovodica-Pletvar-Kozjak-Sivec-Nebregovo. The digging of marble from the marble mass Sivec has a long history which is best documented with the numerous art and architectonic arts made by the marble of the marble mass Sivec (the large number of arts in Heraklea, Stibera, Stobi and other archeological localities in Macedonia). But, the more serious exploitation of the marble of the marble mass Sivec is linked to the period of formation of the "Marble Company" – Prilep (immediately after the WW2). So, it could be said that the organized mine production of marbles from the marble mass Sivec exists for the last 65 years, where the quantity of the dug blocks continuously increased, and today it is around 25 000 m^3. In this period, a number of geological and mine researches are financed by the 'Marble Company" (in 1969 complete systematic geological researches for the larger part of the marble mass Sivec are made by the Industroprojekt – Zagreb; then structural researches of the Sivec marbles, in the period from 1986 to 1995, are made by N. Dumurdžanov et al., 1994). Also, it should be mentioned that based on the extraordinary petrographic-mineralogy, physical-mechanical and esthetic characteristics, the marbles from the marble mass Sivec are used in the industry as architectonically decorative stone, and on a world level they are known under the name "SIVEC". Detailed mineralogy research of the marbles of the marble mass Sivec are made by Jovanovski, Boev and Makreski, 2013.

APPLIED METHODLOGY

For defining the detailed petrographic mineralogy characteristics of the marble of the type SIVEC, the following methodology of work is applied:

I.a) X-ray structural analyses

X-ray structural studies are made with the instrument of type D 500 Siemens with a complete computer software support, with Cu-mono-chromatic extraction in 40 KV and 30 mA, with appliance of automatic variable input diaphragm. The optimal balance line-phone is provided automatically by computer support PDP $11/23^+$.

The assignation of the phases in quantitative analyses is made by the program package Difrak 11 in the programs EVAL and IDR.

The quantitative balance is made according to the methods of Peterand Kalmanwith pre-determined coefficient of calibration (quantity of corundum) for some mineral phases.

Concoctions with angle orientation are made $2\theta = 3 - 60^{o}$.

I.b) Differential thermic analyses (DTA, TGA)

The differential thermic analyses are made on Derivato graph Q-1500-D with the following working conditions:

– weight of the sample – 500 mg;

– sensitivity according to TG – 200 mg;

– sensitivity according to DTA – 1/10 and DTG – 1/10;

– warming speed – 10 ^{o}C/min;

– temperature interval of the research 15 – 20 ^{o}C up to 1000 ^{o}C;

– inert supplement – Al_2O_3;

– environment in the stove – no turbulence air.

I.c) Chemical researches are made by application of the method ICP-MS.

I.d) Physical-mechanical characteristics are made according to ISO.

I.e) The determination of the level of whiteness is made on a sample dried on a temperature of 105^{o}C, insinuated on a colander of 0.071 mm and the whiteness is determined with the instrument "Carl ZeisYena".

GEOLOGICAL AND TECTONICAL FEATURES

The marbles of the marble mass "Sivec" are spread in NW-SW direction, with a length of 3 to 4 km and width of 0.5 to 1.5 km and general descent to NE with a descent of foliation of marbles from 25 to 40^{o}. To SW, with the layer zone, the gneisses-micaschists are separated from the Prilep anticline. To the NE over the marbles there lay members of the mixed series (gneisses, cipolines, micaschists) and here the contact is presented with an old, reverse layer, closed and masked with the Precambric metamorphic processes, whereas towards NW and SE it is tectonically sunk under the layers of the Pelagon neo-tectonic ravine (Fig. 1) (Arsovski et al., 1984).

From the regional tectonic survey, the marble mass of "Sivec" enters in the system of long and relatively narrow anticlinal and synclinal structures, with sinking axis towards SE and inversion of the structures towards SW, developed to SW in the space between the Mukos mountain to east and the Prilep anticline to west (Figs. 1 and 2).

