



Alpine regional metamorphism of Föderata Group metacarbonates (southern Veporicum, Western Carpathians, Slovakia): P–T conditions of recrystallization

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P–T conditions of the Alpine regional metamorphism of carbonate successions which form the cover sequence of the southern Veporicum crystalline basement have been determined. The P–T estimates were calculated on the basis of microprobe chemical analyses of equilibrium mineral assemblages together with analyses of bulk rock chemical composition. The calibrated geothermic reactions Cal–Dol and Kfs–Phl were used. Geothermometric and geobarometric data were obtained using the *SOLV CALC*, *TWO* and *PERPLEX* software programs in combination with phengite geobarometry. The metacarbonates were formed from a sedimentary-carbonate protolith in low-pressure and low-temperature conditions of greenschist facies in the kyanite stability field: $T_{\text{Cal}} = 354\text{--}476^\circ\text{C}$, $T_{\text{Ab-Or}} = 329\text{--}453^\circ\text{C}$, $P \approx 0.3\text{--}0.5$ GPa, during Cretaceous orogeny.

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INTRODUCTION

Calcite-dolomite geothermometric data based on Powell *et al.* (1984) calibration were used by Iró and Radvanec (1997) for hydrothermal carbonates in an ore deposit system. They determined the temperature of the alteration processes leading to the formation of Fe–Mg ankerites in the range of 300–350°C at the Nižná Slaná locality (Gemericum Unit). Radvanec and Prochaska (2001) used the binary phase diagram of Powell *et al.* (1984) to estimate the temperature range (370–400°C) of different calcite and dolomite generations at the Dúbrava ore deposit (Tatricum Unit). The calcite-dolomite geothermometry applied to regional metamorphosed carbonates has not previously been attempted in Slovakia. The metacarbonate localities investigated are in the Dobšiná Brook valley, the Plačková valley and the “Tuhár Mesozoic area”. This work presents new data on the metamorphic development during Alpine orogenic events in the southern Veporicum Unit. Previously published metamorphic recrystallization data from siliciclastic metasediments (Korikovsky *et al.*, 1992; Lupták *et al.*, 2003) are then compared with our data from the metacarbonate successions.

GEOLOGICAL SETTING

The cover of the southern Veporicum crystalline basement is composed of the Late Paleozoic Revúca Group consisting of the Pennsylvanian Slatviná Formation and the Permian Rimava Formation (Vozárová and Vozár, 1982, 1988), together with the Mesozoic sequence of the Föderata Group, that was firstly defined by Rozložník (1935). This group is distinguished from the cover sequence of southern Veporicum as well as from northern Veporicum by the presence of Pennsylvanian/Permian deposits and the absence of Keuper facies (Biely *et al.*, 1996). The basement of the southern Veporicum is only partly covered by the Föderata Group (Fig. 1), and thus specific localities have been chosen.

The age of the Föderata Group is based on lithofacies criteria and on rare biostratigraphic data confirming the Triassic age of the metasedimentary rocks. Microfloral assemblages of Ladinian–Carnian age were found in dark shales, which form interlayers within the black and grey crystalline limestones (Biely and Planderová, 1975). Dark, sandy shales with intercalations of dark cherty limestones were assigned to the Carnian (Cordevolian–Julian) based on conodont ages (Straka, 1981).

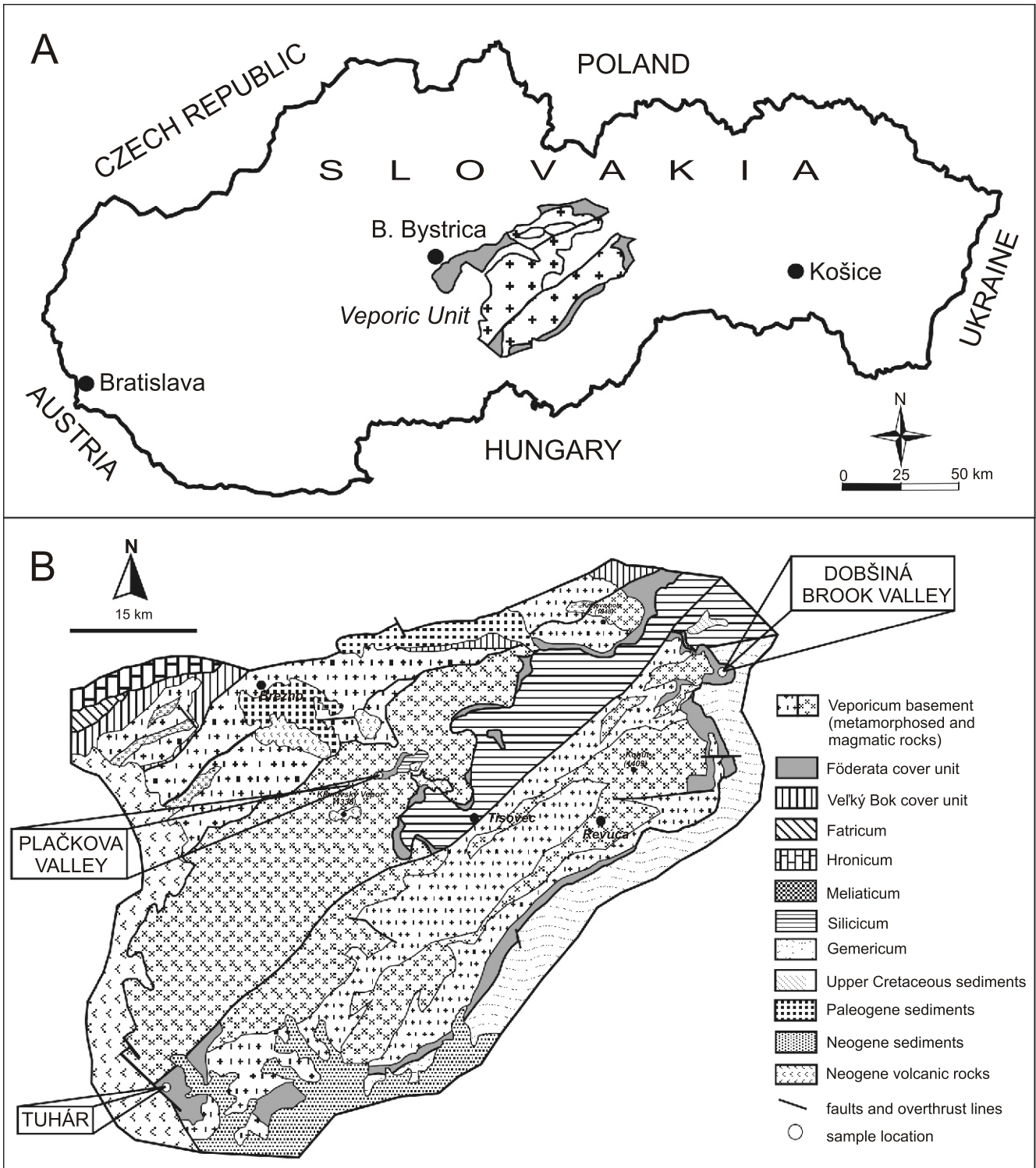


Fig. 1. Tectonic sketch (Vozár *et al.*, 1998) and simplified map of the Veporicum (Hók *et al.*, 2001) with samples localities

Due to the absence of Jurassic rocks, Plašienka (1981, 1983, 1993) deduced a lithostratigraphically differentiated development of the Triassic metacarbonates. Lithological differences exist among the individual occurrences of the Föderata Group. Generally, the pre-metamorphic succession of the Middle and Upper Triassic is formed by dolomites (rauwackes), dark and light crystalline limestones, marly and siliceous cherty limestones, sandy and marly shales with lenses of dark cherty lime-

stones and dolomites. The whole thickness varies in thickness from 200–450 m (Biely *et al.*, 1996).

Pink and light grey massive and platy metacarbonates occur on both river banks of the Dobšiná Brook valley. They overlie rawwackes or dark metacarbonates and underlie cherty metacarbonates and black shales. The age of these marbles has not been palaeontologically determined due to intense deformation and recrystallization. Vozár (in Bajaník *et al.*, 1983)

classified the metacarbonates based on their lithological composition and their stratigraphic position as Middle Triassic (Anisian–Ladinian).

In the Plačková valley, near the Diel saddle, the Föderata Group metacarbonates occur in a NE–SW directed fault zone (Vojtko in Kováč *et al.*, 2004). This rock sequence underwent ductile deformation. Dark and black laminated metacarbonates (Anisian) are present, intercalated with pale, laminated metacarbonates (Anisian–Ladinian) and dolomites (Norian).

The Middle Triassic Tuhár marbles are present in the middle part of the metacarbonate Tuhár succession. These marbles locally grade into siliceous and cherty metacarbonates, considered to be the most deep-water part of the Föderata Group (Plašienka in Bezák *et al.*, 1999). Siliceous and cherty metacarbonates developed from the underlying Anisian dark platy metacarbonates, locally in direct contact with basal cavernous dolomites (Straka and Vozár in Vass *et al.*, 1992). According to their position in the succession and by analogy with other areas of the Föderata Group, the siliceous and cherty metacarbonates correspond probably to the upper Anisian/Ladinian. Lithologically, these carbonates are similar to the Steinalm, Wetterstein and Ramin limestone facies

(Plašienka in Bezák *et al.*, 1999). These metacarbonates are sedimentary rocks of the Middle to Upper Triassic carbonate platform, in which the primary sedimentary textures were destroyed during recrystallization (Straka and Vozár in Vass *et al.*, 1992). The whole thickness of the Tuhár marbles reaches ~200 m (Plašienka in Bezák *et al.*, 1999).

METHODS

The field study focused on sampling metacarbonate rocks for geothermobarometry, and geochemical and isotopic measurements from the localities (Fig. 2) of Dobšiná Brook valley (DP), Plačková valley (PLD) and Tuhár (TU).

