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Metamorphic dolomitic marble-hosted talc from the Mulvoj area in the Western Pamir Mountains, Tajikistan

Mohssen Moazzen[1,*], Intizor Silmonov[1], Sangin Elnazarov[2]

[1]Department of Earth and Environmental Sciences, University of Central Asia, Khorog, 736000, Tajikistan
[2]Department of Geology, Khorog State University, 109 Shoteymur street, Khorog, 736000, Tajikistan

*Corresponding author: mohssen.moazzen@ucentralasia.org

Abstract

Talc is crystallized in the metamorphic dolomitic rocks of the southwest Pamir mountains in the Mulvoj area, Tajikistan. Field studies show that talc is restricted to metamorphic dolomitic marble layers in the garnet-mica schist and gneiss. The layers are parallel to the original sedimentary bedding and schistosity of the metamorphic rocks. Petrography and whole rock geochemistry reveal calcite, tremolite, quartz and dolomite as the main mineral phases in the talc-bearing metamorphosed dolomitic rocks, while calcite is absent in the samples without talc. XRD studies show that talc samples are almost pure, and geochemistry indicates very low Fe and Cr and very high Mg contents. Geochemical features along with field observations clearly shows that Mulvoj talc is not originated from peridotite. Based on phase relations studies in the CaO-MgO-SiO_2-H_2O-CO_2 system, the reaction between dolomite, quartz, and water at pressure greater than 2 kbar and temperature up to ~460°C and X_{CO2} up to 0.6 was the main talc forming reaction. Talc and calcite consuming reaction produced tremolite, dolomite and binary (CO_2-H_2O) fluid.

Keywords: Talc, meta-dolomite, mineral reactions, Pamir, Tajikistan

1. Introduction

Talc [$Mg_3Si_4O_{10}(OH)_2$] is a hydrous magnesium silicate with industrial, medical and cosmetic applications (Vitra 1998; Borowski et al. 2015). It can form by different mineralogical reactions in ultramafic, mafic and dolomitic metasedimentary rocks. On this basis, talc deposits can be classified into the serpentinite-hosted and carbonate-hosted deposits (Tosca et al. 2011; Ali-Bik et al. 2012). Talc forms from serpentine minerals in the hydrothermally altered ultramafic and mafic rocks. Serpentine changes to talc by influx of CO_2-bearing hydrothermal fluids (Liu 1986; Muraishi 1988). Talc can form at the margins of a serpentinite body in contact with the country rocks (Gil et al. 2022). Dolomitic marble reacted with quartz and water-rich or Si-rich fluids, produces talc (Pieczka et al. 1998; Wilamowski, Wiewiora 2004; Saccocia et al. 2009; Woguia et al. 2021). Apart from the industrial importance, study of talc-bearing rocks can provide insights on the nature of high-pressure and low-temperature metamorphism and possible fluid recycling within the mantle by talc-bearing assemblages subduction (Zhang et al. 1995). Spandler et al. (2008) studied the talc-bearing blueschists and eclogites from New Caledonia and concluded that they subducted to depths of up to 70 km with potential to transport significant amounts of H_2O to greater depths than serpentinite. Schreyer and Abraham (1975) studied high pressure assemblages of kyanite-gedrite and kyanite-talc from the Sar e Sang area of Afghanistan and talc formation in these rocks.

Abraham and Schreyer (1976) attributed the talc and phengite rocks in Piemontite Schist from Serbia to formation under very high-water pressures.

Talc is significant in geological studies also for its role in weakening the crust in regional-scale fault systems. Interconnected films of talc require small volume fractions to attain the frictional weakness in the fault zones (Moore, Rymer 2007). Collettini et al. (2008) reported talc plus serpentinites, tremolite and chlorite in the high strain regions of a fault core, which can weaken the fault zone and facilitate creeping. Talc can also be associated with mineralization. A good example is the Rędziny deposit in Sudetes, Poland which comprises a weathered polymetallic mineralization in dolomitic marbles, where talc is formed along with Ca-Fe arsenate, arsenopyrite and quartz (Pieczka et al. 1998) Talc occurs in SW Pamir Mountains of Tajikistan. Talc is formed in the ultra-magnesian rocks in this area along with kyanite, magnesio-hornblende, tourmaline and rare quartz. Grew et al. (1994, 1998) reported kornerupine-bearing rocks from three localities in SW Pamir Mountains in Kuhi-lal, Darai-Stazh and Mulvoj. Kornerupine occurs with all these minerals (Grew et al. 1998). They propose a prograde metamorphism at 650°C and 7 kbar for the formation of assemblages containing the most mineral phases (Grew et al. 1998). Considerable amount of talc mineralization in dolomitic layers in gneissic rocks in the Mulvoj area produced economically valuable deposits, similar to those in the Nangahar province of Afghanistan (Tahir et al. 2018). The main minerals in the Mulvoj talc mine are dolomite, quartz, calcite and tremolite. Field relations, petrography and geochemistry of these rocks are studied here to provide new data on protolith and CO_2 mole fraction and temperature conditions of formation of talc.

2. Geological Setting

Pamir Mountains are part of the Alpine-Himalayan orogen, located at convergence of Tien Shan, Karakoram, and Hindu Kush (Ruzhentsev, Shvolman 1981; Hubbard et al. 1999). Middle to Late Eocene metamorphism in the Pamir brought about by crustal thickening and pressure and temperature increase associated with the India–Eurasia collision (Fraser et al., 2001). Based on stratigraphical, lithological, and structural features, Pamir is divided into Northern Pamir, Central Pamir and Southern Pamir in Tajikistan (Burtman, Molnar 1993). The northern Pamir, which records a Pre to Late Carboniferous ocean basin, separates the Central Pamir from northern Eurasian lands by Palaeozoic sutures (Hildner 2003). The Kunlun arc and related arc magmatism (Jiang et al. 2008) indicate the subduction and following collision sutures (Fig. 1). The Central Pamir (Fig. 1) mainly consists of metamorphosed and deformed Precambrian and Palaeozoic rocks. It shares many similarities with Western Hindu Kush and represents more likely a continental fragment which collided with Eurasia in Permian following the closure of the Carboniferous oceanic basin (Rembe et al. 2021). Southern Pamir is separated from the Central Pamir by Rushan-Pshart Mesozoic suture (Fig. 1), which is characterized by Permian to Triassic marine sediments and ophiolitic rocks composed of pillow basalt, chert, andesite and serpentinized peridotite lenses (Zanchetta et al. 2018). The Southern

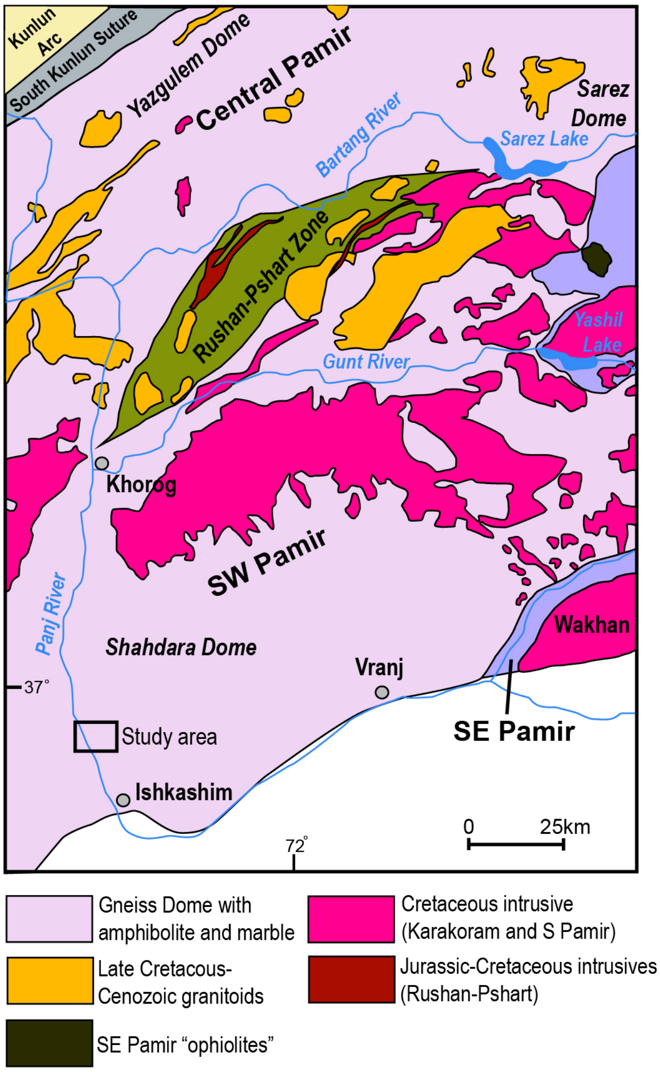

Figure 1. Geological Map of the Southwestern Pamirs (modified from Vlasov et al. 1991, Schwab et al. 2004 and Angiolini et al. 2013). The study area is indicated by a box.

