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Original paper

Manganese-rich garnet–quartz rocks and gneisses in the Bohemian part of the Moldanubian Zone: lithostratigraphic markers

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Manganese-rich garnet–quartz rocks and gneisses occur in the Varied Group of the Moldanubian Zone, Bohemian Massif, in close association with amphibolites, marbles and accompanying graphite gneisses. Fine-grained garnets contain (mol. %) 26–37 spessartine, 36.8–45.9 almandine, 11.1–14.3 pyrope and 2.9–21.0 grossular. Minor amphibole present in some samples is ferrimagnesiohornblende with 0.17–0.22 Mn *pfu*. Accessory ilmenite contains 24–34 mol. % pyrophanite and 1.7–5.8 hematite. Some closely associated impure calcite marbles (or amphibolites) carry Ti-bearing andradite, epidote, diopside–hedenbergite, and accessory magnetite.

Data from the Varied Group indicate that manganese enrichment took place both under oxidizing and reducing conditions, but the Mn-garnet–quartz rocks are oxidic. Normalization of major-element contents in the Mn-rich rocks by average abundances in Varied Group paragneisses shows ten- to hundred-fold enrichment in MnO and a slight to moderate increase in CaO and P_2O_5. Values for Na_2O and K_2O indicate severe depletion in some samples, but contents of other oxides are close to unity. Comparison of chondrite-normalized REE patterns in Mn-rich rocks with data for ordinary paragneisses (Varied Group) also indicates that detrital component in Mn-rich rocks was closely comparable to material supplied for protolith of paragneisses. This permits to ascribe the spike of Mn to likely short-lived exhalative processes.

Manganese-rich garnet–quartz rocks and gneisses remained unnoticed till now mainly owing to a small thickness of their layers, typically less than 1 m. Structural relations in regions carrying Mn-rich rocks indicate their occurrence in relict domains of preserved D_1 structures with NW–SE trending foliation. It is suggested that in regionally prevalent areas dominated by superimposed refoliation (D_2, D_3) the thin layers of Mn-rich rocks were likely reduced to boudins dispersed in paragneiss matrix. Comparison with published data for similar Mn-rich rocks abroad (including the so-called coticules) strongly indicates a lithostratigraphic correlation potential of Mn-rich garnet–quartz rocks.

Keywords: Mn-rich garnet–quartz rocks, Ti-andradite–epidote marbles, exhalative processes, lithostratigraphic markers, Český Krumlov Varied Group, Moldanubian Zone

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1. Introduction

Numerous volcanosedimentary units of various ages worldwide carry sedimentary horizons rich in manganese, grading in some cases to economic Mn deposits (Bühn et al. 1992) or polymetallic deposits (Spry and Wonder 1989). Garnet quartzites passing to garnet-rich rocks with a high content of spessartine are an occasional member of lithological assemblage and were raised to the status of exploration guide (Wonder et al. 1988). Following the prevailing interpretation of garnetiferous rocks rich in Mn as products of mixing of exhalative material released from syn-volcanic vents at the sea-floor with detrital material, the horizons of such rocks represent a record of highly specific events during accumulation of the volcanosedimentary column.

In the Czech part of the Moldanubian Zone in the Bohemian Massif the occurrences of garnet–quartz rocks and Mn-rich gneisses have received little attention (Vrána 1977, 1992) and remained largely unknown till present. The main reason for this is the minimal thickness of metasedimentary Mn-rich horizon (horizons?), typically less than 1 m. This is unfortunate, as Mn-rich garnet–quartz rocks potentially represent means of lithostratigraphic correlation in the complexly deformed gneisses and migmatites of the Moldanubian Zone in southern Bohemia, i.e., metamorphic complex so far resisting a reliable lithostratigraphic classification. It is probably not by mere coincidence that most of occurrences reported in this article are from domains with preserved NW–SE to WNW–ESE structural trend, considered as the oldest recognised structural pattern in the Czech part of the Moldanubian Zone (Kodym 1972; Vrána 1979; Vrána and Šrámek 1999). Attention is also paid to associated rocks documenting an increased oxygen fugacity environment, i.e. rocks with an assemblage Ti-andradite + epidote +

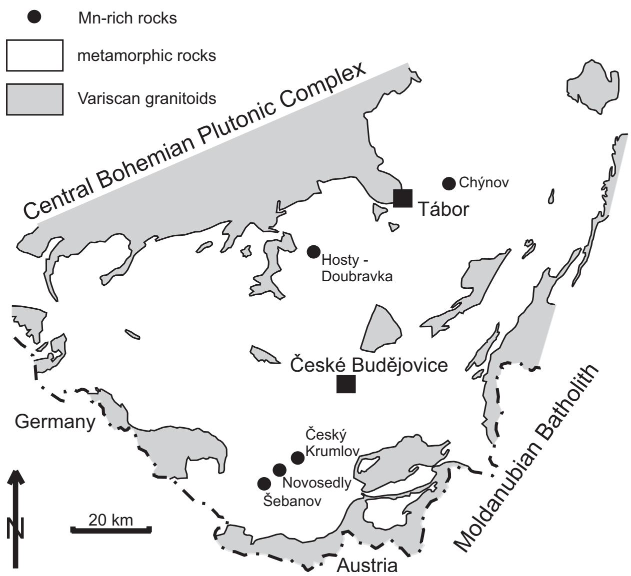

Fig. 1 Localities of Mn-rich rocks in southern Bohemia, Czech Republic.

magnetite, which occur in close proximity to the Mn-rich garnet–quartz rocks.

2. Geological setting

The Moldanubian Zone is a heterogeneous complex of several major allochthonous units assembled during the Variscan orogeny and modified by several superimposed Variscan deformation and recrystallization events. The principal members are the Monotonous Group, Varied Group, and Gföhl Unit (Fiala et al. 1995). Allochthonous segments of older basement are also incorporated, including the Palaeoproterozoic Světlík orthogneiss in southern Bohemia (Wendt et al. 1993; Fiala et al. 1995) and the Mesoproterozoic Dobra gneiss in Lower Austria (Gebauer and Friedl 1994; Friedl et al. 2004). The Monotonous Group, composed dominantly of biotite and sillimanite–biotite paragneisses, with widely scattered orthogneiss bodies, subordinate quartzite, calc-silicate gneiss and amphibolite, is assumed to be mainly Neoproterozoic in age, as the protoliths to the orthogneisses were dated between *c.* 550 Ma and 508 Ma (Vrána and Kröner 1995; Košler et al. 1996). The Varied Group is probably Cambro–Ordovician (Fiala et al. 1995; Drábek and Stein 2003; Janoušek et al. 2008; Košler et al. 2011). The Varied Group contains abundant layers of marble, calc-silicate gneiss, graphite gneiss, quartzite and amphibolite in addition to dominating paragneisses.

There is some uncertainty concerning the internal coherence of the Varied Group, as according to some interpretations, it can be divided into the Český Krumlov and Sušice–Votice groups, based on distinct lithology and geographic distribution (Kodym and Suk 1958; Jenček and Vajner 1968). In any case, an overview of the localities of manganiferous rocks is presented in Fig. 1 and simplified sketches of geological situation in the individual areas in Fig. 2.

3. Localities

The list of studied localities with GPS co-ordinates is given in Tab. 1.

3.1. Pacova hora quarry near Chýnov

The local sequence of the Varied Group (Fig. 2a) includes calcite and dolomite–calcite marbles, rare metadolomites, amphibolites, calc-silicate rocks, muscovite–biotite gneisses, and minor quartzites. In 1985 quarrying operations exposed a 60 cm thick layer of amphibole–garnet calc-silicate gneiss rich in Mn, directly bordering amphibolite layer (Fig. 3). Calcite marble within several metres of the Mn-rich layer is represented by a silicate-rich variety carrying aggregates of minerals rich in Fe^{3+} such as andradite, epidote, accessory magnetite, in addition to diopside (Figs 4–5). Relations of rock types in the quarry were characterized by Orlov (1931), geology of the broader area by Suk et al. (1977), mineralogy in the quarry and nearby caves by Litochleb et al. (1997, 2004),

Tab. 1 Sample locations of the studied Mn-rich rocks

Locality No.	Locality	Sample	WGS-84-N	WGS-84-E	Main minerals
1	Chýnov	BD60a	49°25.84'	14°49.85'	Grt–Qtz with Pl and minor Hbl
1	Chýnov	BD58	–"–	–"–	Ti-andradite–hedenbergite/diopside–calcite
1	Chýnov	CV1	–"–	–"–	epidosite/marble with Ti-andradite and diopside
2	Doubrava	TYV108	49°16.36'	14°22.68'	Grt–Qtz
3	Český Krumlov	13*			Cal–Cpx–Pl
4	Novosedly	BD129	48°47.80'	14°15.20'	Grt–Phl–Prh–Gr–Qtz–Pl
5	Šebanov	VE127b	48°45.30'	14°12.46'	Grt–Qtz
6	Šebanov	VE127e	–"–	–"–	Ti-andradite–hedenbergite–Pl in amphibolite

