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PRECURSORS LITHOLOGY AND THE ORIGIN OF THE CENTRAL BOHEMIAN PLUTON (BOHEMIAN MASSIF)

(6 Figs., 1 Tab.)

Abstract: Geochemical features of individual various types of granitoids of the Central Bohemian Pluton were evaluated and compared by means of simple methods: the position in TAS diagram of volcanic rocks together with REE and some trace elements distributions and with regard to the petrography and geological position on the Central Bohemian lineament at the boundary of two different geological units, Bohemicum and Moldanubicum. The study led to the conclusion that the diversity of granitoids is due to the geochemical persistency of the source rocks (precursors lithology — i.e. various volcanic-subvolcanis rocks, pyroclastics, volcanosedimentary rocks) from which the granitoids originated. Different types of granitoids may be ranged into four geochemically individualized zones subparallel with the lineament where they originated from or by mixing of different source material. The reasons were summarized which support the model of origin at shallow levels by in situ granitization.

Резюме: Авторы изучали геологические черты гранитоидов Центрального чешского плутона при помощи простых методов: позиции в TAS диаграмме для вулканических пород, вместе с распределением элементов редких земель и некоторых элементов-следов, и изучением петрографии и геологической позиции Центрального чешского плутона на границе двух различных геологических единиц, Богемикума и Молданубикума. На основе этого изучения было сделано заключение что разновидности гранитоидов являются результатом геохимической постоянности исходных пород (литология пород-предвестников — т. зн. различных вулканических-субвулканических, пирокластических, вулканоосадочных пород) из которых возникали эти гранитоиды. Разновидности изучаемых гранитоидов можно разделить на четыре самостоятельные геохимические зоны субпараллельные с линеаментом где гранитоиды возникали из различного первичного материала или его смешанием. Автори разюмировали данные подтверждающие модель возникновления гранитов на небольших глубинах, в процессе гранитизации «in situ».

Introduction

The present paper represents a brief summary of the main conclusions from a more detailed study of individual intrusions of the Central Bohemian Pluton (further CBP) which will be presented in separate papers. It deals with the generation of these intrusions.

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The geological setting and the petrological features of the CBP were many times described in the Czech literature and we refer to the papers below. Nevertheless, we would like to emphasize two points: 1 — the boundary posi-

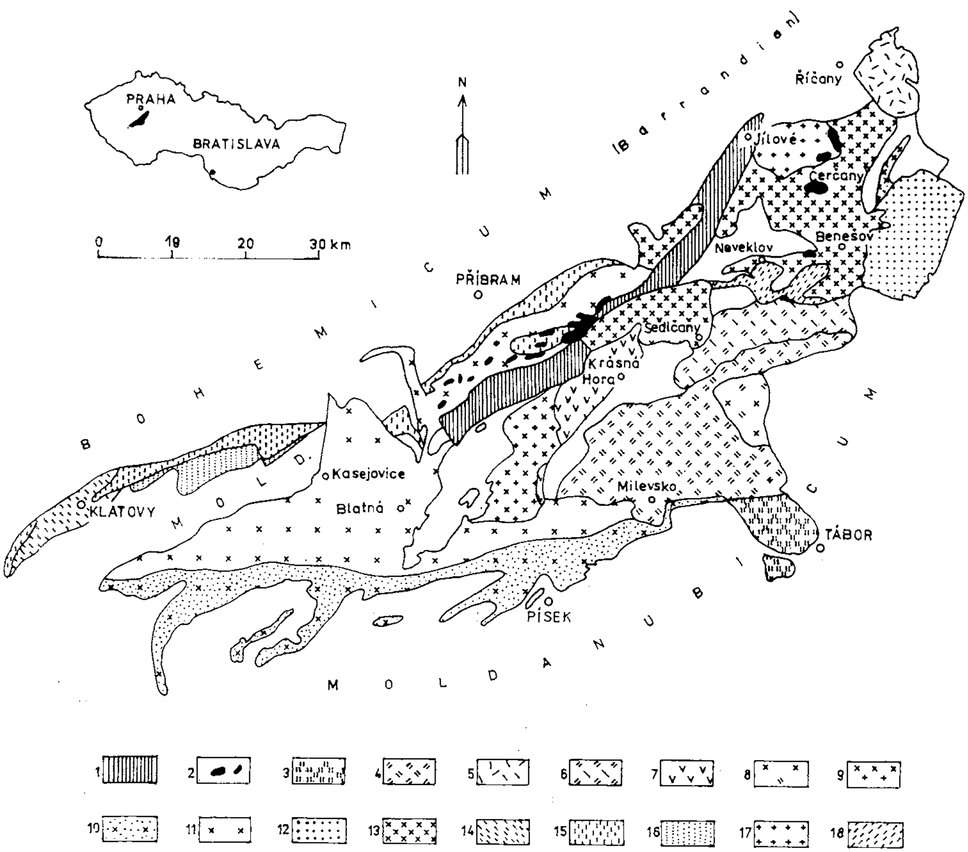


Fig. 1. Geological map of the Central Bohemian Pluton according to K o d y m, O. et al. (1967).

Legend: 1 — Jílové zone (metavolcanics); 2 — basic rocks of the CBP; 3 — Tábor type (bi two-px syenite); 4 — Čertovo břemeno type (bi ± amph. "durbachite"); 5 — Říčany type (porph. bi granite ± musc.): 6 — Sedlčany type (porph. bi granodiorite ± amph.); 7 — Těchnice type (porph. bi granodiorite ± ho); 8 — Sedlec type (bi granodiorite); 9 — Kozárovice type (bi-ho granodiorite); 10 — Červená type (bi granodiorite ± ho); 11 — Blatná type (bi granodiorite ± ho); 12 — Benešov type (bi granodiorite); 13 — Sázava type (bi-ho tonalite); 14 — Klatovy type (small-porphyritic, bi granodiorites); 15 — marginal type (porph. bi granodiorite ± ho and Nýrsko type bi granodiorite); 16 — Kozlovice type (bi granodiorite ± mu, ± cord.); 17 — Požáry type (bi granodiorite, trondhjemite); 18 — Maršovice type (bi granodiorite ± cord.).

Blatná granodiorite includes also Příbram granodiorite, Hudčice granodiorite and Zvíkov granodiorite.

Sázava tonalite includes also Vltava granodiorite. Kosova hora, Něčín and Mrač little bodies are not shown in the map.

tion between two entirely different tectonic units of the Bohemian Massif (in the sense of Chaloupský, 1988), i. e. the volcano-sedimentary Bohemicum (called Teplá-Barrandian domain by Zoubek ed., 1988) and gneiss-migmatitic Moldanubicum (called Moldanubian region by Zoubek ed., op. cit.), and 2 — the extreme petrographic diversity of the CBP which is unique not only among other granitoids of the Bohemian Massif, but also in the whole Central European Variscan belt. Analogies — manifested especially by the presence of the basic series — with the Andean batholiths rather than Variscan European granitoid massifs were pointed out (Palivcová, 1984). The petrographic picture of the pluton is given in Fig. 1.

