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The PT — conditions of equilibrium for some pyrope peridotites and country rocks in the Moldanubian area at Mohelno (Eastern Moravia, Czechoslovakia)

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Температурные условия и условия давления при возникновении пироповых перидотитов и их вмещающих пород в молданубику в районе Могелна

Индексные минералы пироповых ультрабазитов и вмещающего гранулит изучались при использовании микросонды. На основании полученных данных и при использовании различных геотермических отношений и давления разных авторов были вычислены соответствующие температурные условия и условия давления возникновения этих пород. Минералогические ассоциации гранатовых перидотитов соответствуют условиям их эквilibрации при температуре 1123—1060 °C при давлении приблизительно 18 килобар. Пироксены встречаются и в других ультраосновных породах пришли в состояние равновесия при температурных условиях ниже 200 °C. Сложной является интерпретация полученных данных соответствующих минералогических пар для пород, которые возникли биметасоматическим процессом между перидотитом и гранулитом. На выбранном разрезе района Могелна были изучены те породы, которые содержат амфибол, биотит, гранат и местами клинопироксен. Раздельные величины эквilibрации возможно получить различными методами. Например по Перчуку (1970) условия равновесия бы возникли при температурах приблизительно 600° даже 650 °C, по методу Гангулиго (1979) температурные величины значительно выше.

The PT-conditions of equilibrium for some pyrope peridotites and country rocks in the Moldanubian area at Mohelno (Eastern Moravia, Czechoslovakia)

Pt-conditions were calculated for mineral assemblages of garnet peridotite and country granulite and biotite gneiss at the Mohelno locality in the eastern Moldanubian area. The mineral association of garnet peridotite originated at a temperature of 1123—1060 °C and a pressure of about 18 kbar. The temperature found using two different

thermometers for formation of the banded granulite and granulite gneiss with hornblende and biotite were from 600 (650) °C to 800 (850) °C, respectively. The conditions for the origin of bimetasomatic reaction rocks with garnet, clinopyroxene and hornblende correspond either to a temperature of 600—650 °C using Perchuk's method (1970) or to 860—910 °C using Ganguly's method (1979).

The presence of pyrope peridotite and eclogite bodies in the crystalline schists and gneisses is one of the characteristic features of the Moldanubicum of the Bohemian Massif. The largest peridotite and eclogite bodies are very often surrounded by granulite and granulite gneiss. Similar relations have been described in the Central Massif in Kazakhstan, the Muyun-Kum Massif in the USSR Tchein-Schan and the Uralian Ufalei in the USSR, etc.

It follows from petrographical and mineralogical data that the pyrope peridotite often corresponds to the conditions in the upper mantle (temperature up to 1200 °C, pressure up to 25—30 kbar) when the temperature in the crust is less than 700—800 °C and the pressure less than 10 kbar. However, it is more difficult to explain the structural and metamorphic history of polymetamorphosed and polyphase deformed terrains, to which the Bohemian Massif belongs, see e. g. the memory age of Gföhl gneiss (1813 Ma) and its Hercynian age 341 ± 4 Ma of its monazite or the surprising lower age of the granulite = 345 ± 5 Ma (O. van Breemen et al. 1982). Therefore it would seem to be useful to carry out systematic structural (Bowes-Hopgood and Misař, in press) and petrological (this article) studies of peridotite bodies and their surroundings.

A unique possibility in this respect is offered by a very well exposed section along the Jihlava river near Mohelno. There many peridotite bodies are infolded in granulite formations, biotite gneisses

and Gföhl gneiss and migmatites. A classical deep metamorphic contact of bimetasomatic character between garnet peridotite and country granulite and gneisses was found by Z. Misař (1980) and shown to participants of the working group "Ophiolites". N. L. Dobretsov collected the main varieties of rocks from this section and, together with E. V. Popov, carried out the microprobe analyses in the laboratory of the Geological Institute of the Academy of Sciences in Novosibirsk.

