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Hydrothermal mineralization at Domašov nad Bystřicí in the Nízký Jeseník Uplands

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Abstract. Hydrothermal veins of the Alpine type, some of which contain sulphides of Cu, Pb, and Zn, cross-cut the Variscan flysch sequences (composed of sandstones, conglomerates, shales, and siltstones) in the Nízký Jeseník Uplands (in the NE part of the Bohemian Massif). Apart from numerous ore occurrences without economic significance, this mineralization also generated several ore deposits that were formerly worked mainly for silver and lead. Hydrothermal veins of differing type, composition, and age are abundant in the quarry at Domašov nad Bystřicí (north of a historical ore district in the Bystřice valley). The oldest of them are syntectonic veins (sometimes coarse-fibrous) composed mainly of quartz, calcite, and chlorite of the clinochlore-chamosite solid solution series; albite is sporadically present in the gangue. These veins do not contain sulphides aside from occasional pyrite. The study of primary fluid inclusions indicates solution concentrations of 15 to 23 wt.% NaCl equiv. At the studied locality, sulphides (pyrite, chalcopyrite, galena, sphalerite) occur in younger veins and veinlets composed mainly of quartz and carbonates (calcite, and minor carbonate of the dolomite-ankerite series). Three groups of fluid inclusions are distinguished based on the salinity of solutions trapped in the calcite and quartz (in wt.% NaCl equiv.) in the ranges of 17–22, 8–11, and 0.4–4.3. Homogenization temperatures of the fluid inclusions in calcite and quartz from both vein types range from 65–90 °C indicate relatively low precipitation temperatures. Thermometric data obtained by fluid inclusion techniques are not in agreement with the temperatures estimated from the chlorite compositional geothermometers that give temperatures corresponding to mesothermal conditions.

Key words: Moravian-Silesian Culm, hydrothermal veins, sulphides, chlorite compositional geothermometry, fluid inclusions

Introduction

Hydrothermal veins composed mainly of quartz and carbonates (calcite, and less often carbonate of the dolomite-ankerite series, see Zimák 1999a) occur throughout the entire Moravian-Silesian Culm area. In some veins chlorite of the clinochlore-chamosite solid solution series occurs (Zimák 1999b). Sulphides represented by sphalerite, galena (locally argentiferous), chalcopyrite, and pyrite are often part of the hydrothermal mineralization (Losert 1962, Bernard et al. 1981). This sulphide mineralization was of interest to miners primarily in the Middle Ages, though mining activity continued in some places up to the beginning of the twentieth century (see Štrejn 1964, Novák and Štěpán 1984, Novák 1986).

One of the historical mining districts in the Moravian-Silesian Culm is the Bystřice district situated in the valley of the river Bystřice, between the village of Hrubá Voda on the north and the town of Velká Bystřice on the south. The most significant ore accumulation in this district was probably the "Zlatý důl" deposit near Hlubočky-Mariánské Údolí, sometimes called Lošov in the literature (Novák and Štěpán 1984, 1985, Zimák and Večeřa 1991). North of the Bystřice district, the hydrothermal sulphide mineralization occurs in a large shelf quarry that is situated about 1.5 km south of Domašov nad Bystřicí, on a steep slope above the right bank of the Bystřice river (Fig. 1). The mining there ended in 1999. Concise data on the ore mineralization in the Domašov quarry has been given by Kruťa (1958), Skácel et al. (1968), and Zimák (1994). Slobodník et al. (1995) and Zimák (1999a, b, c) published data on some of the minerals and the conditions of their formation. It is very probable that the hydrothermal mineralization genetically corresponds to Alpine-type veins.

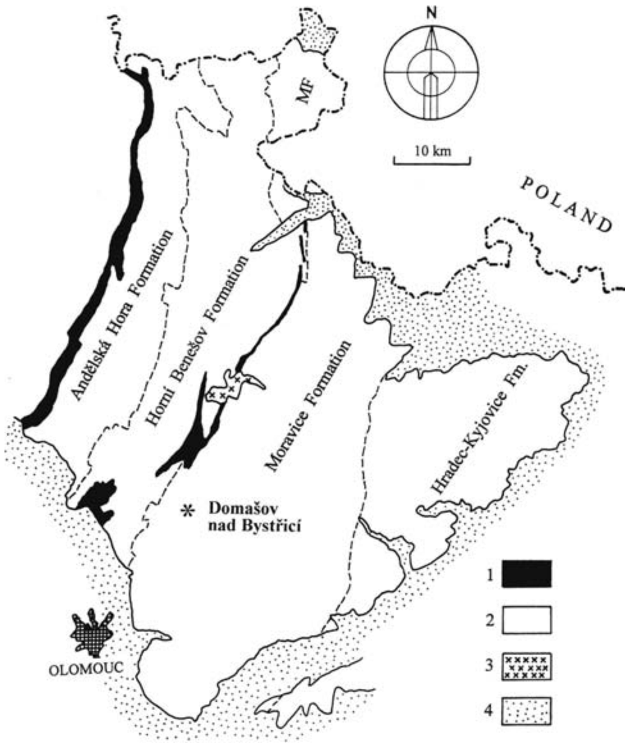

Figure 1. Synoptic geological map of the Nízký Jeseník Uplands and Odra Hills. MF – Moravice Formation. Explanations: 1 – pre-flysch formations and Devonian volcanics of the Vrbno Group and Šternberk-Horní Benešov Zone, 2 – Variscan flysch sequences of the Famennian to Namurian ages, 3 – neovolcanics, 4 – Neogene sediments.