Similarly as in many other complex granitoid bodies controversial models of origin of the CBP were formulated: in situ granitization model leading to initial anatexis (Palivcová, 1965) the orthomagmatic model by fractional crystallization and differentiation (Steinocher, 1969) and anatectic magmatic model from the lower crustal source, with some part subjected to recrystallization (Vejnar, 1973). Newly, hybridization (magma mixing) model is applied for some intrusions (Holub, 1988). In addition to these models, some other attempts were made to find some regularities in the exceptional variability of plutonic rocks, e. g. with respect to the mineralogy and geochemistry of main rock-forming minerals (Poubová, 1974; Fiala et al., 1976; Neužilová, 1973, 1978; Minařík — Povondra, 1976), geochemistry of trace elements (Vejnar, 1974; Tauson et al., 1977; partly Vlašímský, 1975 and Minařík et al., 1979), radioactive elements (Fatková, 1967; Bubeníček et al., 1967; Mannová, 1975), RE elements (Bouška et al. 1984; partly Holub, 1977) and trend surface elements analyses (Rajlich — Vlašímský, 1983). Most authors evaluated the data in favour of magmatic models, however no consensus was attained among different divisions according to these criteria.

The two magmatic models mentioned above (those of Steinocher and Vejnar) were formulated especially on the basis of major geochemistry, the third (Palivcová) on the basis of geological and petrographical features only. In the present paper, an attempt is made to evaluate the geochemistry of the CBP from the point of view of the granitization model, in spite of doubts and rejection of geological importance of this model by prominent petrologists (e. g. Mehnert, 1987).

The paper was stimulated above all by the papers of Pitcher (1978, 1979, 1983, 1987 etc.) with objective and precise formulations of main geological problems of granite origin in the light of recent research as well as by many papers of his co-workers, further by the demonstration of different typological groups of granitoids (I, S, A) in the CBP by Cambel et al. (1980) and more precisely in the unpublished map of Jakeš — Pokorný (1983). Not at least, it was stimulated by the fact that the typology is inadequated for some substantial parts of the CBP (s. c. durbachitic rocks) even if a more complete Pitcher's scheme (1983) is used. Our access to the geochemical evaluation is based on some presumptions which are summarized in the following paragraph.

Presumptions and methods

We start our investigations from the following presumptions:

1. Central Bohemian Pluton was generated *in situ, i. e. in shallow levels* (first kilometers) as supposed by Palivcová (1965) and shown on examples of some intrusions e. g. by Orlov (1943), Vlašímský (1986), Palivcová et al. (1988), Vlašímský in print. It originated *during Variscan orogeny* in the zone of Central Bohemian lineament — a deep-faulst zone ("Central Bohemian suture zone" according to Röhlich — Šťovíčková, 1968, Central Bohemian shear zone according to Rajlich et al., 1988). Most K/Ar data concentrate in a relatively restricted range of 330—340 m.y. (Dubanský in Zoubek ed., 1988). Some scarce Rb/Sr data are 336 ± 11 and 336 ± 6 for Písek granite in Semice quarry and pegmatite in the same quarry respectively (Afanasyev et al., 1977). Only some limited number gives data about 450 m.y. for durbachites. Rb/Sr from aplopegmatite in Tábor syenite 425 ± 9 m.y. (Afanasyev et al., l. c.). The Rb/Sr isochrone for Blatná granodiorite gives 331 ± 9 m.y. and 0.7072 ± 0.015 for $^{87}Sr/^{86}Sr$ for the same granodiodite (Bremen et al., 1982).

2. The main process of granitoid formation was in situ *granitization leading to initial anatexis* (in the definition given in Palivcová et al., 1988). The pressure and heat conditions for this process were most probably caused by the transpression movements (pure and simple shearing) in the Central Bohemian shear zone. An additional heat source from the volcanic activity in the deep fault cannot be excluded (M. P.).

3. *Two main tectonic units* mentioned above take part on the geological structure of CBP precursory elements (source regions). There is no consensus among Czech geologists nor among the present authors on the tectonic character of these units and their boundary. They are interpreted in different ways according to the preferred tectonic scheme. In the deep-faults tectonic model of the Bohemian Massif (Šťovíčková, 1973; Röhlich — Šťovíčková, 1968), the units represent two different blocks with a third transitional block between them. Chaloupský (1988) used the steep gravimetric gradient as dividing line between the blocks (Fig. 2). They are interpreted by him (1989) as "autochthonous units whose lateral movement greatly restricted". In opposite, a strike slip up to 105 km (unrealistic according to our view) is numerically proposed by Rajlich et al. (1988) in the Central Bohemian shear zone. In the plate-tectonic model (Cháb et al., 1983) the units represent two different lithospheric plates.

Here the simple terms of Chaloupský (1988) are used for the units which were source regions of the CBP granitoids:

1. *Moldanubicum* — i. e. an old sialic continental block or plate with thick continental crust;

2. *Bohemicum* — i. e. a block or plate with Proterozoic "oceanic" crust (Röhlich — Šťovíčková op. cit.; Jakeš et al., 1976) with a cover of Upper-Proterozoic and Lower-Paleozoic sediments and volcanics (Barrandian region).

One of the present authors (M. P.) is inclined to the deep-fault tectonic model, two others (J. W., V. L.) prefer the plate-tectonic model. The difference in tectonic schemes is not extraordinarily essential for granitoid genesis but the virtual presence of a huge lineament.

4. The conditions of the granitization process *did not exceed the conditions of amphibolite facies,* more probably its lower degrees, according to coexisting minerals thermometry (Poubová, 1974; Žežulková, 1982; Lang et al., 1978). The temperature of 400—700 °C (450—800 MPa) is given for the amphibolite facies and 250—400 °C (300—500 MPa) for the albite-epidote-amphibolite facies (Suk, 1979). Temperatures of 550—600 °C at only 100—200 MPa were deduced for the contact aureoles of Andean granitoids in accord with estimated thickness of 4—8 km for the roof of the batholiths (Pitcher, 1978, p. 164).

5. For granitization in amphibolite facies, *we do not assume allochemical alterations* in the original rocks. The granitization is thought to be an isochemical process (Palivcová et al., 1988). Thus the rocks of the CBP correspond chemically to the original volcanics, pyroclastics, tufitic and sedimentary rocks of the source complex, inclusive some older intrusive and perhaps also metamorphic rocks from the sialic Moldanubian unit.

Simple methods were used to compare chemistry of the granitoids. Providing that volcanic rocks were precursors (the term is used in the sense of parent rocks, source rocks) of granitoids, TAS diagram combined with evaluation of microchemistry (especially REE) should show what kind of volcanic rocks were present. The source of sedimentary material may be estimated as well, if — according to Taylor — Mc Lennan (1985) — *sedimentary rocks retain the chemistry of the source rocks* of their provenience region. The aim of the paper is to distinguish various types of presumably magmatic rocks — therefore the use of a diagram for true-magmatic, i.e. volcanic rocks is fully substantiated.