For geothermobarometry, the metacarbonate equilibrium mineral assemblages were chosen. Coexisting mineral pairs were analysed by the electron microprobe *CAMECA SX 100* (State Dionýz Štúr Geological Institute, Bratislava). 15 kV and 10–20 nA were the measuring conditions. The electron beam diameter (5–10 µm) was changed during measurements to avoid misleading analyses due to carbonate evaporation. Mg – forsterite,

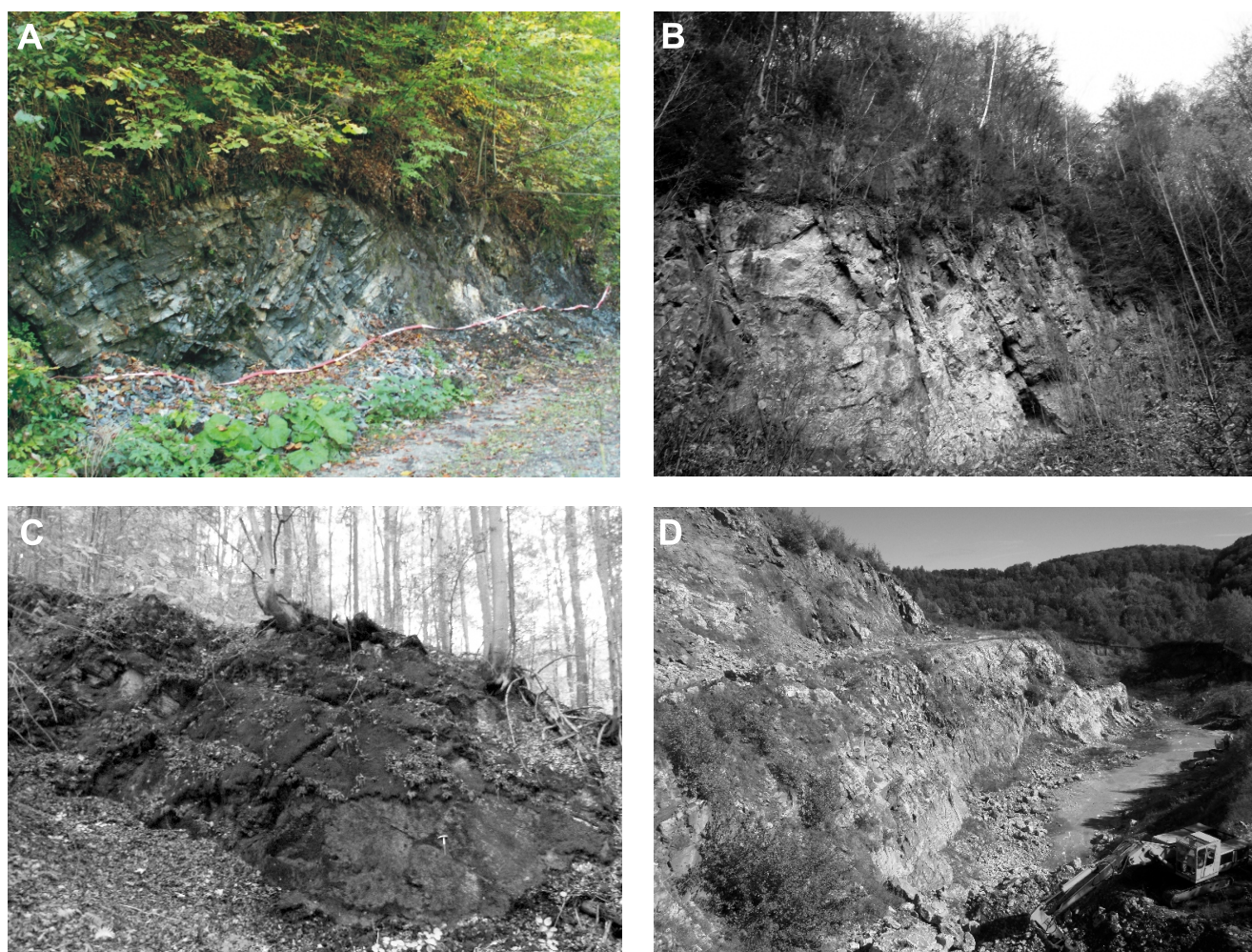


Fig. 2A – exposure of folded platy marbles about 15 m long on the left side of the Dobšiná Brook valley, looking from the direction of Dobšiná, B – view of the abandoned quarry on the right side of the Dobšiná Brook valley, C – the Plačková valley, D – actively mined part of the quarry near Tuhár

Ca – wollastonite, Fe – fayalite, Sr – SrTiO₃, Mn – rhodonite were used as analytical standards for carbonate analyses. For micas and feldspars Si, Ca – wollastonite, Na – albite, K – orthoclase, Mg – forsterite, Al – Al₂O₃, Fe – fayalite, Mn – rhodonite, Cr – Cr, Ni – NiO, Ti – TiO₂, Sr – SrTiO₃, Ba – barite, P – apatite, F – LiF, Cl – NaCl as calibration standards were used.

Recrystallization temperatures of the metacarbonates were determined using the calcite-dolomite solvus calibration data of Anovitz and Essene (1987) and McSwiggen (1993). A recalculated phengite component of white mica was used to evaluate recrystallization pressure conditions (Massone and Schreyer, 1987). The program *SOLV CALC* vers. 2.0 (Wen and Nekvasil, 1994) has been applied for feldspar solvus geothermometry. For the P–T diagram construction the position of Puhán's (1978) reaction $3\text{Dol} + \text{Kfs} + \text{H}_2\text{O} = \text{Phl} + 3\text{Cal} + 3\text{CO}_2$ was calculated using *TWQ* software vers. 2.32 (Berman, 2007). *PERPLEX* vers. 07 (Connolly, 2007) has been used to determine the chemographic phase relations in metacarbonates. The whole rock chemical analyses for the P–T pseudosection constructions in the KCFMAS-HC system were analysed at Analytical Laboratories Ltd., Vancouver, Canada (Table 1). Concentrations of the major elements were determined by the ICP-AES method. Detection limits for SiO₂, TiO₂, Al₂O₃, MnO, MgO, CaO, Na₂O, K₂O are defined on the level of 0.01 wt.%. Fe₂O₃ has the detection limit 0.04 wt.%, P₂O₅ 0.001 wt.% and Cr₂O₃ 0.002 wt.%. The CO₂ content was determined by LECO analyses in AcmeLabs with the detection limit ±0.02 wt.%. Mineral abbreviations follow Siivola and Schmid (2007).

Table 1

The whole rock chemical analyses of samples DP-1, DP-9, DP-17 and PLD-3

Oxides [wt.%]	Sample			
	DP-1	DP-9	DP-17	PLD-3
SiO ₂	1.34	1.33	0.90	4.44
TiO ₂	<0.01	0.01	<0.01	0.06
Al ₂ O ₃	0.23	0.27	0.25	1.42
Cr ₂ O ₃	<0.002	<0.002	<0.002	<0.002
FeO	0.20	0.11	0.05	0.41
MnO	<0.01	<0.01	<0.01	<0.01
MgO	1.97	3.96	2.02	2.75
CaO	53.98	50.44	53.88	48.49
Na ₂ O	0.02	<0.01	<0.01	<0.01
K ₂ O	0.14	0.1	0.1	0.56
P ₂ O ₅	0.029	0.021	<0.01	0.06
CO ₂	40.48	42.09	44.26	40.22
Total	98.41	98.34	101.47	98.46

PETROLOGY

METACARBONATES FROM DOBŠINÁ BROOK VALLEY (DP)

The granoblastic texture is formed by alternations of regular lamination with chaotically distributed coarse-grained twinned lamellar and fine-grained calcite aggregates, which grade into

fine-grained mylonitic material (Fig. 3A). Isolated lenses of the coarse-grained calcite aggregates in a fine-grained matrix have been observed locally. Calcite and dolomite porphyroblasts show a range of transformational changes to porphyroclasts during the following cataclastic deformation (Fig. 3B). The dolomite porphyroblasts form sharp-bordered rhombohedra inside the polycrystalline calcite aggregates. Fe-stained microstylolites (Fig. 3C) contain increased concentrations of metamorphic micas (muscovites, rarely chlorites) accompanied by polyhedral opaque minerals (pyrite, magnetite). Opaque minerals are secondarily altered to Fe-oxides. Anhedronal grains and aggregates of non-undulatory quartz are locally present in the fine- and coarse-grained calcite domains. Quartz aggregates with undulatory extinction are locally present (Fig. 3D). Isolated platy metamorphic micas are associated with the fine-grained calcite matrix. Parallel oriented phlogopite crystals within the foliation show a partial undulatory extinction (Fig. 3E). In DP metacarbonates K-feldspars (microcline) and albitic plagioclases have been identified. Albite forms isolated grains with rarely preserved twinning lamellae (Fig. 3F). The metamorphic mineral assemblage is consequently formed by Cal + Dol + Qtz + Ms (Phg) + Phl + Kfs + Ab.

METACARBONATES OF PLAČKOVA VALLEY (PLD)

Differentiated fine- to coarse-grained calcite aggregates are arranged in granoblastic textures. Rotated calcite porphyroblasts are locally present with features of pressure twinning. Dolomite occurs in this assemblage as rhombohedral porphyroblasts (Fig. 4A). Isolated anhedronal non-undulatory quartz grains within the coarse calcite matrix domains alternate with rarer polycrystalline undulatory quartz aggregates. Metamorphic white mica forms plastic deformed aggregates with the slight undulatory extinctions. A white mica crenulation cleavage (Fig. 4B) is weak and is mostly concentrated in the Fe-stained microstylolitic domains. Accessory pyrite is commonly oxidized and a graphite pigment is present in the calcite matrix. The PLD metacarbonates contain the following metamorphic mineral equilibrium assemblages: Cal + Dol + Qtz + Ms (Phg) ± Phl.

METACARBONATES FROM TUHÁR (TU)

The equigranular calcite granoblastic microstructure (Fig. 4C) displays slight deformation and preferred orientation, with local transitions from fine- to medium-grained matrix. The metacarbonates are locally cut by secondary fractures filled with coarse-grained calcite. Microstylolites with increased pyrite concentrations are present (Fig. 4D). Graphite is irregularly distributed. In some places calcite porphyroblasts show a distinct lamellar pressure twinning. Dolomite porphyroblasts are regularly distributed in the fine-grained calcite domains (Fig. 4E). Dolomite is frequently clouded with secondary iron staining and graphite. Quartz forms isolated anhedronal grains and polycrystalline mosaic aggregates with an intense undulatory extinction. White micas are represented by platy muscovite in a calcite matrix (Fig. 4F). Isolated pyrite grains frequently have pseudo-hexagonal sections and are partly transformed to secondary Fe-oxides (hematite and goethite).

