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Genetic model of sulfide mineralization of the Ransko gabbro-peridotite massif (Bohemia, Czechoslovakia)

Model geneze sulfidického zrudnění ranského gabroperidotitového masívu

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Abstract: The Ransko gabbro-peridotite massif intruded along the discordance between the mesozonal and epizonal crystalline complexes of the core of the Bohemian Massif. The oldest partial intrusion of the massif, gabbro-dolerite, was followed by the main phase of low-pyroxene olivine gabbros. Peridotite with rounded olivine cumulated in the lower zone and plagioclase-rich rocks concentrated in the upper zone. The Ni-Cu mineralization was connected with troctolites of the middle zone. The differentiation was disrupted by a younger intrusion of pyroxene-rich gabbros. Origin of the inner fluid-like structure of the massif is a result of an intrusion into the not fully consolidated rocks.

The Zn-Cu deposit Obrázek (massive sulfide type) is younger than the quartz diorite intrusion and related metasomatic hornfels. The Ransko massif together with both types of sulfide deposits were affected by epizonal regional metamorphism.

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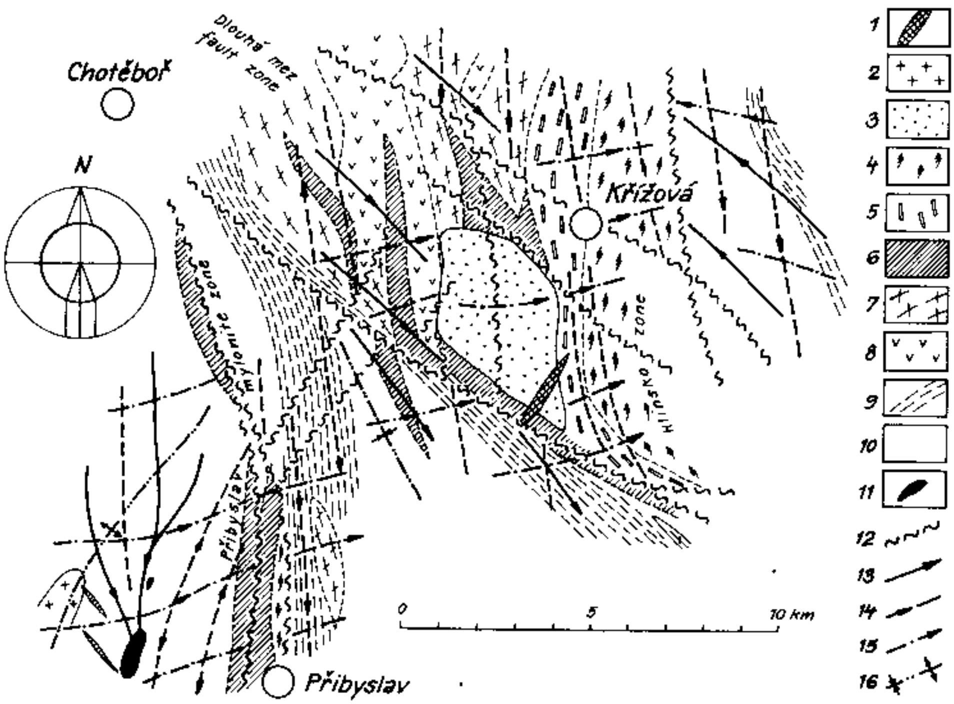
Introduction

The small and blind Zn-Cu massive sulfide and several Ni-Cu disseminated ore bodies are the main types of ore mineralization in the Ransko massif. The liquation of Ni-Cu sulfides was supposed to take place at depth (MÍSAŘ et al. 1974). The Zn-Cu ore body was connected with the hydrothermal activity around a small intrusion of quartz diorite. POKORNÝ (1969) recognized long and complex thermal history of sulfides. KUDĚLÁSKOVÁ-KUDĚLÁSEK (1964) supposed epigenetical origin of the Ni-Cu ore. The chemistry of spinellides and structural observation of metasomatic hornfels led WATKINSON et al. (1978) to the conclusion that the xenolith of the Zn-Cu massive sulfide body was incorporated in the Ransko massif. However, comparative study of the contact phenomena of xenoliths, metasomatic hornfels and magmatic rocks (MÍSAŘ et al. 1974, NĚMEC-HOLUB 1980), confirmed the original result of HOLUB-POKORNÝ (1970) about the origin of the metasomatic hornfels.

Geological setting and age of the massif

The Ransko massif is located on the intersection of two major structural systems with long geological history. The first system, trending NW-SE, corresponds to the southern margin of the Labe tectonic zone. The second system, striking NNE-SSW, follows the



1. Geological scheme of the Ransko massif vicinity
1 – porphyry, *2* – granodiorite, *3* – Ransko gabbro-peridotite massif, *4* – phyllites and phyllonites, *5* – porphyroides of the Vítanov group, *6* – gneisses of the Malín group, *7* – migmatites of orthogneiss type, *8* – gabbroamphibolites, *9* – Varied Group of the Moldanubicum and the Kutná Hora crystalline units, *10* – gneisses and migmatites of the same units, *11* – serpentinite, *12* – main faults and mylonite zones, *13* – prefoliation fold axis, *14* – pre-plutonic lineation of the Moldanubicum, *15* – younger lineation of the Vítanov group, *16* – fold axis connected with Moldanubian pluton rise.

deep-seated boundary between the Czech and Moravian blocks of the Moldanubicum and continues to the NNE as the Hlinsko graben zone. The Ransko massif is surrounded by several geological units of the Bohemian massif. Relations of these units (Moldanubicum, Kutná Hora crystalline complex, Železné Hory complex, Hlinsko zone) are still under discussion (MÍSAŘ et al. 1983).

The geological history of the area is shown in tab. 1. The Ransko massif intruded into the structural discordance between the strongly metamorphosed Kutná Hora crystalline complex and the epizonally metamorphosed Vítanov group of the Hlinsko zone. Both units are separated by a metakeratophyre zone. Xenoliths incorporated in the flat north, west and south endocontacts of the Ransko massif build up a zone of bottom magmatic breccia. The contact zone of the Ransko massif with the Vítanov group is steep and xenoliths are very rare in it.

Table 1

Correlation of tectonic, metamorphic and magmatic events in the Ransko massif and its vicinity (Holub 1977)

stage of development	Cadomian cycle		Variscan cycle	
	orogen	platform	orogen	platform
	Upper Proterozoic	Lower Cambrian	Ordovician – Carboniferous	Carboniferous – Permian
Kutná Hora area	high-grade metamorphism, high diversity of fold axis	?	folding with axis N–S, migmatitization	polymetallic mineralization, intrusions of porphyries, lamprophyres and granodiorites
Havlíčkův Brod area				
NW vicinity of the Ransko massif			younger foliation with sillimanite	flat folding
Vítanov group	low-grade metamorphism, fold axis N–S	thermal metamorphism	low-grade metamorphism, fold axis W–E	faulting
Ransko massif		intrusion of mafic rocks Ni-Cu ore	low-grade metamorphism, cleavage of W–E direction quartz diorites Zn-Cu ore	faulting, porphyry dikes

The mineral assemblage of xenoliths and their metamorphic grade is similar to that of the country rocks. The epizonally transformed keratophyres of the Vítanov group are thermally affected by Ransko massif. However, the massif itself was epizonally metamorphosed together with the Vítanov group. At least two different structural planes, each connected with epimetamorphism, are present in the Vítanov group (HOLUB 1977). Thus, the Ransko massif intruded between both stages of epizonal metamorphism. The age of the intrusion is most probably Lower Cambrian (MAREK 1970).

Fabric of the massif

The Ransko massif forms a conic intrusion rapidly narrowing to the depth of 3 km. The mass of the body is geophysically indicated to a depth of 10 km (GRUNTORÁD -VÁLEK 1971). The results of a new drilling made it possible to describe the fabric of the massif to the depth of about 1 km. The west part of the massif is a part of originally flat limb of a knee-like intrusion. The central part of the massif with a NE striking ore zone was its steep limb.

The central ultrabasic body steeply continues without changes in mineral composition to the depth of more than one kilometre. Peridotite cumuli (several metres in diameter) are surrounded by plagioclase peridotites and by troctolites with layering.

Peridotite-troctolite blocks and discontinuous layers (size from several centimetres to hundred metres) occur in both pyroxene gabbros and together form zones of mixed rocks. These zones of mixed rocks connect the large peridotite bodies. The layers of Ni-Cu ores are situated in mixed zones or in their continuation into peridotite bodies.

Gabbrodolerites build up individual bodies mostly near the NW and SE contact of the Ransko massif and rarely they were found also in mixed zones.

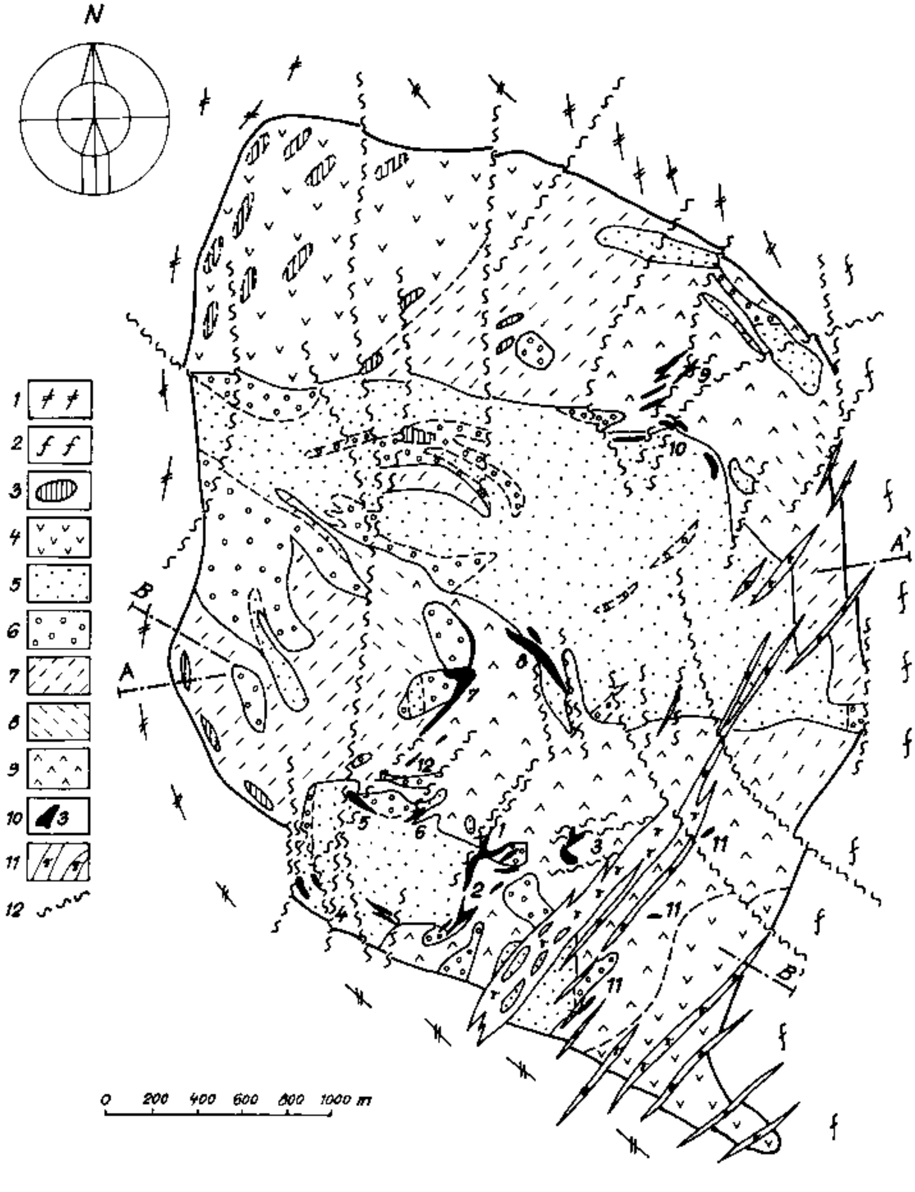
Petrology

Magmatic rocks of the Ransko massif can be divided into three associations. The oldest is an Ni-Cu-bearing gabbro-peridotite association. Several small intrusions of quartz diorite are younger, probably of Silurian age. Metasomatic hornfels and Zn-Cu ores are connected with them. The youngest intrusion (Upper Carboniferous) is an association of porphyry dikes.

Rocks of gabbro-peridotite association were described in detail by WEISS (1962), MÍSAŘ et al. (1974), and BOUŠKA et al. (1977).

