# A discussion of geochemistry of regionally metamorphosed skarns of the Krušné hory Mountains, Czech Republic, and implications for their genesis

## Diskuse geochemie regionálně metamorfovaných skarnů Krušných hor, Česká republika, a závěry pro jejich genezi (Czech summary)

*(12 text-figs.)*

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Skarns of the Přísečnice area in the Krušné hory Mountains were affected by a regional metamorphism corresponding to central zones of the almandine amphibolite facies. Hence, their premetamorphic origin is unclear. Geochemical investigations have shown that the skarn chemistry can be best explainned by an original high-temperature metasomatism of contact metamorphic type of appropriate rocks (limestones, to lesser extent schists), caused by fluids derived from an igneous source. Precambrian banded iron ores which were considered by Kotková (1991) to be a premetamorphic protolith of the skarns display another geochemical signature. The skarns of the Přísečnice area exhibit significant positive Eu anomalies. However, these anomalies do not represent a specific feature of volcano-sedimentary iron ores, as they also occur in skarns of contact metasomatic type. In both cases they are derived from ascending ore-bearing fluids and hydrothermal solutions from which Eu coprecipitated with Fe.

*Key words:* skarns, regional metamorphism, genesis, the Krušné hory Mts., Bohemia

## Introduction

The pre-metamorphic genesis of skarns affected by regional metamorphism is often unclear, since many of their original features were obliterated. Assuming isochemical character of regional metamorphism, one of possible ways of constraining skarn genesis is investigation of their geochemistry. For the regionally metamorphosed skarns of the Přísečnice area (central part of the Krušné hory Mountains) this was done by Kotková (1991), who concluded that the skarns represent metamorphosed volcano-sedimentary layers which also contained banded iron ores. She published a great number of whole-rock major and minor element analyses. However, she utilized them only partly. Therefore, this article is intended to make their evaluation more complete. Besides, chemical determinations performed by the Geoindustria Laboratory, Prague, which are listed by Šrein (1992), were also used. Unfortunately, most of the REE data are difficult to use as determinations of Ce are evidently wrong. It is well known (cf. Šrein 1992) that all Precambrian basic rocks of the Přísečnice area, including the skarns, behaved due to their topomineral influence as traps for the younger Variscan pneumatolythic and hydrothermal input which was not linked up with the original skarn-forming processes. Thus, there is a possibility that much of Cu, Pb, Zn, Sn, Sb, Ag, U and Th present in the skarns were not associated with the skarn-forming processes and, therefore, will be excluded from our considerations. Furthermore, the abundances given for Bi are evidently wrong due to application of an analytical technique inappropriate for determination of very small contents. It should be also noted that the $Fe_2O_3$ abundances presented in Table 3 of Kotková (1991) are, in fact, total iron as $Fe_2O_3$. Analytical techniques used for chemical determinations are given in the paper cited. A total of 35 rock samples are characterized by Kotková (1991). For this discussion, only samples having simple mineralogy were selected (Table 1).

The skarns form several large lenticular bodies located in three horizons which are characterized by occurrences of scarce marbles. The whole complex is part of the Přísečnice Group which presumably is of Proterozoic or even Lower-Paleozoic age as far as lithology is concerned. The skarn bodies are located in neighbourhood of a large orthogneiss massif and hosted by mica schists and two-mica gneisses. The skarn bodies consist of cores dominated by pyroxene and andradite rocks which often carry magnetite ore, and marginal types composed of amphibole rocks, almandine-biotite schists, and gneisses and hornfelses enriched in Ca. The latter two rock types are designated as marginal skarn schists. For details, see Zemánek (1959), Chrt and Neumann (1968), Lorenz and Hoth (1967), Němec (1979), Kotková (1991), and Šrein (1992).

## Minerals and mineral assemblages

The skarn assemblages, mostly monomineral or bimineral, are characterized in this paragraph. The skarn bodies of the Přísečnice area were metamorphosed, together with the whole region, to the medium zones of almandine amphibolite facies (at about 600 °C - Kotková 1991), probably during the Cadomian orogeny. Hence, it is intended to distinguish metamorphic assemblages which developed only during regional metamorphism from those typical of high-temperature metasomatic skarnization which, however, could be preserved during regional metamorphism, if the pT conditions did not surpass those prevalent during skarnization.

Clinopyroxene. It belongs to the diopside-hedenbergite series. Its composition varies within a wide range of 11-83 % hedenbergite. Pure hedenbergite is absent. The $Al_2O_3$ content is low (some tenths of a per cent). It is relatively MnO-poor (1.6 wt % at maximum) which is a characteristic feature of the skarns of the Přísečnice area. Trace element contents are low compared with clinopyroxenes of igneous rocks (Moxham 1960). The REE patterns are usual for this mineral except for a significant positive Eu anomaly (Fig. 1).

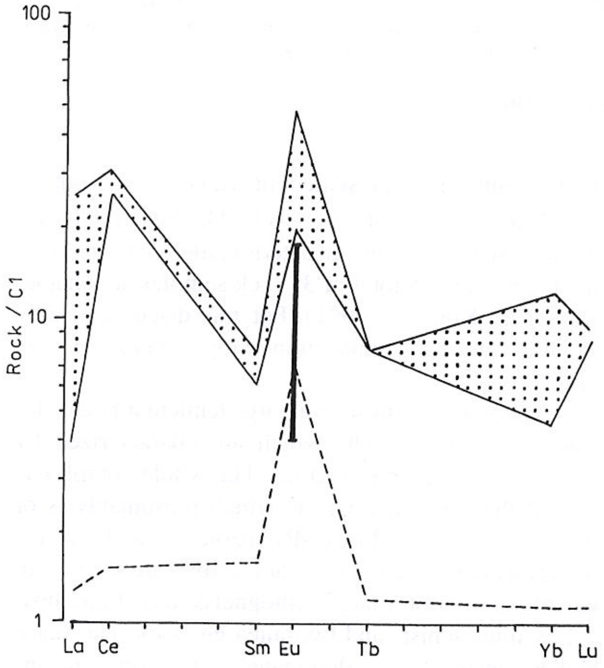

Fig. 1. Chondrite-normalized REE abundances in three amphibole skarn rocks (*dotted field*) and in pyroxene skarn (*dashed line*). The Přísečnice area. The Tb contents of the amphibole rocks lay below the detection limit. Hence, the detection limit was conventionally used for the Tb content in the Fig. Heavy line gives range of Eu concentrations in pyroxene rocks. Data from J. Kotková (1991) and V. Šrein (1992)

The geochemical signature of pyroxene skarns (Table 1) is determined by the chemistry of pyroxene. Only their $Al_2O_3$ contents are enhanced indicating an admixture of other minerals. Neither mode of occurrence nor the geochemical signature of pyroxene provide features enabling determination of the skarns origin.