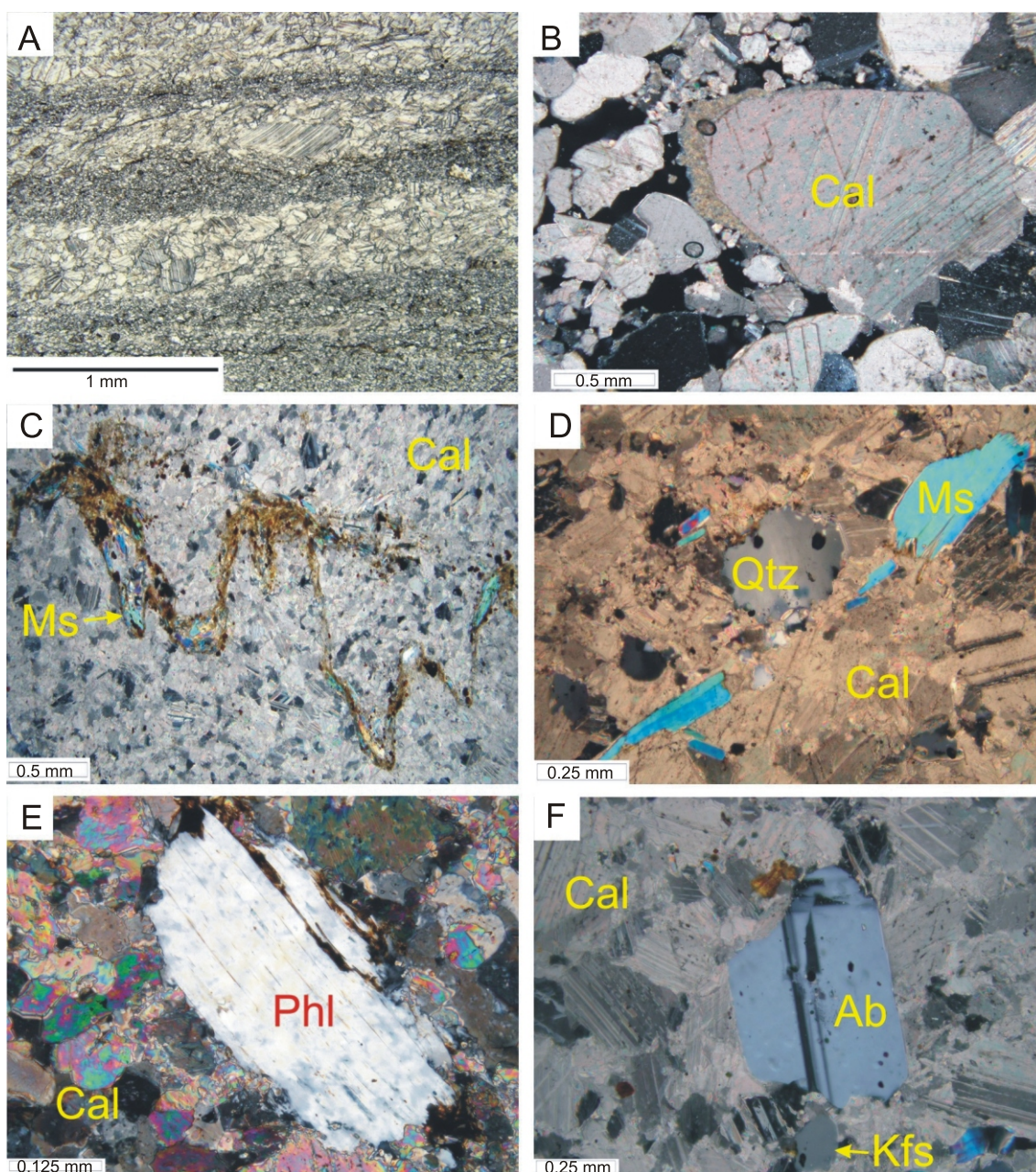


Fig. 3. Microstructural relations in the DP sample

A – regular mylonitic lamination in granoblastic texture, B – calcite porphyroclasts, C – microstylolites containing muscovite, D – muscovite and quartz in the calcite domains, E – parallel oriented phlogopite crystals, F – albite as isolated grains with rarely preserved twinning lamellae; Ab – albite, Cal – calcite, Kfs – K-feldspar, Ms – muscovite, Phl – phlogopite, Qtz – quartz

Opaque mineral concentrations are connected with microstylolites that separate fine- and coarse-grained calcite aggregates. The metamorphic mineral assemblage is formed by Cal + Dol + Qtz \pm Ms (Phg).

CHEMICAL COMPOSITION OF THE MINERALS

CALCITE AND DOLOMITE

Calcite analyses were obtained from grains coexisting with dolomite. The PLD calcites and dolomites have elevated FeCO_3

relative to those of the other units (Table 2). The average molar fraction of X_{MgCO_3} from calcite compositions range from 0.017 to 0.025, with very low contents of X_{FeCO_3} 0.001–0.014 (Tables 2 and 3). The dolomite porphyroblasts from the Dobšiná Brook valley are the most homogeneous (Fig. 5A, B).

WHITE MICAS

In the Föderata Group metacarbonates, muscovites as white micas have been identified (Table 4). Their stoichiometric formulas are as follows:

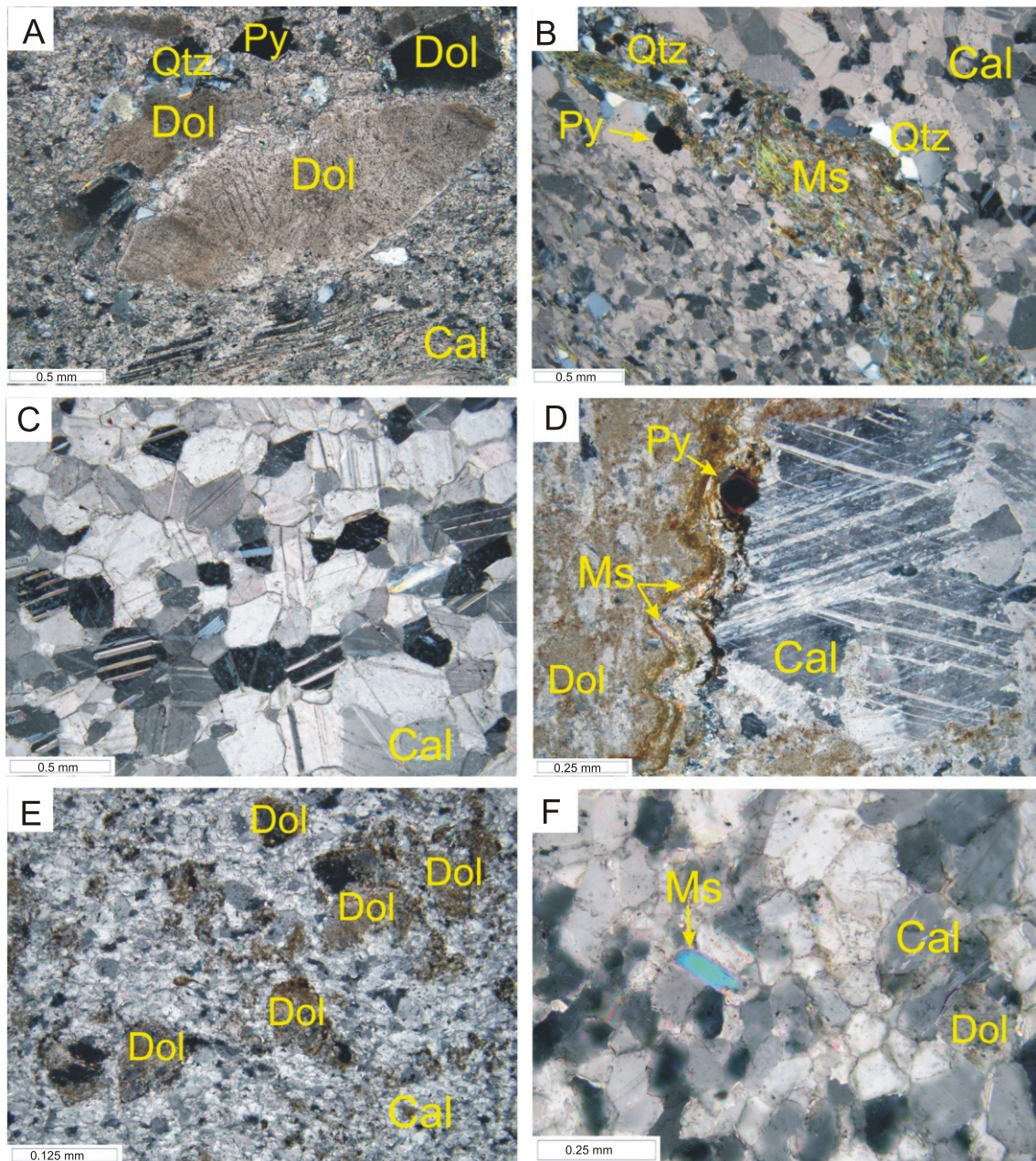


Fig. 4. Microstructural relations in the PLD and TU

A – dolomite porphyroblasts (PLD), **B** – white mica crenulation cleavage (PLD), **C** – granoblastic texture (TU), **D** – microstylolite zone with pyrite and muscovite (TU), **E** – distribution of porphyroblastic dolomite in calcite matrix (TU), **F** – muscovite in calcite matrix (TU); Dol – dolomite, Py – pyrite, other explanations as in [Figure 3](#)

1. DP: $(K_{0.93-0.94}Na_{0.01-0.03}Ca_{0-0.01})(Al_{1.49-1.71}Mg_{0.24-0.36}Fe_0Ti_{0.03-0.04})[Al_{0.72-0.73}Si_{3.27-3.28}O_{10}](F_0OH)_2$
2. PLD: $(K_{0.86-0.88}Na_{0.04-0.06}Ca_0)(Al_{1.65-1.70}Mg_{0.21-0.26}Fe_{0.04-0.05}Ti_{0.01})[Al_{0.78-0.79}Si_{3.21-3.22}O_{10}](F_0OH)_2$
3. TU: $(K_{0.79-0.93}Na_{0.01-0.12}Ca_{0.02})(Al_{1.52-1.82}Mg_{0.10-0.47}Fe_{0.01-0.09}Ti_{0.01-0.02})[Al_{0.55-0.85}Si_{3.15-3.45}O_{10}](F_0OH)_2$

In the TU and DP metacarbonates most white mica compositions are muscovite with some analyses classed as phengite ([Fig. 6](#)). In the PLD metacarbonates only muscovite compositions are present. The primary lithology mainly influenced the modal quantity of white mica in the metacarbonates. In the TU samples the muscovite is present only in accessory amounts, compared with the DP samples where muscovite is common.

PHLOGOPITE

Phlogopite is the stable index mineral in the biotite zone within the greenschist facies stability field in the metacarbonates studied. In the sample DP-7 phlogopite was identified as a stable part of the metamorphic mineral assemblage ([Table 4](#) and [Fig. 6](#)). In the sample PLD the transition phase between muscovite and phlogopite was identified, which probably reflects submicroscopic intergrowths of muscovite and phlogopite ([Fig. 6](#)). The phlogopite stoichiometric formula from the DP sample has the following formulation: $(K_{0.95}Na_{0.02}Ca_{0.01})(Al_{0.07}Mg_{2.85}Fe_0Ti_0)[Al_{0.89}Si_{3.10}O_{10}](F_0OH)_2$ ([Fig. 5A](#)).

