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Hydrothermal activity in the Strzelin granite, SW Poland

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Abstract: The Strzelin granite is a good example of a granitic body altered by hydrothermal fluids. The alteration is visible mainly as bleached zones located along fractures filled by hydrothermal minerals in the following order: quartz, feldspars, muscovite, chlorite, clinozoisite, prehnite, laumontite or kaolinite, calcite. Based on mineralogical composition and the frequency and size of the secondary minerals, three degrees of alteration (slight, moderate and strong) are, for practical purposes, distinguished within the granite. The 22 chemical reactions have been noted taking into account substrates and products of alteration. Mass balance calculations for every degree of alteration reveal different element behaviors. In the highly altered granite, silica was removed from the system and H_2O, iron and CO_2 added. The volume of rock decreased. The least mobile element was Al. The minerals laumontite and prehnite indicate zeolite-facies P-T conditions down to 70 m below surface. Below, incomplete prehnite-pumpellyite facies assemblages begin to appear.

Key words: hydrothermal alteration, granite, degree of alteration, Strzelin, Lower Silesia

INTRODUCTION

The chemical, mineral and textural composition of the granite in the Strzelin massif (for the geological map *see* Fig 1, p. 218 *in* Oberc-Dziedzic 2007) was changed by hydrothermal fluids that migrated along fissures, caverns, microfractures, cleavage planes and grain interstices. Indications of alteration are (1) the presence of mineralized veins of different thicknesses composed of minerals crystallized at lower temperatures; (2) a presence of bleached zones associated with fractures filled with hydrothermal minerals where the degree of alteration increases towards the veins; (3) replacement of primary minerals in the host granite by secondary minerals. Differences in hydrothermal-mineral associations reflect differences in fluid chemical composition, temperatures, pH and host rock compositions.

Intense hydrothermal alteration is well seen in the northern part of the Strzelin massif and especially in the Main Quarry (Fig. 1 *in* Oberc-Dziedzic 2007). This is the only quarry located in a stock-like intrusion from which a thick and flat apophyses and dykes branch off. The nearby Mikoszów quarry is located on the granite apophysis and there the alteration is unique. Thus, the presence and intensity of alteration is connected mainly with the form of granite. The Strzelin granite is poor in pegmatites.

Field examination, and the work of Oberc (1972) and Oberc-Dziedzic *et al*. (1996), underpin the following tectonic history of the granite.

1. Intrusion of medium-grained leucocratic granite into partially consolidated fine -grained granite;

2. Formation of pegmatites and aplites;
3. Shearing and N-S fractures (270/70);
4. Hydrothermal activity;
5. Shearing and formation of NW-SE (236/70) fracture system;
6. Tensional regime and hydrothermal activity;
7. Development of WSW-ENE/90 and horizontal fractures.

Two stages of hydrothermal activity are indicated above. Alternatively, it is possible that all fractures (Fig. 1 *left*) were simultaneously formed and later only two sets of them were opened to permit access by hydrothermal fluids (Figs. 1 *right*, 2 and 3).

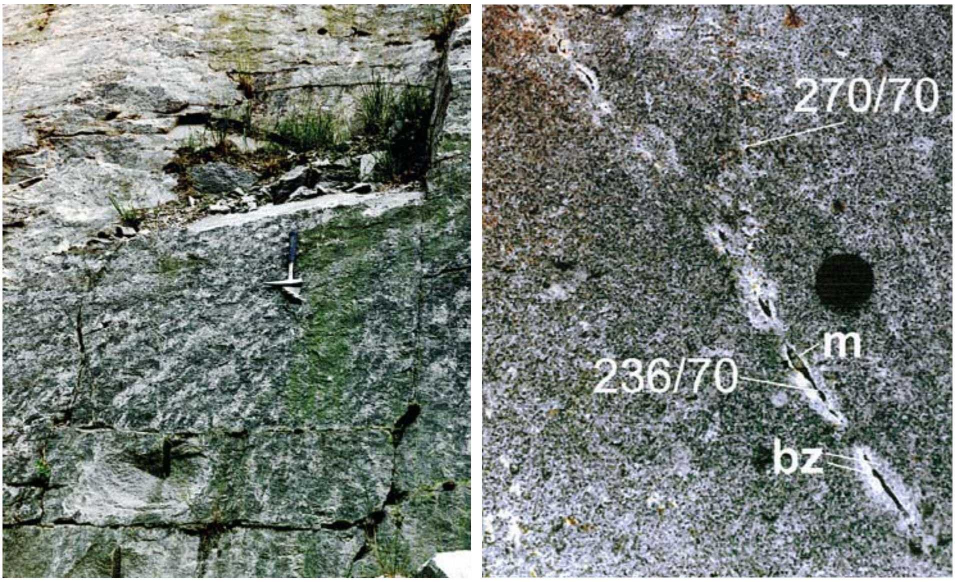

Fig. 1. Hydrothermal alteration in the Main Quarry of the Strzelin granite. *Left* – three-dimensional fracture system: horizontal, WSW-ENE vertical and NW-SE vertical (plane of view); *right* – sequence of fractures with hydrothermal veins; the N-S system predates the 236/70 fracture system, the variable thickness of veins, their mineralization (m) and bleached zones (bz) associated with them are clearly seen.

