GEOLOGICKÝ ZBORNÍK — GEOLOGICA CARPATHICA 30, 4, BRATISLAVA, DECEMBER 1979

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# GEOCHEMISTRY OF RARE EARTHS IN METABASITES OF THE WEST CARPATHIANS

*(8 Tab., 9 Figs)*

Abstract: In the article is evaluted the distribution of rare earths (TR) in metabasites of the West Carpathians. On the basis of their contents it has been established that originally, tholeiites the character of which is close to that of the oceanic tholeiites, are concerned. The similarity of contents of the individual elements from the group of rare earths confirms the genetical relationship of metabasites of tatraveporides and thier origin in the pre-variscan Central European Paleozoic sea.

Резюме: В статьи делают оценку распределения редких землей (TR) в метабазитах Западных Карпат. На основании их содержания определено что первоначально речь идет о толеитах, характер которых близкий океаническим толеитам. Сходство содержаний отдельных элементов группы редких землей подтверждает генетическое родство метабазитов татровепоридов и их возникновение в доварийском среднеевропейском палеозойском море.

Much attention is devoted to trace elements by geochemists and petrologists in the last time. This interest is conditiond by the possibility to apply the data about changes of concentration of trace elements in the rocks of various genesis in solution of several fundamental questions of petrology. An important part in clearing up of problems of the primary character of metamorphites, degree of contamination of primary magma or degree of partial smelting, play the elements of the rare earth group. These form together with yttrium a very connatural group of elements, which are characterized by common occurrence in the same environments, often also in the same minerals. The extreme members of this group, the lightest (lantanium and cerium) and the heaviest ytterbium and lutetium are different from each other, what makes possible fractionation (redistribution) of rare earths in dependence on physical-chemical conditions during the geological processes. On the basis of distribution of rare earths we may conclude, in reverse direction, on physical-chemical conditions of the origin of rocks and minerals. As characteristic indicative relations are used ratios of element couples Nd/La, La/Yb, La/Sm, Ce/Yb and further pair ones or summary relations e. g. $\sum Ce/\sum Y$, $\sum TR$.

The great affinity of chemical properties of rare earths is evident from the specific structure of their electron envelopes. They occur mainly as trivalent cations although europium appears also as $Eu^{2+}$ and cerium as $Ce^{4+}$. The elements of rare earths are divided into two subgroups: lighter cerium — from La to Gd with more basic properties and havier yttrium — from Tb to Lu, which has less basic properties. In calculations also yttrium is included in this group. In geochemical investigation distribution of rare earths is compared in chondrites (primitive character of distribution) with distribution of rare earths in va-

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rious other types of rocks. Primitiveness (so called chondrite distribution) is characterized by approximately equal or little higher contents of light rare earths in contrast to heavy ones. Rocks with primitive TR distribution are of mantle origin whereas in crustal rocks TR redistribution took place by the influence of various geological processes. The rare earths tend to concentrate in residual magmas, in which the amount of alkalies is higher. We can also speak about subsequently originated correlation between TR and alkalies. The fundamental factor of enrichment of rare earths in some geological environment are volume ratios of ions. This is confirmed by yttrium, which is not a rare earth and, nevertheless, accompanies TR (its radius and charge are as of Er).

The present work is a further contribution to general geochemical investigation of metabasites of the West Carpathians. The metabasites of the West Carpathians are part the Paleozoic metamorphosed complex. The degree of their metamorphosis is relatively high (amphibolite facies, more rarely facies of green schists). The character of metabasites was also influences by various processes (spilitization, hydrothermal alternation, diaphthoresis etc.). The dominant form of occurrence of metabasites are submarine effusions and only subordinately hypabyssal bodies of little dimensions, variable grain size and mineral composition. Identical samples as in the work by B. Cambel, E. Martiny, J. Spišiak, 1979 were analysed. In this work are mentioned further data about selection of samples and their documentation. The determination of rare earths was carried out in the Central Laboratory of the Czechoslovak Uranium Industry. Stráže pod Ralskem, by the method of neutron activation analysis, analyst Ing. Čeněk Urban.

The basic rocks differ from one another in the character of TR distribution. The content of light TR gradually increases from oceanic tholeiites through continental tholeiites to alkalic olivine basalts with relatively constant contents of heavy TR. J. G. Schilling (1972) points to correlation between the contents of alkalies and heavy TR in various types of basites originated in island arcs, oceanic ridges and in continental basalts. Each petrochemical group, however, is characterized by a particular model of TR distribution. Is this variability play the degree of selective remelting, depth and PT conditions of this process, fractional crystallization taking place during ascent of magma and tectonic conditions an important part. The study of TR distribution makes us possible to distinguish various types of basic rocks, gives us information about the source orea of basites in the mantle. J. G. Schilling (1972) mentioned that midleoceanic ridges produce tholeiitic magmas with low content of light TR On the contrary, tholeiites of plateau-basalts and other continental basalts are enriched in light TR in contrast to the foregoing ones.

The data about contents of rare earths in metabasites of the West Carpathians are mentioned in Tables 1, 2, 3, 4, 5. In these tables the analyses of metabasites are grouped on the basis of regional subdivision. Besides that, a particular table (Table 7) from rocks with higher contents, mainly of light TR (La, Ce), was compiled. The arithmetic and geometric means, standard devation, variation coefficients of individual sets but also of larger groups are summarized in Table 6. In calculation of TR average contents, with regard to technical conditions of analyses, the following values were substituted for underlimit contents (ND): La – 1, Ce – 1; Eu – 0,25; Tb – 0,1; Tm – 0,4; Yb – 0,15; Lu – 0,1. In order to eliminate anomalous values two arithmetical means were calculated: the