Garnet. Garnets of both grossular-andradite and grossular-almandine series occur in the skarns (Němec 1967a, Kotková 1991). They appear separately. Grossular-andradite occurs in the skarn cores. Members close to andradite largely prevail, as is usual in iron skarns (Einaudi - Burt 1982). Almost pure andradite with only 0.15-0.21 wt % $Al_2O_3$ and 0.21-0.24 wt % MnO was identified at Vykmanov (Šrein 1992). Andradite is poor in trace elements including the REE (Table 1, Fig. 2), but its Eu content is very high. According to Klein (1983) andradite is absent in Precambrian banded iron ores metamorphosed up to the sillimanite zone. The Přísečnice Group is generally assumed to be of Precambrian age (Lorenz 1979). Consequently andradite skarns cannot represent metamorphosed banded iron formation.

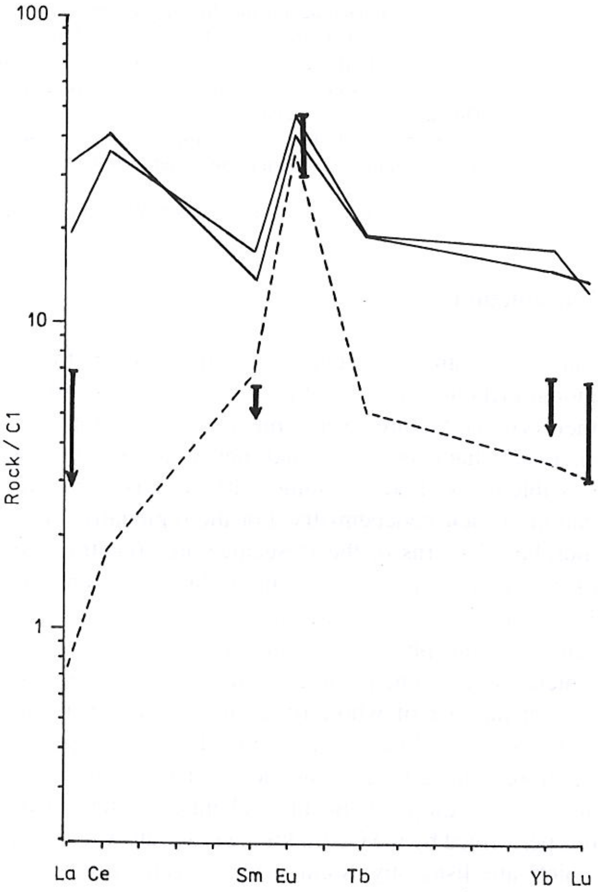

Fig. 2. Chondrite-normalized REE abundances in almandine skarn rocks (*full lines*) and in one andradite skarn sample (*dashed line*). The Přísečnice area. For Tb content of almandine rocks the limit of detection was taken. Heavy lines with bars indicate concentration ranges of elements in andradite skarn samples others than that given by the *dashed line* (arrows indicate that some measured values lay below the detection limit). Data from J. Kotková (1991) and V. Šrein (1992)

Occurrence of both almandine and grossular-almandine is restricted to margins of the skarn bodies. Almandine is a major constituent of almandine-biotite schists at the „Přísečnice“ and Kovářská skarn bodies

Table 1. Average chemical composition of skarns of the Přísečnice area and their host rocks

| Rock | Number of analyses | $Al_2O_3$ wt % | $TiO_2$ wt % | CaO wt % | MgO wt % | $Fe_2O_3$ wt % | MnO wt % | Co ppm | Ni ppm | V ppm | Cr ppm | Sc ppm | Zr ppm | La ppm | Sm ppm | Eu ppm | Yb ppm | Lu ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gneiss | 2 | 13.1 | 0.55 | 2.4 | 1.7 | 2.9 | 0.03 | n.d. | 25 | 66 | 78 | n.d. | 164 | 21$^+$ | 2.5$^+$ | 0.5$^+$ | 1.3$^+$ | 0.19$^+$ |
| Marginal skarn schist | 2 | 9.8 | 0.45 | 13.1 | 7.6 | 6.9 | 0.14 | n.d. | 19 | 70 | 76 | n.d. | 116 | 16.5$^+$ | 2.2$^+$ | 0.4$^+$ | 1.1$^+$ | 0.17$^+$ |
| Epidote pyroxene rock | 3 | 12.7 | 0.13 | 20.0 | 4.8 | 16.0 | 0.40 | 7.4 | 26 | 80 | 52 | 8.5 | 86 | 18 | 3.8 | 2.6 | 1.97 | 0.31 |
| Amphibole rock | 3 | 10.4 | 0.31 | 10.1 | 4.9 | 28.0 | 0.29 | 24 | 12 | 38 | 48 | 7.6 | 54 | 5.1 | 1.46 | 2.4 | 1.80 | 0.41 |
| Almandine rock | 2 | 17.9 | 0.48 | 12.2 | 1.4 | 29.5 | 0.67 | 11 | 8 | 55 | 103 | 8.5 | 100 | 8.8 | 3.1 | 3.4 | 3.5 | 0.46 |
| Andradite skarn | 4 | 3.8 | 0.07 | 27.4 | 2.0 | 24.9 | 0.38 | 5.2 | 8 | 30 | 8 | 0.61 | 5 | 2.3 | -1 | 0.87 | -1 | 0.13 |
| Pyroxene skarn | 10 | 2.9 | 0.07 | 18.2 | 7.6 | 22.6 | 0.36 | 16.5 | 9.5 | 8 | 8 | 1.15 | 17 | 3.2 | -1 | 0.69 | -1 | 0.16 |
| Average schist (according to Veizer 1983) | | 13.8 | 0.77 | - | - | - | 0.12 | 19 | 68 | 130 | 90 | 13 | 160 | 92 | 6.4 | 1 | 2.6 | 0.7 |
| Average carbonate rock (according to Veizer 1983) | | 0.8 | 0.07 | - | - | - | 0.15 | 0.1 | 20 | 20 | 11 | 1 | 19 | - | 1.3 | 0.2 | 0.5 | 0.2 |

$^+$Approximate value (derived graphically from Fig. 6 of J. Kotková 1991).
n.d. not determinated

which are hosted by mica schists (Němec 1967a). Occurrence of grossular-almandine is restricted to assemblages high in Ca content. It appears as admixture in amphibole and pyroxene rocks and locally also constitutes separate pods. The pyralspite component usually prevails over the grossular component (Fig. 3). As expected, almandine is richer in contents of trace elements than andradite (Table 1, Fig. 2). Compared with almandine of other metamorphic rocks, the LREE content in the skarn almandine is higher. However, the analyses given in Table 1 do not refer to pure almandines but to almandine rocks. Abundant accessory titanite probably also contributes significantly to the bulk rock REE content.