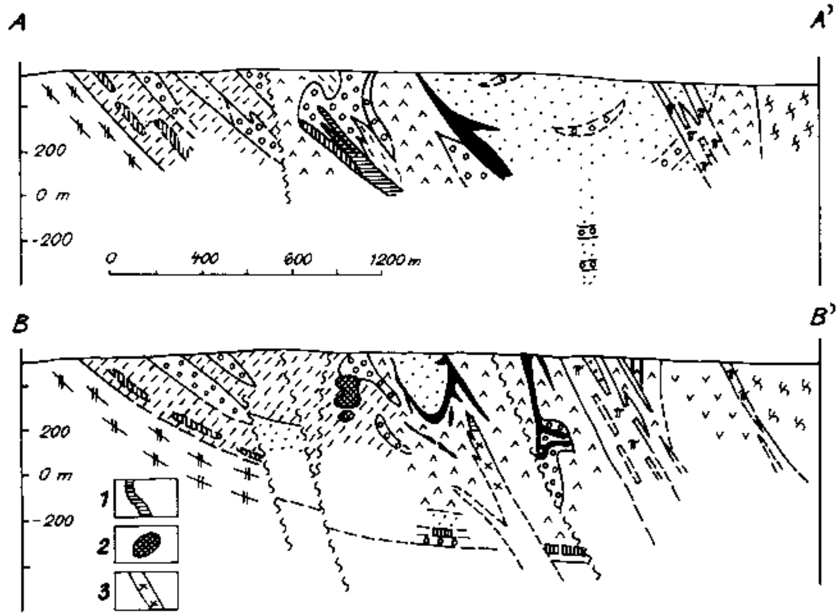
According to KOMÍNEK et al. (1983) rocks of this association are divided in three groups. Dark pyroxenic gabbros (first group) with doleritic texture (gabbrodolerites) is located near the NW and SE contact of the massif and contain a lot of country rock xenoliths. Euhedral islets of labradorite-bytownite are surrounded by andesine-labradorite, clinopyroxene and primary hornblende.

Autohydrothermal alteration and sulfide inclusions are rare. The second group of pyroxene-poor olivine gabbros, a product of primary magma differentiation, builds up the main part of the massif. Olivine cumuli were separated near the bottom, while plagioclase near the roof of the magmatic chamber. A wide spectrum of different



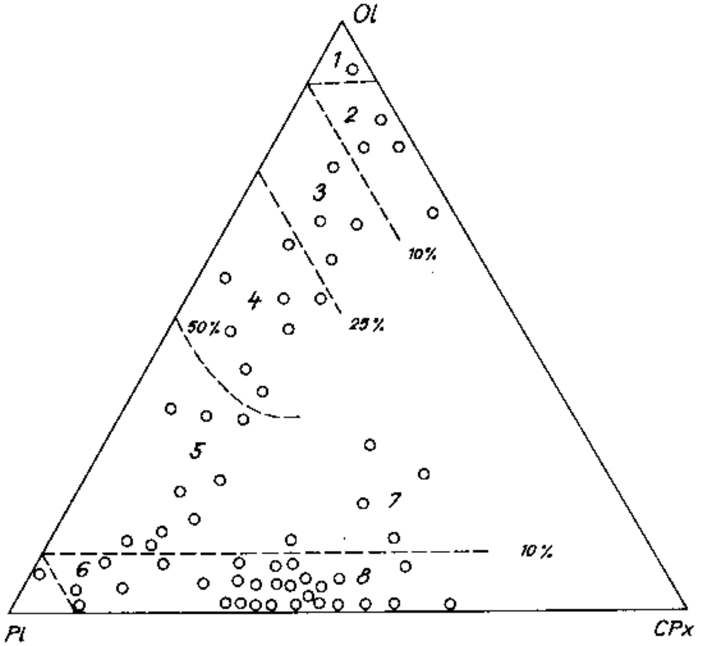
2. Geological scheme of the Ransko massif

1 – Kutná Hora crystalline unit, *2* – Vítanov group of the Hlinsko zone, *3* – xenoliths, *4* – gabbrodolerites, *5* – plagioclase peridotites and peridotites, *6* – troctolites, *7* – pyroxene-poor gabbros, *8* – pyroxene-rich gabbros, *9* – mixed gabbro zone, *10* – orebodies: 1 – Jezírka, 2 – Jezírka-south, 3 – Doubravka, 4 – Tůně-west and south, 5 – Tůně-north, 6 – Tůně-přikontaktní, 7 – Obrázek-north, 8 – Josef, 9 – Řeka, 10 – Řeka-south and east, 11 – small east showings, 12 – blind Zn-Cu orebody Obrázek; *11* – porphyries, *12* – main faults.



3. Geological cross-sections

1 – metasomatic hornfelses, *2* – Zn-Cu ores, *3* – quartz diorites. For further explanation see fig. 2.



4. The rocks of the Ransko massif in olivine - plagioclase - clinopyroxene classification

Gabbro-troctolite group: *1* – dunite, *2* – peridotite, *3* – plagioclase peridotite, *4* – troctolite, *5* – olivine gabbro, *6* – gabbro. Pyroxene-rich gabbro group: *7* – olivine-pyroxene gabbro, *8* – pyroxene gabbro. Results of thin-section planimetry are plotted.

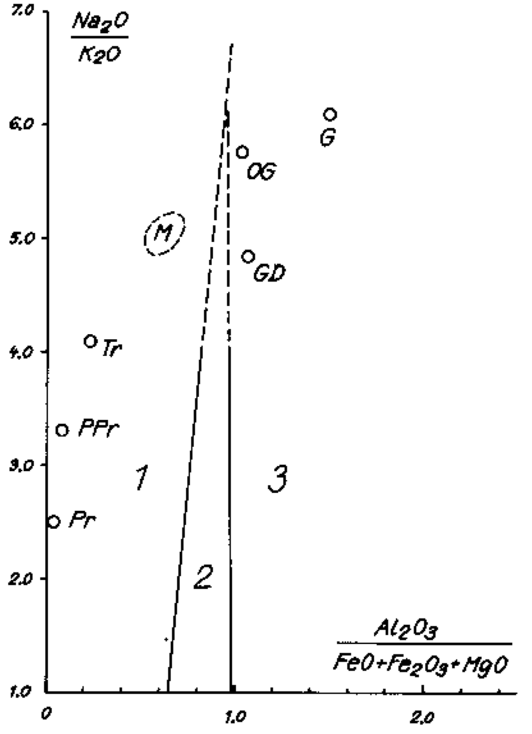
varieties of olivine gabbros and troctolites was present in the transitional middle zone. The differentiation was disrupted by an intrusion of clinopyroxene-rich gabbros (third group). The fluid-like texture of the mixed rock types along the contacts between the second and third groups is a result of the intrusion into not fully consolidated magma.

The association of quartz diorites is heterogeneous. The quartz diorites of the inner part of the narrow stocks have a high content of sulphur (pyrite, pyrrhotite). The outer apical parts of stocks are built of metasomatic hornfels. Quartz diorite stocks discordantly penetrate the rocks of the gabbro-peridotite association and xenoliths.

The dike swarm of the porphyry association divides the central and the east part of the massif. The intrusion of the dikes is connected with the creation of the Hlinsko graben. The downslip of the east part of the massif is around 700 m. General difference between the original altitude of the east and west contacts of the Ransko massif is 1.5 – 2 km.

Chemical composition of the rocks

MÍSAŘ et al. (1974) paid great attention to the chemical composition of rocks. BOUŠKA et al. (1977) studied the distribution of transition metal elements and REE. In the period of 1978 – 1982 a new collection of about 8000 samples was assayed for trace elements



5. Relative content of Al in rocks of the Ransko massif. (Diagram after Bogatikov et al. 1981)
1 – Al-poor basalt, *2* – normal basalt, *3* – Al-rich basalt. Ransko massif: Pr – peridotites, PPr – plagioclase peridotites, Tr – troctolites, OG – olivine gabbros, G – pyroxene gabbros, GD – gabbrodolerites, M – probable mean composition of primary magma.

Table 2

Chemical composition of magmatic rocks of the Ransko massif

	1		*2*		*3*		*4*	
n	14		12		11		14	
	x	s_x	x	s_x	x	s_x	x	s_x
SiO_2	35.88	0.85	36.75	1.48	38.48	1.63	41.96	1.58
TiO_2	0.16	0.10	0.15	0.07	0.20	0.06	0.16	0.08
Al_2O_3	2.51	0.76	5.09	0.76	7.76	2.30	20.12	4.22
Fe_2O_3	8.58	1.96	5.47	0.58	4.52	1.11	2.00	1.94
FeO	5.10	1.37	7.01	0.64	7.36	0.68	6.89	8.22
MgO	34.80	2.44	32.36	1.72	26.26	1.16	11.78	3.72
CaO	1.78	1.26	3.33	0.74	5.7	1.51	12.01	1.75
Na_2O	0.20	0.14	0.26	0.10	0.41	0.21	0.83	0.24
K_2O	0.08	0.05	0.08	0.05	0.10	0.06	0.14	0.16
H_2O	10.78	0.93	8.39	2.43	7.77	0.74	3.68	1.21

	5		*6*	*7*	*8*	*9*	*10*
n	18		1	1	1	6	2
	x	s_x				x	x
SiO_2	44.97	1.35	45.98	43.32	46.50	70.26	65.70
TiO_2	0.28	0.9	0.26	0.20	0.27	0.57	0.30
Al_2O_3	21.95	3.28	18.76	27.48	20.10	13.56	14.29
Fe_2O_3	1.56	1.05	1.20	2.29	1.33	0.68	0.36
FeO	4.35	1.48	5.28	1.69	3.95	2.58	2.68
MgO	8.44	2.69	10.01	4.79	9.63	2.95	1.37
CaO	14.08	1.71	14.92	14.90	15.88	2.82	4.75
Na_2O	1.11	0.36	1.13	1.20	1.10	3.78	3.30
K_2O	0.18	0.06	0.23	0.13	0.15	0.24	4.71
H_2O	3.81	1.16	1.03	3.28	1.17	1.54	1.82

1 – peridotite, *2* – plagioclase peridotite, *3* – troctolite, *4* – olivine gabbro, *5* – pyroxene gabbro, *6* – gabbro-dolerite, *7* – plagioclase-rich gabbro, *8* – pyroxene-rich gabbro, *9* – quartz diorite, *10* – porphyry, *n* – number of analyzed samples, x – mean, s_x – standard deviation.
For original data see Mísař et al. (1974), Bouška et al. (1977), Němec - Holub (1982), Komínek et al. (1983).

and some of them for major elements, too (KOMÍNEK et al. 1983). The results are presented in tabs. 1 and 2.

The study of macroelement distribution revealed that gabbrodolerite composition is similar to the average one in all the massif. Gabbrodolerites have slighly lower contents of Al and are rich in Mg and Fe. The gabbro-peridotite association is distinguished by the content of alkalies and a very high Na/K ratio (Na/K in peridotites is 2–4, troctolites 10, gabbros 6 – 8 and gabbrodolerites 5). The average chemical composition of the rocks of the gabbro-peridotite group shows that primary magma was depleted of alkalies

Table 3

The undisturbed geochemical field (in ppm) of main rock types

	n	Pb	Zn	Cu	Ni	Co	B
1	273	2	100–260	80–300	300	40–200	10–60
2	88	4	120–300	140–300	400	100–150	10–60
3	246	9	140–240	50–350	400	50–150	10–60
4	101	2–11	90–150	50–350	250	45–160	11–65
5	260	2–9	120	100–300	50–450	20–150	20
6	25	10–50	40	8–40	10–25	4–12	4
7	21	30–90	50	10–60	7–20	3–6	20
8	59	10–50	50–140	45–300	30–200	10–60	20
9	51	5–50	50	20–100	5–40	4–8	4

	Sb	Ba	Mn	Cr	Ti	V
1	5–15	10	1000–1500	1000–2000	600–800	30–70
2	5–15	10	1000–1500	1000–2000	600–800	30–70
3	5–15	10	1000–1500	1000–2000	600–800	30–70
4	5–15	10–50	200–300	200–300	1000–2000	40–200
5	5–15	10–50	200–300	200–300	1000–2000	40–200
6	?	?	?	?	?	?
7	?	?	?	?	?	?
8	?	?	?	?	?	?
9	?	100–1000	?	?	?	100–500

The contents of Ag is below 0.06 ppm, of Mo, Sn, W below 3 ppm in all cases.
1 – peridotite, *2* – plagioclase peridotite, *3* – troctolite, *4* – olivine gabbro, *5* – pyroxene gabbro, *6* – quartz diorite, *7* – porphyry, *8* – gabbroamphibolite, *9* – gneiss.

(Na/K ratio around 5), with SiO_2 content 40 wt.% and contents of Al, Fe, Mg the same as olivine gabbro.

Quartz diorite has high content of SiO_2 (70 %) and relatively low content of alkalies (4–5 % of K_2O + Na_2O) and high Na/K ratio (10–20).

BOUŠKA et al. (1977) studied the distribution of transition metals, REE and alkali metals in representative samples (except gabbrodolerites). They found out that the distribution of Cr, Mn, Fe, Co, Ni and probably Cu and Zn is connected with troctolites and peridotites. The contents of K, Rb, Sc, Ti, V and the shape of chondrite-normalized patterns of REE are identical for all members of the gabbro-peridotite group. Pyroxene gabbros are rich in Sc, Ti, V, K, Rb, Cs, Ba and REE.