Table 1

Little Carpathians — MK

| Sample No. | La | Ce | Sm | Eu | Tb | Tm | Yb | Lu | Y | ΣTR | $\frac{\sum Ce}{\sum Y}$ | La/Yb | La/Sm | La/Ce | Ce/Yb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AM— 1.10—MK | ND | ND | 1,4 | 1,0 | 0,32 | ND | ND | 0,25 | 15 | 20,52 | 0,21 | — | — | — | — |
| AM— 3.10—MK | 2,1 | 5,2 | 2,6 | 1,3 | 0,34 | 1,9 | 0,6 | 0,26 | 22 | 36,3 | 0,45 | 3,5 | 0,81 | 0,41 | 8,67 |
| AM— 4.10—MK | ND | ND | 1,4 | 1,0 | 0,30 | 1,2 | 1,3 | 0,28 | 21 | 28,48 | 0,19 | — | — | — | — |
| AM— 5.10—MK | 6,9 | 8,2 | 4,1 | 1,4 | 0,56 | 1,2 | 1,7 | 0,23 | 27 | 51,29 | 0,67 | 4,06 | 1,68 | 0,84 | 4,82 |
| AM— 6.10—MK | 2 | 14,5 | 3,9 | 3,1 | 0,75 | 1,1 | 2,8 | 0,8+ | 46 | 74,85 | 0,46 | — | — | — | 5,18 |
| AM— 7.10—MK | 4,3 | — | 1,1 | — | — | — | — | — | 17 | — | — | — | 3,91 | — | — |
| AM— 8.1 —MK | ND | ND | 1,1 | 1,0 | 0,15 | 1,1 | 1,1 | 0,35 | 15 | 21,8 | 0,23 | — | — | — | — |
| AM— 9.10—MK | 2 | ND | 2,3 | 1,2 | 0,32 | ND | 1,0 | 0,32 | 28 | 30,04 | 0,28 | — | — | — | — |
| AM—11.10—MK | ND | — | 1,9 | — | — | — | — | — | 26 | — | — | — | 0,53 | — | — |
| AM—12.10—MK | 13,5+ | 29+ | 4,3 | 1,9 | 0,55 | 1,2 | ND | 0,25 | 28 | 78,85 | 1,62+ | — | 3,14 | 0,47 | — |
| AM—14.10—MK | 7,5 | 10 | 4,6 | 1,9 | 0,65 | 1,0 | 1,4 | 0,22 | 34 | 61,27 | 0,64 | 5,36 | 1,63 | 0,75 | 7,14 |
| AM—40.10—MK | 8,5 | 7,8 | 2,8 | 1,8 | 0,42 | ND | 3,2 | 0,68 | 33 | 58,6 | 0,55 | 2,66 | 3,04 | 1,09 | 2,44 |
| $\overline{x}$ | 4,23 | 7,87 | 2,63 | 1,56 | 0,44 | 0,99 | 1,34 | 0,36 | 26 | 46,2 | 0,53 | | | | |
| $\overline{x}^{+}$ | 3,39+ | 5,52+ | | | | | | 0,32+ | | | 0,41+ | | | | |
| $\overline{x}^{+-}$ | average calculated not including the values marked with asterisk | | | | | | | | | | | | | | |

Contents of rare earths (TR) in metabasites of the Little Carpathians (MK)

Table 2

Inovec, Tribeč, Suchý, Malá Magura — ITSM

| Sample No. | La | Ce | Sm | Eu | Tb | Tm | Yb | Lu | Y | $\sum TR$ | $\frac{\sum Ce}{\sum Y}$ | La/Yb | La/Sm | La/Ce | Ce/Yb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AM—38.13—T | 8,5 | 3,8 | 4,7 | 2,1 | 0,40 | 1,4 | 2,0 | 0,16 | 35 | 77,16 | 0,33 | 4,25 | 1,81 | 2,24 | 1,90 |
| AM—30.13—T | ND | 33+ | 3,7 | 2,4 | 0,80 | ND | 3,0 | 0,66 | 57 | 101,96+ | 0,65 | — | — | — | 11,00 |
| 173—34.2—T | 9,5 | 10,5 | 5,6 | 2,0 | 0,62 | ND | 1,2 | 0,21 | 38 | 68,03 | 0,68 | 7,92 | 1,70 | 0,90 | 8,75 |
| 175—34.4—T | 3,8 | 7,4 | 3,7 | 1,9 | 0,65 | 1,5 | 1,7 | 0,25 | 27 | 47,9 | 0,54 | 2,24 | 1,03 | 0,51 | 4,35 |
| 115—17.1—M | 14,0+ | 18,5 | 6,5 | 1,7 | 0,45 | 1,1 | 0,92 | 0,25 | 20 | 63,42 | 1,79+ | 15,22 | 2,15 | 0,76 | 20,10 |
| $\overline{x}$ | 7,36 | 14,64 | 4,84 | 2,02 | 0,58 | 0,96 | 1,76 | 0,30 | 35,40 | 71,69 | 0,80 | | | | |
| $\overline{x}^{+}$ | 8,95+ | 10,05+ | | | | | | | | 64,13+ | 0,55+ | | | | |

Contens of rare earths in metabasites of the Inovec, Tribeč, Suchý and Malá Magura (I, T, S, M)

Table 3

Malá Fatra, Nízke Tatry, Vysoké Tatry — MF, NT, VT

| Sample No. | | La | Ce | Sm | Eu | Tb | Tm | Yb | Lu | Y | $\sum TR$ | $\frac{\sum Ce}{\sum Y}$ | La/Yb | La/Sm | La/Ce | Ce/Yb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 133 —24. 3—MF | | 18,5 | 16 | 9,4+ | 2,7 | 0,75 | 2.4 | 2,3 | 0,32 | 54 | 106,37 | 0,78 | 8,04 | 1,97 | 1,16 | 6,96 |
| 136 —25. 2—MF | | 12,0 | 23+ | 9,6+ | 2,2 | 0.9 | 1.5 | 1,8 | 0,23 | 20 | 71,23 | 1,92+ | 6,66 | 1,25 | 0,52 | 12,78 |
| AM—17.22—MF | | 6,8 | 9,1 | 3,9 | 1,3 | 0,55 | 0,95 | 1,2 | 0,25 | 23 | 46,15 | 0,78 | 5,7 | 2,27 | 0,75 | 7,56 |
| 125 —21. 3—MF | | 9,0 | 5.4 | 6,4 | 1,6 | 0,50 | 1,4 | 1,4 | 0,20 | 52 | 77,90 | 0,41 | 6,42 | 1,4 | 1,67 | 3,86 |
| 138 —37. 1—NT | | 13,5 | 31+ | 2,7 | 0,9 | 0,64 | 1,3 | 1,4 | 0,22 | 38 | 89,66 | 1,16 | 9,64 | 5,0 | 0,44 | 22,24 |
| AM—21.36—NT | | 5,1 | 0,85+ | 2,2 | 1,7 | 0,52 | 1.2 | 2,5 | 0.36 | 26 | 40,43 | 0,32 | 2,04 | 2,32 | 6,0 | 0,34+ |
| 148 —29. 2—VT | | 21+ | 18 | 5,2 | 2,3 | 0,60 | 1,2 | 1,1 | 0,23 | 33 | 82,63 | 1,29 | 19,1 | 4,04 | 1,17 | 16,36 |
| 144 —28. 1—VT | | 2,3 | 3,1 | 2,9 | 1,0 | 0.44 | ND | 1,3 | 0,24 | 32 | 43,68 | 0,27 | 1,77 | 0,79 | 0,74 | 2,38 |
| AM—15.29—VT | | 2,8 | 4,3 | 4,2 | 1,6 | 0,26 | ND | 1,0 | 0,22 | 37 | 51,78 | 0,33 | 2,80 | 0,66 | 0,65 | 4,30 |
| 171 —33. 1—B | | 1,8 | 3,6 | 3,3 | 1,1 | 0,50 | ND | 1,2 | 0,20 | 18 | 30, | 0,48 | 1,5 | 0,55 | 0,5 | 3,00 |
| | $\overline{x}$ | 9,28 | 11,43 | 4,89 | 1.64 | 0.56 | 1.11 | 1.52 | 0.24 | 33,30 | 63,99 | 0.77 | | | | |
| | $\overline{x}^+$ | 7,98+ | 8,50+ | 3,74+ | | | | | | | | 0,58+ | | | | |

