# REGIONAL TYPIZATION OF THE IRON SKARNS OF THE BOHEMIAN-MORAVIAN HEIGHTS (ČESKOMORAVSKÁ VRCHOVINA)

REGIONÁLNÍ TYPIZACE SKARNŮ Fe ČESKOMORAVSKÉ VRCHOVINY

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*Abstract*

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The skarns of the Bohemian-Moravian Heights can be classified as iron skarns. They are pre-Variscan in age and have been regionally metamorphosed in a migmatization zone under abyssal conditions. Apart from some input of granitic metatect from enclosing gneisses, metamorphism took place isochemically. Due to metamorphism the skarns acquired the petrographical characteristics of metamorphic rocks. During regional metamorphism, almandine, grossularite-almandine and hornblende originated. Diopside-hedenbergite, grossularite-andradite, epidote and magnetite are relict minerals. Minerals of the skarns are characterized on the basis of their chemical composition. Chemical equilibria of some assemblages are discussed by use of partition coefficients and the phase rule. To discuss the premetamorphic genesis, the following features of the skarns are important: Striking geological and partly petrographical similarities to bodies of marbles of the region; spatial relations to massifs and large complexes of orthogneisses (in some of them, presence of relict greisens was proved); evidence of relict metasomatic zoning and stage development, which is especially obvious in the superposition of magnetite mineralization on older silicate assemblages; presence of minerals (or pseudomorphs after them) which can originate only under conditions of contact metamorphism; presence of geochemical features enabling a distinction between skarns-after-carbonates and skarns-after-noncarbonates. All these features suggest that, before regional metamorphism, the skarns were typical primary skarns developed through a high-temperature metasomatism, mostly of carbonate rocks, which was caused by magmatogeneous ore fluids. The hypothesis that they have been originally submarine-exhalative deposits is not sufficiently supported.

Key words: Skarns, regional metamorphism, genesis, Czechoslovakia.

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## Introduction

During last decades, many papers have been published on the skarns of the Bohemian-Moravian Heights, following their opening by quarrying, mining and prospecting works. The results were summarized by the author in 1979. Since then, some further papers have appeared making a new comprehensive treatise on them desirable.

The term "skarn" has changed its meaning many times (compare Burt 1983, Legler and Baumann 1983, Kwak 1987). In Czech literature, the original Swedish meaning is mostly maintained. Skarns are designated as rocks consisting dominantly of clinopyroxene, Ca garnets and other Ca silicates (calcic skarns) or Ca-Mg and Mg silicates (magnesian skarns). Magnetite-containing amphibolites and iron-poor calc-silicate hornfelses ("erlans") even though also sometimes called skarns, are not considered here.

Usually skarns have been produced by high-temperature metasomatism of carbonate, partly also aluminosilicate rocks, by action of magmatogeneous fluids and solutions. The skarns of the Bohemian-Moravian Heights, which are pre-Variscan, possibly even Cadomian in age, have been affected by regional metamorphism under abyssal conditions, which imprinted them with the character of metamorphic rocks. With the exception of Fenoscandia, similar rocks are unknown in the world. Due to the regional metamorphism, their original premetamorphic genesis is unclear. However, their uniform petrographical features and geochemical similarities suggest the same origin.

The territory considered includes the whole Bohemian-Moravian Heights, as fas as to the town Kutná Hora in the north. In addition, the locality of Kottaun (near the Austrian town Drosendorf) in Austrian Waldviertel is included. It is only 3 km away from the Czechoslovak frontier. Recently this locality has been investigated in great details by Götzinger (1981).

## Geology

(a) Location of skarns. The skarns occur in the Moldanubicum as well as in the metamorphic complexes of Kutná Hora and Svratka. Usually they appear in groups (Fig. 1). Only the skarn at Malešov near Kutná Hora is isolated; however, it lies near the Cretaceous basin under which some further occurrences could be hidden. The skarn bodies appear in areas covered by extensive complexes of orthogneisses and their migmatites (in particular, migmatites of the Gföhl type) or in close proximity to isolated orthogneiss bodies (the Sázava area, the Blanice furrow, the Žďár area). In contrast they are absent in large areas formed exclusively by monotonous biotite-sillimanite paragneisses and their migmatites, as are the areas on both sides of the Central Massif of the Bohemian-Moravian Heights (Fig. 1) or in the Strážek Moldanubian metamorphic complex. The Svratka metamorphic complex, which is very rich in two-mica orthogneisses, is also rich in skarns, especially in its southern part.

The skarns are always a part of paraseries (paragneisses, mica schists) and also contain, even if rarely, intercalations of these rocks. Sometimes it seemed that they were embedded directly in orthogneisses, but a prospection performed by drilling has usually shown (for instance, at Kordula) that they were accompanied by paragneiss. Exceptional occurrence of small skarn pods in light coloured Gföhl orthogneiss at Ruda near Velké Meziříčí and at Biskupice (Koutek and Čech 1974) probably represents boudins folded into orthogneiss.

As a rule the skarn bodies are situated either directly at orthogneiss' contacts (Vlastějovice, Budeč) or lie only some tens or hundreds of meters away from the contact. The skarn/orthogneiss contact planes are always tectonical. Evidently, the contacts separating domains of different rigidity were very suitable moving planes. Strikingly, most skarns are located in deformation zones or near deeply reaching faults, which were founded in pre-Variscan time and continuously reactivated in younger periods. This fact was stressed already by Weiss et al. (1982). The skarns at the Zlaté Hory village lie in the Blanice furrow (Fig. 1), the skarns of the Sázava area along the Sázava fault, the skarns of the Žďár area along the Železné hory Mountains and Křídla faults, the skarns of the central part of the Svratka metamorphic complex at the Sněžné fault, the skarns in the south of the Svratka metamorphic complex near a deformation zone at the Moldanubicum/Svratka complex contact, the

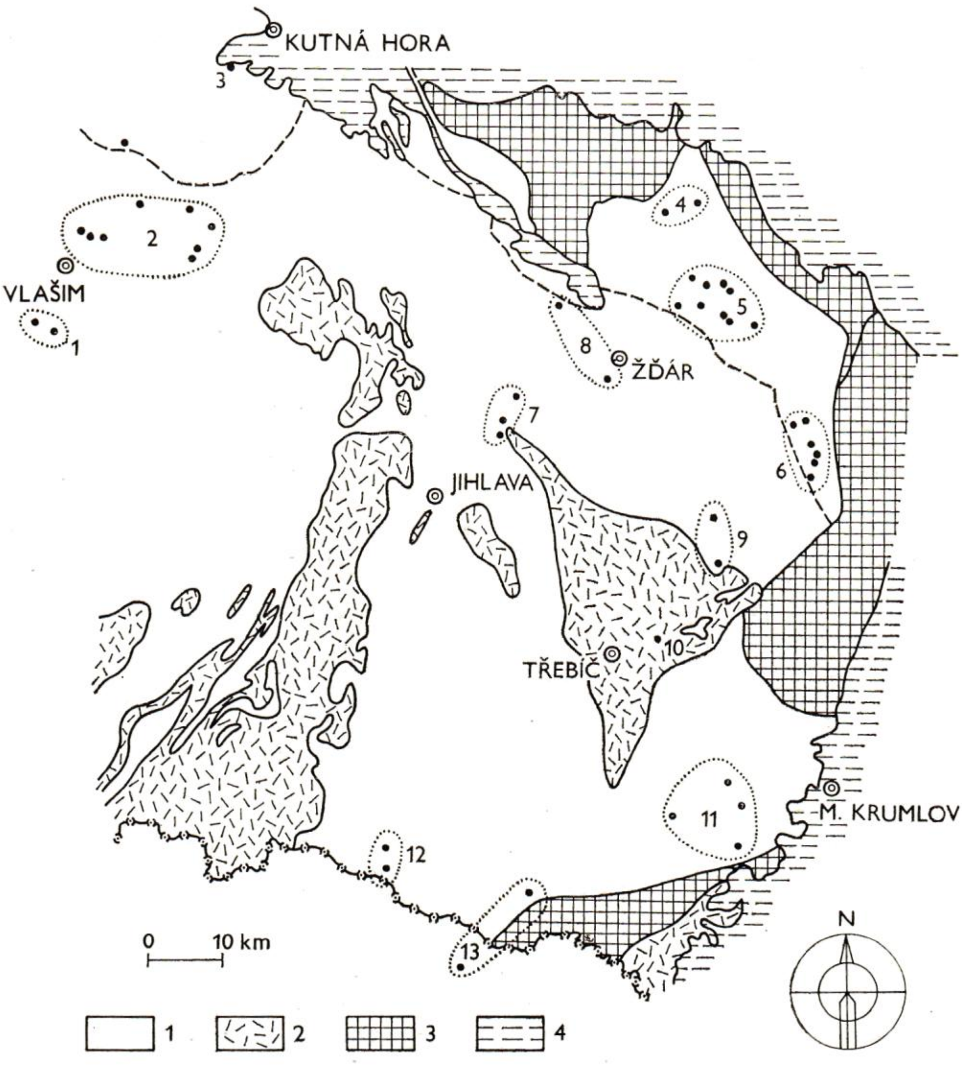



Fig. 1. Geological sketch-map of Bohemian-Moravian Heights.
Explanation of rock signs: 1 — Moldanubian crystalline schists, 2 — acid plutonic rocks, 3 — Moravikum, Polička metamorphic complex and the Železné hory Mts. system, 4 — sedimentary rocks. Skarn occurrences: 1 — Blanice furrow, 2 — Sázava area, 3 — Malešov locality, 4—6 northern, central and southern skarn areas in the Svratka metamorphic complex, 7 — Polná area, 8 — Žďár area, 9 — Velké Meziříčí area, 10 — Hostákov locality, 11 — Moravský Krumlov area, 12 — Županovice area, 13 — Kottaun area.

Obr. 1. Přehledná geologická mapa Českomoravské vrchoviny.
Výklad značek hornin: 1 — krystalické břidlice moldanubika, 2 — kyselé plutonické horniny, 3 — moravikum, poličské krystalinikum a Železné hory, 4 — sedimentární horniny. Výskyty skarnů: 1 — blanická brázda, 2 — sázavská oblast, 3 — Malešov, 4—6 oblasti výskytu skarnů v severní, střední a jižní části svrateckého krystalinika, 7 — oblast Polné, 8 — žďárská oblast, 9 — oblast V. Meziříčí, 10 — Hostákov, 11 — oblast M. Krumlova, 12 — županovická oblast, 13 — oblast u Kottaun.

skarns at Ruda (near Velké Meziříčí) and Hostákov near the Bíteš and Třebíč faults. The skarns at Polná are situated in the Přibyslavice fault zone, and the skarns of the Županovice area are at a N-S striking fault coinciding with the Dyje valley and probably associated with the prominent Přibyslav fault zone. The latter two skarn areas are interresting in that no orthogneiss complex occur in their immediate proximity. The Sněžné fault is oriented approximately W-E. Thus, it cuts the NW-SE trending geological belts at obtuse angle. Consequently, the distribution of the skarns seems to be related to the tectonic, rather than to the geological patterns of the region.

The skarns always appear in areas where marbles occur. If several marble-containing belts are present, as in the Svratka metamorphic complex, the skarns are not resctricted only to one zone, but occur in several zones. This is the same situation as recorded by Hoth and Lorenz (1966) in western Krušné hory Mountains (western Bohemia).

Sometimes the skarns seem also to be associated with zones of calc-silicates of regional metamorphism. This refers particularly to calc-silicate horizon more than 3 km long, running between Zlaté Hory and Mladá Vožice in the Blanice furrow. In it only few solitary bodies of true skarns occur.

The skarns are never associated with amphibolites. Serpentinites, in addition to marbles, have been encountered only in the Kordula skarn field (the Moravský Krumlov area).