Geology

The Mohelno peridotite body, together with garnet amphibolite, granulite and granulite gneiss, forms a complicated structural unit overthrust on the Moravicum. The western and southern margin of this "peridotite-granulite" unit is of tectonic character with mylonite and ultramylonite. The Mohelno peridotite body and surrounding granulite represent a local synform with steeply dipping metamorphic foliation along the western margin but with nearly horizontal planes in the east. In the internal structure of the Mohelno peridotite body, the banded and laminated textures (alternating bands of harzburgite differing in the amount of pyroxene and olivine, and dunite bands) do not correspond to the predominant structures of the country rocks. New structural investigations (Bowes-Hopgood and Misař, in press) have indicated that the peridotite body and the

granulite were folded together during some later folding phase. Simultaneously, a new distinct metamorphic foliation with garnet, hornblende and biotite in the granulite rocks and metamorphic foliation with stretched pyropes in peridotite were developed.

The contact between the peridotite and the granulite, studied at this first step only along the road cut by Mohelno, is marked by a complex rock association of high temperature metamorphic-bimetasomatic origin. Some of the contact rocks, e. g. biotite schist, hornblende-biotite schist, biotite-hornblende-garnet schist were studied and their PT conditions of equilibration were calculated from the microprobe data. However, amphibolites, garnet amphibolites, spotted amphibolites, and many rock varieties of diorite, granite and gabbro composition have been found at other parts of the contact (Fig. 1). All bimetasomatic

reaction rocks forming the contact and its petrological and geochemical character are now being studied by Dudek, Misař and Jelínek.

Microprobe mineral analyses and conditions for the origin of rocks

The index minerals from pyrope peridotite of the Mohelno body and minerals from some country rocks, as well as the minerals of some bimetasomatic reaction rocks from the contact zone were analysed by the microprobe method. All secondary minerals and low temperature minerals were omitted.

Minerals of pyrope lherzolite and harzburgite

The main mineral components of the Mohelno peridotite (Table 1-1) are pyrope,

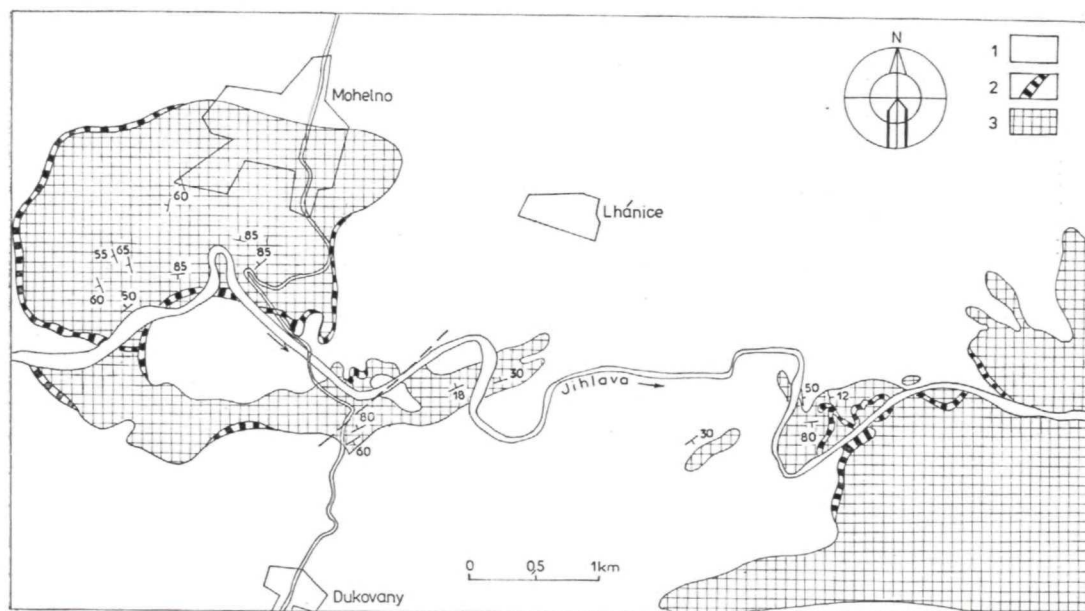


Fig. 1. Geological scheme of the Mohelno area. Original map of Dudek, Misař, and others. 1 — granulite and granulite gneiss, 2 — high temperature reaction zone at the contact between peridotite and granulite, 3 — garnet peridotite