Geological setting

Detailed data on the geological setting of the Domašov quarry and its surroundings were published by Fencl and Svatoš (1960). The quarry exposes flysch sediments of the Moravice Formation. Greywackes that contain petromictic conglomerates (gravelites, in some places even medium-grained conglomerates) are dominant. The greywackes contain intercalations of siltstones and mudstones (clayey shales). As already mentioned by Fencl and Svatoš (1960), the layers of flysch sediments in the quarry are slightly crimped, having a strike of 30–45° and a dip of 40–60° towards the SE. Due to dislocations the complex of flysch sediments has been segmented into partial blocks that are vertically cross-shifted. The conglomerates can be heavily strained along the dislocations.

Flysch sediments exposed in the quarry are dislocated by joints with dips predominantly exceeding 60°. Most of these joints are vertical or steep, with strikes to the W-E or NW-SE (probably the oldest joint system in Domašov quarry), or with a NNE-SSW strike and a WNW dip (see Fig. 2A, B). Hydrothermal mineralization occurs in the joints. In some cases there is a clear relation between the type of mineralization and the joint's spatial orientation.

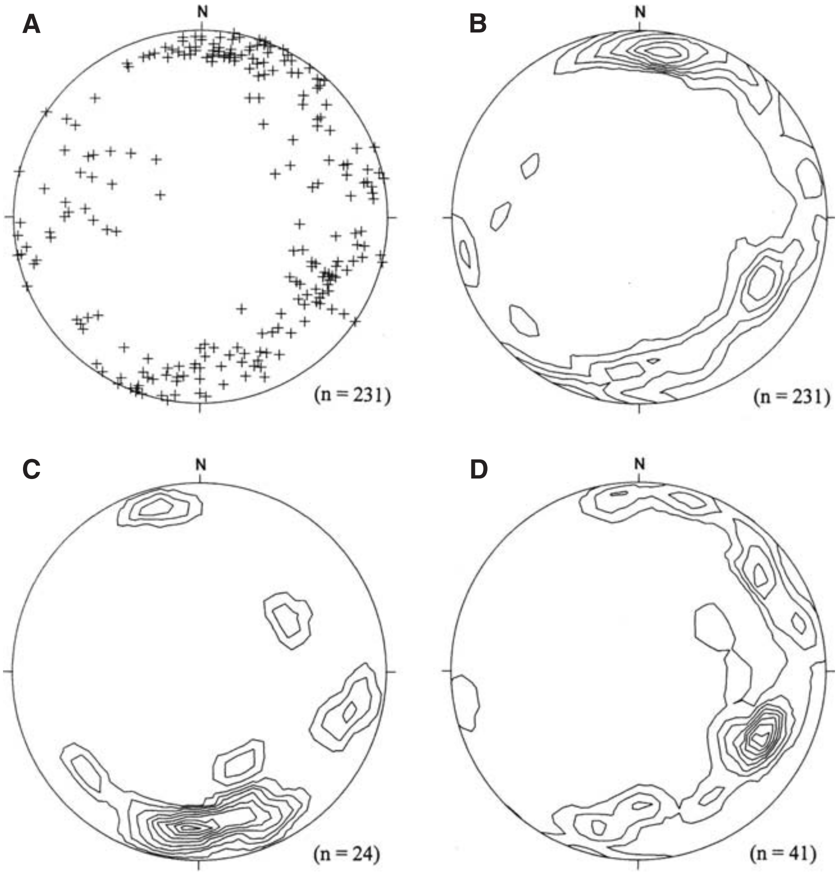

Figure 2. Diagrams of joint poles (projection of lower hemisphere) in the quarry at Domašov nad Bystřicí. A, B – all measured joints, both with and without the occurrence of hydrothermal mineralization, C – of joints filled with hydrothermal quartz-calcite gangue with chlorite, D – of small quartz-calcite veinlets.

Methods

All of the chemical analyses presented in this paper were obtained using a CamScan electron microscope, with an attached EDX analyzer Link AN 10 000. The microscope was operated at an accelerating voltage of 20 kV, with corrections carried out by ZAF-4 programme.

Fluid inclusions were studied on a Chaimexa apparatus using optical microthermometry (Poty et al. 1976). The apparatus was calibrated for temperatures ranging from –100 °C to 400 °C with Merck chemical standards for the temperature of the melting point of distilled water and that of phase changes in inclusions with pure CO_2. The degree of reproducibility was ±0.2 °C for temperatures below 0 °C, and ±3 °C for temperatures up to 200 °C. Fluid salinity was calculated according to the method of Bodnar (1993).

Results

Hydrothermal vein types

Steep joints of 70–110° are often filled with quartz-calcite veins that contain chlorite. They usually reach 10–30 cm in thickness, but can swell up to 60 cm. Quartz occurs in at least two macroscopically distinguishable generations. Of these, milky or off-white quartz is predominant. In some places it can be grey-green in colour, with worm-like inclusions of chlorite. This type of quartz forms xenomorphic grains strongly affected by deformation processes, as demonstrated by granulation and undulatory extinction. These mineralized joints are intersected by veinlets of off-white, sometimes almost colourless quartz. Calcite is usually less abundant than quartz, and has the form of granular aggregates of off-white to light ochre colour (depending on the level of supergene alteration of the gangue). Apart from the previously mentioned inclusions in quartz, chlorite also forms larger aggregates composed of small green scales that are optically negative, significantly pleochroic (X = light yellow, Y = Z = yellow-green to green), and which show anomalous blue interference colours. In some veins, chlorite of optically similar properties was also recognized as worm-like inclusions in calcite. The occurrence of albite in the form of imperfect plates (up to 4 mm in size) along the borders of veins or on the walls of vugs in the quartz gangue (as plates up to 4 mm in size that are attached to druses of quartz crystals) are rather exceptional.