13* – whole-rock chemical analysis reported by Bouška et al. (1985)

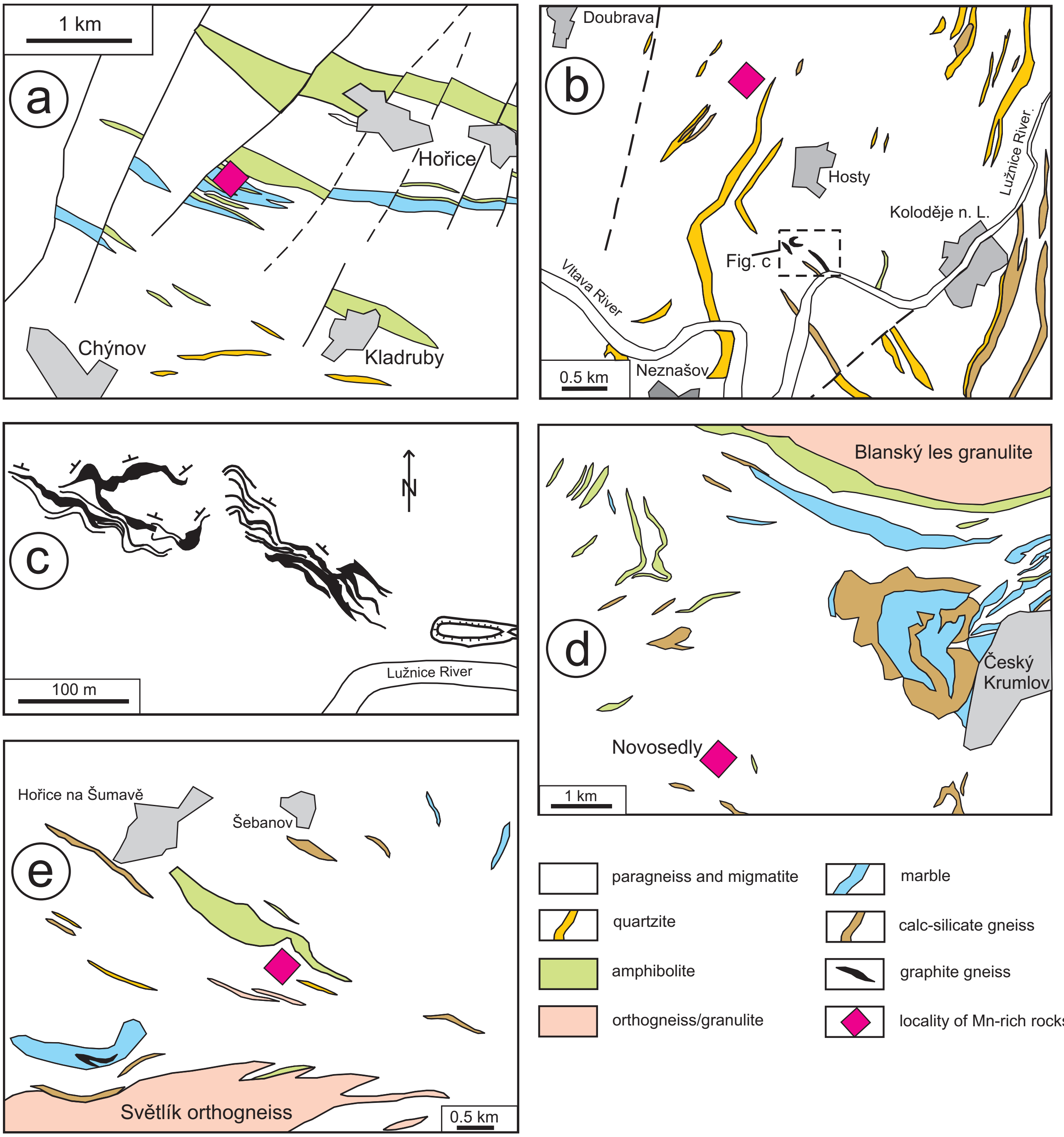

Fig. 2 Simplified geology of areas with occurrence of Mn-rich rocks, based on 1:25 000 maps of the Czech Geological Survey. **a** – Chýnov; **b** – Hosty–Doubrava; **c** – pattern of graphite gneisses in the Hosty graphite deposit, based on documentation of exploration trenches (Tichý 1975); **d** – Český Krumlov–Novosedly; **e** – Šebanov. Note the prevalence of NW–SE trending structural patterns (D_1 generation).

while geochemistry and petrology of amphibolites was studied by Janoušek et al. (2008).

A tendency to local enrichment in Mn is independently documented by rare occurrence of the violet variety of tremolite in marble ("hexagonite", containing up to 0.29 wt. % MnO, Litochleb and Sejkora 2007).

3.2. Hosty–Doubrava villages near Týn nad Vltavou

The occurrence of fine-grained garnet–quartz rock enriched in Mn (Fig. 2b) was briefly described by Vrána (1977). Associated are graphite–biotite quartzite and amphibolite. Some loose fragments occur 1 km NW of Hosty

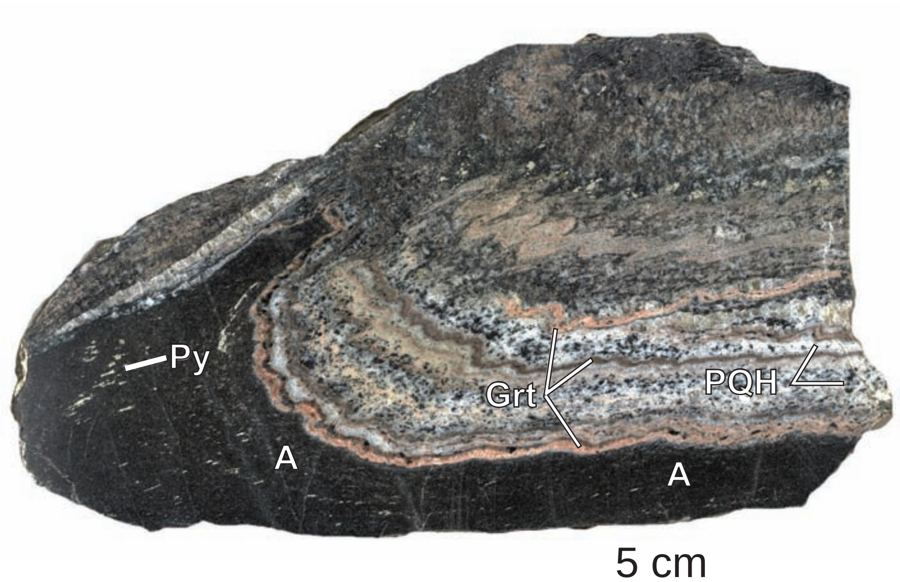

Fig. 3 Conformable contact of banded garnet–quartz rock (with plagioclase and amphibole) with amphibolite. Grt – garnet bands, PQH – plagioclase–quartz–hornblende bands, A – foliated amphibolite with pyrite (Py) partly aligned parallel to the fold's axial cleavage. Locality 1, Pacova hora near Chýnov.

village, not far of Hosty graphite deposit, Fig. 2b (Tichý 1975). West and SW of Koloděje nad Lužnicí, there is a relict domain of early, NW–SE trending D_1 structures (Fig. 2b–c), overprinted in wider area by younger D_2 NNE–SSW structures (Fig. 2b). A detailed plan of graphite gneiss distribution, resulting from graphite exploration campaign (Tichý 1975), and shown in Fig. 2c, serves as an example of a domain with D_1 structures still preserved.

3.3. Městský vrch graphite deposit in Český Krumlov

Calc-silicate rock enriched in manganese was documented by whole-rock chemical analysis reported by Bouška et al. (1985). Location of this sample is not shown in Fig. 2d as the accurate sampling site in Český Krumlov is uncertain.

Fig. 4 Dark brown Ti-andradite aggregates in impure marble with hedenbergite/diopside and epidote. Sample CV1, locality 1, Pacova hora near Chýnov.

3.4. Novosedly village near Český Krumlov

Garnet–phlogopite–pyrrhotite–graphite–quartz–anorthite rock was encountered in the borehole NV-1 at a depth of *c.* 1 400 m (Fig. 2d). The Český Krumlov Varied Group was represented here by calcite marbles, calc-silicate rocks, graphite–biotite gneisses and amphibolites. Geology and petrology of the borehole section was described by Fediuková (1985).

3.5. Šebanov village 11 km SW of Český Krumlov

Blocks of fine-grained garnet–quartz rock, locally with minor calcic amphibole, cummingtonite and magnetite bands, occur in fields at local elevation 2.2 km south of the village of Šebanov (Fig. 2e). They are accompanied by amphibolite with lenticular aggregates of dark brown Ti-andradite up to 1 cm across, diopside–hedenbergite and local scapolite, calc-silicate gneiss and a phlogopite–diopside rock.