Table 2

Microprobe analyses of calcite and dolomite from Dobšiná Brook valley (DP) and Plačková valley (PLD) metacarbonates

Sample	DP-2	DP-2	DP-8	DP-8	DP-14	DP-14	DP-16	DP-16	PLD-1	PLD-1	PLD-2	PLD-2
Phase	Cal	Dol	Cal	Dol	Cal	Dol	Cal	Dol	Cal	Dol	Cal	Dol
Average values [wt.%]												
FeO	0.03	0.14	0.03	0.04	0.03	0.02	0.03	0.02	0.84	5.19	0.72	5.98
MnO	0.01	0.01	0.02	0.01	0.00	0.02	0.01	0.02	0.08	0.18	0.07	0.17
MgO	1.19	21.70	1.15	20.88	1.04	21.18	0.90	21.51	0.81	17.16	0.79	16.86
SrO	0.04	0.05	0.04	0.04	0.04	0.03	0.14	0.04	0.11	0.04	0.09	0.04
CaO	54.41	30.88	55.40	30.37	53.14	30.59	54.63	30.88	53.20	29.88	53.45	29.24
Total	55.68	52.78	56.64	51.35	54.26	51.84	55.72	52.48	55.03	52.46	55.12	52.30
Formula normalization to 6 oxygens												
Fe ²⁺	0.021	0.109	0.023	0.031	0.023	0.016	0.023	0.016	0.653	4.034	0.560	4.648
Mn ²⁺	0.008	0.006	0.017	0.011	0.004	0.014	0.007	0.014	0.061	0.142	0.056	0.135
Mg ²⁺	0.716	13.086	0.696	12.594	0.624	12.774	0.545	12.973	0.489	10.351	0.474	10.168
Sr ²⁺	0.034	0.044	0.030	0.031	0.037	0.023	0.121	0.036	0.089	0.031	0.080	0.036
Ca ²⁺	38.887	22.068	39.592	21.708	37.980	21.862	39.044	22.072	38.020	21.359	38.201	20.901
Total	39.666	35.314	40.358	34.375	38.669	34.688	39.740	35.110	39.313	35.917	39.372	35.888
FeCO ₃	0.044	0.226	0.048	0.065	0.048	0.032	0.048	0.032	1.355	8.369	1.161	9.643
MnCO ₃	0.016	0.013	0.035	0.024	0.008	0.029	0.014	0.030	0.128	0.297	0.118	0.282
MgCO ₃	2.485	45.396	2.415	43.687	2.166	44.312	1.889	45.001	1.696	35.907	1.645	35.274
SrCO ₃	0.057	0.074	0.050	0.052	0.062	0.039	0.205	0.060	0.151	0.052	0.135	0.060
CaCO ₃	97.111	55.111	98.873	54.211	94.847	54.595	97.504	55.119	94.947	53.338	95.399	52.196
Total	99.713	100.820	101.421	98.039	97.131	99.008	99.660	100.243	98.277	97.964	98.458	97.455
X _{CaCO₃}	0.975		0.976		0.977		0.981		0.969		0.971	
X _{MgCO₃}	0.025		0.024		0.022		0.019		0.017		0.017	
X _{FeCO₃}	0.001		0.001		0.001		0.001		0.014		0.012	

Explanations as in Figures 3 and 4

Table 3

FELDSPARS

Microprobe analyses of calcite and dolomite from the Tuhár (TU) metacarbonates

Sample	TU-1	TU-1	TU-2	TU-2	TU-4	TU-4	TU-7	TU-7
Phase	Cal	Dol	Cal	Dol	Cal	Dol	Cal	Dol
Average values [wt.%]								
FeO	0.11	0.88	0.08	0.74	0.08	0.74	0.07	0.48
MnO	0.02	0.05	0.02	0.02	0.02	0.04	0.01	0.04
MgO	0.87	20.36	0.88	20.67	0.90	20.64	0.87	21.29
SrO	0.02	0.01	0.01	0.01	0.03	0.01	0.02	0.03
CaO	54.68	31.08	54.76	30.91	54.62	30.95	54.71	30.81
Total	55.70	52.39	55.75	52.36	55.66	52.38	55.67	52.64
Formula normalization to 6 oxygens								
Fe ²⁺	0.086	0.684	0.062	0.575	0.062	0.575	0.054	0.373
Mn ²⁺	0.015	0.043	0.013	0.019	0.018	0.032	0.007	0.027
Mg ²⁺	0.526	12.280	0.533	12.467	0.546	12.448	0.522	12.836
Sr ²⁺	0.017	0.011	0.005	0.007	0.025	0.008	0.017	0.022
Ca ²⁺	39.081	22.214	39.140	22.091	39.036	22.121	39.098	22.020
Total	39.724	35.231	39.753	35.159	39.687	35.184	39.697	35.278
FeCO ₃	0.177	1.419	0.129	1.193	0.129	1.193	0.113	0.774
MnCO ₃	0.031	0.089	0.027	0.039	0.038	0.067	0.014	0.057
MgCO ₃	1.825	42.600	1.848	43.247	1.892	43.181	1.810	44.528
SrCO ₃	0.028	0.018	0.009	0.011	0.042	0.013	0.029	0.037
CaCO ₃	97.595	55.474	97.743	55.168	97.485	55.243	97.638	54.990
Total	99.656	99.599	99.756	99.659	99.586	99.697	99.604	100.386
X _{CaCO₃}	0.980		0.980		0.980		0.981	
X _{MgCO₃}	0.018		0.019		0.019		0.018	
X _{FeCO₃}	0.002		0.001		0.001		0.001	

Explanations as in Figures 3 and 4

In the DP metacarbonate samples the metamorphic K-feldspars have an albite component in the range of Ab_{2.32} and Ab_{6.57}, with the formula (K_{0.90-0.92}Na_{0.02-0.07}Ca_{0-0.01})Al_{1.00-1.01}Si_{2.9-3.00}O₈ a Pl-Ab: (Na_{0.94-0.99}K_{0-0.01}Ca_{0-0.05})Al_{0.99-1.03}Si_{2.96-3.02}O₈. The associated albites have an anorthite content of An_{4.82} to An_{10.33} (Table 5). The feldspars' coexisting microstructures are seen in the BSE images (Fig. 7D-F).

GEO-THERMOBAROMETRIC CALCULATIONS

PHENGITE GEOBAROMETRY

Pressure conditions estimates are derived from phengite compositions of white micas using Massone and Schreyer (1987), from the assemblage white mica + Kfs + Phl + Qtz, which was found in metacarbonates from DP (Table 4). The intensity of regional metamorphism across the Föderata Group varies, as do the differ-

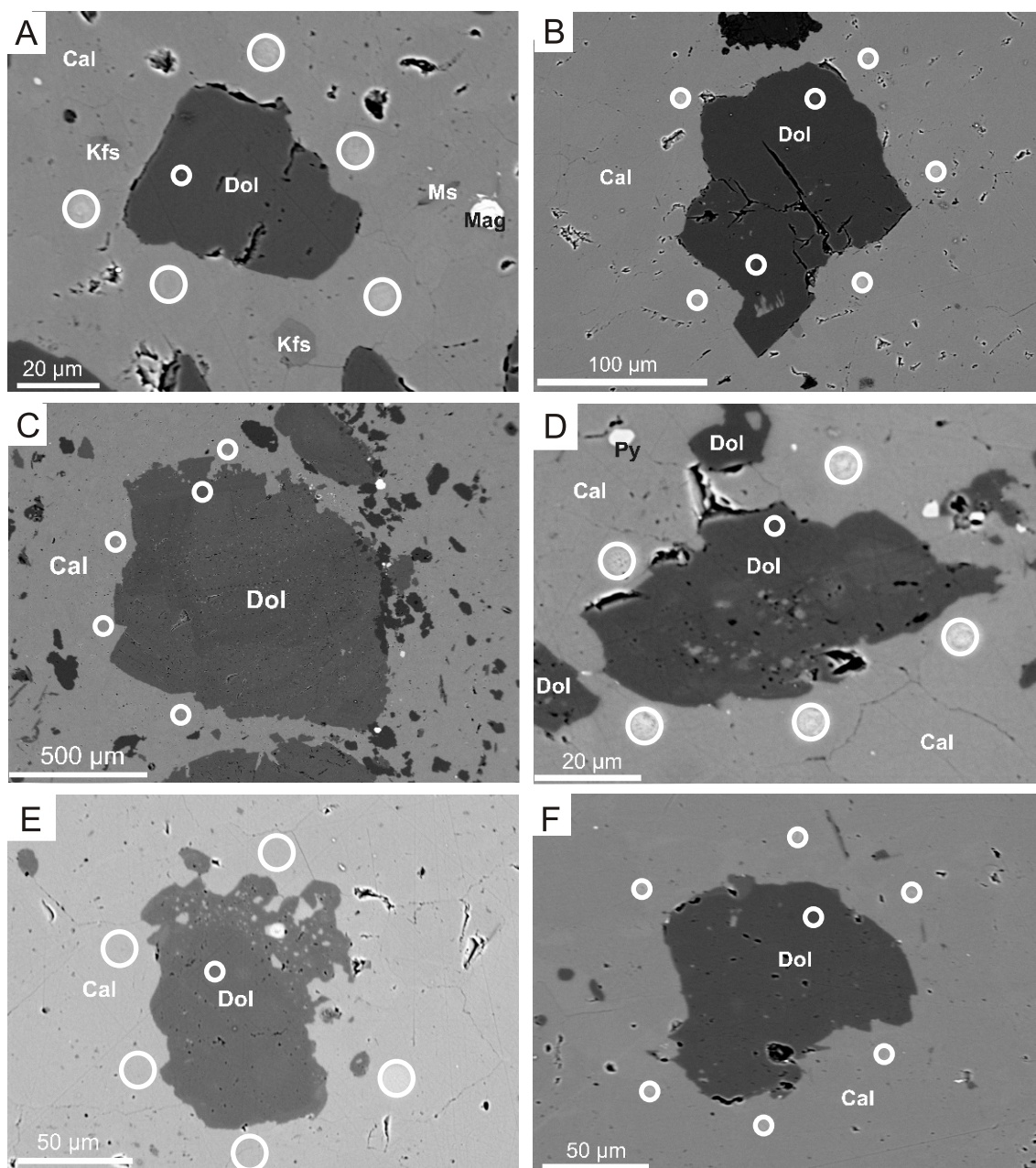


Fig. 5. Back-scattered electron (BSE) images of calcite and dolomite in metacarbonates

A – sample DP-2, B – sample DP-16, C – sample PLD-2, D – sample TU-1, E – sample TU-4, F – sample TU-7, analysed points are in white; Mag – magnetite; other explanations as in [Figures 3 and 4](#)

ent mineral assemblages and P–T conditions. Mineral assemblages of DP and in part also PLD metacarbonates indicate pressure conditions in the range of 0.4–0.5 GPa, as phlogopite-forming reactions occurred. This is in contrast to the TU samples, where phlogopite and feldspars are absent and Ms is present with Cal + Dol + Qtz, suggesting a lower pressure range of 0.3–0.35 GPa. The P–T conditions of phlogopite-bearing assemblages were experimentally determined by Puhán and Johannes (1974) and Puhán (1978), based on the reaction $3\text{Dol} + \text{Kfs} + \text{H}_2\text{O} = \text{Phl} + 3\text{Cal} + 3\text{CO}_2$ which gives pressures ranging from 0.4 to 0.6 GPa at 400–650°C with X_{CO_2} 0–1.

CALCITE-DOLOMITE SOLVUS GEOTHERMOMETRY

The chemical composition of the end-member carbonate components of metamorphic calcites, coexisting with dolomites, were calculated to molar fractions X_{CaCO_3} , X_{MgCO_3} and X_{FeCO_3} . For the calculation of recrystallization conditions ([Table 6](#)), the solvus calibrations of Anovitz and Essene (1987) and McSwiggen (1993) were used. A temperature variation of $\pm 50^\circ\text{C}$ is assumed for the Anovitz and Essene (1987) calculation. The X_{MgCO_3} in calcite is the most temperature-dependent parameter and is the highest in the DP samples ([Table 2](#)).

The recrystallization temperatures of calcite in the TU samples range from 354 to 416°C at the pressures from 0.3 to 0.35 GPa. A slight increase in temperature (405–471°C) is shown at pressures from 0.3 to 0.4 GPa, from the PLD samples. The highest temperatures, ranging from 460 to 476°C are from the DP samples at pressures ranging from 0.4 to 0.5 GPa (Table 6 and Fig. 8).