Sulphide minerals are represented by very sporadic pyrite, which forms small grains in the gangue or soft films on the fissures running through the gangue. The spatial orientation of these veins is shown in Fig. 2C. The most frequent type of hydrothermal mineralization in the Domašov quarry involves calcite or quartz-calcite veinlets about 1–2 mm thick (exceptionally to 5–6 mm). Some of these have a significant zonal structure, the outer part of which is composed of quartz, and the central part of calcite. Sulphides occur on the veinlets only in the form of very sporadic pyrite grains that appear at the contact of the veinlet with the wall rock (generally the greywacke). The veinlets are related to various joint systems, the most significant of them being the system with a NNE-SSW strike and 60–70° WNW dip (see Fig. 2D).

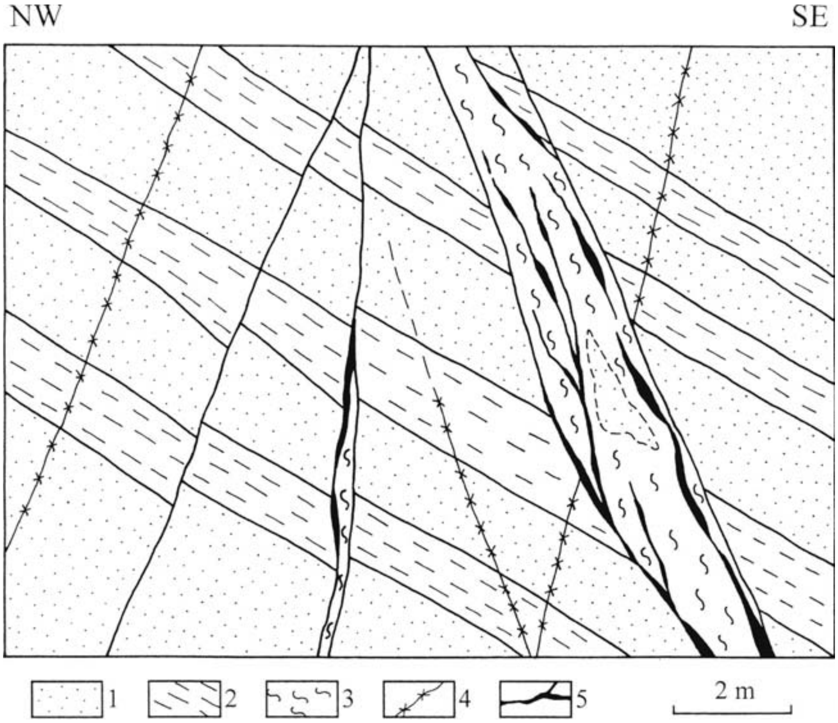

Figure 3. Schematic profile of dislocation zone with hydrothermal mineralization in the quarry at Domašov nad Bystřicí, 3rd level.
1 – greywacke, 2 – clay shale, 3 – mylonite, 4 – quartz (± calcite) veins with chlorite, 5 – quartz-carbonate veins with sulphides.

The greywackes contain tiny (capillary) veinlets composed of calcite, sometimes also of quartz. Sulphides are locally frequent in these veinlets, represented mostly by granular sphalerite of medium brown to dark brown colour (with frequent inclusions of chalcopyrite), and by granular chalcopyrite. Galena and pyrite are present less often. In the quarry face, these veinlets were found only in the greywackes (on the 4th level), where they are present as filling in steep joints that strike in various directions. It is worth mentioning that both the sphalerite and chalcopyrite in direct proximity of the mineralized joints push the matrix back to the greywackes, thereby surrounding the clasts in some places. Within the 2nd and 4th levels, a significant fracture zone of the N-S strike (350° to 10°) and predominately 70–85° dip towards the E (Fig. 3) was observed. In some segments this zone dips to the west. Discontinuous subparallel joints accompany this zone. The thickness of the fracture zone reaches 0.5 to 1.5 m. It has been filled mainly by debris that has been hydrothermally altered (bleached) in some segments; in some places it has the texture of sandy clay. A relatively young tectonic dislocation apparently altered the above mentioned quartz-calcite veins with chlorite. Hydrothermal mineralization related to this fracture zone is of quartz-carbonate stockwork with relatively abundant sulphides. Individual quartz-carbonate veinlets and veins of the stockwork are 0.5 to 15 cm thick, and rarely swell into lentil shapes with thicknesses up to 40–50 cm. The dividing and tailing out of the lodes in veins located in the central part of the fracture zone is commonly observed. The structures of some segments with hydrothermal mineralization resemble ladder-like veins. Thicker veins usually run along the border of a fracture zone. Plentiful smaller veinlets run out of those veins, both into the debris occupying the fracture zone and into the wall rock (mostly greywackes), which is penetrated by a network of irregularly running fissures in the surrounding of the dislocation, often with hydrothermal mineralization. The prevalent component of the hydrothermal mineralization in the fracture zone and its direct surroundings is off-white quartz, which in some parts shows strong tectonic disruption. In some segments the gangue is of breccia structure, in which fragments of quartz gangue and wall rock are cemented by white, yellowish, and sometimes even light pinkish calcite. In the frequent voids there are calcite crystals up to 1 cm in size (in short prisms, and less often scalenohedral), which are white or off-white, sometimes yellowish. Off-white or slightly yellowish carbonate of the dolomite-ankerite series is rarely present, and is not macroscopically distinguishable from calcite. The calcite is accompanied by apatite, which is discernable only when examining thin sections by microscope (hypautomorphic profiles of small individual crystals). Softly scaled chlorite is present only in insignificant amounts.

