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Chemistry of the Bohemian granitoids: Geotectonic and metallogenic implications

Chemismus českých granitoidů: geotektonické a metalogenetické implikace

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Abstract: Nine pre-Variscan and 40 Variscan granitoid types in Bohemia have been defined on the basis of statistical evaluation of more than 700 chemical analyses.

Pre-Variscan granitoids in non-metamorphosed state were studied in the Bohemicum and Lugicum blocks. The Lusatian massif is metallogenically most specialized with the longest differentiation suite consisting of granodiorite to highly differentiated (Tanvald) granite, typical for the late orogenic intra-block setting. The Chvaletice granite exhibits the characteristics of anorogenic granites emplaced at the onset of continental rifting. Other massifs (Kladruby, Stod, and Tis) reprezent a comon calc-alkaline granitoids.

Four groups of Variscan granitoids can be identified:

- group of tonalite-granite plutons located at major block boundaries (the Central Bohemian and the Železné hory plutons), without any granite-related mineralizations,
- group of granodiorite-granite plutons within consolidated crystalline blocks (e. g. the Karlovy Vary, the Moldanubian and the Krkonoše plutons), accompanied in particular by Sn and W mineralizations,
- group of acidic volcano-plutonic complexes linked with late Variscan extensional tectonics in the eastern Krušné hory Mts., accompanied by Sn and W mineralization similar to the previous group,
- group of granodiorites with a primitive chemistry and with manifestations of alkaline metasomatism (the Čistá and Štěnovice massifs).

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1. Introduction

The Bohemian Massif is one of the fundamental structural units of the eastern branch of European Variscides (Suess 1888, Kossmat 1927, Franke 1989). A correct interpretation of the geological setting (geotectonic position) of granitoid plutons can provide valuable information for proper understanding of the geological evolution of the Bohemian Massif and its position within the Variscan system. The geotectonic interpretation is also closely related to the metallogenic one, being widely applicable in exploration for mineral raw materials.

Apart from classifications based on modal analysis (Streckeisen 1976) or on norm systems (e.g. La Roche et al. 1980), granitoids can also be classified according to the style of associated mineralization (the Russian school, e. g. Tauson 1977) or according to their geotectonic setting (Chappell - White 1974, Loiselle - Wones 1979, Pearce et al. 1984, Pitcher 1987 etc.). All these classifications have been applied to the Bohemian Massif, e. g. by Sattran and Klomínský (1970), based on metallogenic criteria, or Jakeš and Pokorný (in Vacek et al. 1983) and Klomínský (1988), according to geotectonic setting. However all these previous studies were either based on analyses of major elements only or on incomplete and heterogeneous data on trace elements.

The project "Regional Geochemistry of the Bohemian Massif" (Čadková et al. 1984) collected sufficiently reliable data on the content of a large spectrum of trace elements from most of the granitoid plutons of the Bohemian Massif. This database enabled a non-biased statistical evaluation of evolutionary trends of the individual plutons and a new view of their geotectonic and metallogenic classification.

This paper focuses on granitoids within the tonalite-granite range, without considering the associated mafic and durbachitic rocks. Granitoids of the Brunovistulicum block, on which we lack suitable data, have not been classified.

2. Data sources

Our classification is based on a set of 550 chemical analyses of granitoids gathered within the project "Regional Geochemistry" (Čadková et al. 1984), which covered almost all granitoid massifs of Bohemia. This set of so far most complex analyses includes besides the major oxides, more than 30 trace elements determined by in the early lighties available methods.

Analyzed were:
– major elements: SiO_2, TiO_2, Al_2O_3, Fe_2O_3, FeO, MnO, MgO, CaO, Li_2O, Na_2O, K_2O, P_2O_5, F, S, C_{org}, CO_2, H_2O^+, H_2O^- (wet chemistry in the laboratories of the Czech Geological Survey, Praha),
– trace elements (XRF): As, Ba, Cr, Nb, Ni, Rb, Sr, W, Y, Zn, Zr (laboratory of the Unigeo, Brno),
– trace elements (optical emission spectroscopy): Ag, B, Be, Bi, Cu, Mo, Pb, Sn, V (laboratories of the Czech Geological Survey, Praha),
– trace elements (neutron activation): REE, Cs, Hf, Sb, Sc, Ta (laboratory of the Geoindustria, Černošice),
– trace elements (gamma spectrometry): U, Th (laboratory of the Geofyzika, Brno).

For areas which were insufficiently sampled within the regional geochemical project (the Krušné hory Mts., the Orlické hory Mts.) or not included (the Kladruby and Rozvadov massifs, some sections of the Moldanubian pluton), the data set was supplemented by unpublished analyses from research reports dated between 1985–1994, mostly carried out by identical methods.

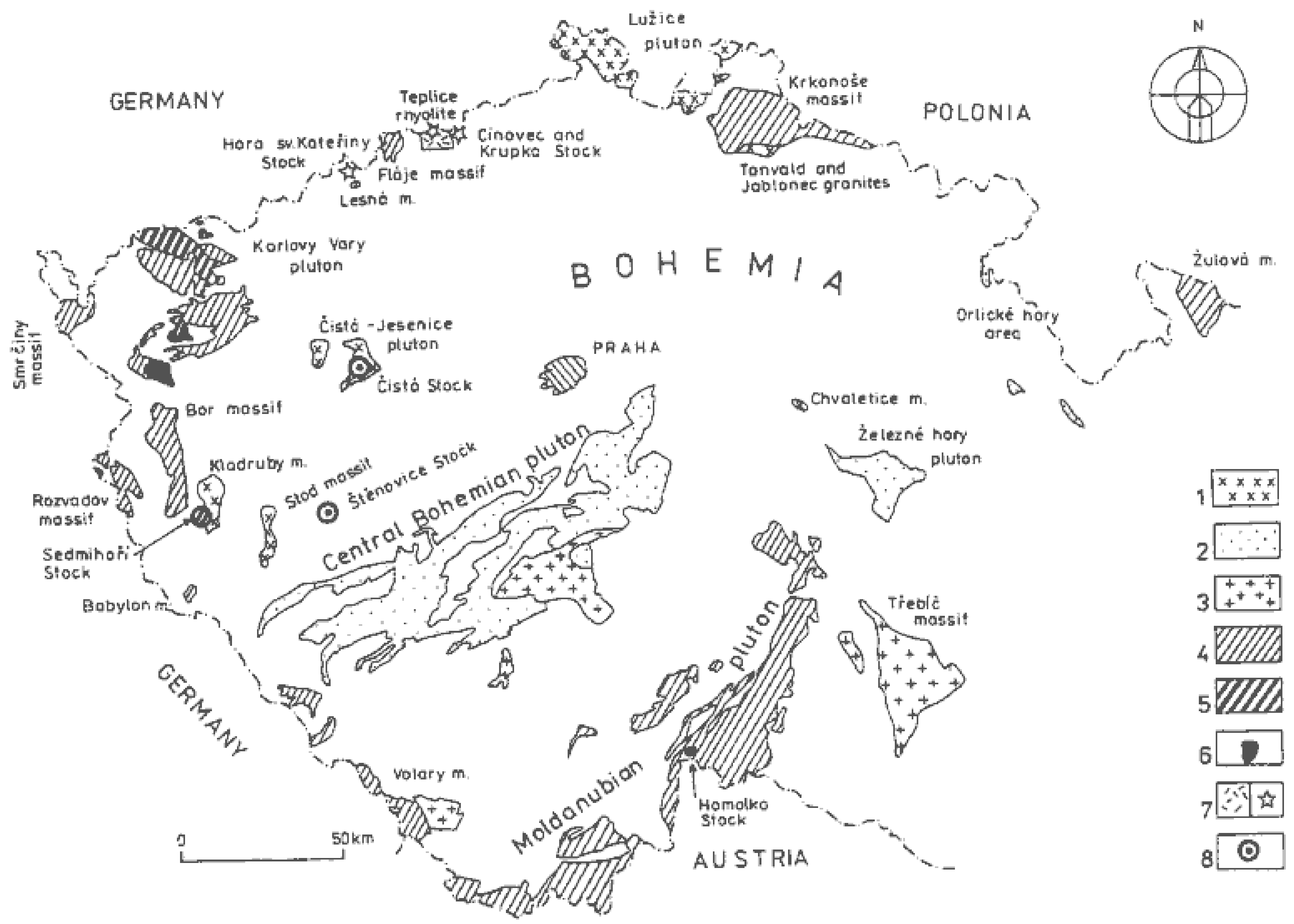
A serious drawback of the data by Čadková et al. (1984) is the absence of major element analyses from the Central Bohemian pluton. For these are as we use data by Vejnar (1973), Holub (this volume) and unpublished data by various authors.

3. Data processing

The chemical data were processed using multivariance statistical methods. The elements possibly fulfilling the following criteria were used in the calculation:
– low mobility during weathering
– reliability of analytical procedure
– well-defined petrogenetic interpretability

The elements Ba, Ce, Li, Pb, Rb, Sc, Th, Y and Zr seam to relatively best fulfill these requirements. Subsequent statistical evaluation indicated that the content of Rb, Sr, Zr, Th and Ce provides maximum information and their distribution enables to define individual rock types and evolutionary trends.

Based on cluster analysis, samples within each massif were separated into groups. Homogeneity of the established groups was subsequently verified by the fuzzy set and scatter analysis. The homogeneous sample groups were correlated with a geological map and with petrographic descriptions. If chemical data were in agreement with petrographic ones and the areal distribution of the sample



1. Sketch map of granitoids in Bohemia. 1 – Pre-Variscan plutons; 2–8 – Variscan granitoids: 2 – tonalite-granodiorite plutons; 3 – durbachitic rocks; 4–6 – granodiorite-granite plutons: 4 – less differentiated granitoids; 5 – strong diferentiated granite; 6 – Li-mica granite; 7 – volcano-plutonic complexes: volcanites, granites; 8 – Čistá-type granodiorite.

groups could be cartographically expressed, a rock "type" was defined. By rock type we understand a smallest unit of the intrusive complexes which is, based on our present knowledge, objectively chemically definable and geologically mappable. Yet each type could have been generated as a product of one or several intrusions or processes. More than one petrographic facies were distinguishable in some of the types, even though these facies do not statistically differ from each other in their chemistry. The defined types reflect our present degree of knowledge of the individual massifs. The subdivision in the less known massifs may probably be elaborated in greater detail through further systematic sampling.

After removing the extreme values, average concentrations of all elements were calculated (the most important ones are summarized in Table 1 and 2), basic petrographic characteristics were defined and their distribution was plotted on the map (Fig. 1).

Differentiation trends of the individual plutons and their inter-relations were investigated by factor and correspondence analysis.

4. Characteristics of the rock types

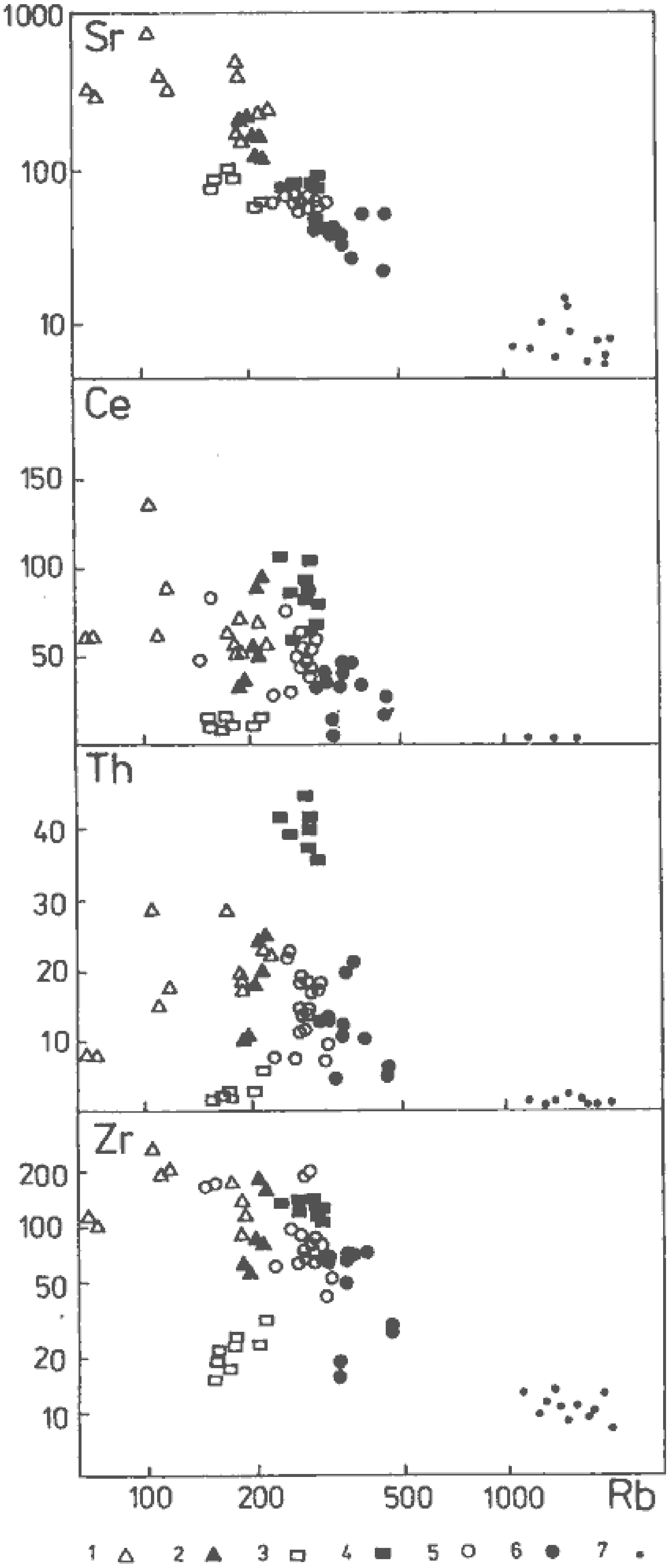
4.1. Pre-Variscan granitoids (Tab. 1)