Contents of rare earths in meabasites of the High Tatra, Low Tatra and Malá Fatra (VT, NT, MF)

Table 4

Veporides — VEP

| Sample No. | La | Ce | Sm | Eu | Tb | Tm | Yb | Lu | Y | $\sum TR$ | $\frac{\sum Ce}{\sum Y}$ | La/Yb | La/Sm | La/Ce | Ce/Yb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AM—18—VEP | 2,1 | 6,4 | 2,9 | 1,3 | 0,50 | 1,3 | 1,2 | 0,20 | 27 | 42,9 | 0,42 | 1,75 | 0,72 | 0,33 | 5,33 |
| AM—19—VEP | ND | ND | 2,5 | 1,4 | 0,40 | 1,3 | 1,8 | 0,42 | 29 | 38,82 | 0,18 | — | — | — | — |
| AM—23—VEP | 1,1 | 3,4 | 0,8 | 0,5 | 0,30 | 0,90 | 0,32 | 0,06+ | 3+ | 10,38 | 1,27 | 3,44 | 1,38 | 0,32 | 10,63 |
| AM—24—VEP | 5,2 | 5,5 | 2,6 | 1,4 | 0,60 | 1,40 | 0,72 | 0,38 | 26 | 43,8 | 0,51 | 7,22 | 2,0 | 0,95 | 7,64 |
| AM—25—VEP | 4,5 | 4,3 | 3,1 | 1,4 | 0,58 | 2,40 | 0,78 | 0,22 | 24 | 41,28 | 0,48 | 5,77 | 1,45 | 1,05 | 5,51 |
| AM—26—VEP | 17+ | 36+ | 4,3 | 2,3 | 0,80 | 1,10 | 1,10 | 0,28 | 29 | 92,68 | 1,80 | 15,45 | 3,95 | 0,47 | 32,73 |
| AM—27—VEP | 8,1 | 23+ | 4,4 | 1,6 | 0,48 | ND | 0,56 | 0,30 | 23 | 61,84 | 1,50 | 14,46 | 1,84 | 0,35 | 41,07 |
| 196—47.2 —VEP | 7,7 | 8,9 | 9,2+ | 1,5 | 1,2 | 2,4 | 3,8+ | 0,58 | 21 | 56,28 | 0,94 | 2,03 | 0,84 | 0,87 | 2,34 |
| 202—48.6 —VEP | 5,2 | 6,6 | 2,5 | 0,85 | 0,32 | 0,95 | 1,4 | 0,24 | 32 | 64,36 | 0,84 | 3,7 | 2,08 | 0,97 | 4,7 |
| 235—57.12—VEP | 23+ | 26+ | 4,1 | 1,2 | 0,82 | 2,2 | 2,1 | 0,24 | 31 | 90,66 | 1,49 | 10,95 | 5,61 | 0,88 | 12,38 |
| 304—75.5 —VEP | 4,5 | 5,4 | 2,5 | 1,2 | 0,26 | 1,7 | 0,75 | 0,16 | 166+ | 182,47+ | 0,08+ | 6,0 | 1,80 | 0,83 | 7,2 |
| 305—75.6 —VEP | 3,4 | 5,3 | 2,0 | 0,67 | 0,40 | ND | 1,1 | 0,22 | 10 | 23,49 | 0,94 | 3,09 | 1,7 | 0,64 | 4,82 |
| $\overline{x}$ | 6,9 | 10,98 | 3,42 | 1,37 | 0,56 | 1,37 | 1,3 | 0,27 | 35,08 | 62,41 | 0,87 | | | | |
| $\overline{x}^+$ | 4,28+ | 5,2+ | 2,88+ | | | | 1,08+ | 0,29+ | 25,20+ | 51,50+ | 0,95+ | | | | |

Contents of rare earths in metabasites of the Veporide crystalline (VEP)

Table 5
Spišsko-gemerské rudohorie Mts. — SGR

| Sample No. | La | Ce | Sm | Eu | Tb | Tm | Yb | Lu | Y | $\sum TR$ | $\frac{\sum Ce}{\sum Y}$ | La/Yb | La/Sm | La/Ce | Ce/Yb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AM—29—SGR | ND | 18 | 3,4 | 2,0 | 0,34 | ND | 4,0 | 0,68 | 33 | 62,82 | 0,64 | — | — | — | 4,5 |
| AM—30—SGR | 1,9 | 2,1 | 2,1 | 0,75 | 0,46 | 1,5 | 0,72 | 0,13 | 25 | 34,66 | 0,25 | 2,64 | 0,4 | 0,9 | 2,92 |
| AM—31—SGR | 6,5 | — | 1,7 | — | — | — | — | — | 26 | — | — | — | 3,82 | — | — |
| AM—32—SGR | 5,1 | 6,7 | 3,1 | 1,5 | 0,40 | ND | 1,0 | 0,18 | 26 | 44,38 | 0,59 | 5,1 | 1,65 | 0,76 | 6,7 |
| AM—34—SGR | 32+ | 31+ | 9,1+ | 3,7 | 0,90 | 2,2 | 1,6 | 0,16 | 42 | 122,66+ | 1,62+ | 20+ | 3,52 | 1,03 | 19,38 |
| $\overline{x}$ | 9,3 | 14,45 | 3,88 | 1,99 | 0,53 | 1,13 | 1,83 | 0,29 | 30,4 | 66,13 | 0,78 | | | | |
| $\overline{x}^+$ | 3,63+ | 8,93+ | 2,58+ | | | | | | | 47,29+ | 0,49+ | | | | |