(b) Shape and fabric of skarn bodies. The skarns form lenticular or tabular bodies inserted concordantly into paragneiss or mica schist series. They are tens or a few hundreds of meters along strike and several meters to some tens of meters thick. In the southern part of the Svratka metamorphic complex (in the surrounding of the town Nedvědice), where the skarns are especially abundant, some much smaller bodies also occur (they are not traced in Fig. 1). The biggest skarn body is that of Županovice, which is up to 250 m thick.

In the skarn bodies, core consisting of feldspar-free assemblages (pyroxene and garnet skarns), and marginal zones of various thickness and composition are usually distinguishable. The latter consist of varied feldspar hornfelses and schists, less frequently of epidosites, feldspar-free almandine-biotite schists and other rocks. The skarn bodies also contain rare paragneiss and marble intercalations, and abundant pegmatite and feldspar dykes and schlieren. The major assemblages are as follows:

(1) Calcic skarns. They are present in all skarn bodies as their main constituent, with the exception of some smaller bodies in the Sázava area which consists only of skarn hornfelses. The skarn cores are preponderantly almost monomineral pyroxene skarns and subordinately garnet and amphibole skarns. Only in the Županovice area scarce fayalite also occurs. Calcic skarns are carriers of magnetite ore.

(2) Magnesian skarns. It is a feldspar-free assemblage composed of Mg-rich minerals (mostly diopside, forsterite, phlogopite, Mg spinel). They form layers up to several m thick which never occur alone, but in small quantities accompany normal calcic skarns in the Višňové, Kordula, Slatina, Ruda at Velké Meziříčí and Budeč localities. All these localities occur in the eastern part of the Moldanubicum. Unclear is the character of a Mg-rich rock found in marginal skarn schist of the Županovice skarn (Němec 1963b). Within the skarn bodies, magnesian skarns occur only rarely (Kordula). They are confined to margins of skarn cores or to marginal skarn schists. The magnesian skarn are often selectively mineralized by magnetite up to a complete replacement.

(3) Varied feldspar-bearing hornfelses and schists (skarnoids) of skarn margins. They display massive, banded or schlieren structures, and, in areas

of migmatization, have been also migmatized. Felsic constituents are predominant. The rock consists of plagioclase, orthoclase, quartz, clinopyroxene, hornblende, biotite and various garnets, except for andradite. Magnetite is absent in them.

(4) Skarn epidosite. The rock is composed almost entirely of fine grained epidote. It forms layers up to several meters thick in some skarn bodies of the Svratka metamorphic complex (Sejřek, Věchnov, Fryšava, Líšná).

(5) Almandine-biotite schist. Along with other marginal rock types, it forms envelopes of skarn bodies embedded in mica schists (the Svratka metamorphic complex) or some micaschist-near paragneisses (Županovice, Kottaun). Their layers are up to several meters thick. They consist of almandine and subordinate biotite. Through a plagioclase admixture, they pass over continuously into biotite-garnet gneiss of the skarn mantles. Sometimes, they also contain hornblende and/or cummingtonite.

(6) Marbles. They have been found in most localities in which geological ore prospecting has been carried out intensively. They occur both in skarn cores and marginal skarn schists. Their layers are at most several meters thick. Their quantity is low, except for the hidden skarn bodies of Věchnov, were they sometimes prevail over skarns. All types are present, namely calcic marbles, dolomite marbles and calcic dolomite marbles. Their content of silicates varies considerably (Fig. 2). H o u z a r (1988) noticed that Moldanubian dolomite marbles rich in silicates are partly dedolomitized. This holds also for marbles of the skarn localities (Fig. 2).

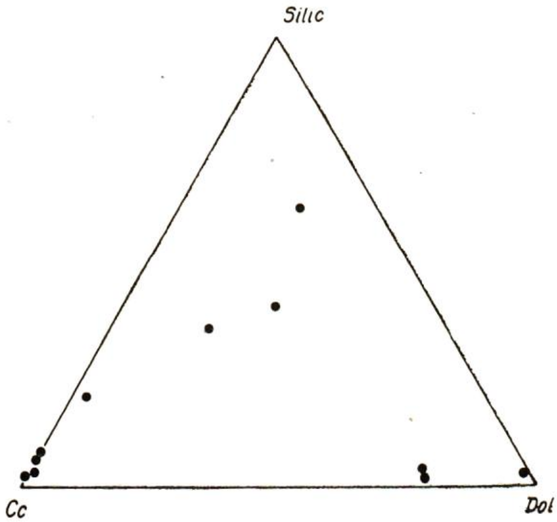



Fig. 2. Composition of marbles associated with skarns (wt. %).
Cc — calcite, Dol — dolomite, Silic — silicates.
Obr. 2. Složení mramorů sdružených se skarny (hmot. %).
Cc — kalcit, Dol — dolomit, Silic — silikáty.

(7) Pegmatites and granitoids. Skarn bodies are penetrated abundantly by dykes and schlieren of pegmatites. They are mostly several cm to several m thick. The postmetamorphic igneous pegmatites are rare. They contain muscovite, and sometimes even fluorite, axinite and schorl. Pegmatites which represent a granitic metatect set free of gneisses during their migmatization

are most frequent. They are to various degrees contaminated by skarn components and, therefore, contain abundant biotite or hastingsitic amphibole. The pegmatite/pyroxene skarn contacts are lined with narrow reaction rims composed mostly of amphibole.

Dykes of postmetamorphic granitoids, probably of Variscan age, are only rare (Županovice, Budeč; N ě m e c 1963d).

## Main minerals

(a) Calcic skarns

Pyroxene. The skarn pyroxene belongs to the diopside-hedenbergite series. Its mg number ($MgO/MgO+FeO_{tot.} \times 100$, at.) depends on mineral association and locality. Pyroxene of pyroxene skarns is usually ferrosalite and hedenbergite (mg 4—60), that of varied hornfelses salite. However, almost pure hedenbergite, known in some primary skarns (B u r t o n et al. 1982), does not occur. Hence, pyroxene of the skarns under study did not originate through the reduction of andradite.

Pyroxene associated with hornblende is always more magnesium-rich than pyroxene of almost pure pyroxene skarns (Table 1). Evidently, in amphibole-pyroxene skarns, iron prefers amphibole (P e r č u k 1970) leaving more magnesium for pyroxene.

Tab. 1. The average mg number of pyroxene in pyroxene skarns and in amphibole skarns.

Tab. 1. Průměrný kvocient mg pyroxenu z pyroxenických skarnů a z amfibolických skarnů.

| Locality<br>Lokalita | Rock<br>Hornina | Number of samples<br>Počet vzorků | Average mg<br>Průměrné mg | Author<br>Autor |
|---|---|---|---|---|
| Pernštejn | pyroxene skarn<br>pyroxenický skarn | 24 | 44 | P e r t o l d o v á (1986) |
| | amphibole skarn<br>amfibolický skarn | 7 | 61 | |
| Županovice | pyroxene skarn<br>pyroxenický skarn | 14 | 25 | P e r t o l d o v á (1986) |
| | amphibole skarn<br>amfibolický skarn | 9 | 48 | |
| Kottaun | pyroxene skarn<br>pyroxenický skarn | 128 | 21 | G ö t z i n g e r (1981) |
| | amphibole skarn<br>amfibolický skarn | 16 | 56 | |

The oxidation state of iron is variable, but $Fe^{3+}$ does not exceed 15 % of total Fe (Fig. 3). An exception is a pyroxene from hollows in the Vlastějovice skarn, in which 25 % of total Fe is trivalent (Ž á č e k 1985). This pyroxene has also high $Al_2O_3$ content (2.09 wt. %).

MnO of pyroxene shows mostly a relation to its FeO content. If FeO increases by 1 %, MnO increases approximately by 0.07 % (N ě m e c 1970a). The highest MnO contents are characteristic of the Županovice and Kottaun

Tab. 2. Average contents of some oxides in pyroxenes (wt. %).
According to Götzonger (1981), Žáček (1985) and Pertoldová (1986).
Tab. 2. Průměrné obsahy některých kysličníků v pyroxenech (hmot. %).
Podle Götzinger (1981), Žáček (1985) a Pertoldová (1986).

| Locality Lokalita | Number of samples Počet vzorků | MgO | MnO | | $Al_2O_3$ | | $Na_2O$ | |
|---|---|---|---|---|---|---|---|---|
| | | Average Průměr | Range Rozsah | Average Průměr | Range Rozsah | Average Průměr | Range Rozsah | Average Průměr |
| Županovice | 25 | 6.15 | 1.48—3.50 | 2.01 | 0.20—1.90 | 0.64 | 0.03—0.56 | 0.17 |
| Kottaun | 40 | — | — | 2.19 | — | 0.48 | — | 0.42 |
| Pernštejn | 33 | 8.83 | 0.34—1.20 | 0.76 | 0.21—2.19 | 0.89 | 0.06—1.05 | 0.41 |
| Vlastějovice | 6 | 5.77 | 0.16—1.48 | 0.53 | 0.50—2.09 | 1.27 | 0.33—0.65 | 0.45 |

Tab. 3. Chemical composition of cummingtonite, anthophyllite and fayalite (wt. %).
Tab. 3. Chemické složení cummingtonitu, antofylitu a fayalitu (hmot. %).

| Number Čís. | Mineral | Locality | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | MnO | MgO | CaO | $Na_2O$ | Author |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Cumming- | Županovice | 45.70 | 0.00 | 0.43 | — | 43.07* | 3.54 | 3.75 | 0.44 | 0.06 | Pertoldová (1986) |
| 2 | tonite | Pernštejn | 47.18 | 0.11 | 0.52 | — | 44.88* | 2.54 | 0.59 | 1.14 | 0.03 | Pertoldová |
| 3 | | | 51.24 | 0.00 | 0.78 | — | 30.31* | 2.14 | 11.71 | 0.72 | 0.10 | Pertoldová |
| 4 | | | 50.93 | 0.00 | 0.80 | — | 29.32* | 1.78 | 14.56 | 0.57 | 0.13 | Pertoldová |
| 5 | | | 51.95 | 0.04 | 1.68 | — | 27.09* | 1.19 | 14.24 | 0.70 | 0.10 | Pertoldová |
| 6 | | | 53.82 | 0.25 | 1.64 | 1.16 | 25.52 | 0.37 | 14.48 | 1.43 | — | Němec (1971) |
| 7 | | Sejřek | 50.43 | 0.02 | 0.80 | 2.08 | 33.07 | 0.69 | 9.48 | 1.88 | — | Němec |
| 8 | | | 51.23 | 0.20 | 1.02 | 0.35 | 30.45 | 1.08 | 10.82 | 2.63 | — | Němec |
| 9 | | Ruda at | 52.09 | 0.12 | 0.99 | 0.00 | 33.86 | 0.27 | 9.89 | 1.66 | — | Němec |
| 10 | | Čachnov | | | | | | | | | | |
| | | Kottaun | 51.95 | 0.03 | 0.96 | — | 25.60* | 0.09 | 16.85 | 0.58 | 0.16 | Götzinger (1981) |
| 11 | Antho- | Pernštejn | 50.88 | 0.19 | 7.16 | — | 23.58* | 0.40 | 14.04 | 0.15 | 0.60 | Pertoldová (1986) |
| 12 | phyllite | | 45.04 | 0.18 | 9.90 | — | 22.73* | 0.66 | 17.38 | 0.16 | 0.93 | Pertoldová |
| 13 | Fayalite | Županovice | 30.40 | 0.00 | 0.00 | — | 62.14* | 6.31 | 1.14 | 0.00 | 0.00 | Pertoldová |

* Total Fe as FeO. — Celkové Fe jako FeO.

localities (Fig. 1), which are also richest in Fe. There, MnO attains up to 3.5 wt. %, that is 12 % of the johannsenite component.

Nevertheless pronounced regional differences also exist (Table 5). Thus, pyroxenes of the Županovice and Vlastějovice skarns possess almost identical average FeO contents, but different MnO contents.