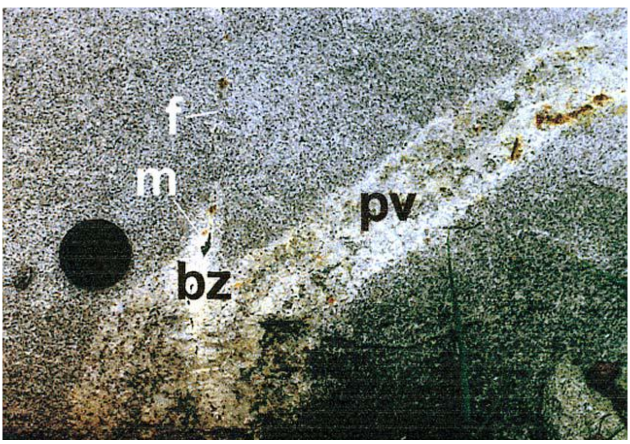

Fig. 2. Post-magmatic phenomena, succession of events: 1 – pegmatite vein (pv) formation; 2 – shearing; 3 – fractures (f), mineralisation (m) and development of bleached zones (bz).

By comparison with the unaltered granite, three stages of increasing intensity of alteration was defined: the granite may be slightly-, moderately- or strongly altered**.** The

Fig. 3. Example of granite cut by multiple hydrothermal veins of different thickness.

main factors taken into account in classifying samples were the presence of biotite, relative proportions post-biotite chlorite and spherulitic chlorite, plagioclase compositions and quantities of hydrothermal minerals.

Slightly altered granite differs from unaltered rock in a number of ways. Post-biotite chlorite prevails over biotite. Plagioclase anorthite contents are lower. Other hydrothermal minerals such as prehnite or spherulitic chlorite are rarely present.

Granite altered to a moderate degree contains a greater proportion of hydrothermal minerals. Almost all biotite grains are replaced by chlorite. The altered granite is enriched in water as indicated by the whole rock geochemistry. Plagioclases compositions are albite or albite/oligoclase.

Strongly altered granite does not contain biotite. Plagioclases are composed of albite with 1-2% anorthite. Spherulitic chlorite prevails over post-biotite chlorite, the amount of quartz decreases and hydrothermal minerals are common. The bleached zones, typically 5 mm wide but ranging from 2-20 mm, exemplify the highly altered granite. The main mineral is albite which predominates over potassium feldspar and quartz. Hardly any chlorite, muscovite, calcite, clinozoisite or titanite is present.

Borders between portions of granite that have suffered different degrees of alteration are clearly visible, but not sharp. Transitional zones can be 1-3 mm wide. Hydrothermally altered Strzelin granite is illustrated on Fig. 4 where the stronly altered zone, 1-1.5 cm thick, is bleached and the border with moderately altered granite is uneven. The bleached zone fringes a hydrothermal vein filled with chlorite (Ciesielczuk, Janeczek 2004).

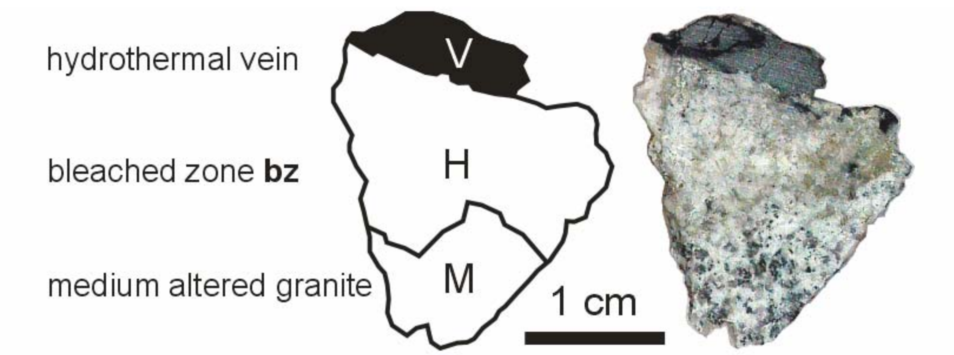

Fig. 4. Hydrothermally altered granite adjacent to a chlorite vein (V). A strongly-altered bleached zone (bz) passes outwards into moderately altered granite (M).