Pamir is divided into South-eastern Pamir and the South-western Pamir. South-eastern Pamir consists of a Late Carboniferous to Early Permian sedimentary sequence made up by siltstone, clay. Sandstone, and limestone, covered by Triassic limestone, radiolarite and siltstone, and eventually by unconformable Jurassic limestone (Kukhtikov, Vinnichenko 2010). South Pamir experienced metamorphism at 750-800°C at a depth of ~55 km (Hacker et al. 2017). The South-western Pamir is similar to the Central Pamir in terms of rock types and deformation and metamorphism (Pashkov, Budanov 1990). The main rock types are metamorphosed rocks, intruded by several Mesozoic and Paleogene granitoids (Fig. 1). Drugova et al. (1976) and Kiselyov and Budanov (1986) propose an early granulite facies metamorphism for the South-western Pamir at 750°C temperature and 9.7 Kbar pressure, followed by a lower grade metamorphism at 600 to 650°C temperature and 3.5 to 5.5 kbar pressure. Grew et al. (1994) also suggest two stages of metamorphism in the South-western Pamir. The first phase was a moderate-pressure amphibolite facies at 650°C and ~7 kbar, followed by a decompression metamorphism at 5 kbar and slightly higher temperature of 650-700°C. Pamir peak metamorphism occurred during the Late Oligocene to Early Miocene (Searle et al.

2010). Peak metamorphism was followed by exhumation of a series of extensional gneiss domes in the Southern and Central Pamir terranes, that lasted until the Late Miocene to Early Pliocene (Stübner et al. 2013). Included among these gneiss domes are the Shahdara dome in the South-western Pamir terrane and the Yazgulem and Sarez domes in the Central Pamir terrane (Fig. 1). The largest area of Cenozoic mid to lower-crustal rocks in the Pamir are exposed in the Shahdara dome (Stearns et al. 2015), which is dominated by orthogneiss and granitoids (Schwab et al. 2004) and biotite and muscovite-rich schists.

The Mulvoj area mainly consists of foliated and folded high-grade gneiss and schist, with intercalations of dolomitic marble layers (Fig. 2), ranging from about 10 cm to few ten meters in thickness (Fig. 3A,B). The main minerals in gneiss are quartz, plagioclase, garnet, biotite, kyanite and sillimanite. It shows distinct gneissosity and occasional folding (Fig. 3C). The rocks are mainly fresh with minimum alteration effects and pale in colour in the field exposures. The schistosity in the pelitic schist is materialized by abundant oriented biotite flakes. Other minerals are quartz, occasionally sillimanite and rare plagioclase and opaque minerals. The lack of muscovite and chlorite in the schists supports their high-grade nature. Dolomitic marble is pale yellow in colour and appears as distinct layers. Marbles of the Mulvoj area contain relatively large amphibole (tremolite) crystals (Fig. 3D), which are aligned parallel in dolomitic marbles, indicating lineation in the rock due to deviatoric stress during their formation. Some patches of almost pure calcite can be found in the field. These calcite patches appear as well-crystallized calcites with rhombohedral structure (Fig. 3E). Talc appears as pure mineral in the field and it is along with calcite in considerable amounts (Fig. 3F) Mining to extract talc was active during the Soviet time in the Mulvoj area. The mine is at an elevation of ~800 m from the village level in a rough topography. Metal pillars and wires were used to carry talc ore from the mine site to the village. Figures 3G and H show some remaining mining structures in the area.

3. Samples and analytical methods

More than 30 samples of the talc and associated rocks were collected during two fieldworks in the Mulvoj area of the Ishkashim district in SW Pamir, during spring and autumn 2021. 15 thin sections were made from the selected samples for petrography studies. Whole rock major elements were analysed in 5 talc samples and one dolomitic marble, using X-ray fluorescence (XRF) method. The samples were crushed to less than 5mm in a steel jaw crusher and then were pulverized in a disc mill equipped with a tungsten carbide milling cup to <60µm. 0.5 g of powdered rock sample was mixed with Lithium-tetraborate ($Li_2B_4O_7$) to make glass

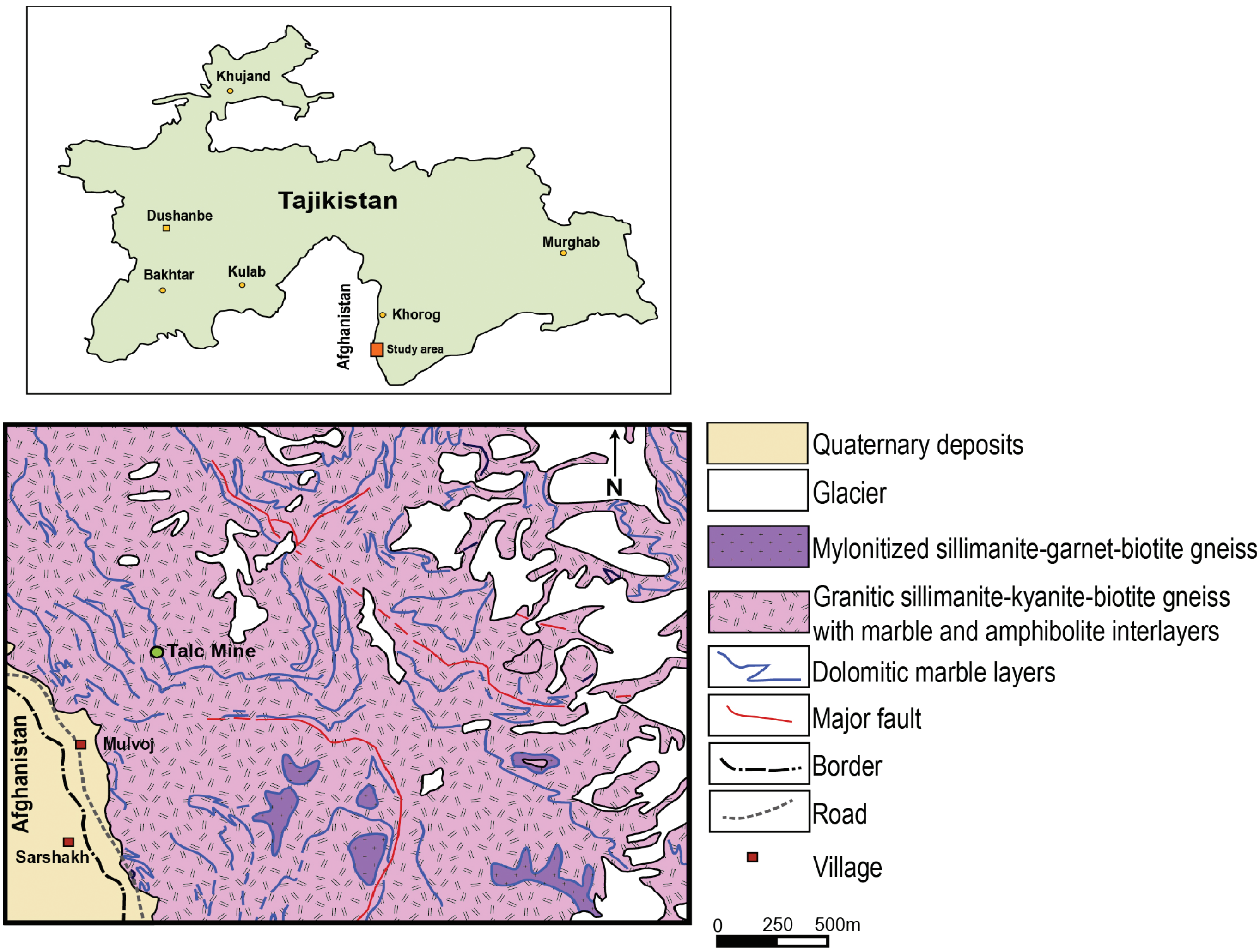

Figure 2. Simplified geological map of the Mulvoj area in the Ishkashim district of Tajikistan (Based on Vlasov et al. 1991).