The $Na_2O$ and $Al_2O_3$ contents of the pyroxenes examined are variable, but low. This is usual with the skarn pyroxenes. Considerable differences, particularly in the $Al_2O_3$ contents, exist among individual localities (Table 2). In

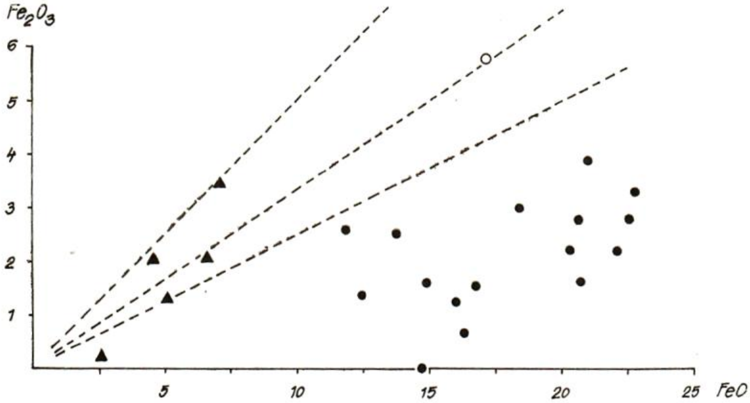



Fig. 3. FeO and $Fe_2O_3$ contents (direct determinations, wt. %) of pyroxenes of calcic skarns (dots), magnesian skarns (triangles) and of crystals in a cavity in pyroxene skarn, Vlastějovice (open circle).
Obr. 3. Obsah FeO a $Fe_2O_3$ (přímá stanovení, hmot. %) pyroxenu skarnů Ca (plné kroužky), skarnů Mg (trojúhelníky) a krystalů z dutin pyroxenického skarnu, Vlastějovice (prázdné kroužky).

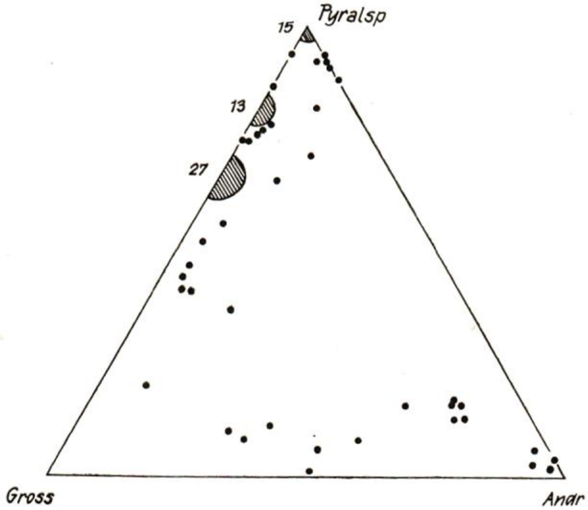



Fig. 4. Compositional distribution of garnets, plotted in terms of grossularite (Gross), andradite (Andr), and pyralspite (Pyralsp). Figures give numbers of points in shaded areas.
Obr. 4. Složení granátů, vyjádřené složkou grosularovou (Gross), andraditovou (Andr) a pyralspitovou (Pyralsp). Čísla udávají počty bodů ve vyšrafovaných plochách.

the Županovice skarn, pyroxene associated with amphibole, an Al-bearing mineral, is also rich in $Al_2O_3$ (range 0.7—1.2 wt. %; average 0.83), whereas pyroxene of amphibole-free assemblages is lower in $Al_2O_3$ (range 0.2—0.6 wt. %; average 0.34).

Garnet. An overview on the chemistry of garnets is given by Fig. 4. The points cluster there in two separate branches, the grossularite-andradite one and the grossularite-pyralspite one. The former is identical to garnets of primary skarns. These garnets occur in the cores of the skarn bodies, forming monomineral aggregates or they are disseminated in the pyroxene skarn. Grossularite-rich garnets are absent; however, this is also common in primary skarns (Einaudi and Burt 1982). On the other hand, almost pure andradite does occur; it is especially pure in the Kottaun (Götzinger 1981).

The other garnet trend corresponds to grossularite-almandine, with almandine mostly prevailing over grossularite. This garnet appears in most garnet-pyroxene skarns and in all amphibole-rich skarn types. Pyralspite is a garnet of marginal garnet-biotite schists and associated rock types.

The proportion of spessartine is very low in grossularite-andradite and almandine (Fig. 5), but increases in grossularite-pyralspite, where it attains a maximum of 25 %. However, similar to pyroxene, the MnO content of garnets is determined primarily by local factors. Skarns rich in Mn (Županovice, Kottaun) also have spessartine-rich grossularite-pyralspites.

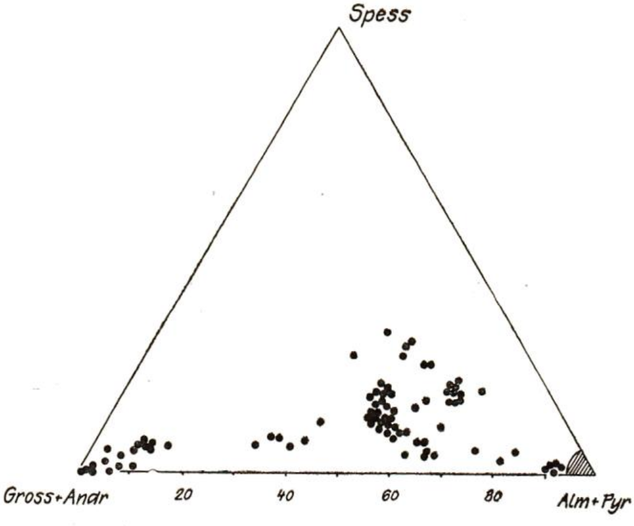



Fig. 5. Compositional distribution of garnets, plotted in terms of grossularite + andradite (Gross, Andr), almandine + pyrope (Alm, Pyr), and spessartine (Spess).
Obr. 5. Složení granátů, vyjádřené složkami grosular + andradit (Gross, Andr), almandin + pyrop (Alm, Pyr) a spessartin (Spess).

The pyrope component in grossularite-pyralspite is low (at most 8 %). In almandine of the almandine-biotite schists, it increases up to 20 %, the content common in garnets of the wall-rock garnet-biotite gneisses. A maximum of 26 % has been found (Pertoldová 1986) in a garnet of an anthophyllite-garnet schist (the Pernštejn skarn), an assemblage especially rich in magnesium.

Almandine and grossularite-almandine are minerals typical of regional metamorphism. A formation of the latter requires, in addition to a suitable host rock composition, also PT conditions at least of the almandine-amphibolite facies (N ě m e c 1967). In primary skarns only grossularite-spessartine can originate.

Calcium-aluminium amphiboles. This type predominates in skarns and marginal rocks. It is sparsely scattered in pyroxene skarns, but subordinately also forms major constituent of rocks. In L e a k e's (1978) classification schema, various names could be given to individual amphibole samples. However, they are essentially of one type. Namely, as Fig. 6 shows, they cluster in one series streching between hornblende, and ferropargasite or hastingsite (P e r t o l d o v á 1986, who determinated only total Fe and computed $Fe^{3+}$ from crystal formulae, underestimated the $Fe^{3+}$ contents; direct $Fe^{3+}$ determinations gave essentially higher values — N ě m e c 1970c).

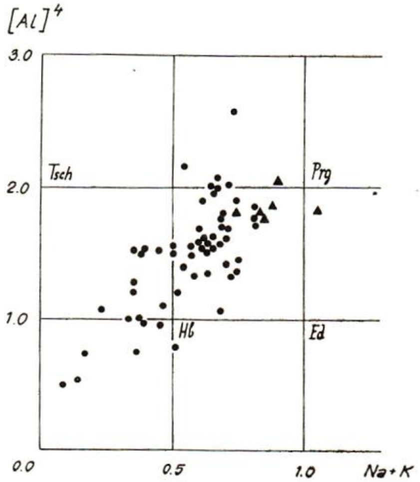



Fig. 6. Compositional distribution of amphiboles, number of atoms p. f. u. Tsch — tschermakite, Prg — pargasite, Hb — hornblende, Ed — edenite, triangles — pegmatite amphiboles.
Obr. 6. Složení amfibolů, počet atomů ve formulové jednotce. Tsch — tschermakit, Prg — pargasit, Hb — obecný amfibol, Ed — edenit, trojúhelníky — amfiboly z pegmatitů.

Fig. 7 displays the following data: mg number of almost all amphiboles does not exceed 50, even not in Mg-rich assemblages; evidently, amphibole is a concentrator of iron. Amphiboles highest in iron are from magnetite-containing pyroxene skarns and contaminated skarn pegmatites. Alumina contents of amphiboles vary according to parageneses, increasing in the rock sequence: garnet-pyroxene skarns, garnet-amphibole skarns, marginal skarn assemblages (varied hornfelses, almandine-biotite schists, almandine-amphibole schists). It is clear that amphiboles reflect the alumina level of the host rocks.

Fig. 8 shows comparison of the contents of alkalis in amphiboles from skarns at Pernštejn and Županovice and from skarn pegmatites of various localities. In the given sequence, the sum of alkalies and especially the $K_2O$ contents increase. The Na a K contents found in the amphiboles of the Pernštejn locality are typical for Ca-Al amphiboles, but in the other two groups, the $K_2O$ contents are above-average. What refers to pegmatite amphiboles, hosted by postassium-rich rocks, it is no surprise. However, explication

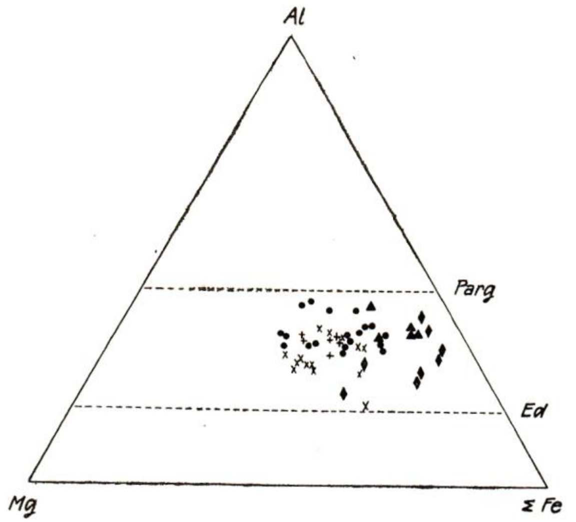



Fig. 7. Compositional distribution of amphiboles, plotted in terms of Mg, Σ Fe, and Al (at. %). Assemblages: garnet-amphibole skarns (crosses), garnet-pyroxene skarns (Andrew crosses), pyroxene Ca skarns and magnetite-bearing garnet-pyroxene skarns (diamonds), rocks of skarn margins: varied hornfelses, almandine-biotite and amphibole-biotite schists (dots), contaminated pegmatites (triangles).

Obr. 7. Složení amfibolů, vyjádřené jejich obsahy Mg, Σ Fe a Al (at. %). Asociace: granáticko-amfibolické skarny (křížky), granáticko-pyroxenické skarny (šikmé křížky), pyroxenické skarny Ca a granáticko-pyroxenické skarny s magnetitem (kosodélníky), horniny skarnových okrajů: pestré rohovce, almandinicko-biotitické a amfibolicko-biotitické břidlice (body), kontaminované pegmatity (trojúhelníky).