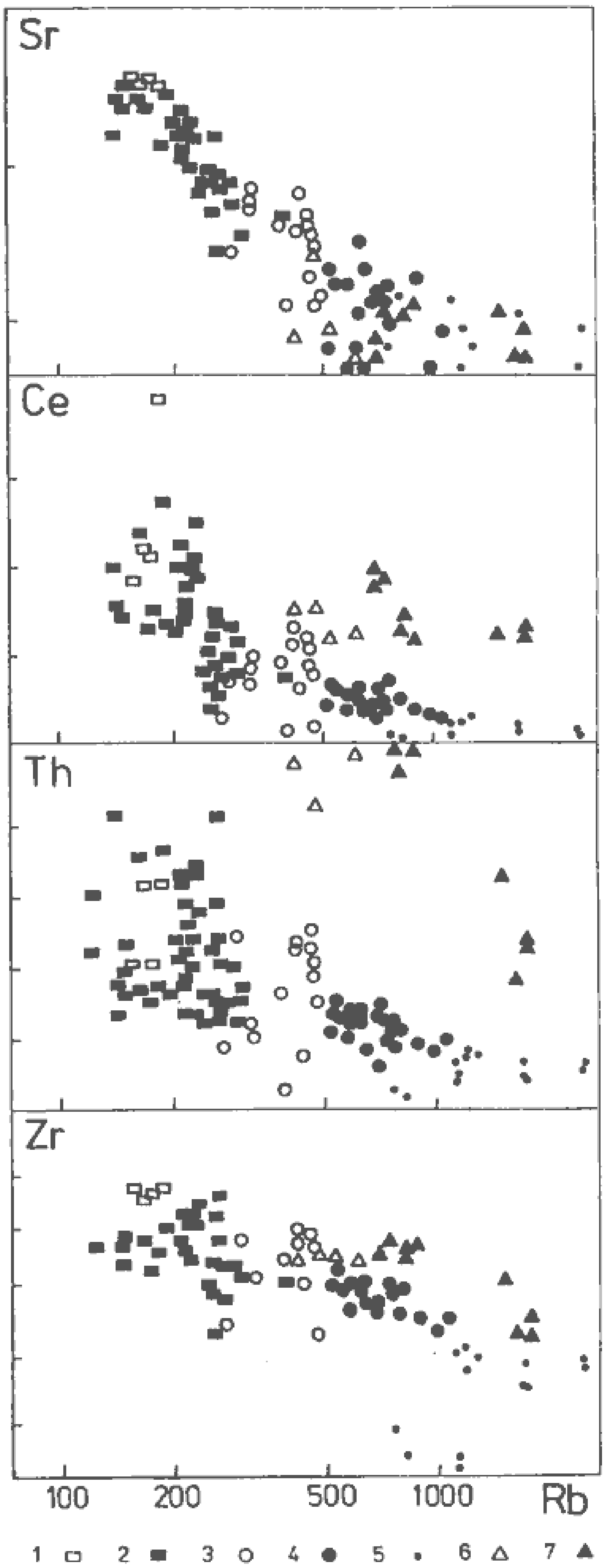
This group includes both reliably dated granitoid plutons (the Stod pluton of Cambrian age, the Lusatian pluton of Cambrian-Ordovician age, and the Kladruby massif of Ordovician age) and bodies as yet undated or dated with little reliability, for whose pre-Variscan age there are geologic indications (the Tis granite, the Tanvald and Jablonec granites and the Chvaletice massif).

The **Stod massif** lies 20 km southwest of Plzeň. It is markedly elongated in N-S direction. The Ar/Ar method corroborated a Cambrian age (518 Ma, Kreuzer et al. 1991). Two rock types have been petrographically distinguished here (Hejtman 1984): the Drnov biotite granite and the Merklín hornblende-biotite granodiorite. Chemically, the massif is inhomogeneous, but the above mentioned petrographic types could not be distinguished. It is characterized by low silica (60–62 %), K_2O (< 2.5 %) and Th contents (Fig. 4, 6a).

Table 1. Chemical characteristics of pre-Variscan granitoids (major elements in wt %, other in ppm)

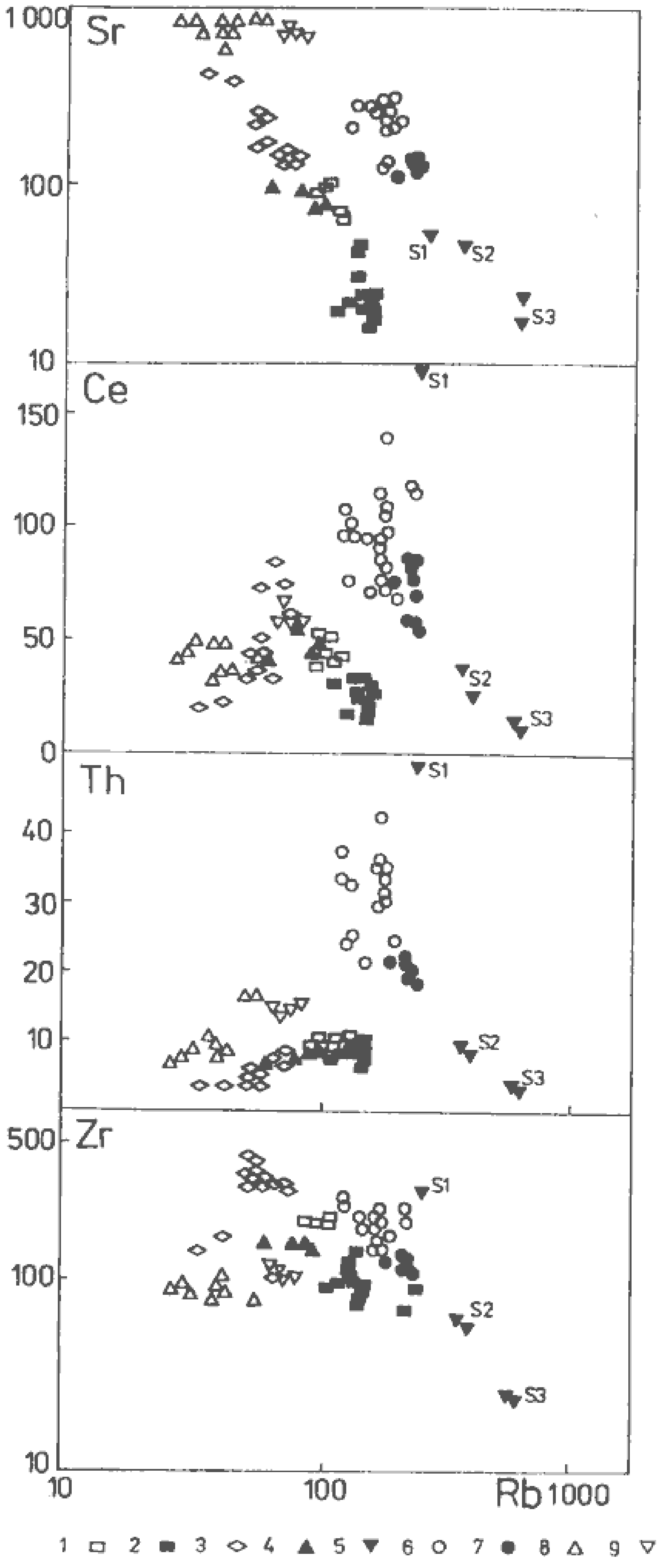
	Lužice pluton				Čistá-Jesenice pluton		Western Bohemia		Chvaletice
	Zawidov granod.	Rumburk granite	Jablonec granite	Tanvald granite	Petrohrad granod.	Tis granite	Stod massif	Kladruby granite	granite
SiO2	66.5	75.3	74.9	74.7	68	74.4	65	72.5	75.7
TiO2	0.7	0.14	0.05	0.02	0.68	0.18	0.7	0.26	0.19
Al2O3	15.6	13.15	13.8	14.6	14.7	13.4	15.8	14.2	12.4
Fe2O3	0.55	0.42	0.29	0.15	0.75	0.3	1	0.7	0.39
FeO	3.9	1.1	0.96	0.76	3.6	1.4	4.4	1.7	1.37
MgO	1.7	0.3	0.17	0.08	1.3	0.3	1.1	0.7	0.25
CaO	2.6	0.55	0.58	0.28	1.8	0.66	3.4	2.1	0.79
Na2O	3.5	2.8	4.1	4.4	3.4	3.6	4.4	4	3.66
K2O	3.5	4.7	4.4	4.3	3.7	4.6	2.1	2.6	4
P2O5	0.25	0.19	0.08	0.13	0.18	0.11	0.2	0.09	0.03
Ba	831	170	70	-50	821	393	832	480	600
Cs	8.1	7.4	15	38	4	6	3	6	3.3
Ga	20	24	34	42	23	19	18	13	13
Hf	6	3	2.2	1.4	5.7	3.5	10	5.8	9
Li	61	35	121	265	49	55	26	36	11
Nb	9	7	12	25	7	6	8	6	9
Pb	18	20	26	12	23	21	13	15	6
Rb	120	251	334	610	102	150	57	80	129
Sc	14	4.4	4.4	8.6	12	5.8	17	7	3.8
Sr	164	35	20	5	86	30	199	82	32
Th	10	10	13.6	10.5	10	10	6	8	17
U	3	9	16	6.5	4.5	5	4	5	6
Y	28	31	33	29	37	26	32	26	77
Zn	56	18	24	36	81	54	93	59	41
Zr	177	73	43	17	189	101	304	153	163
La	29	11	8	4	26	15	25	27	33
Ce	57	28	24	10	44	28	46	46	65
Sm	5.3	2.7	3.2	1.6	5.5	3.2	7.5	5.8	9.2
Eu	1.4	0.3	0.17	-0.1	1.16	0.4	2.1	1.1	0.84
Yb	2.6	2.8	2.7	1.4	2.7	2.2	4.8	2	7.35
Lu	0.43	0.41	0.39	0.17	0.43	0.34	0.77	0.24	0.75



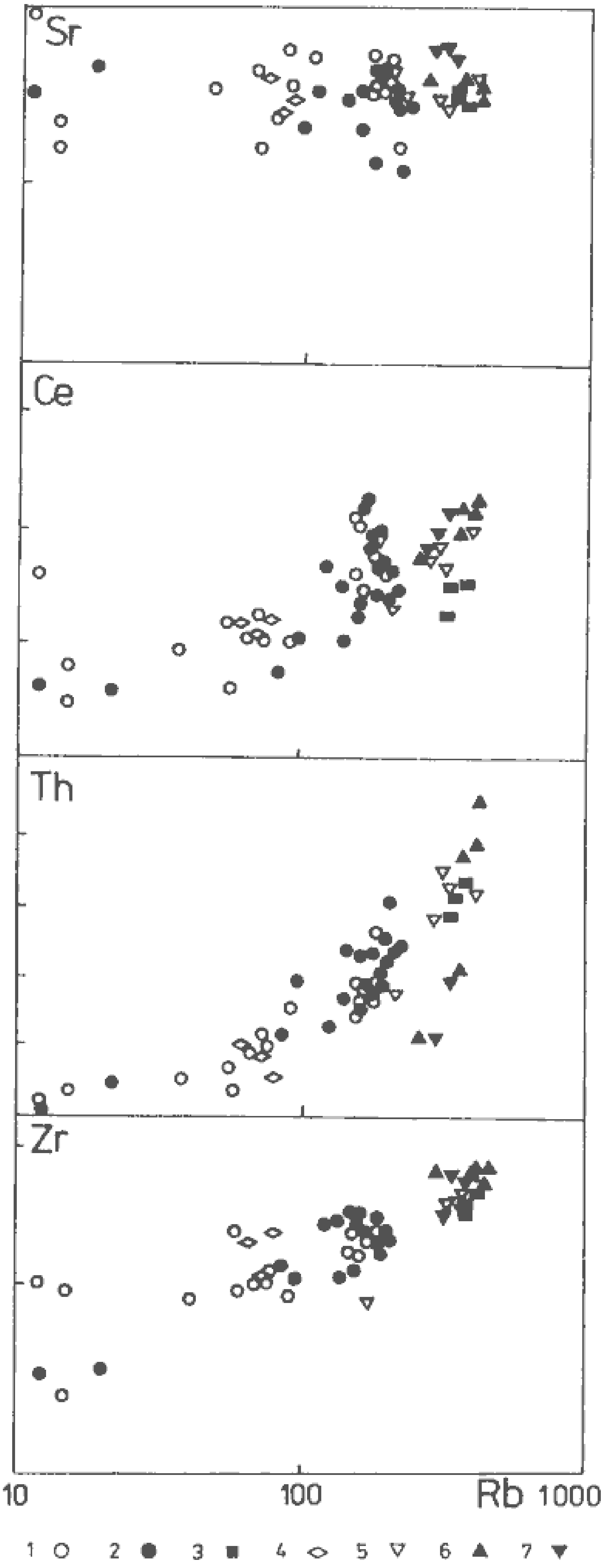


2. Distribution of some trace elements in granitoids in Moldanubicum. 1 – Freistadt type; 2 – Volary type; 3 – Lásenice type; 4 – Trhové Sviny type; 5 – Čímĕř type; 6 – coarse grained two-mica granite (Eisgarn type); 7 – Homolka type.