Contents of rare earths in metabasites of the Spišsko-gemerské rudohorie Mts. (SGR)

Table 6

| Mountain range | | La | Ce | Sm | Eu | Tb | Tm | Yb | Lu | Y | ΣTR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MK | A.p. | 4,55 | 7,87 | 2,85 | 1,56 | 0,43 | 0,99 | 1,34 | 0,36 | 26,9 | 46,20 |
| n = 10 | s.v. | 4,30 | 8,76 | 1,31 | 0,65 | 0,18 | 0,47 | 1,01 | 0,20 | 9,4 | 21,65 |
| | v.k. | 94,60 | 111,33 | 45,99 | 41,78 | 42,52 | 47,96 | 75,77 | 56,05 | 34,98 | 46,87 |
| | G.p. | 2,94 | 4,11 | 2,54 | 1,45 | 0,39 | 0,87 | 0,91 | 0,32 | 25,44 | 41,48 |
| I.T.S.M. | A.p. | 7,36 | 14,64 | 4,84 | 2,02 | 0,58 | 0,96 | 1,76 | 0,30 | 35,40 | 71,69 |
| n = 5 | s.v. | 5,07 | 11,60 | 1,21 | 0,25 | 0,16 | 0,53 | 0,80 | 0,20 | 13,97 | 19,96 |
| | v.k. | 68,97 | 79,29 | 25,2 | 12,81 | 27,62 | 55,41 | 45,86 | 65,79 | 39,47 | 27,84 |
| | G.p. | 5,32 | 11,25 | 4,71 | 2,00 | 0,56 | 0,81 | 1,62 | 0,26 | 33,29 | 69,53 |
| MF, NT, VT, | A.p. | 9,28 | 11,43 | 4,89 | 1,64 | 0,56 | 1,11 | 1,52 | 0,24 | 33,30 | 63,99 |
| n = 10 | s.v. | 6,81 | 10,08 | 2,73 | 0,60 | 0,17 | 0,62 | 0,51 | 0,05 | 12,41 | 25,01 |
| | v.k. | 73,43 | 88,23 | 55,99 | 36,60 | 30,75 | 55,85 | 33,80 | 21,17 | 37,26 | 39,09 |
| | G.p. | 6,85 | 7,26 | 4,29 | 1,54 | 0,54 | 0,95 | 1,45 | 0,24 | 31,28 | 59,49 |
| VEP | A.p. | 6,90 | 10,98 | 3,42 | 1,27 | 0,55 | 1,37 | 1,30 | 0,27 | 35,08 | 62,41 |
| n = 12 | s.v. | 6,63 | 11,01 | 2,07 | 0,64 | 0,27 | 0,69 | 0,93 | 0,13 | 42,11 | 44,84 |
| | v.k. | 96,16 | 100,32 | 60,69 | 36,68 | 48,98 | 50,55 | 71,93 | 48,94 | 120,05 | 71,85 |
| | G.p. | 4,66 | 7,17 | 2,96 | 1,19 | 0,50 | 1,18 | 1,06 | 0,24 | 23,84 | 50,13 |
| SGR | A.p. | 10,00 | 14,45 | 4,42 | 1,98 | 0,52 | 1,12 | 1,83 | 0,28 | 31,50 | 66,13 |
| n = 4 | s.v. | 14,77 | 12,89 | 3,16 | 1,25 | 0,25 | 0,88 | 1,49 | 0,26 | 7,85 | 39,45 |
| | v.k. | 147,71 | 89,26 | 71,54 | 62,98 | 68,52 | 78,63 | 81,55 | 91,29 | 24,92 | 59,66 |
| | G.p. | 4,19 | 9,41 | 3,76 | 1,69 | 0,48 | 0,85 | 1,46 | 0,22 | 30,80 | 58,67 |
| TATRIDES | A.p. | 7,00 | 10,65 | 4,06 | 1,68 | 0,51 | 1,03 | 1,49 | 0,30 | 31,16 | 58,41 |
| n = 25 | s.v. | 5,77 | 9,80 | 2,17 | 0,58 | 0,18 | 0,53 | 0,78 | 0,16 | 11,69 | 24,26 |
| | v.k. | 82,45 | 92,10 | 53,50 | 34,44 | 35,23 | 51,34 | 52,60 | 53,00 | 37,52 | 41,54 |
| | G.p. | 4,65 | 6,31 | 3,55 | 1,59 | 0,48 | 0,88 | 1,23 | 0,27 | 29,16 | 53,13 |
| TATRIDES + VEP | A.p. | 6,97 | 10,75 | 3,85 | 1,55 | 0,52 | 1,14 | 1,43 | 0,29 | 32,43 | 59,71 |
| n = 37 | s.v. | 5,97 | 10,06 | 2,13 | 0,57 | 0,21 | 0,60 | 0,83 | 0,15 | 25,23 | 31,79 |
| | v.k. | 85,70 | 93,54 | 55,39 | 36,94 | 40,07 | 42,49 | 57,94 | 51,56 | 77,79 | 53,24 |
| | G.p. | 4,65 | 6,58 | 3,34 | 1,44 | 0,48 | 0,97 | 1,17 | 0,26 | 27,31 | 52,14 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TATRIDES + VEP | A.p. | 7,26 | 11,11 | 3,91 | 1,59 | 0,52 | 1,14 | 1,47 | 0,29 | 32,34 | 60,33 |
| +SGR | s.v. | 7,02 | 10,23 | 2,21 | 0,65 | 0,21 | 0,61 | 0,89 | 0,16 | 24,03 | 32,09 |
| n = 41 | v.k. | 96,65 | 92,09 | 56,51 | 41,15 | 40,27 | 54,20 | 60,83 | 54,77 | 74,31 | 53,19 |
| | G.p. | 4,60 | 6,81 | 3,38 | 1,47 | 0,48 | 0,96 | 1,20 | 0,26 | 27,64 | 52,74 |

Summary table of arithmetic and geometric means, standard deviations and variation coefficients in the studied groups of the Tatraveporides and Gemerides. In statistical treatment the following values were substituted for under-limit contents (MD): La-1, Ce-1, Eu-0,25, Tb-0,1, Tm-0,4, Yb-0,15, Lu-0,1. For incompleteness of data were eliminated from the treated groups the analyses AM-7.1-MK, AM-11.10-MK, AM-31-SGR.