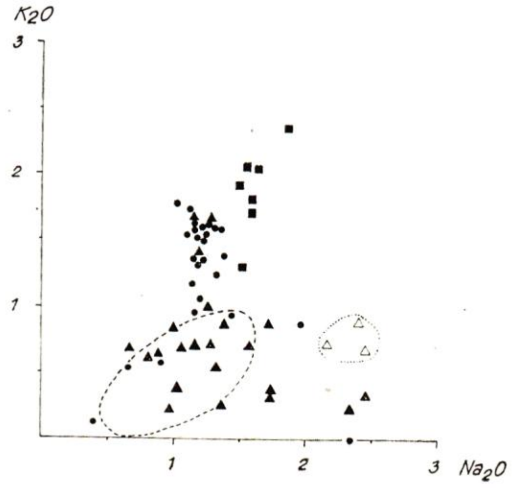



Fig. 8. $Na_2O$ and $K_2O$ contents (wt. %) of amphiboles.
Solid triangles — Pernštejn locality, dots — Županovice locality, quadrangles — skarn pegmatites, open triangles — primary skarn, Ginevro (Elba). Field of usual alkali contents in amphiboles of various genesis is enclosed by broken line.

Obr. 8. Obsahy $Na_2O$ a $K_2O$ (hmot. %) amfibolů.
Plné trojúhelníky — lokalita Pernštejn, body — lokalita Županovice, čtverce — pegmatity ve skarnech, prázdné trojúhelníky — primární skarn, Ginevro (Elba). Pole obvyklých obsahů alkalií v amfibolech různé geneze je vyznačeno čárkovanou linií.

must be searched for skarn amphiboles. The skarn amphiboles originated during an invasion of the skarns by a granitic gneiss metatect set free during migmatization of wallrock gneisses (N ě m e c 1968a). Possibly alkalis in skarn amphiboles reflect the character of the metatect.

Cummingtonite and anthophyllite. Cummingtonite is rare in the skarns. Primary cummingtonite appears only in the hornblende + almandine assemblage accompanying marginal almandine-biotite schists in some skarns of the Svratka metamorphic complex and the Kottaun area. Both areas represent intermediate metamorphic zones of the almandine-amphibolite facies. In the Moldanubicum, in the Županovice and Bělčovice skarns, cummingtonite developed by the breakdown of fayalite and by the alteration of hornblende.

The primary cummingtonite of the skarn margins is usually Mg-rich (Table 3). It often shows the beginning of alteration to hornblende due to a Al and Ca addition. In the Pernštejn skarn, a Fe-rich cummingtonite (grunerite) almost free from MgO has also been found (Table 3). Its assemblage is extraordinarily Fe-rich and Mg-poor (only 1.00 wt. % MgO in hornblende, 0.54 wt. % MgO in almandine). Grunerite could originale through reaction: magnetite + quartz = grunerite. The magnetite + quartz assemblage is common in the skarns of the Svratka metamorphic complex.

In the Županovice and Bělčovice skarns, a Fe-rich cummingtonite originated through the breakdown of fayalite, which is essentially an olivine hydration. Superfluous iron exsolved as magnetite dust. In these localities, cummingtonite sometimes developed also through alteration of hornblende, along its contacts with fayalite or magnetite, obviously due to a diffusional addition of iron.

Anthophyllite has been found only in the Pernštejn and Smrček skarns. In the first locality, the host-rock is a half meter thick layer in the marginal skarn zone, consisting of quartz with minor anthophyllite and almandine. The same assemblage, with additional gahnite, occurs also in the second locality (N o v o t n ý 1968). The anthophyllite of the Pernštejn skarn is MgO- and especially $Al_2O_3$-richer than cummingtonite (Fig. 12, Table 3). Chemically, it lies in the anthophyllite-gedrite boundary. Both cummingtonite and anthophyllite originated in the Pernštejn skarn under identical PT conditions. The reason of appearance of cummingtonite in one rock and anthophyllite in the other, evidently is a distinct CaO content of their host-rocks. Cummingtonite, which contains some CaO, is confined to rocks relatively rich in CaO: hornblende is abundant in them and cummingtonite only balances a partial CaO deficit of the rock. On the other hand, anthophyllite is almost CaO-free. Its host-rock, even though chemically similar to the preceeding one, is extremely low in CaO.

In contrast to cummingtonite, very low in $Al_2O_3$, anthophyllite has an $Al_2O_3$ content comparable to that of hornblende. From this point of view, anthophyllite substitutes in fact in the pertinent rock for hornblende (compare also Fig. 12). This view is also supported by transitions from anthophyllite schist into a hornblende schist.

Biotite. Biotite is almost entirely absent in the skarn cores, but is abundant in marginal skarn rocks, in particular in almandine biotite schists. It is preponderantly siderophyllite-eastonite. For details, see N ě m e c (1969). Transitions from wallrock gneiss to marginal skarn rocks are marked in its chemistry, especially in its $TiO_2$ content. In the Županovice locality, its average $TiO_2$ contents are (wt. %): 3.1 (gneiss), 2.4 (contact gneiss), 1.5 (almandine-biotite schist). The import of Ca (which binds Al), Fe and Mg from the skarn cores causes basification of marginal rocks. Thus, the chemical composition of biotite changes, in the rock sequence given above, from eastonite-si-

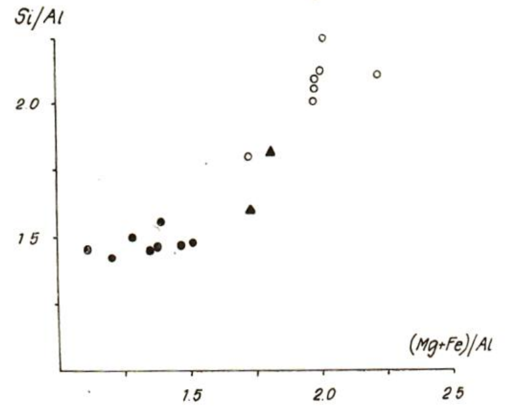



Fig. 9. Si/Al and (Mg+Fe)/Al ratios of biotites, Županovice locality.
Assemblages: garnet-biotite gneiss (dots), the same, at the skarn contact (open circles), garnet-biotite schists (triangles).
Obr. 9. Poměr Si/Al a (Mg+Fe)/Al biotitu, Županovice.
Asociace: granáticko-biotitická rula (body), totéž, na kontaktu se skarnem (prázdné kroužky), granáticko-biotitická břidlice (trojúhelníky).

derophyllite to phlogopite-annite, according to the $Al_2O_3 \rightarrow (Fe, Mg)O + SiO_2$ substitution (Fig. 9). Concomitantly the alkalinity, defined as the (N+K)/Al ratio, increases in biotite.

Plagioclase. Plagioclase is a typical mineral of marginal skarn schists and gneisses. Skarn cores are feldspar-free. Its Ca content dependes on the environment. In the Županovice skarn, oligoclase occurs in mantle gneiss, labradorite in contact gneiss and bytownite in a garnet-hornblende skarn. Varied hornfelses of the skarn margins are hybride rocks. Hence, composition of their plagioclase is variable. It is mostly andesine and bytownite-anorthite. The former is associated with almandine-rich garnets, the latter with grossularite-rich garnets. For details, see Němec (1975b).

Epidote. Epidote appears in skarn epidosites and in posterior veinlets. The range of $Al/Fe^{3+}$ substitution in it is 25—34 %. This is almost the maximum iron saturation possible. For analyses, see Němec (1975b).

(b) Magnesian skarns

Pyroxene of the magnesian skarns in diopside or Mg-rich salite (mg 66—92). Its $Fe^{3+}$ amounts mostly to 20—30 % of total Fe and is significantly higher than that of the calcic skarn pyroxene (Fig. 3). Mica of the magnesian skarns is phlogopite with mg mostly 82—91 (Němec 1969). In rocks transitional from magnesian skarn to gneiss, mg of micas decreases to 75. $Al_2O_3$ varies considerably in phlogopite, perhaps due to the presence or absence of spinel in the rock. The amphibole type proper to magnesian skarns is tremolite, found especially in the Slatina skarn. However, hornblenditic amphibole, originated probably under an input from calcic skarns, is more frequent. Olivine, probably forsterite, is colourless or yellowish in thin sections. Spinel has not been examined chemically. It is dark green under a microscope and, therefore, probably rich in the hercynite component.

(c) Marbles

Minerals of marbles have been examined in the localities of Kottaun (Götzinger 1981), Pernštejn (Pertoldová 1986) and Kuklík (Novák

1988). In the first two localities, marble forms small bodies directly in the skarn, and at Kuklík, it forms a thick layer at the skarn contact. In the Kottaun skarn, carbonate is an almost pure (96 %) calcite with a rhodonite admixture; other minerals of the rock correspond to those of a normal skarn. Carbonate of the Kuklík skarn is dolomite. For the chemical analyses of the silicates of the Kuklík and Pernštejn localities, see Table 4. All the silicates are magnesian endmembers of the pertinent series. They correspond to minerals of marbles not associated with skarns (Novák 1988).

Tab. 4. Minerals of carbonate rocks associated with skarns (wt. %).
Tab. 4. Minerály karbonátových hornin sdružených se skarny (hmot. %).

| Locality Lokalita | Pernštejn | Pernštejn | Kuklík | Kuklík | Kuklík |
|---|---|---|---|---|---|
| Author Autor | Pertoldová (1986) | Pertoldová (1986) | Novák (1988) | Novák (1988) | Novák (1988) |
| Mineral | Diopside | Tremolite | Tremolite | Forsterite | Phlogopite |
| $SiO_2$ | 53.77 | 57.55 | 57.40 | 40.14 | 41.24 |
| $TiO_2$ | 0.02 | 0.00 | 0.06 | 0.01 | 0.84 |
| $Al_2O_3$ | 2.09 | 1.19 | 0.65 | — | 14.83 |
| $FeO_{tot.}$ | 1.83 | 1.82 | 0.40 | 1.24 | 0.49 |
| MnO | 0.05 | 0.07 | 0.00 | 0.04 | 0.00 |
| MgO | 17.32 | 24.05 | 26.18 | 57.34 | 29.01 |
| CaO | 24.98 | 12.20 | 13.06 | 0.00 | 0.05 |
| $Na_2O$ | 0.26 | 0.06 | 0.07 | — | 0.22 |
| $K_2O$ | 0.00 | 0.06 | 0.07 | — | 8.87 |
| F | — | — | — | — | 0.65 |
| $H_2O^+$ | — | — | — | — | 4.04 |
| Total Součet | 100.32 | 97.00 | 97.99 | 98.77 | 100.24 |
| O = 2F | | | | | 0.27 |
| Corrected total — Korigovaný součet | | | | | 99.97 |

## Chemical equilibrium

Partition coefficients. The skarns under study show polyphase development. Detailed examinations of mineral grains by electrone microprobe, even in mineralogically homogeneous assemblages, have revealed heterogenities not only among individual grains, but even within individual grains (Götzinger 1981). Notwithstanding, the distribution of elements between coexisting minerals points approximately to chemical equilibrium, as demonstrated for the pyroxene/hornblende and cummingtonite/hornblende pairs (Figs. 10, 11). The distributions observed approach those given in the literature (Perčuk 1970) for the minerals. Fig. 11 shows that in one sample, in addition to hornblende equilibrated with cummingtonite, two further nonequlibrated hornblendes, perhaps of another origin, occur. A mineral, usually not equilibrated with skarn silicates, is magnetite. It replaces them often drasticcally (see below).

Number of mineral phases. The number of mineral phases of skarns complies with the phase rule. This can be demonstrated in mica- and feldspar-free marginal assemblages of the Pernštejn skarn. Si and Al are always their main chemical components. Na, K and sometimes Ca or even Mg may be excluded

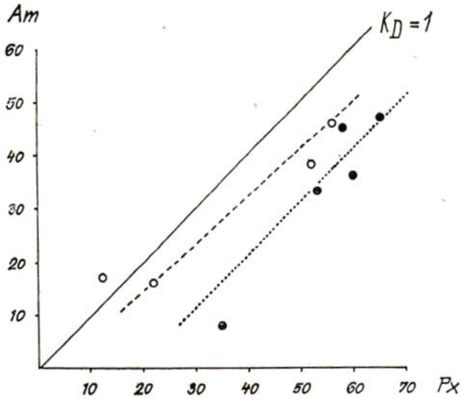



Fig. 10. Distribution of Fe and Mg between pyroxene and amphibole in pyroxene skarn. Px — mg number of pyroxene, Am — mg number of amphibole. Dots — Pernštejn skarn, open circles — Županovice skarn.
Obr. 10. Distribuce Fe a Mg mezi pyroxen a amfibol v pyroxenických skarnech.
Px — mg pyroxenu, Am — mg amfibolu. Body — skarn u Pernštejna, prázdné kroužky — skarn u Županovic.