Hydrothermal mineralization in the fracture zone is relatively rich in sulphides, including pyrite, chalcopyrite, galena, and yellow-brown sphalerite. Their quantity is highly variable. Pyrite is the most abundant and occurs mainly in quartz-rich parts of the veinlets as large granular aggregates with sizes up to several cm, or also small hypautomorphic crystals (cubes or pentagonal dodecahedrons to 2–3 mm in size or cubes combined with dodecahedrons). Sporadic inclusions of sphalerite were found in pyrite (hypautomorphic to automorphic profiles of tetrahedral crystal types). Pyrite is often strongly cracked; the fissures within it are filled with carbonate and sometimes also chalcopyrite. Chalcopyrite preferentially binds to the calcite in the hydrothermal gangue, where it is present as xenomorphic grains and irregular aggregates with sizes on the order of several mm. However, in the central part of the fracture zone (on the second level) sulphide veinlets up to 1.5 cm thick, and in which chalcopyrite is significantly prevalent over pyrite, are present in some parts of the quartz-calcite gangue. Irregular aggregates of sphalerite and galena, up to 1 cm in size, occur in the quartz and quartz-carbonate veinlets, usually in association with pyrite and very sporadic chalcopyrite. Sphalerite, quartz, and some galena constitute the earliest crystallized minerals of those veinlets. Evidence of their plastic deformation can be observed particularly on the larger individual galena crystals as the curving of their triangular bases. Carbonate of the dolomite-ankerite series, together with galena and chalcopyrite, penetrates the sphalerite along numerous joints (in some places the sphalerite was clearly being replaced by carbonate). The youngest hypogene mineral of those veinlets is calcite.

On the second level, relatively rich Cu mineralization has been documented in a joint of 125° strike and 70–80° SW dip, running through the conglomerate and the greywacke. The joint is filled with debris, quartz, and chalcopyrite that is almost completely altered into chalcosite, covellite, and mainly stilpnosiderite and chrysocolla accompanied by malachite. Pyrite relics occur locally. The maximum thickness of the vein fillings is about 10 cm. Carbonate leaching has probably produced rare vugs in the gangue that were secondarily filled with powdery limonite.

In addition to the types of mineralization described above, small veinlets of off-white quartz (either without sulphides, or with pyrite only) occur in the Domašov quarry. Veinlets of pinkish calcite (accompanied by carbonate of the dolomite-ankerite series) are also quite frequent. A veinlet up to 1 cm thick, with distinct zonal structure, has been found irregularly running through the mined block of greywacke conglomerate. The outer part of this veinlet is composed of carbonate of the dolomite-ankerite series, while the central part is of calcite. Hypautomorphic pyrite grains and Ni-Fe-Co sulphides also occur in the carbonate of the dolomite-ankerite series (see below).

Only a few fragments of up to 15 cm thick quartz-barite gangue were found in the dump material. White barite forms platy aggregates (with crystals up to 2.5 cm in size) in the central part of the vein.

Chemical composition of selected minerals

Aside from CaO, the EDX analyses resulted in the following calcite composition (in wt.%): 0–1.19 FeO, 0–0.58 MgO, 0.25–1.31 MnO, 0–0.31 SiO_2 and 0–0.35 P_2O_5 (contents of FeO, MgO and MnO determined by wet analyses fall into given limits – see Zimák 1999a). The results of five representative calcite EDX analyses (excluding SiO_2 and P_2O_5 contents) are given in Table 1. The composition of carbonates of the dolomite-ankerite series corresponds to Fe-dolomite or Mg-ankerite (classification according Trdlička and Hoffman 1976).

When examining a thin section of a roughly 2 cm thick carbonate veinlet (calcite and Mg-ankerite, see analyses Nos. 8 and 9 in Table 1), irregularly shaped grains were visible in the electron image in a part composed predominantly of calcite. Their size did not exceed 1 μm. The EDX analysis of one point gave a composition of 18.86 wt.% CaO, 0.47 wt.% FeO, and 40.78 wt.% TR_2O_3 in which LREE (Ce > La > Nd > Sm > Pr) predominate. Due to the small size of the TR-mineral grain, the result of this analysis cannot be regarded as representative, as adjacent calcite was also present within the analyzed site. The mineral in question might be calkinsite-(Ce) (see Zimák and Novotný 2002).

The chlorite EDX analyses (see Table 2) show them to be Mg-Fe chlorites of the clinochlore-chamosite series (in the classification of Wiewióra and Weiss 1990). Under the classification of Melka (1965), which is based on the number of Si atoms in tetrahedral position and on the F/FM value, chlorites of the quartz-calcite veins correspond mainly to chamosite or clinochlore, and sometimes to thuringite or ripidolite (Table 2, Nos. 10–15). A very similar situation occurs in many other quartz-carbonate veins in

Table 1. Chemistry of calcite (Nos. 1–5) and carbonates of dolomite-ankerite series (Nos. 6–9), in wt.%