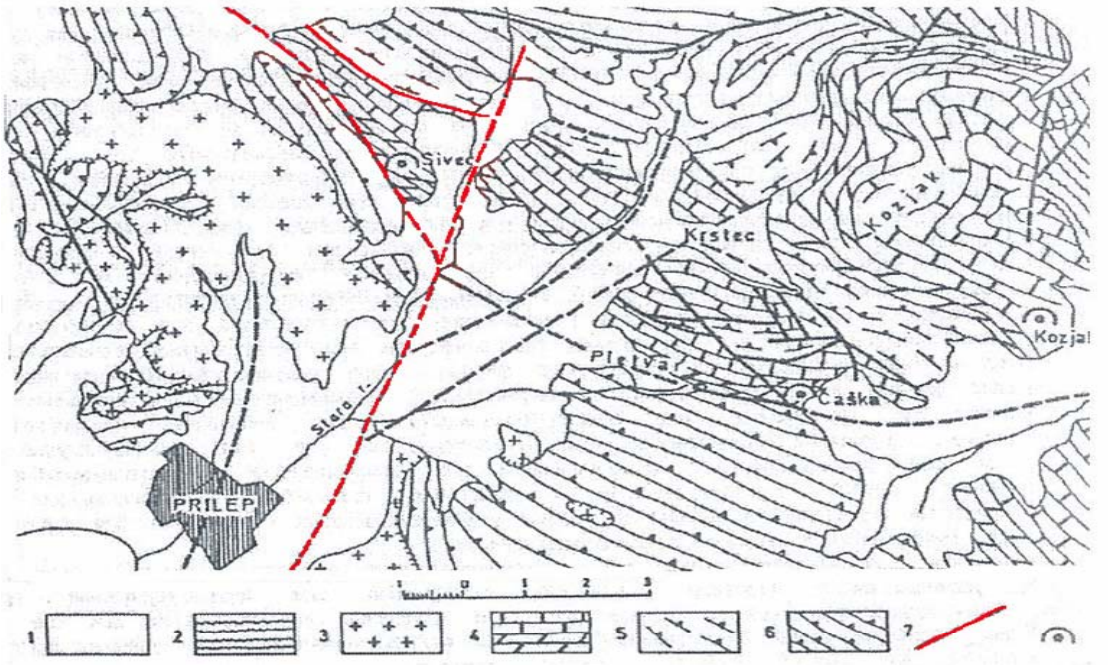


Fig. 1. Geotectonic location of the locality Sivec in the space of the marble mass Sivec–Pletvar–Kozjak
1 – Neogene and Quarter layers: 2 – Rifey cambric metamorphic complex (phyllitoides, metadiabases, amphibolic schists and marbles); 3 – Granites; 4 – Marble series; 5 – Mixed series (albitic gneisses, micaschists, marbles and cipolines); 6 – Gneisses-micaschistes series; 7 – Fault; 8) Surface dig of marble Sivec

In cross-section, from SW to NE, in the lower levels of the marble table "Sivec" there are developed homogenized, dolomitic, white with sugar structure, fine grain marbles, with a tendency to transition to middle grain in depth, the width of the zone is about 250–300 meters. This area in the work of the Marble Company in the direction of the development of the mine "Sivec" is partly revealed in the working lot No. 1 and 2, to a greater extent in the working lot number 5 and mostly in working lot number 6. This zone, towards NE incorrectly merges into partial strip gray-white dolomitic marble with jets, nests and tracks of calcite with locally stored foliation and traces of microlayers in higher parts of the series to the east the marbles of marble mass "Sivec" cross the strip calcite and calcite-dolomitic marbles (Dumurdžanov et al., 1994; Arsovski et al., 1977; Arsovski et al., 1984).

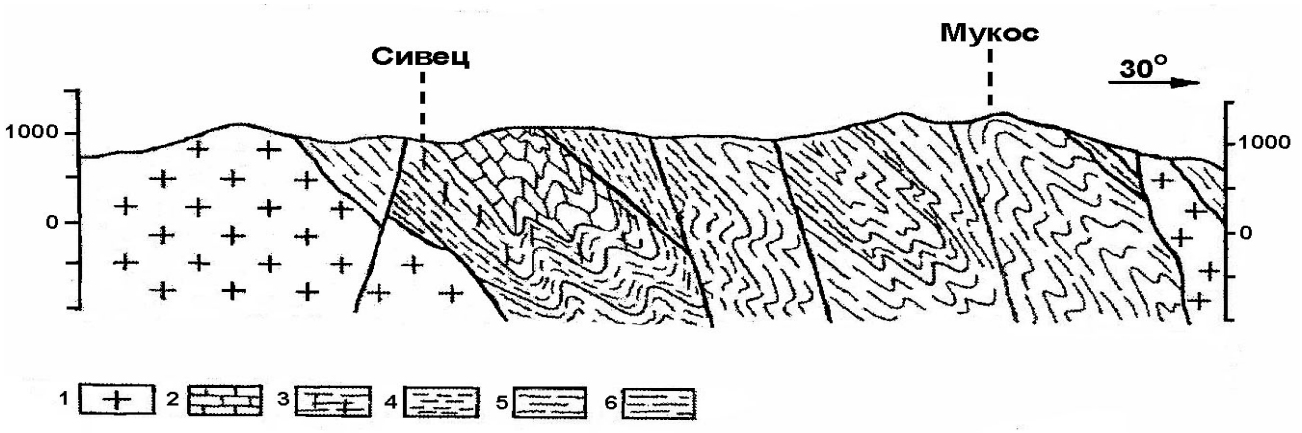


Fig. 2. Schematic geological profile of the space of the marble mass Sivec,
1. – Granites; 2. – Calcite marble; 3. – Dolomitic marble; 4. – Mixed series; 5. – Micaschists series; 6. – Gneisses series

General appearance of the marble mass "Sivec" is castification, which is predominantly expressed along the main rupture direction (NW–SE and NE–SW) and relative surface damage on the marble mass (somewhere more, somewhere less) as a consequence of processes of surface decomposition which is more intense fissure systems and the crushing. This neo-tectonic damage on the blockage of the marble mass "Sivec" in the western part of the mass reaches depth of up to about 4–5 meters (rarely more along the main rupture), while in direction NE and N, where the terrain morphology rises to 800 – 1200 m, the damage grows and reaches a thickness of several dozen meters. Such phenomena of surface decomposition of the marble mass is primarily due to the abrasive activity of the former Pliocene-Pleistocene Pelagon lake, which is most intense in the western part, where most of the old carstification is practically eroded (Stojanov, 1968).

The main damage of the blockage of the marble table in vertical and lateral direction is a consequence of rupture tectonics represented by faults and fissure systems (most of the major fault zones cut the marble mass).