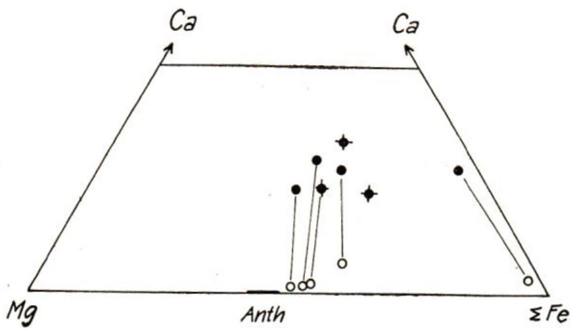



Fig. 11. Compositional distribution of coexisting hornblendes and cummingtonite, in terms of Mg, Σ Fe, and Ca.
Dots with asterisk — hornblendes derived from one and the same sample. Anth — range of anthophyllite composition. Pernštejn and Sejřek skarns.
Obr. 11. Distribuce Mg, Σ Fe a Ca mezi koexistující amfibol a cummingtonit.
Kroužky s čárkami — amfibol pocházející z téhož vzorku. Anth — rozsah složení antofylitu. Skarny u Pernštejna a Sejřku.

as independent components due to their very low contents. Si is always very abundant. Thus, it is a superfluous component which sometimes makes quartz appear as an additional phase, independent from all the others. The following relations can be stated: In the quartz + garnet assemblage, Ca and Mg are very low and form a solid solution in almandine. All $R^{2+}$ together act as one component. In the pertinent rock, only one phase, in addition to quartz, is present. In the ACF diagram (Fig. 12), the point of the rock is close to the almandine site. — The quartz + garnet + anthophyllite and the quartz + garnet + cummingtonite assemblages are characterized by very low Ca, but Mg is too hight to be fully accomodated in garnet. Hence, Mg behaves as an independent component. Compared with the preceeding assemblage, a further mineral appears. In Fig. 12, the points of these rocks lie on the almandine —

anthophyllite (cummingtonite) join. — The quartz + garnet + cunmmingtonite + hornblende assemblage is characterized by high Mg and Ca. They both act as independent component; hence, a further mineral, compared with the preceeding assemblage, is present. In Fig. 12, the point lies within the triangle.

In such a way, unstable assemblages can also be detected. Thus, in one rock sample having the quartz + garnet + cummingtonite assemblage, Mg is

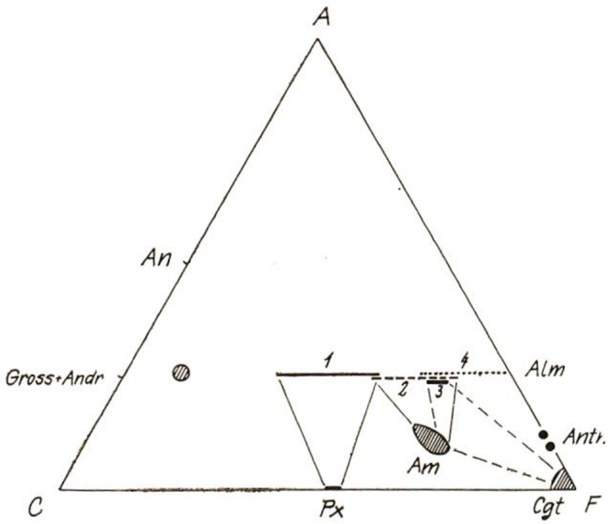



Fig. 12. ACF diagram of skarn assemblages, Pernštejn.
Gross-Andr — grossularite-andradite, Px — pyroxene, Cgt — cummingtonite. Am — hornblende, Anth — anthophyllite. Garnets coexisting with pyroxene (1), hornblende (2), cummingtonite (3), and garnets of amphibole- and pyroxene-free assemblages (4). Data from P e r t o l d o v á (1986).

Obr. 12. Diagram ACF skarnových asociací, Pernštejn.
Gross-Andr — grosular-andradit, Px — pyroxen, Cgt — cummingtonit, Am — ob. amfibol, Anth — antofylit. Granáty koexistující s pyroxenem (1), ob. amfibolem (2), cummingtonitem (3) a granáty asociací bez amfibolu a pyroxenu (4). Data převzata od P e r t o l d o v é (1986).

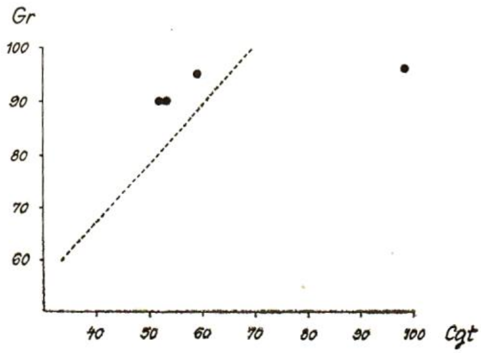



Fig. 13. Mg and Fe distribution between cummingtonite and garnet, Pernštejn skarn. Iron number Fe/Fe+Mg × 100. Broken line — equilibrium distribution, according to M a r a k u š e v (1966). Data from P e r t o l d o v á (1986).

Obr. 13. Distribuce Mg a Fe mezi cummingtonit a granát, skarn u Pernštejna.
Kvocient Fe — Fe/Fe+Mg × 100. Čárkovaná linie — rovnovážná distribuce podle M a r a k u š e v a (1966). Data převzata od P e r t o l d o v é (1986).

extraordinarily low to be an independent component. If the assemblage is equilibrated, the number of phases ought to be lower by one. Evidently, this indicates chemical disequilibrium, as is also documented by Fig. 13. There, the iron number (Fe/FeO+MgO × 100, at.) of cummingtonite and coexisting almandine of the skarns are plotted. While the points of all other samples lie near the equilibrium line given by M a r a k u š e v (1966), the point of the rock discussed is far from it.

### R e g i o n a l m e t a m o r p h i s m

The skarns are premetamorphic unit and have been already regionally metamorphosed. This is conspicuous particularly in signs of their tectonical deformation and their mineralogy.

(1) Tectonism. Tectonism is evidenced especially in wallrock gneisses and varied marginal skarn hornfelses by their detailed plastic folding. In contrast to them, the skarns behaved as competent bodies and the paragneiss inclusions in them retained their monoschematical structure and straight foliation planes. Skarns yielded to stress only by fracturing and their fragments have been sometimes transported as eliptic boudins through marbles or gneisses. Banding in the skarn boudins and foliation of the enclosing gneisses are parallel, but sometimes include obtuse angles (N ě m e c 1979). Ore exploration has shown that whole skarn bodies represent, in fact, large-scale boudins enclosed plastically by their mantle gneisses.

Fissures in skarns served as paths for granitic metatect penetrating into the skarns from wallrock gneisses, which gave rise to contaminated pegmatites, and veinlets of amphibole and grossularite-almandine in pyroxene skarns.

(2) Mineralogy. In the skarns, only minerals stable under PT conditions of regional metamorphism are present. Thus, they contain abundantly hornblende which is absent in the primary skarns, except for very few occurrences (for instance, Ginevro in the Elba; D i m a n c h e 1970). Similarly, almandine and grossularite-almandine do not occur in the primary skarns, but are abundant in regionally metamorphosed rocks. Almandine appears sometimes as veinlets even directly in pyroxene skarn (Županovice). Grossularite-almandine

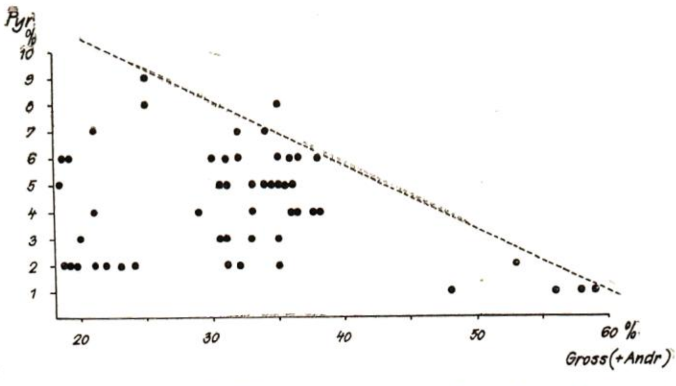



Fig. 14. Content of pyrope (mol. %) in grossularite-almandine, Županovice and Pernštejn skarns.
Data from Pertoldová (1986).
Obr. 14. Obsah pyropové složky (mol. %) v grosular-almandinu, skarny u Županovic a Pernštejna.
Data převzata od P e r t o l d o v é (1986).

is of special importance for the paragenesis. In skarn cores characterized by iron-rich minerals, its presence precludes the appearance of the pyroxene + plagioclase assemblage, typical for primary skarns (in Fig. 12, the pyroxene-plagioclase joint cuts the garnet line; hence, the reaction Pyrox + Plag = Gross-Alm takes place). Under PT of almandine-amphibolite facies, grossularite-almandine can accomodate only little pyrope (its share depends on the grossularite and andradite content of the garnet; Fig. 14). Thus, in marginal rocks of skarn bodies, where Mg content of pyroxene increases, the pyroxene + plagioclase assemblage is often preserved (for instance, in the Budeč skarn).

Possible consequences of regional metamorphism of the skarns are also the general occurrence of pyrrhotite (pyrite is only a scarce posterior fissure mineral) and the absence of hydrothermal alterations around impregnations of the sulphide ore.

In the skarns of the Bohemian-Moravian Heights, some minerals typical of primary skarns, but unstable under PT of regional metamorphism, are absent. It refers especially to vesuvianite and ilvaite (for conditions of their development, see Hochella et al. 1982 and Gustafson 1974). If they occasionally appear in the skarns, they are product either of retrograde metamorphism (ilvaite in fissures of the Županovice skarn; Němec 1964b) or of interaction of postmetamorphic igneous magmas with the skarns. Such is the origin of vesuvianite lining contacts of pegmatite dykes in the Líšná skarn, and of vesuvianite in pyroxene skarn at Hostákov (the skarn body is a part of a paragneiss block included in the granosyenite massif of Třebíč; Houzar and Němec (1985).

(3) The type of minerals present in skarns agrees with the metamorphic grade of the area. Thus, the skarns of the Svratka metamorphic complex, which has been metamorphosed in the medium zones of the almandine-amphibolite facies, contain abundantly epidosites and sparse primary haematite and cummingtonite. In the skarns of the Moldanubicum which has been metamorphosed mostly to the highest zone of the almandine-amphibolite facies, the named assemblage and minerals are absent. Only in the Županovice area, which, even though it also belongs to the Moldanubicum, has been metamorphosed to a somewhat lower zone of this facies, do epidosites and cummingtonite rarely occur.

(4) Chemical changes during metamorphism. Regional metamorphism has been connected with migmatization of gneisses enclosing the skarn bodies, in the course of which some elements became mobile. The composition of the skarn minerals formed in this period shows that water, fluorine and components of feldspars (Na, K, Al) have been introduced into the skarns. The mobility of alumina must be especially emphasized, because it behaves inertly during processes of primary skarnization. Of skarn components, iron also became partly mobile, whereas Mg remained inert. This is inferred from veinlets penetrating the skarns, which are formed of iron-rich minerals such as hornblende, almandine, grossularite-almandine, and fayalite. Probably also in this period the marginal feldspar schists have been partly converted into almandine-biotite schists through an iron intrusion from the skarn cores (see below).