Analysis No.	1	2	3	4	5	6	7	8	9
CaO	52.05	51.47	51.28	54.41	51.55	30.48	29.89	28.94	29.98
FeO	1.87	0.17	1.91	–	1.08	16.75	15.06	18.87	17.32
MgO	0.58	–	0.41	–	0.28	8.73	10.33	8.29	8.40
MnO	0.29	0.25	1.31	0.37	1.13	1.60	0.96	0.50	1.18
Number of cations on the basis of $Ca^{2+} + Mg^{2+} + Fe^{2+} + Mn^{2+}$ = 1 (calcite) or 2 (dolomite-ankerite):									
Ca^{2+}	0.954	0.994	0.943	0.995	0.960	1.07	1.05	1.04	1.07
Fe^{2+}	0.027	0.003	0.027	–	0.016	0.46	0.41	0.53	0.48
Mg^{2+}	0.015	–	0.010	–	0.007	0.43	0.51	0.42	0.42
Mn^{2+}	0.004	0.004	0.019	0.005	0.017	0.04	0.03	0.01	0.03

Note: calcite from thick quartz-calcite vein with chlorite (anal. No. 1), approx. 10 cm thick vein of white and pinkish calcite (anal. No. 2), carbonate veinlet (calcite > Fe-dolomite) with pyrite and Ni-Fe-Co sulphide (anal. Nos. 3–7), crystals of calcite in caverns of quartz gangue (anal. No. 4), crystallized calcite in the filling of dislocation zone (anal. No. 5), carbonate veinlet (calcite > Mg-ankerite) with sphalerite and other sulphides (anal. No. 6), veinlet composed of calcite and Mg-ankerite (anal. Nos. 8–9).

Table 2. Chemistry of chlorites (results of FDX analyses in wt.%, number of cations is standardized to 14 atoms of oxygen) and chlorite geothermometry

Analysis No.	10	11	12	13	14	15	16	17	18
SiO_2	26.50	26.28	25.74	25.22	28.19	28.14	27.96	27.48	27.88
Al_2O_3	21.44	21.18	20.33	20.04	22.58	22.24	22.83	21.96	23.32
FeO	29.44	30.83	25.81	26.00	27.86	27.21	33.45	35.25	33.18
MgO	12.56	11.40	13.67	13.59	14.30	14.77	6.66	6.38	7.00
MnO	0.69	0.70	0.55	0.70	0.47	0.65	–	–	–
Total	90.63	90.39	86.10	85.55	93.40	93.01	90.90	91.07	91.38
Number of cations on the basis of 28 negative charges:									
Si	2.75	2.76	2.78	2.75	2.79	2.80	2.92	2.90	2.89
Al	2.62	2.62	2.58	2.57	2.63	2.60	2.81	2.73	2.85
Fe	2.56	2.71	2.33	2.37	2.31	2.26	2.92	3.11	2.87
Mg	1.94	1.78	2.20	2.21	2.11	2.19	1.04	1.00	1.08
Mn	0.06	0.06	0.05	0.06	0.04	0.06	–	–	–
F/FM	0.57	0.61	0.52	0.52	0.53	0.51	0.74	0.76	0.73
Chlorite compositional geothermometry (°C):									
T_1	254	254	239	265	236	247	167	185	167
T_2	283	281	277	283	274	272	247	251	253
T_3	341	337	331	341	328	324	286	292	295
T_4	193	194	185	189	185	183	187	191	190
T_5	348	346	336	346	334	330	299	306	308
T_6	261	256	261	266	258	256	209	212	217

Note: Thick quartz-calcite veins with chlorite (Nos. 10–11 – subtly scaled chlorite aggregates, Nos. 12–13 – worm-like inclusions of chlorite in quartz, Nos. 14–15 – subtly scaled aggregates and worm-like inclusions of chlorite in calcite, Nos. 16–18 – carbonate (calcite and Mg-ankerite) veinlet with sphalerite and other sulphides containing only insignificant amount of chlorite.

Table 3. Chemistry of sphalerite (in wt.%)

Analysis No.	19	20	21	22	23	24	25
Zn	66.06	65.57	67.34	62.34	64.20	63.65	65.60
Fe	0.42	2.60	1.57	2.76	2.75	3.07	1.06
Cd	0.64	–	–	0.39	0.39	0.34	–
S	31.09	33.31	32.85	33.90	31.14	30.97	33.06
Total	98.21	101.48	101.76	99.39	98.48	98.03	99.72
Number of cations on the basis of 1 S:							
Zn	1.043	0.965	1.005	0.929	1.011	1.008	0.973
Fe	0.008	0.045	0.027	0.046	0.051	0.057	0.018
Cd	0.006	–	–	0.003	0.004	0.003	–
Total	1.056	1.010	1.032	0.978	1.066	1.068	0.991

Note: yellowish brown sphalerite from a quartz-carbonate vein (No. 19), small grains of sphalerite (the colour cannot be assessed) on carbonate (calcite > Mg-ankerite) veinlets (Nos. 20–22), dark brown sphalerite from a tiny veinlet in a greywacke (Nos. 23–24), medium brown sphalerite from a tiny veinlet in a greywacke (No. 25).

the flysch of the Nízký Jeseník and Oderské vrchy uplands (see Zimák 1999b). The chlorite present in trace amounts in the sulphide/carbonate veinlet is of a different chemical composition (Table 2, Nos. 16–18). According to the classification of Melka (1965), it is chamosite with relatively high F/FM ratios.