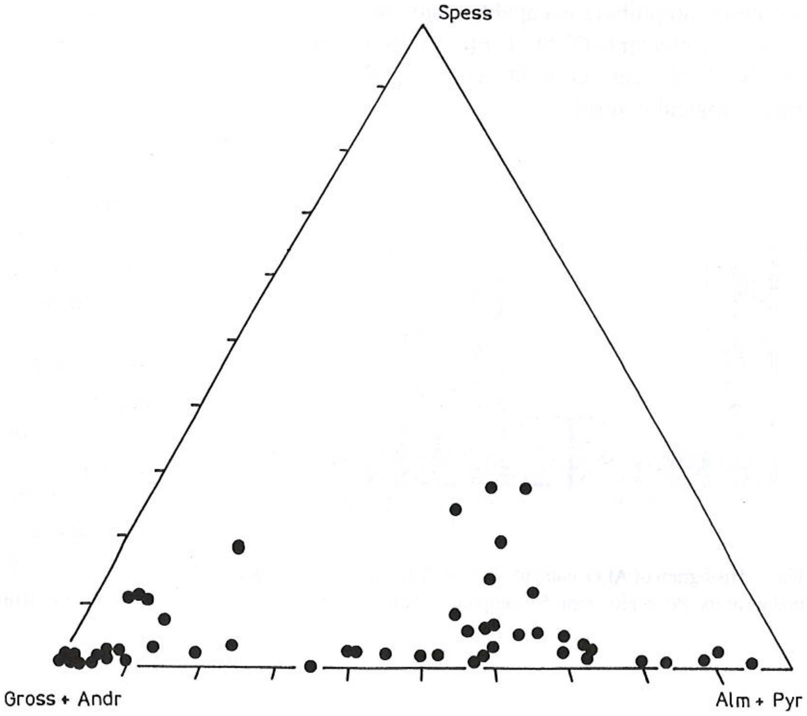

Fig. 3. Composition of garnets from skarn bodies of the Přísečnice area in terms of spessartine, grossular+andradite and almandine (+pyrope). Data from V. Šrein (1992)

Almandine is a mineral typical of regionally metamorphosed rocks. The same also applies for grossular-almandine. Its development requires, in addition to appropriate bulk rock composition, also pressures prevalent at the highest zones of greenschist facies (Němec 1967b). Hence, in the Přísečnice area, it is encountered not only in skarns but also in amphibolites hosted by marbles (Lange 1964).

Many grossular-almandines display enhanced MnO contents. They are observed in skarns of the Přísečnice area (Fig. 3) as well as in those of Western Moravia (Němec 1991). Due to crystallochemical reasons (Němec 1967b) grossular-almandine is a suitable sink for Mn which accumulates in it. Kotková (1991) assumes the Mn-rich garnet to be disequilibrium relic of the previous lower-grade metamorphism. However, this garnet essentially is a grossular-almandine (Fig. 3) for which the above characteristic is valid. In low-grade metamorphic schists garnets of similar composition are met with only in high-pressure glaucophane schists (Hashimoto 1968).

Amphibole. Amphiboles in the skarns of the Přísečnice area are of two types (Fig. 4): tremolite-actinolite and a slightly aluminous amphibole classified by Šrein (1992) mostly as Fe-edenite and Fe-hornblende. Tremolite-actinolite displayes Ti contents similar to clinopyroxene (Fig. 5) and could originate through any kind of retrograde alteration of pyroxene. However, the high-Al amphibole develops in metamorphic rocks under conditions of almandine amphibolite facies, being a typical mineral of regional metamorphism (Winkler 1967). It is absent in skarns of the contact metamorphic type. This amphibole is major constituent of the amphibole rocks listed in Table 1. Due to complicated bonding relations of its crystal structure, amphibole is capable to retain a great variety of trace elements (Table 1, Fig. 1). However, its unusually high Eu content is not due to some mineralogical control.

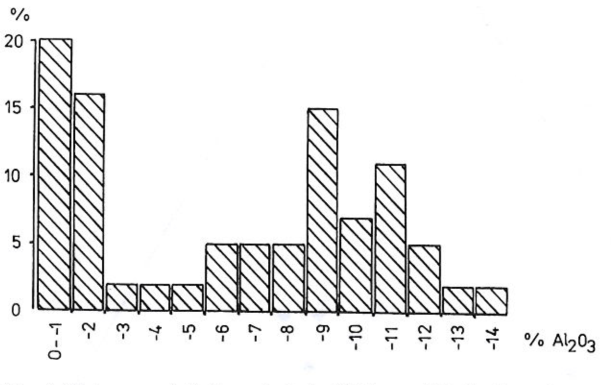

Fig. 4. Histogram of $Al_2O_3$ contents (wt %) in amphiboles from skarn bodies of the Přísečnice area. 55 samples. Data from V. Šrein (1992)

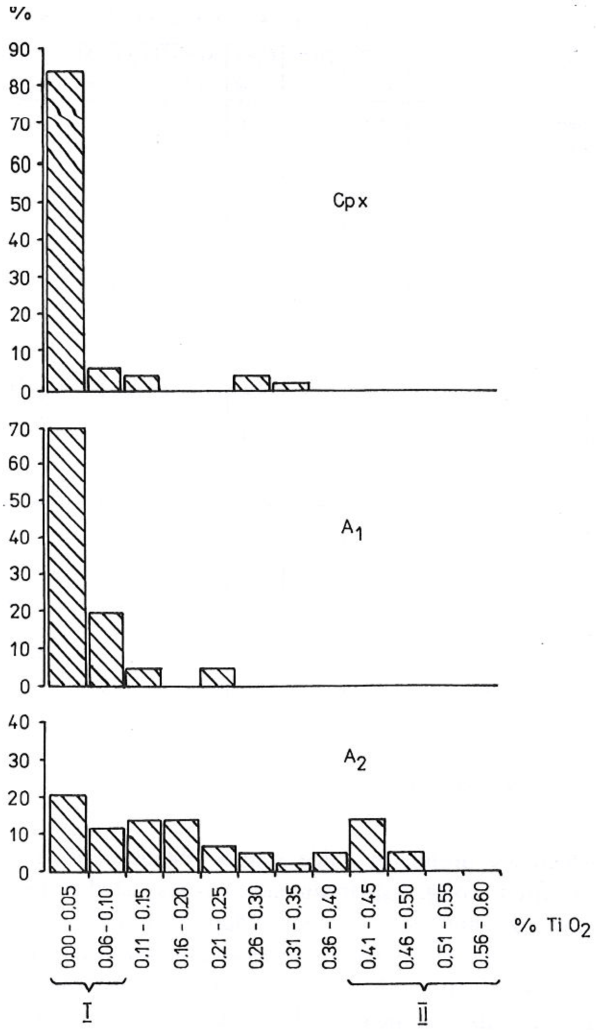

Fig. 5. Histogram of $TiO_2$ contents (wt %) in 50 pyroxene samples (Cpx), in 20 amphibole samples with $Al_2O_3$ contents below 2 wt % ($A_1$) and in 42 amphibole samples with $Al_2O_3$ contents above 2 wt % ($A_2$). Skarns of the Přísečnice area. I - range of $TiO_2$ contents in pyroxene zone, II - ditto for host gneisses. Data from V. Šrein (1992)