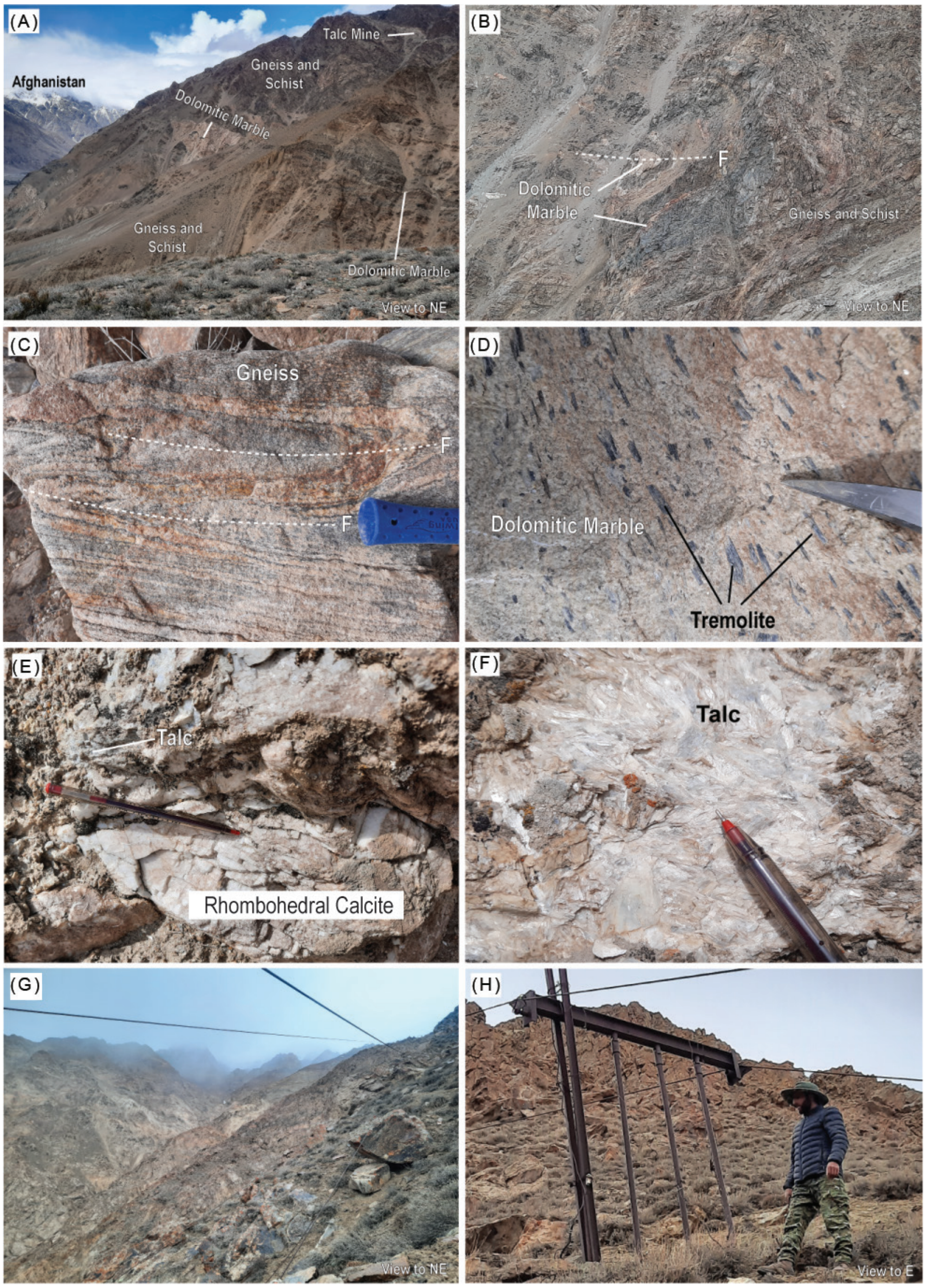

Figure 3. Field photos from the metamorphic rocks in the Mulvoj area. (A) Dolomitic marbles within the gneiss and schist. (B) Large open fold in the metamorphic rocks. (C) Tight folds in gneiss. (D) Tremolite along with carbonate in the dolomitic marble. (E) Rhombohedral pure calcite. (F) Talc in the Mulvoj mine site. (G) and (H) Remaining of old mining metal zip-lines and pillars.

beads. The beads were used for XRF analyses. Then they were dissolved using microwave-assisted multi-acid digestion in a mixture of pure nitric, hydrofluoric, and hydrochloric acids. The solution was used to analyse trace elements after required dilution using a Perkin Elmer SCIEX ELAN 6000 inductively coupled plasma mass spectrometer. International and internal standards were used for the calibrations. The results for major, minor and trace elements are shown in Tables 1 and 2, along with the detection limit for each method and element. One sample of talc deposit from the study area was analysed by X-ray diffraction (XRD, Phililps PW1730) diffractometer to find out the mineral composition. The powdered pellet of sample was pressed using a hydraulic press. CuKα 0.15418 nm radiation was generated using the Phillips PW1730 X-ray generator operated at 40kV and 30mA. Sample preparation and analyses were carried out in the Earth and Environmental Sciences laboratory of University of Central Asia in Khorog, Tajikistan and Zarazma Laboratories in Iran.

4. Results

4.1. Petrography

Mulvoj dolomitic marbles have a simple mineralogy and are made from dolomite (Dol) as the main mineral phase. Dolomite shows equigranular and mosaic texture (Fig. 4A), consistent with crystallization at temperature

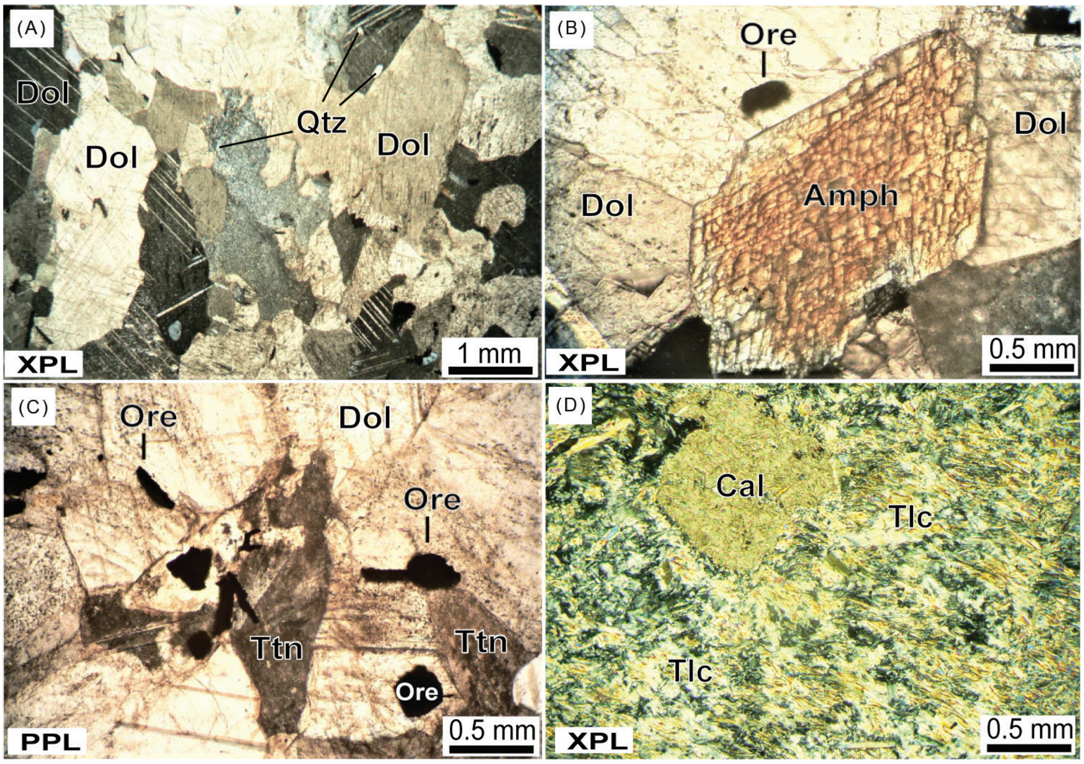

Figure 4. Microscopic photos from different rock types in the Mulvoj area. (A) Dolomite with minor quartz. (B) dolomite, opaque minerals and idioblastic amphibole (tremolite) in a metamorphic dolostone. (C) Relatively large titanite in textural equilibrium with dolomite. (D) Talc sample with minor calcite.

of ~500°C (e.g. Covey-Crump, Rutter 1989) during metamorphism. It is characterized by its cleavage and twinning planes under the microscope (Fig. 4A). Other mineral phases in the rocks are amphibole (Amph), rare quartz (Qtz), opaque minerals (Ore) and titanite (Ttn). Amphibole is the second abundant mineral in the studied marble samples. It ranges from 1mm to 5mm in size (Fig. 4B) and is colourless in the plain polarized light, indicating high Mg and low Fe content. This classifies amphibole in the Mulvoj marble as tremolite (Tr). Quartz appears as minor phase in the samples (Fig. 4A). Titanite (sphene) appears as wedge-shaped tiny crystals (~0.2mm across) to relatively large (1.5 mm across) grains in the rocks (Fig. 4C). It formed in textural equilibrium with other minerals in the rocks, since is well-crystalized and is in mutual contact with other minerals. Opaque minerals are more likely Fe-Ti oxides. Talc (Tlc) appears along with rare amount of calcite (Fig. 4D). Microscopic studies on eight samples of the Mulvoj area (from different outcrops and layers in one outcrop) shows that dolomite appears along with quartz in some samples with occasional occurrence of tremolite. Talc is accompanied by either calcite or calcite and quartz in the studied rocks. No equilibrium assemblages containing both calcite and dolomite was observed in the studied samples. Based on these observations, the main mineral assemblages in eight studies samples of the dolomitic marble can be classified as follows.

Dol+Tr±Qtz [1]

Tlc+Cal [2]

Tlc+Qtz+Cal [3]

4.2. Mineralogy and geochemistry

One sample of talc from the study area was analysed by XRD method to find out the mineral composition. XRD graph with mineral phase peaks is shown in Figure 5A. As shown in the graph, talc is the main mineral in the studied sample.