Table 1. Mineral composition of unaltered and variously altered Strzelin granite

	P	Slightly altered granite					Moderately altered granite				
Sample	8C	17	8B	37/2	47/2	48/3	68	J1/1	8A	7A	6
Ca-Na feldspar	XXX	XXX	XXX	XXX	XXX	XXX	X	X	X	X	X
K-feldspar	XXX	XXX	X	XXX	XX	XX	XX	X	X	XX	XX
quartz	XXX	XXX	XXX	XX	XXX	XXX	XXX	XXX	XXX	XX	XXX
biotite	X	X	X		x	X	X				
partly chloritized biotite	X	X	X	X	X		X		X		X
postbiotite chlorite	X	x	X	X	x		x		X	X	x
saussurite	X	X		XX	X		X		XX	XX	X
albite		X	X	X	X	X	XX	XX	XX	XX	X
spherulitic chlorite			X	X	X			X		X	X
clinozoisite					x			X	X	X	x
prehnite			x	X	X		x	X	XX	X	X
laumontite									x	x	x
garnet							x				
calcite							x	X	x	X	
titanite				X			x		x		
muscovite					X		X				

Note: P – unaltered granite

	Strongly altered granite										
Sample	5	3	7B	47/1	48/1	48/2	62	J1/2	37/1	4	GSA
Ca-Na feldspar											
K-feldspar		XX	XX	XX	XXX	XX	X	X	XX		
quartz	XX		X	XXX			XX		X		XXX
postbiotite chlorite	XX	x	x	X				x	X	x	X
saussurite		XX	XX	X	X	X		XX	XXX	X	
albite	XX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
spherulitic chlorite		XXX	XX	X		XX	XX	XX	X	XXX	
clinozoisite	X	X	X		x	X	x	XX	x	XX	
prehnite	X	XX	X	X	X	X	XX	XX	X	XX	X
laumontite			x					x		x	
calcite	XX X	X	X	x	XX	X	X	x	x		X
titanite	x	x	X		x		X	x	x	X	X
muscovite				X	X	X	X				X

PETROGRAPHIC AND MINERALOGICAL FEATURES

The mineral compositions of unaltered- and variously altered Strzelin granite are presented in Table 1. Rocks showing the same apparent degree of alteration can deviate from the overall pattern in their mineral and chemical composition. The petrographic characteristics of the hydrothermally altered Strzelin granite are exemplified here by those of individual samples – unaltered (sample no 19), slightly altered (no 17), no 68 for moderately altered and strongly-altered granite (no 62).

Unaltered granite

The unaltered Strzelin granite (sample 19) is a grey, subhedral, medium to fine-grained biotitic granite with chaotic texture. The most abundant mineral is subhedral white plagioclase. Plagoclase grains range in size from 1.5 to 4 mm and are typically normally zoned. The anorthite content, which in the grain cores is <50%, decreases to 15% towards the rim (Table 2). Rare small (0.1-0.5 mm), homogeneous albite grains occur. Anhedral grains (1-5 mm) of microcline contain <9% albite (Table 3). Anhedral grains of quartz are also common. Flakes of biotite (0.1-1.5 mm) typically form aggregates and show light brown to dark reddish-brown pleochroizm. The biotite chemical composition is constant in the unaltered granite and differs from those in altered part (Table 4). Value of Fe/(Fe+Mg), the lowest encountered, ranges from 0.69 to 0.71; the Mg content in unaltered-granite biotite is the highest.

Even in the unaltered granite, some biotite flakes are partly chloritized and the central parts of some plagioclase grains slightly saussuritized. Accessory minerals include zircon, apatite and titanite. The density of the unaltered granite is 2.658 g/cm^3.

Table 2. Chemical composition of plagioclase in unaltered and variously altered Strzelin granite

	Unaltered granite Sample 19				Slightly altered granite Sample 17				M. a. granite Sample 68	Strongly altered granite Sample 62	
	core	transition zone		rim	core	transition zone		rim			
SiO_2	55.74	59.10	61.01	64.26	61.48	61.28	62.99	63.45	65.82	68.40	68.17
TiO_2	-	0.06	0.05	0.02	-	0.02	-	-	-	-	-
Al_2O_3	28.15	25.64	23.80	22.17	24.56	23.36	22.63	21.78	21.29	20.70	20.63
FeO	0.02	0.05	0.05	0.28	-	-	0.05	0.19	0.13	-	0.01
MnO	0.02	0.02	0.02	-	-	0.35	-	0.33	-	-	-
MgO	-	-	-	0.01	0.02	-	-	-	-	0.01	-
BaO	-	0.08	0.20	0.11	-	-	-	-	-	0.03	-
CaO	10.08	7.29	5.19	3.26	5.38	4.21	3.55	2.72	2.17	0.33	0.22
Na_2O	5.52	7.66	8.68	10.02	7.90	9.16	10.26	10.37	10.53	10.88	11.05
K_2O	0.11	0.20	0.35	0.29	0.14	0.23	0.33	0.35	0.07	0.05	0.06
total	99.64	100.10	99.35	100.42	99.47	98.60	99.81	99.20	100.00	100.40	100.14
AB	49	65	74	83	72	79	82	86	90	98	99
AN	50	34	24	15	27	20	16	12	10	2	1
OR	1	1	2	2	1	1	2	2	-	-	-

Note: M. a. – moderately altered

Slightly altered granite

Slightly altered medium-grained granite (sample 17, Table 1) consists of feldspars, quartz, biotite and small amounts of zircon and post-biotite chlorite. Large (2-3.5 mm) euhedral plagioclase grains are characterized by albite twinning and most are normally zoned. They are less anorthite rich than in unaltered granite (Table 2). Narrow, discontinuous zones of secondary albite rim some of these plagioclases. Large (1.5-5 mm) anhedral grains of microcline contain <12% albite (Table 3). Biotite, in <2 mm flakes, contains more Fe and less Mg than that present in unaltered granite; Fe/(Fe+Mg) is higher and ranges from 0.78-0.80 (Table 4).