Probably within the marble table there are remains of older tectonics, but the main rupture tectonics that adversely affects the blockage of the marble mass "Sivec" is young and is linked to the processes of formation of the ravine neo-tectonic Pelagon valley in Pliocene (newly established and reactivated old tectonics). Pelagonian ravine as its part is formed by gravitational faults from two directions, NW–SE and NE–SW, with elements of angling to N–S and E–W. The first system of faults with gravity fall towards the SW corner of the land of 60–800 is known as neo-tectonic fault along which there are registered lower seismic tremors, and this limits the marble mass of the southwestern side. The second very important structure limits the mass to the southeast along the river to the village of Prisad and Prilep Lake with the stretching direction NE-SW and it is subvertical to vertical descent.

The such expressed tectonics of this part of the Pelagon metamorphic complex very clearly tectonically defines the marble mass "Sivec" where the space is defined between the already mentioned main ruptures (Fig. 1).

PETROGRAPHIC-MINERALOGY FEATURES

Marbles from the marble mass "Sivec" have exceptional, unique petrographic, mineralogical characteristics in terms of their structure and present mineral association that is a consequence of the specific genesis of this section of marble Pelagon metamorphic complex. Marbles have extraordinary freestone grainy structure which merges to secondary structure transitions to mosaic, and in places there appears porfiroblastic structure (Fig. 3). In the crushed zones there appears catechistical structures and places and the appearance of milonitic structures. Dolomite grain size ranges from 0.1 to 0.5 mm. Dolomite grains are partly rounded and they have expressed crushing. The places have elliptical cross sections and poorly elongated in the direction of crushing. The dolomite grains rarely have an irregular polygonal shape. Despite the dolomite grains there are also calcite grains as well as unique variety of exotic minerals (corundum, fluorite, paragonite, fengite, titanite, rutile, epidotic minerals, chlorite, cosmatite, quartz, calcite, phlogopite, diaspore, almandine, etc.). The mineralogy of marbles from Sivec is very well represented in the monograph Minerals from Macedonia (Jovanovski, Boev, Makreski, 2013), as well as works of Erdmannsdorffer (1925), Barić (1960, 1969), Stojanov (1968, 1977), Jersek et al. (1999). This specific mineral association is a result only in the space of the marble mass "Sivec", the granite rocks are in the closest contact with the marbles from the marble mass in Pelagonia and only here the metamorphic transformations are highlighted.

Based on the detailed mineralogy research with application of the methods of x-ray diffraction (Fig. 4 a, b, c, d, e, f), as well as the research with application of DTA, TGA analyses (Fig. 5a. b. c. d. e. f), the following characteristics of the marble of type SIVEC could be defined (Table 1).