(5) Three phases of regional metamorphism can be recognized in the skarns. The first two have taken place under PT of the almandine-amphibolite and cordierite-amphibolite facies. The older one is characterized by low $P_{H_2O}$, as documented by the stability of the pyroxene-almandine assemblage. The younger phase has been associated with migmatization of the skarn mantles

and has been characterized by high $P_{H_2O}$. In this stage, almandine grains inbedded in pyroxene skarn reacted with pyroxene, and hornblende coronas developed around them. A two-stage progressive metamorphism has been also documented in West-Moravian granulites (partial migmatization of granulites; Dudek et al. 1974), in metabasites (amphibolization of margins of serpentinite bodies; Kudělásková et al. 1961) and in marbles (Novák 1988).

The most recent phase of regional metamorphism represents its concluding stage (Cháb and Suk 1977) and is very restricted. It is characterized by local actinolithization, epidotization, prehnitization, calcification and the origin of fissure fillings (epidote, prehnite, calcite, quartz, pyrite). Its PT corresponds to the greenschist facies.

(6) Temperature of the progressive metamorphism, deduced on the basis of minerals and mineral assemblages, has been estimated at 600—700 °C by the author (Němec 1979), at 620 °C for the Kottaun locality by Götzinger (1981) and at 650—700 °C for the Županovice and Pernštejn localities by Pertoldová (1986). Gneiss migmatites of the two latter localities formed, according to Pertoldová, at a lower temperature (about 600 °C). This also agrees with the two-stage progressive metamorphism observed in the skarns. Pertoldová (1986) found practically identical temperatures of gneiss migmatization in both localities. She concluded that the temperature of metamorphism of the Svratka complex was identical to that of the Moldanubicum. However, such a generalization is not allowed, because the surroundings of Županovice have been metamorphosed to a somewhat lower grade than the other Moravian Moldanubicum. Gneisses of this area contain disthene, and skarn contain almandine-biotite schists, epidosites and cummingtonite.

## Geochemistry

The skarns of the Bohemian-Moravian Heights can be classified as iron skarns. Cu and Zn ores are present in them only in subordinate quantities. Iron ores are represented by magnetite and confined exclusively to the skarn cores. The remark of Pertold (in Bernard and Pouba 1986) that magnetite layers are interbedded in gneiss mantling the Županovice skarn is not corroborated neither by field observations or any data in the literature. Haematite appears very rarely, only in skarns of the Svratka metamorphic complex, but not in the Moldanubicum. (Haematite described from magnetite ores of the skarn at Ruda near Velké Meziříčí — Koutek and Čech 1974 — developed probably through an extraordinarily intensive superfacial weathering, characteristic for the locality). Iron contents of skarn silicates vary according to individual areas and localities (Table 5).

All skarn have high Co content which prevails over Ni (Fig. 15) and sometimes gave rise to cobaltine (Svratouch, Budeč, Rešice). Bi in small amounts occurs uniformly throughout the skarns (Table 5). Only in the Skarn of Svratouch does its quantity increase up to hundredths % (Němec 1975a). In contrast to Zn and Sn, which are preponderantly camouflaged in skarn silicates, Bi cannot substitute into them and forms separate Bi minerals (bismuthinite, native bismuth). Gold is typical trace element of the skarns in the north of the Svratka metamorphic complex. All skarns have enhanced In contens, which, for instance, in the Županovice skarn vary between 1 and 35 ppm.

Mo and W are elements depleted in the skarns of the Bohemian-Moravian Heights. Their average Mo content is only 0.24 ppm (Němec 1977). Molybdenite has been found only in some skarns of the central and northern parts of the Svratka complex (Svratouch, Kuklík). The W content of the skarns is mostly below 1 ppm. However, W is an element typical of the more recent Variscan acid plutonic rocks. In all places where scheelite has been found in the skarns, relations to Variscan igneous rocks are obvious. Thus, in the skarn of Vepřová, scheelite occurs in a skarn penetrated by pegmatite dykes, and in the skarn at Hostákov, W derives from the granosyenite of Třebíč, which

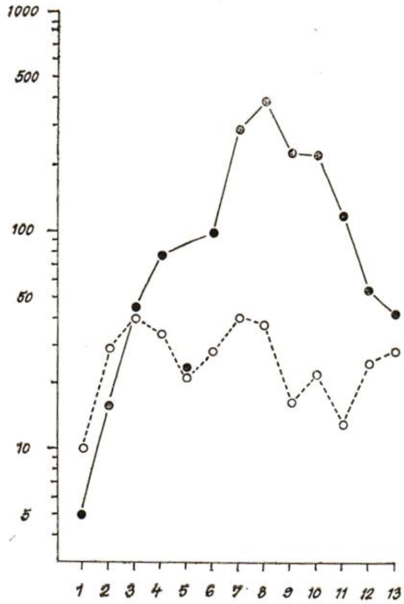



Fig. 15. Ni and Co contents (ppm), section across the Pernštejn skarn.
Ni — circles, Co — dots. 1 — gneiss, 2 — mica schist, 3 — garnet-biotite gneiss at skarn contact, 4 — garnet-biotite schist, 5—13 — skarn assemblages. Data from Pertoldová (1986).

Obr. 15. Obsahy Ni a Co (ppm), řez skarnem u Pernštejna.
Ni — kroužky, Co — body, 1 — rula, 2 — svor, 3 — granáticko-biotitická rula v kontaktu se skarnem, 4 — granáticko-biotitická břidlice, 5 až 13 — skarnové asociace. Data převzata od Pertoldové (1986).

Tab. 5. The average contents of some elements in magnetite-free pyroxene skarns.
Tab. 5. Průměrný obsah některých prvků v pyroxenických skarnech prostých magnetitu.

| Area Oblast | Moravský Krumlov | Žďár | Županovice | The Svratka metamorphic complex Svratecké krystalinikum | Přísečnice (the Krušné hory Mts., western Bohemia) |
|---|---|---|---|---|---|
| Fe (wt. %) | 8.8 | 13.1 | 18.3 | 17.3 | 14.7 |
| Mn (wt. %) | 0.17 | 0.40 | 1.6 | 0.83 | 0.48 |
| Zn (ppm) | 130 | n. d. | 370 | 760 | n. d. |
| Sn (ppm) | 57 | 310 | 39 | 17 | n. d. |
| Bi (ppm) | 2.4 | n. d. | 3.4 | 2.5* | n. d. |

* The skarn of Svratouch is excluded.
Skarn u Svratouchu není zahrnut.

n. d. = not determined
nestanoveno

includes the skarn-containing paragneiss block; the granosyenite crystallized from a magma especially rich in W (H o u z a r and N ě m e c 1985).

Flurine is relatively high in the skarns. In pyroxene skarns, its content does not exceed 0.20 wt. %, but in phlogopite, it attains 5.2 wt. %, and in hornblende 1.4 wt. %. Fluorine in the skarns is partly premetamorphic (for instance, the quartz-fluorite pods in the Županovice skarn), partly imported along with migmatitic metatect (N ě m e c 1968b) and pegmatites, which often contain abundant fluorite (Vlastějovice, Líšná, Věcov, Županovice).

The Mn content of the skarns is relatively low, but varies in individual areas (Table 5). The skarns of the Županovice area and even more the skarn of Kottaun are highest in Mn. The Fe/Mn coherence, usual in primary skarns, is conspicuous also in the Bohemian-Moravian Heights. For details, see N ě m e c (1970a).

Zn contents of skarns differ in individual areas (Table 5). This is valid also for the Svratka metamorphic complex. There, the average Zn content of pyroxene skarns is 150, 430 and 1260 ppm in its northern, central and southern parts, respectively. An Fe/Zn coherence, wellknown in primary skarns (B u r t 1972, E i n a u d i and B u r t 1982), is also observable, but is looser than the Fe/Mn coherence. In skarns containing high Zn in silicates, sphalerite occurs abundantly (in particular, Županovice and Smrček). Sphalerite is alway associated with pyroxene skarns, which are easily sulphidized, as demonstrated experimentally (Gamble 1982, Serdobinceva et al. 1986). In gneisses and quartz-rich marginal skarn schists of the Županovice and Smrček skarns, gahnite instead of sphalerite has originated (N ě m e c 1973a).

Sn is also variable in the skarns (Table 5). Especially high is the Sn content in the skarns of the Žďár area; there, up to 0.185 wt. % Sn has been found in a hornblende sample (the Budeč locality; N ě m e c 1972). Cassiterite has not been detected there. However, it is wellknown from primary skarns (E i n a u d i et al. 1981) that Sn substitutes into skarn silicates during skarnization processes, and only after their alteration is set free as cassiterite. Hastingsitic amphiboles of primary Sn skarn contain up to 0.8 wt. % Sn (K w a k 1983, 1987).

Minerals of sulphide phases are mostly rare in the skarns, but significant for their regional distinction. The skarns of the Sázava and Moravský Krumlov areas (Fig. 1) are very poor in sulphides (only scarce pyrrhotite and pyrite present). In the skarns of the Županovice area and those in the south of the Svratka metamorphic complex, abundant pyrrhotite, sphalerite and chalcopyrite, and scarce galena and arsenopyrite occur. For the Budeč skarn, abundant pyrrhotite and chalcopyrite are typical, sphalerite and arsenopyrite are very rare there. The skarns in the north of the Svratka comples (Ruda at Čachnov, Svratouch) are characterized by relatively frequent arsenopyrite, and very scarce chalcopyrite and sphalerite; galena is entirely absent. The Svratouch skarn is also unique in its richess in cobaltine, relatively abundant Bi minerals and the presence of molybdenite and native gold. For details, see N ě m e c (1965).

## S k a r n s a n d m a r b l e s

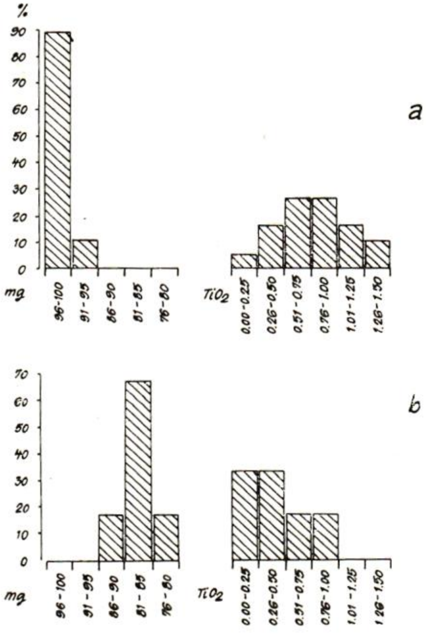
Skarns and marbles are associated in terrain and posses many similarities, as will be shown below. The West-Moravian marbles have been characteribed recently by N o v á k (1987, 1988) and H o u z a r (1988).

(1) Geological setting and shape of bodies. The marble bodies are inbedded in biotite and biotite-sillimanite paragneisses and only exceptionally

also in light coloured Gföhl gneiss. Their bodies are lenticular, which is explained by their extraordinarily high plasticity (D u d e k 1962). During folding, they were compressed and pushed into multiple folds. Their thickness varies between several dm and 50 m, except for the Vratěnín (Drosendorf) series in the south, where the marble layers are much thicker. However, no skarns occur there. — By geological setting, and shapes and dimensions of their bodies, the skarns correspond to marbles.

(2) Rock types and minerals. Dolomitic marbles prevail considerably in eastern part of the Moravian Moldanubicum, whereas calcic marbles largely predominate in the Svratka metamorphic complex (N o v á k 1988). The latter are usually pure, but dolomitic marbles are rich in silicates (diopside, olivine, phlogopite, tremolite), which sometimes form layers or schlieren in them. The mg number of the silicates is as follows: phlogopite 95—100, amphibole (tremolite, rarely pargasite) 93—99, forsterite 96—99, spinel 92—97.