FELDSPAR SOLVUS GEOTHERMOMETRY

The Ab–Or mineral pair exists only in the DP metacarbonates, so this method was used just for this sample (Fig. 7D–F). A temperature interval of feldspar recrystallization that ranged from 329 to 453°C at pressures of 0.4–0.5 GPa was obtained by application of *SOLV CALC* vers. 2.0 (Table 6 and Fig. 9).

CHEMOGRAPHIC RELATIONS IN THE KCMAS-HC SYSTEM

The chemographic composition of the DP metacarbonate samples is shown in ternary diagrams (Fig. 10).

Phase relations in the mineral assemblages Cal + Dol + Qtz + Ms (Phg) + Phl + Kfs + Ab were graphically interpreted in the KCMAS-HC (K₂O–CaO–MgO–Al₂O₃–SiO₂–H₂O–CO₂) system recommended by Bucher and Frey (2002) for metacarbonates, which cannot be chemically determined in CMS-HC

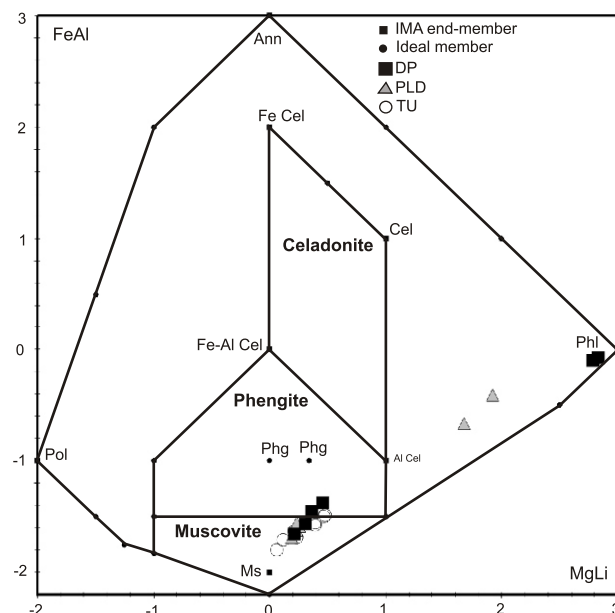


Fig. 6. Mg-Li vs. Fe-Al composition diagram of di-octahedric K-micas in metacarbonates from the Dobšiná Brook valley (DP), Plačková valley (PLD) and Tuhár (TU) after Tischendorf *et al.* (2004)

Micas represent two groups. The first falls within the muscovite field in transition to the phengite field and the second towards the phlogopite field; Ann – annite, Pol – polyolithionite, other explanations as in Figure 3

Table 4

Microprobe analyses of micas in metacarbonates from the Dobšiná Brook valley (DP), Plačková valley (PLD) and Tuhár (TU)

Sample	DP-7	DP-7	DP-16	DP-17	PLD-1	PLD-2	TU-2	TU-4	TU-8
Phase	Ms (Phg)	Phl	Ms (Phg)	Ms (Phg)	Ms	Ms	Ms	Ms	Ms
Values [wt.%]									
SiO ₂	49.31	44.54	50.13	49.94	48.68	48.77	47.78	52.15	49.02
Al ₂ O ₃	31.34	11.72	28.69	28.66	31.37	31.92	34.24	26.62	31.26
TiO ₂	0.72	0.05	0.69	0.90	0.19	0.17	0.31	0.16	0.44
MgO	2.41	27.39	3.66	3.65	2.61	2.09	1.05	4.74	2.19
FeO	0.01	0.00	0.00	0.05	0.93	0.69	1.59	0.21	1.46
MnO	0.02	0.01	0.02	0.00	0.00	0.00	0.01	0.03	0.02
CaO	0.06	0.08	0.06	0.03	0.00	0.01	0.24	0.27	0.34
Na ₂ O	0.21	0.12	0.09	0.15	0.33	0.44	0.97	0.08	0.41
K ₂ O	11.12	10.74	11.21	11.07	10.43	10.23	9.44	11.08	10.10
Total	95.04	94.66	94.55	94.45	94.54	94.33	95.62	95.35	95.24
Formula normalization to 11 oxygens									
Si	3.266	3.105	3.279	3.278	3.209	3.219	3.153	3.449	3.255
Al ^{iv}	0.734	0.895	0.721	0.722	0.791	0.781	0.847	0.551	0.745
Al ^{vi}	1.712	0.068	1.490	1.495	1.646	1.703	1.816	1.523	1.700
Ti	0.036	0.003	0.034	0.045	0.009	0.008	0.015	0.008	0.022
Mg	0.238	2.846	0.357	0.357	0.256	0.206	0.103	0.467	0.216
Fe ²⁺	0.000	0.000	0.000	0.003	0.051	0.038	0.087	0.012	0.081
Mn	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.002	0.001
Ca	0.005	0.006	0.004	0.002	0.000	0.001	0.017	0.019	0.024
Na	0.027	0.017	0.012	0.019	0.043	0.057	0.124	0.011	0.053
K	0.939	0.955	0.935	0.927	0.877	0.861	0.795	0.934	0.856

Ms (Phg) – muscovite (phengite), other explanations as in Figure 3

Table 5

Microprobe analyses of feldspars in metacarbonates from the Dobšíná Brook valley (DP)

Sample	DP-1	DP-1	DP-1	DP-1	DP-2	DP-2	DP-8	DP-8
Phase	Ab	Or	Ab	Or	Ab	Or	Ab	Or
Values [wt.%]								
SiO ₂	68.53	65.39	67.83	64.34	69.22	65.05	68.90	64.68
Al ₂ O ₃	19.61	18.58	20.02	18.41	19.29	18.28	19.54	18.26
FeO	0.00	0.00	0.01	0.00	0.03	0.11	0.05	0.03
CaO	0.57	0.13	1.18	0.12	0.08	0.01	0.52	0.23
Na ₂ O	11.73	0.70	11.21	0.72	11.21	0.24	11.19	0.65
K ₂ O	0.13	15.51	0.15	15.42	0.15	15.62	0.14	15.19
Total	100.57	100.32	100.40	99.02	99.98	99.32	100.34	99.05
Formula normalization to 8 oxygens								
Si ⁴⁺	2.983	3.000	2.961	2.994	3.016	3.013	2.997	3.004
Al ³⁺	1.006	1.005	1.030	1.010	0.991	0.998	1.002	1.000
Fe ²⁺	0.000	0.000	0.000	0.000	0.001	0.004	0.002	0.001
Ca ²⁺	0.026	0.007	0.055	0.006	0.004	0.001	0.024	0.011
Na ⁺	0.990	0.062	0.949	0.065	0.947	0.022	0.944	0.059
K ⁺	0.007	0.908	0.008	0.916	0.008	0.923	0.008	0.900
Total	5.012	4.982	5.003	4.991	4.967	4.961	4.978	4.975
An	5.02	1.34	10.33	1.22	0.75	0.15	4.82	2.31
Ab	94.28	6.34	88.91	6.57	98.40	2.32	94.40	5.99
Or	0.70	92.32	0.76	92.21	0.85	97.53	0.79	91.70

Or – orthoclase, other explanations as in Figure 3

Table 6

Calculated P–T conditions of metamorphism of metacarbonates from the Dobšíná Brook valley (DP), Plačková valley (PLD) and Tuhár (TU)

Sample	DP	DP	DP	DP	PLD	PLD	PLD	PLD	TU	TU	TU
Geobarometer pressure (GPa)	Phg (M & S)										
	–	0.4	0.45	0.5	–	0.3	0.35	0.4	–	0.3	0.35
Geothermometer	Cal–Dol (A & E)	Cal–Dol (McS)	Cal–Dol (McS)	Cal–Dol (McS)	Cal–Dol (A & E)	Cal–Dol (McS)	Cal–Dol (McS)	Cal–Dol (McS)	Cal–Dol (A & E)	Cal–Dol (McS)	Cal–Dol (McS)
Temperature [°C]											
T _{min.}	327	384	392	400	311	405	413	421	306	354	362
T _{max.}	418	460	468	476	374	455	463	471	365	409	416
T _{average}	374	421	429	437	345	433	441	449	335	381	389
Standard deviation	28	24	24	24	17	13	13	13	17	14	14
Geothermometer	Temperature [°C]	Pressure (GPa)									
SOLV CALC		0.4	0.45	0.5							
Kfs–Ab (N & B)	T _{min.}	378	379	385							
	T _{max.}	404	447	453							
	T _{average}	391	409	414							
Kfs–Ab (E & G)	T _{min.}	339	392	362							
	T _{max.}	390	416	446							
	T _{average}	367	401	411							
Kfs–Ab (L & N)	T _{min.}	356	334	390							
	T _{max.}	375	400	395							
	T _{average}	367	374	392							
Kfs–Ab (F & L)	T _{min.}	342	329	353							
	T _{max.}	393	417	404							
	T _{average}	374	372	379							
Standard deviation		10–15	17–27	15–25							

A & E – Anovitz and Essene (1987), E & G – Elkins and Grove (1990), F & L – Fuhrman and Lindsley (1988), L & N – Lindsley and Nekvasil (1989), McS – McSwiggen (1993), M & S – Massone and Schreyer (1987), N & B – Nekvasil and Burnham (1987); explanations as in Figures 3 and 4