Epidote. It displays the highest possible saturation with Fe. The analyzed epidote rocks contained considerable amounts of pyroxene, and locally also amphibole (compare MgO in Table 1). Nevertheless, the geochemical signature of the rocks is evidently controlled by epidote which serves as an excelent sink for LREE (Fig. 6). Epidote rocks are only subordinate in the skarns of the Přísečnice area. They can be a product of regional metamorphism as well as a pre-metamorphic metasomatic relict rock.

Host gneisses. Concentrations of major components and geochemical signature of the rocks are common (Fig. 6). Some gneisses contain abundantly accessory allanite (Kotková 1991).

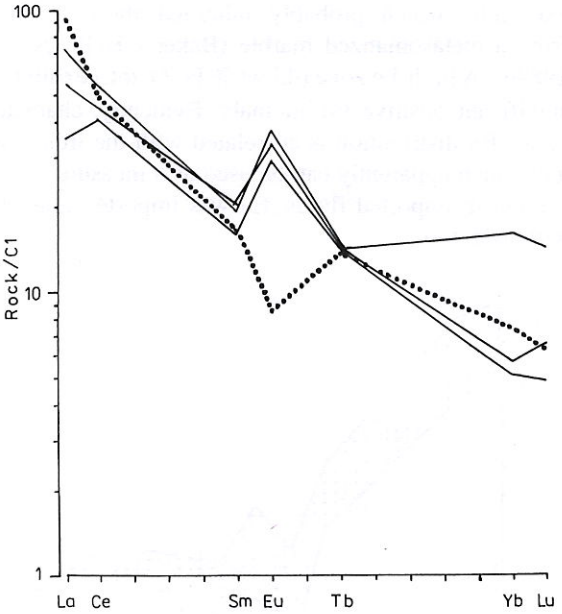

Fig. 6. Chondrite-normalized REE abundances of epidote rocks in the skarn bodies of the Přísečnice area (*full lines*) and in the host gneiss (*dotted line*). Data from J. Kotková (1991)

## Origin of the skarns through regional metamorphism

Kotková (1991) argued that the skarns are metamorphosed quartzose volcano-sedimentary iron ores. Below, we will try if this hypothesis is tenable in view of the present observations.

(1) $SiO_2$-$Fe_2O_3$-$Al_2O_3$ *diagram*

Kotková (1991) plots average composition of the skarns into this diagram (Fig. 7) and derives validity of her hypothesis from it. However, a coincidence with Precambrian banded iron ores is only illusory being caused by omission of CaO which is a prominent and inevitable component of skarns. It is easy to show that any typical Fe-rich Ca skarn of contact metamorphic type plots in the field of banded iron ores.

(2) Eu *anomalies*

Prominent positive Eu anomalies are characteristic of all skarn types of skarn bodies of the Přísečnice area (Figs. 1, 2). Only the host gneisses exhibit negative Eu anomalies. However, positive Eu anomalies are not specific for Precambrian banded iron ores, as Kotková (1991) suggested.

(a) Positive Eu anomalies in volcano-sedimentary iron ores. They occur in oxidic as well as in sulphidic iron ores (Graf 1977, 1978, Freyer 1977, 1983) older than 2.5 Ga (Danielson et al. 1992), while younger ores are free of them. Both trends can be found in chemical sediments between 2.5 and 2.3 Ga. This feature is explained by a global change in conditions controlling REE mobilization. Evidently, Archean sea-water was enriched in Eu. Recent studies (Bau - Moller 1992, Bau - Dulski 1992, Danielson et al. 1992) have shown that majority of the REE content present in Fe ores was supplied by hydrothermal ore fluids rich in Eu. Only a minor part of it was extracted from crustal rocks penetrated by the fluids (for details, see Bau 1991). Its majority derived from upper mantle sources as convin-

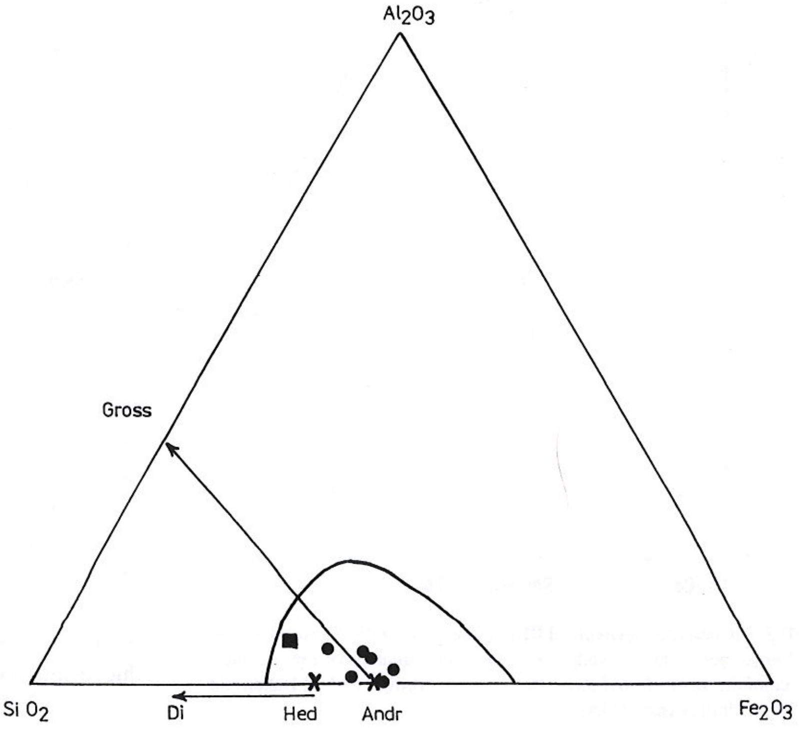

Fig. 7. $SiO_2$-$Fe_2O_3$-$Al_2O_3$ diagram showing field of Precambrian banded iron ores (after T. Majumder 1982). *Dots* - contact metamorphic skarns of the Pribalkhash region, central Asia (after to V. G. Bogomolov 1966); *square* - average of skarns of the Přísečnice area (after to H. Kotková 1991). Di - diopside; Hed - hedenbergite; Gross - grossular; Andr - andradite