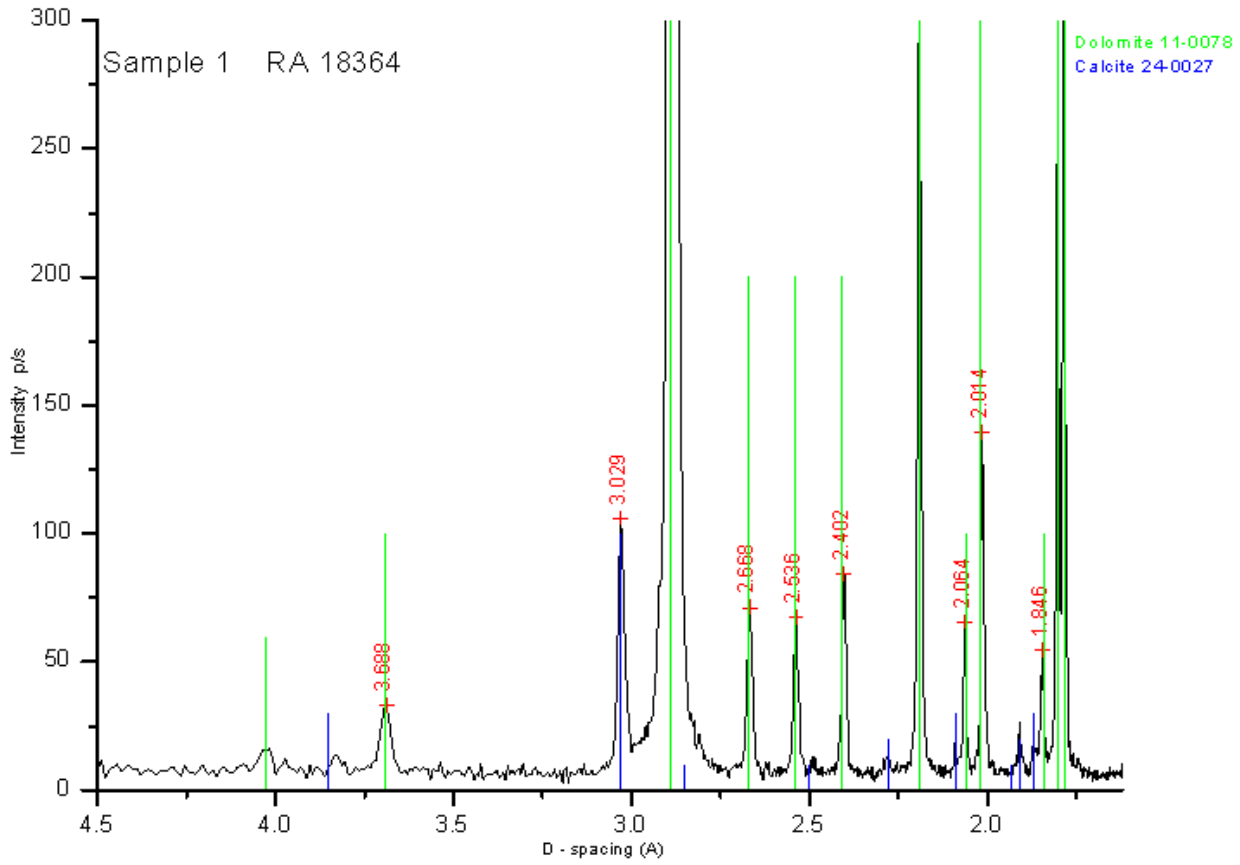
T a b l e 1

Mineralogy characteristics of the marble of type SIVEC

Present minerals	Presence in percentage (%)
Dolomite	95.88 – 99.02
Calcite	0.47 – 3.92
Quartz	0.34 – 1.44
Accessory minerals	Corundum, fluorite, paragon, fengite, titanite, rutile, epidote, chlorite, phlogopite, diaspore, almandine, zoisite
Whiteness	Higher than 89.6

a) **b)** **c)**

Fig. 3. Variations of the color in the marble of SIVEC type


Sample 1 RA 18364
Dolomite 11-0078
Calcite 24-0027
Intensity p/s
D - spacing (A)
3.698
3.029
2.668
2.536
2.402
2.064
2.014
1.846

Fig, 4-a.

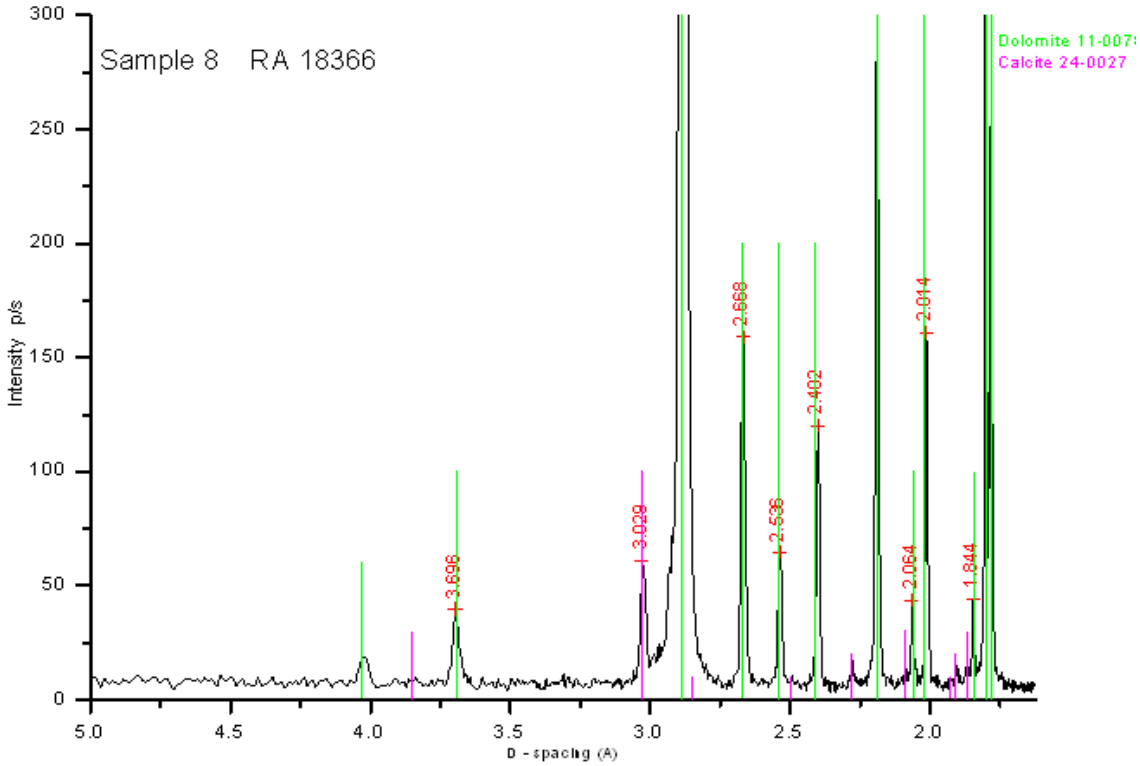
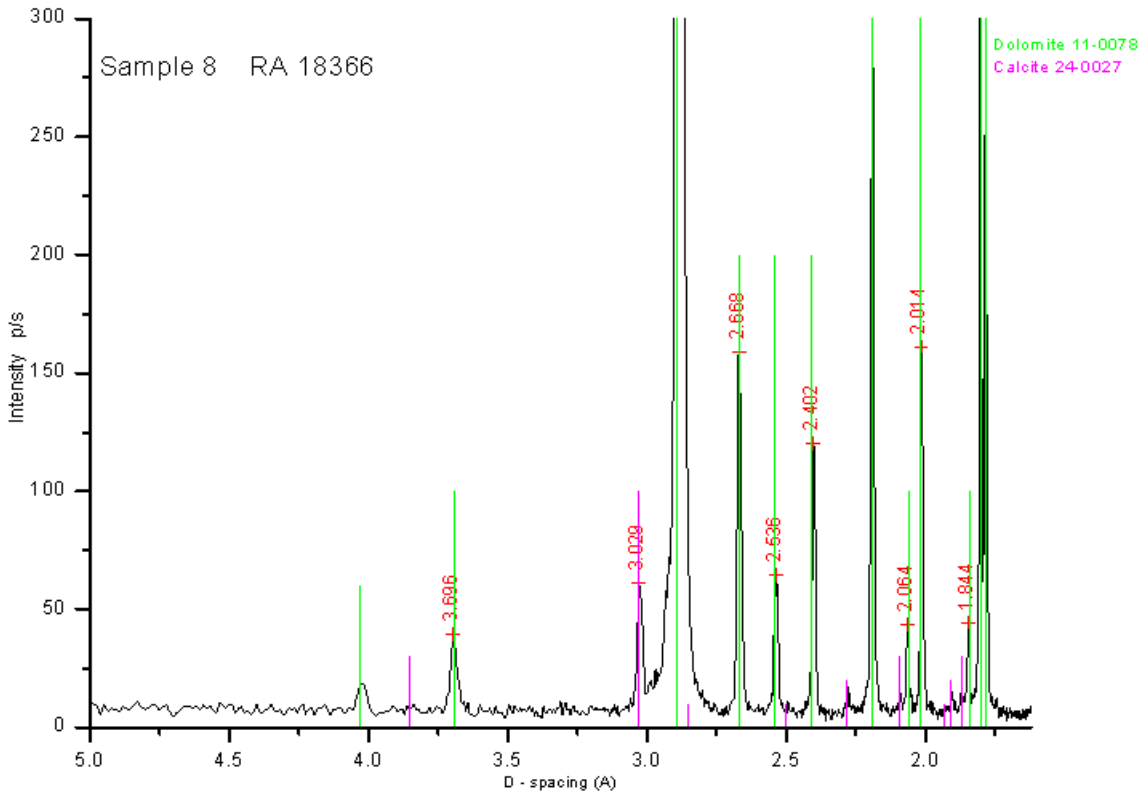