A large number of all available major element analyses (about 500) was collected from published papers (especially Vejnar, 1973 and Explanations to the maps 1:25 000, ÚÚG Prague) as well as unpublished analyses from the previous chemical laboratory of the GÚ ČSAV, Prague (M. P.). The chemical analyses were checked in respect to their geological position, to the respective granitoid type as well as to the petrography. Both geologically uncertain analyses and altered rocks were excluded. The petrographic names do not always correlate as different qualitative as well as quantitative classifications (according to Niggli, also Johannsen, Hejtman, newly Streckeisen. Water-free analyses were used in the TAS diagram.
no modal analysis. Consequently the chemical petrographical classification of Streckeisen —Le Maitre (1979) was applied to correlate the used petrographic names (see Tab. 1). A good coincidence was found of the commonly used petrographic names of individual granitoid types with the maxima in the chemical classification as well as with the modal available data according to Streckeisen. Water-free analyses were used in the TAS diagram.

In this short communication only main features of the rock chemistry could be shown. This is especially true for the complicated and important group of basic rocks which will be evaluated in more detail elsewhere. Also the concrete comparative data of preserved precursors and of the CBP surroundings will be given in detailed paper. The data on microchemistry, especially of REE published up today are scarse and some were published in an unsuitable form (averages). Many new data not yet available are in preparation for publication by some authors. According to our view, new data will make more accurate some details in individual intrusions, they will, however, not essentially influence the main geochemical patterns shown in this paper.

Result: precursors lithology

The evaluation of geochemical data of individual types are tabellary presented in Tab. 1 and graphically in the lithological sketch map of the CBP in Fig. 2.

It follows from the detailed geochemical study, that the idea of the in situ granitization origin of the CBP suggested in previous works is well consistent with our results. Geological position of geochemically defined groups as seen on Fig. 2 supports the view that the geological and petrographical division of the types of the CBP into zones subparallel with the NW margin (contact line) as well as the Central Bohemian lineament is fully substantiated. This view is in aggreement with previously published assumptions (e. g. Steinocher, 1969; Palivcová, 1965; Tauson et al., 1977) though with some important modifications. The latter division of Tauson et al., according to trace elements geochemistry, is closet to our new deductions.

The new results may be formulated as follows: Four geochemically distinct groups of the CBP granitoids were established which have their unaltered, non-granitized equivalents in original rocks of the Teplá-Barrandian region, in the Jílové volcanic zone, sedimentary "islet zone" (see below and also the map on Fig. 1) and Moldanubian crustal rocks. The four geological as well as geochemical zones of granitoids — interpreted as petrogenetic groups — are demonstrated on Fig. 2. They will be briefly characterized.

1. Granitoids — equivalents of Moldanubian volcanics (Fig. 3a, b). *Čertovo břemeno type, Tábor syenite* (s. c. durbachitic, i. e. lamproitic types) and also monzogranitic *Říčany type* belongs to this group. The rocks have typical geochemical features of a mature continental crust i.e. high alkali content with K»Na, high Th, high LREE. Magmas of these compositions correspond to volcanic filling of major rift zones at the continental margins, such as Eastern rift of Africa (Barker et al., 1972; Barberi et al., 1970) and its continuation towards N across Arabian penninsula up to Anatolia boundary. The mentioned durbachitic rocks at the margin of Moldanubian continent have perfectly the same geochemistry as well as mineralogical and many textural features like the recent volcanics. These "durbachitic" rocks of the CBP are here interpreted as granitized slightly alkaline volcanics on Moldanubian continental rift. The possiblity of their origin from volcanic precursors was already previously referred by Palivcová (1965) and Tauson et al. (1977). This presumption may be newly supported also by geophysical evidence of the shape of the Čertovo břemeno body suggesting a large cauldron (Dobeš — Pokorný, 1988). Geochemical characteristics of the Tábor syenite are inconsistent with Vejnar's hypothesis (1973) that "these rocks are intensively altered rocks of the first (i.e. tholeiitic) phase ... Some of them have lost their original character almost completely and shifted their composition into the suite of pluto-

Table 1

The evaluation of geochemical data of individual rock types

Sources	Rock	Th-content ppm	type	TAS diagram classification	Streckeisen — Le Maitre
Moldanubian	Tábor syenite	23. 3	—	prevailing trachyandesite, trachyte	alkali feldspar syenite, quartz syenite, alkali feldspar syenite syenite
	Čertovo břemeno durbachtite	16.4-32.9	—	wide compositional range trachyandesite, trachyte, dacite, (alkali) rhyolite	quartz alkali feldspar syenite, quartz syenite, alkali feldspar syenite, syenite, quartz monzonite
	Říčany granite	21.2-32.5	A	narrow compositional range, trachyte, dacite, (alkali)-rhyolite	granite, quartz syenite
	Sedlčany granodiorite	24.0	S	trachyte, dacite, rhyolite	granite, quartz syenite
	Kosova hora, granite	25.3	—	rhyolite	granite
	Mrač granodiorite	18.1	S	dacite, rhyodacite	granite, granodiorite
Moldanubian + Jílové zone	Těchnice granodiorite	18.0	I	dacite	granodiorite, quartz monzonite
	Sedlec granodiorite	15.3	—	trachyte, dacite	granite, quartz monzonite
	Vltava granodiorite	15.8	I	trachyandesite, trachyte, andesite, dacite	quartz monzonite, quartz monzodiorite, monzonite
	Kozárovice granodiorite	22.4	I	trachyandesite, trachyte, dacite	quartz monzonite
	Hudčice granodiorite	—	—	andesite, dacite	—
	Červená granodiorite	7.9-13.2	S	andesite, dacite, trachyandesite, trachyte	granite, granodiorite, quartz syenite, quartz monzonite, quartz monzodiorite, monzonite
	Blatná granodiorite	17.7	S	dacite, trachyte, rhyolite	granite, granodiorite, tonalite, quartz syenite, quartz monzonite, quartz monzodiorite
	Zvíkov granodiorite	—	S	rhyolite, dacite	—
	Benešov granodiorite	10.4-24.0	S	andesite, dacite, rhyolite, trachyte, trachyandesite	granite, granodiorite, quartz-syenite, quartz monzonite, quartz monzodiorite

Tab. 1

Jílové zone	Sázava tonalite	6.3-12.7	I	wide compositional range: basaltic andesite, andesite, trachybasalt, trachyandesite, trachyte	granodiorite, tonalite, quartz monzonite, quartz monzodiorite
	Něčín granite	6.8		rhyolite	granodiorite, granite
	Libčice granite	—		rhyolite	—
Barrandian + Moldanubian	Příbram granodiorite	17.4		rhyolite, dacite, rhyodacite	granite
	Nýrsko granite	—	—	trachyte	quartz syenite
	“marginal type” granite	5.0-55.2		wide compositional range: rhyolite, rhyodacite, dacite	alkali-feldspar granite, granite, granodiorite, quartz monzodiorite
	Klatovy granodiorite	23.5	S	rhyolite, rhyodacite	granite, quartz monzonite, quartz monzodiorite
	Kozlovice granodiorite	7.24-11.7	S	andesite, trachyandesite dacite	—
	Požáry granodiorite	16.9	I	narrow compositional range: rhyolite, dacite	granodiorite, tonalite