The common feature of all above-described occurrences of Mn-rich metasediments is an association with amphibolites, marbles, graphite gneisses and quartzites of the Varied Group. In the Český Krumlov Varied Group calcitic and dolomitic marbles and calc-silicate gneisses associated with graphite gneisses contain *c.* 2 to 10 vol. % scapolite with 2.4–2.6 wt. % Cl, which indicates formation from sediments containing halite. The protolith rocks are interpreted as an evaporate-bearing sequence

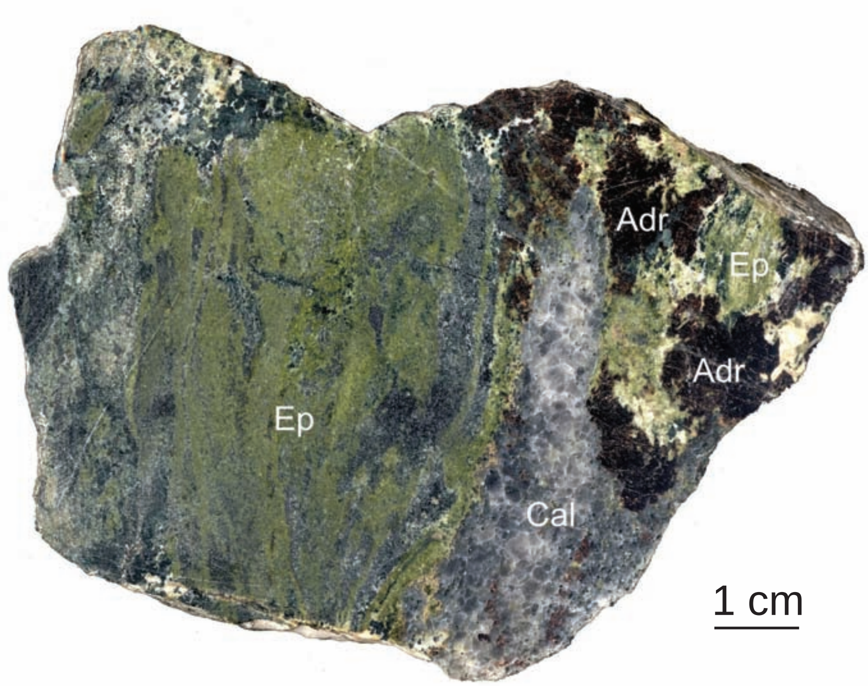

Fig. 5 Dark brown Ti-andradite aggregates (Adr) with epidote (Ep) in banded epidosite–calcite marble (Cal). Locality 1, Pacova hora near Chýnov.

deposited in a lagoon-like environment (Křibek et al. 1997). A similar Na/Ca scapolite was documented in calc-silicate gneiss from the Pacova hora quarry near Chýnov.

4. Analytical methods

Major-element whole-rock analyses were done by wet chemical methods in the laboratory of the Czech Geological Survey, Prague. Minor and trace elements in some whole-rock samples were determined by XRF and/or by ICP-MS in the same laboratory.

Mineral analyses were obtained using CAMECA SX 100 WDS electron microprobe at the Joint Laboratory of the Institute of Geological Sciences, Masaryk University and Geological Survey, Brno. The analytical conditions varied according to the mineral analysed, but usually involved 15 kV of accelerating voltage, probe current of 10–20 nA, and acquisition time of 10–30 s. The standards used were spessartine (Si, Mn), almandine (Fe), andradite (Ca), $MgAl_2O_4$ (Mg), hornblende (Ti), sanidine (Al, K), albite (Na), fluorapatite (P) and chromite (Cr). Some analyses were carried out with the CamScan 3400 electron microscope using energy dispersion analyser Link ISIS at the Czech Geological Survey, Prague. Analytical conditions were in this case 2.5 nA, 15 kV, 60 s counting time on sample and 120 s on standard.

Data handling, recalculation and plotting were performed by the R language package *GCDkit* (Janoušek et al. 2006). Mineral formulae recalculation used largely worksheets presented on Web by A. Tindle. Especially the set for amphiboles, based on Mogessie et al. (1990) procedure, was useful, as it provides for determination of ferrous/ferric ratio. Mineral abbreviations in this paper follow Kretz (1983).

5. Petrography and mineral chemistry

5.1. Chýnov

Banded garnet–quartz–plagioclase ± hornblende rock, sample BD60a, directly at contact with amphibolite (Fig. 3) is composed of very fine-grained garnet (Fig. 6a) exhibiting a strong compositional zoning (Fig. 7), mainly with (mol. %) 36.6–47.5 Alm, 26.0–30.4 Sps, 8.5–21.4 Grs, 11.1–13.8 Prp, and 0.2–6.2 Adr (Tab. 2). Plagioclase has composition of ~An_{46}. Amphibole corresponds to ferrimagnesiohornblende or ferritschermakite (Tab. 3) (Leake et al. 1997). Accessory minerals include ilmenite with 24 mol. % pyrophanite and 5.8 mol. % hematite (Tab. 4), magnetite, pyrite and apatite.

Impure calcite marble with Ti-andradite aggregates 3–10 mm, diopsidic pyroxene and epidote (sample BD58, Fig. 4) contains garnet with *c.* 70 mol. % andradite, 5.5 wt. % Al_2O_3 and 0.6–1.2 wt. % TiO_2 (Tab. 2). Clinopyroxene contains 0.35–0.5 Fe^{2+} *pfu*, minor Fe^{3+}, Al and Na (Tab. 3).

5.2. Hosty–Doubrava

Loose skelet in the field. The rock contains 20–30 vol. % garnet in anhedral to subhedral grains set in granular quartz mosaic with accessory biotite. Garnet contains (mol. %) 45.9 Alm, 37.0 Sps, 14.2 Prp, and 2.9 Grs. Associated biotite, in part altered, contains 1.9 wt. % MnO (Vrána 1977). Apatite and graphite are accessory components.

5.3. Český Krumlov, Městský vrch graphite deposit

According to Bouška et al. (1985), the calc-silicate rock (analysis No. 13 in Tab. 1) with 3.53 wt. % MnO also contains *c.* 8 wt. % carbonates. It was not possible to locate rock sample to this archival analysis.

5.4. Novosedly, NV-1 borehole, 1 420 m

Garnet–phlogopite–pyrrhotite–graphite–quartz–anorthite rock features nearly complete sulphurization of iron. Phlogopite is represented by a nearly colourless variety containing only 1.50 wt. % FeOt. Garnet forms colourless to whitish lenticular porphyroblasts up to 7 mm long, which contrast with the dark, graphite-rich matrix. Garnet contains (mol. %) 53.0–72.4 Sps, 26.3–43.6 Grs, 0.8–1.2 Prp and 0–2.7 Alm (Tab. 2). The rock contains 11 wt. % graphite and *c.* 5 wt. % pyrrhotite and plagioclase of bytownite–anorthite (An_{89}) composition. Host rocks include calcitic and dolomitic marbles with layers of graphite gneiss, calc-silicate gneiss, paragneiss and amphibolite.

5.5. Šebanov

Garnet–quartz rock shows quartzitic layers with minor garnet alternating with Grt-rich layers grading to several mm thick laminae of garnetite (Fig. 6c). Garnet composition corresponds to (mol. %) 38.5–41.3 Alm,