Sample 8 RA 18366
Dolomite 11-007
Calcite 24-0027
Intensity p/s
D - spacing (A)
3.696
3.029
2.668
2.536
2.402
2.064
2.014
1.844

Fig. 4-b.


Sample 8 RA 18366
Dolomite 11-0078
Calcite 24-0027
Intensity p/s
D - spacing (A)
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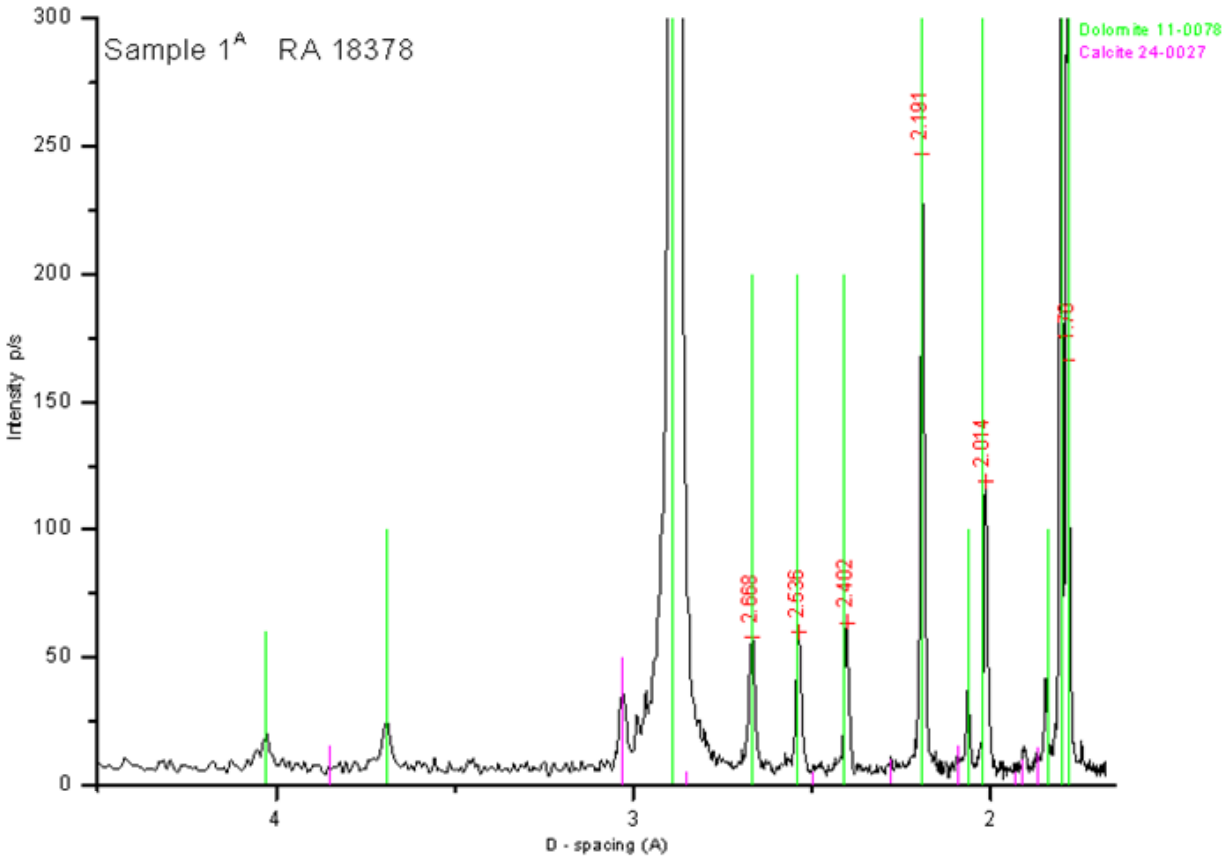
3.029
2.669
2.536
2.402
2.014
2.064
1.844

Fig. 4-c.