cingly shown by epsilon Nd data (Derry - Jacobson 1990). Thus, a positive Eu anomaly in the iron ores indicates that the element was brought in by hydrothermal fluids. Disappearance of the Eu anomaly towards the Proterozoic marks a change from mainly high-temperature hydrothermal to low-temperature alteration (Danielson et al. 1992). REE coprecipitated with iron hydroxides. The REE distribution in banded iron ores is usually not affected by diagenesis and low- to high-grade regional and contact metamorphism (Bau 1993).

(b) Positive Eu anomalies in contact-metasomatic skarns and in hydrothermal deposits. Only few data are available in literature on REE in skarns, even though they exceptionally form there also economically important accumulations (Mariano 1989, Meinert 1992). Two examples are given below.

W-Mo skarns of Bergslagen, Central Sweden (Baker - Hellingswerf 1988a). REE patterns of individual skarn types are shown in Fig. 8. The grossular-bearing zone (5 and 7 wt % $Fe_2O_3$tot.) is high in REE content and has large negative Eu anomalies. It seems to be obvious that this type represents endoskarn which essentially took over its REE signature from metasomatized Proterozoic granites and biotite schists. The andradite-bearing zone (18 wt % $Fe_2O_3$ tot.) displays low REE abundances and lacks Eu anomaly. It is an exoskarns which probably inherited these features from a metasomatized marble (Baker - Hellingswerf 1988b). A high-Fe zone (45 wt % $Fe_2O_3$ tot.) exhibits a significant positive Eu anomaly. Evidently, character of the Eu distribution is correlated with the iron content which apparently can be used as a measure of ore content in imported fluids. Eu was imported together with iron, too.

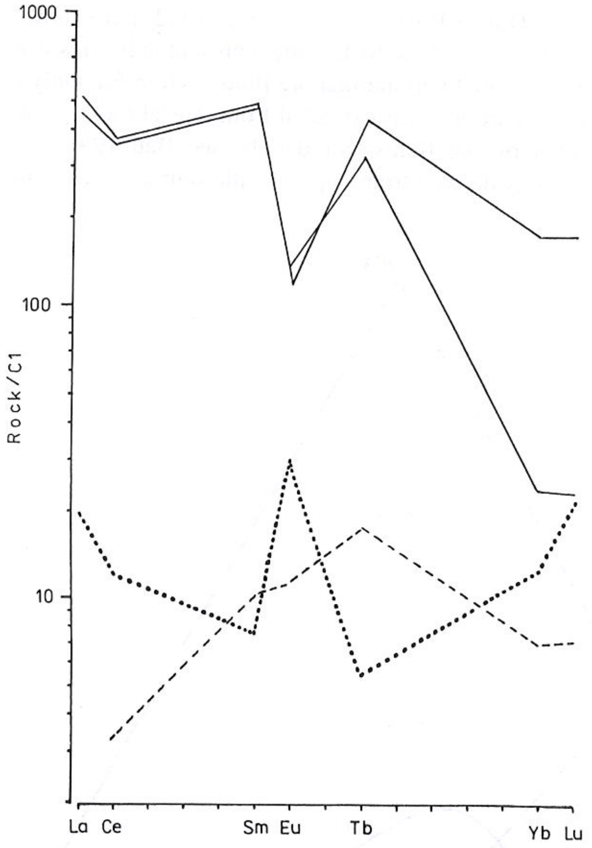

Fig. 8. Chondrite normalized REE abundances in W-Mo skarns of W Bergslagen, central Sweden. *Full line* - grossular zone; *broken line* - andradite zone; *dotted line* - Fe skarn. According to J. H.Baker and R. H. Helligswerf (1988)

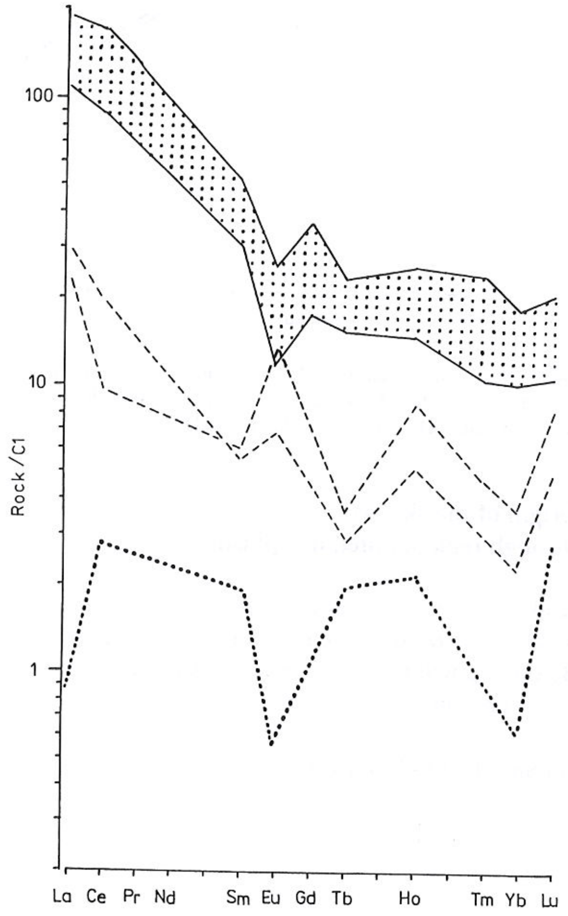

Fig. 9. Chondrite-normalized REE abundances in skarns of the Štiavnica Island, Slovakia. *Dotted field* - range of 7 garnet-epidote rocks; *dashed lines* - pyrite-magnetite skarns; *dotted line* - pure magnetite

Skarns of the Štiavnica Island, Slovakia. For geology of the area, see Káčer - Ivan (1992), and Koděra - Chovan (1994). The skarns of Tertiary age are of the magnetite-hematite type. They are associated with Mesozoic limestones and dolomites and consist of older Mg-skarns and younger Ca-skarns composed of vesuvianite, garnet, epidote, pyroxene and anorthite. It is obvious that the latter type represents an endoskarn, as also indicated by its REE distribution characterized by conspicuous negative Eu anomalies. Positive Eu anomalies appear in skarns carrying pyrite-magnetite ore (Fig. 9). In the Štiavnica Island, Eu was also introduced into the skarns together with Fe. However, it is camouflaged in silicates, not in magnetite (Fig. 9). Due to its large ionic radius, $Eu^{2+}$ is rejected by magnetite (mineralogical control).