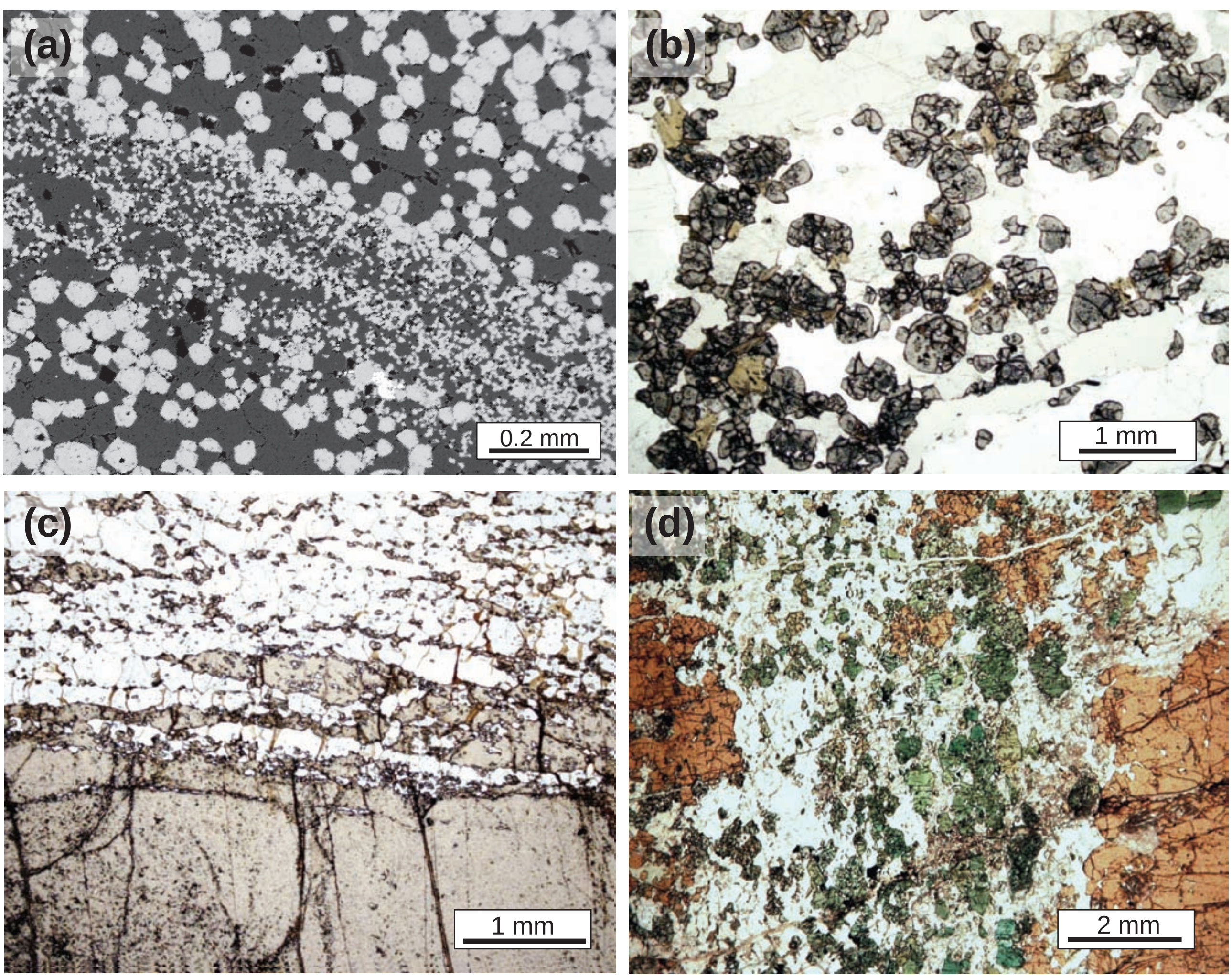

Fig. 6 Microstructures of Mn-rich garnet–quartz rocks (a–c): **a** – sample BD60a, Chýnov, BSE image; **b** – sample TYV108, Hosty–Doubrava; **c** – sample VE127b, Šebanov; **d** – Ti-andradite–hedenbergite–plagioclase rock associated with amphibolite, sample VE127e, Šebanov. Figs b–d are photomicrographs using plane polarized light.

Tab. 2 Composition of garnet (wt. % and apfu)

locality	Chýnov	Chýnov	Chýnov	Chýnov	Doubrava	Novosedly	Novosedly	Šebanov	Šebanov	Šebanov	Šebanov
sample	BD60a	BD60a	BD58	BD58	TYV108*	BD129	BD129	VE127b	VE127b	VE127e	VE127e
	core	rim	1	2		1	2	34	37	core	rim
SiO_2	37.55	37.67	35.62	35.99	38.1	37.58	38.65	37.87	37.41	36.02	36.47
TiO_2	0.39	0.00	1.22	0.65	n.d.	0.10	0.10	0.02	0.02	0.56	0.96
Al_2O_3	19.45	19.86	5.65	5.54	20.8	20.51	21.41	20.44	20.53	4.97	6.54
$Fe_2O_3^*$	2.01	1.55	18.27	18.51	0.0	0.00	0.00	1.38	1.29	19.23	17.11
FeO^*	19.81	17.23	6.28	6.49	20.2	0.00	0.80	18.06	19.33	7.55	7.48
MnO	13.14	11.34	0.15	0.21	16.1	31.01	23.61	14.97	14.64	0.92	0.66
MgO	3.21	11.34	0.19	0.13	3.5	0.30	0.20	3.47	3.58	0.09	0.16
CaO	5.04	9.00	31.91	31.91	1.0	10.10	15.34	4.98	3.93	30.69	30.60
Na_2O	0.00	0.04	0.00	0.00	n.d.	0.00	0.00	0.05	0.01	0.00	0.00
Total	100.60	99.41	99.29	99.46	99.7	99.60	100.11	101.19	100.73	100.04	99.98
Atoms / 12 oxygens											
Si	2.999	3.014	2.978	3.006	3.048	3.024	3.031	2.994	2.979	3.012	3.016
Al^{iv}	0.001	0.000	0.022	0.000	0.000	0.000	0.000	0.006	0.021	0.000	0.000
Al^{vi}	1.840	1.880	0.563	0.573	1.964	1.946	1.983	1.906	1.911	0.516	0.667
Ti	0.023	0.000	0.077	0.041	0.000	0.006	0.006	0.001	0.001	0.035	0.060
Fe^{3+}	0.121	0.093	1.149	1.164	0.000	0.000	0.000	0.082	0.077	1.210	1.065
Fe^{2+}	1.324	1.153	0.439	0.454	1.369	0.000	0.079	1.194	1.287	0.528	0.517
Mn	0.889	0.769	0.011	0.015	1.091	2.114	1.568	1.003	0.987	0.065	0.046
Mg	0.382	0.329	0.024	0.016	0.417	0.036	0.023	0.409	0.425	0.011	0.020
Ca	0.431	0.772	2.858	2.856	0.084	0.871	1.289	0.422	0.335	2.750	2.712
Total	8.010	8.010	8.120	8.126	7.973	7.997	7.978	8.017	8.024	8.128	8.103
Almandine	41.8	36.6	0.0	0.0	45.9	0.0	2.7	38.5	41.3	0.0	0.0
Andradite	6.2	4.7	67.4	68.0	0.0	0.0	0.0	4.1	3.9	71.2	62.6
Grossular	8.5	21.4	31.3	30.7	2.9	26.3	43.6	10.0	7.4	25.8	34.9
Pyrope	13.1	11.2	0.9	0.6	14.2	1.2	0.8	13.7	14.3	0.4	0.8
Spessartine	30.4	26.1	0.4	0.6	37.1	72.4	53.0	33.6	33.1	2.6	1.8

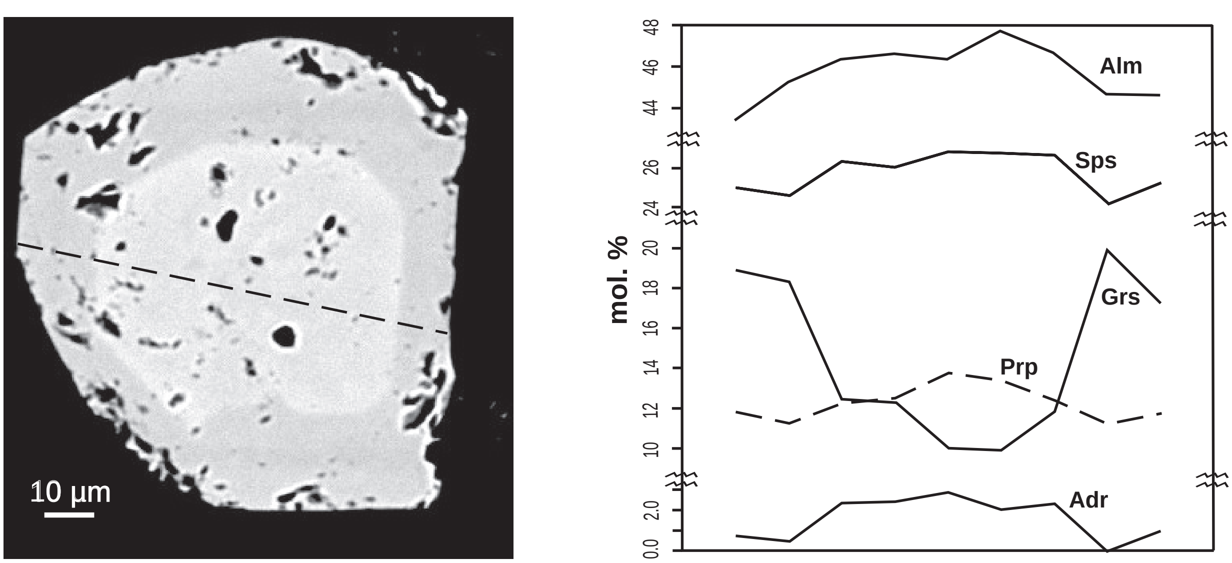

Fig. 7 Compositional zoning of garnet in amphibole–garnet–quartz–plagioclase banded rock, sample BD60a, Chýnov.