Chemical composition of five samples from Mulvoj talc along with one dolomitic marble are provided in Tables 1 and 2. As it can be seen in Table 1, the SiO_2 content for the talc samples ranges from 59.73 to 61.07 wt%, while the SiO_2 content for the marble sample is 3.21 wt% (Table 1). The MgO contents for talc samples range from 31.98 to 33.21 wt% and Fe_2O_3 content (as whole Fe in the samples) has very low amounts of 0.59 to 0.75 wt%. The contents of CaO, TiO_2, Al_2O_3, Fe_2O_3, MnO, Na_2O, K_2O and P_2O_5 are low and range from <0.5 to 1.35 wt%. The CaO and MgO contents for the marble sample is 29.07 and 20.76 wt% respectively, characterizing it as dolomitic rock. Whole-rock trace element concentrations are given in Table 2. Most of the trace elements have similar concentration for all three analysed samples. The Ce and La contents in all samples are equal to 1 ppm, while the Y, Be, Cr, Zn and Zr contents are below the detection limit of the method used.

5. Discussion

5.1. Mineralogy

XRD analyses indicate almost pure talc for the samples from the Mulvoj mine (Fig. 5A). Commonly chlorite can be found along with talc in dolomite-hosted talc deposits

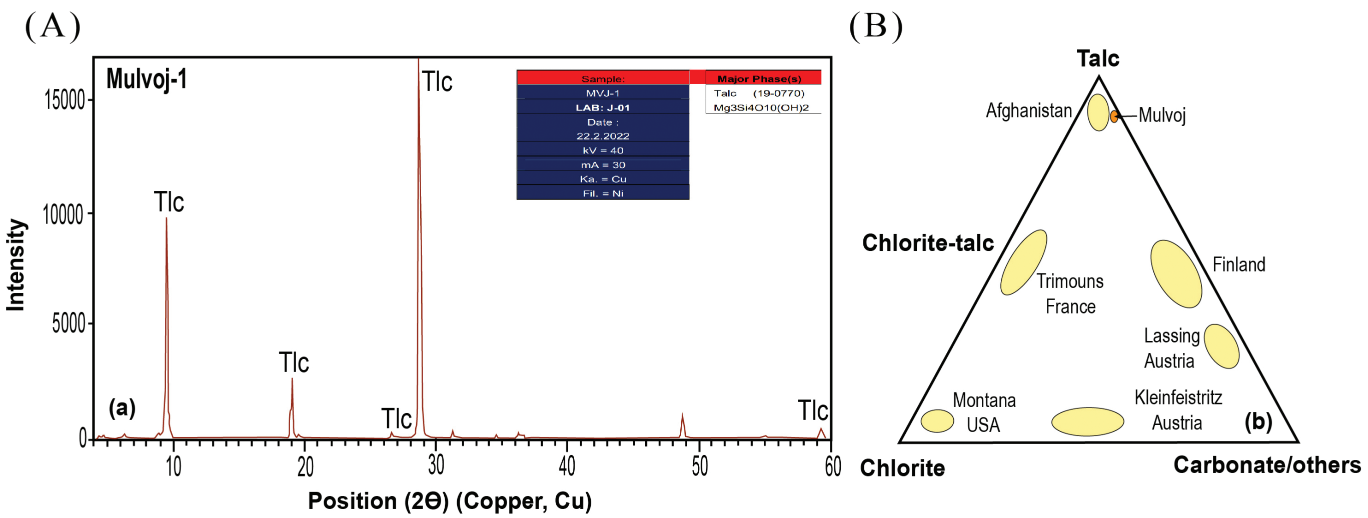

Figure 5. (A) XRD pattern for the studied talc sample. The vertical axis shows the intensity of peaks (proportional to the amount of the mineral phase in the studied sample) and the horizontal axis shows the 2Θ angle of the X-ray diffraction, which is indicative of the mineral phase. The sample is composed almost entirely from talc. (b) Classification of Mulvoj talc based on chlorite and carbonate content. Some talc occurrences are shown for comparison (Afghanistan from Tahir et al. 2018; Trimouns, France from Boutin et al. 2016; Montana, USA from Anderson et al., 1990; Austria, from Prochaska, 1989, Finland from GTK. www.gtk.fi).

Table 1. Major oxides of the studied samples by XRF (wt%).

Sample No.	Detection	MVJ1	MVJ2	MVJ3	MVJ4	MVJ5	MVJ6
Rock type	Limit (wt %)	Talc	Talc	Talc	Talc	Talc	Marble
SiO_2	0.05	60.76	61.07	60.41	59.73	60.12	3.21
TiO_2	0.05	0.08	0.08	0.07	0.07	0.08	<0.05
Al_2O_3	0.05	1.35	1.26	1.14	1.14	1.18	1.28
BaO	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
CaO	0.05	0.19	0.12	0.14	0.19	0.18	29.07
Fe_2O_{3*}	0.05	0.64	0.71	0.75	0.61	0.59	0.62
K_2O	0.05	0.31	0.32	0.30	0.29	0.31	<0.05
MgO	0.05	32.29	33.21	31.98	32.55	32.64	20.76
MnO	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.17
Na_2O	0.05	0.27	0.22	0.30	0.27	0.29	0.19
P_2O_5	0.05	<0.05	<0.05	0.06	<0.05	<0.05	0.09
SO_3	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Total	-	95.89	96.99	95.15	94.85	95.39	55.39

*all Fe as Fe_2O_3.

Table 2. Trace and rare earth element (REE) composition of the analysed talc samples by ICP-MS; all in ppm.

Sample	DL*	MVJ1	MVJ2	MVJ3	Sample	DL	MVJ1	MVJ2	MVJ3
Ag	0.5	<0.5	<0.5	<0.5	Pb	1	4	4	4
As	5	1.5	1.5	1.4	Sb	5	0.88	0.79	0.86
Be	1	<1	<1	<1	Sc	0.5	0.8	0.8	0.7
Cd	0.1	0.35	0.34	0.35	Sr	2	6	6	6
Ce	1	1	1	1	Th	5	<5	<5	<5
Co	1	1	<1	1	U	5	<5	<5	<5
Cr	1	<1	<1	<1	V	1	12	12	11
Cu	1	3	2	2	Y	0.5	<0.5	<0.5	<0.5
La	1	1	1	1	Yb	0.2	0.2	0.2	0.2
Li	1	16	17	16	Zn	1	<1	<1	<1
Mo	0.5	0.55	0.53	0.55	Zr	5	<5	<5	<5
Ni	1	11	9	9					

*DL = Detection limit, ppm

(e.g., Moine et al. 1989; Schärer et al. 1999) and can form intergrowth with talc (Veblen 1983). No chlorite was found under the microscope or in the XRD studies in the Mulvoj talc samples. The lack of chlorite in our samples can be attributed to the low Al_2O_3 (1.28 wt%) content in the protolith marble. Figure 5B illustrates the mineralogical composition of the studied samples in the ternary diagram of talc-chlorite and carbonate/other minerals. Some talc deposits of the world are shown for comparison. Mulvoj talc is almost pure with low carbonate content and is similar to talc deposits from Afghanistan in this regard (Tahir et al. 2018). Hydration of ultramafic rocks produces talc along with serpentine (usually antigorite, Bucher, Grapes 2011). No serpentine was found in the studied samples, testifying for non-ultramafic protolith. Moreover, the absence of serpentine group minerals indicates that talc in the Mulvoj mine crystalized directly from reaction between dolomite and quartz in the presence of water-rich fluid (Tosca et al. 2011; Bjerga et al. 2015).

5.2. Geochemical features

Geochemically, the composition of talc is diagnostic for its protolith type (e.g., ultramafic and Mg-carbonate; Prochaska 1989). Talc formed from minerals in ultramafic rocks hydration is enriched in Ni, Fe and Cr, compared to Mg-carbonate hosted talc (Prochaska 1989). Large ionic lithophile elements such as K and Li, indicative of crustal components, are usually higher in content in talc formed from Mg-carbonates (Yalçin, Bozkaya 2006). Mulvoj talc samples are rich in MgO and poor in Al_2O_3 and Fe_2O_3 (t) (Fig. 6). Major oxides such as TiO_2, $Fe_2O_{3(t)}$ and MnO and minor elements such as Cr are strikingly low in the studied samples (Table 1), compared to talc formed from serpentine minerals hydration. Na_2O (0.22 to 0.30 wt%) and K_2O (0.29-0.32) contents are instead relatively high, while Na_2O and K_2O contents of talc from hydration of peridotites are very low, mainly below the detection limits (Moine et al. 1989) of the conventional analytical methods used. Such geochemical features are in accordance with a sedimentary origin and show that the Mulvoj talc did not originate from peridotites.

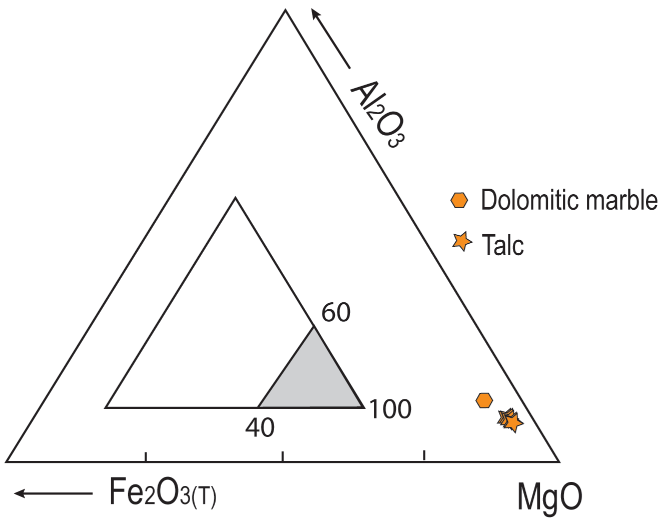

Figure 6. Al_2O_3-Fe_2O_3(T)-MgO diagram classifies the Mulvoj talc as Mg-rich talc with very small Fe and Al content.