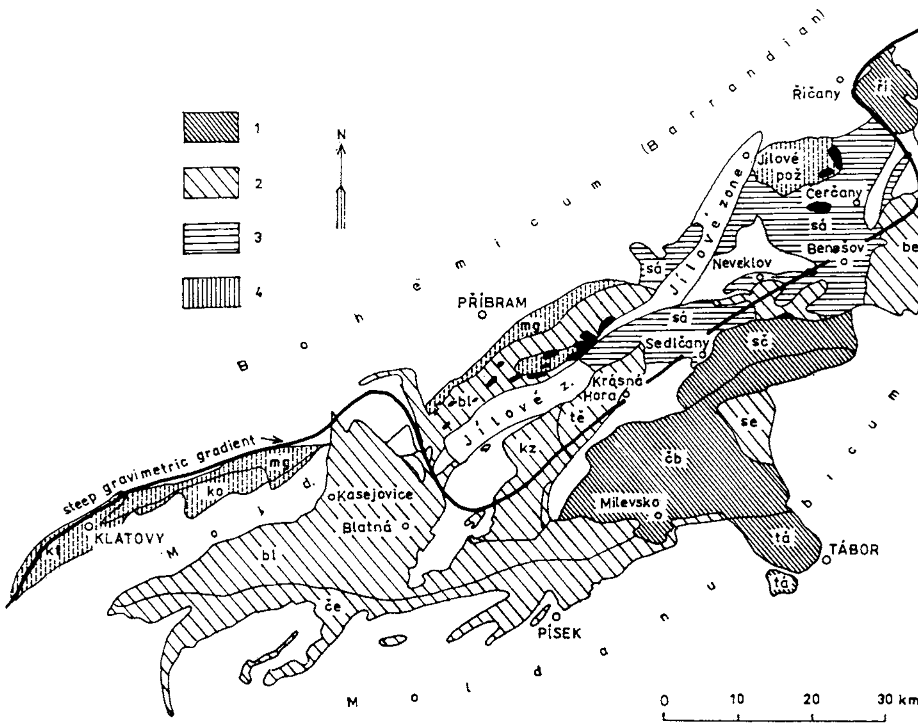


Fig. 2. Four geochemically and petrographically distinct zones in the CBP according to precursors lithology of the granitoid rocks.
1 — Moldanubian rift volcanic and volcanosedimentary series, mature continental crust source; 2 — recycled material from Moldanubian continent + Jílové zone (island arc, J. W.), mixed crust/mantle source; 3 — Jílové zone equivalents, partly recycled mantle source; 4 — Moldanubian + Barrandian volcanosedimentary material, partly from mature island arc (J. W.), mixed crust/mantle source. Rock types as in the Fig. 1.

nic rocks (syenite of Tábor)." The macro- and microelement content inclusive REE (Fig. 3b) is entirely different from tholeiites and by no secondary alterations nor alkali import the highly fractionated and differentiated durbachitic magma can be achieved from primitive tholeiites. In this sense, the feldspatization theory of Röhlichová (1964) and Palivcová (1965) needs reinterpretation (see Palivcová et al., 1988). The TAS diagram (Fig. 3a) clearly proves the special position of these rocks distincly different from tonalitic rocks of the following zone.

Říčany granite is the only A-type granite (monzogranite) in the CBP newly interpreted as volcanic-subvolcanic neck (ring body) according to the present authors (in print). With regard to metallogeny, it can be ranged into Sn-W plumasitic granites however slightly different and without economic significance (Tauson et al., 1977). The analogy with Armorican Ploumanac'h centred body was newly presumed by the authors above.

A further type, *Sedlčany granodiorite,* is also ranged into the Moldanubian group though it belongs by the mode of formation into the following sedimentary groups, as documented also by its S-character. Its cource material is derived however, exclusively from Moldanubian crust. In REE geochemistry it is akin to Tábor syenite. A part of *Benešov type* (S-type), *Mrač granodiorite* and *Kosova hora type* belong to Moldanubian source, too.

2. Granitoids the precursors of which were Jílové zone volcanics.
Jílové zone — preserved as a tectonically uplifted belt in the central zone of the CBP — corresponds to the island arc according to Waldhausrová (1984). It originated during Proterozoic times on the oceanic crust and produced geochemically immature continental crust. The rocks which are spatially and genetically joined to the Jílové zone, i.e. *Sázava tonalite,* a great part of the rocks of the *basic series,* and small acid bodies of *Něčín* and *Libčice granodiorites* — have the same geochemical features like Jílové volcanics: The position in