Also the calcic skarns are richer in magnesia in eastern Moldanubicum than in the Svratka metamorphic complex (Table 5; Mg can be estimated according to the Fe figures). The magnesian skarns seem to correspond to the silicate layers of the dolomitic marbles. Except for magnetite, they consist of



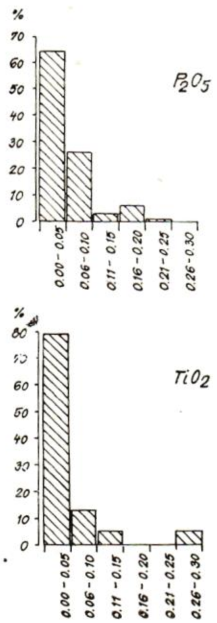




Fig. 16. Distribution of $TiO_2$ (wt. %) and of mg numbers in phlogopite of marbles (a — 19 samples; data of N o v á k 1988) and of Mg skarns (b — 6 samples).

Obr. 16. Distribuce $TiO_2$ (hmot. %) a kvocientů mg ve flogopitu z mramorů (a — 19 vzorků; data převzata od N o v á k a 1988) a ve skarnech Mg (b — 6 vzorků).

Fig. 17. $P_2O_5$ and $TiO_2$ (wt. %) distribution in 68 marble samples of the West-Moravian Moldanubicum and of the Svratka metamorphic complex.
Data from N o v á k (1987).

Obr. 17. Distribuce $P_2O_5$ a $TiO_2$ (váh. %) v 68 vzorcích mramorů ze západomoravského moldanubika a ze svrateckého krystalinika.
Data převzata od N o v á k a (1987).

the same minerals having only a slightly different compositions (compare Fig. 16). Spinel of the magnesian skarns seems to be considerably richer in iron, but it is there always associated with magnetite.

(5) Minor and trace elements. Elements behaving inertly during skarnization processes, as P and Ti, vary in the skarns and marbles within the same ranges (compare Fig. 17 with corresponding diagrams in N ě m e c 1968c, 1970b). Zn is a typical element introduced into marbles by ore fluids during their skarnization. In the marbles, its content is mostly constant not exceeding 150 ppm (Fig. 18). In the skarns, it varies very considerably, attaing sometimes high values. Only in the skarn of the Moravský Krumlov area, does Zn display the same level as in the marbles; otherwise, it is essentially higher (Table 5; compare N ě m e c 1973b).

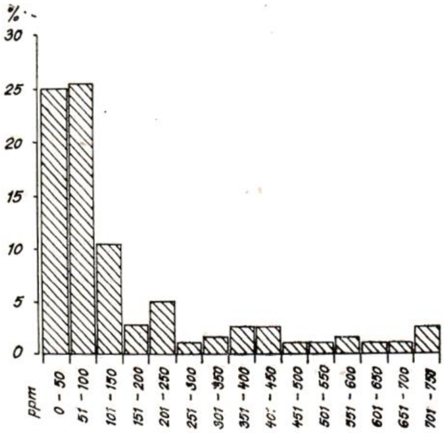



Fig. 18. Zn distribution (ppm) in 61 marble samples of the West-Moravian Moldanubicum and of the Svratka metamorphic complex.
Data from N o v á k (1987).
Obr. 18. Distribuce Zn (váh. %) v 61 vzorcích mramoru ze západomoravského moldanubika a ze svrateckého krystalinika.
Data převzata od N o v á k a (1987).

## P r e m e t a m o r p h i c g e n e s i s

Original genesis of the skarns is obscured by their regional metamorphism. Opinions on their genesis published up to the year 1985 have been discussed by the author (N ě m e c 1979, 1988). Recently, P e r t o l d a n d S u k (1986) considered them to be decarbonized ankerites, and P e r t o l d o v á (1986) and P e r t o l d o v á et al. (1987) as submarine-exhalative iron ores. Nevertheless, most features of the skarns favour the idea of their development through a high-temperature replacement of mostly carbonate rocks by magmatogeneous fluids and solution. The reasons for it are given in the following paragraph along with a discussion of other hypotheses.

(1) General remarks. Examination of metamorphosed sedimentary iron ores (K l e i n 1973) as well as primary skarns overprinted by regional metamorphism (N e w b e r r y et al. 1986) have shown that original structures and minerals are retained in relicts up to a high grade of metamorphism. The oldest silicates of primary skarns originate at 400—650 °C (B u r t 1977, E i n a u d i et al. 1981), the skarns of the Bohemian-Moravian Heights have been regionally

metamorphosed at 600—700 °C. Hence some relict assemblage could survive in them.

If we subtract minerals of regional metamorphism from the skarn assemblages, diopside-hedenbergite and grossularite-andradite, minerals typical of primary skarns, remain. Futhermore rock textures and structures always show that these minerals are older than the minerals of the regional metamorphism. However, the question of wollastonite remains open. High $P_{CO_2}$ usually prevents its crystallization in regionally metamorphosed rocks. In fact, it is missing in the skarns under study (it has been found only exceptionally in quartz-calcite pods in the Županovice skarn; there, it probably developed either during retrograde metamorphism or during the transition to the metamorphism of the Abukuma type — compare abundant cordierite in the wallrock gneisses). However, wollastonite is a characteristic mineral of many primary skarn and its relicts could be expected also in the skarns under study, naturaly if it was originally present in them. Namely, wollastonite is absent, for instance, in low--temperature skarns of the pyroxene-garnet facies (Žarikov 1968).

Among Algonkian sedimentary rocks of the Barrandien region, which, for time reasons, could be considered as the sedimentary equivalent of Moldanubian paraseries, no rocks chemically comparable to skarns are present. Hence, Pertold and Suk (1986) consider the ankerite layer occuring there as premetamorphic material of the skarns. It is a known fact (Klein 1973) that ankerite can be preserved under sufficient $P_{CO_2}$ even up to the sillimanite zone. However, relict marbles in the skarn bodies are of another type.

(2) Relations to magmatism. Primary skarns are usually closely associated with igneous massifs. So were they also in the Bohemian-Moravian Heights. In associated orthogneisses, premetamorphic greisens are sometimes pre-

Tab. 6. The average compositions of orthogneisses associated with skarns.
Tab. 6. Průměrné složení ortorul sdružených se skarny.

| Locality Lokalita | Sázava area | Zlaté Hory | Budeč | Pernštejn |
|---|---|---|---|---|
| Number of analyses Počet analýz | 9 | 5 | 1 | 4 |
| $SiO_2$ | 76.27 | 75.56 | 74.53 | 73.80 |
| $TiO_2$ | 0.13 | 0.11 | 0.13 | 0.20 |
| $Al_2O_3$ | 12.75 | 12.87 | 12.34 | 13.30 |
| $Fe_2O_3$ | 0.25 | 0.29 | 0.42 | 1.02 |
| FeO | 0.78 | 1.06 | 1.53 | 1.28 |
| MnO | 0.02 | 0.03 | 0.05 | 0.04 |
| MgO | 0.16 | 0.23 | 0.63 | 0.40 |
| CaO | 0.83 | 0.73 | 1.47 | 0.85 |
| $Na_2O$ | 2.78 | 2.83 | 2.64 | 2.97 |
| $K_2O$ | 4.79 | 4.74 | 3.81 | 4.77 |
| $P_2O_5$ | 0.29 | 0.22 | 0.16 | 0.31 |
| F | 0.24 | 0.12 | n. d. | n. d. |
| $H_2O^+$ | 0.61 | 0.70 | 0.96 | 0.60 |
| $H_2O^-$ | 0.14 | 0.12 | 0.10 | 0.28 |
| Total Součet | 100.04 | 99.58 | 99.24* | 99.82 |

* 0.47 % $CO_2$ in the sum — v součtu   n. d. = not determined — nestanoveno

sent if the regional metamorphism permitted preservation of muscovite. The greisens are especially abundant at orthogneiss/skarn contacts (N ě m e c 1988). The same is frequently found in primary skarns (B u r t 1977, E i n a u d i et al. 1981). At the same time the skarns of the Bohemian-Moravian Heights display a relation to the deep faults and deformation zones. Only the skarns of the Županovice and Polná areas, which also lie on significant faults, are at considerable distance from orthogneiss massifs. But even in some primary skarns, especially in those of the Zn type, a similar situation exists (distal skarns; E i n a u d i et al. 1981).

Table 6 gives the compositions of orthogneisses associated with the skarns. P e r t o l d o v á (1986) is right in pointing to their too acid character. Primary skarns, particularly those of the iron type, usually are associated with more basic granitoids (E i n a u d i et al. 1981). Regional metamorphism can cause chemical changes in rocks (M e h n e r t 1968), but it is difficult to estimate them. It can be noted here that, for instance, in the western Krušné hory Mountains (western Bohemia) comparable primary skarns are also associated with acid granites (H o t h and L o r e n z 1966, L o r e n z and H o t h 1967, S c h ü t z e l 1970).

(3) Features of metasomatism and of stage development. Metasomatical zonation and stage development are characteristic of primary skarns. The skarns under study always have a pronounced core/marginal rock zonation with sharp contacts not only petrographically, but also chemically and geochemically. Also small-scale zonation is present. Thus, the hidden bodies at Věchnov show a marble — magnetite — skarn — mica schist zonation (N ě m e c 1963a). However, a similar zonation is not as frequent as expected.

Some rocks of skarn margins display a chemical composition unusual for sedimentary rocks. Some rocks have high MgO associated with extremely low CaO and alkalis. Several marginal types are even lower in alkalis than the pyroxene skarn. Similar compositions suggest a special origin, perhaps by leaching or metasomatism.

The autonomy of distribution of magnetite ore in the skarn bodies, stressed already by K o u t e k (1950), is striking. Magnetite is always resctricted to skarn cores, but distributed irregularly without any relation to the shape of skarn bodies or the fabric and layering of the enclosing schists. The chemical composition of the host rocks is mostly independent from the presence of magnetite and its quantity. For examples, see N ě m e c (1963c, 1964a). It is most striking in magnesian skarns, which are, in spite of their extreme Mg abundance, selectively mineralized by magnetite up to ther entire replacement. This clearly demonstrates a stage development so typical for primary skarnization. Selectivity of the Mg skarns for ore deposition seems to be due to their iron deficiency, making them chemically unstable in relation to iron-bearing fluids and solutions.

The relations given above bear witness of the only limited reaction ability of minerals during regional metamorphism. The same is also suggested by the magnetite + quartz assemblage, often encountered in the skarns in the south of the Svratka metamorphic complex, which only exceptionally reacted to cummingtonite, in spite of the presence of hydroxyle-bearing minerals in the association. All these facts contrast with theories explaining origin of the skarns by regional metamorphism of heterogeneous mixed lithologies, because a very high reactivity must be supposed.

Subtracting minerals of regional metamorphism from skarn assemblages, one- or two-phase associations remain, a number usual in metasomatic units.

It contrasts with polyphase calc-silicate hornfelses (erlans) of regional metamorphism frequent in the region under consideration.

(4) Index minerals. These minerals can originate only under PT specific for a paragenesis and are, therefore, typical of it. So the high-temperature metasomatic origin of the skarns is indicated by andradite and pseudomorphs after ilvaite. Andradite, which is common in the skarns, originates in metamorphic rocks almost exclusively under conditions of contact metamorphism (N ě m e c 1979, 1988). In regionally metamorphosed rocks, it originates only under extraordinarily high $P_{O_2}$ (S i v a p r a k a s h 1983, N e w b e r r y et al. 1986; in regionally metamorphosed sedimentary iron ores of Northern Michigan — H a a s e 1982 — it occurs only in vicinity of metabasite sills and probably is of a contact metamorphic type). However, the environment during regional metamorphism of the Bohemian-Moravian Heights has been preponderantly strongly reductive as evidenced by the $Fe^{3+}/Fe^{2+}$ rations of skarn minerals (hornblende, almandine, micas) developed in this period.