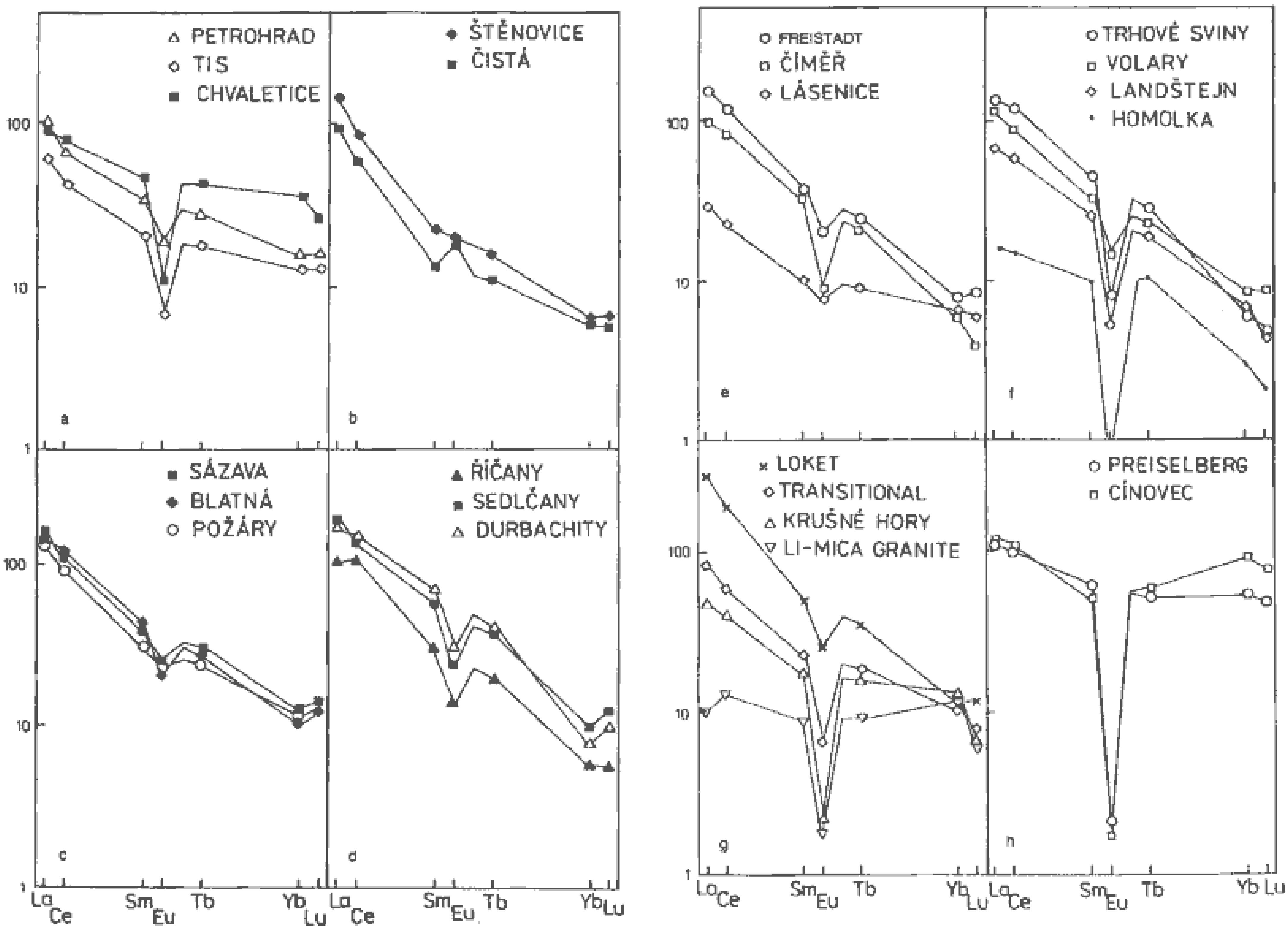
3. Distribution of some trace elements in granitoids in NW Bohemia. 1 – Loket type; 2 – mountain granites; 3 – transitional granites; 4 – "Krušné hory" granites; 5 – Li-mica granites; 6 – Preiselberg-type granites; 7– Cínovec-type granites.



4. Distribution of some trace elements in granitoids in W Bohemia. 1–4 – Pre-Variscan granitoids: 1 – Petrohrad type; 2 – Tis type; 3 – Stod-massif; 4 – Kladruby-massif; 5–9 – Variscan granitoids: 5 – Sedmihoří-ring massif (with phases S1 to S3); 6 – Bor massif; 7 – Babylon-massif; 8 – Čistá-stock; 9 – Štěnovice-stock.



5. Distribution of some trace elements in granitoids in Central Bohemian pluton. 1 – Sázava type; 2 – Blatná type; 3 – Říčany type; 4 – Požáry type; 5 – Sedlčany type; 6 – Čertovo břemeno type; 7 – Tábor type.



6. Distribution of REE (chondrite normalized). a – W Bohemia and Chvaletice massif; b – Čistá and Štěnovice stocks; c+d – Central Bohemian pluton; e+f – Moldanubian pluton; g – Karlovy Vary pluton (Slavkovský les part); h – volcanoplutonic complex in eastern Krušné hory Mts.

The **Kladruby massif** was not sufficiently sampled within the Regional geochemistry project. Isolated data from the biotite granite/granodiorite in the central part of the massif correspond to other pre-Variscan granites (Rb/Sr and Rb/Th plots in Fig. 4). The massif have been considered to be of Variscan age (Neužilová - Vejnar 1966). This was also confirmed by K/Ar dating yielding an age of 370–290 Ma (Šmejkal 1964), but during preparation of this paper to print confirmed Voves (1994) pre-Variscan age of the main body of the Kladruby massif by Rb-Sr method, giving 464 ± 36 Ma.

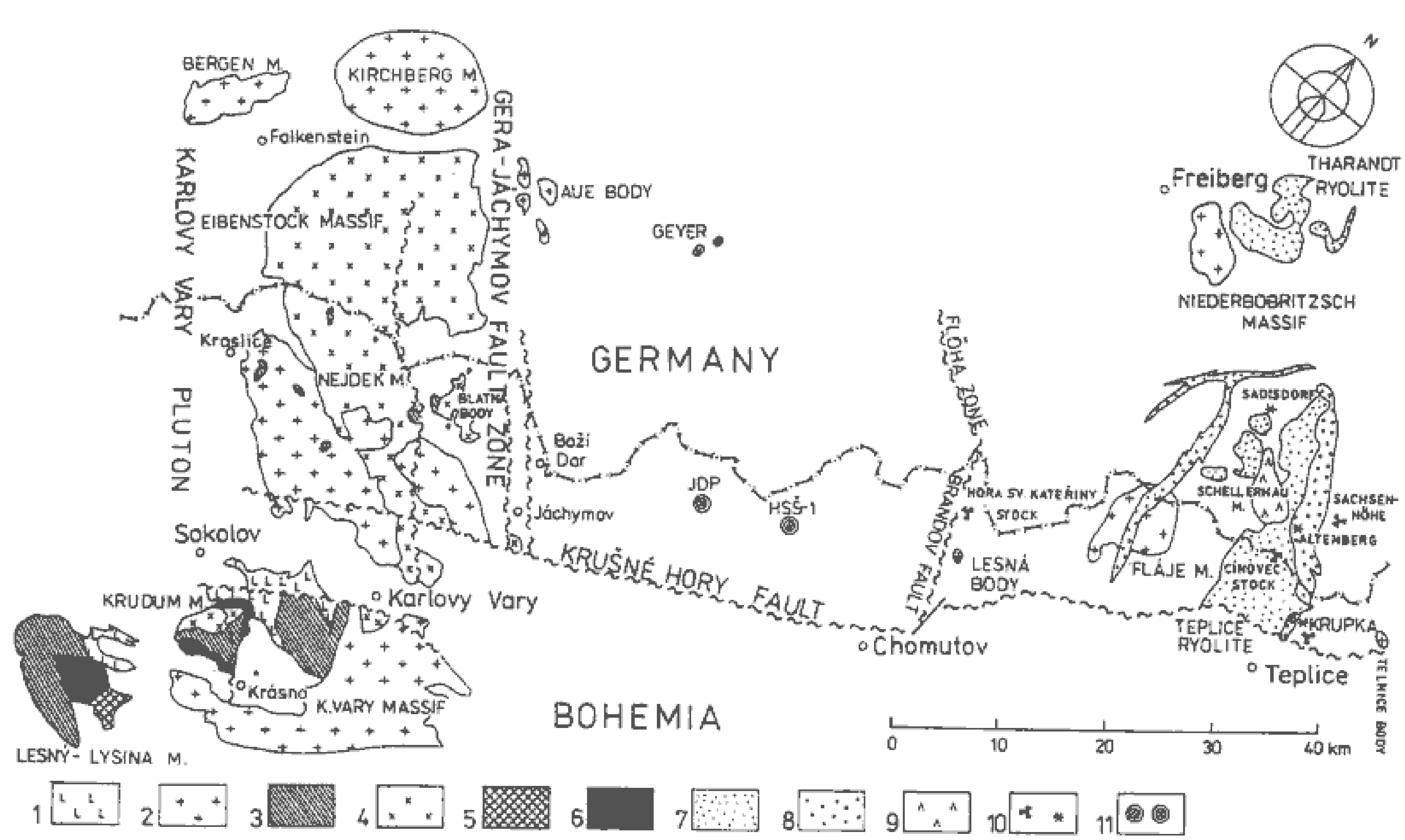
The **Tis massif** (part of the Čistá-Jesenice pluton) lies 100 km west of Prague (the hidden part of these massif is much larger, see paper by Kopecký et al., this volume). Geological indications suggest a pre-Upper Carboniferous age: the age of 450–320 Ma obtained by the K/Ar method (Šmejkal 1964) appears to be influenced by argon loss during intrusion of the Čistá granodiorite. A striking petrographic resemblance with rocks of the Lusatian pluton, low U and Th values and the sedimentation of the Upper Carboniferous on the already deeply eroded massif suggest a Cadomian age (Chlupáčová 1970). Chemically, two types have been defined (compare Orlov 1932, Chlupáčová 1970):

– the Petrohrad type, comprising a biotite granodiorite at Stebno and Petrohrad,

– the Tis type, comprising a biotite granite at Tis and Žihle and a muscovite-bearing biotite granite south and east of Jesenice (richer in potassium in comparison with the Petrohrad type). Both types exhibit low contents of compatible elements (Ce, Zr and Th), characteristic for all the pre-Variscan granitoids (Fig. 4, 6a). There are no analytical data available to characterize the eastern and northern parts of the massif covered by Carboniferous sediments.

The **Lusatian (Lužice) pluton** is the largest pre-Variscan granitoid complex in the Bohemian Massif. Most of it lies in Germany, only a smaller portion reaches into northern Bohemia. The only dating performed by the conventional K/Ar method (Šmejkal 1964) yielded data of great scatter. Based on geologic relations, the pluton is younger than the Upper Proterozoic and older than the Upper Ordovician. Domečka (1970) and Opletal et al. (1983) distinguished two basic granitoid types here – the medium-grained, biotite "Zawidów" granodiorite and the medium- to coarse-grained "Rumburk" granite. Our analytical data are in agreement with this subdivision.

The granites in the south rim of the Krkonoše-Jizera massif, known as the "Tanvald granite" (Kvičinský 1986)



7. Schema of granite type distribution in NW Bohemia. 1 – Loket type granite; 2 – "mountain" type granites; 3 – "transitional" type granites; 4 – "Krušné hory Mts." type granites; 5 – albite-muscovite granite Kladská type; 6 – albite-zinnwaldite-topaz granites ("lithium granites"); 7 – Teplice rhyolite; 8 – granite porphyry; 9 – Preiselberg type granite; 10 – albite-zinnwaldite-topaz granite "Cínovec" type: outcrops, hidden stocks; 11 – boreholes.

have been newly attributed to the Lusatian pluton. Based on their geologic position, they are obviously older than the Krkonoše-Jizera ("Liberec") granite, but younger than the Ordovician (Klomínský 1969). Chemically, two petrographically similar granites, both medium-grained, two-mica, have been distinguished within the so called Tanvald granite:

- the "Jablonec" type, west of the Jablonec town,
- the "Tanvald" type, near towns Smržovka and Tanvald, chemically significantly more differentiated, trending toward the tin-bearing granites.

It is the Lusatian pluton, the only pre-Variscan granitoid complex of the Bohemian Massif, where we can find a significant differentiation suite of the Zawidów-Rumburk-Jablonec-Tanvald types, whose youngest member is already close to the ore-bearing granites.

The **Chvaletice massif** intruded Late Proterozoic sediments in eastern Bohemia, west of Pardubice. Based on available analytical data, it is chemically homogeneous. It differs from the other pre-Variscan granites by a low content of Al and P (Al_2O_3 around 12 %, P_2O_5 0.03 %) and by high Y and HREE contents (Fig. 6a), which is attributable to its anorogenic or rifting-related position (compare diagram after Pearce et al. 1984, Fig. 11). Drozen et al. (this volume) interpret the evolution of this region in a similar manner, suggesting a Late Proterozoic rifting in the area of the Chvaletice massif. An age of 408 Ma (the Rb-Sr whole-rock method, Laciok and Bendl, unpublished data) would argue against the Proterozoic rifting hypothesis.

4.2. Variscan granites

4.2.1. The Bohemian part of the Krušné hory (Erzgebirge) Mts., Slavkovský les and Smrčiny (Fichtelgebirge)

This is the classical ore-bearing (Sn, W) area of Variscan magmatism straddling the border between Bohemia and Saxony, studied in detail geologically, petrographically and geochemically many times (Fiala 1968, Jarchovský - Štemprok 1979, Štemprok 1986, 1991 etc., Breiter - Seltmann 1995). Yet, only the latest detailed geochemical data have shown a distinct differences in evolution of the western and eastern parts of the area (Breiter et al. 1991b). All comparisons of the Bohemian and German parts of it done hitherto, have been based on inhomogeneous chemical data collections (Baumann et al. 1974, Tischendorf et al. 1989) and they are not entirely dependable. Our interpretation therefore covers only the Bohemian part of the Krušné hory Mts.