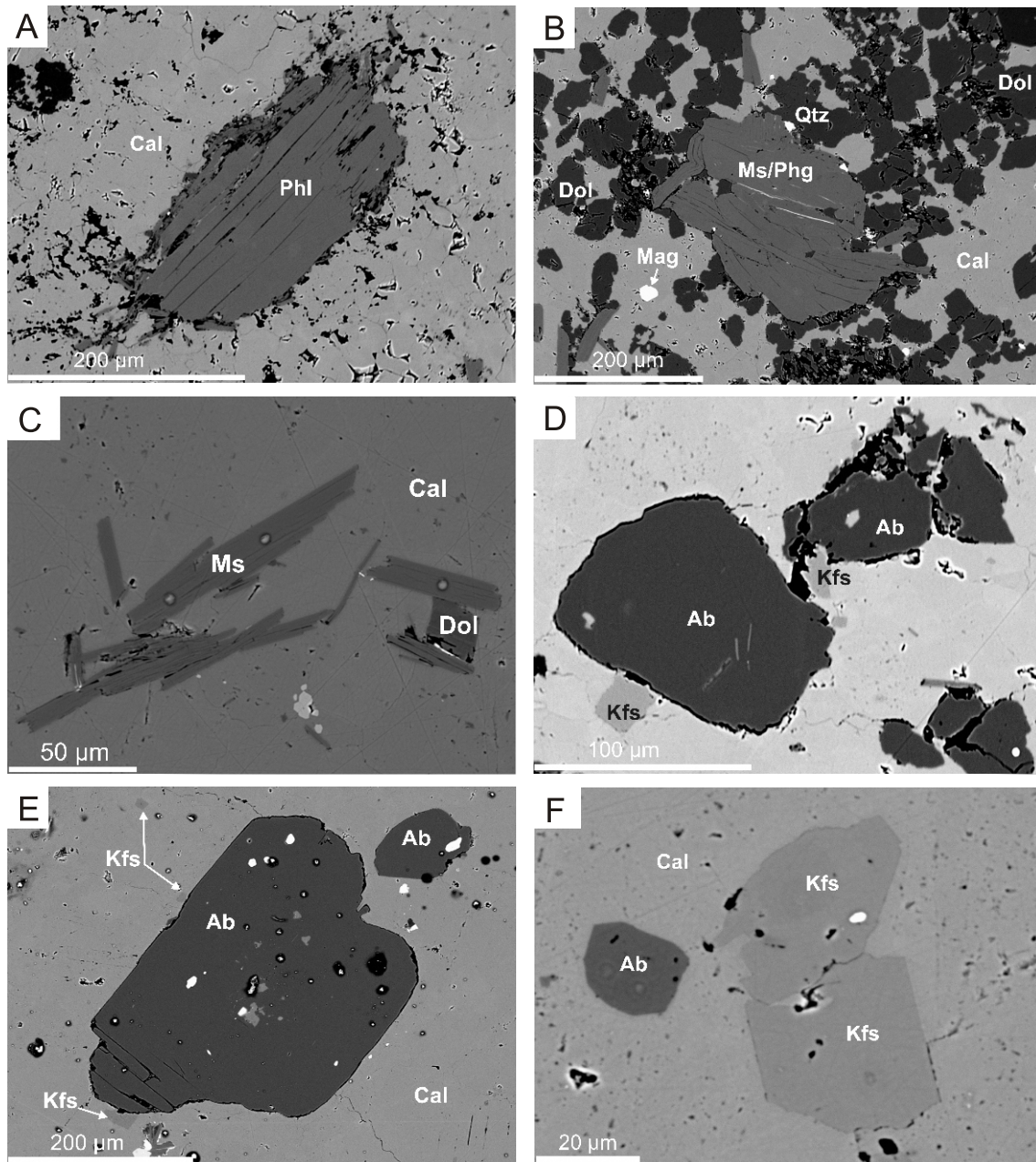


Fig. 7. Back-scattered electron (BSE) images of muscovite/phengite, phlogopite, K-feldspar and albite in metacarbonates, metamorphic K-feldspar and albite coexist in metacarbonates from the Dobšiná Brook valley

A – sample DP-7; B – sample DP-17; C – sample TU-4; D, E – sample DP-2; F – sample DP-8; explanations as in [Figures 3–5](#) and [Table 4](#)

(CaO-MgO-SiO₂-H₂O-CO₂) system. In the ternary K₂O-CaO-MgO chemographic projection three stability fields have been recognized, representing stable mineral assemblages: (1) Kfs + Cal + Dol, (2) Kfs + Dol + Phl and (3) Phl + Dol + Mgs at a pressure of 0.4 GPa.

The stability of phlogopite is maintained in grey fields in the triangle ([Fig. 10](#)). A temperature of 447°C is considered as representing transition conditions, where the new stable Kfs + Cal + Phl assemblage is transformed from the initial mineral assemblage (Kfs + Cal + Dol). Micas and feldspars are the most important silicate minerals present in metacarbonate mineral assemblages of the southern Veporicum Föderata Group.

Phlogopite-forming reactions included dolomite as an essential source of the magnesium component. The bulk potassium concentration in the primary protolith enabled the progressive K-feldspar and phlogopite-forming reaction.

Low values of the mole fraction of CO₂ ($X_{CO_2} \sim 0.15$) in the DP metacarbonate assemblages ([Fig. 10](#)) is suggested by the absence of tremolite, diopside, wollastonite and other minerals, which are commonly formed by decarbonisation reactions at higher X_{CO_2} values. Low values of X_{CO_2} were also indicated by the calculated phase relations on the isobaric T- X_{CO_2} diagram ([Fig. 11](#)).

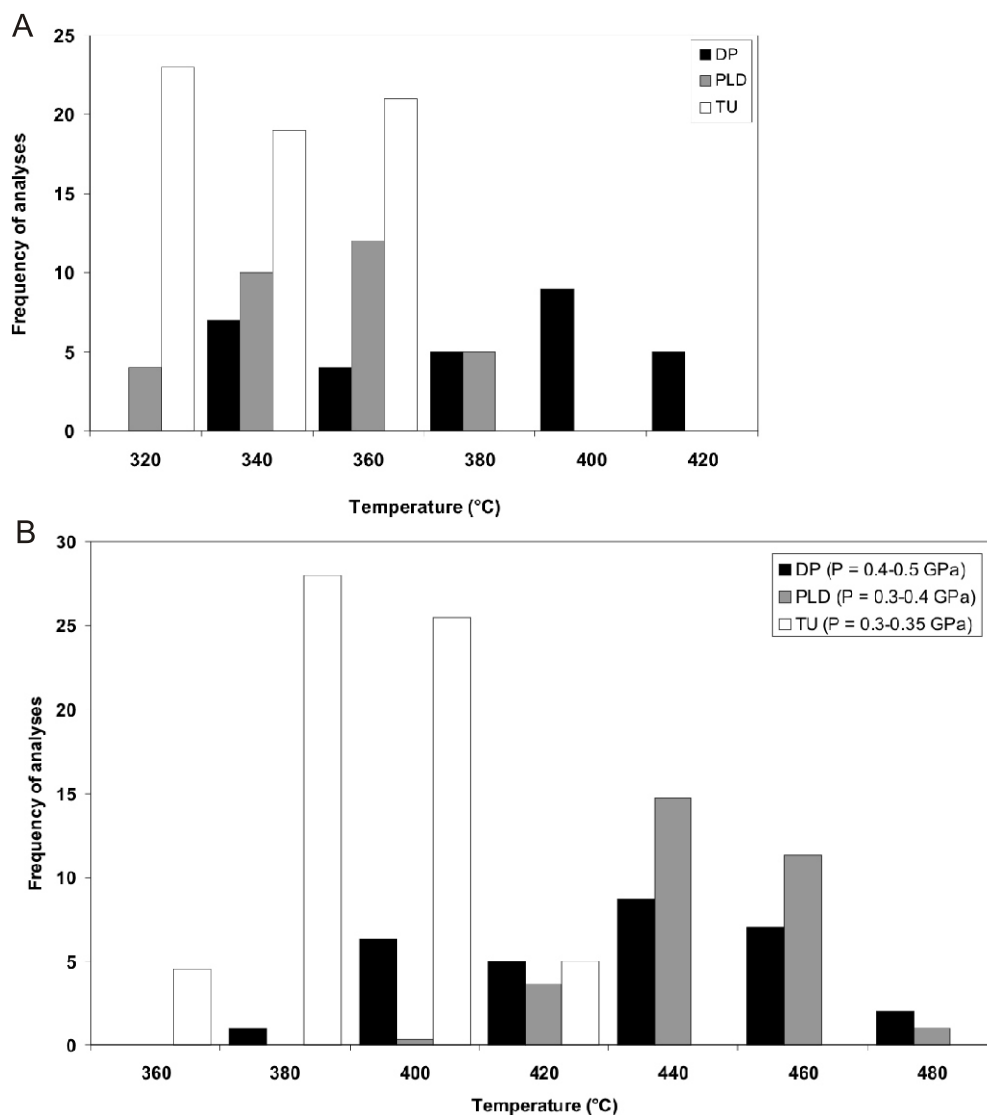


Fig. 8. Histograms of calcite-dolomite geothermometry calculated using the calibrations

A – Anovitz and Essene (1987), B – McSwiggen (1993)

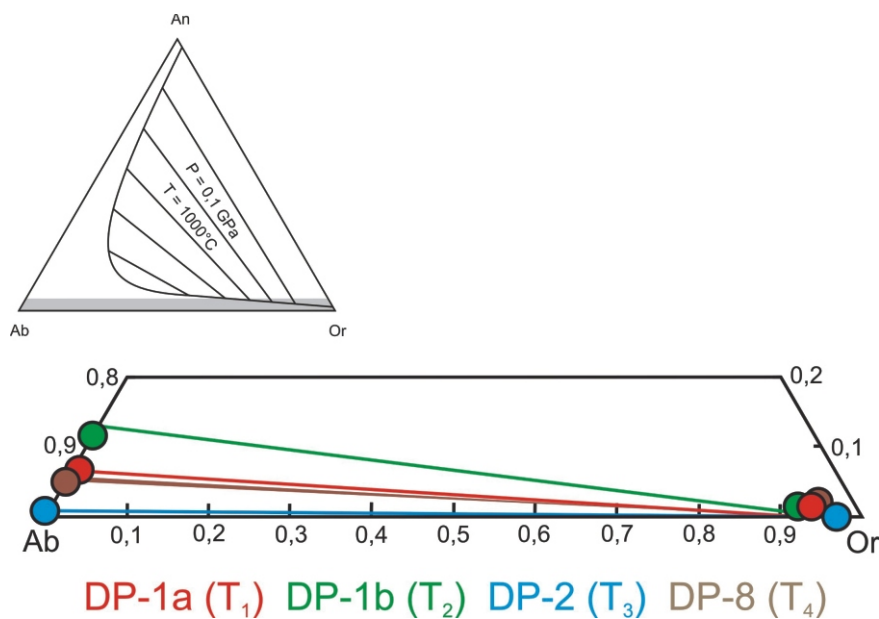


Fig. 9. Ternary phase diagrams of feldspar compiled in *SOLV CALC* vers. 2.0 (Wen and Nekvasil, 1994)

The segments mark linear representations of feldspar composition at specified temperature (T_{1-4}) and pressure ($P = 0.4-0.5$ GPa) conditions; An – anorthite, other explanations as in Figure 3 and Table 4

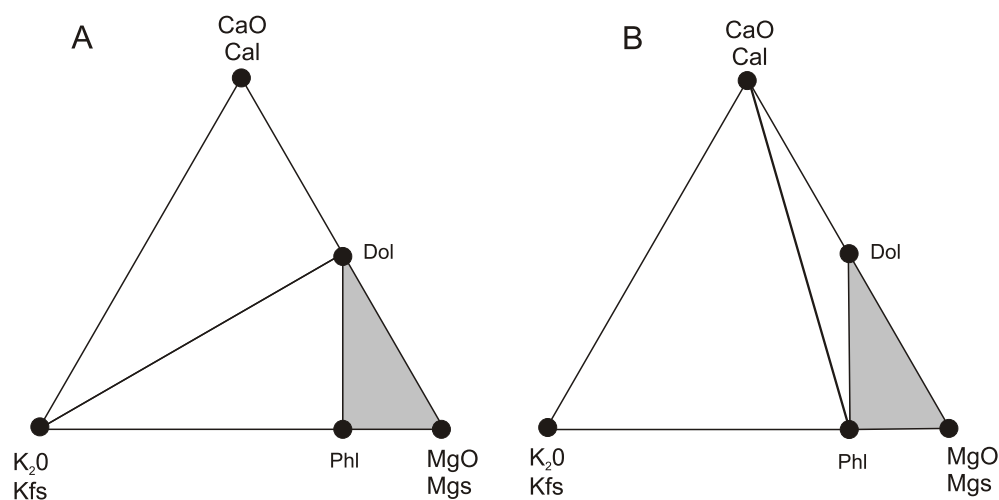


Fig. 10. Composition diagram of the KCMAS-HC system, the X_{CO_2} value is 0.15 at 0.4 GPa