In both areas, Eu was imported into the skarns by ore fluids, and precipitated simultaneously with Fe. Similar relations occur also in hydrothermal deposits (Whitford et al. 1988, Bens - Taylor 1985). This is particularly well shown in Tasman deposits where positive Eu anomalies occur only in pyrite ore, but not in base metal ore.

(c) Conclusion for the Přísečnice skarns. As shown above, Eu anomalies in all types of the Fe deposits considered have the same origin. Eu appears to have precipitated in volcano-sedimentary ores where ore fluids reached the ocean floor. If appropriate country rocks were encountered during their ascent, Eu was deposited under suitable PT conditions in skarns or hydrothermal ores. Thus, positive Eu anomalies are not linked with a specific type of ore deposits. Also, it should be also taken into consideration that, according to Danielson et al. (1992), positive Eu anomalies only occur in Archean volcano-sedimentary deposits, whereas the Přísečnice Group belongs lithologically to Late Precambrian.

### (3) *Interrelations of chemical components of the skarns*

According to Kotková (1991, p. 230) the skarns represented originally „volcano-sedimentary iron-rich complex composed of various rock types, including significant carbonate and pelitic components and volcanic rocks". Accordingly, individual skarn types ought to be metamorphosed products of various mixtures of these lithologies. All chemical components of each skarn type should, in principle, exhibit the relations corresponding to the ratios of mixing of the starting protoliths. Let us consider, for instance, the marginal skarn schists (Table 1). Their CaO, MgO and MnO contents are many times higher than those of the gneisses, so that an essential admixture of carbonates to pelitic sediments is to be taken in consideration. However, contents of other elements of marginal skarn schists are similar to those of the gneisses. The almandine rock displays high Ti, Cr and V contents so that a considerable proportion of a volcanic admixture should be assumed in its protolith. In contrast to that, the almandine rock is very poor in Ni, and its Co/Ni ratio is reversed as compared with the same ratios of basic volcanics in which the Ni content is many times higher than that of Co (Turekian 1977). The same holds also for Precambrian oxidic iron ores in which Ni/Co ratios vary between 4 and 80 (Davy 1983, Klein and Beukes 1989). Similarly, all marginal skarn types are considerably richer in REE (except for La) than the country gneisses as well as the pyroxene and andradite skarns of the skarn cores.

It may be concluded that the explanation of the skarn origin given by Kotková (1991) faces considerable difficulties.

## Origin of the skarns through high-temperature metasomatism

This hypothesis anticipates origin of skarns by a high-temperature metasomatism of carbonate and to a certain extent also pelitic rocks caused by ore-bearing fluids of igneous origin. We will, at first, exclude from consideration the amphibole and almandine rocks which both are typical assemblages of regional metamorphism and concern possible primary metasomatic assemblages which include marginal skarn schists, and pyroxene and andradite skarns. It may be suggested that the regional metamorphism was conservative and did not change essentially their mineral composition and that they only recrystallized. Recrystallization of andradite can be safely assumed in view of its perfect optical isotropy. It can be realized that the protolith of the actual host gneisses acted as paleosome of the marginal skarn schists and the actual relict marbles as paleosome for proper skarn assemblages. The gneisses were chemically investigated (Table 1). For marbles global average composition of carbonate rocks (according to Veizer 1983) has been used. During a high-temperature metasomatism, elements behaving inertly (Al, Ti, V, Cr, Zr) are retained and contribute to geochemical signature of the product. For marginal skarn schists, this signature coincides with that of the host gneisses, for the pyroxene and andradite skarns it coincides with that of marbles (Table 1). This is also demonstrated in Fig. 10 which shows that Cr contents of the pyroxene zone and of the marble are identical. Typical introduced elements are Fe, Mn, and Co. Europium was also imported, as indicated by its positive correlation with Fe (Fig. 11. MgO instead of $FeO_t$ was plotted there, because Eu is evidently contained only in silicates being independent from the abundancy of magnetite in the rocks. Thus, Eu is negatively correlated with Mg.) Accordingly, Eu coprecipitated with Fe. However, Eu did not take part in the metasomatism of metapelites because they retain their negative Eu anomalies. By aid of metasomatism sharp boundaries between individual skarn assemblages (Fig. 10) and low number of mineral phases in individual skarn zones, difficult to explain if regional metamorphism of mixed lithologies would be supposed, are best explained. The almandine, amphibole and, particularly, the epidote types point by their contents of inert elements to an essential participation of pelitic rocks on their educts (Fig. 12), even though a metasomatic import into them evidently was also considerable.

## Conclusions

Two types of assemblages can be distinguished in the

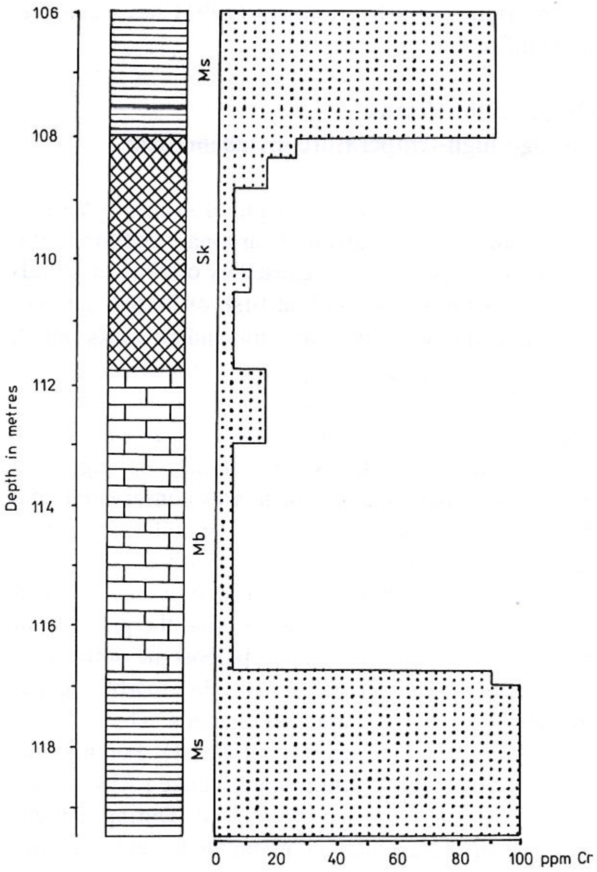

Fig. 10. DV 20/87 (Orpus) drillhole, the Přísečnice area. Cr contents of muscovite gneiss (Ms), marble (Mb) and skarn (Sk). After J. Šafařík (1988)