Tab. 3 Composition of amphiboles and clinopyroxenes (wt. % and apfu)

Locality	Chýnov	Chýnov	Chýnov	Chýnov	Chýnov	Šebanov	Šebanov	Šebanov	Šebanov
Sample	BD60a Hbl 1	BD57 Hbl 46	BD57 Hbl 47	BD58 Cpx 1	BD58 Cpx 2	VE127b Hbl 35	VE127b Cum 32	VE127b Cum 33	VE127e Cpx 6
SiO_2	45.12	45.26	43.61	48.09	51.21	47.52	53.75	54.29	45.33
TiO_2	0.51	0.46	0.60	0.08	0.03	0.66	0.12	0.10	0.32
Al_2O_3	10.20	10.08	12.39	1.82	0.58	8.27	0.00	1.55	4.23
Cr_2O_3	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00
V_2O_3	n.a.	0.09	0.12	0.00	0.00	0.06	0.00	0.02	0.00
$Fe_2O_3^*$	11.63	17.20	11.90	4.15	1.96	14.23	0.00	0.00	7.32
FeO^*	5.91	0.41	5.37	15.07	11.03	2.97	19.20	18.96	11.42
MnO	1.50	1.40	1.13	0.16	0.20	1.79	4.11	4.29	0.42
MgO	10.92	12.50	11.10	6.38	10.72	12.71	16.78	17.21	6.63
CaO	10.51	9.76	10.79	22.20	23.90	10.36	1.76	1.53	21.46
Na_2O	1.02	1.13	1.45	0.95	0.43	0.89	0.10	0.11	1.43
K_2O	0.23	0.15	0.24	0.00	0.00	0.24	0.04	0.00	0.00
P_2O_5	n.a.	n.a.	n.a.			0.02	0.03	0.00	
ZnO	n.a.	0.01	0.04			0.07	0.00	0.09	
BaO	n.a.	0.06	0.00			0.00	0.00	0.07	
F	n.a.	0.14	0.14			0.11	0.03	0.02	
H_2O^*	2.05	2.01	1.99			2.06	2.01	2.06	
O=F		–0.06	–0.06			–0.05	–0.01	–0.01	
Total	99.60	100.60	100.84	98.90	100.06	101.91	97.92	100.20	98.56
Atoms / 23 oxygens (amphiboles); 6 oxygens (clinopyroxenes)									
Si	6.607	6.495	6.323	1.929	1.965	6.754	8.015	7.882	1.834
Al^{IV}	1.393	1.505	1.677	0.071	0.026	1.246	0	0.118	0.166
Al^{VI}	0.368	0.199	0.440	0.015	0.000	0.139	0	0.147	0.036
Cr			0.003						
Ti	0.056	0.050	0.065	0.002	0.001	0.071	0.013	0.011	0.010
Fe^{3+}	1.282	1.857	1.298	0.125	0.056	1.522	0.000	0.000	0.223
Fe^{2+}	0.724	0.049	0.651	0.505	0.354	0.353	2.394	2.302	0.386
Mn	0.186	0.170	0.139	0.005	0.007	0.215	0.519	0.528	0.014
Mg	2.384	2.674	2.399	0.381	0.613	2.693	3.730	3.725	0.400
Zn		0.001	0.004			0.007		0.010	
Ca	1.649	1.501	1.676	0.954	0.983	1.578	0.281	0.238	0.930
Na	2.290	0.314	0.408	0.074	0.032	0.245	0.029	0.031	0.112
K	0.043	0.027	0.044			0.044	0.008	0.000	
F		0.064	0.064			0.049	0.014	0.009	
OH^*	2.000	1.936	1.936			1.951	1.986	1.991	
Total	16.982	16.842	17.127	4.061	4.037	16.867	16.989	16.992	4.111

* ferrous/ferric ratio, H_2O and OH contents calculated from stoichiometry
Sample BD57 is an aliquot (paratype) to sample BD60a

33.2–33.6 Sps, 13.7–14.3 Prp, 7.4–10.0 Grs, and 3.9–4.1 Adr (Tab. 2). Accessory calcic hornblende is ferrimagnesiohornblende with *c.* 0.2 Mn *pfu*. Minor manganoan cummingtonite contains 2.3 Fe^{2+} *pfu* and 0.5 Mn *pfu* (Tab. 3). Accessory ilmenite carries increased Mn corresponding to 32 to 34 mol. % pyrophanite, and minor hematite (Tab. 4). Accessory magnetite has nearly ideal simple composition. Dark brown andradite-rich aggregates in amphibolite (Fig. 6d) carry garnet with *c.* 70 mol. % andradite, 0.6–1.0 wt. % TiO_2 and 5.0–6.5 wt. % Al_2O_3 (Tab. 2). Associated clinopyroxene contains 0.39 Fe^{2+} *pfu*, 0.40 Mg *pfu*, 0.22 Fe^{3+} *pfu*, slightly increased Al and Na (Tab. 3). There is also abundant amphibole, which was not analyzed, and Ca-rich scapolite.

Tab. 4 Composition of ilmenite and magnetite (wt. % and apfu)

Mineral	ilmenite	magnetite	magnetite	ilmenite	ilmenite	magnetite
Sample	BD60a	BD60a	CV1	VE127b	VE127b	VE127b
SiO_2	0.19	0.10	0.00	0.01	0.02	0.02
TiO_2	48.65	0.05	0.00	51.37	50.81	0.04
Al_2O_3	1.18	0.00	0.04	0.00	0.01	0.06
Cr_2O_3	n.a.	n.a.	n.a.	0.00	0.00	0.01
V_2O_3	n.a.	n.a.	n.a.	0.03	0.00	0.17
$Fe_2O_3^*$	6.16	66.63	67.11	1.82	2.42	66.74
FeO^*	32.48	30.23	30.18	30.17	30.33	30.10
FeOt	38.02	90.19	90.57	31.80	32.51	90.15
MnO	11.35	0.08	0.04	15.66	14.90	0.08
MgO	0.00	0.00	0.00	0.10	0.10	0.01
CaO	0.00	0.00	0.00	0.00	0.00	0.00
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00
Nb_2O_5	n.a.	n.a.	n.a.	0.02	0.08	0.00
UO_2	n.a.	n.a.	n.a.	0.02	0.00	0.00
Total	99.4	97.09	97.37	99.07	98.68	97.05
Atoms						
Si	0.005	0.004	0.000	0.000	0.001	0.001
Ti	0.920	0.001	0.000	0.982	0.974	0.001
Al	0.035	0.000	0.000	0.000	0.000	0.003
Fe^{3+}	0.116	1.989	2.000	0.035	0.047	1.993
Fe^{2+}	0.683	1.003	0.999	0.642	0.648	0.999
Mn	0.242	0.003	0.001	0.337	0.323	0.003
Mg	0.000	0.000	0.000	0.004	0.004	0.001
Mol. %						
Ilm	67.9			64.1	64.8	
Pyr	24.0			33.7	32.3	
Gei	0.0			0.4	0.4	
Hem	5.8			1.7	2.3	
Crn	1.7			0.0	0.0	

6. Whole-rock compositional relations

6.1. Gneissic rocks

Major-element whole-rock analyses of manganiferous rocks are presented in Tab. 5, analyses of trace elements in Tab. 6. Normative Ab, Or and An values (Catanorm) calculated from whole-rock analyses of manganiferous rocks are shown in comparison with similar values for paragneisses of the Varied Group (n = 6, René 2006) in Fig 8. The Mn-rich rocks are relatively enriched in Ca and yield lower normative orthoclase.

Multielement diagram (Fig. 9) presents comparison of whole-rock composition of manganiferous rocks with Moldanubian paragneisses of the Varied Group. Average of six paragneiss analyses published by René (2006) is used in the normalization. Abundances of SiO_2, TiO_2, Al_2O_3, FeO^t, MgO in manganiferous rocks are similar to the paragneiss values, CaO and P_2O_5 are moderately to strongly elevated, but MnO enrichment of twenty to hundred times is by one order of magnitude higher than that of CaO and P_2O_5. Sodium and potassium are slightly or very strongly depleted, indicating a decrease or absence of feldspars in the detrital material. The tendency to Na_2O and K_2O decrease is most prominent in Mn-garnet quartzite VE127 from Šebanov (Fig. 9).

The REE distribution patterns for three samples of manganiferous rocks (Chýnov, Šebanov and Novosedly) (Fig. 10) are compared with the REE abundances in the Moldanubian paragneisses of the Varied Group (René 2006). The relations strongly indicate supply of detrital material compositionally similar for both the manganiferous rocks and paragneisses of the Varied Group. The garnet–quartz rock from Šebanov is somewhat different in having a higher La, lower Sm and a steeper linear trend of the light REE, reflected by ratios La_N/Yb_N = 17.90 and La_N/Sm_N = 11.34 (Tab. 6).