Table 3. Chemical composition of K-feldspar in unaltered and variously altered Strzelin granite

	Unaltered Sample 19		Slightly altered Sample 17		Moderately altered Sample 68		Strongly altered Sample 62	
SiO_2	64.28	64.54	63.89	63.25	65.31	64.73	64.09	65.02
TiO_2	0.06	0.08	0.11	0.07	-	0.02	-	-
Al_2O_3	18.18	18.22	18.44	19.17	18.81	18.52	19.33	19.06
FeO	-	0.05	0.38	0.29	0.09	0.05	0.01	0.01
MnO	-	-	0.09	-	-	-	0.05	0.02
MgO	-	-	-	-	-	-	-	-
BaO	0.02	0.05					0.22	0.27
CaO	0.04	0.04	-	0.13	0.03	0.01	-	0.04
Na_2O	0.58	1.05	0.44	1.28	1.59	0.92	0.21	0.15
K_2O	15.38	15.10	15.64	14.87	14.14	15.76	17.04	17.23
total	98.54	99.13	99.00	99.07	99.97	100.01	100.95	101.80
AB	5	9	4	12	14	8	2	1
AN	-	-	-	1	-	-	-	-
OR	95	91	96	87	86	92	98	99

Table 4. Chemical composition of mica in unaltered and variously altered Strzelin granite

	Unaltered granite (sample 19)			Slightly altered granite (sample 17)				Moderately altered granite (sample 68)		
SiO_2	34.80	35.92	35.79	34.25	33.66	33.70	34.10	34.02	35.27	32.86
TiO_2	3.51	3.14	2.99	3.04	2.98	2.66	2.64	1.10	1.55	1.30
Al_2O_3	15.81	15.36	15.94	16.40	16.09	16.61	17.00	20.75	20.40	20.92
FeO	24.70	24.69	23.90	28.77	29.49	29.87	28.33	27.38	27.63	28.96
MnO	0.52	0.43	0.49	0.22	0.46	-	0.11	0.85	0.61	0.86
MgO	5.66	5.84	6.05	4.23	4.22	4.45	4.46	3.52	3.38	4.38
BaO	0.37	0.29	0.05	-	-	-	-	-	-	-
CaO	-	0.03	-	-	0.08	0.08	-	0.04	0.32	0.07
Na_2O	0.12	0.13	0.09	0.08	0.12	0.15	0.11	0.10	0.16	0.09
K_2O	8.85	8.85	8.56	9.35	9.27	8.82	9.63	8.59	8.24	8.71
H_2O*	3.84	3.86	3.89	3.77	3.75	3.76	3.78	3.83	3.85	3.79
Total	98.18	98.54	97.75	100.11	100.12	100.10	100.16	100.18	101.41	101.94
Si IV	5.54	5.67	5.65	5.43	5.38	5.36	5.40	5.31	5.41	5.10
Al IV	2.46	2.33	2.35	2.57	2.62	2.64	2.60	2.69	2.59	2.90
T site	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Al VI	0.50	0.53	0.62	0.50	0.41	0.48	0.57	1.13	1.10	0.92
Ti VI	0.42	0.37	0.36	0.36	0.36	0.32	0.31	0.13	0.18	0.15
Fe^{2+}	3.29	3.26	3.16	3.82	3.94	3.97	3.75	3.58	3.55	3.76
Mn^{2+}	0.07	0.06	0.07	0.03	0.06	-	0.01	0.11	0.08	0.11
Mg	1.34	1.37	1.42	1.00	1.01	1.06	1.05	0.82	0.77	1.01
O site	5.62	5.59	5.63	5.71	5.77	5.83	5.71	5.77	5.68	5.95
Ba	0.02	0.02	-	-	-	-	-	-	-	-
Ca	-	0.01	-	-	0.01	0.01	-	0.01	0.05	0.01
Na	0.04	0.04	0.03	0.02	0.04	0.05	0.03	0.03	0.05	0.03
K	1.80	1.78	1.73	1.89	1.89	1.79	1.95	1.71	1.61	1.72
A site	1.86	1.85	1.76	1.92	1.94	1.85	1.98	1.75	1.71	1.76
O	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
OH	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Fe/(Fe+Mg)	0.71	0.70	0.69	0.79	0.80	0.79	0.78	0.81	0.82	0.79

This granite contains more SiO_2 and potassium and less calcium and sodium than the unaltered granite. The density is a slightly higher than the density of the unaltered granite at 2.669 g/cm^3.