Mineral assemblage of talc-bearing rocks confirms this. Figure 7A shows concentration of some elements in the studied samples normalized to chondrite (normalization values are from McDonough, Sun 1995). Mulvoj samples show enrichment in Ti, K, Li and Pb, compatible with crustal material source. In particular Ti enrichment is materialized by the relative abundance of titanite in the studied rocks. One peridotite talc rock from Sivas, Turkey and one serpentinite-hosted talc sample from the Gilów deposit, WS Poland are shown for comparison. As visible in Fig. 7a, the concentration of studied elements in the Mulvoj samples are distinctly different from samples of Turkey and Poland. Figure 7B illustrates upper continental crust composition (Taylor, McLennan 1985) normalized diagram for the studied samples and samples from Turkey and Poland. Li, Mo, Ni, Pb and Ti show concentration in the samples similar to their concentration in the upper continental crust (close to 1), while La, Ce, Sr and Sc show relative depletion. Carbonate minerals can incorporate considerable amounts of Sr and incompatible elements (Andersson et al. 2014; Littlewood et al. 2017). Sr usually concentrates in carbonate or similar to La and Ce, can replace Ca in other Ca-bearing minerals (e.g., Vodyanitskii 2012). Low Sr, Ce and La contents can be attributed to the low concentration of Ca-bearing minerals in the analysed talc samples and/or the lack of intergrowth between Ca-bearing minerals (such as Ca-amphibole) and talc (e.g. Müller et al. 2003). Talc samples from Turkey and Poland, formed from peridotites, show different trends in Fig. 7b.

Pb, Cd and As are among the hazardous elements for human health as they pose several health problems. Recommended heavy elements content in talc, including Pb, in pharmacopeia is <10 ppm (TEP, 2005; TUSP, 2009). The Pb content is 4 ppm for all studied samples, the Cd content varies from 0.34 to 0.35 ppm and the As content is 1.4 to 1.5 ppm in Mulvoj talc samples. U and Th are radioactive elements and pose treat to human health. Uranium anomaly is reported around the Shinbo talc mine in Korea (Chung et al. 1998). Talc contamination with high-U bearing minerals can affect the suitability of talc in pharmaceutical and cosmetic applications. U and Th contents in the studied samples are below the detection limit of the used ICP-MS method. These chemical features make Mulvoj talc suitable in terms of possible application in medical and cosmetic materials production.

5.3. Mineral phase relations, reactions and T-XCO2 estimate

Sedimentary carbonate rocks are predominantly composed of dolomite, calcite and quartz. This mineral assemblage is characteristic of simple CaO-MgO-SiO_2-CO_2 metamorphic system. Hydrous minerals in the metamorphosed carbonate rocks are commonly talc and tremolite. The H_2O necessary for the formation of these phases can be provided either from the pore fluids in the rocks or by infiltration into the rocks from the external sources (Ague 2003; Moazzen et al., 2009; Bucher, Grapes 2011). Pressure and temperature

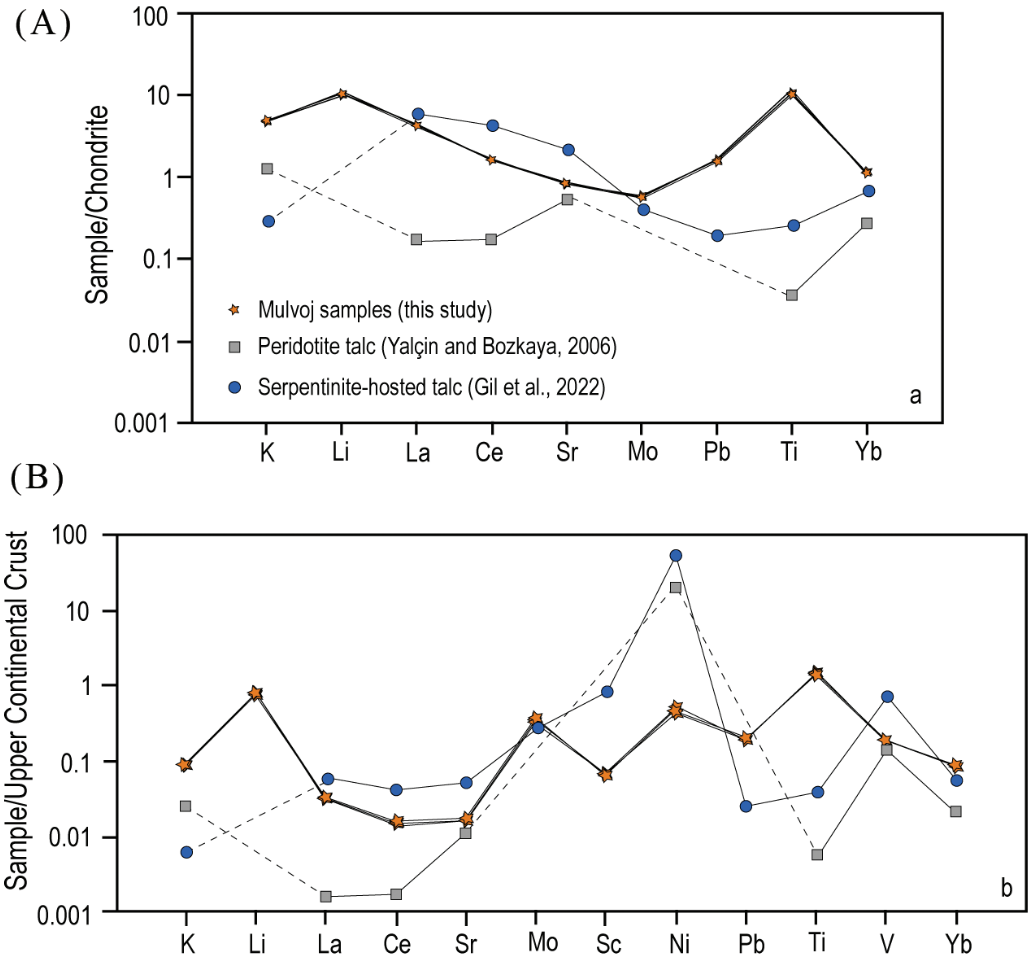

Figure 7. (A) Selected elements concentration in the Mulvoj talc samples normalized to the chondrite values (McDonough, Sun 1995). (B) Elements concentration patterns normalized to the upper continental crust values (Taylor, McLennan 1985). Peridotite-related samples from Turkey (Yalçin, Bozkaya 2006) and Poland (Gil et al. 2022) are shown for comparison.

estimation of peak metamorphism in these rocks usually is problematic due to their simple mineral assemblages, the limited number of minerals in thermodynamic equilibrium (caused by the high degree of freedom in the metamorphic system), as well as the presence of a binary fluid (H_2O-CO_2). Hence, most conventional mineral geothermobarometric methods applicable for meta-basic and meta-pelitic rocks cannot be applied to the meta-carbonates (e.g. López Sánchez-Vizcaıno et al. 1997). The only minor phase potentially suitable for temperature estimation is titanite as Zr content in titanite is used as a thermometer (Hayden et al. 2007). This thermometer is only applicable to system saturated in Zr (zircon) in the rocks. However, no zircon was found in the studied samples, hindering using this thermometer. Equilibrium reactions among mineral phases distinguished in the studied samples are therefore used to estimate the temperature and X_{CO2} during formation of talc, tremolite and calcite in the studied rocks.

According to the petrography and XRD studies, the main minerals in the Mulvoj samples are calcite (Cal), dolomite (Dol), quartz (Qtz), and tremolite (Tr). The phase relations among these minerals can be studied in the CMSH-CO_2 system, where C is CaO, M is MgO, S is SiO_2, and H is H_2O. Considering H_2O and CO_2 as excess phases in the system, CMS components can be shown by a triangular phase diagram (Fig. 8). The arrangement of different tie lines (e.g. Dol-Qtz, Dol-Tlc, Tr-Cal…) defines the sequence of the following mineral reaction:

Dol+Qtz+H_2O = Tlc+Cal+CO_2 [1]

Tlc+Qtz+Cal = Tr+H_2O+CO_2 [2]

Since dolomite along with tremolite is a common minerals assemblage in the studied rocks, based on petrographic studies, the high temperature breakdown reaction of calcite and talc can be considered to form tremolite and dolomite (reaction curve 3 in Fig. 9).