Table 4

Chemical composition of ore minerals (electron microprobe data)

Troilite

environment	localization	*n*	Fe %	Ni %	Co %	S %
unaltered troctolites	Jezírka – main ore body	8	62.9	0.01	0.03	37.0
	Tůně – přikontaktní	3	62.3	0.01	0.03	37.6
altered rocks	Obrázek – vicinity of Zn-Cu ore	2	62.7	0.01	0.05	37.3

Hexagonal pyrrhotite

environment	localization	*n*	Fe %	Ni %	Co %	S %
unaltered rocks	Jezírka – main ore body	5	61.1	0.05	0.02	38.8
	Tůně – přikontaktní	6	61.3	0.01	0.03	38.5
altered rocks	Jezírka – south upper body	3	60.4	0.92	0.05	38.7
	Obrázek – north	7	59.7	0.38	0.04	39.9
altered rocks	Obrázek – vicinity of Zn-Cu ore	2	61.3	0.04	0.02	38.7
Zn-Cu ore	Obrázek	4	61.0	0.04	0.04	38.9

Monoclinic pyrrhotite

environment	localization	*n*	Fe %	Ni %	Co %	S %
unaltered rocks	Řeka	7	59.4	0.27	0.06	40.2
	Jezírka – main ore body	18	58.8	0.12	0.04	40.0
	Tůně – přikontaktní	7	59.6	0.09	0.05	40.1
altered rocks	Jezírka – upper part	2	59.5	0.73	0.06	39.4
	Josef – uralitized gabbros	1	59.1	0.33	0.10	40.4
	Doubravka – upper part	19	59.5	0.40	0.08	40.5
	Obrázek – vicinity of Zn-Cu ore	9	59.4	0.13	0.07	40.3
Zn-Cu ore	Obrázek	3	59.6	0.01	0.07	40.3

A new geochemical exploration (KOMÍNEK et al. 1983) covered the whole massif and showed that the content of elements depends on rock type, erosion level and presence of sulfides (e.g. rocks of gabbro-peridotite group in the central block of the massif have 20 ppm of Cu, the same rocks in the strongly eroded west block 20–200 ppm of Cu, the content higher than 200–300 ppm of Cu indicates zones of mixed rocks with Ni-Cu mineralization).

Table 4 - continuation

Pyrite

environment	localization	*n*	Fe %	Ni %	Co %	S %
Pyrite 1 of Ni-Cu ore in altered rocks	Jezírka – south upper part	1	43.5	0.01	3.64	52.8
	Doubravka – upper part	12	44.7	0.01	1.40	53.1
	Obrázek – north	3	45.5	0.05	1.37	53.1
	Obrázek – vicinity of Zn-Cu ore	8	45.3	0.01	1.04	53.5
Pyrite A of massive Zn-Cu ore		2	46.3	0.01	0.01	53.7
Pyrite A of disseminated Zn-Cu ore in light hornfels		12	46.5	0.03	0.03	53.8
Pyrite 2 of altered rocks	Jezírka – south upper part	3	47.2	0.01	0.01	52.8
	Doubravka – upper part	12	46.5	0.09	0.03	53.8
	Obrázek – north	1	47.9	0.01	0.01	52.0
	Obrázek – vicinity of Zn-Cu ore	3	45.9	0.07	0.02	54.0

Pentlandite

disseminated sulfides of unaltered rocks	gabbro	1	33.1	31.3	4.09	31.5
	troctolite	1	30.0	36.4	2.03	31.5
Ni-Cu ore in unaltered rocks	Řeka – gabbro	5	31.7	31.5	4.04	32.6
	Jezírka – main body, gabbro	9	33.0	31.6	1.91	33.4
	troctolite	16	34.0	30.8	2.02	33.2
	Tůně – přikontaktní	10	33.4	33.6	2.41	33.5
Ni-Cu ore in altered rocks	Jezírka – south upper part	3	29.0	34.7	2.95	32.8
	Obrázek – north	7	28.8	31.7	6.19	33.2
	Doubravka – upper part	19	29.8	32.5	4.67	33.0
	Josef – serpentinized ore	1	35.5	32.0	1.70	30.8
	uralitized ore	1	29.6	33.8	2.74	33.9
	Obrázek – vicinity of Zn-Cu ore	4	34.9	29.0	1.94	33.9

According to Bouška et al. (1977) quartz diorites do not belong among the differentiates of the original basic magma. However, the higher content of Mg indicates any "basic" contamination of quartz diorites.

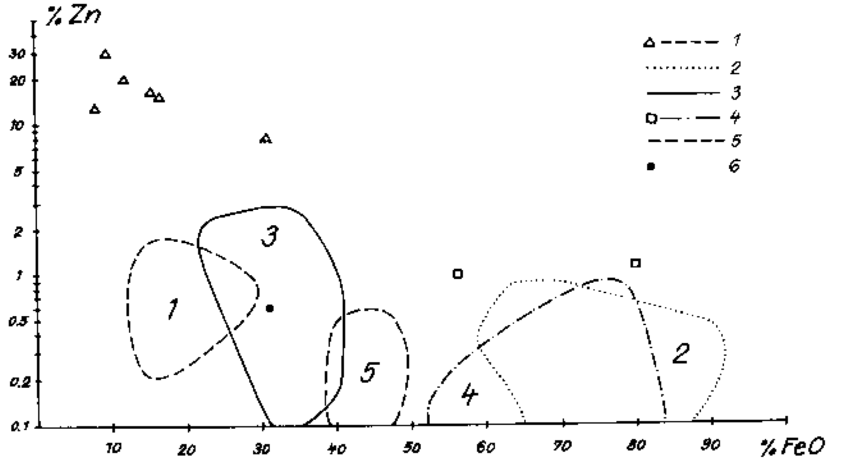
T a b l e 4 - continuation

Chalcopyrite

environment	localization	*n*	Cu %	Fe %	S %
Ni-Cu ore in unaltered rocks	Řeka	2	33.5	31.3	35.2
	Tůně – přikontaktní	8	33.3	31.0	35.0
	Jezírka	5	33.5	31.5	35.1
Ni-Cu ore in altered rocks	Doubravka – upper part	6	32.7	31.9	34.9
	Josef	1	34.8	33.1	32.1
	Obrázek – vicinity of Zn–Cu ore	4	32.7	32.2	35.0
Zn-Cu ore	Obrázek	6	33.0	31.5	35.1

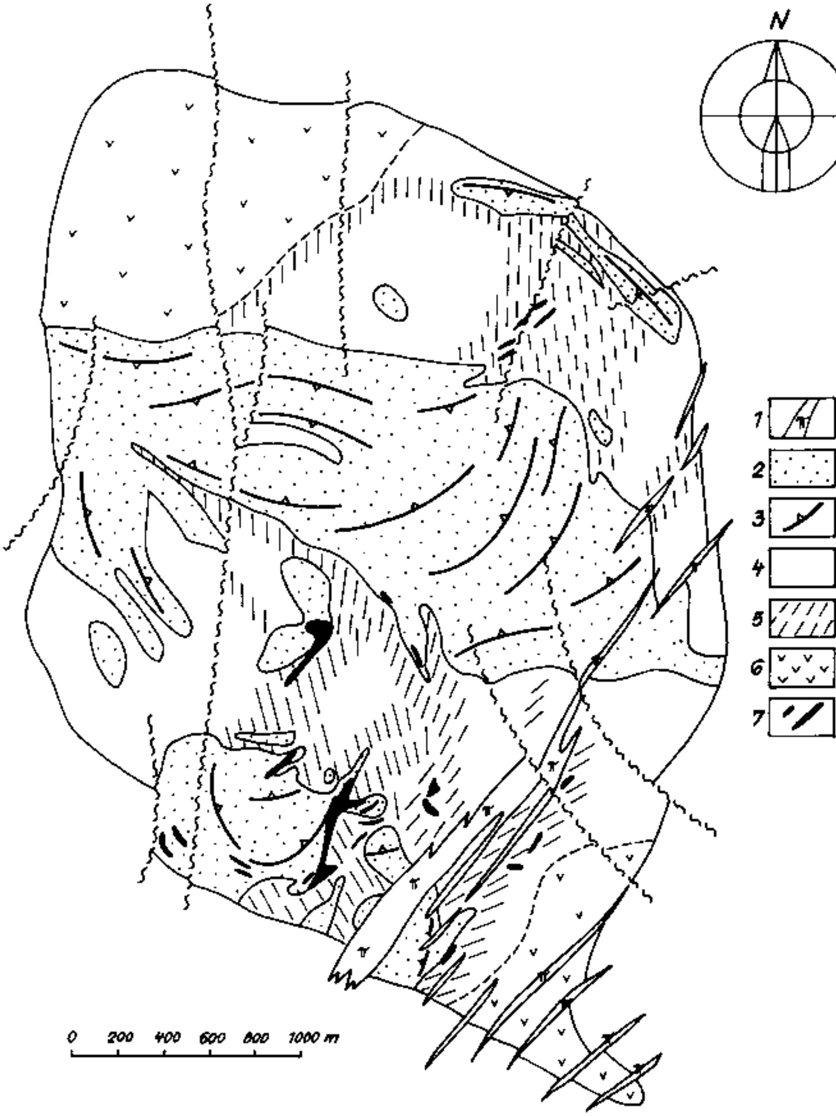
Cubanite

Ni-Cu ore in unaltered rocks	Jezírka	8	22.7	41.5	35.6
	Tůně – přikontaktní	6	23.2	42.4	35.4
Ni-Cu ore in altered rocks	Obrázek – north	2	21.8	42.4	35.9



6. Contents of Zn in spinellides

1 – green spinellide, *2* – monophase dark spinellide, *3* – polyphase spinellide, dark phase, *4* – polyphase spinellide, bright phase, *5* – ilmenite, *6* – chromite.



7. The structure of the Ransko massif
1 – porphyries, *2* – ultramafites, *3* – generalized strike of differentiated zones in ultramafites, *4* – gabbros, *5* – mixed zones, *6* – gabbrodolerites, *7* – outcrops of orebodies.

Rock metamorphism

The metamorphic changes of rocks of the Ransko massif can be possibly divided into five stages :

– contact metamorphism of country rocks and xenoliths,

– autometamorphism of mafic and ultramafic rocks,
– metamorphism in the vicinity of quartz diorites,
– hydrothermal metamorphism,
– low-grade regional metamorphism.

More than 1600 cross- and level sections were constructed mainly in the southern part of the Ransko massif. The next characteristics were followed for each section: tectonics, rocks composition, amount of sulfides, trace element contents and ratios, nature and intensity of metamorphism. All features were used for the exploration of the hidden and blind ore bodies.

Contact metamorphism of country rocks and xenoliths

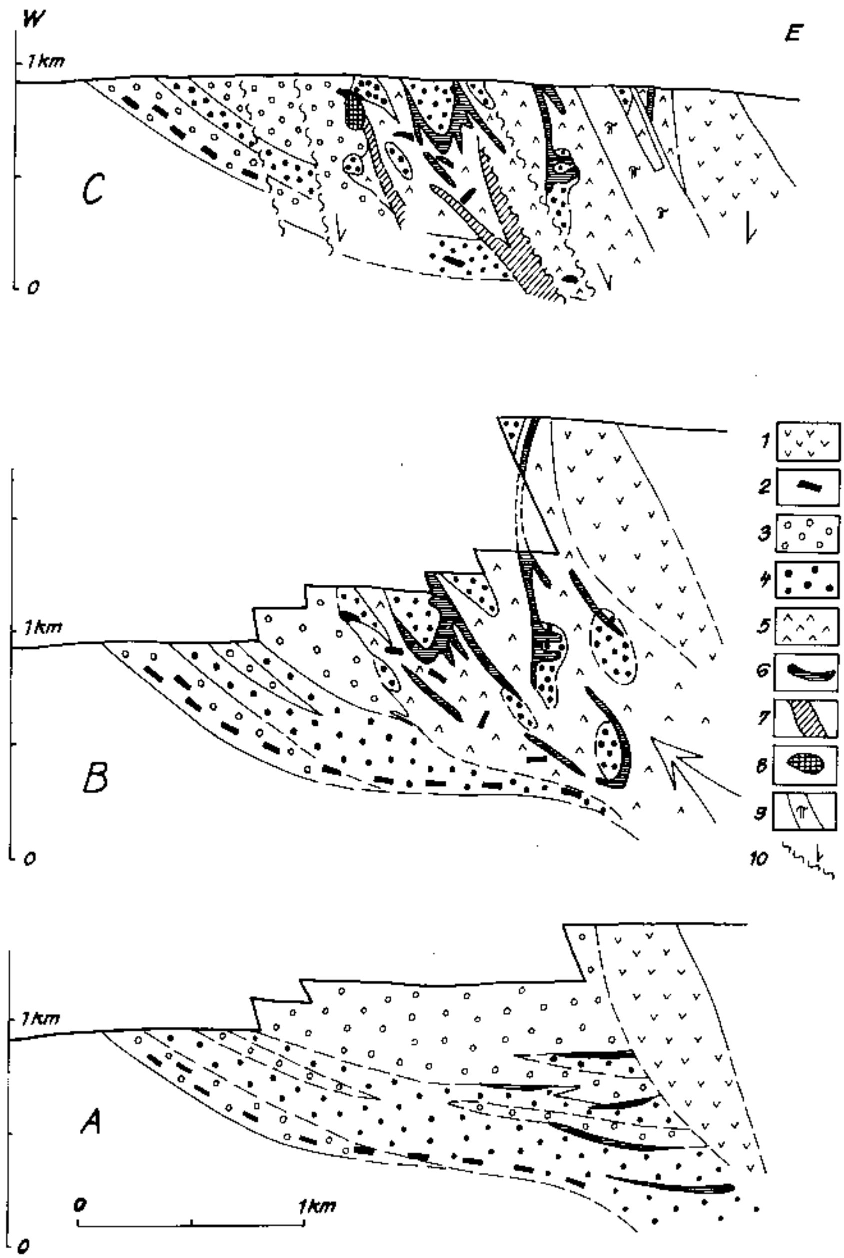
The exocontact rocks and xenoliths are metamorphosed into pyroxene and hornblende hornfels. The thickness of the pyroxene hornfels rim is less than one metre. The knots of biotite, porphyroblasts of albite-oligoclase and rare cordierite are present in fine-grained hornblende hornfels zone. The xenoliths in peridotites are surrounded by a zone of strongly serpentinized rocks, which are penetrated by the albite-oligoclase and quartz-aplitic leucosome (HOLUB 1967). The composition of the leucosome corresponds to the eutecticum of the Ab-SiO_2-H_2O system at the pressure less than 100 MPa and temperature over 850 °C. The veinlets of prehnite, xonotlite and hydro-grossularite are a result of autohydrothermal metamorhphism of medium-size xenoliths.