Table 7

Anomalous TR contents

| Sample No. | La | Ce | Sm | Eu | Tb | Tm | Yb | Lu | Y | $\sum TR$ | $\frac{\sum Ce}{\sum Y}$ | $K_2O$ | $K_2O + Na_2O$ | $TiO_2$ | $SiO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AM—12.10—MK | 13,5 | 29 | 4,3 | 1,9 | 0,55 | 1,2 | ND | 0,25 | 28 | 78,85 | 1,62 | 0,91 | 1,25 | 1,89 | 54,61 |
| AM—34—SGR | 32 | 31 | 9,1 | 3,7 | 0,90 | 2,2 | 1,6 | 0,16 | 42 | 122,66 | 1,62 | 0,04 | 2,93 | 3,94 | 49,20 |
| 133—24.3—MF | 18,5 | 16 | 9,4 | 2,7 | 0,75 | 2,4 | 2,3 | 0,32 | 54 | 106,37 | 0,78 | 0,57 | 1,87 | 3,24 | 50,39 |
| 136—25.2—MF | 12,0 | 23 | 9,6 | 2,2 | 0,9 | 1,5 | 1,8 | 0,23 | 20 | 71,23 | 1,92 | 1,63 | 3,69 | 1,5 | 50,92 |
| 188—37.1—NT | 13,5 | 31 | 2,7 | 0,9 | 0,64 | 1,3 | 1,4 | 0,22 | 38 | 89,66 | 1,16 | 0,70 | 2,04 | 2,49 | 49,98 |
| 148—29.2—VT | 21 | 18 | 5,2 | 2,3 | 0,6 | 1,2 | 1,1 | 0,23 | 33 | 82,63 | 1,29 | 0,60 | 4,11 | 1,98 | 50,50 |
| AM—39.13—T | ND | 33 | 3,7 | 2,4 | 0,8 | ND | 3,0 | 0,66 | 57 | 101,96 | 0,65 | 0,87 | 5,16 | 2,3 | 50,82 |
| AM—26—VEP | 17 | 36 | 4,3 | 2,3 | 0.8 | 1.1 | 1,1 | 0,28 | 29 | 91,88 | 1,85 | 0,72 | 3.2 | 2,56 | 48,36 |
| AM—27—VEP | 8,1 | 23 | 4,4 | 1,6 | 0,48 | ND | 0,56 | 0,30 | 23 | 61,84 | 1,50 | 1,33 | 2,32 | 0,79 | 54,20 |
| 235—57.12—VEP | 23 | 26 | 4.1 | 1,2 | 0,82 | 2,2 | 2,1 | 0,24 | 31 | 90,66 | 1,49 | 0,78 | 6,21 | 1,05 | 54,20 |
| AM—23—VEP | 1.1 | 3,4 | 0,8 | 0,5 | 0,30 | 0,90 | 0,32 | 0,06 | 3 | 10,38 | 1,27 | 0,20 | 3,04 | 0,32 | 54,03 |
| 304—75.5—VEP | 4,5 | 5,4 | 2,5 | 1,2 | 0,26 | 1,7 | 0,75 | 0,16 | 166 | 182,47 | 0,08 | 1,04 | 1,75 | 0,62 | 48,37 |

Analyses of samples with anomalous TR content in metabasites of the West Carpathians first including all values and the second (with cross) not including the values designated with cross.

In the histograms (Figs 1, 2) a particular hatching was used for each group. On the basic of frequency distribution in histograms of individual elements of rare earths we may state that TR contents are approximately equal in all mountain ranges, testifying to a similar genetic position of metabasites of the West Carpathians. How as it is to be seen from numerical evalution and form histograms, all the studied metabasites display similar, relatively primitive TR distri-

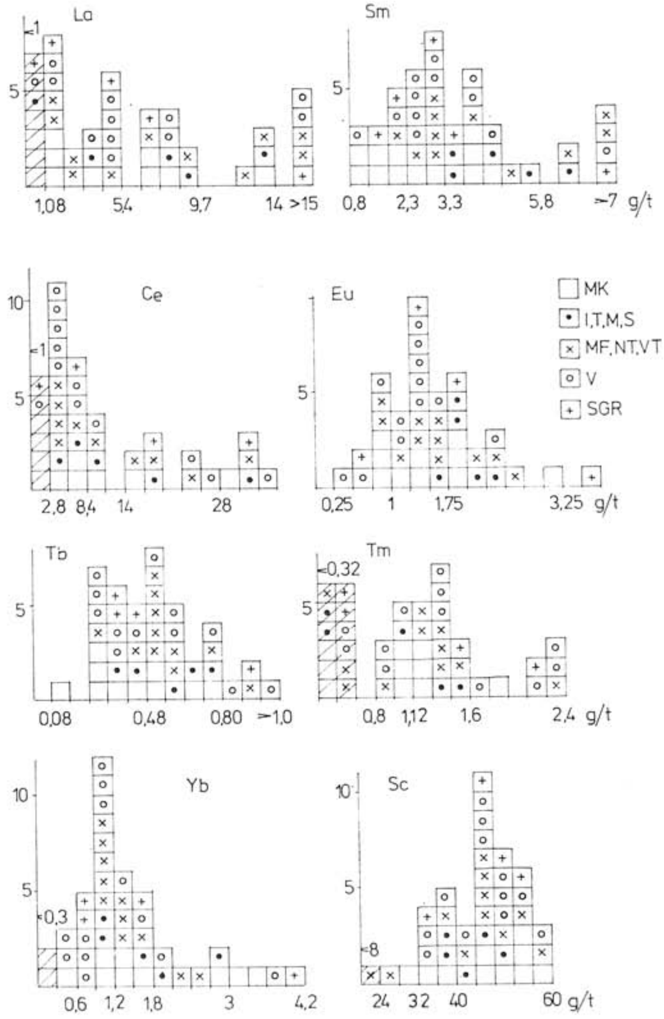


Fig. 1 Histograms of La, Sm, Ce, Eu, Tb, Tm, Yb, Sc contents in metabasites of the West Carpathians. MK — Little Carpathians. ITSM — mountains of Inovec, Tribeč, Suchý, Malá Magura, NT, VT, MF — mountains of Low Tatra, High Tatra, Malá Fatra, VEP — Veporide crystalline, SGR — Spišskogemerské rudohorie.

bution. Higher contents, manly of light TR (Table 7) have rocks, which are near or in direct contact with graphites, feldspthized amphibolic rocks from zones of migmatization and rocks highly tectometamorphically affected (diaphthorized).