Moderately altered granite

The main minerals in the moderately altered granite (sample 68, Table 1) are plagioclase, microcline and quartz. Plagioclases (1.5-2.5 mm) are <10% anorthitic (Table 2). Some smaller (0.1-0.5 mm) grains of plagiocase are albitic in composition. K-feldspar (1-5 mm) contains <14% albite (Table 3). Biotite, muscovite and garnet also occur. The chemical composition of the mica is that of siderophyllite. Fe/(Fe+Mg) is the highest and ranges from 0.79-0.82 (Table 4). The biotite is increasingly chloritized. Muscovite forms small flakes. Accessory minerals include zircon, F-apatite, prehnite, calcite and titanite.

This rock contains more silica, K_2O and H_2O and less Al_2O_3, FeO, MgO and CaO than the unaltered granite (sample 19). With increasing alteration, the density has increased to 2.676 g/cm^3.

Strongly altered granite

Strongly altered, medium-grained granite (sample 62, Table 1) consists of euhedral grains (4 mm) of plagioclase from which anorthite was removed (>98% Ab, *cf*. Table 2). The rock contains potassium feldspar (grains up to 2 mm), for composition *see* Table 3, and quartz. Plagioclases are strongly altered. Any primary zoning is weak or absent. Potassium feldspars are also strongly altered to clay minerals.

This granite contains less FeO, MgO and Na_2O and more CaO, K_2O and H_2O than the unaltered granite. The density is also high at 2.675 g/cm^3.

The hydrothermal association comprises titanite, spherulitic chlorite, prehnite, clinozoisite, calcite, muscovite, albite and clay minerals. Prehnite, the most common hydrothermal mineral, occurs in the central parts of plagioclase and in numerous chlorite -prehnite veins which cut this granite.

Structural formulae for three grains of prehnite are as follows:
m4: $(Ca_{1.94}\,Mn_{0.01}\,Fe_{0.03})_{1.98}\,Al_{2.02}\,Si_{3.00}O_{10.00}\,(OH)_{2.01}$
m2: $(Ca_{1.96}\,Mn_{0.02}\,Fe_{0.01})_{1.99}\,Al_{2.01}\,(Si_{2.99}\,Al_{0.01})_{3.00}\,O_{10.00}\,(OH)_{2.00}$
m4': $(Ca_{2.02}\,Fe_{0.01})_{2.03}\,Al_{1.99}\,(Si_{2.95}\,Al_{0.02})_{2.97}\,O_{10.00}\,(OH)_{1.93}$

Unhedral grains of titanite occur in the chlorite veins. These titanite crystals are very rich in Al. Some typical structural formulae are as follows:
e6: $(Ca_{1.01}\,Mn_{0.01})_{1.02}\,(Ti_{0.60}\,Al_{0.40}\,Fe_{0.01})_{1.01}\,Si_{0.97}\,O_4$ (O, F, OH)
e7: $Ca_{0.99}\,(Ti_{0.61}\,Al_{0.39})_{1.00}\,(Si_{0.98}Al_{0.02})_{1.00}\,O_4$ (O, F, OH)
e2: $Ca_{1.00}\,(Ti_{0.62}\,Al_{0.37}\,Fe_{0.01})_{1.00}\,(Si_{0.97}Al_{0.02})_{0.99}\,O_4$ (O, F, OH).

HYDROTHERMAL VEINS

Hydrothermal veins are connected with the 270/60-70 fracture system and, to a lesser degree, with the 236/70 fractures (Figs. 1-3). The intervals between veins range from 10 cm to 1 m. Locally, veins are very numerous – even every 2 cm. Typically, the veins range in thickness from 1 mm to a few centimeters. Occasional thicker veins also occur. The thickness of individual veins may vary as may that of their alteration zones.

On the basis of macro- and microscopic observations, the sequence of mineral crystallization in the fractures was established. The first mineral to crystallize was quartz in aggregates of crystals (Fig. 5a) and microscopic feldspars (Fig. 5b) followed by muscovite, chlorite, clinozoisite, prehnite (Figs. 5c and d), laumontite/kaolinite and calcite. Pyrrothite, pyrite, chalcopyrite and sphalerite also occur as small (<0.5 mm) grains on quartz, prehnite and chlorite, but not on calcite which is the last mineral to crystallize. Calcite ends the mineral sequence in hydrothermal fracture-filling veins in many granites, *e.g.*, in the Auriat granite (Parneix, Petit 1991). In Strzelin, laumontite does not coexist with kaolinite. Crystallization of laumontite or kaolinite in veins depends on the CO_2 concentration in the hydrothermal fluid (Senderov 1973; Stępisiewicz 1978).