The assimilation of small xenoliths is typically developed around the flat west contact of the Ransko massif. The result is hornblende gabbrodiorite with zonal plagioclase islets and quartz-plagioclase-hornblende matrix. Mineral associations of the endocontact rocks around the east steep contact of the massif originated from metasomatically reworked matrix, enriched with K and H_2O from the exocontact, (olivine+ plagioclase inside poikilitic phlogopite).

The serpentinization of thin channels inside the olivine grains, kelyfitic rims and scarce uralitization (with green spinellides) are probably autometamorphic. Contacts of disseminated Ni-Cu sulfides and primary silicates as well as their contacts in sideronitic ore are sharp. In zones with slight uralitization of clinopyroxenes the intergrowing of sulfides and uralitization products (hornblende, green spinellide and phlogopite) is common. Such mineral association is equilibrated only at the absence of CO_2 and at temperature around 700 °C (WINKLER 1976).

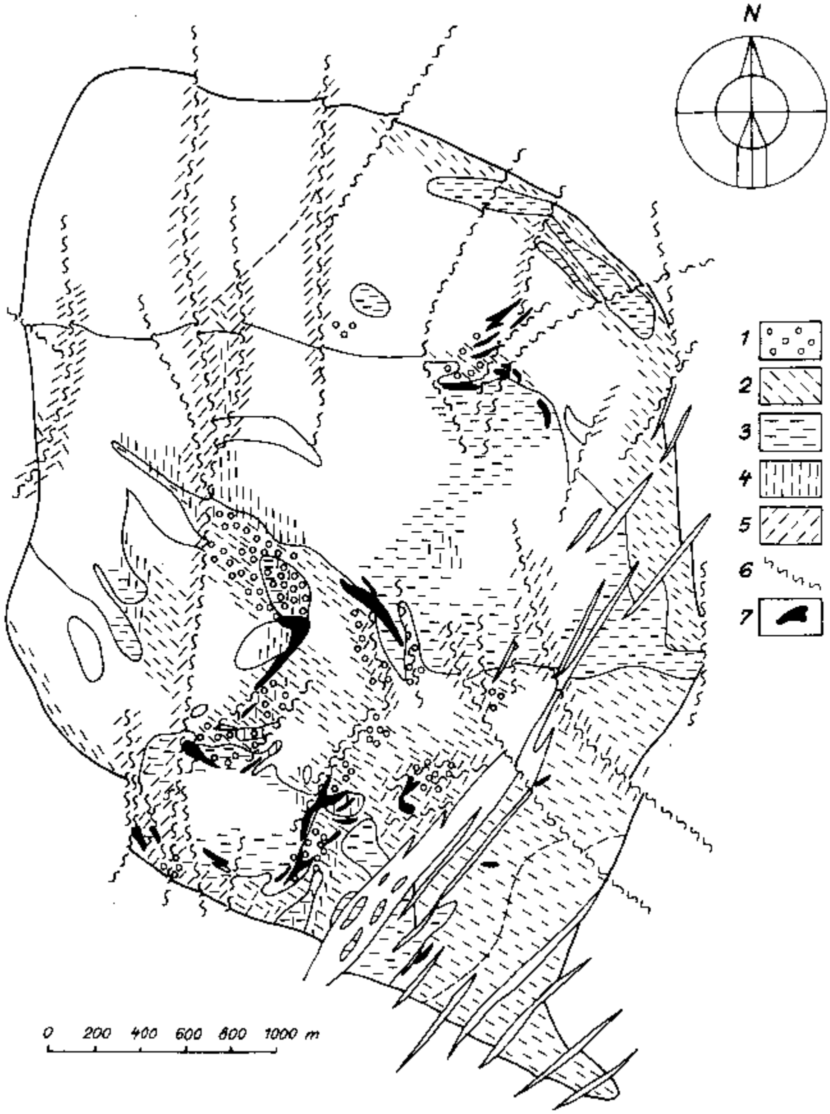
Metamorphism connected with quartz diorites

Rocks containing hyperstenic orthopyroxene were described by MÍSAŘ and POKORNÝ (1960) as hyperite and norite. HOLUB and POKORNÝ (1970) considered these rocks as metasomatites. WATKINSON et al. (1978) supposed the xenolithic origin of the orthopyroxene rocks in the vicinity of the massive sulfide deposits Obrázek, NĚMEC-HOLUB (1982) studied contacts of different xenoliths, orthopyroxene rocks, quartz diorites and



8. Developmental stages of the Ransko massif

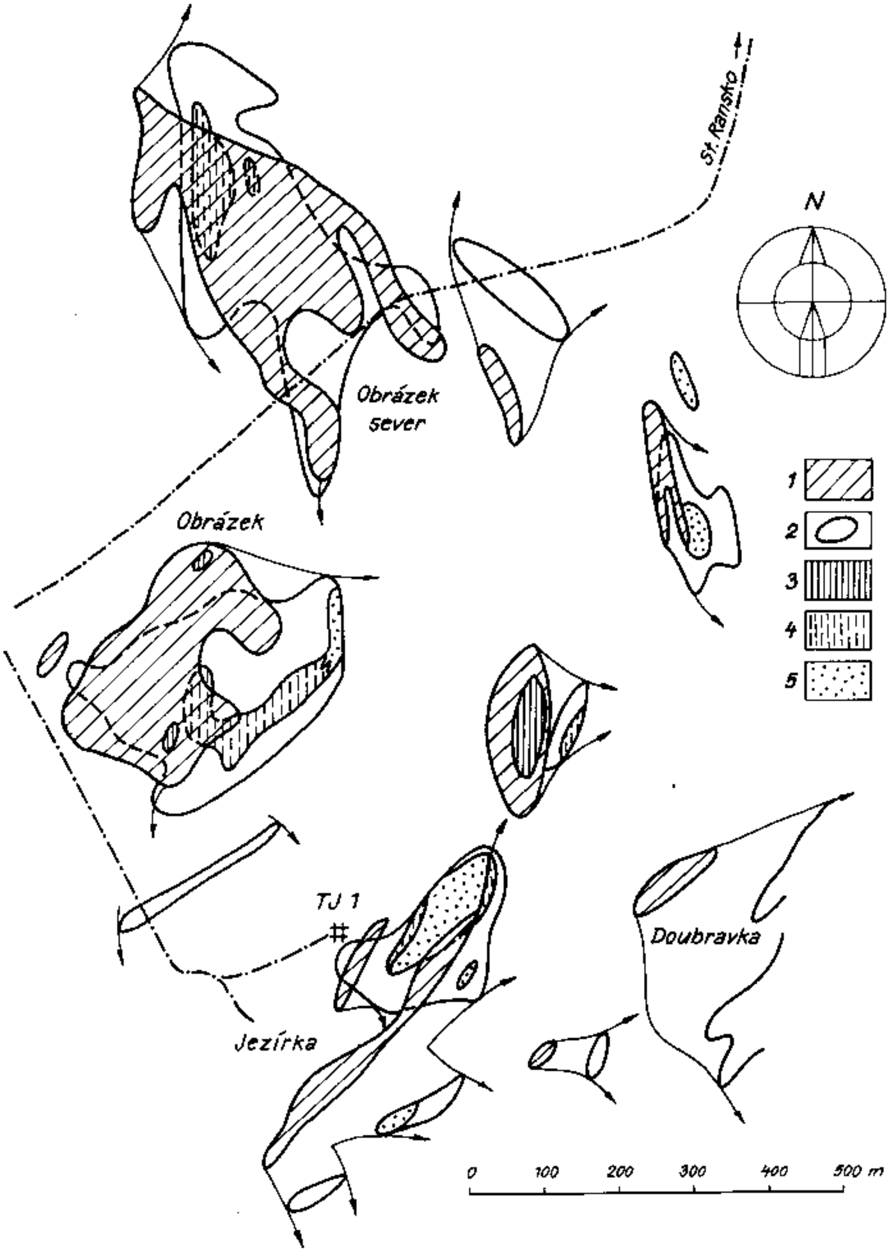
A – stage before the intrusion of pyroxene-rich gabbros, B – stage before the intrusion of quartz diorites, C – today's situation; *1* – gabbrodolerites, *2* – xenoliths, *3* – pyroxene-poor gabbros, *4* – ultramafites, *5* – mixed zones, *6* – Ni-Cu ores, *7* – quartz diorites, *8* – Zn-Cu ores, *9* – porphyries, *10* – normal faults.



9. The distribution of rock alteration
1 – orthopyroxenitization, *2* – serpentinization, *3* – saussuritization, *4* – uralitization, *5* – chloritization, prehnitization, *6* – faults, *7* – ore outcrops.

other magmatites of the Ransko massif. They found that metasomatic hornfels is younger than quartz diorite.

Metasomatic hornfels forms tongue-shaped and columnar zones in apical parts of quartz-diorite bodies. Quartz-containing and quartz-free cordierite-orthopyroxene-pla-

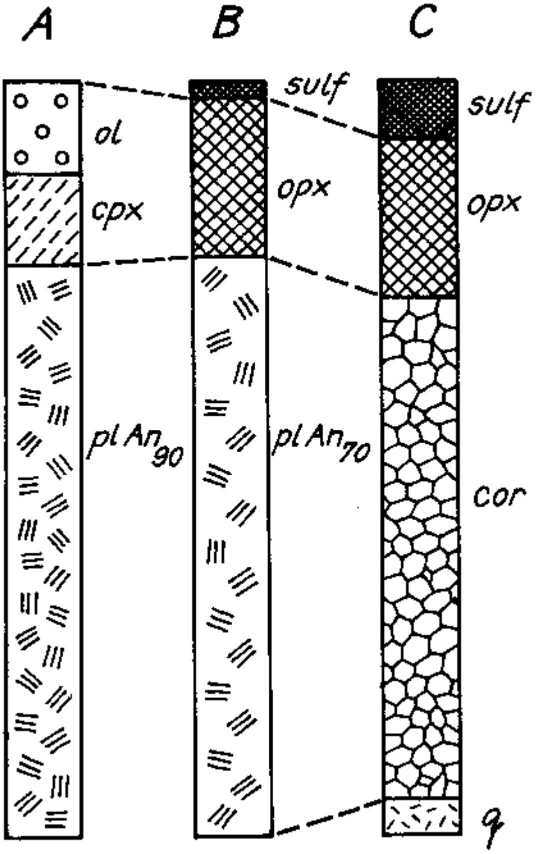


10. Distribution of some alteration in the southern part of the massif (near the surface and at the depth of 250 m)
Orthopyroxenitization: *1* – surface, *2* – depth; metasomatic hornfelses: *3* – surface, *4* – depth; quartz diorites: *5* – depth only.

gioclase hornfelses are present. The sillimanite needles, absent elsewhere, are present only in the quartz. The ore-bearing hornfelses contain sulphides and gahnite in addition. Other minor components are Mg-hercynite, magnetite and pyrrhotite, younger anthophyllite and biotite. Anthophyllite originated by alteration of orthopyroxene, biotite (phlogopite) is a reaction mineral. It appears in barren hornfels only, in cordierite intergranulars, rimming magnetite or pyrrhotite grains.

The quartz-bearing and quartz-free hornfels have originated by metasomatic alteration of quartz diorite or gabbro-troctolite. A typical concentric metasomatic zonation is developed around small bodies of quartz diorite in mafic rocks. The following assemblages succeed from the centre outward: Cord+Opx, Plag+Opx, Plag+Opx+Ol, Plag+Cpx+Ol. The continuous Ca increase is the most striking feature of the zonation.