A remarkable (*c.* 15 to 100 fold) decrease in the FeO^t/MnO ratio, compared to ordinary biotite gneisses of this unit, is the prime feature of Mn-rich rocks (Tab. 5). The high Mn and increased Ca and P contents correspond to a significant role of chemogenic components, whereas the signature of detrital material similar to that supplied for sediments metamorphosed to paragneisses implies a mixed detrital–chemogenic origin of the Mn-rich rocks. Composition of Mn-garnet–quartz rocks indicates that the detrital material was near to quartz-rich sand with a clay component.

6.2. Amphibolites in the Chýnov area

According to Janoušek et al. (2008), several amphibolite samples from the Chýnov quarry have a relatively high ratio Fe_2O_3/FeO = 0.7–1.0 (wt. % values). This is caused by the occurrence of accessory magnetite, the presence

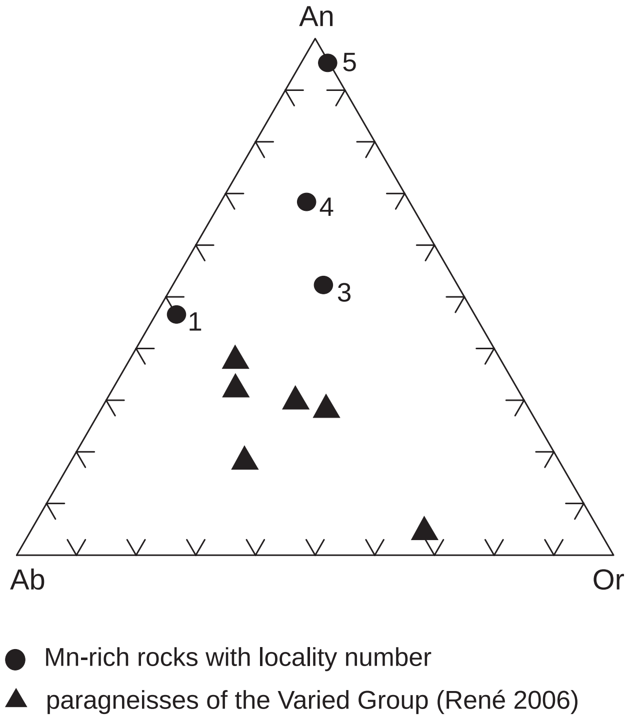

Fig. 8 Comparison of normative feldspar components in Mn-rich rocks with values for paragneisses of the Varied Group, calculated as Cata-norm (Janoušek et al. 2006). Paragneiss data are from René (2006).

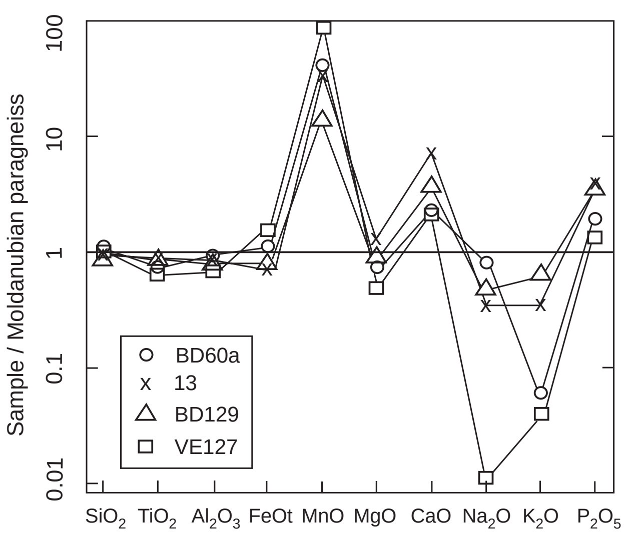

Fig. 9 Multielement plots for the major and minor elements of the Mn-rich rocks normalized by average compositions of the Varied Group paragneisses (n = 6, René 2006).

of *c.* 10 vol. % of unmixed hematite lamellae in accessory ilmenite and probably by elevated Fe_2O_3/FeO ratio in amphiboles. These features may indicate a significant oxidation of protolithic basalts extruded on land surface or in shallow-water, shelf environment (Janoušek et al. 2008). A probable minor increase in the oxidation state during metamorphism is indicated by partial replacement of pyrrhotite by magnetite. Alternatively, some amphibolite layers could have formed via metamorphism of basaltic tuff – i.e., material which would be even more susceptible to early post-deposition oxidation. The possibility of submarine alteration of basalts under shelf conditions is independently indicated by the strongly oxidic calc-silicate assemblage andradite + epidote + diopside + magnetite, interbanded with calcite marble in close proximity to some amphibolites (Litochleb et al. 2004). Thin layers of white quartzite and quartzitic gneiss in calcite and dolomite marbles carrying amphibolites (Orlov 1931) also support the idea of deposition in a shallow sea.

7. Discussion

7.1. The absence of Mn-rich rocks in Moldanubian domains of D_2 and D_3 refoliation

The Mn-rich rocks tend to occur in relict domains of limited extent with preserved D_1 structures and NW–SE trending foliation. It is suggested that in regionally prevalent areas dominated by superimposed refoliation (D_2, D_3) (Vrána 1992; Vrána and Šrámek 1999; Vrána and Bártek 2005) the thin layers of Mn-rich rocks could have been reduced to boudins dispersed in refoliated paragneiss. Accidental sampling of such a boudin seems unlikely, even though the presence of minor cummingtonite in a fine-grained garnet–quartz rock could serve as indication of a former Mn-rich rock presence. Information on crystallinity of graphite in several deposits exploited in the past and on other graphite occurrences (Tichý 1975) confirms the correlation of relatively coarse graphite (and graphite deposits) with relatively rare relict domains with D_1 structures still preserved. They include former productive graphite mines near Mokrá (several km west of the area shown on Fig. 2e), Chvalovice further north (Tichý 1975), Městský vrch deposit in Český Krumlov (Fig. 2d), Hosty deposit (Fig. 2b–c), and occurrences of graphite quartzite and gneisses west of Černovice in the Chýnov area (Suk et al. 1977). On the other hand, the Bližná (Černá v Pošumaví) graphite deposit exploited by the Václav mine till 2000 features N–S to NNE–SSW trending structures compatible with the D_2 refolding/refoliation. At this locality, a high proportion of graphite falls in the technical "amorphous" category (Tichý 1975), reflecting strong mylonitization of the former crystalline graphite due to the superimposed refolding/refoliation.

7.2 Geology of marine Mn-rich sediments

The Mn-quartzites and related Mn-rich metasediments worldwide are often associated with sea-floor basaltic magmatism and attendant exhalative processes. In most

Tab. 5 Major- and minor-element analyses of Mn-rich garnet–quartz rocks and gneisses (wt. %)

Locality	Chýnov	Český Krumlov	Novosedly	Šebanov	Varied Group paragneisses
Sample No.	BD 60a	13	BD 129	VE 127c	(n = 6)
SiO_2	58.86	49.32	47.63	57.59	59.23
TiO_2	0.60	0.72	0.70	0.52	0.80
Al_2O_3	15.42	14.75	13.92	11.71	16.76
Fe_2O_3	0.64	3.42	<0.01	1.76	8,31
FeO	8.25	2.13	6.69	9.88	
MnO	4.19	3.53	1.38	9.98	0.10
MgO	2.97	4.97	3.58	1.93	3.99
CaO	3.98	13.38	6.48	3.74	1.74
Li_2O	0.003	n.d.	0.02	<0.001	
Na_2O	2.21	0.91	1.24	0.01	2.71
K_2O	0.20	1.13	2.14	0.12	3.37
P_2O_5	0.23	0.48	0.47	0.16	0.12
CO_2	0.42	3.85	0.05	0.08	
C	<0.01	n.d.	11.01	0.02	
F	0.03	n.d.	0.24	0.01	
S	0.47	n.d.	3.00	0.02	
H_2O^+	0.94	1.67	1.13	1.74	LOI 2.69
H_2O^-	0.03	0.12	0.12	0.11	
(O = F)	–0.01		–0.10		
(O = S)	–0.12		–0.75		
Total	99.31	100.38	99.32	99.38	99.82
FeO^t/MnO	2.11	1.48	4.85	1.15	74

BD 60a – hornblende–plagioclase–garnet–quartz gneiss
13 – calc-silicate gneiss with high-Ca pyroxene and calcite
BD 129 – phlogopite–pyrrhotite–graphite–quartz–anorthite gneiss with garnet
VE 127c – garnet–quartz rock
Paragneisses (n = 6) – average composition of paragneisses of the Varied Group (René 2006)
** total iron as Fe_2O_3

cases there is a close correlation with coeval basaltic (tholeiitic) volcanism on sea floor, venting of oceanic crust, significant enrichments in Mn transported by upwelling sea water, typically in shallow sea and in proximity to transgression zones of marine sediments on continental crust. The sources of Mn-rich exhalites are interpreted as originating in basic volcanics undergoing pseudohydrothermal alterations, in hydrothermal solutions associated with volcanism and in part in halmyrolysis of sediments during diagenesis (Wonder et al. 1988). The fractionation of Mn from Fe is explained by early precipitation of Fe, relative instability of Mn sulphide and differences in behaviour of Mn and Fe under changing redox conditions (Wonder et al. 1988).