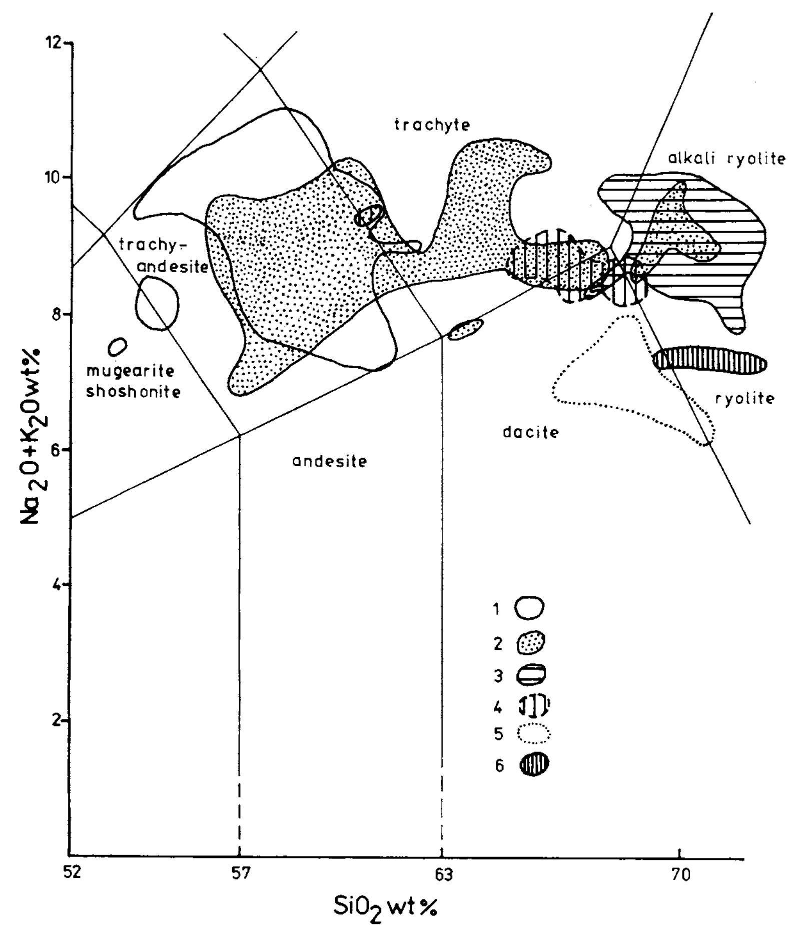


Fig. 3a

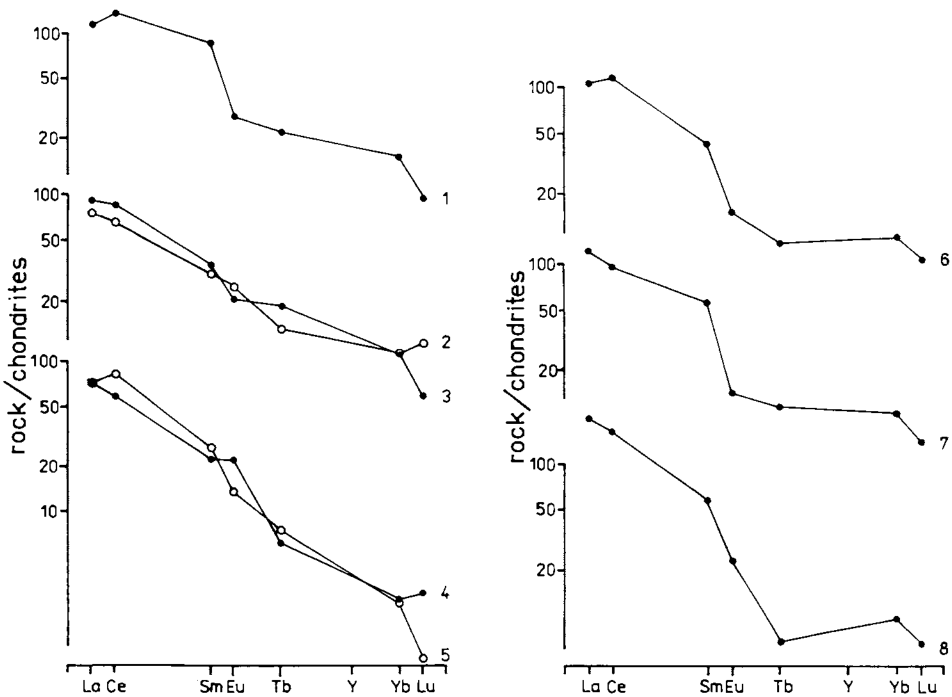


Fig. 3b

Fig. 3a. Total alkali-silica diagram (Le Maitre et al., 1984) of CBP granitoids generated from Moldanubian precursors, continental crust source.
1— Tábor syenite; 2 — Čertovo břemeno durbachites; 3 — Říčany granite; 4 — Sedlčany granodiorite; 5 — Mrač granite; 6 — Kosova hora granite.

Fig. 3b. REE distribution patterns of granitoids generated from Moldanubian precursors.
1 — Tábor syenite; 2, 3 — Čertovo břemeno durbachites; 4, 5 — Říčany granite; 6 — Mrač granite; 7 — Sedlčany granodiorite; 8 — Kosova hora granite. Some graphs show a typical higher content of La, Ce, Sm.

TAS diagram, Na»K, analogy in trace elements and the same REE graphs (Fig. 5a, b). The genetic relations of some rocks of the CBP, especially of the basic rocks, with the Jílové zone, were already previously pointed out by Palivcová (1965) and Vejnar (1973). The latter author ranges e. g. "basic rocks into the older pre-Variscan petrogenetic stage of shallow intrusive types"; tholeiitic magmas which "derived from the higher part of the Upper mantle" was suggested as their source magma. According to our study, the majority of tonalites and a part of basic rocks may be classified rather as slightly calcalkaline than tholeiitic but belonging to one evolution series, mainly according to REE.

We believe that both tonalites and a part of basic rocks represent granitized younger phase of the Jílové zone volcanics and calcalkaline intrusions according to Waldhausrová (1984) and even those members which are present as dyke intrusions only whose volcanic apparatus was eroded. The Jílové zone itself was tectonically uplifted in respect to its surrounding (L e d v i n k o v á et al., 1987) analogously to both Precambrian belts ("shale zones") of the Přbram ore district. This is the reason why we assume that we see today, in the complex tonalitic series, only granitized equivalents of the already geochemically individualized members and not "basic rocks . . . secondarily contaminated by salic material" (V e j n a r, 1973). The fact that in the group discussed geochemical equivalents even of the youngest members of the Jílové zone are involved strongly supports the view that granitization took place in situ at a very shallow level of the first kilometers.

3. The group of granitoids of the belt between the Moldanubicum and the Jílové zone. Similarly to the rocks of the metamorphosed s.c. "islet zone" which is situated in the same area, the geochemical features of the granitoids indicate that their source material was transported from two different regions. According to the REE content and partly also major elements chemistry two