Geochemical investigations reveal a distinct concentric zonation of some trace elements (Ag, Zn, Cu, Mo, Co, Ni) in wall rocks of the stocks of cordierite hornfelses, even of the barren ones. This zonation corresponds to that developed around hydrothermal polymetallic deposits. These haloes, as well as metasomatic zonality, are superimposed on all primary varieties of rocks (inclusive of xenoliths) in the vicinity of cordierite hornfels stocks.



11. Mineral composition at the contact (B) of the olivine gabbro (A) and metasomatic hornfels (C) (according to Holub - Pokorný 1970)
ol – olivine, cpx – clinopyroxene (pigeonite), pl – plagioclase, opx – orthopyroxene, cor – cordierite, q – quartz + sillimanite, sulf – pyrrhotite + pyrite.

Mineral assemblages of metasomatic hornfels correspond to the temperature about 800 °C, medium pressure of H_2O, absence of CO_2 (WINKLER 1976, YODER 1979) and high portion of sulphur (KULLERUD -YODER 1965). The boron content is by two orders higher in metasomatic hornfels than in other rocks of the massif. Then the assemblage of volatiles is necessary to complete by boron.

The strong hydrothermal alteration affects all varieties of rocks around the Zn-Cu massive sulfide body Obrázek (HOLUB-POKORNÝ 1970, NĚMEC-HOLUB 1980). Hydrothermally altered mafic rocks show the following mineral assemblages:

1.1 Serpentine, chlorite, hornblende, oligoclase, Mg-spinel, magnetite, pyrrhotite, pyrite.

1.2 Clinozoisite, chlorite, talc, pyrite, Mg-spinel.

1.3 Prehnite, analcime, harmotome, calcite, natrolite, Mg-chlorite, saponite.

The last assemblage forms veinlets in the outer zone of hydrothermally altered rocks (POKORNÝ 1969).

Regional metamorphism

Products of regional metamorphism appear mostly in the SE part of the Ransko massif. Higher temperature assemblages build up broader zones than the low-temperature ones. The latter are concentrated in and near the fissures. This is opposite zonality as compared with hydrothermal alteration. Mineral assemblages of regional metamorphic origin are:

2.1 Tremolite, oligoclase, Mg-spinel, serpentine.

2.2 Clinozoisite, epidote, oligoclase, chlorite, talc, Mg-spinel.

2.3 Veinlets of prehnite.

2.4 Zeolites (apophyllite, pectolite etc.), calcite.

Discussion of the metamorphic grade

The assemblages of metasomatic hornfelses from the Ransko massif have been equilibrated at temperature higher than 700 °C and low to medium pressure (c.f. data of WINKLER 1976). The assemblage of the outer zone requires high partial pressure of H_2O and temperature below 700 °C. The main hydrothermal alteration surrounding Zn-Cu ore bodies equilibrated at the P-T conditions of 350–700 °C and 200 MPa. Presence of H_2O, CO_2 and Mg-Ca enrichment were important.

The main assemblages of regional metamorphism originated at similar conditions as the assemblage of the outer contact zone of quartz diorites. The saussuritization affected narrower zones in consequence of temperature lowering. Prehnite veinlets indicate the feeding water channels still working after the temperature decrease below 350– 400 °C (HYUING SHIK KIM 1984).

The orthopyroxenitization of the autometamorphosed mafites confirms the rise of the temperature connected with intrusion of quartz diorites.

Spinellides

A great attention was paid to spinellides of the Ransko massif (see ROST 1969, WATKINSON et al. 1978, MÍSAŘ 1979, KOMÍNEK et al. 1983, TRDLIČKA et al. 1985).

The grains of primary spinellides of the olivine gabbro-peridotite group are nearly euhedral. The ovoidal inclusion of pyroxene and, rarely, K-rich phase are present.

These spinellides are usually composed of bright phase (magnetite) and dark phase with variable composition (magnesioferrite, chrompicotite). The association analysis of more than 100 results published by above mentioned authors, indicated the dependence of the dark phase composition on the rock type. The increasing content of Cr (up to 30 %) and decreasing content of Al with increasing amount of olivine are the main features. Ilmenite admixtures are common in primary spinellides in plagioclase-rich gabbros. The Fe-content of the dark phase increases with the presence of Ni-Cu ore (Cr- and Al-rich magnetite). It is necessary to distinguish this magnetite from the secondary one in Ni-Cu ore. The first contains less than 0.1 wt.% of Ni, Co and below 1 ppm of Ag. The secondary magnetite contains 3–6 % of Ni, 0.1– 0.4 % of Co and more than 1 ppm of Ag.

Another type of fine-grained magnetite evolved during the autometamorphic serpentinization of olivine and fills fine serpentinized channels in olivine grains. Green irregular spinellide is a common product of uralitization. Gahnite was found only in primary halo of the Zn-Cu ore bodies.

Assemblages of ore minerals

Assemblages of the scarcely disseminated sulfides in unmetamorphosed magmatites (rock sulfides)

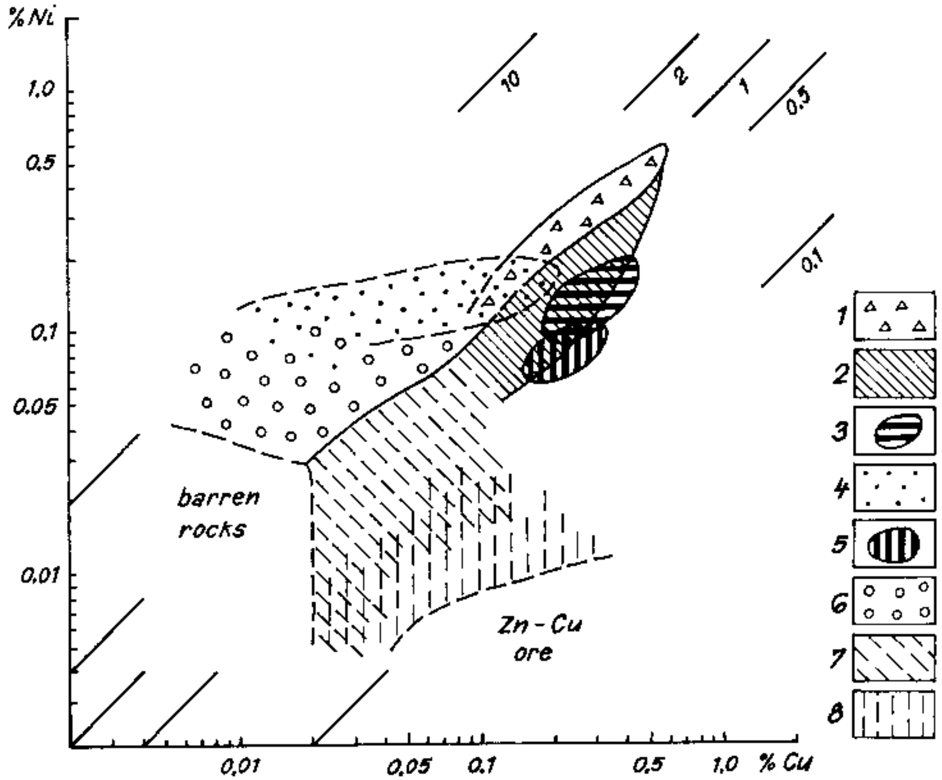
The assemblage and composition of rock sulfides is practically identical in all unmetamorphosed mafic and ultramafic rocks of the Ransko massif. Two main assemblages are present:

1.1 Hexagonal pyrrhotite, chalcopyrite and less common pentlandite.
1.2 Troilite, cubanite and pentlandite.

The second assemblage prevails in troctolites.

Assemblages of Ni-Cu ores in unmetamorphosed magmatites

Main minerals of the unmetamorphosed Ni-Cu ores are monoclinic, hexagonal (or a mixture of both) pyrrhotite, troilite, chalcopyrite, cubanite and pentlandite. The margins of sulfides and host silicates are sharp, the lamellae and needle-like intergrowths with clinopyroxene are less common. Sideronitic textures are typical. Polyphase magnetite, when present, is euhedral. The texture of sulfide aggregates is mostly holocrystalline without distinct succession. The textures of decay of solid solutions are present in Fe



12. Ni/Cu ratio

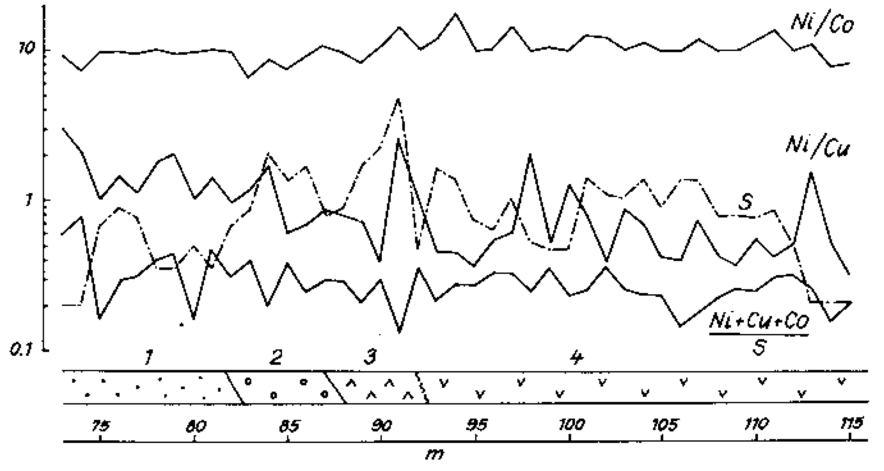
1 – unaltered Ni-Cu ore in troctolites, *2* – unaltered Ni-Cu ore in gabbros (excluding the Řeka orebody), *3* – Řeka orebody, *4* – altered Ni-Cu ore in ultramafites, *5* – altered Ni-Cu ore in gabbros; primary halo Ni-Cu ore in: *6* – troctolites, *7* – gabbros, *8* – primary halo of Zn-Cu ore.

sulfides. The small number of sulfide mineral varieties (3 – 4) in one sample is a distinct feature of these assemblages. The unmetamorphosed ore bodies (more detail description see in MÍSAŘ et al. 1974) are present in the northern part of the massif. Some parts of the deposits Jezírka and Tůně in the south of the massif belong to these assemblages, too.

Three main assemblages are present:

2.1 Hexagonal and H-M mixture of pyrrhotite, pentlandite, chalcopyrite.
2.2 Hexagonal and H-M mixture of pyrrhotite, troilite, pentlandite, chalcopyrite and less abundant cubanite.
2.3 Pentlandite, chalcopyrite, cubanite with less common troilite or monoclinic pyrrhotite.

The first assemblage occurs mostly in gabbros. The H-M mixture of pyrrhotite is common in the southern ore bodies. The ore bodies in troctolites and plagioclase peridotites contain minerals of the second assemblage. POKORNÝ (1969) described



13. Ni/Cu, Ni/Co, (Ni + Cu + Co)/S ratios and sulphur content in P-I adit, main layer, Jezírka orebody
1 – plagioclase peridotite, *2* – troctolite, *3* – pyroxene-poor gabbro, *4* – mixed gabbro zone.