Sample 1A RA 18378
Dolomite 11-0078
Calcite 24-0027
Intensity p/s
D - spacing (A)
2.191
2.669
2.536
2.402
2.014

Fig, 4-d.

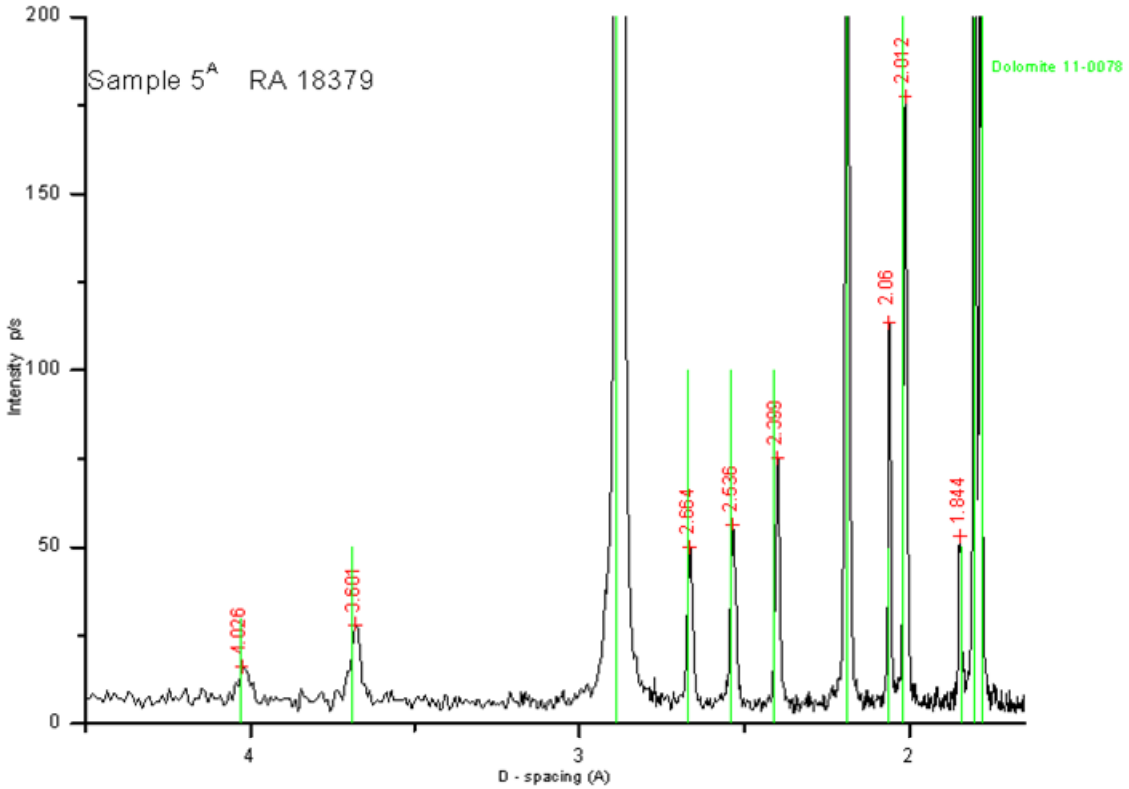


Fig. 4-e.