Based on the trioctahedral chlorites of the clinochlore-chamosite series, we can deduce the physical and chemical conditions of the environment in which they evolved. Much work focused on chlorite thermometry and its applications has been published in the past twenty years (e.g., Caritat et al. 1993, Jiang et al. 1994, and Frimmel 1997). Thermometry based on the chemical composition of chlorites was used by Zimák (1999b, c) when investigating the hydrothermal mineralization in the Jeseník Flysch. Six different geothermometers were used for determining the temperatures of crystallization of chlorites in the hydrothermal veins of the Domašov quarry. In Table 2 and the text below, the thermometers and the calculated temperatures are designated as T_1 to T_6. There are principally three different types of geothermometers:

a) Geothermometer based on the number of vacancies in the octahedral position (Cathelineau and Nieva 1985) [T_1].
b) Geothermometers based on the number of ions of tetrahedral Al (Cathelineau and Nieva 1985 [T_2], Cathelineau 1988 [T_3]).
c) Geothermometers based on the number of ions of tetrahedral Al and Fe/(Fe+Mg) values (Kranidiotis and MacLean 1987 [T_4], Jowett 1991 [T_5], Zang and Fyfe 1995 [T_6]).

Table 4. Chemistry of Ni-Fe-Co sulphide (in wt.%)

Analysis No.	26	27
Ni	29.22	29.38
Fe	20.53	25.32
Co	12.17	11.41
Mn	–	0.24
S	34.52	34.08
Ca	0.61	0.14
Si	0.10	0.19
Total	97.15	100.76
Number of cations on the basis of 1 S:		
Ni	0.463	0.471
Fe	0.342	0.427
Co	0.192	0.182
Mn	–	0.004
Total	0.997	1.084

The results obtained using these geothermometers substantially differ in some cases. The application of chlorite geothermometry to the hydrothermal mineralization in the NE part of the Bohemian Massif has already indicated (Zimák 1999c) that the values provided by geothermometers T_1, T_2, T_4, and T_6 probably approximate the real conditions most closely, while the temperatures calculated using T_3 and T_5 seem too high.

The EDX analysis determined the anorthite content of the albite from hydrothermal mineralization to be $An_{00\text{-}01}$ (with a maximum CaO content of 0.29 wt.%).

Representative analyses of sphalerite formed in the various mineralization types are given in Table 3, in which the Si contents (ranging 0.16–0.30 wt.%) in the analyzed points are not given. When the size of sphalerite grains is large enough for their colour to be determined, the relation between its colour and Fe content can be considered as generally regular (No. 19 with very low Fe content is a yellow-brown sphalerite, No. 25 a medium brown sphalerite, while Nos. 23 and 24 are dark brown sphalerite and have the highest Fe contents). Conversely, the highest Cd contents are in light sphalerite.

EDX analyses gave sphalerite contents of (wt.%) 0.38–0.57 Fe, 0.14–1.01 Cd, and 0–0.02 Mn for yellow-brown sphalerite from a quartz-carbonate veinlet from the stockwork in the dislocation zone, and 2.71–3.08 Fe, 0–0.24 Cd, and 0–0.04 Mn for dark brown sphalerite from a capillary vein in a greywacke. The analyses of individual points are not reported due to the poorness of their stoichiometric results.

Ni-Fe-Co sulphides in the form of isometric hypautomorphic crystals up to 4 μm in size were distinguished in association with pyrite in one of the carbonate veinlets. It appears as a homogenous phase in BSE. The results of two EDX analyses are shown in Table 4 (note that in No. 27 we cannot exclude a bias due to the presence of pyrite in the analyzed spot). Ni-Fe-Co sulphides were not identified.

Fluid inclusion and optical microthermometry

The results of microthermometry are given in Table 5. Fluid inclusions suitable for examination were identified in calcite from a thick quartz-calcite vein with abundant chlorite (sample No. 1), and in quartz and calcite from hydrothermal mineralizations with sulphides (samples Nos. 2, 3).

The identified inclusions can be divided into L-only inclusions (liquid), V-only inclusions (gas), and L+V inclusions (liquid + gas) in relation to their degree of fullness.

Calcite from the quartz-calcite vein with chlorite contains primary inclusions with variable filling. Their shape is of a negative crystal with sizes up to 30 μm. L-only inclusions are predominant. In L+V inclusions (with approximately 5 vol% of gas phase), which are less common, Th ranges from 68 to 80 °C and Tm from 10.6 to –24.6 °C. These values indicate high salinity (to 23.2 wt.% NaCl equiv. – see sample No. 1 in Table 5 and Fig. 4). Te of about –50 °C seems to indicate the system $NaCl\text{-}KCl\text{-}CaCl_2{\pm}MgCl_2\text{-}H_2O$ (Borisenko 1977). Secondary inclusions that are located along healed joints in calcite are entirely of L-only type, and their trapping temperature is estimated to have been 50 °C or less (Goldstein and Reynolds 1994).

In hypautomorphic quartz from sample No. 2 (with calcite and relatively abundant sphalerite), the primary inclusions were distinguished in a 3D distribution, either as "stringy inclusions", or as localized in certain growth zones of the quartz crystals. The inclusions are of irregular shape, with sizes reaching up to 50 μm. L-only inclusions predominate, with less common L+V-inclusions whose gas phase occupies 5 to 70 vol%. Based on analogous observations carried out by Bodnar et al. (1985), the irregular shape and variable filling of these inclusions is indicative of their slow maturation after trapping under temperatures not surpassing 100 °C. "Stringy inclusions" are also formed in conditions of rapid quartz growth under low tempera-

Table 5. Microthermometric data of primary fluid inclusions

Sample No.	Mineral	Tm (°C)	Salinity (wt.%)	Te (°C)	Th (°C)
1	Calcite	–10.6 to –24.6	14.6 to 23.2	–50.0 to –50.5	65 to 80
2	Quartz	–0.3 to –2.6	0.5 to 4.3	–35.0 to –37.5	
2	Quartz	–5.3 to –7.2	8.3 to 10.7	–37.0	
2	Quartz	–13.1 to –21.2	17.0 to 21.5	–50.2 to –56.0	70 to 90
3	Quartz	–0.2 to –0.5	0.4 to 0.9		
3	Calcite	–0.2 to –0.7	0.4 to 1.2		