The evolution of magmatism in the western part of the Krušné hory Mts. (including Smrčiny and Slavkovský les) can be best documented by the Karlovy Vary pluton, which is an example of development of differentiation of a granite pluton (recognized already by Fiala 1968), culminating in the Sn-W ore-bearing Li-mica granite intrusions. Chemically, five rock types have been defined here, in good agreement with petrographic characteristics (Fig. 3, 6g, 7):

- the Loket type, a medium-grained, highly porphyritic biotite granodiorite in the Slavkovský les area,
- the "mountain granite" type in the Nejdek portion of the

Table 2. Chemical characteristics of Variscan granitoids (major elements in wt. %, other in ppm)

	Central Bohemian Batholith						Železné hory Mts.		Čistá	Štěnovice
	Sázava	Požáry	Blatná	Říčany	Sedlčany	durbachitic	Nasavrky pluton		stock	stock
	tonalite	granite	granodiorite	granite	granite	granitoides	granodiorite	granite	granodiorite	granodiorite
SiO2	62.5	66.7	62.6	70	59.7	71	64.6	74.8	69.2	68
TiO2	0.42	0.42	0.51	0.34	0.86	0.25	0.53	0.25	0.3	0.38
Al2O3	15.5	14.6	14.9	15.3	13.5	14.25	16.1	13.1	16.1	16
Fe2O3	1.66	0.94	0.96	0.52	1.2	0.96	0.64	1	0.9	0.9
FeO	4	2.6	3.1	1.3	4.4	2.1	3.3	0.61	1.1	1.6
MgO	2.6	2.4	2.2	1.1	5.4	0.9	2.3	0.6	0.75	1.2
CaO	5.2	2.2	3.3	1.45	3.8	3.1	3.7	1	2.6	3.1
Na2O	3.5	2.9	3.5	3.7	2.7	3.6	3.4	3.1	5.5	5.1
K2O	2.7	5.4	4.1	5.2	6.3	2.6	3.7	4	2.3	2.6
P2O5	0.15	0.31	0.21	0.34	0.6	0.21	0.2	0.05	0.1	0.15
Ba	1163	1313	1081	1010	1475	1491	1353	1850	821	1095
Cs	6.5	3.5	9.5	32.3	25.5	23.5	10.7	2	2	6
Ga	17	13	16	27	17	21	10	4	15	12
Hf	4.3	3.9	4.9	32.3	6.7	8.4	5.3	4.5	4.6	4.9
Li	23	21	33	98	46	35	36	7	18	20
Nb	12	10	14	20	22	25	8	-5	8	8
Pb	28	23	36	74	39	49	19	6	23	34
Rb	121	69	171	354	264	314	154	105	38	72
Sc	24.3	20.7	14.6	5.6	18.2	13.1	12.6	4.5	3.3	5.8
Sr	411	330	313	317	352	376	459	130	810	754
Th	14.6	9.5	20.6	32.2	27.7	30.3	19	21	10	15
U	5.5	4	8.1	7	12.5	11.3	8	6	5	7.5
Y	18	18	16	7	17	17	24	17	8	7
Zn	63	67	63	50	68	70	61	22	38	46
Zr	118	144	156	235	202	320	122	146	103	110
La	35	33	37	26	49	41	31	30	24	38
Ce	67	59	73	70	90	91	56	49	40	59
Sm	5.76	4.77	5.8	4.87	9.1	10.7	5.2	3.1	2.2	3.6
Eu	1.5	1.3	1.29	0.84	1.5	1.85	1.4	0.79	1.1	1.2
Yb	2.17	1.9	1.7	1	1.7	1.37	1.7	1.8	1	1
Lu	0.36	0.37	0.28	0.15	0.33	0.27	0.18	0.24	0.15	0.18

pluton (defined by Laube 1876), denominated also as the "older intrusive complex" (OIC) (Štemprok 1986, Tischendorf et al. 1989) comprising a medium-grained, biotite to two-mica granite,

– the "transitional granite" type (defined by Fiala 1968), comprising a structurally diversified two-mica granite that encompasses the petrographic varieties of Krely, Třídomí, Ovčák and Kynžvart-Žandov in Slavkovský les. Chemically similar are also the Bílá skála granite (called also medium granite YIC/MG and interpreted as a forerunner of YIC) and the Rotava type (also called transitional granites OIC/TG in sine Tischendorf et al.1989 and Förster and Tischendorf 1994) in the Nejdek portion of the pluton,

– the "Krušné hory granite" (defined by Laube 1876), called also the "younger intrusive complex" (YIC) (Štemprok - Tischendorf l.c.), consisting of a medium-grained, porphyritic to coarse-grained biotite granite with topaz. Dark mica is represented by Li-biotite to protolithionite,

– the "Li-mica granite" type, is a fine- to medium-grained, albite-topaz-zinnwaldite granite which often forms cupola-shaped elevations accompanied by near-contact pegmatites and by greisenization. It includes the petrographic varieties of Čistá, Lesný-Lysina and Kladská in Slavkovský les (Fiala 1968) and small stocks in the northern portion of the pluton (Breiter et al. 1991b).

The emplacement of the Karlovy Vary pluton was probably not accompanied by larger volcanic activity, no evidence of it has been found until now.

The evolution of magmatism in the eastern Krušné hory Mts. (east of the Flöha line and east of the Brandov fault) was different. The granite intrusions of the Fláje and Telnice massifs were coeval with the mountain granites (OIC) of the western part of the mountains. They were followed by the Teplice rhyolite extrusion culminating by formation of a caldera and subsequent intrusion of granites of two types:

– the older Preiselberg type, consisting of a medium-grained, porphyritic biotite granite,

– the younger Cínovec type, a medium-grained, albite-zinnwaldite granite, with topaz, forming cupola- or stock-

Table 2 (continuation)

	western and central Krušné hory					eastern Krušné hory		Sedmihoří stock		
	Loket granite	older granites	transitional granites	younger granites	Li-mica granites	Preiselberg granite	Cinovec granite	biotite granite	two-mica granite	musc-turm. granite
SiO2	64.1	71.4	74	74.7	74	75.7	75.2	71.6	73.9	73.8
TiO2	0.81	0.35	0.18	0.1	0.04	0.08	0.03	0.2	0.1	0.02
Al2O3	16.6	14.5	14.2	13.5	14.6	12.3	12.9	14.05	14.1	14.7
Fe2O3	0.72	0.53	0.45	0.27	0.21	0.8	0.32	1.07	0.47	0.39
FeO	3.3	1.5	0.8	1.1	0.9	0.5	0.8	1.1	0.68	0.37
MgO	1.7	0.8	0.2	0.1	0.1	0.1	0.1	0.24	0.19	0.13
CaO	2.7	1.2	0.5	0.4	0.4	0.6	0.5	1.04	0.54	0.51
Na2O	3.6	3.3	3.2	3.2	3.2	3.1	3.4	3.66	3.62	3.88
K2O	4.4	4.7	4.8	4.7	4.1	5	4.6	5	3.5	3.93
P2O5	0.37	0.23	0.26	0.27	0.45	0.02	0.01	0.09	0.2	0.36
Ba	1281	472	170	52	37	63	50	260	160	25
Cs	9	20	30	67	102	19	31	12	33	50
Ga	33	20	25	29	39	24	35	28	27	28
Hf	10.7	4.9	3.4	2.9	1.9	7.7	7.6	11	2.9	1.7
Li	60	125	153	353	943	121	822	65	200	376
Nb	19	13	16	21	37	35	68	18	13	20
Pb	45	33	24	15	7	33	34	75	35	15
Rb	171	242	393	702	1428	514	1127	250	380	604
Sc	10.8	6.1	3.7	3.6	3.5	3	6	7.9	3.6	3.3
Sr	376	151	39	15	24	13	9	50	37	19
Th	32	25	25	11	4.8	43	68	57	10	4.1
U	4	4	8.3	16	11.8	12	32	5.2	7.5	1.5
Y	28	23	19	25	33	51	53	45	35	30
Zn	74	56	48	50	103	57	29	50	38	26
Zr	341	140	97	72	18	118	100	265	45	26
La	74	42	20	12	2	30	30	118	15	6
Ce	128	72	38	26	8	70	70	215	31	11
Sm	7.8	5.2	3.6	2.8	1.3	9.6	8	15	3.4	1.5
Eu	1.53	0.82	0.39	0.13	0.1	0.12	0.1	0.6	0.26	0.11
Yb	2.15	1.74	1.69	2.12	1.9	9.05	15.2	4.3	1.5	1.3
Lu	0.3	0.26	0.19	0.18	0.15	1.25	1.97	0.6	0.2	0.1

shaped structures passing into subvolcanic conditions (the Knötl stock at Krupka) (Štemprok 1989, Cocherie et al.1991, Eisenreich - Breiter 1993).

The relatively high contents of compatible elements: HREE (Fig. 6h), and Zr, Th (Fig. 3) and the low contents of Al and P are, along with the nature of enclaves in the Teplice rhyolite, indicative of enrichment of the magma by a deep crustal material.

4.2.2. Moldanubicum

Granitoids of the Moldanubian pluton have been traditionally, on the basis of their macroscopic appearance, subdivided into four basic types: the Weinsberg, Freistadt, Mauthausen and the Eisgarn types. They were defined in Austria (Waldmann 1951), but the subdivision was also widely accepted in the Bohemian part of the pluton. Recently, a more genetical classification (Finger - Höck 1986, Liew et al. 1989) distinguish two basic groups: an older, last orogenic, comprising mainly the Weinsberg granite, and an younger, post orogenic, comprising Mauthausen, Freistadt and Eisgarn granites.

Age determinations of the principal components of the pluton by the Rb-Sr method were carried out systematically by Scharbert (Scharbert 1987, 1992, Scharbert - Veselá 1990, Breiter, Scharbert 1995). However, the higher Rb-Sr age of the Mauthausen and Freistadt types does not correspond to geologic evidence – both types are geologically younger than the Weinsberg type.

In the Czech part of the Moldanubian pluton, chemical analyses enabled defining eight basic rock types (Fig. 2, 6e, f, 8):

– the Weinsberg type, mostly comprising a medium-grained, conspicuously porphyritic granodiorite, the oldest member of the Bohemian part of the pluton, particularly wide-spread in the Novohradské hory Mts. (analysed by Hujsl 1981 and Heřmánek 1995),

– the Freistadt type, composed of fine- to medium-grained biotite granodiorite, widespread E of Trhové Sviny and mainly in the surroundings of Kaplice,

Table 2 (continuation)

Moldanubian (South Bohemian) Batholith											
	Weinsberg type	Freistadt type	Lipnice granite	Volary granite	Trh.Sviny granite	Lásenice granite	Číměř granite	Eisgarn granite	subvolcanic dykes	Homolka granite	Kozí hora granite
SiO2	65.5	70.5	69.6	72.1	72.3	74.6	73	73.8	73.6	72.8	75.6
TiO2	0.5	0.5	0.52	0.35	0.38	0.08	0.28	0.18	0.1	0.03	0.08
Al2O3	15.7	14.7	14.7	14.4	14.3	14.7	14.5	14.3	14.2	15.1	12.9
Fe2O3	2.15	0.4	0.41	0.51	0.56	0.39	0.41	0.43	0.72	0.39	0.8
FeO	2.2	2	1.8	1.18	1.2	0.44	1.04	0.73	0.33	0.28	0.19
MgO	1.5	0.84	0.79	0.5	0.5	0.19	0.4	0.25	0.15	0.11	0.08
CaO	2.5	2	1.1	1.1	0.66	0.65	0.72	0.47	0.45	0.51	0.47
Na2O	3.2	3.5	3	3.5	2.86	3.6	3.2	3.23	3.51	4.35	3.38
K2O	4.7	4.2	5.17	4.7	5.45	4.65	5.1	4.66	4.19	3.9	5.04
P2O5	0.3	0.2	0.28	0.2	0.26	0.22	0.3	0.3	0.31	0.73	0.08
Ba	950	1366	628	585	322	256	317	67	55	35	140
Cs		4	7	19	9.1	12.1	13.7	30	36	75	
Ga		20	26	18	23	15	22	24	32	35	
Hf		5	7	3	4.1	1	3.4	2	1.7	1.3	
Li	30	30	75	87	62	33	79	154	200	500	
Nb	8	12	7	10	10	7	10	16	28	51	34
Pb	35	27	10	36	37	37	24	22	11	6	
Rb	170	140	305	203	285	175	271	368	555	1145	340
Sc		6.5	5	5.6	2.9	2.75	3.1	3.3			
Sr	160	290	116	171	74	83	100	40	27	63	23
Th		20	46	18	33	6	17.4	11	4	0.8	
U		3.4	6	5.1	7.2	5.7	7.7	12	5	4.2	
Y		22	14	20	20	14.5	16	18	6	3	18
Zn	6	59	91	48	95	33	79	84	50	93	
Zr	200	170	226	109	131	23	93	54	25	13	27
La		37	60	29	35	5.3	26	14	7	1.3	
Ce		75	157	60	81	11	61	31	15	2.7	
Sm		5.5	10.5	5.3	7	0.7	5.7	3.35	1.6	0.5	
Eu		1.2	0.76	0.88	0.53	0.45	0.57	0.29	0.12	0.02	
Yb		0.3	1.15	0.48	-1	-1	-1	1	0.47	0.2	
Lu		0.2	0.16	0.21	-0.1	0.11	-0.1	0.1	0.05	0.03	

– the Lipnice type, composed od medium- to fine-grained biotite granite in the northern part of the Central pluton, characterized by low SiO_2, and high Ba, Sr, and Zr contents,
– the Trhové Sviny type, consisting of a medium-grained, biotite granite in the northern part of the Novohradské hory Mts., characterized by relatively high Zr, Th and LREE contents,
– the Volary type, composed of a medium- to fine-grained, two-mica granite in the central part of the Šumava Mts.,
– the Lásenice type, a medium- to fine-grained, two-mica granite forming the northwest rim of the Central pluton and the Klenov massif, specific in its low Rb, Zr, Th and REE contents,
– the Číměř type, a medium grained, porphyritic, two-mica granite in the central part of the Central pluton,
– the type of coarse-grained, two-mica granites, geologically younger than the Číměř type, encompassing the granites at Čeřínek, and Landštejn in the northern part of the pluton, in the northern surroundings of town České Velenice, and the Třístoličník-Dreisesselberg massif in the Šumava Mts. This type corresponds best to the Austrian "Eisgarn"-granite from the typus locality.