Cal+Tlc = Tr+Dol+H_2O+CO_2 [3]

We propose that these reactions were responsible for formation of talc and tremolite in the Mulvoj rocks. All reactions are binary-fluid reactions (H_2O-CO_2) with CO_2 release (e.g., Moazzen et al. 2009). More likely, H_2O is provided from the adjacent metamorphic pelitic rocks (mica schists). Reaction curves in the T-X_{CO2} diagram (Fig. 9), constructed using thermodynamic data set of Berman (1988) and considering non-ideal mixing of H_2O-CO_2, used to estimate the T-X_{CO2} relations for the studied rocks (Tahir et al. 2018). The stability field of talc in terms of temperature and X_{CO2} (mole fraction of CO_2 in the fluid) is studied by

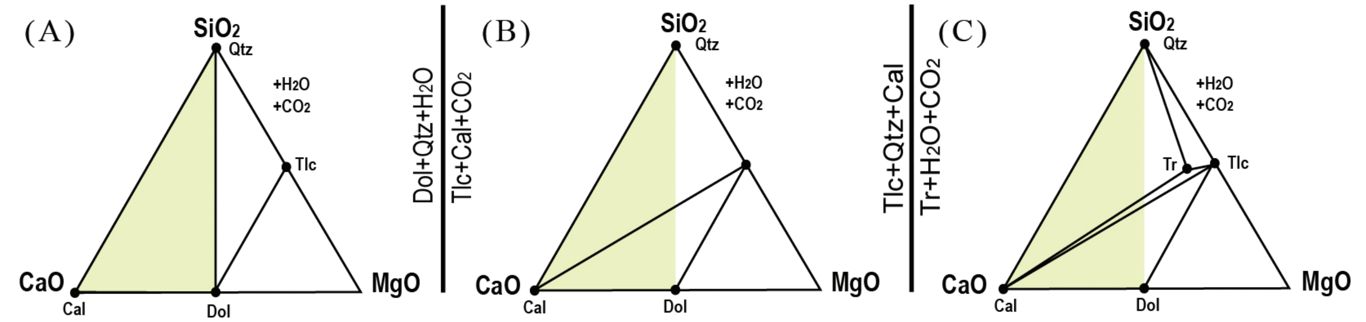

Figure 8. Phase relations for the studied rock samples in the CMSH-CO_2 compatibility diagrams with H_2O and CO_2 as the excess phases. Tie lines define the mineral reactions. (A): Dol+Qtz assemblage, (B): Tlc+Cal±Qtz assemblage (C): Tr-forming reaction.

Gordon and Greenwood (1970), Skippen (1971, 1974) and Slaughter et al. (1975). Talc is stable at pressure greater than 2 kbar and temperature up to ~460°C and X_{CO2} up to 0.6 (Fig. 9). The diagram shows that there is a direct relation between the talc crystallization temperature and X_{CO2} value. Talc can form at much lower temperatures (350°C) when X_{CO2} values are low enough. Other factors including pressure and talc composition (especially Mg/Fe ratio in talc) will control its crystallization temperature.

Calcite reacting with talc forms tremolite as a univariant reaction. It is possible to have talc and tremolite in samples as a univariant mineral assemblages, but they do not appear in the studied samples. This is more likely due to very limited exposure of the assemblage in the study area.

Talc formation by precipitation from hydrothermal fluids (Boutin et al. 2016) can be postulated for the Mulvaj area. Aqueous SiO_2 and Mg^{2+} in fluid react with carbonate to form talc. This reaction releases H^+ (Boutin et al. 2016). There is no evidence for Mg^{2+} metasomatism or presence of aqueous SiO_2 in the Mulvoj area (e.g., silica veins accompanying talc mineralization). The released H^+ can cause acidic alteration, which is not the case in the Mulvoj area.

Talc forms during metasomatism by fluid infiltration from the crystallizing pluton into the siliceous dolomitic rocks within the contact aureole (e.g., Chatir et al. 2022). No evidence of contact metamorphism observed in the studied rocks under the microscope. Furthermore, the Cretaceous intrusive rocks are at considerable distance from the Mulvoj area (Fig. 1), which rules out a contact metamorphic origin for the studied talc deposit.

Previous studies proposed a peak metamorphic event at 650°C to 750°C at ca. 7 to 9.7 kbar in the area (Kiselyov, Budanov 1986; Grew et al. 1994). No high-grade relict minerals (e.g. clinopyroxene, olivine, wollastonite) were observed in the studied metamorphic dolomitic marbles. This implies that the talc-bearing samples are not result of a retrograde metamorphism of high grade rocks. Talc and tremolite formation can be explained by a relatively low temperature trajectory of a prograde regional metamorphism at temperature <460°C, in which H_2O was provided from dehydration metamorphic reactions of the interlayered pelitic (schist) rocks.

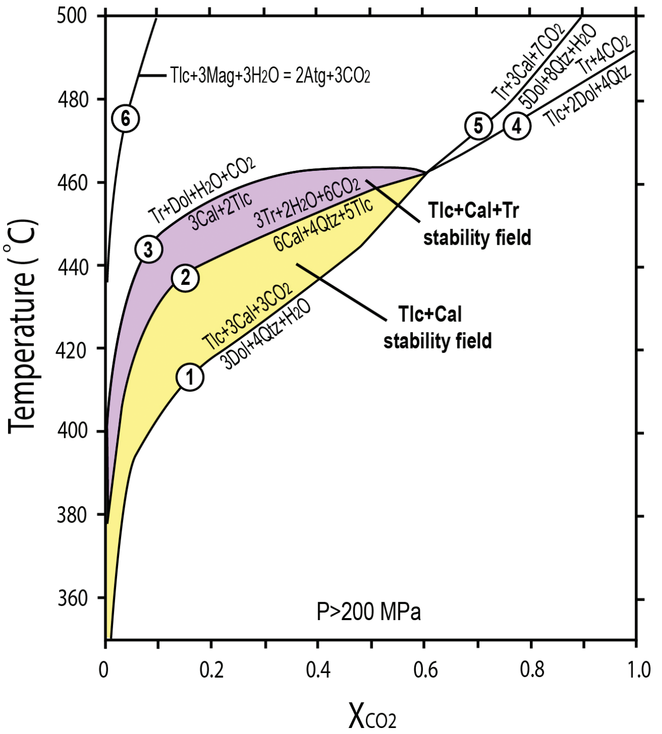

Figure 9. Temperature-X_{CO2} diagram for talc formation in the siliceous system with binary H_2O-CO_2 fluid (Tahir et al. 2018). Stability field for talc + calcite and talc + calcite + tremolite are indicated.

6. Conclusions

Talc in the Mulvoj area of the Ishkashim district occurs in high-grade marble as interlayers in the South-western Pamir gneiss and schist. According to the petrography observations and XRD analyses results, talc is the main mineral in the deposit with subordinate amounts of quartz, calcite and amphibole. Geochemical studies indicate almost equal contents of CaO and MgO for marble, classifying it as dolomitic marble. Considering the minerals in dolomitic marble and talc samples, three main mineralogical reactions were responsible for talc and tremolite crystallization. The reaction at relatively lower temperature consumes dolomite, quartz and H_2O to produce talc, calcite and carbon dioxide, the reaction at relatively higher temperature and almost similar X_{CO2} consumes talc, quartz and calcite to produce tremolite, H_2O and carbon dioxide. The reaction at higher temperature produces tremolite and dolomite by talc and calcite breakdown. Co-existence of talc and calcite and also talc and tremolite in the studied samples put constraints on temperature-CO_2 mole fraction (T-X_{CO2}) of formation of the mineral assemblages of ~340°C up to ~460°C and X_{CO2} from zero (pure water) up to 0.6. This study shows that Mulvoj talc is a marble-hosted talc occurrence and is not related to ultramafic rocks, formed at the low-T trajectory of a prograde metamorphism. Most of the deposit is mined during the Soviet time and the remaining of the talc deposit is not considerable. Therefore, the mine cannot be considered economically valuable, however there is possibility for further exploration and extraction if the demand for talc increases. This will need considerable investment to do more prospecting, re-building the road and re-constructing the metal zip-line.

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References

Abraham, K. & Scheryer, W. (1976). A talc-phengite assemblage in Piemontite Schist from Brezovica, Serbia, Yugoslavia. *Journal of Petrology*, 17, 421-439. https://doi.org/10.1093/petrology/17.4.421.

Ague, J. J. (2003). Fluid infiltration and transportation of major, minor, and trace elements during regional metamorphism of carbonates rocks, Wepawaug schist, Connecticut, USA. *American Journal of Science*, 303, 753-816. DOI: https://doi.org/10.2475/ajs.303.9.753.

Ali-Bik, M. W., Taman, Z., El Kalioubi, B. & Abdel Wahab, W. (2012). Serpentinite-hosted talc-magnesite deposits of Wadi Barramiya area, Eastern Desert, Egypt: Characteristics, petrogenesis and evolution. *Journal of African Earth Sciences*, 64, 77-89. https://doi.org/10.1016/j.jafrearsci.2011.11.002.

Anderson, D. L., Mogk, D. W. & Childs, J. F. (1990). Petrogenesis and timing of talc formation in the Ruby Range, Southwestern Montana, *Economic Geology*, 85, 585-600. https://doi.org/10.2113/gsecongeo.85.3.585.

Andersson, M. P., Sakuma, H. & Stipp, S. L. S. (2014). Strontium, Nickel, Cadmium, and Lead Substitution into Calcite, Studied by Density Functional Theory. *Langmuir*, 30(21). 6129-6133. https://doi.org/10.1021/la500832u.