The correlation relation between the content of alkalies (Figs 3, 4, 5) and content of La or La/Yb, $\sum Ce/\sum Y$ in the studied rocks are not clear. The best dependence is between ratio $\sum Ce/\sum Y$ and the content of $Na_2O + K_2O + TiO_2$ (Fig. 5). Low correlation between potassium and La or La/Yb gives evidence for weak effect of differentiation processes. (This correlation is typical mainly for residual magmas.) The mentioned facts are in good agreement with up to the present investigations, which speak for little variability of basalt magmas, from which West Carpathian metabasites originated (there are almost no acid and ultrabasic members).

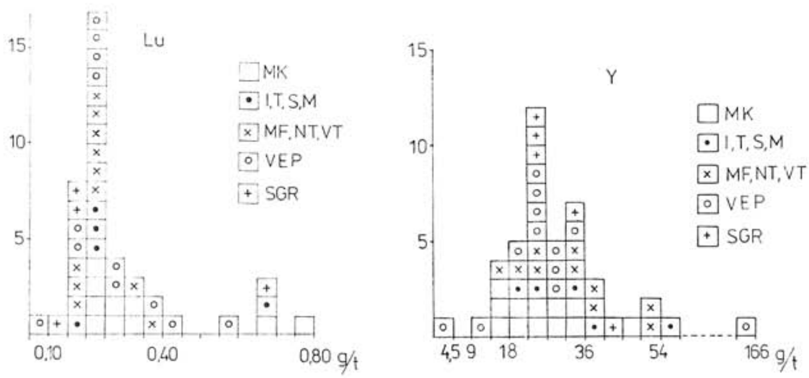


Fig. 2. Histograms of Lu and Y distribution in metabasites of the West Carpathians. Explanations as in Fig. 1.

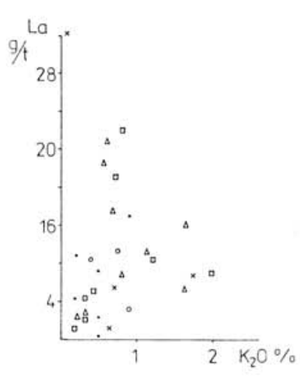


Fig. 3. Graph of dependence of La content on the content of $K_2O$. Analyses with under-limit content of La were not included in the graph. Explanations as in Fig. 1.

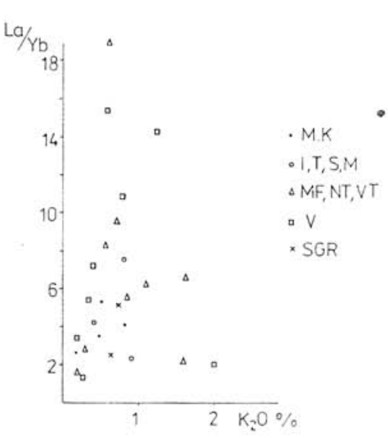


Fig. 4. Graph on dependence of La/Yb ratio on $K_2O$ content. Explanations as in Fig. 1.

In metamorphosis no distinct redistribution of rare earths takes place G. K. Muecke et al. (1978). The mentioned authors established in the study of amphibolites in contact with metapelites that in spite of various changes of chemical composition, mainly in alkales, no change of TR content and some other elements (Ti, P, Zr, Hf, Nv, Ta) took place in these rocks. It results that on the basis of TR distribution in metabasites the primary character of the studied rocks can be determined.

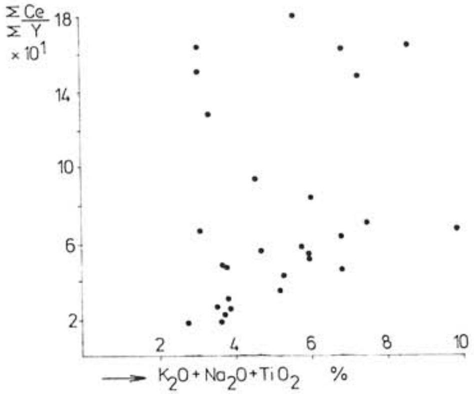


Fig. 5. Graph of dependence of ratio $\sum Ce/\sum Y$ on content of $K_2O + Na_2O + TiO_2$ in metabasites of the West Capathians. $\sum Ce = La + Ce + Sm + Eu$, $\sum Y = Tb + Tm + Yb + Lu + Y$

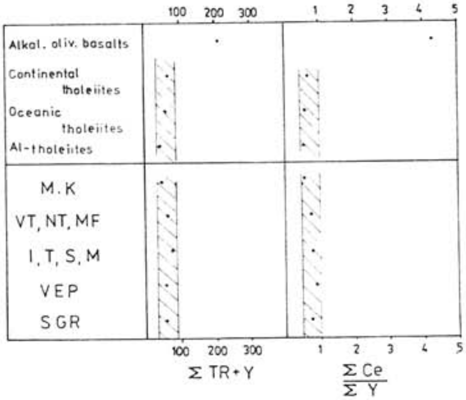


Fig. 6. Comparison $\sum$ TR + Y and ratio $\sum Ce/\sum Y$ in metabasites of the West Carpathians with various basalt types according to J. A. Balašov (1976). $\sum TR + Y = La + Ce + Sm + Eu + Tb + Tm + Yb + Lu + Y$, $\sum Ce/\sum Y$as in Fig. 5.

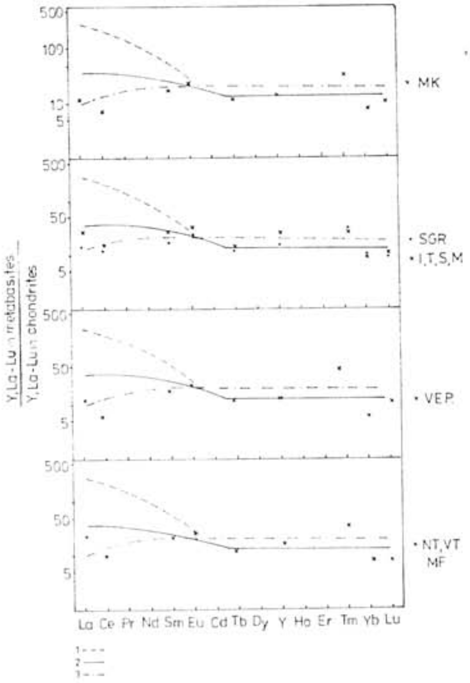


Fig. 7. Contents of rare earths in individual mountain ranges compared with various basalt types according to Herrman et al. 1970. The TR contents are normalized by TR content in chondrite meteorites (Haskin L. A. et al., 1968). 1 — alkalic olivine basalt, 2 — continental tholeiite, 3 — oceanic tholeiite.