Based on the latest studies, several other granite types (geologically younger than the above) can be recognized within the Moldanubicum:
– the Kozí hora-Hirschenschlag type, comprising a fine-grained, biotite granite with indications of greisenization and a Mo-mineralization (Göd 1989, Koller et al. 1993), resembling chemically the Číměř type, but with a different initial Sr ratio (Scharbert 1987),
– a type consisting of vein subvolcanic granite porphyries and dyke granite forming a distinct N-S trending zone stretching from Pelhřimov to Litschau (Klečka - Vaňková 1988, Vrána 1990, Breiter et al. 1994, Breiter - Scharbert 1995),
– the Homolka type, composed of an albite-lithium muscovite-topaz phosphorus rich granite with Sn-Nb-Ta mineralization that forms a stock west of Nová Bystřice (Breiter et al. 1994, Frýda - Breiter 1994, Breiter - Scharbert 1995);

Table 2 (continuation)

	Rozvadov pluton				Bor massif	Babylon massif	Orlické hory area		Žulová pluton		Krkonoše massif
	cordierite tonalite	Rozvadov granite	Barnau granite	Křížový kám. granite	granodiorite	granite	tonalite	granite	granodiorite	granite	granite
SiO2	55.8	73.25	75.34	72	68	71.5	59	69.9	66	74	72.4
TiO2	0.3	0.23	0.09	0.01	0.51	0.28	0.81	0.3	0.83	0.21	0.34
Al2O3	24.6	13.8	13.3	13.91	15.6	14.6	15.3	15.4	15.4	13.7	13.6
Fe2O3	0.7	0.59	0.47	0.3	0.3	0.4	1.5	0.43	0.8	0.44	0.64
FeO	4.8	0.73	0.48	0.3	2.5	1.6	4.7	1.5	3.7	1.3	1.7
MgO	4.7	0.33	0.14	0.02	1	0.6	4.2	1.2	1.3	0.3	0.66
CaO	1.7	0.79	0.48	0.26	2	1.4	5.2	1.7	3.6	1.3	1.63
Na2O	2.1	2.88	3.23	5.68	3.3	3.5	2.8	4.5	3.6	3.4	3.4
K2O	1.5	5.09	3.56	3.95	5.1	4.6	3.9	3.8	3.3	4.5	4.55
P2O5	0.34	0.18	0.33	0.52	0.2	0.17	0.42	0.09	0.19	0.07	0.12
Ba	1510	215		5	1270	553	1533	893	1075	572	362
Cs		30		35	6	16	6.3	8.1	1.7	4.9	13
Ga					18	19	20	20	20	16	25
Hf		2.8		1.5	7	4	5.4	4.8	8.3	4.9	5.4
Li	45	45	175	600	41	92	8	35	33	39	82
Nb	7	-7	19	37	9	8	9	6	15	13	12
Pb	36	33	-7	5	44	37	38	39	15	17	29
Rb	211	233	453	1010	166	229	131	143	90	194	241
Sc					7.8	5.5	23.8	7	12.4	4.8	7
Sr	181	85	-7	7	233	117	467	363	254	116	101
Th		3		2	36	19	5	13	10	17	24
U		3.5		5.5	6	5	2.5	6.5	4	5	7
Y	12	10	7	1.6	17	21	32	15	29	24	41
Zn	110	52	64	98	60	52	75	46	66	41	30
Zr	119	94	16	18	204	113	154	141	284	150	138
La	35	33	6	0.65	56	34	47	32	40	39	34
Ce	76	68	13	1.1	96	64	88	57	83	77	76
Sm	7.65	6.1	1.4	0.14	6.4	5	7.9	4.9	7.5	6.3	5.8
Eu	1.1	0.57	-0.13	-0.02	1.5	0.8	1.6	1	1.6	0.7	0.8
Yb	1.14	0.71	0.61	0.27	1.3	1.8	2.9	1.3	4.5	3.7	3.4
Lu	0.15	-0.13	0.13	0.03	0.22	0.3	0.39	0.19	0.41	0.41	0.6

this type involves bodies situated at the Šejby and Nakolice in the Novohradské hory Mts. (Klečka - Matějka 1992).

The Weinsberg-granite is probably a product of mixing of granitic magma with granulitic lower crust material (Koller et al. 1994). The chemistry of the Lásenice type – low contents of compatible trace elements – is indicative of an origin by anatexis under the conditions close to a granite minimum, where the preponderant part of accessories supplying the magma with trace elements was not melted and remained in the restite. Other granite types can be at first sight considered as the products of melting of predominantly crustal (metasedimentary) material in a gradually evolving magmatic reservoirs with several particular foci of stronger differentiation (the Central pluton, the Novohradské hory Mts. area and the Třístoličník-Dreisesselberg massif). The Homolka-type granites represent a final stage of these evolution.

The Kozí hora-Hirschengschlag type, due to its relatively primitive chemistry and lower Sr_i (Scharbert, pers. comun.) represent probably a new input of magma from different (metaigneous?) source.

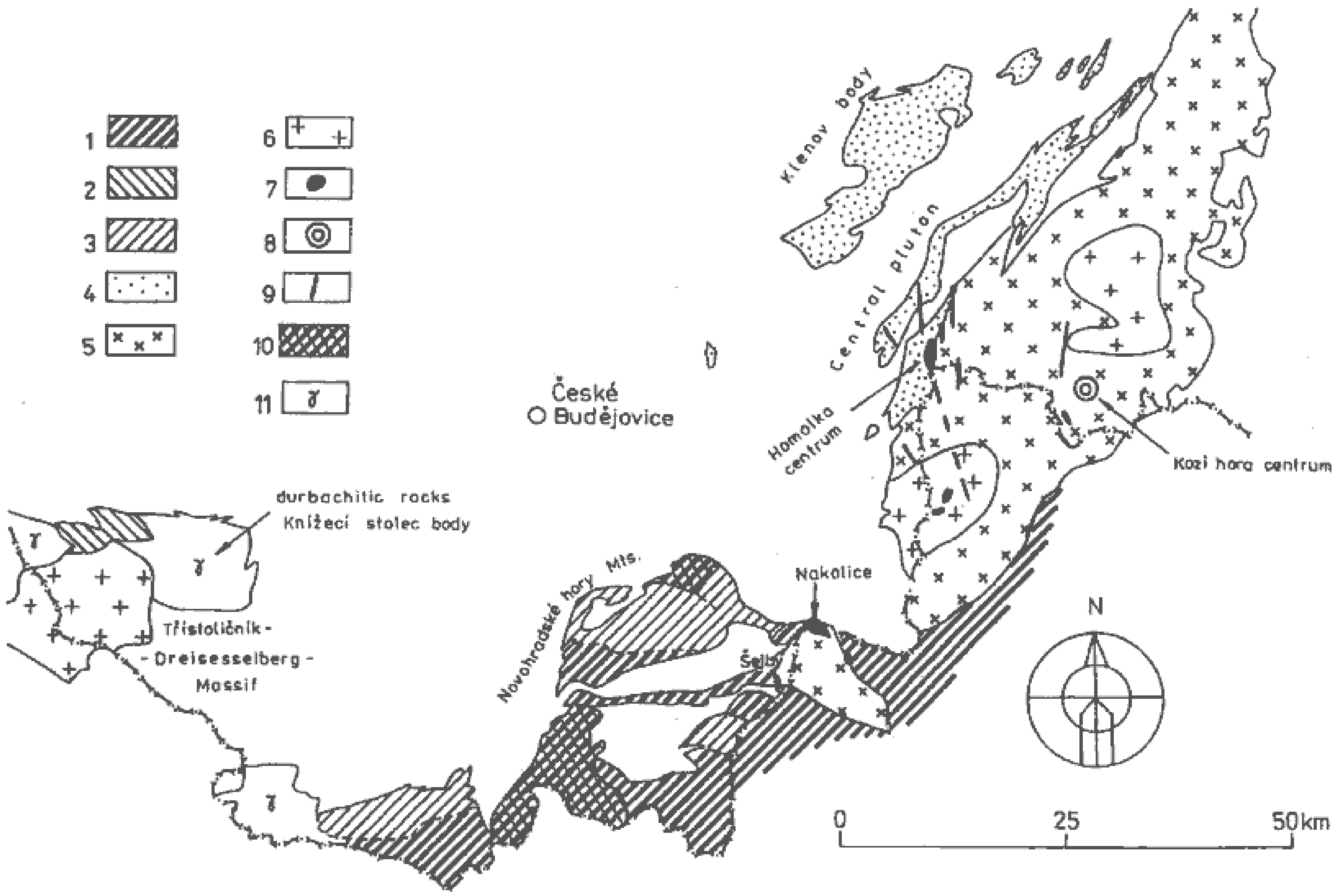
The northern part of the Central pluton and the massifs in the northwest part of the Šumava Mts., could not be reliably classified, due to incoherent sampling.

4.2.3. The Central Bohemian pluton

This is undoubtedly the most complicated magmatic complex in Bohemia. It intruded along the contact of the Moldanubian block on the southeast and the Bohemicum block on the northwest. Unfortunately, only trace-element analyses are available, but even these support the basic subdivision of the pluton by Holub et al. (this volume) into six rock types (Fig. 5, 6b, c, 9):

– the Sázava type, a biotite-hornblende tonalite in the northwest portion of the pluton,

– the Požáry type, leucocratic biotite granite (trondhjemite), locally muscovite-bearing, in the northern part of the pluton,



8. Schema of granite type distribution in Moldanubicum. 1 – Weinsberg type; 2 – Volary type; 3 – Trhové Sviny type; 4 – Lásenice type; 5 – Čímeř type; 6 – coarse grained two-mica granite (Eisgarn type); 7 – Homolka type; 8 – Kozí hora-Hirschenschlag type; 9 – subvolcanic dykes; 10 – Freistadt type; 11 – parts of pluton without interpretations.

– the Blatná type, a biotite granodiorite in the southwest part of the pluton,
– the Říčany type, a biotite granite, locally muscovite-bearing, situated in the eastern part of the pluton,
– the Sedlčany type, a biotite granite in the eastern part of the pluton,
– the durbachitic rocks (the "Čertovo břemeno" melagranite and the Tábor syenite) in the southeast part of the pluton.

The behavior of some trace elements in the Central Bohemian pluton (Fig. 5) differs from other described plutons. The contents of Zr, Th and LREE in the suite starting from the intermediate to the acidic rocks (the Sázava-Blatná-Říčany types) do not show a decreasing gradient as usual, but they increase or remain at the same level. The strontium contents in tonalites, granodiorites and granites are roughly the same. Graphs of the inter-dependence of contents of elements within the individual rock types are roughly parallel (see Fig. 5). This indicates that these rocks could not have resulted from differentiation of the same magma. An origin from independent portions of magmas that were gradually generated at the contact of the Moldanubicum and the Bohemicum is more likely (recently supported by Sr-Nd investigation by Janoušek - Rogers 1994). The focus of the magmatism most probably drifted eastward, i. e. toward the Moldanubicum.

The Sedlčany type represents chemically a transition from the Říčany granite to the durbachitic rocks, which is in good agreement with the suggestions of Holub et al. (this volume) explaining the origin of this rock by mixing of two magmas. The chemistry of the durbachitic rocks is quite specific and its evaluation is beyond the scope of this paper. It is discussed in detail by Bowes and Košler (1993) and Holub et al. (this volume).

The Požáry type, very acidic and at the same time geochemically primitive rock may represent a rest magma after differentiation of the Sázava-tonalite.

4.2.4. The West Bohemian pluton

It involves several smaller massifs (Fig. 10) whose inter-relations are not well understood and most of whose are not unequivocally dated. Most of the massifs are related to N-S trending tectonics and they are generally elongated in this direction. Proceeding from NW toward SE, the Rozvadov massif at the German border, the Bor massif, the Sedmihoří stock, and the small Babylon massif near Domažlice belong to this group. Hejtman (1984) considered the Stod, Kladruby, Čistá and Štěnovice massifs to belong to this group, but the Čistá and Štěnovice stocks exhibit a markedly distinct chemistry and the Stod, Kladruby, and Tis massifs are of pre-Variscan age (Fig. 4).

The Rozvadov massif was formed in two phases (Breiter - Trzebski 1994, Breiter - Siebel 1995). The older portion comprises a complex of cordierite granitoids highly contaminated by their gneissic wall-rocks. A sequence of three types intruded during the younger phase:
– fine-grained, two-mica granite (Rozvadov type),
– medium-grained, two-mica granite (Bärnau type),
– fine-grained, leucocratic, phosphorus-rich albite-zinnwaldite granite with topaz, of the "Křížový kámen-Kreuzstein" type, which is chemically analogous to the ore-bearing Li-mica granites in the Krušné hory Mts. and Moldanubian batholith.

The **Bor massif** consists of two main rock types: of a contaminated hornblende-biotite granodiorite to diorite (redwitzite?) and of a biotite granodiorite. The set of chemical analyses is relatively inhomogeneous, indicating a certain internal differentiation, but it does not enable a clear-cut subdivision that would correspond to the existing geological map. High thorium content typifies the Bor massif.

The **"Sedmihoří stock"** is geologically and chemically independent from the Kladruby massif, and is undoubtedly of Variscan age. It exhibits a ring structure (Bartošek et al. 1969) and consists of four subsequent magmatic events:
– intrusion of medium- to coarse-grained biotite granite with orthite,
– intrusions of N-S trending granite porphyry dykes of subvolcanic character,
– intrusion of medium-grained two-mica granite,
– intrusion of fine-grained muscovite-tourmaline granite.

Some indications of Sn- and W-mineralization were found within the stock.

The age of the Sedmihoří stock by the Rb-Sr method gives 313 ± 50 Ma (Voves 1994).

The **Babylon massif** is a relatively homogeneous body composed of a porphyritic biotite granite which becomes two-mica granite at the north contact.

4.2.5. The Čistá and Štěnovice massifs

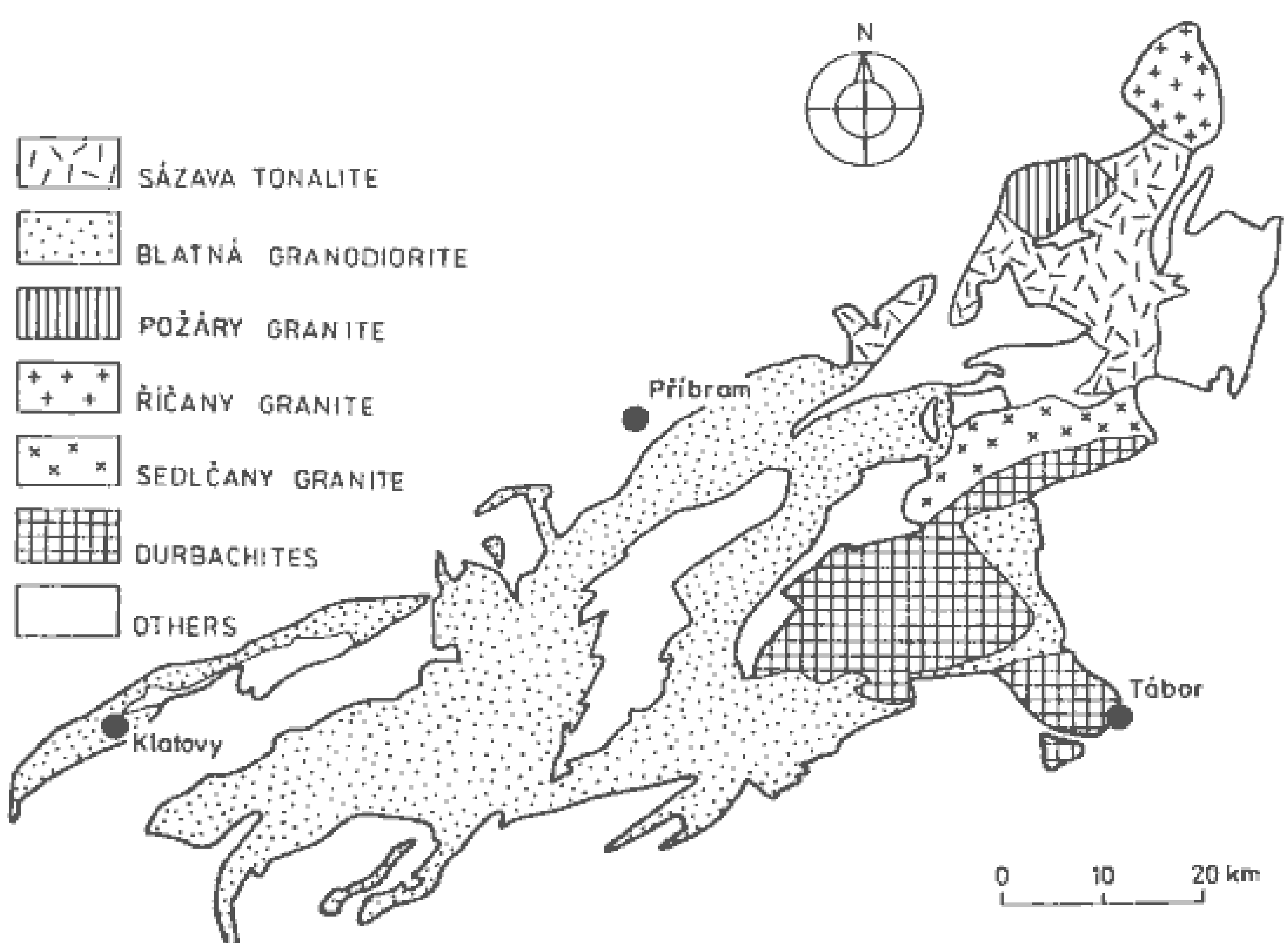
The Čistá granodiorite stock (90 km west of Praha, 8 km in diameter) is geographically a part of the Čistá-Jesenice pluton. It intruded on a junction of several faults. The N-S trending "Plzeň" fault (Šťovíčková 1973), with the small Štěnovice granodiorite massif lying on it 50 km southward, is the most important one. The Čistá massif is ring-shaped, it has an inexpressive zoned structure, and has, according to Kopecký et al. (this volume), a system of radial and concentric faults.