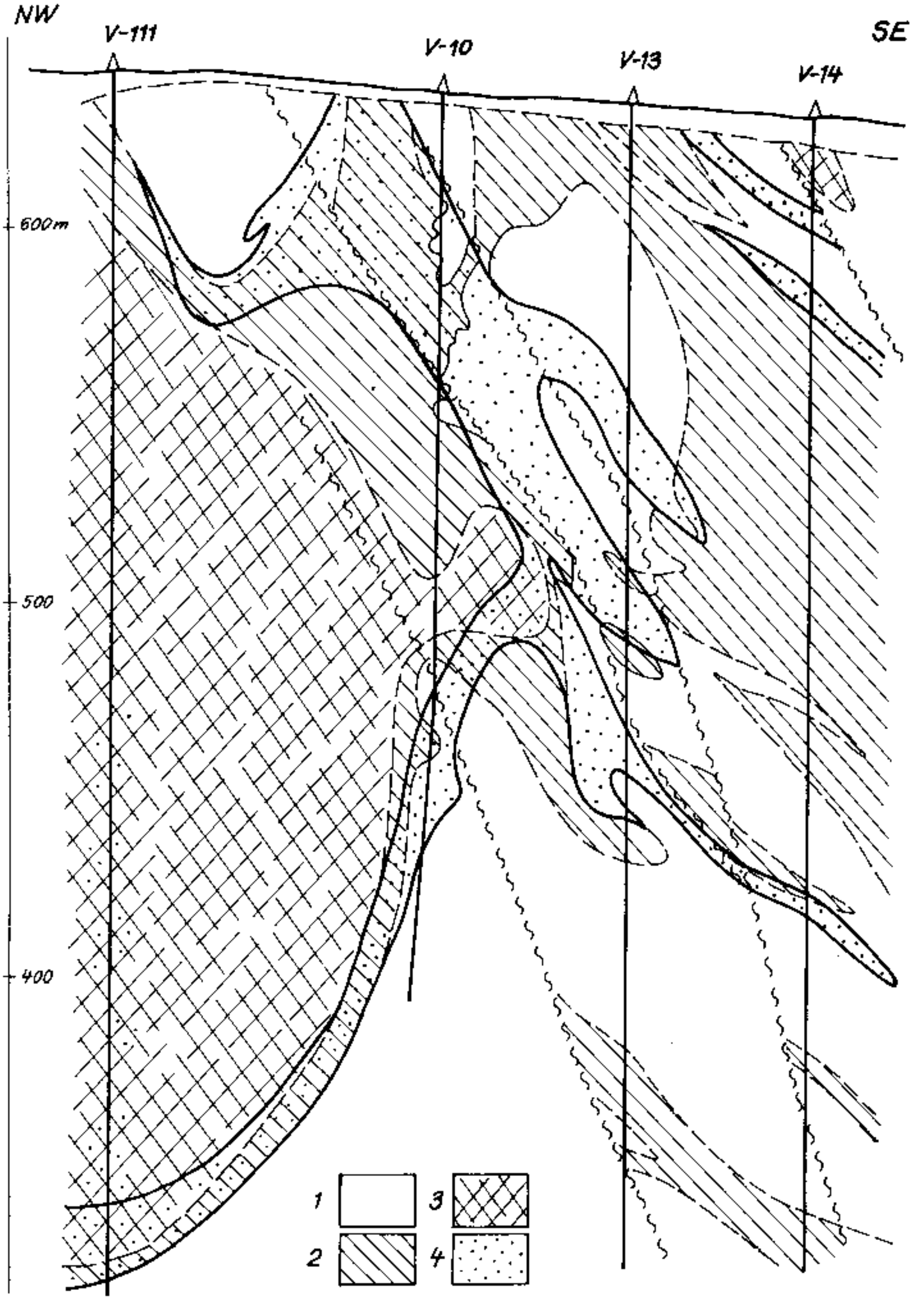
veinlet-like massive Ni-Cu sulfides intergrowing only slightly uralitized clinopyroxenes. The third assemblage builds up these veinlets, similarly as apical parts of the Tůně, Přikontaktní and Jezírka ore bodies. Euhedral plagioclase and clinopyroxene and exsolution of sphalerite are common in this assemblage which probably represents "pegmatite ore" known from other Ni-Cu deposits.

Assemblages of sulfides in metamorphosed mafites and ultramafites

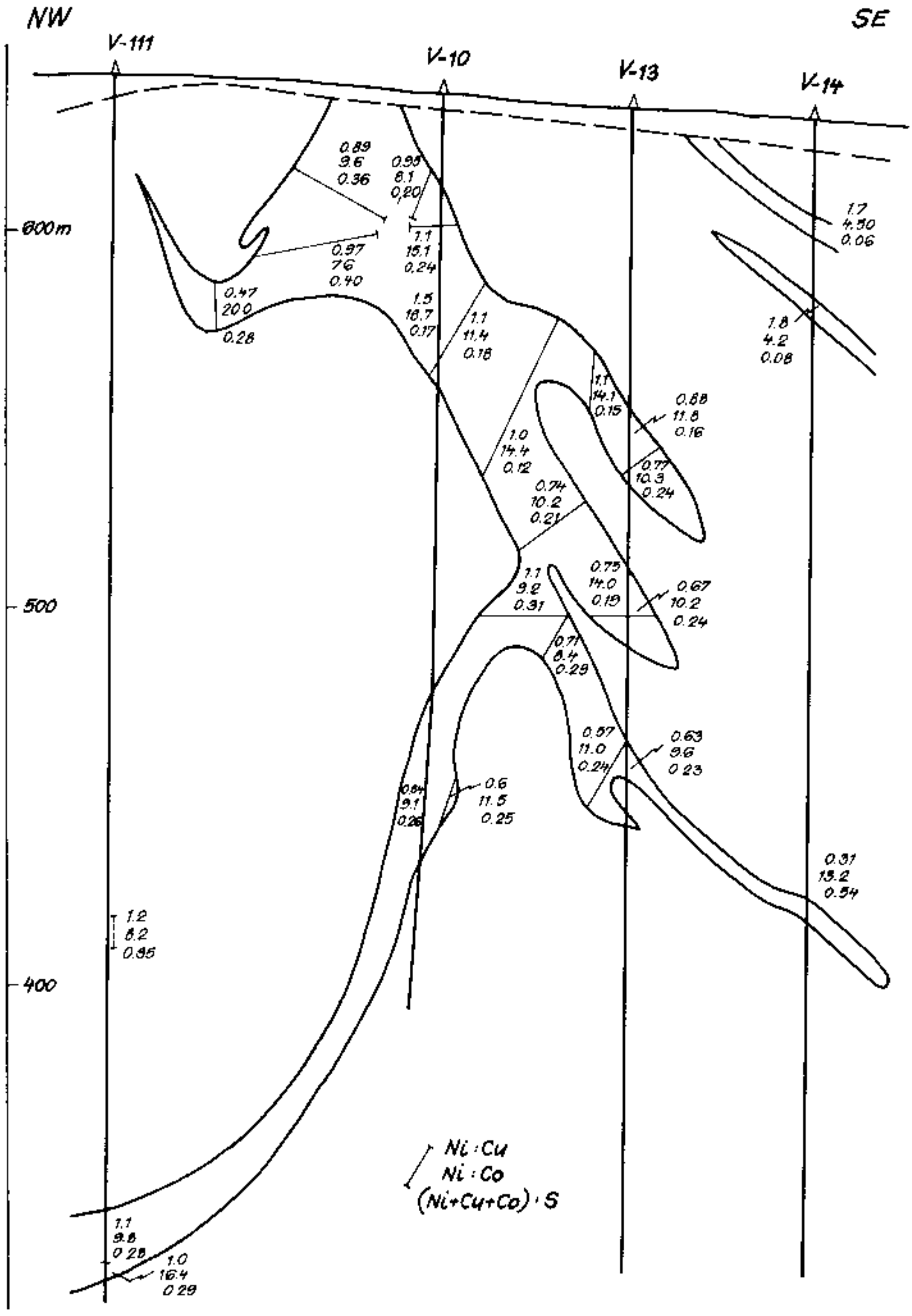
The next sulfide assemblages are present in strongly metamorphosed and altered rocks:

3.1 Monoclinic pyrrhotite, Co-rich euhedral pyrite 1 and less common chalcopyrite.
3.2 Monoclinic pyrrhotite, Co-poor xenomorphic pyrite 2, chalcopyrite.
3.3 Euhedral pyrite 3.
3.4 Pentlandite, magnetite and other Fe-oxides.

These assemblages are end members. The primary simple assemblages of 3 – 4 minerals are partly substituted by new or recrystallized minerals. The result is a high number of "coexisting" minerals in one sample. The most complicated is the mineral composition of Ni-Cu layers overprinted by primary halo of the Zn-Cu orebody. Hexagonal, monoclinic and H-M mixture of pyrrhotite, Co-rich pentlandite, chalcopyrite, cubanite together with pyrite 2, sphalerite, millerite and Ni-mackinawite are present. All these minerals are intimately connected with pyroxenes and their alteration products (uralite or anthophyllite).



14. Geological cross-section of the central part of the Jezírka orebody
1 – gabbros, *2* – troctolite, *3* – plagioclase peridotite, *4* – Ni-Cu ore.



15. Ni/Cu, Ni/Co, (Ni + Cu + Co)/S ratios in the same cross-section

The euhedral pyrite 1 (TRDLIČKA - HOFFMAN 1985) is Co-rich and is present in slightly metamorphosed rocks where the primary troilite and cubanite are gradually disappearing. The uralite in the vicinity of pyrite 1 is enriched with Ni. Pyrite 1 and monoclinic pyrrhotite are probably products of alteration of the primary sulfides. The released Co concentrated in pyrite 1 and Ni in monoclinic pyrrhotite and uralite. The temperature of the recrystallization was higher than 500 °C. The resistance of the pyrite 1 to the youngest plastic deformations is probably the reason of the microscopically apparent succession of sulfides (ATKINSON 1975, ROSCOE 1975).

The assemblage with xenomorphic, Co-poor pyrite 2 is connected with intensively uralitized rocks. Mostly euhedral and trace-elements free pyrite 3 is connected with veinlet assemblages containing clinozoisite, epidote or prehnite.

The relics of primary sulfides surrounded and penetrated by magnetite and other Fe-oxides are present in serpentinized ultramafites. Pentlandite and less chalcopyrite are present as armoured relics in fully hydrothermally oxidized ore. Magnetite and other Fe-oxides (with high Cu, Ni, Co and Ag content) form veinlets and fan-like aggregates (TRDLIČKA - HOFFMAN 1985). This type of ore alteration (typical of metamorphosed Ni-Cu ores of the Petchenga area (POLFEROV 1979)) requires high temperature, high pressure of H_2O and acid environment (ROSE - BURT 1982).

Zonation of Ni-Cu ores

POKORNÝ (1969) found the Ni/Cu ratio to depend on the host rock olivine content (gabbro 0.4–0.7, troctolites 0.8–1) of the Jezírka orebody. The distribution of Ni, Cu, Co and S in orebodies Řeka and Josef was described by MÍSAŘ et al. (1974). The complex evaluation of more than 30 000 ore samples brought more information about Ni, Cu, Co and S distribution.

The Ni/Cu ratios for intersections of the orebody in unaltered gabbros is 0.3–1, in troctolites and plagioclase peridotites 0.7–1.7 and in "pegmatite ore" it is below 0.7. Some ore bodies exhibit stable ratios (Řeka), other distinct zonation. The central part of the Tůně-Přikontaktní body has the Ni/Cu ratio of gabbros 0.55, increasing toward the wings to 0.8–1.2 and from 1 to 2–3 in troctolites. Likewise the Ni/Co ratio increases from 7– 8 to 14–15. The apical part of this blind orebody is built by "pegmatite ore," the wings and lower part of the orebody are relatively enriched with pyrrhotite.

The largest orebody Jezírka has the most complex distribution of elements mentioned above. The lower part of the main layer follows the contact of gabbros and plagioclase peridotite. The Ni/Cu ratio is relatively stable (gabbro 0.9, troctolite 1 and plagioclase peridotite 1.1) along the main rock contact. However this ratio decreases along the dip of the upper layer (from 1.2 to 0.3). This zonation is similar to that of the syngenetic Ni-Cu of the Petchenga area, SSSR (POLFEROV 1979). The southern Jezírka orebody shows the minimum of the ratio in altered gabbros above the quartz diorite stock. Ni/Co ratio increases positively with the increasing content of S (from 8–10 to 14–15). The highest values are again in "pegmatite" ore (18 – 20) and lowest in a pyritic layer of the hanging wall of the main layer (4–5). A similar Co-rich pyritic halo is in the upper part of the Doubravka orebody.

The Ni-Cu ratio of Ni-Cu orebodies in the vicinity of metasomatic hornfels and Zn-Cu orebodies is very variable with the average of 0.6–0.2. The mineral paragenesis of the Ni-Cu sulfides indicates its barrier function for penetrating solutions.

The serpentinization influences the Ni/Cu ratio of the Ni-Cu layers in different ways. The ratio decreases to 0.7 in the case of the slight serpentinization. Cu was mobilized from strongly serpentinized rocks and the Ni/Cu ratio increased to 20. The Ni/Cu ratio is mostly constant during serpentinization but the content of S significantly decreases..

Ni/Cu (0.5–0.7) and Ni/Co (8–9) ratios are constant in Ni-Cu ores of uralitized and saussuritized gabbros. But the high content of S and presence of pyrite are distinct features of these ores.

Primary haloes of the Ni-Cu ores

Twenty one elements (Ag, As, B, Ba, Bi, Co, Cd, Cu, Cr, Hg, Mn, Mo, Ni, Pb, Sb, Sn, Ti, V, W, Zn, Zr) were estimated by a combination of optical emission and roentgen fluorescence analyses. The data evaluation was carried out by system modelling (Holub - Komínek 1985).