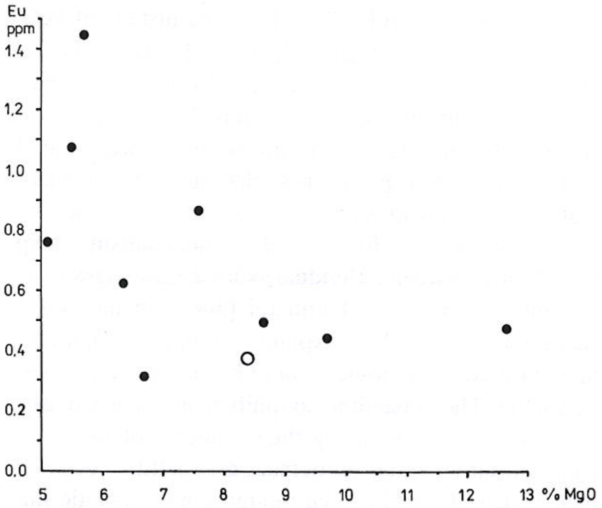

Fig. 11. MgO contents (wt %) vs. Eu contents (ppm) of pyroxene skarns of the Přísečnice area. *Circle* - sample rich in magnetite. Data from V. Šrein (1992)

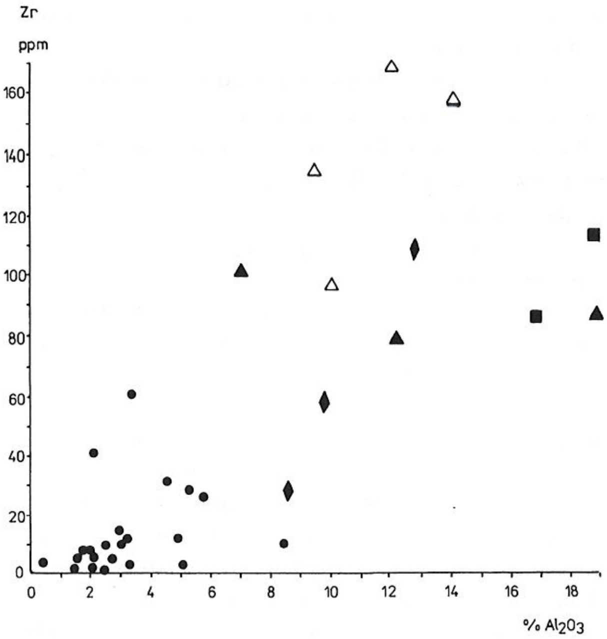

Fig. 12. $Al_2O_3$ contents (wt %) vs. Zr contents (ppm) of rocks in skarn bodies of the Přísečnice area. *Dots* - skarn assemblages; *diamonds* - amphibole rocks; *squares* - almandine rocks; *closed triangles* - epidote rocks; *open triangles* - marginal skarn schists and host gneisses. Data from V. Šrein (1992)

bodies of regionally metamorphosed skarns of the Přísečnice area: those of regional metamorphism (almandine and amphibole rocks) and those which could have developed already earlier through a high-temperature metasomatism mostly of limestones (pyroxene and andradite skarns and partly also marginal skarn schists). Two hypotheses are applied to explain their geochemical features: conservative regional metamorphism of appropriate protoliths including also volcano-sedimentary banded iron ores, and metasomatism of a contact metamorphic skarn type, caused by igneous fluids. Differentiated chemistry of the skarn assemblages cannot be conveniently explained without metasomatism. Precambrian banded iron ores display a different geochemical signature. Salient positive Eu anomalies occurring in the skarns of the study area are not a specific feature of volcano-sedimentary iron ores but they also exist in skarns of the contact-metasomatic type.

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## Geochemie regionálně metamorfovaných skarnů Krušných hor a závěry pro jejich genezi

Mezi hlavními minerálními asociacemi těles regionálně metamorfovaných skarnů centrální části Krušných hor je možno rozlišit asociace vzniklé až při regionální metamorfóze (asociace almandinické a amfibolické) a asociace, které mohly vzniknout již dříve vysokoteplotním zatlačením převážně karbonátového eduktu magmatogenními rudními fluidy (skarny pyroxenické, andraditické, možná i okoloskarnové rohovce a břidlice). V předložené studii je učiněn pokus vysvětlit chemismus a mikrochemismus těchto asociací jednak pomocí hypotézy konzervativní regionální metamorfózy vhodného eduktu, obsahující i křemité páskované rudy Fe, jednak metasomatózou kontaktně metasomatického typu. Ukazuje se, že bez předpokladu metasomatózy lze těžko vysvětlit diferencovaný chemismus skarnových asociací. Prekambrické páskované křemen-magnetitové rudy mají odlišnou geochemickou signaturu. Výrazné pozitivní anomálie Eu, přítomné v krušnohorských skarnech i ve zmíněných typických vulkanogenně-sedimentárních rudách, pocházejí z Eu přineseného hydrotermálními rudními fluidy. Nejsou však specifické jen pro tento typ rud Fe, ale objevují se i ve skarnech kontaktně metasomatického typu.

## *RECENZE*

M. J. Le Bas (edit.): **Milestones in geology. - Geological Society Memoir No. 16, 272 s.**
The Geological Society, London 1995.

Vloni oslavila anglická geologická společnost, založená jako první na světě již v roce 1807, 150. výročí nepřetržitého vydávání časopisu Journal of the Geological Society (do roku 1971 The Quaterly Journal of the Geological Society of London). Toto jubileum bylo příležitostí k vydání sborníku Milestones in Geology, iniciovaného hlavním redaktorem časopisu dr. Mikem Le Bas. Snahou sborníku bylo upozornit na některé zásadní poznatky a ideje, které v časopise během jeho historie vyšly, a konfrontovat je se současným stavem geologického poznání. Proto je vhodné připomenout velmi stručně témata, o nichž je ve sborníku pojednáno.