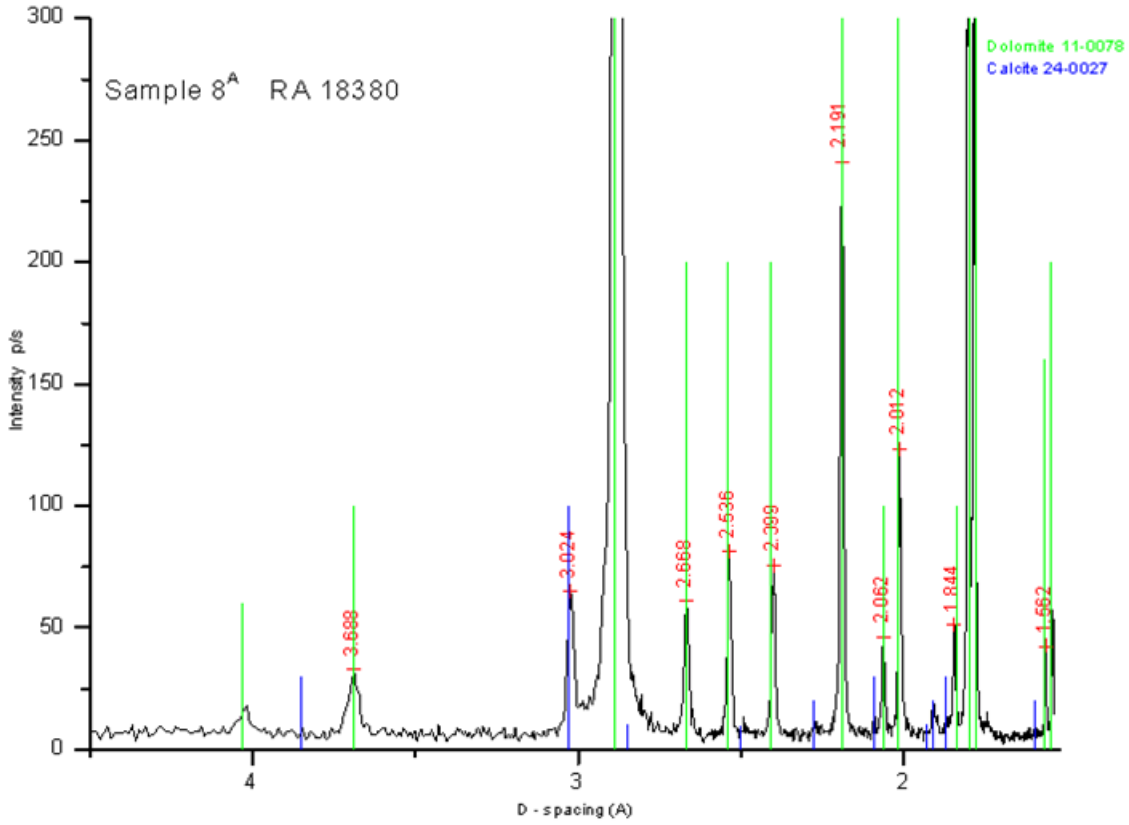


Fig. 4-f.

Fig. 4-a, b, c, d, e, f: XRD diagrams of the marble of SIVEC type

Fig. 5-a.

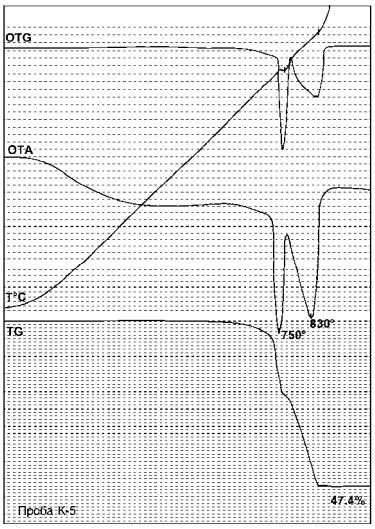


Fig. 5-b.

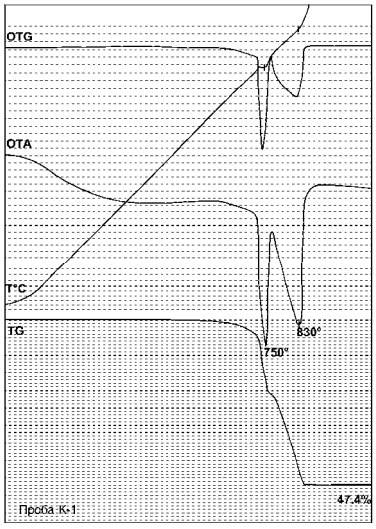


Fig. 5-c.

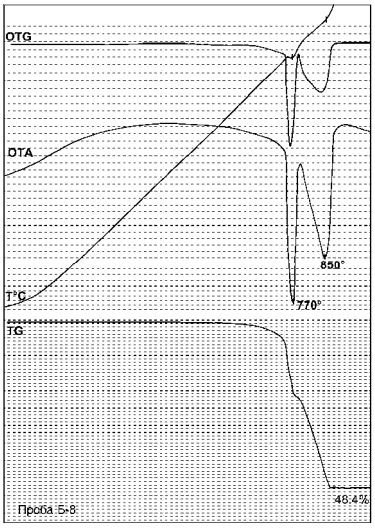


Fig. 5-d.

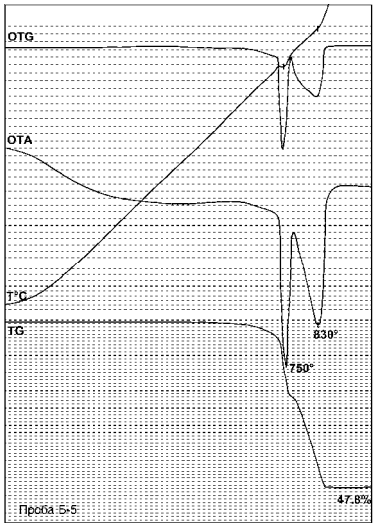


Fig. 5-e.

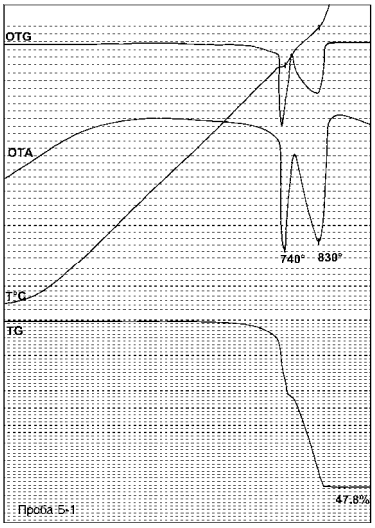


Fig. 5-f.

Fig. 5-a, b, c, d, e, f: DTA, TGA diagrams of the marble of SIVEC type

Chemical characteristics

The presence of the main elements and elements in traces in the marble of the type SIVEC is presented in the Table 2.