Chemical analyses of minerals from Bohemian pyroxenites and peridotites

Tab. 1

Components	Gar	Cpx	Opx	Gar	Cpx	Opx	Gar	Cpx	Gar Paděra	Opx (1980)
	Mohelno (1)			Staré, (Fiala — Paděra 1977) (2)			Horní Bory (3)		Mohelno (4)	
SiO ₂	39,3	51,8	54,2	40,89	53,18	56,14	41,23	52,72	42,21	54,72
TiO ₂	0,33	0,69	0,19	0,49	0,46	0,16	—	—	0,01	0,00
Al ₂ O ₃	22,0	7,11	5,07	21,14	3,74	1,45	23,29	6,00	22,59	3,84
Cr ₂ O ₃	1,33	—	—	1,66	0,81	0,09	—	—	0,15	0,33
FeO	8,13	2,69	7,02	10,22	2,90	7,03	12,94	5,53	14,20	10,25
MnO	0,25	0,09	0,12	0,31	0,11	0,15	0,41	—	0,23	0,11
MgO	20,30	13,9	31,7	20,54	17,10	30,98	15,56	14,28	15,62	29,7
CaO	5,07	19,9	0,86	4,45	19,31	1,30	5,98	19,62	4,18	0,13
Na ₂ O	—	2,18	0,12	—	2,42	—	—	1,40	0,00	0,03
K ₂ O	—	0,0	0,0	—	0,12	—	—	—	—	—
Total	96,71	98,36	99,28	99,70	100,26	100,30	99,41	99,68	99,19	99,11
Si	3,028	1,900	1,892	2,940	1,920	1,940	3,009	1,925		
Ti	0,018	0,019	0,005	0,026	0,013	0,004	—	—		
Al	1,854	0,370	0,209	1,790	0,160	0,060	2,006	0,259		
Cr	0,075	—	—	0,096	0,023	0,003	—	—		
Fe	0,487	0,083	0,205	0,573	0,087	0,168	0,788	0,169		
Mn	0,015	0,003	0,004	0,022	0,004	0,004	0,026	—		
Mg	2,124	0,759	1,649	2,190	0,920	1,751	1,690	0,776		
Ca	0,389	0,781	0,032	0,374	0,746	0,048	0,469	0,765		
Na	—	0,155	0,008	—	0,169	—	—	0,101		
Total	7,990	4,005	4,003	8,111	4,042	3,978	7,988	3,995		
Fe + Mn	19,1	10,2	11,2	21,8	8,66	10,2	32,5	17,9		
Fe + Mn + Mg										
1)	—		1043			1092				
2)		1123			1128			1022		
3)	—		820			1070				
4)		1066			1087			934		

Estimation of temperature according to: 1) Perchuk, 1977; 2) Ganguly, 1979; 3) Davis, Boyd, 1966; 4) Ellis, Green, 1979;

clinopyroxene and orthopyroxene. The result of microprobe analyses of garnet-clinopyroxenite (3) from the quarry near Bory, of "garnet orthopyroxenite" (from a larger inclusion (4) in the Mohelno peridotite — Paděra, 1980, in Misař ed 1980) as well as the pyrope peridotite (2) from the Staré bore hole (Fiala and Paděra, 1977) are also added for comparison.

The analyzed pyroxenes and pyrope of the Mohelno peridotite are analogous to

those in the pyrope lherzolite from bore hole T-7 as described by J. Fiala and K. Paděra (1977). The equilibration of two-pyroxene association indicated by Perchuk's (1977) thermometer corresponds to a temperature close to 1100 °C. Boyd's thermometer (Davis and Boyd, 1966) indicates a temperature 820 °C and 1070 °C probably due to the higher content of sodium in clinopyroxene. Mysen's clinopyroxene-garnet thermometer-barometer

(Mysen and Heier, 1972) shows the conditions of equilibration of the garnet — clinopyroxene pair at a temperature 1150 °C and at a pressure of 18 kbar (Fig. 2). These

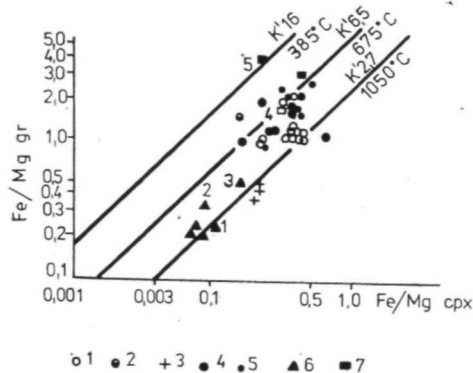


Fig. 2. Distribution of Fe and Mg between coexisting garnet and clinopyroxene in Moldanubian eclogites and pyrope peridotites (Dudek and Fediuková, 1974). 1 — eclogites inside of peridotite bodies surrounded by granulite, 2 — eclogites of "deep fault zones", 3 — pyrope-almandin eclogites in gneisses, 4 — eclogites in gneiss complex together with peridotite, 5 — pyrope-almandin-grossular eclogites in gneisses and migmatites, 6 — pyrope peridotite, 7 — eclogite-like rocks in gneisses. Points 1—3 correspond to garnet peridotite of Mohelno and Staré and to garnet clinopyroxenite of Bory (tab. 1) points 4 and 5 to the rocks of the tab. 2