Banded Mn-rich quartzites consisting of mm to cm thick bands rich in garnet alternating with quartzitic (or quartz–feldspathic) laminae are interpreted as having formed by dominant exhalite material (spessartine-rich bands) and continent-derived detritus, mostly quartz and Al-rich minerals.

Manganese formations are often accompanied by oxidic iron formations in condensed Proterozoic sequences deposited on continental shelves (Bühn and Stanistreet 1997). It was suggested that increased salinity in isolated oceanic basins resulted in increased solubility of Mn and Fe. Similar relations were observed in Phanerozoic, whereas in the present-day setting the oceanic sources and precipitation areas of long-term preservation are widely separated in space (Bühn and Stanistreet 1997).

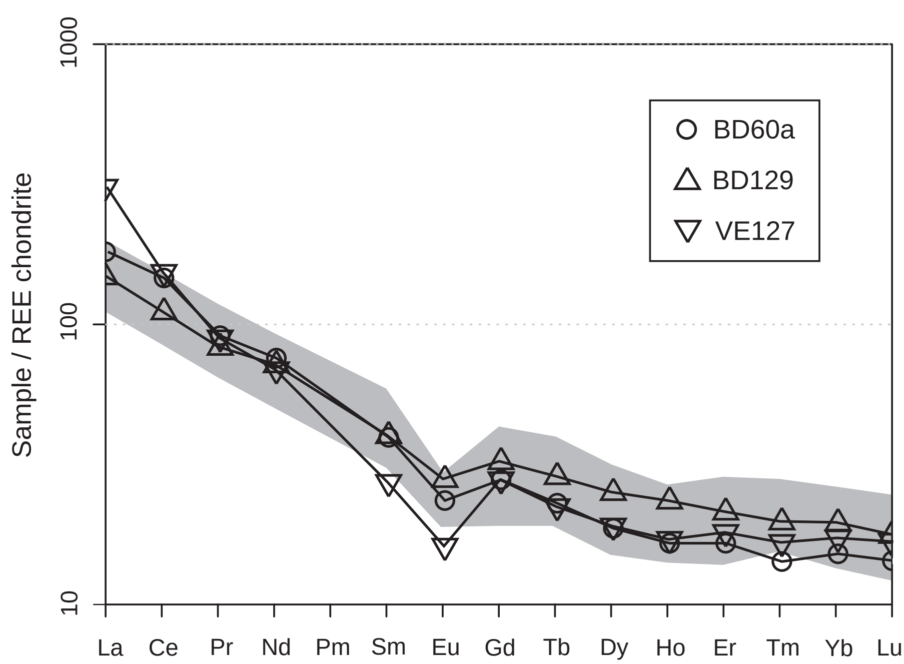

Fig. 10 Distribution patterns of the rare earth elements in manganese-rich rocks. Chondrite values according to Boynton (1984). Grey field corresponds to variation in six paragneiss samples of the Varied Group (René 2006).

Tab. 6 Comparison of selected trace-element concentrations in Mn-rich rocks and average Moldanubian paragneisses (ppm)

Sample	BD60a	VE127	BD129	paragenisses (n = 6)*
Rb	6	3	166	148
Sr	300	2	1000	184
Zr	91	143	93	204
Y	35	40	43	36
Nb	8	6	9	
Sn	< 2	< 2	< 2	
Mo	3	< 1	14	
Cr	72	119	98	131
Ni	42	28	48	44
Cu	21	12	78	
Zn	47	47	132	
Pb	4	< 2	12	
As	< 1	< 1	2	
U	< 2	< 2	3	5
La	57.3	97.7	46.7	51.3
Ce	120.5	126.2	91.1	102.9
Pr	11.32	11.12	10.28	11.7
Nd	46.3	42.1	43.8	45.9
Sm	7.84	5.42	7.95	9.0
Eu	1.76	1.21	2.09	1.7
Gd	7.36	7.36	8.52	8.2
Tb	1.11	1.08	1.38	1.3
Dy	6.14	6.25	8.22	7.6
Ho	1.21	1.25	1.71	1.5
Er	3.54	3.87	4.57	4.4
Tm	0.47	0.55	0.65	0.7
Yb	3.23	3.68	4.16	4.0
Lu	0.47	0.55	0.58	0.6
La_N/Yb_N	11.96	17.90	7.57	8.65
La_N/Sm_N	4.60	11.34	3.70	3.59
Eu/Eu^*	0.89	0.59	0.78	0.61

* average for paragneisses of the Varied Group (René 2006)

Metamorphosed Neoproterozoic Mn-rich rocks of the Damara Belt in Namibia are associated with iron formation and supermature metaquartzarenites resting unconformably on the pre-Damaran basement (Bühn et al. 1992). The facial evolution indicates transgression on subsiding shelf, starting with quartzarenites followed by chemical sediments carrying ore-bearing Mn-rich horizon, overlain by carbonates and pelitic schists. Extensive amphibolite belt (former sea-floor basalts) occurs at some distance. Garnet–quartz rocks rich in Mn, including banded types, are associated with several Mn-rich lithologies including ore-grade types (Bühn et al. 1992).

Palaeozoic Mn-rich rocks associated with sulphide deposits and iron formations in the Appalachians of Georgia, USA, occur in a thrust sheet comprised of metabasalts, volcanogenic alteration products and a quartzite member (Wonder et al. 1988). Banded spessartine-rich garnet–quartz rocks (coticules) are a dominant rock type of the local Mn-formation. Garnet-bearing iron formations were interpreted as a hybrid between Fe and Mn–Fe formations. According to Wonder et al. (1988) the garnet– quartz rocks (coticules) contain between 20 and 50 vol. % of hydrothermal material (exhalite), the rest being pelagic–terrestrial detrital material. Thomson (2001) tried to assess the proportions of hydrothermal, hydrogenous and pelagic material in Mn-garnet–quartz metasediments of two formations in New England using geochemical criteria. The results indicate that deciphering the likely protoliths for individual coticule occurrences is difficult. The absence of negative Ce anomaly is considered as excluding the role of hydrothermal processes (related to sea-floor vents). Also it became clear that coticule geochemistry does not appear to be unique to a particular formation and may be variable within a formation, or even in individual horizon (Thomson 2001). Differences in coticule compositions do not necessarily preclude stratigraphic correlation.

Discussion of relations of greenschist- to amphibolite-facies Mn-rich garnet–quartz rocks to gondites, which were metamorphosed mainly under granulite-facies conditions, as well as to ore-grade Mn-rich rocks, is beyond the scope of the present study.

7.3. Potential informations on early stages of metamorphic crystallization in Mn-rich garnetiferous rocks

In manganiferous rocks, the crystallization of spessartine-rich garnet starts at significantly lower temperatures than would correspond to an appearance of almandine-dominated garnet as index mineral in the Barrovian sequence of metamorphic zones. In the Venn–Stavelot Massif, Upper Salmian (Lower Ordovician) of the Belgian Ardennes, spessartine with hydrogarnet component appeared early in carpholite-bearing metapelites at conditions estimated to ~300 °C and 0.1–0.2 GPa (Theye et al. 1996). In several areas of Lower Palaeozoic in the eastern USA, the garnet–quartz rocks (coticules) occur in the chlorite zone (Thomson 2001).

In garnet–quartz rocks of the Moldanubian Zone of southern Bohemia, the fine-grained garnet could possibly date from early stages of regional metamorphism. However, low-Ca samples from Hosty–Doubrava and Šebanov localities contain garnet with minimal compositional variation (Prp ~ 13–14 mol. %), in line with the presence of amphibolite-facies mineral assemblages in the surrounding rocks. Compositionally zoned garnet in relatively Ca-rich sample of finely banded amphibole–quartz–plagioclase–garnet rock from Chýnov (Figs 6a, 7), with 11–13 mol. % Prp, can also be interpreted as compatible with amphibolite-facies conditions. The mechanism leading to a very strong zoning in the grossular component, (core 10 mol. %, rim 20 mol. %) (Fig. 7), is not fully understood at present. It can possibly reflect a significant pressure increase in the course of garnet crystallization. This situation would indicate either re-equilibration of early low-P–T mineral assemblage, or possibly a quick onset of the amphibolite-facies conditions. The assemblage kyanite + zoisite in local aluminous pods in calcite marble in the Chýnov quarry, retrogressed to plagioclase + corundum during the decompression stage (Vrána 1991), indicates increased pressure conditions (min. 0.7–1.0 GPa ?).