In Figs. 6, 7, 8 we plotted the contents of individual rare earths (Tables 1, 2, 3, 4, 5) normalized by the average TR content in chondritic meteorites (L. A. Haskin et al., 1968). As is to be seen from Figs 6, 7, 8 metabasites of the West Carpathians show TR distribution close to the oceanic tholeiites. On the contrary to oceanic tholeiites they are relatively enriched in La, Eu and Tm and impoverished in Ce, Tb, Yb, Lu. It is to be seen in Fig. 8 mainly, where the scale is extended on purpose. To a similar conclusion we may come also when

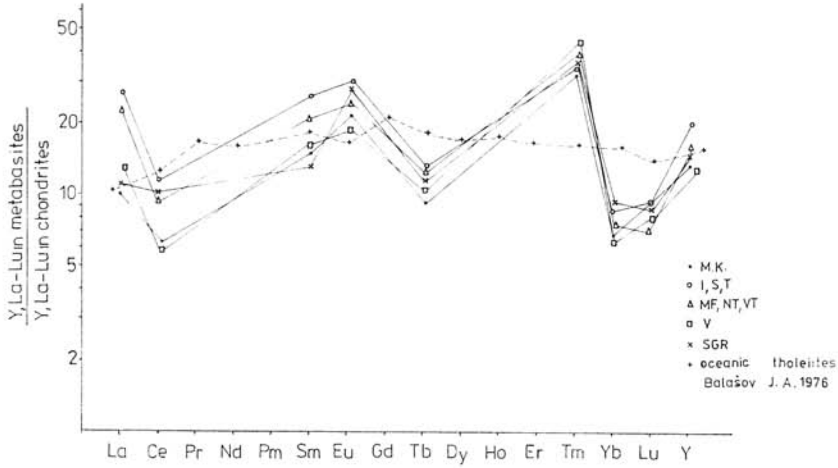


Fig. 8. Contents of rare earths in West Carpathian metabasites normalized by TR content in chondrite meteorites (Haskin L. A. et al. 1968).

comparing the average TR contents in metabasites of the West Carpathians (Table 6) with TR contents in various types of basic rocks according to data from literature (Table 8). Differences in TR contents are also between individual mountain ranges (Table 6). The highest contents of rare earths (TR) show metabasites of the Tribeč and Malá Magura; the lowest ones metabasites of the Little Carpathians.

We observe a good correlation in the graph of dependence of ratio of light to heavy TR ($\sum Ce/\sum Y$) on the total content of rare earths ($\sum TR$) — Fig. 9.

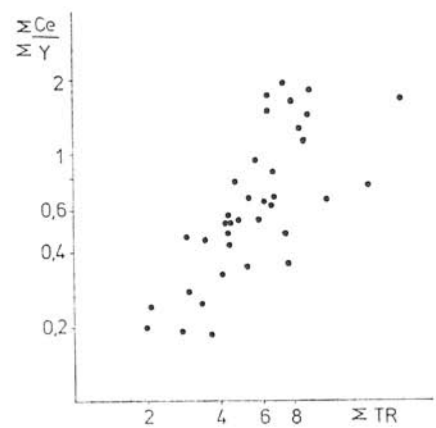


Fig. 9. Graph of dependence of $\sum Ce/\sum Y$ ratio to total TR content. Explanations as in Fig. 6.

Table 8
Content (in ppm) of rare earths in basites

| Rock/locality | No. of determinations | La | Ce | Pr | Nd | Sm | Eu | Gd |
|---|---|---|---|---|---|---|---|---|
| 1. chondrites | 20 | 0,3 | 0,84 | 0,12 | 0,58 | 0,21 | 0,74 | 0,32 |
| 2. alkal. basalts basanites | 5 | 141,1 | 249,5 | — | — | 20 | 4,29 | — |
| 3. alkal. basalt/Iceland | | 13,1 | 29,9 | — | 17,0 | 3,81 | 1,54 | — |
| 4. kimberlites/totally | | 107,2 | 213,6 | 16,05 | 87,9 | 13,7 | 3,23 | 8,4 |
| 5. basalt/East Alps Rom. | 1 | 20 | 44 | 4,1 | 16,8 | 3,28 | 0,90 | 2,82 |
| 6. Al-basalts/A Sardinia | 8 | 15,03 | 33,11 | — | 22,2 | 3,95 | 1,12 | 3,93 |
| 7. basalts/Appenines | | 4,4 | 13 | — | — | — | — | — |
| 8. plateau-basalts/ Iceland | 15 | 11,8 | 27,8 | — | 17,5 | 5,13 | 1,8 | 6,22 |
| 9. basalts/Iceland | 14 | 11,5 | 26,1 | — | 16,2 | 4,3 | 1,5 | 5,34 |
| 10. basalts/Japan | | 23 | 44,0 | — | — | 5,4 | 1,5 | — |
| 11. basalts/Cyprus | | — | 2,02—3,22 | — | 1,96—3,57 | 0,83—1,37 | 0,31—0,68 | 1,11—1,61 |
| 12. metabasalts/Cyprus | | — | 0,70—0,94 | — | 0,77—9,89 | 0,42—3,95 | 0,19—1,41 | 0,89—3,94 |
| 13. tholeiitic basalt | | 10,4 | 26,1 | — | 18,9 | 5,3 | 1,9 | — |
| 14. tholeiite/Atl. Ocean | 6 | 2,85 | 5,0 | 1,11 | 4,28 | 1,59 | 0,55 | — |
| 15. tholeiite/Japan | 8 | 2,75 | 10,7 | — | — | 2,8 | 2,07 | — |
| 16. tholeiites | 64 | 3,36 | 10,3 | 1,87 | 9,87 | 3,49 | 1,26 | 5,05 |
| 17. higly Al-tholeiites tholeiites with | 17 | 3,10 | 8,71 | 1,58 | 7,86 | 2,80 | 1,03 | 3,46 |
| 18. $Al_2O_3$ 16 % | 47 | 3,46 | 10,83 | 1,97 | 10,6 | 3,75 | 1,34 | 5,43 |
| 19. tholeiites/oceanic tholeiites/Siberian | 7 | 4,3 | 14,9 | 2,5 | 14,0 | 4,7 | 1,6 | 7,1 |
| 20. platform | 163 | 13 | 29 | 4,3 | 16,5 | 4,2 | 1,3 | 4,7 |
| 21. orthoamphibolites (USSR) | | 24 | 51,5 | 7,2 | 31,0 | 7,4 | 1,8 | 6,7 |