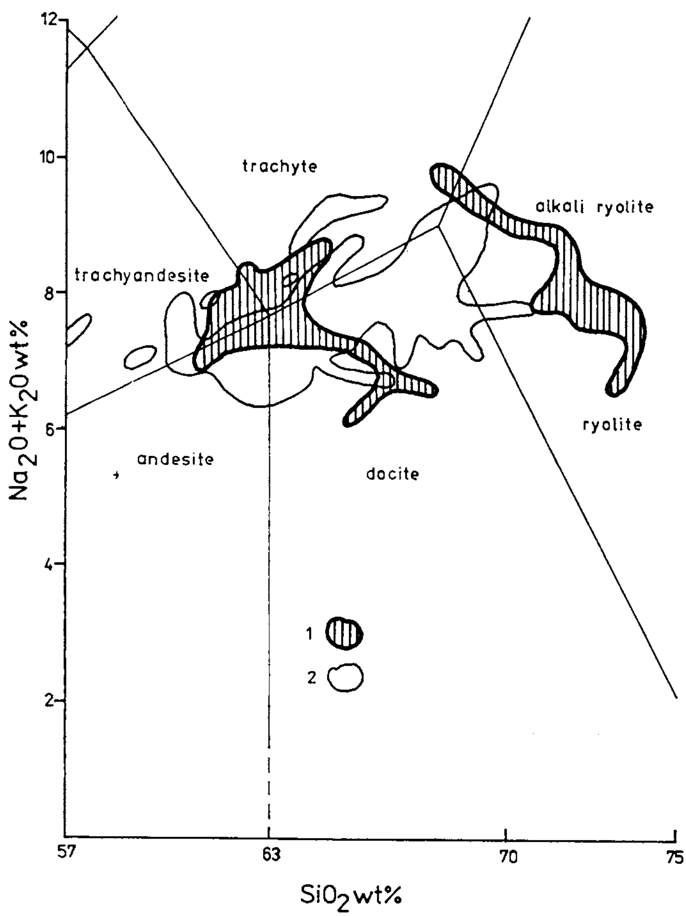


Fig. 4a

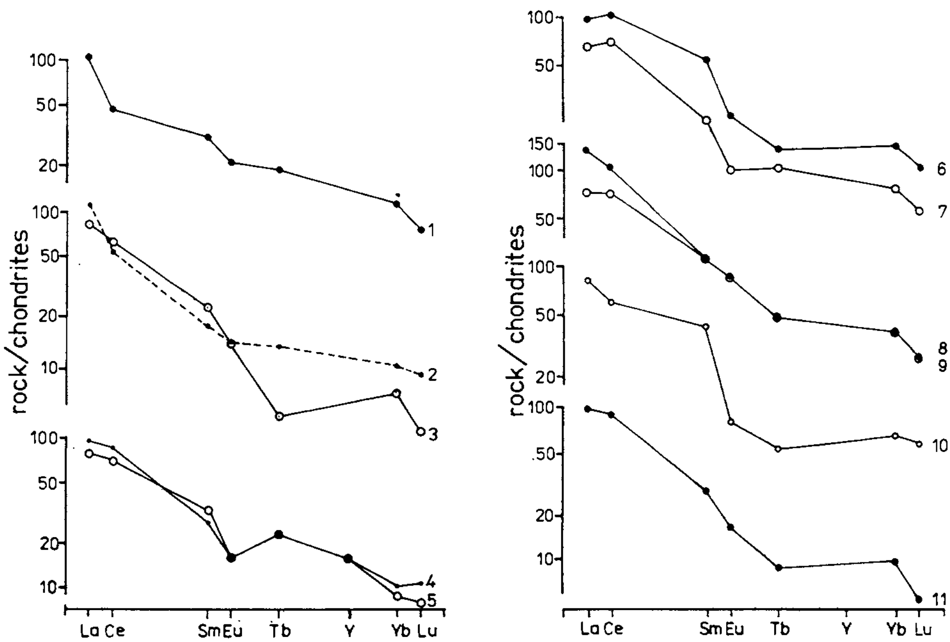


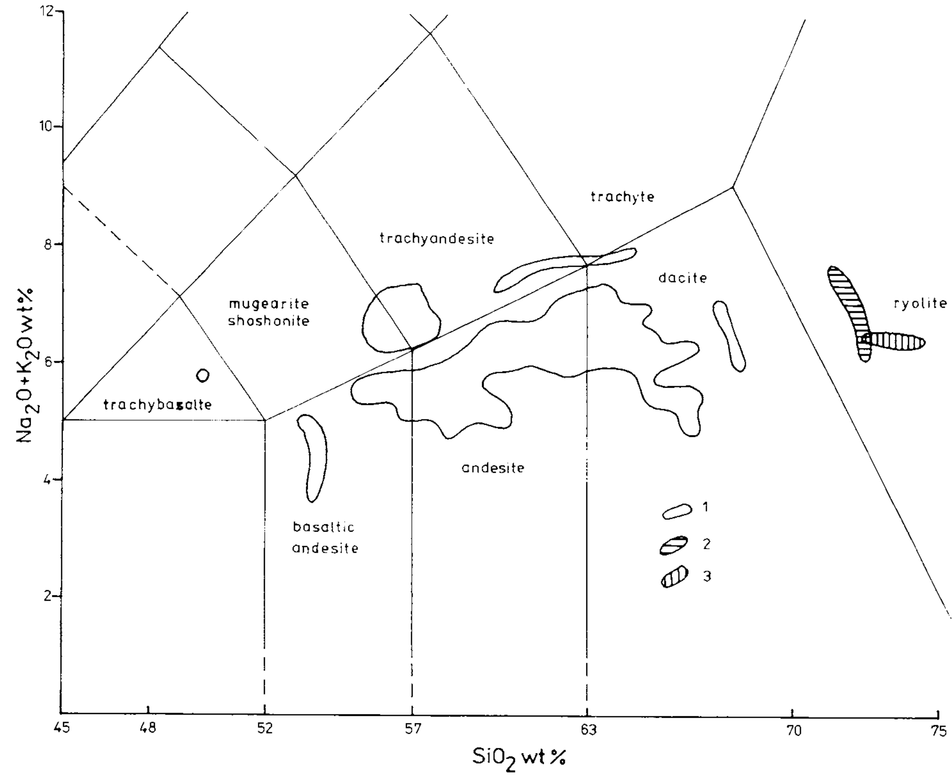
Fig. 4b

Fig. 4a. Total alkali-silica diagram (Le Maitre et al., 1984) of granitoids generated from mixed crust/mantle material (Moldanubian + Jílové zone precursors).
1 — Benešov granodiorite, two distinct types; 2 — a common field for Sedlec granodiorite, Vltava granodiorite, Kozárovice granodiorite, Těchnice granodiorite, Blatná granodiorite, Červená granodiorite, Zvíkov granodiorite.

Fig. 4b. REE distribution patterns of granitoids generated from mixed crust/mantle material (Moldanubian + Jílové zone precursors).
1 — Sedlec granodiorite; 2, 3 — Vltava granodiorite; 4, 5 — Kozárovice granodiorite 6, 7 — Benešov granodiorite; 8, 9 — Červená granodiorite; 10 — Těchnice granodiorite; 11 — Blatná granodiorite.

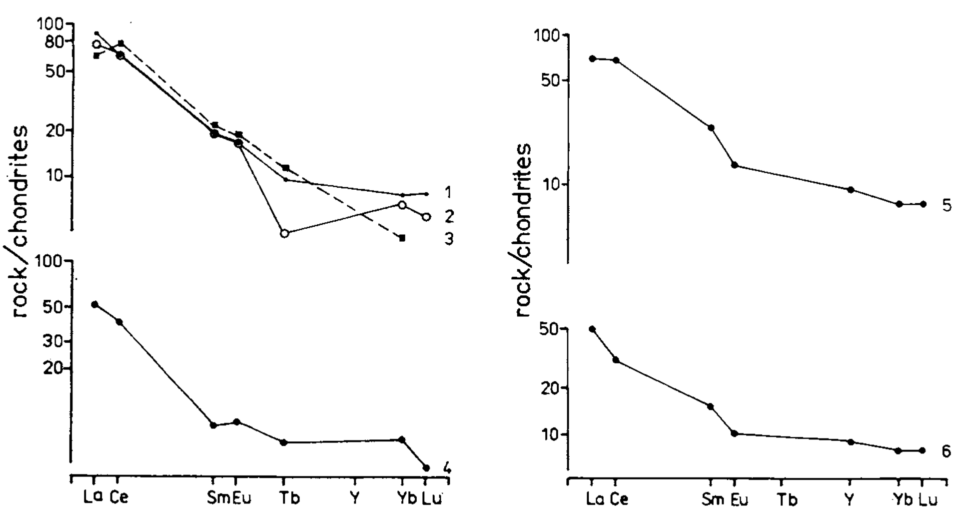
subgroups may be observed the geochemistry of which clearly depends on the proportions of clastic, volcanoclastic or may be even pyroclastic material from Jílové zone and Moldanubian continent. Towards ESE the occurrence of the material with geochemically mature features is dominant. This is in a good agreement with Taylor's and Mc Lennan's view (1985) that geochemical characteristics of sediments correlate with the geochemical characteristics of their source areas. In the CBP, this fact is well evident and it once more strongly supports the view that the granitization took place in situ and in shallow levels. A shallow level of granitization may be also deduced from the Vlašímský's observations in the mines of Příbram ore district (1986): the postplutonic denudation corresponds to the value of about 1500 m.