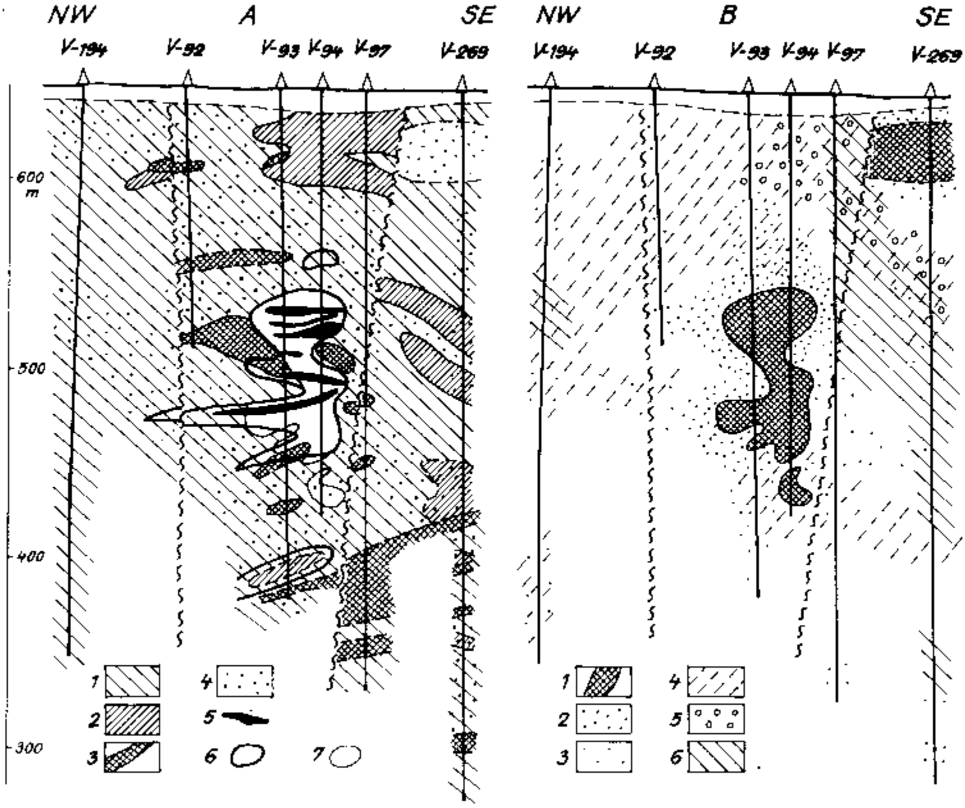
As main pathfinders were found Ag and Ni. Their content is more than ten times higher in primary halo than in normal field. Contents of Cu, Co, Cr, Pb and Zn were found to be three to ten times higher (subordinate pathfinders). Elements depleted as compared with normal field were not found. Zn and Ni change their order when primary halo is situated in altered rocks. W and B are next subordinate indicators in such case.

The thickness of the primary haloes in cross sections, as indicated by new multiplicative variables $Ag \times Pb \times Zn$ and $Ni \times Co \times Cu$, is 50–200 m. A positive correlation exists between the thickness of ore bodies and size of haloes. The Ni-Cu ore zone of the Ransko massif is indicated by a 200 ppm content of Cu. The hidden orebodies inside the ore zone are indicated by the $Ag \times Pb \times Zn$ value of the order of thousands. The primary haloes in the serpentinized plagioclase peridotites are several hundred metres thick. Around the orebody Josef, exists a distinct transversal zonality to the contact of altered gabbros with serpentinized plagioclase peridotite. Co and Ag are concentrated in ultramafites close to the contact. The zones rich in Pb, Zn, Cu and Ni follow farther in serpentinized rocks. Such a zonality was not found at the contacts of the unmetamorphosed rocks. This transversal zonation is most probably connected with regional metamorphism and water circulation.

Primary haloes of Ni-Cu orebodies in fresh rocks have relatively low contrast and slight zonation. According to Grigorjan et al. (1976) these features are characteristic of syngenetic Ni-Cu ores.

Assemblages of the Zn-Cu ores

The Zn-Cu mineralization is connected with metasomatic hornfelses of both types. Sulfide layers are flat with either sharp or disseminated contacts. Massive ore penetrates all hydrothermally altered rocks. The xenoliths of gneisses and gabbroamphibolites are penetrated by massive sphalerite, rimmed by disseminated pyrite and chalcopyrite. The

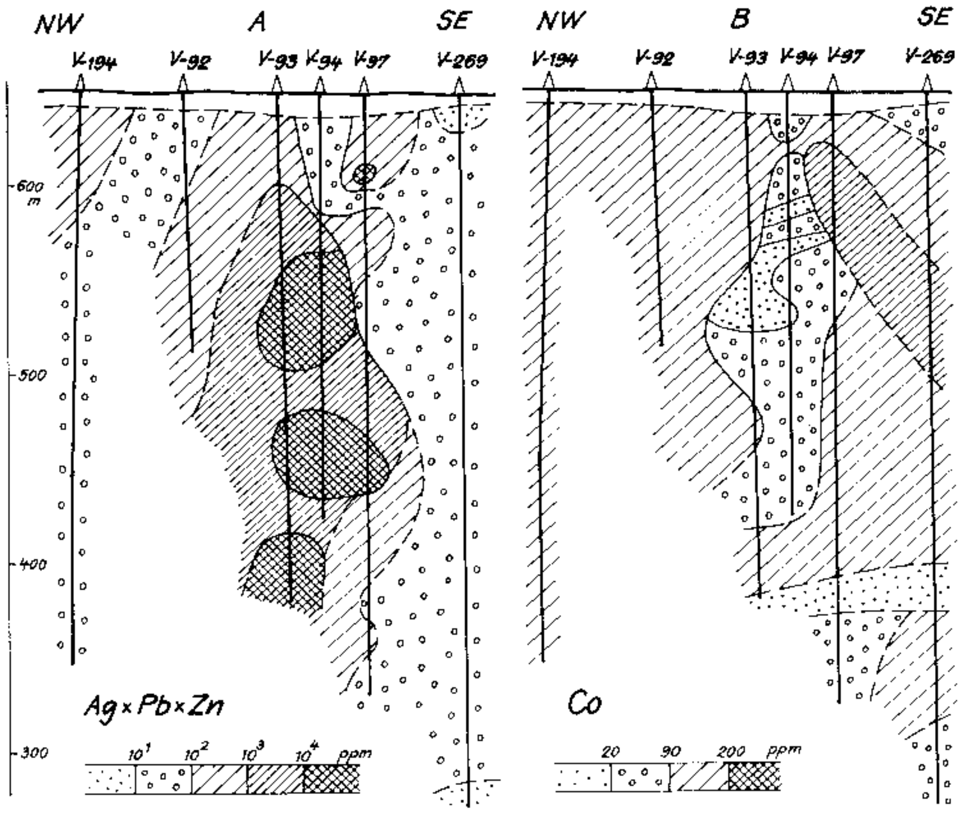


16. Geological cross-section (A) and distribution of alterations (B) of the Zn-Cu Obrázek orebody
A: *1* – pyroxene-poor gabbros, *2* – troctolite, *3* – xenoliths, *4* – disseminated Fe-sulfides, *5* – massive Zn-Cu ore, *6* – disseminated Zn-Cu ore, *7* – metasomatic hornfelses; B: *1* – metasomatic hornfelses, *2* – strong orthopyroxenitization, *3* – slight orthopyroxenitization, *4* – uralitization, serpentinization and chloritization, *5* – prehnitization, *6* – strong chloritization.

banded structure of the massive ore is a result of the changing amount of sphalerite, barite and pyrrhotite as well as variability of their grain size.

Xenomorphic grains of brown sphalerite form aggregates and veinlets. Sphalerite is usually inclusion-free, rarely, some grains contain chalcopyrite, pyrrhotite and galena. Contents of Fe (8 – 9 %) and Cd (less than 1 %) are constant. The content of Co (up to 6 %) increases close to the contact of the orebody.

Mostly automorphic grains of pyrite (up to several centimetres) are surrounded and penetrated by sphalerite, chalcopyrite and pyrrhotite. Contents of Ni and Co are less than 1%. TRDLIČKA and HOFFMAN (1985) described this pyrite as pyrite 1 common for both, Ni-Cu and Zn-Cu ores. A detail revision of the samples localization reveals that the typical pyrite 1 (with high Co content) is present only in intensively altered Ni-Co



17. Primary haloes in the same cross-section

layers near the Zn-Cu orebody. Automorphic pyrite of the Zn-Cu ore with contents of Ag and Mn in tens of ppm and Cu in thousands of ppm we describe as pyrite A.

Xenomorphic grains of pyrrhotite form aggregates and veinlets, commonly penetrate as the sulphides mentioned above as the rock-forming silicates. Pyrrhotite is mostly monoclinic, the content of Ni is less than 1 %. Contents of Ag and Mo are higher than in pyrrhotites of Ni-Cu ores. The lowest contents of trace elements showed pyrrhotites from quartz-cordierite hornfelses.

Xenomorphic chalcopyrite forms aggregates and veinlets closely connected with pyrrhotite. Chalcopyrite of the Zn-Cu ore is rich in Ag and Cd and poor in Co and Ni as compared with chalcopyrites of Ni-Cu ore.

The gray to white, mostly cataclastic barite, penetrated by sulfides, appears in sphalerite ore in the upper part of the Obrázek orebody.

The secondary pyrite (pyrite B) forms aggregates, veinlets and less automorphic grains in metasomatic hornfelses. This pyrite penetrates and corrodes all minerals mentioned above. Pyrite B is rich in Ag, Mo, Mn and depleted in Bi, as compared with pyrite 2. Pyrite B is probably of the same age as pyrite 2 of the Ni-Cu ores and both are connected with regional metamorphism.

Zonation of Zn-Cu ore

The orebody Obrázek has distinct mineralogical zonality. The massive sphalerite-barite ore builds up four flat layers in the upper part of the orebody. The content of barite decreases with depth. The massive pyrrhotite-chalcopyrite-pyrite ore with some molybdenite, connect sphalerite layers in the central part of the orebody. This zonality is fully developed in metasomatic hornfelses. The massive ore, penetrating hydrothermally altered gabbros, consists mostly of monoclinic pyrrhotite, chalcopyrite and subordinate sphalerite. Pyrite A, pyrite B and rare troilite are present. The mineral assemblage of monoclinic pyrrhotite (poor in trace elements), pyrite B, magnetite, polyphase spinellide and haematite is present below the orebody, in quartz-cordierite hornfelses.

Primary halo of Zn-Cu ore

The primary haloes around the Zn-Cu ore body are built up by two zones. The inner, differentiated zone (20–50 m thickness) continues flatly from blind orebody to the surface forming an anomaly 100–150 m to the south of the orebody. The inner zone disappears 200 m below the orebody in metasomatic hornfelses. The main pathfinders of the inner zone are Ag, Pb, Zn, Mo, Ba and Cu (anomaly contrast 10–160). Hg, Sn, W and B are subordinate indicators. Anomaly contrasts of Ni, Co and Cr are less than one. The longitudinal zonation of the inner zone is very distinct. Maximum of Ba is in the upper part of the halo. The main orebody is surrounded by Ag, Pb, Zn, Cu and Mo. The value of multiplicate variable $Ag \times Pb \times Zn$ is by more than three orders higher in the inner zone than in the outer zone.

The outer zone of the primary halo differs from the inner one in the absence of zonality. Most pathfinders have lower anomaly contrast. The outer halo zone is similar to the haloes of the Ni-Cu ore except the presence of B, Sn and W. The size of the outer zone is several hundreds of metres.

Genetic model of the sulfide mineralization

The original olivine tholeiitic magma differentiated in the transit magma chamber into gabbrodolerites and parental magma of the gabbro-troctolite group. This type of differentiation describes Distler et al. (1979) from the trap formation of the Norilsk area (USSR). The chemical composition of gabbrodolerites is probably very close to that of the primary magma. The differentiation of the gabbro-peridotite group followed the intrusion in the flat part of the body. The practically constant composition of olivines and plagioclases is probably a result of preintrusive crystallization of these minerals. Olivine cumulated in the lower part of the magma chamber, plagioclase in the upper part. Some elements and minerals (Cr, Ni, Co, Cr-spinellides) concentrated in the olivine layer, other (V, Ti, illmenite, Mg-magnetite) concentrated in the upper, gabbro layer.

The contents of Ca and Fe in clinopyroxenes differ in the layers mentioned. Pyroxenes in troctolites are Fe-rich, in gabbros Ca-rich. The Ni-Cu ore assemblage in troctolites are Fe-rich (troilite, cubanite), too. The iron-rich troctolites build probably a transition zone between the gabbros and olivine cumulates. This stage of differentiation can be characterized as a differentiation in a closed system.

A partly-open system of differentiation continued in the steep part of the intrusion. The presence of sulfides in the today "ore zone" with mantle composition of sulphur (POKORNÝ 1969) and presence of autometamorphism confirm the additional supply of the volatiles from the deeper level of the magmatic chamber. The Ni-Cu sulfides concentrated mainly in the troctolite layers and less in adjoined gabbros and plagioperidotites. The pausity of both, sulfides and autometamorphism in the flat west part of the Ransko massif, confirm this model.

The pyroxene gabbros intruded into a not fully consolidated environment. Both groups of rocks mixed and ultramafite layers were transformed into blocks (xenoliths) floating in the gabbros. Sulfide layers moved with magma and due to more mobile state penetrated into both gabbro types for the distance of several hundreds of meters (Doubravka and Řeka orebodies). The main feature of the Ransko massif Ni-Cu sulfides is the affinity to the Fe-rich troctolites. The zonation of elements, minerals and primary haloes of most ore bodies is a result of the differentiation in situ. Ni concentrated in olivine host rocks, Co in pyrite rich halo of orebodies (pyrite 1). The slight contrast zonation of primary haloes as well as simple mineralogy of the unmetamorphosed ores confirm the syngenetic origin of the Ni-Cu orebodies.