Note: sample 1 is calcite from a quartz-carbonate-chlorite vein on 2nd level, sample 2 is quartz from an ore veinlet with sphalerite from the fracture belt on 3rd level, sample 3 is quartz and calcite from a veinlet with ore mineralization from the fracture belt on 3rd level.
Tm – temperature of the last ice crystal melting
Te – eutectic temperature
Th – temperature of homogenization

tures. Te and Tm were measured only in two-phase inclusions. L-only fluid inclusions showed metastable behaviour after freezing. Based on the Tm and Te values, two or three types of trapped fluids of differing salinity and composition can be distinguished in the examined quartz (see Table 5 and Fig. 4). Te around –37 °C corresponds at the system $NaCl\text{-}KCl\text{-}MgCl_2\text{-}H_2O$; Te around –50 °C corresponds to $NaCl\text{-}KCl\text{-}CaCl_2 \pm MgCl_2\text{-}H_2O$. In some L-only inclusions in the quartz from sample 2 a small gas bubble appeared after the first freezing. The Th of those inclusions was determined roughly in the range of 70–90 °C. The presence of a gas phase in the inclusions subsequent to the cryometric experiments was probably caused by the disruption of the inclusion walls during cryometry, and the given temperature range must be considered with certain discount.

Most of the inclusions in quartz from sample No. 3 are of the L-only type, with only about 5 % being L+V-inclusions with 5–30 vol% of gas phase. The inclusions are of irregular shape, with sizes reaching up to 15 µm in maximum. The measured Tm values between –0.2 and –0.5 °C correspond to salinities of 0.4 to 0.9 wt.% NaCl equiv. In sample No. 3 calcite occurs in two generations. The calcite grains that crystallized first contain a great quantity of fluid inclusions about 2 µm in size. However, we were unable to obtain any thermometric data on them. This calcite is interveined by up to 0.5 mm thick veinlets of younger calcite with fluid inclusions with highly variable fillings (L-inclusions, V-inclusions, and L+V-inclusions with 5–50 vol% of gas phase). The Tm values in the L+V-inclusions range from –0.2 to –0.7 °C, which corresponds to salinities between 0.4 and 1.2 wt.% NaCl equiv. (see Table 5 and Fig. 4).

Products of supergene processes

The hydrothermal mineralization of the dislocation zone has been strongly affected by supergene processes in parts that are relatively rich in sulphides. The products of the supergene processes cause the ochre colour of the dislocation zone and its immediate surroundings, while parts containing more abundant Cu-mineralization display a pronounced blue-green tint. The prevalent supergene products are oxyhydroxides of iron and unspecified clay minerals (X-ray analyses indicate the presence of allophane). Secondary copper minerals are abundant in some places; these include mainly chrysocolla, chalcocite, covellite, and less frequent malachite.

Oxyhydroxides of Fe occur mainly in the form of ochre films and ground aggregates (e.g., lining vugs), in the form of silky, pitch-black stilpnosiderite (formed by chalcopyrite alteration), and as black and brown pseudomorphs from pyrite. X-ray analyses of the ochre limonite that fills the vugs were obtained using a HZG-4/C diffractometer, Cu-radiation, Ni-filter, with a shift speed of 2°2theta/min. The analyses show lines with the following d-values (in 10^{-10} m): 6.22 (75), 4.15 (100b), 3.36 (75), 3.28 (85), 2.689 (80), 2.494 (50), 2.469 (60), 2.446 (100), 2.166 (75), 1.933 (50), 1.800 (60), 1.717 (40) and 1.600 (50). These d-values indicate the presence of goethite and lepidocrocite.

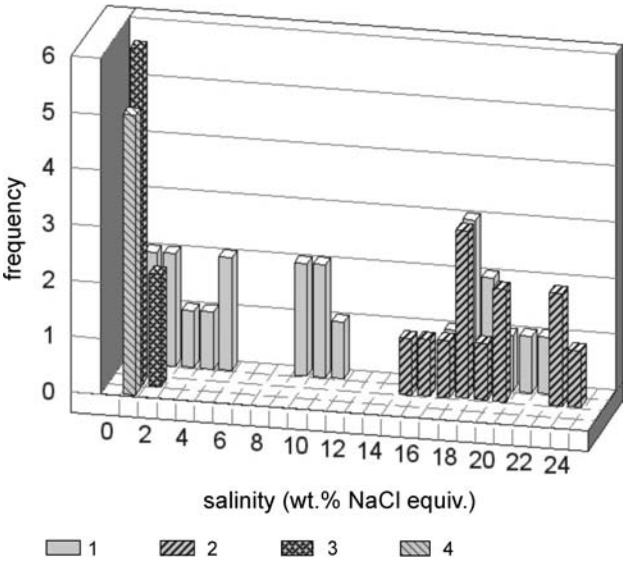

Figure 4. Chart of fluid inclusion salinity of studied minerals. Explanations: 1 – sample No. 2 quartz, 2 – sample No. 1 calcite, 3 – sample No. 3 calcite, 4 – sample No. 3 quartz.

Chalcocite generated by the replacement of chalcopyrite is slate-coloured in polished sections and optically isotropic. Aggregates of chalcocite display an abundance of irregular grains or underdeveloped tablets of covellite. Both secondary Cu-sulphides occur together with limonite (stilpnosiderite) and relicts of chalcopyrite or pyrite.