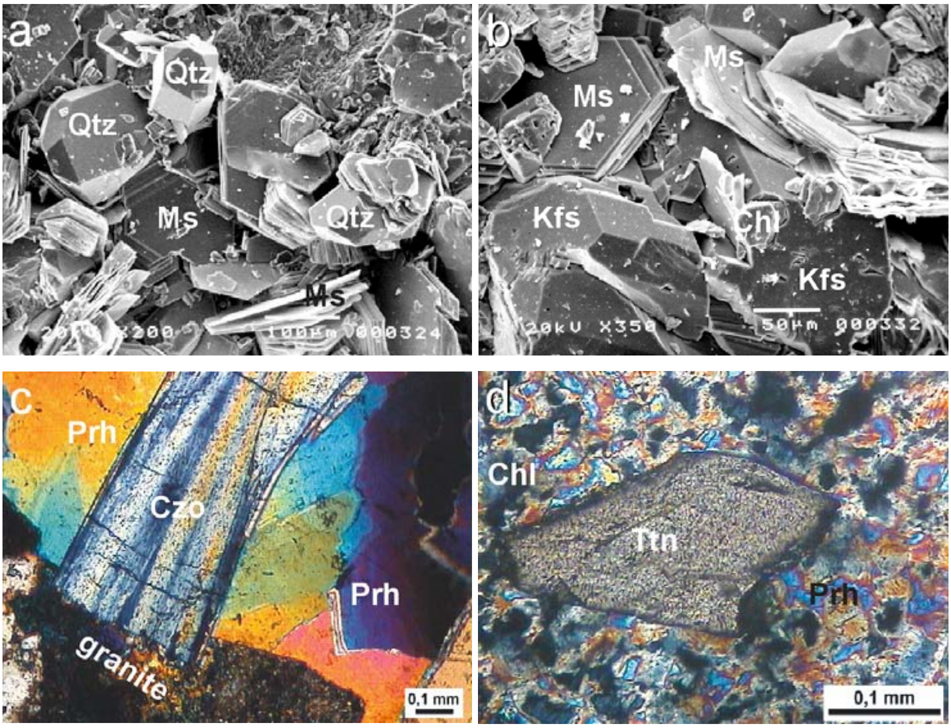

Fig. 5. Hydrothermal minerals crystallized in veins in the Strzelin granite. a) Quartz (Qtz) and muscovite (Ms). b) K-feldspar (Kfs), muscovite (Ms) and spherulitic chlorite (Chl). c) Fragment of clinozoisite (Czo)-prehnite (Prh) vein adjacent to granite. d) Fragment of chlorite (Chl)-prehnite (Prh)-titanite (Ttn) vein. a, b – SEM images; c, d – polarizing microscope, crossed polars.

To encounter the entire mineral sequence in an individual vein is rare. The most common veins are quartz-chlorite veins with prehnite (Fig. 4) or clinozoisite (Fig. 5c) and laumontite or calcite. Quartz-prehnite veins are also common as are monomineralic veins with laumontite or chlorite or calcite or quartz.

The distribution of hydrothermal minerals in veins is usually symmetric though the width of quartz or prehnite zones can vary along the vein.

Based on examination of 54 veins, the following order of mineral frequency was established: quartz (most common), chlorite, prehnite, calcite, muscovite, laumontite, ore minerals, clinozoisite and kaolinite. The most abundant minerals are those that crystallized first. Laumontite was noted in veins and in the granite down to 70 m subsurface. Below that, only prehnite is present.

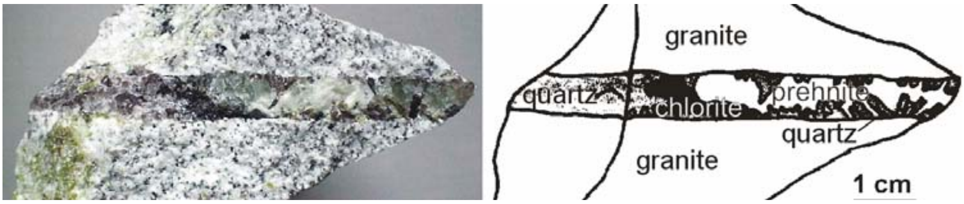

Fig. 4. Hydrothermal vein 8 mm thick with quartz, chlorite and prehnite.

Hydrothermal processes

As many as 22 hydrothermal alteration reactions may be recognized in the Strzelin granite. Biotite was replaced by (1) chlorite or (2) chlorite + titanite. Microcline was replaced by (3) clay minerals, (4) sericite and (5) albite. Post-biotite chlorite and spherulitic chlorite were replaced by muscovite (6 and 7 respectively). Plagioclase was replaced by (8) clay minerals, (9) albite, (10) sericite, (11) clinozoisite, (12) laumontite, (13) prehnite, (14) sericite + prehnite, (15) prehnite + calcite, (16) clinozoisite +calcite, (17) muscovite + calcite, (18) sericite + prehnite + calcite, (19) prehnite + clinozoisite + calcite, (20) sericite + prehnite + clinozoisite, (21) albite + calcite and (22) sericite + prehnite + clinozoisite + calcite.

Individual samples of altered granite differ in mineral and chemical composition; different alteration processes affected each. The reactions in which biotite, plagioclase, microcline and chlorite were involved are shown on Fig. 7.