The Štěnovice massif seems also to be ring-shaped (Klomínský 1965), but gravimetric investigation revealed a N-S trending high, mostly covered by wall-rock consisting of Proterozoic sediments (Mrlina, personal communication).

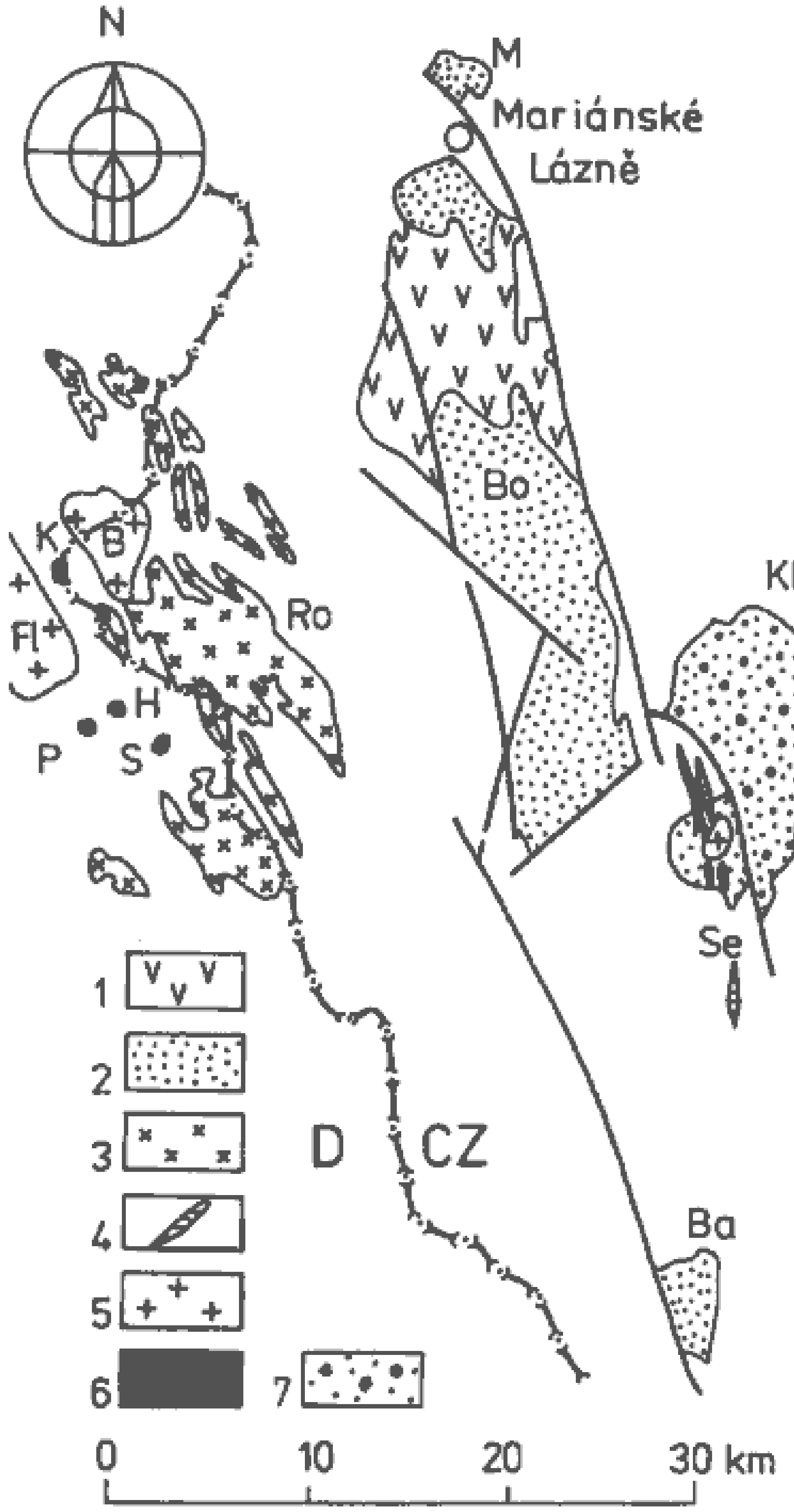
Both massifs are formed by a medium-grained, biotite granodiorite. Their chemical composition differs strikingly from all the other granitoids of the Bohemian Massif; they show an extremely high Sr content (Fig. 4) and in particular a positive Eu-anomaly (Fig. 6d), along with $Na_2O > K_2O$ and a high Hf/Zr ratio. Manifestations of alkaline metasomatism have been found at the near-contact zone of the Čistá massif (see Kopecký et al., this volume).

4.2.6. The Krkonoše-Jizera massif

It lies at the border with Poland. It is chemically relatively homogeneous, formed by coarse-grained porphyritic biotite granite (Klomínský 1969). Variscan age was confirmed by the Rb-Sr method in the Polish part of the massif (330–325 Ma, Pin et al. 1988). It differs considerably in its high trace-element contents (Zr, Th and REE) from the nearby pre-Variscan granites (the Jablonec and the Tanvald granites).



9. Schema of granite type distribution in the Central Bohemian pluton (compiled after Holub).



10. Schema of granite massifs in western Bohemia. 1–6 – Variscan granitoids: 1 – contaminated hornblende-biotite granodiorite of Bor-massif; 2 – biotite granodiorite to granite; 3 – fine-grained biotite- to two mica granite of Rozvadov-type; 4 – felsitic granite porphyry; 5 – differentiated two-mica and muscovite granite; 6 – albite granite Křížový kámen type; 7 – pre-Variscan biotite granite; B – Bärnau body; Ba – Babylon massif; Bo – Bor massif; Fl – Flossenbürg massif; H – Hagendorf stock; K – Křížový kámen stock; Kl – Kladruby massif; M – Mariánské Lázně body; P – Pleystein stock; Ro – Rozvadov massif; S – Silbergrube stock; Se – Sedmihoří stock.

4.2.7. The Orlické hory Mts. and the Silesicum

The several small granitoid bodies in the Orlické hory Mts. and in the Zábřeh series at the border of Bohemia, Moravia and Poland can be subdivided into two basic types (Opletal et al. 1980):

- hornblende-biotite granodiorites (tonalites) at Pěčín, Kunvald, Bystřec, Mistrovice and Heřmanice near Šumperk,
- biotite granites at Olešnice, Litice, Helvíkovice and Bílá Voda.

Both types are chemically relatively compact with the clark concentration of trace-elements. Opletal et al. (1980) consider both types as pre-Carboniferous, although the existing K /Ar data yield 295–360 Ma (Šmejkal in Opletal et al. 1980).

The Žulová massif, lying east of the Ramzová thrust zone, i. e. in Silesia, is composed of two rock types:

- a biotite granodiorite in the western part of the massif,
- biotite granite in its eastern part.

Both types differ significantly in their chemistry and exhibit a conspicuous differentiation trend. Typical feature is the increase in Th contents toward more acidic rocks, mineralogically reflected by an abundance of orthite.

4.2.8. The Železné hory pluton

It forms a trianguloid body in the Železné hory Mts. in eastern Bohemia. The most significant features of its structure are interpreted in different ways (see Drozen et al. this volume). There is a certain geologic and petrographic resemblance to the Central Bohemian pluton.

Regardless of the varying geologic interpretations, two chemically very distinct rock complexes can be distinguished:

- tonalites to granodiorites (environs of Skuteč),
- biotite "red" granites at Žumberk and Lukavice.

The chemistry is on the whole quite primitive, the element distribution is similar to that in tonalites and granodiorites of the Central Bohemian pluton.

(Part of the pluton near the east contact is markedly influenced by assimilation of the gneissic wall rock and has not been included in the classification. There are no available and usable data from the south part of the pluton, from the so-called Všeradov complex of probable pre-Variscan age.)

5. Geotectonic Implications

Statistical evaluation of chemistry of all the types of Variscan granitoids defined above enabled to define four groups of massifs or plutons which correspond to evolutionary phases of the Variscan orogen and to the differing geotectonic position of their intrusions. Overall characteristics of these four groups are obvious from Fig. 2, 3, 4, 5 and 6.

1. A group of tonalite-granodiorite plutons marks the onset of Variscan magmatism in Bohemia (geologic evidence suggests a Devonian or Carboniferous age). It forms a SW-NE trending zone that separates in the northwest the Moldanubian block from the Bohemicum. The central Bohemian and the Železné hory plutons belong to this group. The position of tonalites in the Orlické hory Mts. is not quite clear. Chemically, these are plutons with a wide range of major-element contents (gabro-tonalite-granodiorite-granite), but with small differences in their trace-element contents. There is no correlation between Rb and Sr contents, Zr, Th and Ce contents show a rather increasing trend toward the more acidic rocks. The contents of granitophile elements such as Li, Cs, Sn etc., oscillate around the clark values.

2. A group of granodiorite-granite plutons corresponds

temporally to the culminating post-orogenic magmatic stage (of Carboniferous or possibly Permian age, according to geologic evidence). The plutons are situated within consolidated crystalline blocks. They frequently consist of a large number of separate intrusions, forming conspicuous differentiation suites culminating in specialized Sn- and W-bearing, extremely differentiated rocks. The Moldanubian pluton, the Karlovy Vary and the Smrčiny (Fichtelgebirge) plutons, the Rozvadov massif and the massif of Sedmihoří in western Bohemia belong to this group. The Krkonoše-Jizera, the Žulová, Bor and Babylon massifs do not contain similar highly differentiated granites. Their evolution was terminated either before the ore-bearing stage, or the Sn-W-mineralized granites have not been reached by the present erosional level.

The granitoid magma in this group is characterized by a high positive correlation within the groups of compatible (Sr, Ba, Zr, REE, Th) and incompatible (Li, Rb, Cs, F) trace elements. Inter-correlation of both groups of elements is strongly negative, the Žulová massif being the only exception.

3. This group of volcano-plutonic complexes is linked with late-Variscan extensional tectonics. At present, the only known representative is the volcano-plutonic complex formed by the Teplice rhyolite and by the Preiselberg and Cínovec granites of Westphalian C-Permian (?) age in the eastern Krušné hory Mts. Characteristic is a granite intrusion marking the collapse of a caldera composed of rocks of the probably comagmatic volcanic complex. Significantly higher contents of Zr, Y, and particularly of Th and HREE and lower contents of Al and P distinguish this group from group 2. Contribution of a deeper-seated source or second-stage melting of granulitic source rocks during the magma genesis is likely. Chemically identical, but lacking any preserved volcanic material, is the granite stock on the Hora Svaté Kateřiny village.

The youngest Moldanubian granitoids – the felsic porphyries and the Homolka granite are closely related to the extensional tectonics, but chemically, they belong to the other Moldanubian plutonic rocks, i. e. to the 2nd group.

4. A group of probably deep-seated magmas with manifestations of alkaline metasomatism. Time of the intrusion cannot be established with certainty, due to the lack of dependable isotopic data. This group consists of granodiorites with anomalous magnetic properties of the Čistá and Štěnovice massifs. Both intrusions are related to tectonism. Geophysical pattern of the Čistá massif (Bartošek et al. 1969) suggests a stock with deep-seated influence. The rock chemistry is primitive (Rb<Sr), the positive Eu-anomalies are indicative of feldspars of cumulate character or of a precursor rich in plagioclases of possible anorthosite type. All this, including the alkaline metasomatism manifestations (Kopecký et al., this volume), is indicative of a deep magmatic origin, independent of other Variscan magmatic phenomena in the Bohemian Massif.

Comparing the above defined plutonic groups in the Bohemian Massif with the systems of Pitcher (1987), group 1 can be attributed to continental-margin plutons (Andean type), group 2 can be classified as collisional plutons (Hercynian type) and groups 3 and 4 as anorogenic plutons. According to Pearce et al. (1984) group 1 is product of "arc" magmatism, group 2 collisional magmatism and group 3 "anorogenic" magmatism. Position of group 4 is problematical (Fig. 11).

The pre-Variscan granitoids of Bohemia form, except for the Lusatian pluton, relatively small and simple, little differentiated bodies that are difficult to interpret. The Lusatian pluton and the Tis (+ Petrohrad) granite belong to the intra-block, granodiorite-granite pluton types, whose late differentiates (the Tanvald type) exhibit a tin-bearing trend. The Chvaletice granite bears certain features of an anorogenic (rifting-related) position – low Al and P, high Y and HREE (Fig. 11). Geotectonic position of the Stod massif is unclear.