A – the phase diagram represents the temperature stability of phlogopite at 444°C, B – stable mineral assemblage with phlogopite at 447°C; Mgs – magnesite, other explanations as in Figures 3 and 4

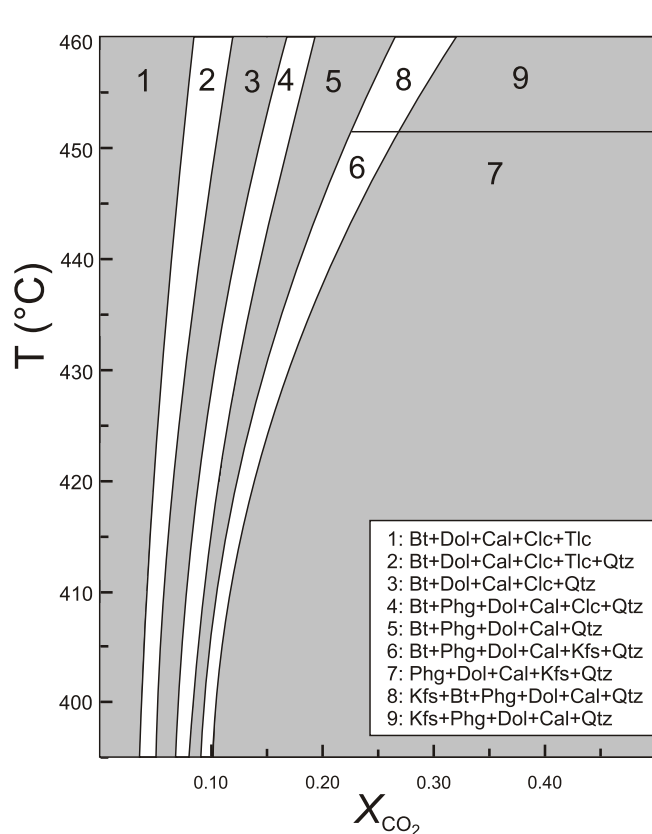


Fig. 11. T- X_{CO_2} phase diagram of metacarbonate rock from DP is represented by divariant fields (white) and trivariant fields (grey) of stable mineral assemblage. Program *PERPLEX_07* modelling determined nine stable mineral assemblages in the temperature range of 400–460°C and X_{CO_2} interval 0–0.5 at a constant pressure of 0.4 GPa

Bt – biotite, Clc – clinocllore, Tlc – talc, other explanations as in Figures 3, 4 and Table 4

T- X_{CO_2} PHASE DIAGRAM

We assume element and fluid migration took place during metamorphism in the carbonates. The presence of metamorphic $\text{H}_2\text{O}-\text{CO}_2$ fluids with ($X_{\text{H}_2\text{O}} \sim 0.9$) influenced the metamorphic mineralogical changes during recrystallization of the carbonates, associated with white micas forming, with a prevailing phengite composition.

The mineral assemblage Bt + Phg + Dol + Cal + Kfs + Qtz fits in a divariant stability field (Fig. 11) and corresponds with the mineral assemblage of the DP metacarbonates, at temperatures of approx. 410°C, $X_{\text{CO}_2} \sim 0.1$ and at 440°C, $X_{\text{CO}_2} \sim 0.2$, and at 460°C, $X_{\text{CO}_2} \sim 0.3$ respectively at constant pressure of 0.4 GPa.

P-T PSEUDOSECTION DIAGRAM IN THE KCFMAS-HC SYSTEM

P-T pseudosection diagrams of metacarbonates for samples DP-1, DP-9, DP-17 and PLD-3 (Fig. 12) were modelled using the *PERPLEX_07* program (Connolly, 2007). Pseudosections were formed in KCFMAS-HC ($\text{K}_2\text{O}-\text{CaO}-\text{FeO}-\text{MnO}-\text{Al}_2\text{O}_3-\text{SiO}_2-\text{H}_2\text{O}-\text{CO}_2$) system from the whole-rock chemical analyses of metacarbonates. The thermodynamic database (Holland and Powell, 1998, revised, 2002) was used for modelling of stable mineral assemblages in the metacarbonates.

The stable mineral assemblages shown in the pseudosection diagrams show the importance of fluid composition on mineral assemblages during low-grade metamorphism. In the calculation of pseudosection solution models for dolomite and calcite (Anovitz and Essene, 1987), phengite (Holland and Powell, 1990), biotite (Holland and Powell, 1998) and plagioclase – K-feldspar (Fuhrman and Lindsley, 1988) were used. A simplified metacarbonate bulk composition is shown in the pseudosections, containing linearly arranged stable mineral

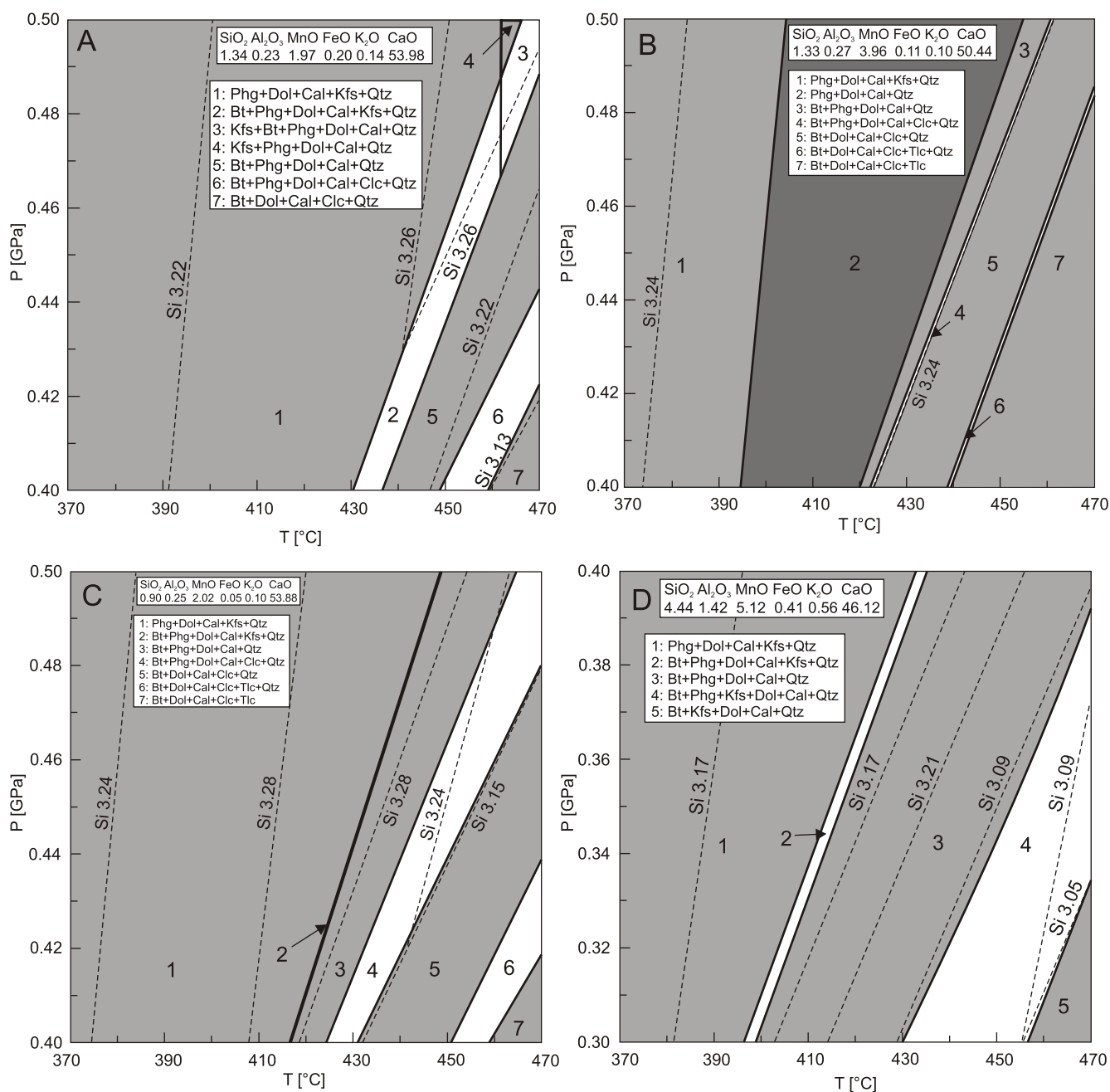


Fig. 12. Composition pseudosections of the metacarbonates calculated in the KCFMAS-HC system from the bulk rock compositions of samples from the Dobšiná Brook valley (DP) and Plačková valley (PLD)

A – sample DP-1, **B** – sample DP-9, **C** – sample DP-17, **D** – sample PLD-3, black lines represent the calculated Si-isopleth; other explanations as in Figures 3, 4, 11 and Table 4

assemblages, grouped into di-, tri- and tetravariant fields. In the pseudosection diagrams, five mineral phases (Phg, Dol, Cal, Kfs, Qtz) are generally present in the trivariant stability fields (light grey).

Divariant stability fields (white) with six mineral phases (Bt, Phg, Kfs, Dol, Cal, Qtz) are not common in diagrams (Fig. 12). A tetravariant stability field (dark grey) represents four mineral phases (Phg, Dol, Cal, Qtz) in the DP-9 sample (Fig. 12B). All modelled combinations of the stable mineral assemblages are shown in pseudosection diagrams for 0.4 to 0.5 GPa for the DP samples and from 0.3 to 0.4 GPa for the

PLD samples, with temperature intervals from 370 to 470°C (Fig. 12). These are first data of this type for the Slovak part of the Western Carpathians.

The phengite Si-isopleths, that are stable in the divariant- and trivariant fields of the pseudosection diagram, were determined from the chemical composition of samples DP-1, DP-9, DP-17 and PLD-3. The steep positive slopes of the phengite Si-isopleths in the pseudosections (Fig. 12) do not allow a pressure estimate for these assemblages. Our results suggest that the phengite Si-content of the white mica in the mineral assemblage depends on the chemical composition of the metacarbonates.

DISCUSSION

Vrána (1966, 1980) studied Alpine metamorphic processes of the Veporicum granitoids and siliciclastic metasedimentary rocks of the Föderata Group. Comparisons (Vrána, 1965) were made among the dark grey foliated calcite and dolomite marbles with siliciclastic metasedimentary rocks in the middle part of the Veporicum, south of the Zbojská saddle. Based on index minerals, Bt + Chl, he determined the grade of the Alpine metamorphism of the southern Veporicum Mesozoic cover in greenschist facies conditions.

The low-grade metamorphism in Triassic argillaceous schists and clayey limestones of the Föderata Group were described by Plašienka *et al.* (1989). The temperature was determined by a Kübler's index in the range of 300–350°C at a fluid pressure at 0.2–0.3 GPa. Vozárová (1990) summarized the metamorphic conditions in the Gemicum and Veporicum contact zone. Based on the existence of the index minerals Cld + Ky, Vozárová (1990) suggested temperatures of metamorphism of 400–450°C, which correspond to greenschist facies conditions, at pressures of 0.4–0.6 GPa and suggested a geothermal gradient of around 10–15°C/km. Korikovsky *et al.* (1992) determined the temperature of anchimetamorphism of Permian sandstones of the Struženík (Föderata) Group to be approx. 200–300°C.