Chrysocolla forms soft blue-green films and colloform (botryoidal) aggregates on the vug walls in the part of the gangue affected by the supergene processes. On the polished sections, chrysocolla is visible as a grey, optically isotropic mineral with low reflectiveness and strong inner reflexes in green to blue-green colours. In penetrating light it only has a very light green tint without noticeable pleochroism. Its aggregates have distinctive spherulitic structures; individual grains within the aggregates show positive elongation, medium birefringence, $n_\alpha = 1.580\text{–}1.595$. The identification of this mineral was confirmed by IR spectroscopy. The EDX analysis detected only Cu and Si in the chrysocolla. Malachite forms only random films or small fibrous aggregates with radial structures accompanying chrysocolla.

Discussion and conclusions

At the quarry near Domašov nad Bystřicí, five main types of hydrothermal mineralization that fill the joints or dislocation zones in flysch sediments (greywackes, conglomerates, siltstones and shales) are distinguished:

1. Quartz-calcite veins with chlorite of the clinochlore-chamosite series (F/FM = 0.51–0.61, Si = 2.75–2.80), in some places containing albite ($An_{00\text{–}01}$) and pyrite. They are usually steep veins up to 30–40 cm thick and of an approximately E-W strike. They probably represent the earliest phase of hydrothermal mi-

neralization at this site. Substantial tectonic alteration is apparent in these veins. Coarse, fibrous structures typical of syntectonic veins (formed by the crack-seal mechanism) are observed in the smaller veins. Homogenization temperatures of the primary L+V inclusions in calcite from this type of mineralization range between 65 and 80 °C. The relatively low melting temperatures (–10.6 to –24.6 °C) of these inclusions point to a high salinity in the range of 14.6–23.2 wt.% NaCl equiv. The use of four different chlorite geothermometers (Cathelineau and Nieva 1985, Kranidiotis and MacLean 1987, Zang and Fyfe 1995) resulted in moderately high chlorite crystallization temperatures (183–283 °C). These temperatures were obtained in chlorite associated with quartz (where the primary fluid inclusions were not suitable for optical microthermometry), and in chlorites occurring in veins composed of quartz and younger calcite, the fluid inclusions of which enabled the microthermometric analysis. Veins of this type were previously studied by Slobodník et al. (1995). These authors recognized the L+V inclusions of unclear genesis in quartz and calcite, with homogenization temperatures in the range of 50–140 °C and Tm from –23 to –33 °C, which indicate very high salinity. Based on the arrangement of primary L-inclusions parallel to quartz growth zones, those authors assumed formation at temperatures of about 50 °C. It is necessary to comment on the differences between the temperatures determined by chlorite thermometry and the results of the optical microthermometry of fluid inclusions in quartz and calcite. Chlorite always represents the earliest crystallized component of the examined veins, and its formation could have taken place under mesothermal conditions. The younger generations of quartz and calcite were apparently formed from epithermal solutions.

2. Calcite and quartz-calcite veinlets, mostly 1–2 mm thick, related to different joint systems (predominantly striking to the NNE-SSW and dipping 60–70° to the WNW). Sulphides are represented only by very rare pyrite.
3. Fibrous veinlets restricted to certain places within the greywackes (mainly on 4th level). These veinlets are composed of quartz, calcite, sphalerite (with 2.7–3.1 Fe wt.% and 0–0.4 Cd wt.%), chalcopyrite, galena, and pyrite.
4. Hydrothermal mineralization of the stockwork type related to a steep dislocation zone of N-S strike (observable within the 2nd and 4th levels). Veins and veinlets within the gangue are composed of quartz, calcite, carbonate of the dolomite-ankerite series, and locally abundant sulphides including pyrite, chalcopyrite, galena, and sphalerite (with 0.4–0.6 Fe wt.% and 0.1–1.0 Cd wt.%). Three types of fluids have been distinguished in the primary fluid inclusions: a) Those with salinity between 17.0 and 21.5 wt.% NaCl equiv. (probably trapped during the earliest generation of hydrothermal quartz at this site), and homogenization temperatures between 70 and 90 °C. These parameters are similar to those of the fluids in the primary inclusions in the quartz-calcite veins with chlorite. b) Fluids with salinity between 8.3 and 10.7 wt.% NaCl equiv. trapped in quartz. c) Fluids with salinity between 0.4 and 4.3 wt.% NaCl equiv. trapped in the latest quartz and calcite in veinlets from the dislocation zone. These veinlets contain sulphide mineralization and rare chlorite with F/FM = 0.73–0.76 and Si = 2.89–2.92. On the basis of its composition, a temperature range of 167–253 °C was calculated using the four above-mentioned geothermometers. Again, these temperatures are significantly higher than those indicated by optical microthermometry.
5. Hydrothermal mineralization on quartz (or quartz-carbonate) veins on the steep joint of NW-SE strike on the 2nd level. These veins were strongly affected by supergene processes. Only chalcopyrite and pyrite were identified as primary ore minerals. Supergene products are represented primarily by limonite, chrysocolla, malachite, chalcocite, and covellite.

The examination of the fluid inclusions and chlorite thermometry indicate that the syntectonic quartz-calcite veins containing chlorite were formed first from mesothermal fluids. The younger, post-Variscan generation of quartz and calcite, and the hydrothermal mineralization of Cu, Pb, and Zn sulphides, are all of epithermal origin. Sterile syntectonic veins were formed from highly saline solutions, whereas the fluids trapped in minerals accompanying the sulphides show only low salinity. The study of other similar sites will help to decide whether or not this conclusion applies to the entire Moravian-Silesian Culm region.

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