6. Metallogenic implications

Based on the spatial and occasionally even temporal coincidences of the ore- and some non-metallic deposits related to the defined granitoid varieties, several metallogenic types of Variscan plutons can be delimited:

a. type of tonalite-granodiorite plutons occurring at block boundaries (the Central Bohemian pluton being the typical body) – without directly genetically related ore mineralization,

b. type of granodiorite-granite (intra-block) plutons (the Karlovy Vary and Moldanubian plutons are typical) with a close genetic relation to Sn, W, Li, (± Mo, Nb, Ta) and F-mineralizations. The volcano-plutonic complex of the eastern Krušné hory Mts. (geotectonic group 3) is metallogenically similar.

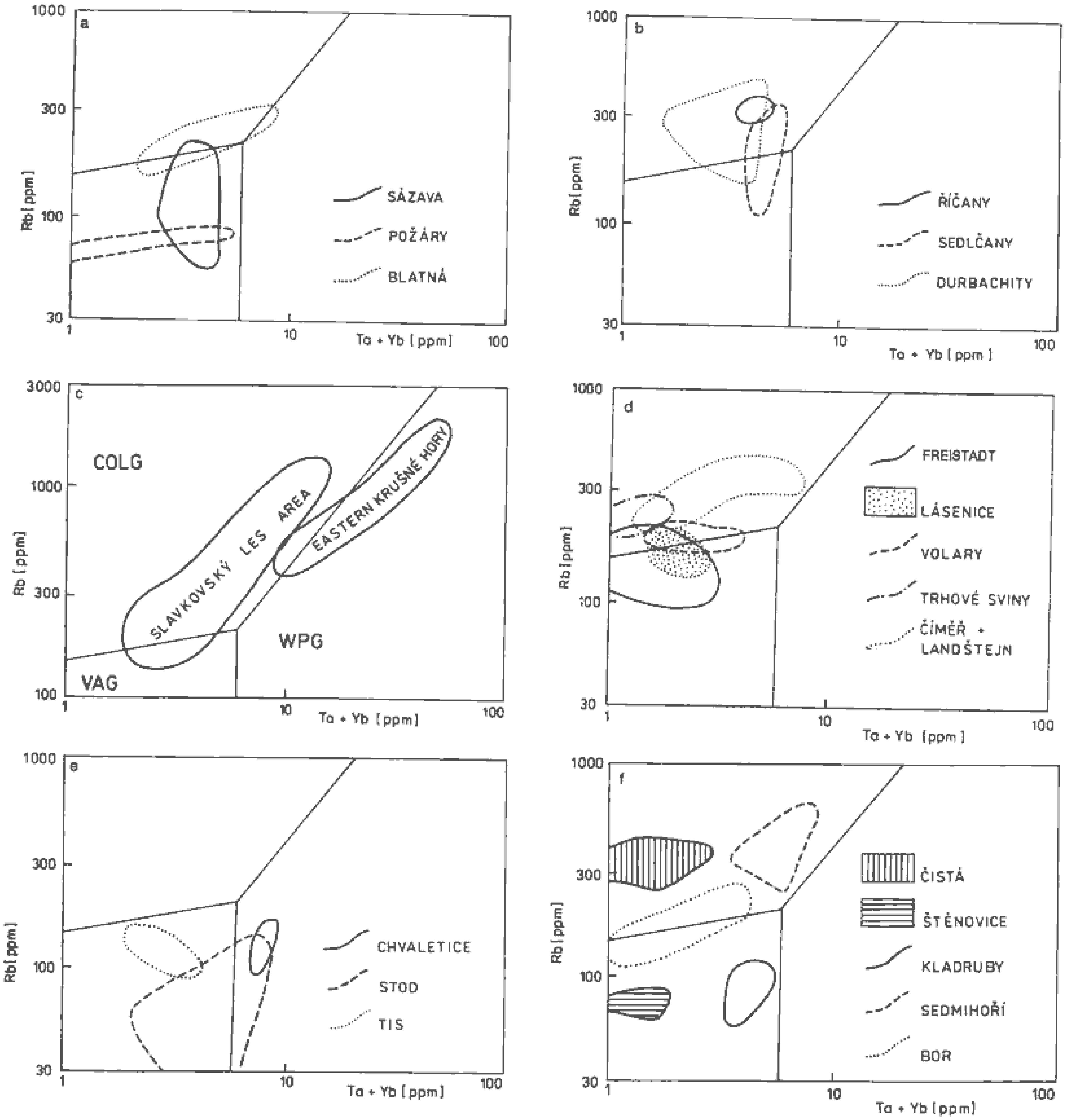
c. type of primitive deep-seated magmas with manifestations of alkaline metasomatism on deep-seated intra-block faults (the Čistá granodiorite being a typical body) – alkaline metasomatism (fenitization), accompanied by Zr and Mo indications, is linked with the stock contact.

7. Discussion

In the last 25 years metallogenic models of Variscan magmatites in the Bohemian Massif were based fundamentally on the conception of the "petro-metallogenic series" defined by Sattran and Klomínský (1970). Further papers dealing with this topic (Sattran 1981, Vacek et al. 1983, Klomínský 1988), have not brought any substantial progress. Sattran and Klomínský (l.c.) defined four metallogenic granitoid series:

1. the Sn + W series – represented by granites of the Krušné hory type in northwest Bohemia, the Tanvald-type in north Bohemia (considered to be Variscan) and the coarse-grai-ned Moldanubian granites (Landštejn etc.),

2. the "transitional", W + Mo series – granites of the mountain type in northwest Bohemia, the Krkonoše Mts. granites, the Rozvadov massif, the Sedmihoří granite, granites of the Bor massif and the Říčany granite in the Central Bohemian pluton,



11. Tectonic setting interpretation diagram after Pearce et al. (1984). a+b – Central Bohemian pluton; c – Karlovy Vary pluton (Slavkovský les part), volcanoplutonic complex of eastern Krušné hory Mts.; d – Moldanubian pluton; e – Chvaletice massif, Tis and Petrohrad granites; f – Čistá and Štěnovice granodiorite, Kladruby massif, Sedmihoří stock, Bor massif.

3. the "transitional" Mo + Au series – granodiorites of the Bor massif, the Kladruby, Čistá, Štěnovice and Žulová massifs,

4. the Au series – tonalites and granodiorites of the Central Bohemian pluton and the Železné hory pluton.

We consider the approach of Sattran and Klomínský (l.c.) as methodologically unacceptable, since portions of the same magmatic complex are often attributed to different metallogenic series (the Krušné hory Mts., the Moldanubicum, the Central Bohemian pluton etc.). The difference consists only in the magmatic differentiation degree and therefore in the degree of concentration of metallic elements and metallogenic productivity. Also, the use of molybdenum, which is metallogenically unimportant in the Bohemian Massif, as a typomorphic element, does not appear plausible. Logic requires to put always a complete, genetically related complex of rocks to a single metallogenic type. The actual mineralization styles then depend on the differentiation degree reached by the pluton or its part.

Therefore we propose to omit the two "transitional" series of Sattran and Klomínský (l.c.) and we accept only the three, clear-cut metallogenic pluton types defined in the previous chapter.

Orlov (1932) and Klomínský (1988) suggested some similarities between the Čistá and Štěnovice massifs and the Central Bohemian pluton. But the specific chemical features of the Čistá and Štěnovice granodiorites (high Sr content and positive Eu-anomalies) has not been found in any of the rocks of the Central Bohemian pluton. Also affinity between the Říčany granite (Central Bohemian pluton) and the Melechov massif in the northern part of the Moldanubian pluton suggested by Klomínský (1988) is not supported by our data. Both granites belong to different geochemical types. The hypothetical Říčany batholith, which, on the basis of gravimetric data of, involves both these granites (Tomek 1975) (if it even exists), cannot be a homogeneous body.

We must also critically evaluate the idea of a specific position of the so called "small intrusions" (Bartošek et al. 1969), to which these authors put the Sedmihoří stock, the Štěnovice, Čistá and Fláje massifs. They exhibit a roughly isometric shape, have 3–8 km in diameter and are located on important faults. The Sedmihoří stock has a neatly zoned ring structure, the Čistá granodiorite forms a circular stock with an inexpressive zoned structure, the other bodies lack any zoned structure. Chemical data have shown quite explicitly the above massifs to belong to different genetic groups. Only the Čistá and Štěnovice massifs correspond Bartošek s et al. (1969) concept of a deep magma source and of an ascent along deep-rooted, extensional N-S trending faults, being essentially anorogenic. The Sedmihoří intrusion undoubtedly belongs to the group of late-stage, Sn-W mineralized, granodiorite-granite massifs, such as the Karlovy Vary and Moldanubian plutons. Only the structural conditions at the intrusion site – intersection of faults – gave rise to a stock. After all, the highly differentiated, Li-rich granites of the Krušné hory Mts, and of the Moldanubicum commonly form stocks, although without any conspicuous zoned structure. The Fláje massif in the Krušné hory Mts, is formed by a mountain-type granite, fully equivalent to the mountain granites of the Karlovy and Smrčiny massifs.

The discovery of highly differentiated Li-rich granites (previously known only in the Krušné hory Mts.), made lately in the Rozvadov massif (the Křížový kámen type, Breiter - Trzebski 1994) and at several localities in the Moldanubicum (the Homolka type, Breiter et al. 1994), points to a great similarity of the late-stage Variscan magmatism in the Saxothuringian and Moldanubian blocks and provides a wide scope for Sn-W ore exploration that might cover a considerable portion of the Moldanubian block.

We would also like to express our opinion on the popular classification of I- , S- and A-type granitoids (Chappell - White 1974, Loiselle - Wones 1979) in the Bohemian Massif. This classification was applied in the Bohemian Massif by Jakeš and Pokorný (in Vacek et al. 1983) and Klomínský (1988). Štemprok (1986) and Tischendorf et al. (1989) attempted to apply it in the Krušné hory Mts, Liew et al. (1989) and Finger (1994) in the Moldanubicum. In many cases, the above mentioned authors, while using the same criteria, have arrived at quite contradictory interpretations. For instance, the Krušné hory-type granites in northwest Bohemia are attributed to S- (Štemprok l.c.), I- (Tischendorf l.c.) and A- (Klomínský l.c.) types! On the whole, we consider application of the I-S classification criteria (Chappell - White 1974) to central European Variscides as not entirely fitting. These criteria were conceived in southeast Australia in a magmatic regime located on the continent-ocean contact, whereas the European Variscan granitoids were generated predominantly in the final stage of collision of continents or microcontinents. Therefore, on the basis of the most general geologic criteria our type of tonalite-granodiorite plutons (e. g. the Central Bohemian pluton) can be only very roughly identified with the I-type of Chappell and White and the granodiorite-granite type plutons with the S-type. However, individual chemical and isotopic criteria of Chappell and White should not be applied to the central European Variscides.

The term A-granite has been obscured by the different approach of many authors to such an extent, that its use is mostly questionable. Is it the geologic position that is essential for the use of the term A-granite, or only certain chemical characteristics fulfilled more or less by all highly differentiated granitoid magmas? We therefore avoid the use of the I-S-A classification and have rather tried to interpret the conditions of granitoid genesis in terms of Pitcher (1987) and Pearce (1984) (see above). (Compare discussion about M-S-I-A typology in Clarke 1993).

The pre-Variscan granitoids (except for the Chvaletice granite) differ significantly from the Variscan granitoids in their lower content of Zr, Th and REE. This is well-documented by granites of the west Bohemian area (see Fig. 4). The differences in contents of these elements can be used as one of the rough indicators of chronologic position of those massifs that have not been reliably dated (for example Kladruby massif).

Finally, we would like to make an assessment of how much the interpretation of granitoid plutons could contribute to recognition of a structure of the Variscan orogen. The documented zoning of the main pluton types, i.e. tonalite-granodiorite plutons in the central, NE-SW trending zone and the granodiorite-granite plutons within the Moldanubian and Saxothuringian blocks is in contradiction with the classical concept of SE-NW zoning of the eastern part of the Variscides (Suess 1888, Kossmat 1927). The character of the Central Bohemian pluton indicates an origin on a continental margin with manifestations of subduction and mixing of magmas generated at various depths and derived from different sources. On the other hand, the plutons of the Moldanubicum and Saxothuringicum originated under the regime of a thick and differentiated continental crust. A certain SE-NW trending zoning can be observed only in the character of the youngest differentiates, i.e. the Sn-W bearing granites. Chemical and geological features typical of an anorogenic setting increase in number from the Moldanubicum to the eastern Krušné hory Mts. (Tischendorf - Förster 1992, Breiter 1994).

In addition to new geological and paleontological data from the Barrandian basin (Patočka et al. 1994, Chlupáč

1994), the granitoid chemistry is another evidence for interpreting the Bohemian Massif as a mosaic of blocks with different pre-Variscan development, brought and linked together only in Variscan times. The A-type affinity of Chvaletice-granite and a discovery of granite xenoliths with strong alkali-metasomatism in Tremadocian basalt at Otmíče in Barrandian basin (Fiala 1977) suggest pre-Variscan rift-like event on the NW-border of Moldanubicum (breakdown of Gondwana, compare Franke 1994). In this interpretation, the Bohemicum block is a relict of a shelf (probably Saxothuringian ?), Lower Paleozoic of the Barrandian basin represents a remnant ocean-type basin situated between the continental Moldanubian and Saxothuringian blocks. (Owing to the occurrence of Variscan alkaline metasomatism in the Čistá massif, we have to assume, even in the Bohemicum block, an old continental-type crust underlying Proterozoic sediments). The Staré Sedlo- and Mirotice-orthogneiss (Košler - Farrow 1994) an the Central Bohemian pluton are products of Devonian-Carboniferous "arc" magmatism on the NW-rim of Moldanubicum indicating closure of "Barrandian" ocean.

8. Conclusions

Eight unmetamorphosed pre-Variscan and 40 Variscan granitoid types have been defined in Bohemia. Interpretation of the pre-Variscan granitoids is difficult, mainly due to the lack of age determinations of some massifs. The geological setting and the scarce Ar/Ar and Rb/Sr ages argue for predominantly Cambrian and Ordovician ages of the intrusions.

The intra-plate affinity of the Chvaletice granite and the granite xenoliths with a strong alkali metasomatism in the Tremadocian basalt at Otmíče (Fiala 1977, Frýda, personal commun. 1994) reflect breakdown of Gondwana and opening of a Paleozoic basin on the NW border of the Moldanubian block.