data are similar to those found by Ganguly (1979) and Ellis and Green (1979). The calculated temperature and pressure for Mohelno peridotite seem to be slightly lower than for pyrope peridotite from inclusions in granulite of Bory (Misař — Jelínek — Jakeš, 1984) and slightly higher than the data of J. Fiala and K. Paděra (1977). For the garnet peridotite of Bory the calculated temperature is 1190—1278 °C at an assumed pressure of 35 kbar. The PT-conditions calculated for Bory banded peridotite containing olivine, clinopyroxene and orthopyroxene are of a temperature 990 °C—1170 °C and pressure of

23 kbar. Many garnet pyroxenites from the locality Bory were studied by Z. Misař — E. Jelínek and P. Jakeš (1984). They show the temperature of the origin to be 820 °C (average) at a calculated pressure of 23 kbar. The data for the some Bory garnet pyroxenite (table 1) are higher than Ganguly's (1979) or Ellis and Green's thermometers are used. See also new data of Šanc and Rieder (1983) for the PT-conditions of equilibration of garnet ± orthopyroxene lamellae in clinopyroxene (940 ± 20 °C— $3,6 \pm 6$ kbar).

Minerals of country gneiss and granulite

Of the minerals of the contact bimetasomatic rocks (5) garnet, hornblende and rare clinopyroxene were analysed (Table 2). In addition to these minerals biotite of banded granulite gneiss and gneiss were also studied by the microprobe method (6, 7).

Perchuk's (1970) clinopyroxene-hornblende thermometer indicates a rather lower temperature for the origin of the mineral pair (600—650 °C). Ganguly's garnet-clinopyroxene thermometer indicates a higher temperature for the same rocks ($T = 879$ — 916 °C at 10 kbar). According to Ellis and Green's thermometer the temperature is 775 °C.

The interpretation of the given PT-conditions of equilibration for the bimetasomatic rocks at the contact between the peridotite and granulite is not unambiguous as different thermometers were used. However, it is also primarily more complicated because of the bimetasomatic origin of these contact rocks and their unequilibrated mineral assemblage.

Some estimates are also made for the PT-conditions of the origin of banded granulitic rocks (Table 2) containing garnet, clinopyroxene, hornblende, biotite and sometimes orthopyroxene (not analysed).

Microprobe analysis of minerals from country gneisses of the Mohelno peridotites

Tab. 2

Components	Contact bimetasomatic zone (5)					Banded granulite gneiss (6) melanocratic band				
	Gar-2	Gar-1	Cpx	Hb-1	Hb-2	Gar I	Gar II	Cpx	Hb	Bi
SiO ₂	38.7	38.8	51.8	47.2	44.5	39.2	38.9	51.6	45.2	35.8
TiO ₂	0.55	0.46	0.42	0.92	1.64	0.22	0.40	0.46	1.84	3.19
Al ₂ O ₃	20.7	21.2	2.84	5.65	10.02	21.1	21.4	3.21	9.43	14.9
FeO	26.2	24.6	9.73	11.5	13.9	26.5	24.9	8.85	13.7	18.9
MnO	0.56	0.44	0.10	0.09	0.06	0.52	0.39	0.15	0.08	0.10
MgO	6.99	7.91	13.3	12.9	13.2	7.57	8.96	13.1	13.0	12.6
CaO	6.70	6.49	20.8	17.2	11.4	5.42	6.21	21.5	11.5	0.29
Na ₂ O	—	—	0.75	0.88	1.83	—	—	0.80	1.72	0.12
K ₂ O	—	—	0.11	0.17	0.50	—	—	0.01	0.69	0.08
Total	100.40	99.90	99.85	97.21	97.05	100.53	100.16	99.68	97.16	94.98
Si	3.000	2.997	1.937	7.092	6.602	3.023	2.987	1.931	6.701	2.742
Ti	0.032	0.027	0.012	0.103	0.184	0.013	0.023	0.013	0.205	0.184
Al	1.886	1.925	0.125	0.985	1.755	1.913	1.934	0.142	1.648	1.347
Fe	1.707	1.589	0.304	1.426	1.733	1.708	1.599	0.277	1.704	1.212
Mn	0.037	0.029	0.003	0.011	0.008	0.034	0.026	0.005	0.010	0.006
Mg	0.808	0.910	0.743	2.837	2.924	0.869	1.024	0.729	2.868	1.433
Ca	0.556	0.537	0.835	2.722	1.807	0.447	0.429	0.860	1.821	0.024
Na	—	—	0.055	0.253	0.528	—	—	0.058	0.496	0.017
K	—	—	0.005	0.031	0.095	—	—	0.001	0.130	0.888
Total	8.025	8.014	4.018	15.443	15.642	8.007	8.023	4.015	15.583	7.853
(Fe + Mn) . 100										
Fe + Mn + Mg	68.3	64.0	29.2	33.6	37.3	66.7	61.3	27.9	37.4	45.9
T °C*	600					650				
T °C**	369—916					356—858				