After a considerable span of time, the quartz diorites intruded mostly along the zones of mixed rocks. The metasomatic reaction in their apical parts led to the origin of cordierite metasomatic hornfelses. The rise of Zn-Cu sulfide mineralization followed the hornfels origin. The zonation of ore minerals and primary haloes as well as hydrothermal alteration of host rocks confirm epigenetic origin of this massive sulfide-type mineralization. Ore mineral structures and textures show the metamorphic influence.

Regional metamorphism affected the Ransko massif including the ore content. Temperature of metamorphic conditions gradually decreased from 700 °C to 350 °C. Metamorphism was conducted by a large carry in of H_2O from the east contact of the massif. The next stage of metamorphism, below 350 °C, was concentrated in narrow zones and at last, along main dislocations. The regional metamorphism and the intrusion of quartz diorites are of Silurian age.

K tisku doporučil Z. Mísař

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Model geneze sulfidického zrudnění ranského gabroperidotitového masívu

(Résumé anglického textu)

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Ze zpracování výsledků nových průzkumných prací plyne, že ranský gabrový a plagioperidotitový masív je vícefázovou intruzí, původně kolenovitého tvaru. V prvé fázi intrudovaly gabrodolerity, které tvoří magmatickou brekcii podél plochého podložního kontaktu v z. části intruze a samostatné dílčí těleso na JV. V další fázi intrudovaly horniny troktolitové řady (typ A, Bouška et al. 1977), v nichž při diferenciaci trapového typu vznikly likvační polohy Ni-Cu-sulfidů v přívodní části intruze. Diferenciací vzniklá stavba byla porušena intruzí mladších pyroxenických gaber (typ B). Intruze pňů křemenných dioritů je výrazně mladší a je pravděpodobně současná s epizonální metamorfózou postihující zvláště v. část masívu.

V ranském gabrovém a plagioperidotitovém masívu je známo několik sulfidických asociací lišících se genezí. Jsou tady Fe-sulfidy (převážně pyrit 2 a monoklinický pyrhotin), vyskytující se podél kontaktů masívu, které vznikly pravděpodobně v důsledku snížené rozpustnosti sulfidů v kontaminovaných gabrech. Primární, syngenetické sulfidy vytvářejí sulfidickou fázi vtroušených sulfidů jednoduchého složení. Tyto vtroušeniny neobsahují pyrit. Obdobné složení mají asociace Ni-Cu-rud v nepřeměněných horninách, u nichž rovněž konkrétní mineralogické složení závisí na obsahu olivínu a na železitosti pyroxenů v okolní hornině. Část těchto rud dospěla až k pegmatitovému stadiu vývoje. Při mladších přeměnách v okolí křemenných dioritů a metasomatických rohovců došlo ke vzniku složitých minerálních asociací a nových rovnovážných stavů mezi sulfidy, silikáty a oxidy.

S vývojem hydrotermálních systémů v okolí pňů křemenných dioritů je spjat i vznik kyzových Zn-Cu-rud. Přetrvávající epizonální metamorfóza, postihující za přínosu H_2O v. a j. část masívu, způsobila vznik reliktních asociací sulfidů v serpentinizovaných horninách, dále vznik asociací obohacených sírou v přeměněných gabrech a rekrystalizaci části minerálů Ni-Cu a Zn-Cu-rud. Hydrotermální přeměny v okolí dislokací byly pak provázeny vznikem pyritu 3 a monoklinického pyrhotinu.

Vysvětlivky k tabulkám

Tabulka 1. Korelace tektonických, metamorfních a magmatických pochodů v ranském masívu a jeho okolí.

Tabulka 2. Průměrné chemické složení magmatických hornin masívu. *1* – peridotit, *2* – plagioperidotit, *3* – troktolit, *4* – olivinické gabro, *5* – pyroxenické gabro, *6* – gabrodolerit, *7* – typické gabrotroktolitové řady, *8* – typické gabropyroxenické řady, *9* – křemenný diorit, *10* – porfyrit.

Průměrné hodnoty vypočteny na základě analýz publikovaných in Mísař et al. (1977), Němec - Holub (1982) a Komínek et al. (1983).

Tabulka 3. Hodnoty neporušeného geochemického pole (v ppm) hlavních horninových typů.

Tabulka 4. Chemické složení rudních minerálů (výsledky elektronové mikrosondy).

Vysvětlivky k obrázkům

1. Schéma strukturní stavby v okolí ranského masívu.
   1 – žulové porfyry, *2* – granodiority centrálního moldanubického plutonu, *3* – ranský gabroperidotitový masív, *4* – fylity vítanovského souvrství a fylonity v přibyslavské mylonitové zóně, *5* – porfyroidy vítanovské série, *6* – jemnozrnné pararuly typu malínské skupiny, *7* – migmatity ortorulového vzhledu, *8* – gabroamfibolity, *9* – pestrá skupina moldanubika a kutnohorského krystalinika s. l. (průběh pestrých vložek), *10* – ruly a migmatity moldanubika a kutnohorského krystalinika s. l., *11* – hadce, *12* – hlavní zlomy a mylonitové zóny, *13* – osy vrás starších než hlavní foliace, *14* – hlavní lineace starší než periplutonická migmatitizace v moldanubiku, *15* – mladší lineace typicky vyvinutá v hlinské zóně, *16* – osy vrás spjaté s výstupem centrálního moldanubického plutonu.
2. Geologická mapa ranského gabroperidotitového masívu.
   1 – kutnohorské krystalinikum, *2* – vítanovská skupina hlinské zóny, *3* – xenolity krystalinika, *4* – gabrodolerity, *5* – plagioperidotity a peridotity, *6* – troktolity, *7* – gabra a olivinická gabra troktolitové řady, *8* – gabra pyroxenické řady, *9* – směs obou typů gaber, *10* – výchozy sulfidických poloh: 1 – Jezírka, 2 – Jezírka-jih, 3 – Doubravka, 4 – Tůně-západ a jih, 5 – Tůně-sever, 6 – Tůně-přikontaktní, 7 – Obrázek-sever, 8 – Josef, 9 – Řeka, 10 – Řeka-jih a východ, 11 – drobné výskyty ve východním bloku masívu, 12 – slepé ložisko Obrázek, *11* – žulové porfyry a syenitové porfyrity, *12* – hlavní dislokace.
3. Geologické řezy masívem.
   1 – metasomatické rohovce, *2* – Zn-Cu-rudy, *3* – křemenný diorit. Ostatní vysvětlivky jako obr. 2.
4. Schéma lokální klasifikace hornin s vynesenými výsledky planimetrických analýz.
   Horniny troktolitové řady: *1* – dunit, *2* – peridotit, *3* – plagioperidotit, *4* – troktolit, *5* – olivinické gabro, *6* – pyroxenické gabro; horniny pyroxenické řady: *7* – olivinicko-pyroxenická gabra, *8* – pyroxenická gabra.
5. Průměrné analýzy hornin masívu vynesené do diagramu pro určení relativního obsahu hliníku v bazaltech (Bogatikov et al. 1981).
   1 – bazalty s nízkým obsahem hliníku, *2* – bazalty s normálním obsahem hliníku, *3* – bazalty s vysokým obsahem hliníku. Horniny ranského masívu: Pr – peridotity, PPr – plagioperidotity, Tr – troktolity, OG – olivinická gabra obou řad, G – pyroxenická gabra obou řad, GD – gabrodolerity, M – pravděpodobné střední složení intrudujícího magmatu.
6. Obsahy Zn ve spinelidech ranského masívu.
   1 – zelený spinelid, *2* – jednofázový tmavý spinelid, *3* – vícefázový spinelid, tmavá fáze, *4* – vícefázový spinelid, světlá fáze, *5* – ilmenit, *6* – chromit. Ojedinělá pozorování jsou vyjádřena značkou.
7. Schéma vnitřní stavby masívu.
   1 – porfyry a porfyrity, *2* – ultrabazika, *3* – generalizovaný průběh diferencovaných zón v ultrabazikách, *4* – gabra obou řad, *5* – zóny pestrého střídání hornin, *6* – gabrodolerity, *7* – výchozy sulfidických poloh.
8. Schéma vývoje ranského bazického masívu.
   A – před intruzí pyroxenických gaber, B – před intruzí křemenných dioritů a porfyrů, C – dnešní stav; 1 – gabrodolerity, *2* – xenolity okolního krystalinika, *3* – gabra troktolitové řady, *4* – plagioperidotity troktolitové řady, *5* – pestré střídání pyroxenických gaber a gaber troktolitové řady, *6* – Ni-Cu-rudy, *7* – křemenné diority, *8* – Zn-Cu-rudy, *9* – porfyry, *10* – poklesové dislokace.
9. Rozšíření intenzívních přeměn hornin v masívu.
   1 – hyperstenizace, *2* – serpentinizace ± méně intenzívní saussuritizace, *3* – saussuritizace, *4* – uralitizace, *5* – přeměny hydrotermálního typu v j. části masívu včetně prehnitizace, *6* – dislokace, *7* – výchozy sulfidických poloh.
10. Rozsah hyperstenizace, metasomatických rohovců a křemenných dioritů v jižní části masívu při povrchu a v hloubce 250 m.

Hyperstenizace: *1* – při povrchu, *2* – v hloubce; metasomatické rohovce: *3* – při povrchu, *4* – v hloubce, *5* – křemenné diority (pouze v hloubce).

11. Minerální složení hornin (B) na kontaktu olivinického gabra (A) a tmavého metasomatického rohovce (C) (upraveno podle Holuba - Pokorného 1970).
    ol – olivín, cpx – klinopyroxen (pigeonit), pl – plagioklas, opx – ortopyroxen, cor – cordierit, q – křemen s akcesorickým sillimanitem, sulf – pyrhotin, pyrit.
12. Diagram poměru Ni/Cu.
    1 – nepřeměněné rudy v troktolitech a plagioperidotitech, *2* – nepřeměněné rudy v gabrech mimo ložisko Řeka, *3* – ložisko Řeka, *4* – zrudnění v alterovaných plagioperidotitech (ložisko Josef), *5* – rudy v alterovaných gabrech; primární aureoly Ni-Cu-rud: *6* – v silně olivinických horninách, *7* – v gabrech, *8* – primární aureola Zn-Cu-rud.
13. Změny poměrů Ni/Cu, Ni/Co, (Ni + Cu + Co)/S a obsahů S v ložiskové poloze Jezírka, překop P-I.
    1 – plagioperidotit, *2* – troktolit, *3* – gabra troktolitové řady, *4* – střídání gaber troktolitové a pyroxenové řady.
14. Geologický řez střední částí ložiska Jezírka.
    1 – gabra obou řad, *2* – troktolity, *3* – plagioperidotity, *4* – Ni-Cu-rudy.
15. Distribuce Ni/Cu, Ni/Co a (Ni + Cu + Co)/S na tomtéž řezu ložiskem Jezírka.
16. Geologický řez (A) a distribuce přeměn (B) na ložisku kyzových Zn-Cu-rud Obrázek.
    A: *1* – gabra a olivinická gabra troktolitové řady, *2* – troktolity, *3* – xenolity hornin kutnohorského krystalinika, *4* – vtroušená mineralizace (převážně pyrit 2, pyrhotin, místy pyrit 1 a Ni-Cu-sulfidy), *5* – masívní rudy (sfalerit, pyrhotin, chalkopyrit, ve svrchní části baryt), *6* – obrys těl vtroušených a prožilkových Zn-Cu-rud, *7* – obrys těl metasomatických rohovců; B: *1* – metasomatické rohovce, *2* – výrazná hyperstenizace, *3* – nevýrazná hyperstenizace, *4* – uralitizace, serpentinizace a nevýrazná chloritizace, *5* – prehnitizace, *6* – výrazná chloritizace.
17. Ložisko Zn-Cu-rud Obrázek. Primární aureoly na tomtéž řezu.

Генетическая модель образования сульфидного оруденения Ранского габбро-перидотитового массива (Чехия, Чехословакия)

Ранский габбро-перидотитовый массив внедрился вдоль несогласного соприкосновения мезозонального и епизонального кристаллических комплексов ядра Чешского массива. За древнейшим частичным внедрением массива, состоящим из габбро-долеритов, следовала главная фаза внедрения оливинового габбро с низким содержанием пироксена. Перидотит, содержащий округленние зерна оливина, накопился в нижележащей, а породы, содержащие больше плагиоклаза, – в вышележащей зоне. Никелево-медное оруденение было связано с троктолитами в средней зоне. Дифференциация магмы прервалась следующим внедрением габбро с высоким содержанием пироксена. Внутренняя текстура массива, подобная флюидальной, является результатом внедрения магмы в не вполне консолидированные породы.

Медно-цинковое месторождение Образек (массивного сульфидного типа) моложе кварцево-диоритовой интрузии и родственного метасоматического роговика. Ранский массив вместе с обоими типами сульфидных месторождений подвергся епизональному региональному метаморфизму.

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