The granitoids of this group are enumerated in Fig. 7a, b. The *Blatná granodiorite* (about 500 km^2) is the most important type of this group. According to Bendl — Vokurka (1988) (isotopic data), the Blatná granodiorite originated by magma mixing of material derived by 30—50 % from the mantle and



trachyte
trachyandesite
dacite
mugearite
shoshonite
ryolite
trachybasalte
andesite
basaltic
andesite
1
2
3
12
10
8
6
4
2
Na2O+K2O wt%
45
48
52
57
63
70
75
SiO2 wt%

Fig. 5a



rock/chondrites
100
80
50
20
10
30
1
2
3
4
5
6
La Ce
SmEu
Tb
Y
Yb Lu
Sm Eu

Fig. 5b

by 50—70 % from the Maldanubian paragneisses. According to our data above, the same effect may be more easily attained by the mixing of clastic sedimentary material including volcanoclastics of various provenience what fits better into the geotectonic scheme. The other types of the group are: *Červená granodiorite, Těchnice granodiorite, Kozárovce granodiorite, Sedlec granodiorite* and one part of *Benešov granodiorite.* Some other types described in the literature but not distinguished in the geological map, represent individualized types of this group: *Vltava type, Zvíkov type, Hudčice type.*

All the rocks have variable geochemistry, mostly K>Na, slightly enriched LREE, relatively high Th. Most of them belong to the S-type, only Vltava and Kozárovice granodiorites are classified as I-type (Jakeš — Pokorný, 1983).

4. The zone of granitoids from the Barrandian and Moldanubian source material. In this fourth group granitoids are involved which are all situated at the NW contact of the CBP, some in narrow elongated, some in rounded bodies: *marginal type, Nýrsko type, Klatovy type, Kozlovice type, Požáry type* (Fig. 6a, b). The group is complicated. The rocks partly belong to the S types, e.g. Kozlovice granodiorite from Lower-Palaeozoic sediments (Palivcová et al., 1988), partly probably also to the slightly alkaline volcanics of hawaiian Na series — Nýrsko type, a part of the marginal type. Volcanics of this character occur in Upper Proterozoic region near Nepomuk and Blovice (Fiala, 1977; Ledvinková in preparation; Pelc — Waldhausrová in prep.). The source of material of Požáry granodiorite (trondhjemite) can be made of both types of the crust at the Moldanubian/Barrandian Upper Proterozoic boundary, or of the accretion pile (J. W.) containing island arc volcanics of the tholeiite — calc-alkaline to slightly alkaline type.

Summarizing we may conclude that the boundaries of the discussed zones are in a good agreement with the geophysical boundary between Moldanubian mature continental crust and Barrandian basin (Bohemicum). This boundary is indicated by the steepest geophysical gravimetric gradient in the Bohemian massif (Fig. 2). The Bohemicum represents — in the geological time before Variscan orogeny — the oceanic crust of Proterozoic age covered by Upper Proterozoic and Lower Palaeozoic volcanosedimentary pile (accretion pile according to J. W., V. L., rift pile according to M. P.). The Palaeozoic sediments continuously grade in this region into the mature sediments of shallower sea.

The data summarized on Figs. 2—6 and in the Tab. 1 indicate that the precursors lithology of granitoids may be well ascertained on the basis of the geochemistry evaluation with respect to the petrography and tectonic position of granitoids. Many problems in the CBP which cannot be answered in the mo-

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Fig. 5a. Total alkali-silica diagram (Le Maitre et al., 1984) of granitoids generated from Jílové zone equivalents (recycled mantle material).
1 — Sázava tonalite; 2 — Libčice granite; 3 — Něčín granite.

Fig. 5b. REE distribution patterns of granitoids generated from Jílové zone equivalents (recycled mantle material).
1, 2, 3 — Sázava tonalite; 4 — Něčín granite. For comparison: 5 — calc-alkaline low K-dacite of the Jílové zone; 6 — calc-alcaline low K-rhyolite of the Jílové zone.

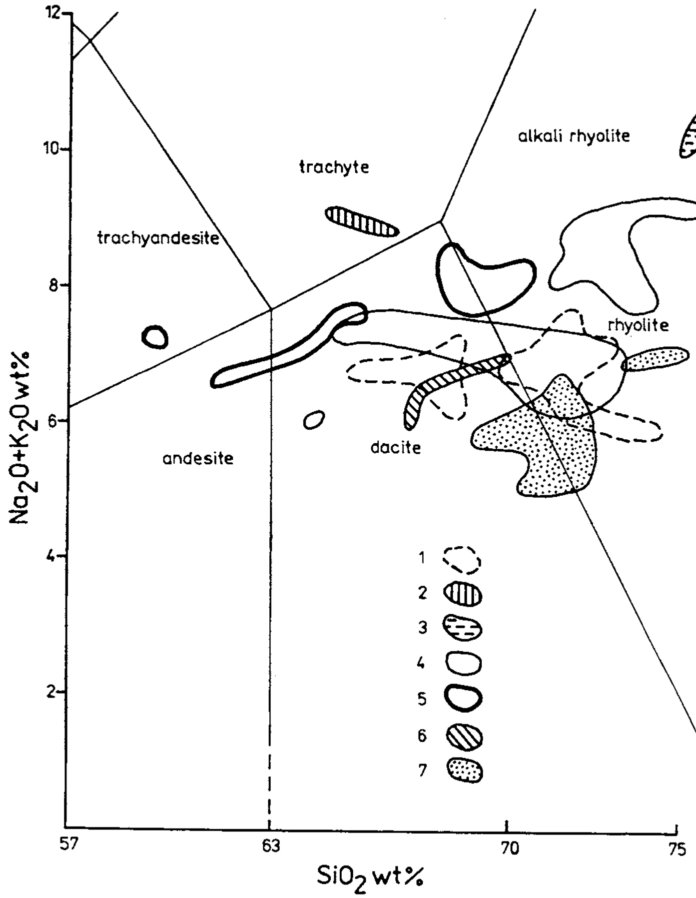
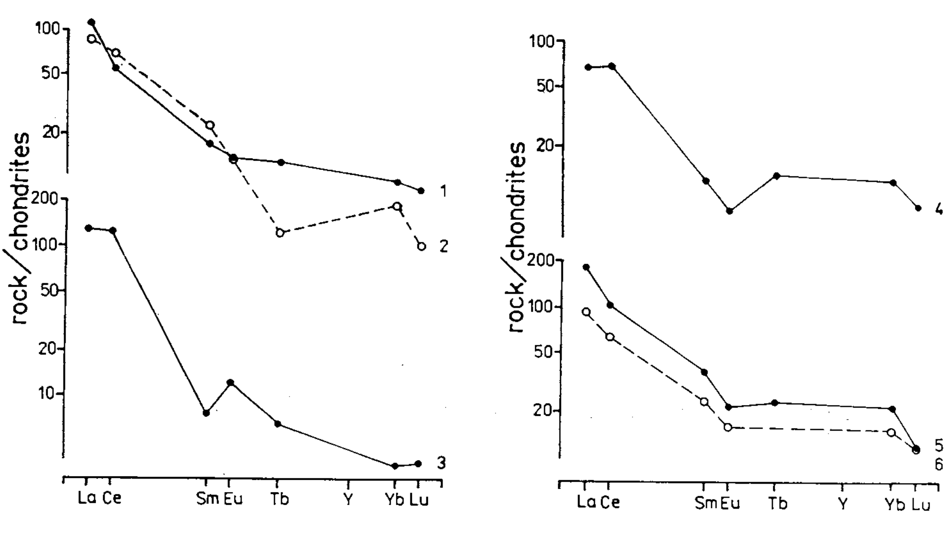

alkali rhyolite
trachyte
trachyandesite
rhyolite
dacite
andesite
12
10
8
6
4
2
57
63
70
75
1
2
3
4
5
6
7
Na_2O+K_2O wt%
SiO_2 wt%