For determination of geothermobarometric conditions of the Alpine metamorphism, Mazzoli *et al.* (1992) used samples of Lower Triassic metapelites from the localities of Pohronská Polhora and Divín, which are interlayered with quartzites. The metamorphic mineral assemblage is formed by Qtz + Ms ± Chl (chlorite) ± Ep (epidote) ± Ab. Based on the b_0 parameter of white micas, the pressure of the Alpine recrystallization was determined to be 0.12 GPa and the temperature was estimated to be 350–400°C at a geothermal gradient of 10°C/km.

Korikovsky *et al.* (1997) published microprobe analyses of carbonate minerals and micas from the Dobšiná Brook valley metacarbonates. The mineral assemblage Cal + Dol + Phl + Phg ± Qtz ± Ab of dolomite marbles from the Dobšiná Brook valley is typical of low-grade greenschist facies conditions within the temperature range of 350–380°C. The MgO content in calcites (0.93–1.17 wt.%) analysed by Korikovsky (*op. cit.*) are almost identical with the analyses given in Table 2. The MgO contents in the phlogopite studied (Table 4) are higher than the data given by Korikovsky *et al.* (1997), where the measured values range from 15.67 to 25.86 wt.%. Calculated Si contents in phengite on the basis of 11 oxygens (3.17–3.27), published by Korikovsky *et al.* (1997), are lower than our data in Table 4. Thus, the maximum pressure given by Korikovsky *et al.* (1997) ranges from 0.8–0.9 GPa. These data point to a significantly higher metamorphic pressures than given in our calculations (0.4–0.5 GPa). Our pressure estimates match better the structural-deformation concept of Plašienka (1999) characterized by low-pressures of up to 0.6 GPa.

The chemical composition of newly formed micas and K-feldspars from the Dobšiná Brook valley were published by Lupták *et al.* (2003). Most of the analyses were based on samples of quartzites with intermediate layers enriched by metapelites. These Ms (Phg) data are very similar to our data from metacarbonates given in Table 4. Lupták *et al.* (2003)

identified, in metacarbonates, the following mineral assemblage: Cal + Dol + Qtz + Ms (Phg) + Kfs ± Chl. For the determination of metamorphic P–T conditions, Kübler's index (KI) of illite was used in combination with chlorite geothermometry (Lupták *et al.*, 2003). Based on illite KI values, metasedimentary rocks of the Föderata Group attained the degree of metamorphism at the boundary between the anchizone and the beginning of greenschist facies. Calculated temperatures by chlorite geothermometers (Cathelineau, 1988; Jowett, 1991 in Lupták *et al.*, 2003) gave higher values. The metamorphic pressures were determined to be 0.4–0.45 GPa at temperatures around ~380°C, calculated from the intersection of chlorite geothermometers using of the program *THERMOCALC* vers. 3.1 (Powell and Holland, 1988) and the metamorphic reaction $3\text{Cel} = \text{Phl} + 2\text{Kfs} + 3\text{Qtz} + 2\text{H}_2\text{O}$ from metapelite enriched by Kfs + Bt (Lupták *et al.*, 2003). These data are approximately consistent with our P–T data obtained from metacarbonates.

The P–T conditions of the Alpine regional recrystallization of metacarbonates are partly different from the results of Lupták *et al.* (2003). The temperature range of 335–380°C at pressure 0.4–0.45 GPa given by Lupták *et al.* (2003) can be compared with the results of metacarbonate recrystallization given by calcite-dolomite solvus geothermometry (384–400°C at pressure 0.4–0.5 GPa) and feldspar geothermometry (329–392°C at pressure 0.45 GPa) as given in Table 6. The minimal temperature of calcite recrystallization is consistent with Lupták's data at an approximate temperature of 380°C. The maximum temperature calculated from feldspar coexistence at 390°C partly corresponds to Lupták *et al.* (2003). The metacarbonate recrystallization temperature reflects the Alpine regional metamorphic maximum of the southern Veporicum Mesozoic cover, culminating in P–T conditions of 453°C ($T_{\text{Or-Ab}}$) and 476°C ($T_{\text{Cal-Dol}}$) a pressure of 0.5 GPa.

Ružička and Vozárová (2009) applied the calcite-dolomite solvus geothermometry to assess the degree of Tuhár marble metamorphic recrystallization (Table 6). The metamorphic carbonate recrystallization occurred in conditions of greenschist facies in the stability field of kyanite. The metacarbonate sample DP-7 is considered to be an exception, since phengite geobarometry and solvus geothermometry suggest temperatures ranging from 440–460°C at pressures of 0.4–0.5 GPa (Fig. 13).

CONCLUSIONS

Research into the Föderata Group metacarbonates from the southern Veporicum cover sequence enhances understanding of metamorphic evolution during Cretaceous orogenesis. Geothermobarometry combined with microscopic, electron-optical methods and whole-rock chemical analyses were used for assessment of metamorphic P–T conditions. The determination of Alpine metamorphic P–T conditions in the southern Veporicum Unit is problematic, because it is dominantly formed by recrystallized successions, in which is difficult to distinguish particular mineral assemblages. The regional metamorphism of Veporicum occurred during a collision event that resulted in thickening of crust during the Cretaceous. The pre-Alpine basement together with its Late Paleozoic and Mesozoic cover suc-

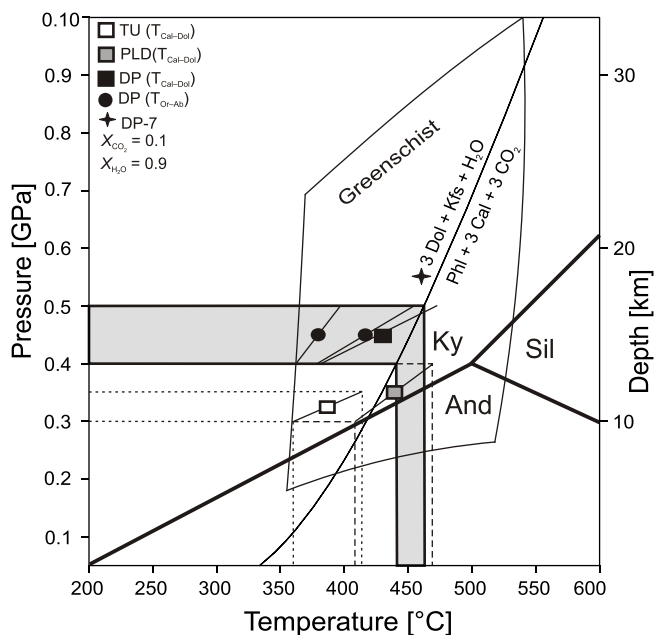


Fig. 13. P–T diagram showing the univariant reaction limiting the stability of phlogopite + calcite

The grey field crossing the temperature axis at 440–460°C represents the range of pressure of the calculated P–T conditions for calcite and dolomite recrystallization. The field of the greenschist facies is after Winter (2001), showing the calcite-dolomite recrystallization temperatures according to (McSwiggen, 1993), axis feldspars recrystallization temperatures calculated by *SOLV CALC* vers. 2.0 (Wen and Nekvasil, 1994). The segments represent the temperature recrystallization range of metacarbonates from the Föderata Group in the south Veporicum Unit. And – andalusite, Ky – kyanite, Sil – sillimanite, other explanations as in Figures 3 and 4

cessions were subjected to regional metamorphic events (e.g., Plašienka, 1999 and references therein).

The metacarbonates studied were formed from the carbonate protolith of the Steinalm, Wetterstein, Ramin and Gutenstein limestones facies at low-temperature and low-pressure conditions of the greenschist facies during Alpine regional metamorphism. The following metamorphic mineral assemblages have been identified:

1. DP samples: Cal + Dol + Qtz + Ms (Phg) + Phl + Kfs + Ab,
2. PLD samples: Cal + Dol + Qtz + Ms (Phg) ± Phl,
3. TU samples: Cal + Dol + Qtz ± Ms (Phg).

The metamorphic pressure conditions of the metacarbonates were determined by phengite geobarometry, based on microprobe analyses of white mica. Pressures range thus from 0.3 to 0.5 GPa. Temperatures of the calcite recrystallization were determined from calcite-dolomite solvus geothermometry using the calibration equations T_1 and T_2 of

Anovitz and Essene, (1987) and McSwiggen, (1993). The results are:

1. DP samples: $T_1 = 327\text{--}418^\circ\text{C} \pm 28^\circ\text{C}$; $T_2 = 384\text{--}476^\circ\text{C} \pm 24^\circ\text{C}$ at $P = 0.4\text{--}0.5$ GPa,
2. PLD samples: $T_1 = 311\text{--}374^\circ\text{C} \pm 17^\circ\text{C}$; $T_2 = 405\text{--}471^\circ\text{C} \pm 13^\circ\text{C}$ at $P = 0.3\text{--}0.4$ GPa,
3. TU samples: $T_1 = 306\text{--}365^\circ\text{C} \pm 17^\circ\text{C}$; $T_2 = 354\text{--}416^\circ\text{C} \pm 14^\circ\text{C}$ at $P = 0.3\text{--}0.35$ GPa.

The temperature data based on feldspar geothermometry for the Dobšiná Brook valley metacarbonates ranges from 329 to 453°C at pressures of 0.4–0.5 GPa. The limits of the stability field of phlogopite + calcite in the KCMAS-HS system gave a temperature interval of 444–447°C at a pressure of 0.4 GPa (Fig. 7). The metamorphic reaction $3\text{Dol} + \text{Kfs} + \text{H}_2\text{O} = \text{Phl} + 3\text{Cal} + 3\text{CO}_2$ gave for sample DP-7 a pressure of 0.4 to 0.5 GPa over a temperature range of 440–460°C (Fig. 13).

The following factors contribute to the diversity of the P–T grade in the metacarbonates within the Föderata Group sedimentary sequence during Cretaceous orogenesis in the southern Veporicum Unit:

1. Variable metamorphic mineral assemblages, within particular metacarbonate localities, belong to the same lithostratigraphic unit. Phlogopite and metamorphic K-feldspar along with plagioclase were identified in the DP samples (Fig. 7D–F). Relict phlogopite was partly present in secondary kaolinite matrix in the PLD samples, while feldspars were absent. Phlogopite and feldspars are completely absent from the TU samples.

2. Differences in chemical composition of metamorphic calcites (the highest values of X_{MgCO_3} were detected in the DP samples, Table 2) correspond to calculated recrystallization temperatures using calibrated geothermometers. Different pressure-temperature effects caused the different structural arrangements of calcite aggregates.

3. The intensity of metamorphic recrystallization processes was controlled by the relation between the depth of tectonic burial and the distance from the Veporicum and Gemericum contact zone. Due to these effects, the metacarbonates from the Dobšiná Brook valley, situated close to the Veporicum and Gemericum contact zone, show the highest metamorphic grade in metacarbonates. The intensity of the metamorphic recrystallization shows a decreasing trend towards the south-west part of the southern Veporicum Unit.

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