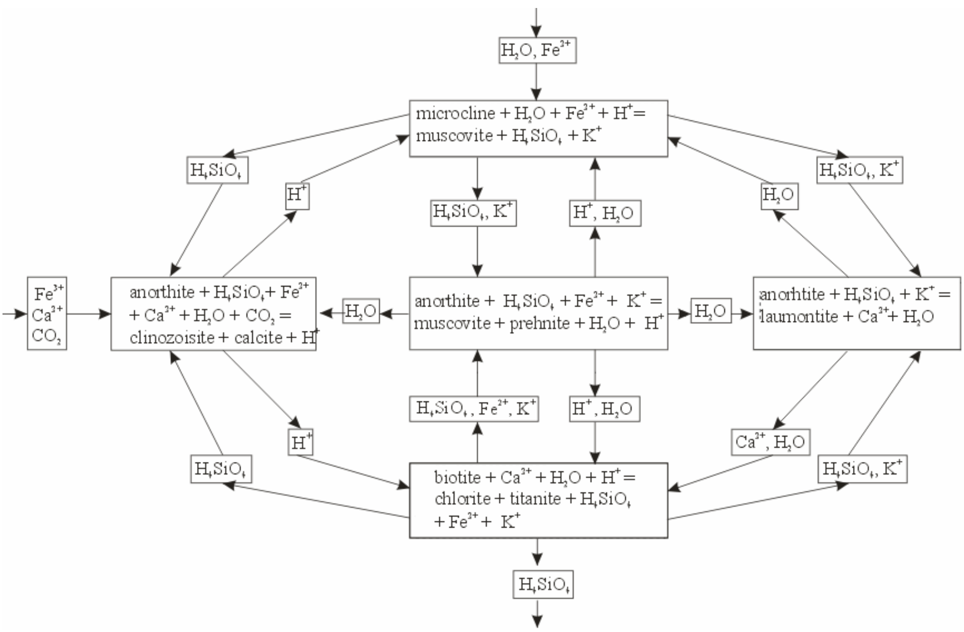

Fig. 7. Reactions between biotite, plagioclase, microcline and chlorite during hydrothermal alteration of the Strzelin granite.

GEOCHEMICAL FEATURES

The major element composition of unaltered Strzelin granite is similar to that of average granite (Ciesielczuk 2000). In considering the geochemistry of slightly, moderately and highly altered granite, mass balance was calculated using the equation of Gresens (1967). Samples 8C (unaltered), 8B (slightly altered), 8A and 7A (moderately altered) and 7B (highly altered) are used here as illustrative examples (Fig. 8).

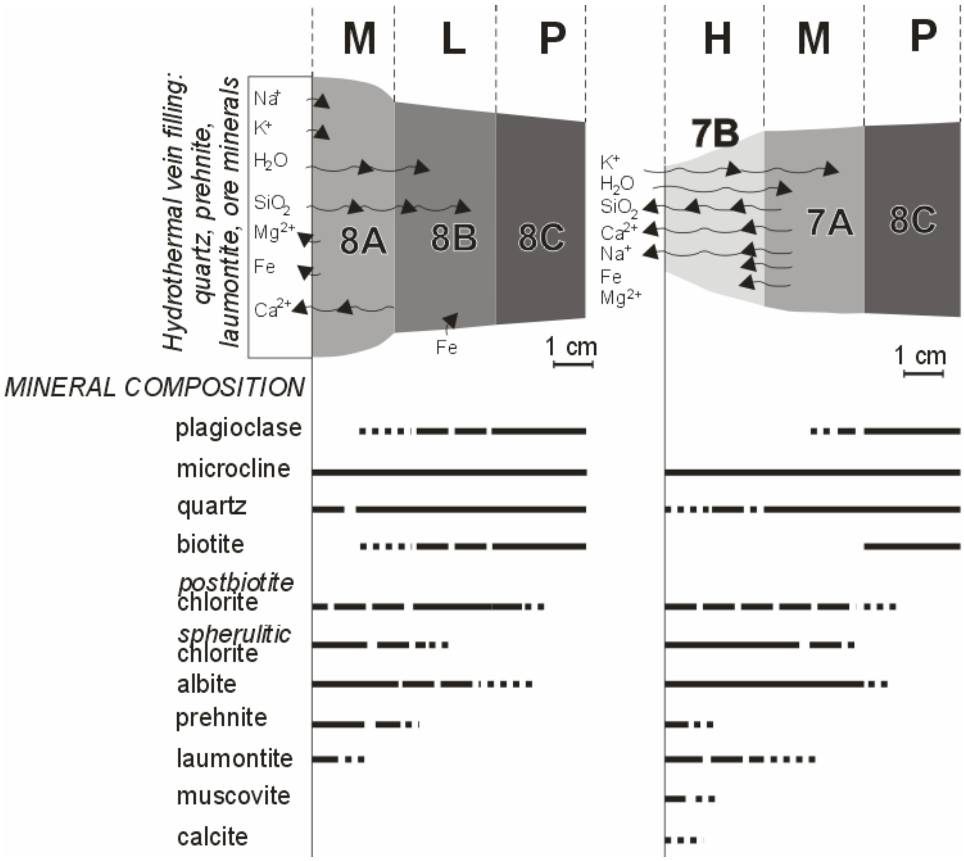

Fig. 8. Mineral compositions and mass balance calculations for unaltered- (sample 8C), slightly altered- (8B), moderately altered- (8A and 7A) and strongly altered (7B) Strzelin granite.