The Lusatian (Lužice) pluton shows a relative long differentiation path and it contains, as the only one among the pre-Variscan plutons, potential ore-bearing partial intrusions (the Jablonec and Tanvald types).

The Čistá-Jesenice, Kladruby and the Stod massifs are in their outcropping portions simple, homogeneous bodies with no perspective of granite-produced mineralization.

The Variscan granitoids have been divided into four groups. The group of tonalite-granodiorite plutons with calc-alkaline chemistry without any granite-produced mineralization in the NW rim of the Moldanubicum (the Central Bohemian pluton, Železné hory pluton, probably the tonalites in the Orlické hory Mts. and the Silesicum) is relatively the oldest (Upper Devonian, Lower Carboniferous). These granitoids are, along with their somewhat older metamorphosed predecessors (the Mirotice gneiss, Košler - Farrow 1994), the product of an arc-related magmatism on a block boundary after the closure of the (oceanic or back-arc ?) Prague basin.

The second, somewhat younger group, is built by granodiorite-granite plutons that intruded into consolidated crystalline blocks (the Moldanubicum, Saxothuringicum). The chemistry of these rocks suggests a crustal origin. Some of these plutons have undergone a long differentiation history with enrichment in litophile elements (Rb, Li, Cs, Sn, U, F) and producing Sn-W deposits (the Karlovy Vary pluton and some indications in the Moldanubian batholith). Other massifs simply show no significant internal differentiation (the Krkonoše, Železné hory and the Bor massifs).

The third group is represented by the late Carboniferous volcano-plutonic complex of the eastern Krušné hory Mts. The sequence of events – extensional faults, rhyolite extrusion, forming of a caldera, intrusion of small granite stocks and the chemical signature suggest already "anorogenic" conditions of the magma genesis, differentiation and intrusion. This magma type produced an important Sn-W (Mo, Sc) mineralization.

These three Variscan granitoid groups correspond to three stages of the culminating development of the Variscan orogen – closure of the sedimentary basin, collision and uplift, decompression and extension.

The fourth group comprises two granodiorite stocks of Carboniferous (?) age in the Bohemicum block – the Čistá and the Štěnovice stocks. They have an exotic chemistry (very high Sr, positive Eu anomaly) and the Čistá stock produced indications of alkaline metasomatism (fenitization). The temporal and genetic relations of these granodiorites to the above defined granitoid groups remain unclear.

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Chemismus českých granitoidů: geotektonické a metalogenetické implikace

(Resumé anglického textu)

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Český masiv je jednou ze základních stavebních jednotek východní větvě evropských Variscid. Mnoho cenných informací pro správné pochopení geologického vývoje Českého masivu (ČM) a jeho postavení ve variském systému může přinést správná interpretace prostředí vzniku (geotektonické pozice) granitoidních plutonů. S interpretací geotektonickou je úzce spjata i interpretace metalogenetická se zcela praktickým významem při vyhledávání nerostných surovin.

Základem této práce je soubor 550 chemických analýz granitoidů shromážděných v rámci projektu "Regionální geochemie" (Čadková et al.1984), které pokrývají téměř všechny granitoidní masivy Čech. Tento soubor dosud nejkomplexnějších analýz zahrnuje vedle hlavních oxidů i stanovení přes 30 stopových prvků v té době dosažitelnými metodami. V oblastech, které nebyly pokryty vzorkováním Čadkové et al. (l.c.), byl soubor doplněn nepublikovanými analýzami autorů.

Chemická data byla zpracována pomocí multivariačních statistických metod – klastrovou, faktorovou a fuzy-analýzou. Pro výpočet byly použity prvky splňující pokud možno tato kritéria:

- malá mobilita při zvětrávání,
- spolehlivost analytického stanovení,
- dobře definovaná petrogenetická interpretovatelnost.

Relativně nejlépe splňují tyto požadavky prvky Ba, Ce, Li, Pb, Rb, Sc, Sn, Sr, Th, Y a Zr. Následné statistické zpracování dokázalo, že maximum informace je obsaženo v obsazích prvků Rb, Sr, Zr, Th a Ce, jejichž distribuce umožňuje definovat všechny horninové typy a vývojové trendy.

Pro všechny definované typy byly po vyloučení extrémních hodnot vypočteny průměrné hodnoty obsahu všech elementů (nejvýznamnější z nich uvádí tab. 1 a 2), stanovena základní petrografická charakteristika a zakresleno jejich rozšíření do map.

Prevariské granitoidy jsou v nemetamorfované podobě zachovány zejména v blocích bohemika a lugika. Jsou to masivy stodský (518 Ma – svrchní kambrium, Kreuzer et al. 1991), kladrubský (464±36 Ma – spodní ordovik, Voves 1994), tiský a petrohradský granit a lužický pluton včetně tanvaldského a jabloneckého granitu (předsvrchnoordovický, Opletal et al. 1983, Kvičinský 1986). S výjimkou lužického plutonu jde o poměrně jednoduchá tělesa granodiorit-granitového typu bez výrazné diferenciace pravděpodobně korové geneze. Společným znakem ve srovnání s variskými granitoidy jsou nižší obsahy U, Th, Zr a REE. Této charakteristice se vymyká pouze chvaletický granit v hraniční oblasti bohemika a moldanubika (408 Ma (?), Bendl, ústní sděl.) s chemickými znaky anorogenního (riftogenního) prostředí vzniku.

Statistické zpracování chemismu variských granitoidů umožnilo definovat 4 skupiny masivů či plutonů, které korespondují s etapami vývoje variského orogenu a rozdílnou geotektonickou pozicí jejich intruzí. Základní charakteristiky těchto 4 skupin jsou nejlépe patrné z obr. 2, 3, 4, 5.

1. skupina tonalit-granodioritových plutonů znamená počátek variského magmatismu v Čechách (na základě geologických dokladů svrchně devonského až karbonského stáří). Tvoří zónu jz.-sv. směru lemující na SZ a S blok moldanubika proti bohemiku. Patří sem středočeský a nasavrcký pluton, příslušnost tonalitů v Orlických horách není zcela jasná. Chemicky jde o plutony s širokým rozpětím obsahů hlavních prvků (tonalit-granit), avšak s malými rozdíly v obsazích stopových prvků. Mezi obsahy Rb a Sr není korelace, obsahy Zr, Th a Ce směrem ke kyselejším horninám spíše rostou. Obsahy granitofilních elementů (Li, Cs, Sn ap.) se pohybují kolem klarkových hodnot. Tento typ plutonů není provázen žádnou s granity přímo spjatou mineralizací.

2. skupina granodiorit-granitových plutonů časově odpovídá vrcholnému postorogennímu stadiu magmatismu (podle geologických dokladů karbonského, možná až permského stáří). Plutony leží uvnitř bloků konsolidovaného krystalinika. Často jsou složeny z velkého počtu dílčích intruzí, tvoří výrazné diferenciační řady vrcholící specializovanými rudonosnými intruzemi. Sem patří zejména moldanubický pluton, karlovarský a smrčinský pluton, rozvadovský masiv a Sedmihoří v západních Čechách. V ostatních masivech (krkonošsko-jizerský, žulovský, borský, babylonský) nebyly silně diferencované granity zjištěny. Jejich vývoj buď skončil dříve, aniž dosáhl úrovně rudonosných granitů, nebo tyto granity nejsou v dnešním erozivním řezu zastiženy.

Chemicky je tato skupina charakteristická vysokou korelací v granitoidním magmatu kompatibilních (Sr, Ba, Zr, REE, Th) i nekompatibilních (Li, Rb, Cs, F) stopových prvků. Vzájemná korelace obou skupin prvků je vysoce záporná.

Nejmladší fáze některých plutonů v saxothuringiku jsou albit-zinnwaldit-topazové granity obohacené cínem a wolframem, které produkovaly ekonomicky významná ložiska těchto kovů (Krásno, Rolava, Přebuz, Horní Blatná). Nejmladší fáze plutonů v moldanubiku jsou fosforem bohaté albit-muskovitové(+topaz) granity, obohacené cínem, niobem a tantalem. Rudní minerály v těchto granitech jsou rozptýleny v hornině a netvoří ekonomicky využitelné koncentrace.

3. skupina vulkano-plutonických komplexů spojená s pozdně variskou extenzní tektonikou. Jediným dosud známým zástupcem je vulkanoplutonický komplex východních Krušných hor tvořený teplickým ryolitem a preiselberským a cínoveckým granitem (westfal C–perm). Charakteristická je intruze granitů po kolapsu kaldery velice pravděpodobně komagmatického vulkanického komplexu. Chemicky je oproti 2. skupině signifikantní vyšší obsah Zr, Y a zejména Th a HREE, a nízký obsah Al a P. Podíl hlubinného zdroje při genezi magmatu je pravděpodobný. Chemicky totožný, avšak bez zachovaného vulkanického aparátu, je granitový peň na Hoře Sv. Kateřiny. Nejmladší fáze, albit-zinnwaldit-topazové granity, jsou nositeli greisenové mineralizace Sn a W (Cínovec), na Krupce též Mo. Charakteristická je příměs Sc.

4. skupina hlubinných magmat s projevy alkalické metasomatózy. Dobu intruze nelze geologicky spolehlivě časově zařadit, spolehlivé izotopické údaje chybějí. Skupinu tvoří anomálně magnetické granodiority čisteckého a štěnovického masivu. Obě intruze jsou tektonicky podmíněné. Geofyzikální obraz čisteckého masivu (Bartošek et al.1969) dokazuje charakter pně s hlubinným dosahem. Chemismus hornin je primitivní, pozitivní Eu-anomálie ukazuje na podíl živců kumulátového charakteru nebo prekursor velmi bohatý plagioklasy, snad anortozitového typu. To vše, včetně projevů alkal. metasomatózy (Kopecký et al., tento svazek), svědčí pro hlubší (spodnokorový ?) původ magmatu, nezávislý na ostatních variských magmatických projevech v ČM.

Vysvětlivky k obrázkům

1. Přehledná mapa granitoidů Čech. 1 – prevariské granitoidy; 2–8 – variské granitoidy: 2 – tonalit-granodioritové plutony; 3 – durbachitické horniny; 4–6 – granodiorit-granitové plutony: 4 – relativně méně diferencované granitoidy; 5 – silně diferencované granity; 6 – lithné granity; 7 – vulkanoplutonické komplexy: vulkanity, granity; 8 – granodiority typu Čistá.

2. Distribuce některých stopových prvků v granitoidech moldanubika. 1 – typ Freistadt; 2 – typ Volary; 3 – typ Lásenice; 4 – typ Trhové Sviny; 5 – typ Číměř; 6 – typ hrubozrnných dvojslídných granitů; 7 – typ Homolka.

3. Distribuce některých stopových prvků v granitoidech severozápadních Čech. 1 – typ Loket; 2 – horské granity; 3 – přechodné granity; 4 – krušnohorské granity; 5 – lithné granity; 6 – typ Preiselberg; 7 – typ Cínovec.

4. Distribuce některých stopových prvků v granitoidech západních Čech. 1–4 – prevariské granitoidy: 1 – typ Petrohrad; 2 – typ Tis; 3 – stodský masiv; 4 – kladrubský masiv; 5-9 – variské granitoidy: 5 – Sedmihoří (s fázemi S1 až S3); 6 – borský masiv; 7 – babylonský masiv; 8 – peň Čistá; 9 – peň Štěnovice.

5. Distribuce některých stopových prvků v granitoidech středočeského plutonu. 1 – typ Sázava; 2 – typ Blatná; 3 – typ Říčany; 4 – typ Požáry; 5 – typ Sedlčany; 6 – typ Čertovo břemeno; 7 – typ Tábor.

6. Distribuce prvků vzácných zemin (normalizováno chondrity). a – západní Čechy a chvaletický masiv; b – čistecký a štěnovický peň; c + d – středočeský pluton; e + f – moldanubický pluton; g – karlovarský pluton; h – vulkanoplutonický komplex východních Krušných hor.

7. Mapka distribuce granitových typů v severozápadních Čechách. 1 – porfyrický biotitický granit "Loket"; 2 – biotitické až dvojslídné "horské" granity; 3 – dvojslídné "přechodné" granity; 4 – biotitické "krušnohorské" granity; 5 – albit-muskovitický granit "Kladská"; 6 – albit-zinnwaldit-topazové "lithné" granity; 7 – teplický ryolit; 8 – granitový porfyr; 9 – biotitický granit typu "Preiselberg"; 10 – pně albit-zinn-

waldit-topazového granitu typu "Cínovec", peň vycházející na povrch, peň skrytý; 11 – významné vrty s vyznačením zastiženého typu granitu.

8. Mapka distribuce granitových typů v moldanubiku. 1 – Weinsberg; 2 – Volary; 3 – Trhové Sviny; 4 – Lásenice; 5 – Číměř; 6 – hrubozrnné dvojslídné granity; 7 – Homolka; 8 Kozí hora; 9 – žilné horniny; 10 – Freistadt; 11 – pro nedostatek dat nezařazené části plutonu.

9. Mapka distribuce granitových typů ve středočeském plutonu (upraveno podle Holuba et al., v tomto sborníku).

10. Mapka rozšíření horninových typů v západních Čechách. 1–6 – variské granitoidy: 1 – kontaminované amfibol-biotitické granodiority borského masivu; 2 – biotitické granodiority až granity; 3 – drobnozrnné biotitické až dvojslídné granity rozvadovského masivu; 4 – granitové porfyry; 5 – diferencované dvojslídné až muskovitické granity; 6 – albitický granit Křížový kámen; 7 – prevariský biotitický granit; B – masiv Bärnau; Ba – babylonský masiv; Bo – borský masiv; Fl – masiv Flossenbürg; H – pně u Hagendorfu; K – pně Křížového kamene; Kl – kladrubský masiv; M – mariánskolázeňský masivek; P – peň Pleystein; Ro – rozvadovský masiv; S – peň Silbergrube.; Se – Sedmihoří.

11. Interpretační diagram podle Pearce et al. (1984). a + b – středočeský pluton: tonality, granodiority, granity + asociované durbachitické horniny; c – karlovarský pluton + vulkanoplutonický komplex východních Krušných hor; d – moldanubický pluton; e – chvaletický masiv, tiský a petrohradský granit; f – čistecký a štěnovický granodiorit, kladrubský masiv, peň Sedmihoří, borský masiv.

Vysvětlivky k tabulkám

1. Charakteristické složení prevariských granitoidů.
2. Charakteristické složení variských granitoidů.