V úvodu sborníku charakterizuje M. J. Le Bas hlavní články a upozorňuje na některé pozoruhodné souvislosti dnešních představ s minulostí. Po stati M. J. S. Rudwicka o historii časopisu je první geologická práce inspirována problémem uniformitarismu v geologii, spočívajícím na více než 200 let starých principech Jamese Huttona (příští rok uplyne 200 let od jeho smrti) a Charlese Lyella. B. F. Windley v článku „Uniformitarianism today: plate tectonics is the key to past“ vyvozuje, že principy deskové tektoniky je možno úspěšně aplikovat nejen v proterozoiku, ale i v archaiku, dlouhodobé změny v produkci zemského tepla ovšem ovlivnily a pozměnily magmatické a metamorfní procesy na deskových rozhraních. Vývoji bazického magmatismu v průběhu času je věnována práce R. P. Halla a D. J. Hughese. Velký význam geochronologie pro objasnění vývoje polymetamorfních terénů je probírán v článku G. Rogerse a B. J. Pankhursta na příkladu Scottish Highlands, kde metody K-Ar, Rb-Sr a U-Pb postupně přispívají k časovému vymezení jednotlivých pochodů. I další dvě práce jsou inspirovány Skotskem. B. J. Bluck se zabývá významem velkých horizontálních posunů, jejichž studium bylo podníceno pracemi o Great Glen Fault na začátku 40. let tohoto století, a jejichž důležitost byla potvrzena na řadě míst, nejvýznamněji pak na deskových rozhraních. Vynikajícím přehledem současného stavu metamorfní petrologie je práce M. Browna: P-T-t evolution of orogenic belts and the causes of regional metamorphism. Základy k takovým studiím položily již před 100 lety práce G. Barrowa a vedly až k dnešní termobarometrii a studiu termodynamiky metamorfních reakcí.

Další čtyři práce jsou věnovány stratigrafické klasifikaci a korelaci, založené převážně na fosiliích. Jde o stratigrafii staršího paleozoika (W. S. McKerrow: The development of Early Paleozoic global stratigraphy) a zejména o významu biostratigrafie. Práce R. A. Forteye „Charles Lapworth and the biostratigraphic paradigm“ ukazuje na analýze Lapworthových prací trvalost biostratigrafických zjištění na rozdíl od strukturních a paleogeografických koncepcí. Součástí je i zajímavá polemika proti mezinárodním standardním profilům s hranicemi jednotek, s kterou by naši stratigrafové asi sotva mohli souhlasit - sporná je podle autora zejména představa o nepřerušenosti profilů. Autor N. J. Riley se věnuje stratigrafii spodního karbonu a provádí korelaci biozon podle různých živočišných skupin, dočteme se však i o seizmostratigrafii těchto jednotek. Studie J. H. Callomona, založená na stratigrafii jury, se zabývá hlavně hranicemi možností biostratigrafie. U jurských amonitů jde o rozmezí asi 250 000 let, ovšem dobrá rozlišitelnost amonitových faunistických horizontů ukazuje na velkou neúplnost i zdánlivě souvislých litologických profilů, což opravňuje do určité míry skeptické názory R. A. Forteye.

Pozoruhodná práce je věnována i mezozoickým obratlovčím faunám, pocházejícím z výplní trhlin a krasových dutin ve vápencích (R. J. Savage). Studie L. R. M. Cockse: Triassic pebbles, derived fossils and the Ordovician to Devonian paleogeography of Europe, je o čtyřech typech faun nalezených ve valounech v triasových slepencích na pobřeží Devonshiru, dvou ordovických a dvou devonských, které jsou odlišné od paleozoických faun jinde v Británii. Tyto fauny podstatně přispěly k poznání paleogeografie ordoviku a devonu v Evropě, která je znázorněna na nových paleogeografických mapkách.

Dvě následující práce navazují na pionýrské studie Sorbyho ze začátku tohoto století. J. R. L. Allen v článku: Sedimentary structures: Sorby and the last decade, charakterizuje sedimentární struktury a jejich význam pro interpretaci prostředí vzniku a při kvantifikaci krátkodobých jevů v horninovém prostředí. B. W. Sellwood pak rozvíjí a shrnuje současné názory na klasifikaci vápenců, prostředí jejich depozice a diageneze a jejich význam v sekvenční stratigrafii (Structure and origin of limestones).

Další soubor prací se týká problémů magmatismu. G. P. L. Walker (Flood basalts versus central volcanoes and the British Tertiary volcanic province) sleduje vztah platóbazaltů k vulkanickým centrům a strukturní i látkové vlastnosti platóbazaltů. Ty mohou přinést daleko více informací pro rozlišení jednotlivých proudů i o podmínkách jejich vzniku, než se zatím předpokládalo. M. Willson (Magmatic differentiation) hodnotí převážně z geochemického hlediska možnosti diferenciace bazických magmat plášťového původu vlivem frakční krystalizace, asimilace, míšení magmat, termogravitační difúze i vznikem nemísitelných tavenin. Vývoj granitoidních hornin z převážně korových zdrojů hodnotí M. P. Atherton (Granite magmatism). Všímá si i problémů granitizace, které před 50 lety „hýbaly“ petrologií, problémů prostoru i výsledků experimentálních studií a studia izotopů pro posouzení významu parciálního tavení a frakcionované krystalizace.

Poslední práce jsou pak věnovány hydrotermálním rudním polím a rudonosným roztokům (A. H. Rankin) a významu, který pro poznání jejich geneze mělo studium kapalných uzavřenin spolu se studiem izotopickým. D. K. Bailey (Carbonate magma) pak řeší vznik a vývoj karbonátických magmat. Zatímco se obecně přijímá, že jde o pozdní diferenciáty alkalických silikátových tavenin v infrakrustálním prostředí, uvádí nově i možnost vzniku dolomitových karbonatitů přímým parciálním tavením plášťových materiálů za podmínek nasycenosti $CO_2$.

Na mnoha místech z článků vyplývá význam precizního pozorování a shromažďování objektivních pozorovacích a experimentálních dat pro rozvoj následných teoretických představ. Na důležitost přesného popisu se nyní bohužel často zapomíná a přistupuje se přímo k interpretaci, založené často na generalizaci předpokládaných skutečností. Sborník tak nejen vzdává hold autorům, kteří posunuli geologické poznání vpřed, ale je i zasvěceným stručným přehledem dnešních geologických znalostí a představ a svědectvím složitého vývoje myšlenek a koncepcí v celém období od jejich zrodu, v historické vývojové souvislosti. Ukazuje na spojení minulosti se současností a na význam minulosti, na který se často a stále více zapomíná. Ukazuje, že některé ze současných moderních teorií jsou ve skutečnosti evergreeny, které se dostaly do centra pozornosti v uplynulém půldruhém století i vícekrát. V tomto směru může být sborník přímo učebnicí pro pokročilé studenty (orientaci v něm usnadňuje i kvalitní rejstřík), lze ho však též doporučit každému geologovi, kterému kromě informace o pokroku v jeho specializaci rozšíří rozhled v oblastech sousedních i vzdálenějších.

*Arnošt Dudek*