Angiolini, L., Zanchi, A., Zanchetta, S., Nicora, A. & Vezzoli, G. (2013). The Cimmerian geopuzzle: new data from South Pamir. *Terra Nova*, 25, 352-360. https://doi.org/10.1111/ter.12042.

Berman, R. B. (1988) Internally consistent thermodynamic data for minerals in the system Na2O-K2O-CaO-MgO-FeO-Fe2O3- Al2O3-SiO2-TiO2-H2O-CO2. *Journal of Petrology*, 29, 445-522. https://doi.org/10.1093/petrology/29.2.445.

Bjerga, A., Konopasek, J.& Pedersen, R. B. (2015). Talc-carbonate alteration of ultramafic rocks within the Laka Ophiolite complex, Central Norway. *Lithos*, 227, 21-36. https://doi.org/10.1016/j.lithos.2015.03.016.

Borowski, M. P., Furmanek, M., Czarniak, K. & Gunia, P. (2015). Steatite-tempered pottery of the Stroke Ornamented Ware culture from Silesia (SW Poland): A Neolithic innovation in ceramic technology. *Journal of Archaeological Science*, 57, 207-222. https://doi.org/10.1016/j.jas.2015.01.021.

Boutin, A., de Saint Blanquat, M. S., Poujol, M., Boulvais, P., de Parseval, P., Rouleau, C. & Robert, J-F. (2016). Succession of Permian and Mesozoic metasomatic events in the eastern Pyrenees with emphasis on the Trimouns talc–chlorite deposit. *International Geology Review*, 105, 747-770. https://doi.org/10.1007/s00531-015-1223-x.

Bucher, K., & Grapes, R. (2011). Petrogenesis of metamorphic rocks. Springer. 441 p. DOI 10.1007/978-3-540-74169-5.

Burtman, V.S. & Molnar, P. (1993). Geological and Geophysical Evidence for Deep Subduction of Continental Crust Beneath the Pamir. Geological Society of America Special Paper, 281, 76. https://doi.org/10.1130/SPE281-p1.

Chatir, A., Berger, J., Ennih, N., Traintafyllou, A., de Parseval, P., Errami, E., Diot, H., Baele, J.-M., Aghzer, A. M., Monnier & C., Boutaleb, M. (2022). Formation of the Nkob talc deposit by contact metamorphism and fluid infiltration into siliceous dolostones (Moroccan AntiAtlas). *Ore Geology Review*, 140, 104629, https://doi. org/10.1016/j.oregeorev.2021.104629

Chung, J. I., Lee, M. S. & Na, C. K. (1988). Geochemical study on the uranium anomaly around the Shinbo talc mine (I) in the light of hydrothermal properties. *Economic and Environmental Geology*, 31(2), 101-110. (In Korean with English abstract).

Collettini, C., Cardellini, C., Chiodini, G., De Paola, N., Holdworth, R. E., & Smith, S. A. F. (2008). Fault weakening due to CO_2 degassing in the Northern Apennines: short- and long-term processes. *Geological Society of London Special Publications*, 299, 175-194. https://doi.org/10.1144/SP299.11.

Covey-Crump, S. J. & Rutter, E. H. (1989). Thermally-induced grain growth of calcite marbles on Naxos Island, Greece. *Contributions to Mineralogy and Petrology*, 101, 69-86. https://doi.org/10.1007/BF00387202.

Drugova, G.M., Moskovchenko, N.I., Sedova, I.S. & Miller, Yu. V. (1976). Metamorphic evolution in the basement of Phanerozoic folded areas (for example, the southwestern Pamirs) (in Russian). In: Thermodynamic Regime of Metamorphism. Leningrad, Nauka, pp. 240-251.

Fraser, J. E., Searle, M. P., Parrish, R. R. & Noble, S. R. (2001). Chronology of deformation, metamorphism and magmatism in the southern Karakoram Mountains. *Geological Society of America Bulletin*, 113, 1443-1455. https://doi.org/10.1130/0016-7606.

Gil, G., Borowski, M. P., Barnes, J. D., Jokubauskas, P., Bagiński, B., Gunia, P. & Ilnicki, S. (2022). Formation of serpentine-hosted talc in a continental crust setting: Petrographic, mineralogical, geochemical, and O, H and Cl isotope study of the Gilów deposit, Gróy, Sowie

Massif (SW Poland). *Ore Geology Review*, https://doi.org/10.1016/j.oregeorev.2022.104926.

Gordon, T. M. & Greenwood, H. J. (1970) The reaction: Dolomite + quartz + water = talc + calcite + carbon dioxide. *American Journal of Science*, 268, 225-242. DOI: https://doi.org/10.2475/ajs.268.3.225.

Grew, E. S., Pertsev, N. N., Yates, M. G., Christy, A. G., Marquez, N. & Chernosky, J. V. (1994). Sapphirine+forsterite and sapphirine+humite group minerals in an ultra-Magnesian lens from Kuhi-Lal, SW Pamirs, Tajikistan: Are these assemblages forbidden? *Journal of Petrology*, 35(5), 1275-1293. https://doi.org/10.1093/petrology/35.5.1275.

Grew, E. S., Pertsev, N. N., Vrána, S., Yates, M. G., Shearer, C. K.& Wiedenbeck, M. (1998). Kornerupine paragenesis in whiteschists and other magnesian rocks: is kornerupine + talc a high-pressure assemblage equivalent to tourmaline + orthoamphibole? *Contributions to Mineralogy and Petrology*, 131, 22-38. https://doi.org/10.1007/s004100050376.

Hacker, B. R., Ratschbacher, L., Rutte, D., Stearns, M. A., Malz, N., Stubner, K., Kylander-Clark, A. R. C., Pfander, J. J. & Everson, A. (2017). Building the Pamir-Tibet Plateau-Crustal stacking, extensional collapse, and lateral extrusion in the Pamir: 3. *Thermobarometry and petrochronology of deep Asian crust. Tectonics*, 36, 1743-1766. https://doi.org/10.1002/2017TC004488.

Hayden, L. A., Watson, E. B. & Wark, D. A. (2007). A thermometer for sphene (titanite). *Contributions to Mineralogy and Petrology*, 155, 529-540. https://doi.org/10.1007/s00410-007-0256-y.

Hildner, E. (2003). The evolution of the Pamir. Report, Technical Universität Bergakademie Freiberg.

Hubbard, M. S., Grew, E. S., Hodges, K. V., Yates, M. G. & Pertsev, N. N. (1999). Neogene cooling and exhumation of upper-amphibolite-facies 'whiteschists' in the southwest Pamir Mountains, Tajikistan. *Tectonophysics*, 305, 325-337. https://doi.org/10.1016/S0040-1951(99)00012-8.

Jiang, Y. H., Liao, S. Y. Yang, W. Z. & Shen, W. Z. (2008). An island arc origin of plagiogranites at Oytag, western Kunlun orogen, northwest China: SHRIMP zircon U–Pb chronology, elemental and Sr–Nd–Hf isotopic geochemistry and Paleozoic tectonic implications. *Lithos*, 106, 323-335. https://doi.org/10.1016/j.lithos.2008.08.004.

Kiselyov, V.I. & Budanov, V.I. (1986). Precambrian Magnesian–Skarn Deposits of the Southwestern Pamirs (in Russian). Dushanbe, Donish, 224 pp.

Kukhtikov, M. M. & Vinnichenko, G. P. (2010). The Paleozoic tectonics zonation of the Pamirs. *International Geology Review*, 23, 881-890. https://doi.org/10.1080/00206818109450970.

Littlewood, J. L., Shaw, S., Peacock, C. L., Bots, P., Trivedi, D. & Burke, I. T. (2017). Mechanism of Enhanced Strontium Uptake into Calcite via an Amorphous Calcium Carbonate Crystallization Pathway. *Crystal Growth and Design*, 17(3), 1214-1223. https://doi.org/10.1021/acs.cgd.6b01599.

Liu, L-P. (1986). Phase transformations in serpentine at high pressures and temperatures and implications for subducting lithosphere. *Physics of the Earth and Planetary Interiors*, 42(4), 255-262. https://doi.org/10.1016/0031-9201(86)90028-2.

López Sánchez-Vizcanio, V., Connolly, J. A. D. & Gómez-Pugnaire, M. T. (1997). Metamorphism and phase relations in carbonate rocks from the Nevado-Fila´bride Complex (Cordilleras Be´ticas, Spain): application of the Ttn + Rt + Cal + Qtz + Gr buffer. *Contributions to Mineralogy and Petrology*, 126, 292-302. https://doi.org/10.1007/s004100050251.

McDonough, W. F. & Sun, S. S. (1995). The composition of the Earth. *Chemical Geology*, 120, 223-253. https://doi.org/10.1016/0009-2541(94)00140-4.

Moazzen. M., Oberhänsli, R., Hajialioghli, R., Moller, A., Bousquet, R., Droop, G. & Jahangiri, A. (2009). Peak and post-peak P-T condition and fluid composition for scapolite-clinopyroxene-garnet calc-silicate rocks from the Takab area, NW Iran. *European Journal of Mineralogy*, 21, 149-162. https://doi.org/10.1127/0935-1221/2009/0021-1887.