Slightly altered granite (sample 8B, *cf.* Fig. 8) was enriched in SiO_2, total FeO and H_2O, and depleted in CaO. The volume of the rock slightly increased during alteration.

Moderately altered granite (8A) was also enriched in SiO_2, H_2O and in Na_2O and K_2O during alteration. Minor amounts of CaO, FeO, MgO were removed. The volume of the rock increased. However, in the case of moderately altered sample 7A (Fig. 8), the volume of the rock was decreased, K_2O and H_2O were added and SiO_2, FeO, MgO, CaO and Na_2O removed.

Strongly altered granite (sample 7B, Fig. 8) is reduced in volume by <21.7% in comparison with unaltered granite. During alteration, K_2O and H_2O were added and SiO_2, CaO, Na_2O removed. Aluminium was the least mobile element during alteration.

Trace element contents changed during alteration. Cl, Th, Rb, La, Ce, Y contents increased and Zn, S, Sr and V contents decreased on average (Ciesielczuk, Janeczek 2004).

In the Strzelin granite, a linear correlation exists for K/Rb, Fe/V (Fig. 9a), Al/Ga, Ba/Sr (Fig. 9b), Ti/V and Y+REE/Na. It has also been confirmed for K/Ba (Fig. 9c) and Ba/Rb, but there is a considerable scattering of the points. Despite literature suggestion, there is no correlation between the following pairs: SiO_2/K, SiO_2/Rb, Ca/Sr, SiO_2/Fe, Mg/Cr, Cr/V (Fig. 9d) and Y+REE/Ca (Ciesielczuk, 2005).

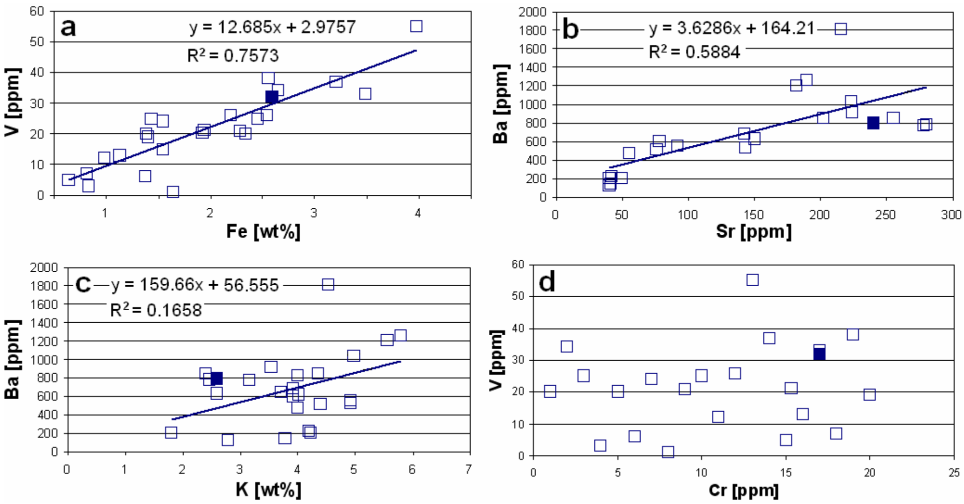

Fig. 9. Correlation between elements in the Strzelin granite: a) Fe/V, b) Sr/Ba, c) K/Ba and d) Cr/V. Full square – unaltered granite.

CONCLUSIONS

Hydrothermal alteration within the stock of the Strzelin granite is marked by bleached zones located along fractures filled by an association of hydrothermal minerals. The sequence of crystallization in veins is as follow: quartz, feldspars, muscovite, chlorite, clinozoisite, prehnite, laumontite/kaolinite, calcite. Some ore minerals are also present. In the granite, the intensity of alteration increases towards the veins. The frequency and thickness of the hydrothermal veins, and the width of the altered zones associated with them, suggest that 20% of the Strzelin stock was affected by hydrothermal fluid**.**

The composition of primary granite minerals changes with increasing alteration. Plagioclase became more albitic. In biotite, Fe/(Fe+Mg) and Fe and Al increase as Mg and Ti decrease. During the alteration, silica was removed from the system and H_2O and CO_2 added. The least mobile element was Al. Alteration also influenced trace element contents.

The presence of laumontite and prehnite in the granite indicates zeolite-facies conditions down to 70 m below surface and incipient prehnite-pumpellyite facies immediately below that depth.

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