and metabasites

| Tb | Dy | Ho | Er | Tm | Yb | Lu | Y | $\Sigma TR + Y$ | $\frac{\Sigma Ce}{\Sigma Y}$ | Reerences |
|---|---|---|---|---|---|---|---|---|---|---|
| 0,49 | 0,31 | 0,73 | 0,21 | 0,33 | 0,17 | 0,31 | 1,8 | 5,12 | 0,9 | Haskin et al. 1966 |
| 2,27 | 11,0 | — | — | — | 4,9 | 0,9 | | | | Battaglia M. et al. 1976 |
| — | 3,42 | — | 1,77 | — | 1,62 | 0,238 | | | | Kay R. et al. 1978 |
| 1,08 | 1,88 | 0,41 | 1,34 | 0,14 | 0,89 | 0,11 | 15,5 | 471,43 | | Kaminskij F. V. et al. 1978 |
| 0,49 | 2,96 | 0,62 | 1,83 | 0,3 | 1,84 | 0,28 | 19 | 119,2 | | Peccerillo A. et al. 1976 |
| 0,65 | — | 0,83 | — | — | 2,25 | 0,359 | | | | Dostal J. et al. 1976 |
| — | — | — | — | — | — | — | 41 | | | Ferrara G. et al. 1976 |
| — | 6,18 | — | 3,3 | — | 3,1 | 0,4 | 34 | | | Gerasimovskij V. I. et al 1978 |
| — | 4,84 | — | 3,1 | — | 3,9 | 0,44 | 30 | | | Gerasimovskij V. I. et al 1978 |
| 0,78 | — | — | — | — | 2,6 | 0,43 | | | | Nishimura S. et al. 1976 |
| 0,52—0,47 | — | — | ND | 0,24—0,28 | 1,19—1,89 | 0,21—0,33 | | | | Smewing I. et al. 1976 |
| ND—0,93 | — | — | 1,65—2,96 | 0,25—0,68 | 1,13—4,1 | 0,3—0,068 | | | | Smewing I. et al. 1976 |
| — | 5,56 | — | 2,79 | — | 2,29 | — | | | | Mac Donald et al. 1964 |
| 1,0 | 2,01 | 0,57 | 1,94 | 0,27 | 1,2 | 0,22 | | | | Graham et al. 1969 |
| 0,77 | — | — | — | — | 3,7 | 0,5 | | | | Masuda et al. 1973 |
| 0,86 | 5,22 | 1,24 | 3,48 | 0,5 | 3,2 | 0,49 | 31,7 | 82 | 3,22 | Balašov J. A. 1976 |
| 0,73 | 3,94 | 0,97 | 2,82 | — | 2,43 | 0,39 | 29,5 | 65,5 | 3,58 | Balašov J. A. 1976 |
| 0,91 | 5,69 | 1,34 | 3,72 | — | 3,49 | 0,55 | 34 | 91,5 | 3,10 | Balašov J. A. 1976 |
| 1,3 | — | 1,7 | 4,9 | 0,8 | 4,0 | 0,7 | 39,3 | 101,7 | | Haskin et al. 1966 |
| 1,3 | 4,3 | 1,3 | 2,5 | — | 2,0 | 0,4 | 23 | 108 | | Balašov et al. 1966 |
| 0,9 | 4,1 | 0,96 | 2,4 | — | 1,9 | — | 28 | 170 | 2,7 | Sidorenko A. V. et al. 1972 |

Continuation of Table 8

| Rock/locality | No. of determinations | La | Ce | Pr | Nd | Sm | Eu | Gd |
|---|---|---|---|---|---|---|---|---|
| 22. orthoamphibolites (USSR) thermolit. amphibolites | | 14,0 | 31,0 | 4,5 | 17,5 | 5,3 | 0,85 | 4,9 |
| 23. (USSR) | | 11,0 | 20,0 | 2,7 | 11,0 | 3,1 | 0,77 | 2,9 |
| 24. paraamphibolites (USSR) | | 6,4 | 13,0 | 2,2 | 10,3 | 3,5 | 0,64 | 4,8 |

TR contents in various types of basalt rocks according to data from literature

## *Conclusion*

1. It results from the distribution of rare earths in metabasites of the West Carpathians that the primary magma, from which metabasites of the Tatraveporides formed, was of tholeiitic character and was close to oceanic tholeiites.

2. The relations between the individual elements or their groups ($\sum Ce/\sum Y$) and also the total TR content confirm the tholeiitic character of magma.

3. The low contents of light TR compared with the content of alkalies and their low mutual correlation we can explain in a part of samples by additional enrichment of rocks in alkalies during metamorphosis, with preservation of original tholeiitic distribution of rare earths.

4. Europium, in comparison with samarium, has always lower contents. It is not a positive anomaly of europium, typical for basic magmas with primitive TR distribution.

5. From the distribution of rare earths in metabasites and comparison with contents of some little mobile elements we can conclude that the contents of rare earths did not relatively change in the process of metamorphosis and therefore on the basis of their distribution we can with sufficient certainty consider the primary character of studied rocks.

6. The similarity of contents of individual elements of the group of rare earths individual mountain ranges of the Tatraveporides but also of metabasites of the Spišsko-gemerské rudohorie Mts. testified to genetic affinity of these rocks.

7. If we take into consideration the present-day palynological and nuclear-geochronological data, then a Paleozoic, at most Late Proterozoic age of these rocks should be supposed. This also testifies that in the Early Paleozoic period (under the pre-Variscan sea) the crust was relatively thin, disturbed by faults and sutures making possible ascent of basalt magmas from the mantle. The processes of collision of the North European and South European subcontinent

| Tb | Dy | Ho | Er | Tm | Yb | Lu | Y | $\sum TR + Y$ | $\frac{\sum Ce}{\sum Y}$ | References |
|---|---|---|---|---|---|---|---|---|---|---|
| 0,87 | 3,6 | 0,63 | 1,95 | — | 1,8 | — | 27 | 115 | 1,8 | Sidorenko A. V. et al. 1972 |
| 0,66 | 2,1 | 0,44 | 1,75 | — | 1,55 | — | 17 | 75 | 1,8 | Sidorenko A. V. et al. 1972 |
| 0,77 | 4,5 | 0,96 | 3,50 | — | 2,8 | 0,6 | 34 | 89 | 0,68 | Sidorenko A. V. et al. 1972 |

in the Early Paleozoic (B. Cambel, K. Patočka, 1979; in press) caused underthrusting of lithospheric plates under the subcontinents and formed conditions for basic magmas ascending from the upper mantle.

Translated by J. Pevný

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Review by D. HOVORKA Manuscript received February 21, 1979