* Perchuk (1970), assemblage Gar-Bi, Gar-Hb, Gar-Cpx); ** Ganguly (1979)

Clinopyroxene-garnet association corresponds to 856—858 °C according to Ganguly's method and to 742 °C according to the Ellis and Green thermometer. For the clinopyroxene hornblende, clinopyroxene-garnet and hornblende-biotite pairs the calculated temperature is 700—800 °C (Perchuk, 1970). The minerals of the leucocratic bands of the same rock and of the granulite with cyanite (8) might have equilibrated under lower conditions (600—650 °C according to the Perchuk thermometer).

Conclusions

The deepest PT-conditions for the origin are fixed in the garnet-clinopyroxene-orthopyroxene mineral assemblage of the Mohelno peridotite. They correspond to the Pt-conditions in the upper mantle. The country banded granulite gneiss and some gneisses, because of their polyphase origin, still contain some relics of older granulite metamorphic association equilibrated at a temperature of cca 700—900 °C. The garnet-biotite pair of biotite gneisses indicates

The mineral association of garnet pyroxenite (eclogite) inside the Mohelno garnet peridotite and also other localities is a special problem. The PT-conditions of the origin of these rocks are about 200 °C and by 23 kbar lower than the PT-conditions of equilibration in the upper mantle garnet peridotite (Misař — Jelinek and Jakeš, 1984). Therefore these pyroxenites may be formed in the uppermost part of the upper mantle or in the lower level of the continental crust.

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only a temperature of 600—650 °C. Similar data are valid for granulite with cyanite occurring inside the granulite formation near the contact with the Mohelno ultrabasic body.

The PT-conditions for equilibration of bimetasomatic rocks at the contact between the peridotite and granulite might be reflected in a higher temperature (granulitic) mineral assemblage and in probably younger and lower (amphibolite facies) mineral assemblage with hornblende and biotite.

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Tlakové a teplotní podmínky vzniku pyropových peridotitů a jejich okolních hornin v moldanubiku v okolí Mohelna

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Indexní minerály pyropových ultrabazik a okolních granulitů byly studovány na mikroskopě. Podle získaných dat a použití různých geotermických a tlakových vztahů různých autorů byly vypočteny příslušné teplotní a tlakové podmínky vzniku těchto hornin. Minerální asociace granátických peridotitů odpovídá podmínkám jejich ekvibrace za teploty 1123—1060 °C při tlaku kolem 18 kilobar. Pyroxenity vyskytující se i v jiných tělesech ultrabazických těles se dostaly do rovnovážného stavu za teplotních podmínek asi o 200 °C nižších. Nejsložitější se jeví in-

terpretace získaných dat příslušných minerálních párů pro horniny, které vznikly bi-metasomatickými pochody mezi peridotitem a granulitem. Z vybraného profilu u Mohelna byly zatím studovány ty, které obsahují amfibol, biotit, granát a sporadicky klinopyroxen. Rozdílné hodnoty ekvibrace lze u nich obdržet podle různých metod. Např. podle Perčuka (1970) by podmínky rovnovážného stavu nastaly přibližně za teplot kolem 600 až 650 °C, podle metody Gangulyho (1979) jsou teplotní hodnoty podstatně vyšší.