In the skarn of Kottaun, G ö t z i n g e r (1981) has stated pyroxene-magnetite myrmekites, whose bulk chemistry corresponds to ilvaite. Probably they are pseudomorphs after it. The upper stability limit of ilvaite is 430 °C (G u s t a f s o n 1974), so that is cannot survive regional metamorphism. Ilvaite is a hydrothermal mineral occurring practically only in contact metamorphic iron skarns. In the skarns of the Bohemian-Moravian Heights, it has been found only exceptionally at Županovice, as a fissure mineral of retrograde metamorphism (N ě m e c 1964b).

There are also index minerals characteristic of high grade regional metamorphism of sedimentary iron ores such as orthopyroxene and aegirine (K l e i n 1973). These minerals are absent in the skarns under study.

(5) Nature of replaced rocks. As shown above similarities exist between marbles and skarns suggesting that skarn cores could be skarnized marbles. Due to their rigidity, the skarn bodies could hardly have achieved their lenticular shapes through tectonism; more probably the marbles were folded before their skarnization. The entire or the almost entire replacement of marble bodies by skarns, observed in most localicites, could have been due to the small dimensions of the marble bodies.

E i n a u d i and B u r t (1982) noticed that skarns-after-carbonates usually inherit the chemistry of the carbonates replaced. Possibly it is the reason why, of the calcic skarns, those relatively high in Mg occur in eastern Moldanubicum, where dolomite marbles almost exclusively appear. The magnesian skarn, which accompany the calcic skarn only at these localities, correspond, except for magnetite, to the layers and schlieren of Mg silicates in dolomites, and perhaps are their altered pre-skarnization relicts.

On the other hand, even relatively Mg-rich calcic skarns partly show independence from their carbonate substratum, obvious, for instance, by presence of grossularite-andradite patches and bands in them. This could be best explained, if intrusion of some ore-bearing fluids is assumed.

The pyroxene and grossularite-andradite assemblages probably are skarns-after-carbonates (in primary skarns, andradite skarn always represents exoskarn), whereas varied hornfelses and schists are partly skarnized aluminosilicates (endoskarns). This is suggested by their chemistry. By content of elements behaving inertly during a high temperature metasomatism (P, Ti), the pyroxene skarns correspond to marbles, and varied hornfelses to paragneisses enclosing the skarn bodies (N ě m e c 1968c, 1970b). The composition of oxygen isotopes of the skarns corresponds also to that of relict marbles and, at the same time, differs from that of metamorphosed sediments of the skarn mantles (P e r t o l d o v á et al. 1987).

P e r t o l d o v á (1986) considers the Sr contents of the Pernštejn skarn to be too low for skarn-after-marbles. The Sr contents of the skarns vary considerably, but occassionally attain high values — 50 ppm in pyrogene skarn, 450 ppm in hornblende skarn. The Sr contents of the marbles of the region are relatively low amounting mostly to 50—300 ppm (N o v á k 1987). Ba, another element typical of carbonates, attains considerable contents in some skarn minerals (up to 1.5 wt. % BaO in micas of the Županovice skarn).

The REE distribution, examined in the Pernštejn skarn by P e r t o l d o v á et al. (1987), is also genetically important. The REE of pyroxene skarns differ clearly by their level and distribution from those of the mica schists enclosing the skarn body, whereas those of marginal skarn rocks are intermediate between them (Fig. 19). The mica schist is relatively low in REE and simultaneously somewhat enriched in LREE in relation to HREE (in the area, monazite

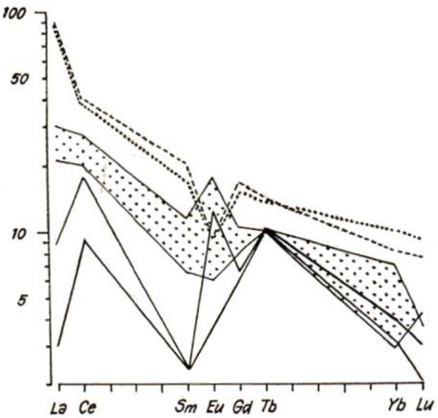



Fig. 19. Chondrite normalized REE distribution in pyroxene skarns (solid lines), mica schist (broken line), garnet-biotite schist (dotted line) and marginal skarn assemblages (dotted field). Pernštejn skarn.
Data from P e r t o l d o v á et al. (1987).
Obr. 19. Distribuce vzácných zemin normovaná na chondrit v pyroxenických skarnech (plné čáry), ve svoru (čárkovaná čára), v granáticko-biotitické břidlici (tečkovaná linie) a v okrajových skarnových asociacích (tečkované pole). Skarn u Pernštejna.
Data převzata od P e r t o l d o v é et al. (1987).

is very frequent in the schists). Its typical negative Eu anomaly testifies to an exhausted crustal salic material. By its REE distribution, the rock corresponds exactly to that of an average graywacke (Fig. 20; H e n d e r s o n 1984). The almandine-biotite schist of the skarn margins which consists only of almandine and biotite, exhibits the same REE pattern in spite of its high Fe content (16.1 wt. % FeO). Probably both developed from the same substratum, but the almandine-biotite schist has been additionally enriched by ferrides imported from the skarn core, as evidence by Fig. 15. Whereas Ni prevails over Co in paraseries, the ratio reverses in favour of Co in skarns, as is usual in iron ores. The same Co prevalence is shown also by the almandine-biotite schist.

The pyroxene skarns, which consist almost entirely of pyroxene, are characterized by REE poverty, as evidenced by comparison with a clinopyroxene of plutonic rocks (Fig. 20). REE in the pyroxene skarns closely approach their distribution in an average limestone (Henderson 1984). Only the La content is different, probably because La cannot substitute into clinopyroxene.

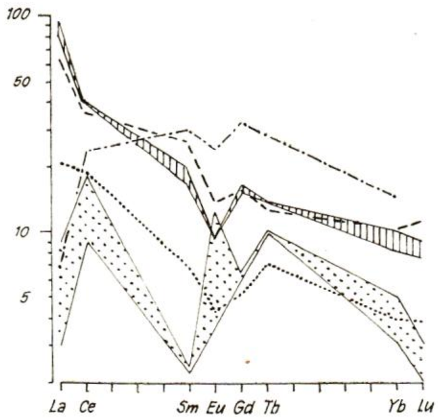



Fig. 20. Chondrite normalized REE distribution in pyroxene skarns (dotted field), and in mica schist and garnet-biotite schist (hashured field); Pernštejn skarn.
Dotted line — average limestone, broken line — average graywacke, dot-and-dashed line — clinopyroxene of the basic Skaergaard intrusion.

Obr. 20. Distribuce vzácných zemin normovaná na chondrit v pyroxenických skarnech (tečkované pole) a ve svoru a granáticko-biotitické břidlici (šrafované pole); skarn u Pernštejna.
Tečkovaná linie — průměrný vápenec, čárkovaná linie — průměrná droba, čerchovaná linie — klinopyroxen z basické intruse u Skaergaardu.

Another difference refers to Eu, which shows a positive anomaly in some samples. Pertoldová et al. (1987) take it as evidence of an exhalative-sedimentary origin of the skarns. However, this criterion is equivocal. In fact, some exhalative sulphide and oxidic iron ores exhibit positive Eu anomalies, if they are accompanied by some volcanic rocks (Graf 1977, 1978), but some limestones also have positive Eu anomalies (Klein and Beukes 1989). Furthermore, Flyn and Burnham (1978) have shown experimentally that Eu present in silicate melts accumulates in Cl-bearing fluids, can be transported by them and precipitates eventually in reductive environments along with ferous minerals. Evidently, more data are needed here.

Of elements, presumably introduced during skarnization processes, indium is especially important. In the skarns, it is bonded in silicates, particularly in hornblende. It is an element typical of skarns (Voland 1969) being sometimes present in them in enhanced quantities (Ivanov and Licinov 1960).

Due to its specific sulphide assemblage, the skarn of Svratouch corresponds to the Co-Bi-Au skarn type, the skarns in the south of the Svratka metamorphic complex approache the Zn-Pb type and those of the Žďár area to the Sn type. Pertoldová (1986), who has noted increased Fe, Mn, Zn, Sn and W contents in the Pernštejn skarn, holds this association as typical of submarine-exhalative deposits. However, these elements are characteristic for primary skarns as well, where they are often accumulated in minable amounts (E i n a u d i and B u r t 1982, K w a k 1987, S m i r n o v 1976). P e r t o l d o v á (1986) reports as much as 110 ppm W in the skarns. Such high values are perhaps due to the skarn type examined by her, which is mostly rich in magnetite. In barren pyroxene skarns, I have stated much lower values (N ě m e c 1977).

(6) Hypothesis of submarine-exhalative or sedimentary origin. G ö t z i n g e r (1981) and P e r t o l d o v á et al. (1987) who recently advocated this hypothesis, unfortunately give no ideas on the original rock setting, minerals, metamorphic processes and reactions involved. All this shall be briefly considered in the following. These deposits usually form extended layers interbedded with pelitic sediments and connected by continuous transitions with them. This was not observed in the skarns examined. No metabasites occur there which could correlate with volcanic greenstones often accompanying Precambrian exhalative or sedimentary ores. The hypothesis is not able to explain the development of large homogeneous masses of monotonous pyroxene skarn up to many tens of meters thick. No sedimentary mineral can directly give rise to them by metamorphism; thus, reaction among the various minerals must be supposed (K l e i n 1973). However, as shown above, reactivity during the last stages of progressive metamorphism was low, having been mostly limited to the domains affected by the input of granitic gneiss metatect. The older stages of progressive metamorphism took place under a somewhat higher temperature, but in a fluid-poor environment, so that reactivity hardly could be much greater. The development of large skarn masses seems to require a much stronger impulse than that caused by regional metamorphism. Volcanogenic exhalative ores do occur in the Moldanubicum (for instance, N ě m e c and P á š a, in print), but they have another geological setting.

(7) Conclusion to genesis. Until now, the genesis of the skarns of the Bohemian-Moravian Heights cannot be assessed with certainty. Their geological, petrographical and geochemical features mostly support the idea that they were already originally ordinary primary skarns developed under a magmatogenic supply. An hypothesis involving regional metamorphism of some submarine-exhalative or sedimentary ores meets with difficulties especially as to the geology. No great emphasis can be laid on the bulk chemical composition of the skarns, because both primary skarns and exhalative-sedimentary ores probably have identical ore sources and, therefore, may be chemically similar.

## SOUHRN

Skarny Českomoravské vrchoviny byly regionálně metamorfovány za abysálních podmínek v zóně migmatizace. Můžeme v nich rozlišit minerály a asociace regionální metamorfózy (almandin, grosular-almandin, obecný amfibol) od minerálů a asociací reliktních (pyroxeny řady diopsid-hedenbergit, granáty řady grosular-andradit, epidot, magnetit, mramory). Minerály skarnů jsou charakterizovány pomocí chemických analýz. Je sledována chemická rovnováha asociací pomocí distribučních koeficientů prvků a fázového pravidla. Následující znaky skarnů jsou závažné při zjišťování jejich předmetamorfní geneze: Nápadné geologické a částečně petrografické podobnosti s tělesy mramorů oblasti. Prostorové vztahy skarnů k masívům a komplexům ortorul; pokud to dovoluje metamorfní stupeň oblasti, obsahují ortoruly reliktní greiseny. Ve skarnových tělesech zjišťujeme relikty metasomatické zonárnosti a etapovitosti původního skarnizačního procesu. Přítomnost minerálů nebo pseudomorfóz po nich, které mohou vznikat jen v podmínkách vysokoteplotní metasomatózy. Přítomnost geochemických

znaků, podle nichž je možno rozlišit původní exoskarny od endoskarnů. — Tyto znaky nasvědčují tomu, že již původně šlo o obvyklé primární skarny, vzniklé vysokoteplotní metasomatózou převážně karbonátových hornin způsobenou magmatogeními fluidy a roztoky.

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