7.4. Role of redox conditions in Mn enrichment of the Moldanubian metasediments

The studied manganiferous rocks include both magnetite- (garnet–quartz rock from Šebanov, banded amphibole–plagioclase–quartz–garnet rock from Chýnov) and graphite-bearing types. Garnet–phlogopite–pyrrhotite–graphite–quartz–anorthite rock from the Novosedly borehole contains 11 wt. % carbon (graphite) and *c.* 6 vol. % pyrrhotite (3 wt. % sulphur). The rock bears only 1.38 wt. % MnO but the colourless Sps–Grs garnet free of iron contains up to 72 mol. % of spessartine component. This is not the single example of Mn-rich garnet in graphite-rich rock in the Bohemian Massif. Novák (1988) described spessartine-rich garnet from graphite in the amphibolite-facies deposit Velké Tresné near Olešnice (Moravian Zone).

Clearly, a larger sample set would be necessary to evaluate the role of redox conditions in the studied area. Data from the Varied Group indicate that the Mn enrichment took place both under oxidizing and reducing conditions: the Mn-garnet–quartz rocks are oxidic but graphite-rich gneiss BD129 crystallized under reducing conditions.

7.5. Manganese-rich rocks in the Moldanubian Zone of western Moravia

Two occurrences of Mn-rich rocks in the Moldanubian Zone of western Moravia, although different in mineralogy from the studied localities in southern Bohemia, compare well by both their association with the Varied Group and only very limited extent (also forming layers less than 1 m in thickness).

(1) Metamanganolite rocks associated with minor quartzite occur near Kojetice, about 4 km west of the Třebíč Pluton, western Moravia. According to Novák and Škoda (2007) several types of Mn-rich rocks are present at the locality: a) braunite–quartz rock with minor hyalophane, spessartine (+ accessory magnetite–rutile intergrowths, pyrophanite, ilmenite, chernovite-(Y) and arsenogoyazite), b) Mn^{3+}-rich andalusite with rims of kanonaite in quartzitic rock with braunite, K-feldspar, albite, hyalophane, spessartine and paragonite (+ accessory minerals), c) garnet-rich rock dominated by Fe-rich spessartine with quartz and accessory minerals, and d) rhodonite-dominated rock forming layers in quartzite only 2 mm thick. This complex group of mineral assemblages developed in a thin quartzite band, which is estimated to less than 0.5 m in width. The metamanganolite is intercalated in weakly migmatized sillimanite–biotite paragneiss, carrying layers of graphite gneiss with V-rich muscovite, calc-silicate rock, calcite/dolomite marble and orthogneiss.

(2) Minor skarn-like rock composed of manganoan hedenbergite, minor spessartine–grossular garnet and bustamite with accessory sphalerite, galena and chalcopyrite occurs in the Varied Group at Meziříčko near Želetava, 25 km WSW of Třebíč, western Moravia (Houzar and Šrein 1995; Houzar et al. 2005). The rocks form boudins in calcite marble, 5 cm thick, incorporated with other lithologies such as quartzite, graphite gneiss, amphibolite and pyroxene gneiss in the complex of sillimanite–biotite paragneiss and cordierite–biotite migmatite.

It is interesting to note that regional pyroxene–garnet skarns (rich in Fe and Ca) in western Moravia and Lower Austria show a weak tendency to Mn-enrichment, as reported by Houzar and Šrein (1995). This type of regional garnet–pyroxene skarns is different from the Meziříčko Mn-rich skarn in that they occur as much larger bodies (up to 300 m thick), locally mineralized with magnetite. Skarns from near Županovice contain on average 2.0 wt. % MnO in high-Ca pyroxenes; the pyroxenes of the Kottaun skarn in Lower Austria show 2.2 wt. % MnO (Houzar and Šrein (1995). Such a tendency to Mn enrichment has not been observed in regional skarns in the northeastern part of the Moldanubian Zone (Němec 1991; Pertoldová et al. 2009) or in southern Bohemia. According to Pertoldová et al. (2009), garnet–pyroxene skarns originated by regional metamorphism of protoliths formed by mixing of detrital material and syn-sedimentary exhalites.

7.6. Comparison with Neoproterozoic Mn-rich horizons in the Chvaletice area

The stratabound Chvaletice Mn–Fe deposit occurs in the eastern part of the Teplá–Barrandian Unit, eastern Bohemia, hosting the largest concentration of Mn in the Bohemian Massif. According to Cháb et al. (1982) and Žák (1982), the deposit is formed by iron meta-manganolites, mostly of carbonate to silicate–carbonate varieties, rich in pyrite, and by graphitic phyllites. The deposition took place in a shallow-water reducing environment with minimal supply of detrital material from crustal sources, with possible participation of biochemogenic processes, under influence of simultaneous volcanism. The differences in age, redox conditions, and associated rock types place the Chvaletice deposit in contrast to the studied Mn-rich rocks in the Moldanubian Zone of southern Bohemia.

7.7. Significance of Mn-garnet–quartz rocks (coticules) in stratigraphic correlations

Since the Roman times, spessartine-rich whetstones were exported from the Belgian Ardennes as highly valued sharpening tools. The term coticule, derived from Latin word for whetstone, became ingrained in geological and petrographical terminology, especially in the eastern states of USA, Great Britain and Ireland. Schiller and Taylor (1965) explored the use of the term coticule in the geological literature of USA since 19th century till present. As follows from data in Clifford (1960), Schiller and Taylor (1965), and Thomson (2001) it is used for fine-grained Mn-garnet–quartz rocks, which closely compare with some samples described in this study. While Theye et al. (1996) in a study of manganiferous rocks in Ardennes did not use the term coticule, Lamens et al. (1986) reported in detail on occurrences of coticules (spessartine metapelites) in the Lower Ordovician in Belgium. Baijot et al. (2011) redefined the term coticule on a historical basis as a rock corresponding to material used for whetstones, composed of minute spessartine crystals (5–20 μm) set in phyllosilicate matrix. Spessartine–quartz rocks should be designated pseudocoticule according to Baijot et al. (2011). Clearly, a terminology bias occurred during decades of study of spessartine–quartz rocks and only future development will show which tendency would prevail in terminology.

In any case, there is growing evidence that Mn-rich garnet–quartz rocks are important lithostratigraphy markers. Besides the type locality in the Lower Ordovician of Ardennes, Mn-garnet–quartz rocks occur in the Ordovician of southern Ireland, possibly the Isle of Man (Kennan and Morris 1999), and in numerous Lower Palaeozoic Appalachian terrains in Nova Scotia, New England (Thomson 2001), Georgia (Wonder et al. 1988), and New Hampshire (Clifford 1960), at levels corresponding the Upper Cambrian, Ordovician and Lower Silurian. In New England nearly continuous coticule horizons extend for distances of up to 350 km (Thomson 2001). This indicates their role as important lithostratigraphy markers in units of moderate to regional dimensions.

In the context of increasing abundance of geochronological information supporting the Cambro–Ordovician age of the Varied Group in the Czech part of the Moldanubian Zone (Fiala et al. 1995; Drábek and Stein 2003; Janoušek et al. 2008; Košler et al. 2011), the occurrences of Mn-rich garnet–quartz rocks (coticules) appear as yet another indication of its Lower Palaeozoic age, particularly with reference to coticule localities in NW Europe and the eastern United States.

8. Conclusions

Manganese-rich rocks represent a notable but minor component of the Varied Group of the Moldanubian Zone in southern and south–central Bohemia. Garnet–quartz rocks and gneisses carrying spessartine-rich garnet are the main Mn-rich rock types. Accessory ilmenite and minor amphiboles participated in manganese partitioning.

Garnet–quartz rocks are oxidic, as indicated by the presence of accessory magnetite, but the gneissic rock with Mn-rich garnet (sample BD129 from Novosedly) carries abundant graphite. Layers of Mn-rich rocks are closely associated with amphibolites, marbles and graphite rocks. Highly oxidic assemblages rich in andradite (Ti-bearing), epidote and accessory magnetite are important in marbles and amphibolites, particularly at Chýnov. Carbonate-facies with rhodochrosite or rhodonite is apparently absent.

The reasons why these rocks remained unnoticed for more than a century of geological research are: a) minimal thickness of the Mn-rich layer (less than 1 m), b) poor exposure, c) limited areal extent of relict domains with early structures (D_1 generation) still preserved.

Widespread effects of penetrative shearing deformations (D_2, D_3) apparently reduced the Mn-rich layer to rare boudins dispersed in the transposed paragneiss matrix. Such boudins would be closely similar to garnet-bearing quartzitic calc-silicate gneisses with ordinary (i.e. low) Mn contents.

The rather unique association of several unusual rock types in the Český Krumlov and Chýnov areas indicates a close correlation of these two occurrences of the Varied Group.

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