T a b l e 2

Chemical and geochemical characteristics of the marble of type Sivec (%)

Component	Probe?	
SiO_2	0.01	0.03
TiO_2	–	0.02
Al_2O_3	0.02	0.03
Fe_2O_3	0.01	0.01
FeO	0.01	0.02
MnO	0.01	0.01
MgO	21.18	19.82
CaO	31.58	31.71
Na_2O	0.03	0.05
K_2O	0.02	0.01
LOI (loose of ignition)	48.11	48.02
Ppm	21	17
Pb	33	21
Zn	5	7
As	2	3
Cd	11	15
Ni	14	16
Co	15	19
Cr	21	25
Cu	5	8

Physical-mechanical characteristics

The marbles of the marble mass Sivec have the following physical-mechanical charactersitics:

Hardness under pressure in dry condition:

P_{max} = 164.40 MPa

P_{min} = 153.40 MPa

P_{sr} = 162.10 MPa

Hardness under preassure in water-saturated condition:

P_{max} = 169.80 MPa

P_{min} = 132.45 MPa

P_{sr} = 146.40 MPa

Hardness under pressure after frizzing and defrizzing from 25 cycles:

P_{max} = 156.6 MPa

P_{min} = 117.5 MPa

P_{sr} = 139.5 Mpa

Water absorbtion:

σ = 0.106%

Volumen of mass:

γ = 2825 kg/m^3

Persistence of attrition with grate:

A = 33.5 cm^3/50 cm^2

CONCLUSION

Based on the tectonic features of the unique marble mass “Sivec”: the following could be said:

The marble mass “Sivec” is limited in space and tectonically and in its largest part it is around the mine Sivec which is part of the Marble Company – Prilep.

– The marble mass is segmented on larger blocks with shattered zones along the main zones and hole systems, which enter deep into the mass, and most of them cut the entire mass.

– Such block tectonic provides relatively larger compact cores of white sugar marbles of the type Sivec, therefore exploitation of commercial blocks with quality of the type SIVEC with annual capacity of 25 000 m^3 is possible within the marble mass SIVEC, but based on the so far knowledges of the marble masses of the Pelagon metamorphic complex, tectonic, petrographic-mineralogy compound, esthetic features, genesis it could be concluded that in the other zones (Bela Pola, Lekovo, Krstec, Pletvar, Belovodica, Veprčani, Melnica, Bešište) it is not possible.

– The mineralogical composition and the present litostratigraphy of the marble mass “Sivec” are partly result of the primary conditions of genesis, but in its largest, these characteristics are linked to the influence of the metamorphic processes, most of all the influence of Pre-Cambric Pelagon granite intrusions over the marbles in terms of their homogenizes, whiteness and dolomitization in particular in the lower levels of mass. The influence of the granites which are here extremely close to the marble mass is manifested with a larger presence of corundum, fluorite, paragonite, fengite, titanite, rutile, epidotic minerals, chlorite,

cosmatite, quartz, calcite, phlogopite, diaspore, almandine, and others. It can be said that the mine Sivec is a unique finding of white sugar marbles, but also, it is only finding of corundum (rubine) in the Republic of Macedonia.

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Р е з и м е

СИВЕЦ – ТИП НА МЕРМЕР
(МИНЕРАЛОГИЈА, БЕЛИНА И ФИЗИЧКО-МЕХАНИЧКИ КАРАКТЕРИСТИКИ)

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Клучни зборови: сивец; мермери; доломит

На основа на тектонските посебности на уникатната мермерна маса, за „сивец"може да се каже следното:

– Мермерната маса „сивец" е ограничена просторно и тектонски и во најголем дел се наоѓа во просторот кој го зафаќа рудникот Сивец кој е во склоп на Мермерниот комбинат – Прилеп.

– Мермерната маса е сегментирана на поголем број блокови со појава на раздробени зони надолж главните раседни зони и пукнатински системи, кои навлегуваат длабоко во масата и повеќето од нив ја сечат и целата маса.

– Ваквата блоковска тектоника овозможува појава на релативно големи компактни јадра на бели сахароидни мермери од типот СИВЕЦ и затоа во мермерната маса е возможна експлоатација на комерцијални блокови со годишен капацитет од околу 25.000 m^3, но врз основа на досегашните познавања на другите зони од мермерната маса на пелагонскиот метаморфен комплекс, тектониката, петрографско-минералошкиот состав, естетските посебности, генезата, може да се заклучи дека во другите зони (Бела Пола, Лековo, Крстец, Плетвар, Беловодица, Вепрчани, Мелница, Бешиште) тоа не е можно.

Минералошкиот состав и присутната литостратиграфија на мермерната маса „сивец" делумно се реазултат на примарните услови на генеза, меѓутоа во голем дел овие карактеристики се поврзани со влијанието на метаморфните процеси, а пред сè со влијанието на прекамбриските пелагониски гранитоидни интрузии врз мермерите во поглед на нивната хомогенизација, избелување и доломитизација, особено истакнати во подолните нивоа на масата. Влијанието на гранитоидите кои овде се внедрени најблиску до мермерната маса се манифестира и со поголема појава на корунд, флуорит, парагонит, фенгит, титанит, рутил, епидотски минерали, хлорит, косматит, кварц, калцит, флогопит, дијаспор, алмандин и др. Може да се каже дека рудникот Сивец покрај тоа што претставува уникатно, во светски рамки, наоѓалиште на бели сахароидни мермери, тој истовремено претставува и единствено наоѓалиште на корунд (рубин) во Република Македонија.