Moine, B., Fortune, J. P., Moreau, P. & Viguier, F. (1989). Comparative Mineralogy, Geochemistry, and Conditions of Formation of Two Metasomatic Talc and Chlorite Deposits: Trimouns (Pyrenees, France) and Rabenwald (Eastern Alps, Austria). *Economic Geology*, 84, 1398-1416. https://doi.org/10.2113/gsecongeo.84.5.1398.

Moore, D. & Rymer, M. (2007). Talc-bearing serpentinite and the creeping section of the San Andreas fault. *Nature* 448, 795-797. https://doi.org/10.1038/nature06064.

Müller, W. F., Schmädicke, E., Okrusch, M. & Schüssler, U. (2003). Intergrowths between anthophyllite, gedrite, calcic amphibole, cummingtonite, talc and chlorite in a metamorphosed ultramafic rock of the KTB pilot hole, Bavaria. *European Journal of Mineralogy*, 15, 295-307. https://doi.org/10.1127/0935-1221/2003/0015-0295.

Muraishi, H. (1988). Studies of the rate of the formation of talc under hydrothermal conditions at 400- 460°C. *Bulletin of Chemical Society of Japan*, 61, 1071-1075. https://doi.org/10.1246/bcsj.61.1071.

Pashkov, B. R., & Budanov, V. I. (1990). The tectonics of the zone of intersection between the Southeastern and Southwestern Pamir (in Russian). Geotektonika, 3, 70-79.

Pieczka, A., Gołębiowska, B. & Franus, W. (1998). Yukonite, a rare Ca-Fe arsenate from Rędziny (Sudetes, Poland). *European Journal of Mineralogy*, 10, 1367-1370.

Prochaska, W. (1989). Geochemistry and genesis of Austrian talc deposits. *Applied Geochemistry*, 4(5), 511-525. https://doi.org/10.1016/0883-2927(89)90008-5.

Rembe, J., Sobel, E. R., Kley, J., Zhou, R., Thiede, R. & Chen, J. (2021). The Carboniferous Arc of the North Pamir. *Lithosphere*, (1): 6697858. https://doi.org/10.2113/2021/6697858

Ruzhentsev, S.V. & Shvolman, V.A. (1981). Tectonics and structure of the Pamir metamorphics. In: Saklani, P.S. (Ed.), Metamorphic Tectonites of the Himalaya. Today and Tomorrow's Printers and Publishers, New Delhi, pp. 27-41.

Saccocia, P. J., Seewald, J. S. & Shanks, W. C. (2009). Oxygen and hydrogen isotope fractionation in serpentine-water and talc-water system from 250 to 450°C, 50

MPa. *Geochemica et Cosmochemica Acta*, 73, 6789-6804. https://doi.org/10.1016/j.gca.2009.07.036.

Scharer, U., de Parseval, P., Polve, M. & de Saint Blanquat, M. Formation of the Trimouns talc-chlorite deposit (Pyrenees) from persistent hydrothermal activity between 112 and 97 Ma. Terra Nova, 11, 30-37. https://doi.org/10.1046/j.1365-3121.1999.00224.x.

Schreyer, W. & Abraham, K. (1975). Peraluminous sapphirine as a metastable reaction product in kyanite-gedrite-talc schist from Sar e Sang, Afghanistan. *Mineralogical Magazine*, 4, 171-180. https://doi.org/10.1180/minmag.1975.040.310.06.

Schwab, M., Ratschbacher, L., Siebel, W., McWilliams, M., Minaev, V., Lutkov, V., Chen, F., Stanek, K., Nelson, B., Frisch, W. & Wooden, J.L. (2004). Assembly of the Pamirs: Age and origin of magmatic belts from the southern Tien Shan to the southern Pamirs and their relation to Tibet. *Tectonics*, 23. https://doi.org/10.1029/2003TC001583

Searle, M.P., Parrish, R.R., Thow, A.V., Noble, S.R., Phillips, R.J. & Waters, D.J. (2010). Anatomy, age and evolution of a collisional mountain belt: the Baltoro granite batholith and Karakoram Metamorphic Complex, Pakistani Karakoram. *Journal of the Geological Society*, 167, 183-202. https://doi.org/10.1144/0016-76492009-043.

Slaughter, J., Kerrick, D. M. & Wall, V. J. (1975). Experimental study of equilibria in the system CaO-MgO-SiO2-H2O-CO2. *American Journal of Science*, 275, 143-162. https://doi.org/10.2475/ajs.275.2.143.

Skippen, G. (1971). Experimental data for reactions in siliceous marbles. *Journal of Geology*, 79, 457-481.

Skippen, G. (1974) An experimental model for low pressure metamorphism of siliceous dolomitic marble. *American Journal of Science*, 274, 487-509. https://doi.org/10.2475/ajs.274.5.487.

Spandler, C., Hermann, J., Faure, K., Mavrogenes, J. A. & Arculus, R. J. (2008). The importance of talc and chlorite "hybrid" rocks for volatile recycling through subduction zones; evidence from the high-pressure subduction mélange of New Caledonia. *Contributions to Mineralogy and Petrology*, 155, 181-198. https://doi.org/10.1007/s00410-007-0236-2.

Stearns, M.A., Hacker, B.R., Ratschbacher, L., Rutte, D. & Kylander-Clark, A.R.C. (2015). Titanite petrochronology of the Pamir gneiss domes: Implications for mid–deep crust exhumation and titanite closure to Pb and Zr diffusion. *Tectonics*, 34, 784-802. https://doi.org/10.1002/2014TC003774.

Stübner, K., Ratschbacher, L., Weise, C., Chow, J., Hofmann, J., Khan, J., Rutte, D., Sperner, B., Pfänder, J.A., Hacker, B.R. & Dunkl, I. (2013). The giant Shakhdara migmatitic gneiss dome, Pamir, India-Asia collision zone: 2. Timing of dome formation. *Tectonics*, 32, 1404-1431. https://doi.org/10.1002/tect.20059.

Tahir, M., Imai, A., Takahashi, R. & Yano, S. (2018). Ore Genesis and Geochemical Characteristics of Carbonate-Hosted Talc Deposits in Nangarhar Province, Afghanistan. *Resource Geology*, https://doi.org/10.1111/rge.12174.

Taylor, S. R. & McLennan, S. M. (1985). The Continental Crust: its Composition and Evolution. Blackwell: Oxford, 312 pp. TEP (2015).

The European Pharmacopoeia. Supplement 5.1. 5th edition, Talc Monograph: 4, 3017-3018.

Tosca, N. J., Macdonald, F. A., Strauss, J., V., Johnston, D. T., Knoll, A. H. (2011). Sedimentary talc in Neoproterozoic carbonate successions. Earth and Planetary Sciences Letters, 306, 11-22. https://doi.org/10.1016/j.epsl.2011.03.041.

TUSP (2007). The United States Pharmacopoeia. 32 NF 27, 3, Official Monograph/Talc, 3649-3651.

Veblen, D. R. (1983) Microstructure and mixed layering in intergrown wonesite, chlorite, talc, biotite, and kaolinite. *American Mineralogist*, 68, 566-580.

Virta, R. L. (1998) Talc and pyrophyllite. In Minerals Yearbook, Metals and Minerals, Vol. I, U.S. Geological Survey, Reston, VA, 891-897.

Vlasov, N. G., Dyakov, Y. A. & Cherev, E. S. (1991). Geological map of the Tajik SSR and adjacent territories. 1:500,000. VSEGEI (Vsesojuznoi Geological Institute), Leningrad, Saint Petersburg.

Vodyanitskii, Yu., N. (2012). Geochemical Fractionation of Lanthanides in Soils and Rocks: A Review of Publications. *Eurasian Soil Science*, 45(1), 56-67. https://doi.org/10.1134/S1064229312010164.

Wilamowski, A. & Wiewióra, A. (2004). Chemical diversity of talcs in relation to their origin. *Acta Mineralogica-Petrographica*, 45 (2), pp. 35-39.

Woguia, D. L., Fagel, N., Pirard, E., Gourfi, A., Ngo bidjeck, L. M. & El ouahabi, M. (2021). Talc schist deposits from central Cameroon: Mineralogical and physico-chemical characterization. *Journal of African Earth Sciences*, 178, https://doi.org/10.1016/j. jafrearsci.2021.104182.

Yalçin, H. & Bozkaya, O. (2006). Mineralogy and geochemistry of Paleocene ultramafic- and sedimentary-hosted talc deposit in the southern part of the Sivas basin, Turkey. *Clay and Clay Minerals*, 54, 333-350. https://doi.org/10.1346/CCMN.2006.0540305.

Zanchetta, S., Worthibgton, J., Angiolini, L., Leven, E. J., Villa, I. M. & Zanchi, A. (2018). The Bashgumbaz Complex (Tajikistan): Arc obduction in the Cimmerian orogeny of the Pamir. *Gondwana Research*, 57, 170-190. https://doi.org/10.1016/j.gr.2018.01.009.

Zhang, R. Y., Liou, J. G. & Comg, B. L. (1995). Talc-, Magnesite- and Ti-Clinohumite-Bearing Ultrahigh-Pressure Meta-Mafic and Ultramafic Complex in the Dabie Mountains, China. *Journal of Petrology*, 4, 1011-1037. https://doi.org/10.1093/petrology/36.4.1011.

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