Fig. 6a

Fig. 6b


100
50
20
200
100
50
20
10
1
2
3
4
5
6
rock/chondrites
La Ce Sm Eu Tb Y Yb Lu

dels of magmatic differentiation, magmatic anatexis or two different magma mixing and interaction, may be well resolved by the in situ granitization model of the granitoid origin.

5. *Basic rocks of the CBP.* In this preliminary short information, all rocks were included into this group which contain less than 54 % SiO_2, i.e. inclusive ultrabasic and some dioritic rocks and also microgranular enclaves.

There exists a number of major element analyses of basic rocks, which are however unevenly distributed and thus not sufficiently representative for the whole series, many concentrated in one body only and lacking in others. The group is very complex and needs more study.

According to the chemistry the basic rocks may be divided as follows:

a) Basic rocks joined to Moldanubicum. The microgranular enclaves studied by Holub (1977) in durbachitic rocks (Písek region — small durbachitic bodies in the close vicinity of the CBP) belong to this group. In the TAS diagram, they are clearly associated with the slightly alkaline series (basic trachyandesites of shoshonitic type, K-rich basaltoid andesite close to trachyandesite). The latter enclave derives from the same source as Tábor syenite according to REE given by Holub (1980), high K and high Th which are typical features for the Moldanubian group of granitoids. Biotites (biotite norites) from Tábor quarry may also be highly probably ranged into this group.

Some other basic rocks with affinity to Tábor syenite in geochemistry may be found in the central part of the CBP, especially in the Kozárovice granodiorite, e. g. a small occurrence at the Lom locality (probably a neck) and the basic rocks from the Lučkovice body (Ledvinková, 1987). On the contrary, the macrochemistry of noritic rocks from Hoštice locality (Rosický, 1922) near Tábor seems to belong to a quite different magma than the enclaves in durbachites.

b) Basic rocks joined to the Bohemicum include a wide range of rocks which plot in the fields of following magmas in TAS diagram: 1) ultrabasic rocks — basanites, picrobasalts; 2) trachybasalts — basic trachyandesites with prevailing Na; 3) olivine basalt; 4) tholeiitic basalts, low-K calc-alkaline basalts, high Al basalts; 5) basaltoid andesites; 6) andesites (these two latter do not belong to basic rocks due to higher SiO_2).

Most of these rocks occur in or close to Sázava, Blatná and Požáry types. According to the REE analyses available, their source seems to be comparable with various basalts, trachybasalts and trachyandesites, basaltoid andesites and

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Fig. 6a. Total alkali-silica diagram of granitoids generated from mixed material, Moldanubian + Barrandian; partly from mature island arc (tholeiitic-calc-alkaline -slightly alkaline volcanic series) according to J. W.
1 — Příbram granodiorite; 2 — Nýrsko granite; 3 — marginal type granite near Klatovy; 4 — marginal type granite near Nepomuk and Příbram; 5 — Klatovy granodiorite; 6 — Kozlovice granodiorite; 7 — Požáry granodiorite.

Fig. 6b. REE distribution patterns of granitoids generated from mixed material (Moldanubian + Barrandian), partly from mature island arc (tholeiitic — calc-alkalinie — slightly alkaline volcanic series) according to J. W.
1, 2 — marginal type granite; 3 — Požáry granite; 4 — Klatovy granodiorite; 5, 6 — Kozlovice granodiorite.

andesites of the Jílové zone. Some may represent (according to J. W.) granitized volcanic and subvolcanic members of the mature island arc which have equivalents in the amphibolites of the Čerčany metamorphosed islet. Ultrabasic rocks situated at the contact with Barrandian Palaeozoic series might correspond to Lower Palaeozoic rift volcanics.

The variability of this group of basic rocks indicates that their precursors were joined to the regions with progressively changing tectonomagmatic regimes.

Discussion

According to Barker (1983) "magma — once generated — moves into or through crust and retains ... some chemical characteristics that were imposed at the site of magma generation" and "the composition of igneous rocks should reflect tectonic conditions at the time of their emplacement". Typology of granites (M, S, I, A types, e. 4. Pitcher, 1983) is based on this assumption. It means that tectonic conditions as well as magma origin are detectable from the composition and geochemistry of granitoids and vice versa, composition of granitoids should be in consistency with tectonic conditions if known — presuming that the granitoids originated as magmatic rocks.

Three main hypotheses — all of magmatic type — are newly widely accepted in the petrogenesis of granitoids in orogenic belts (e. g. Whalen, 1985): restite unmixing (e.g. Chappell et al., 1987), magma mixing (e.g. Popov, 1984; Didier, 1987; Barnes, 1987; Eberz—Nicholls, 1989) and fractional crystallization (e.g. Schermerhorn, 1987; Whalen, 1985 and many others).

Various combinations and modifications are searched to explain the complicated geochemical features in which often mantle as well as crust geochemistry are mixed in erratic and variable manner; thus fractionation of anatectic magma, fractionation and assimilation (Da Paolo, 1981), mixing of magmas of different sources and origin, or also overprinting of one magma or rocks by magmatic to hydrothermal solutions (Atherton — Sanderson, 1987; Key, 1987 etc.) are assumed in individual cases. This leads to the conception of "more and even more granites" (Pitcher, 1987).

Recently a great depth — up to Upper mantle level — is commonly accepted for the origin of granitoid magma; the shallowest depth usually assumed is about 15 km in agreement with experimental results, e.g. 800 °C and 5 kb, 4 % H_2O according to Charoy (1986) for the partial melting in the crust. In contrast to this, a high level crystallization and high level intrusions of granitoids become more and more evident with increasing recent progress in the granite research. "In situ" fractionation (e. g. Whalen, 1985 and many others), "in situ" anatexis (Wickham, 1987), "in situ" magma mixing (Eberz—Nicholls, 1988) is emphasized. The high intrusion level up to 1—2 km and surprisingly persistent average level at 3—4 km of the surface is referred from the huge Peru batholith (Pitcher, 1978) in contrast with unexpected deeper roots for acid members (up to 12 km) i. e. more than for basic granitoids. To rise this granitoid magma from the depth to shallow levels, violent emplacement should be supposed — inconsistent with field evidence of passive emplacement of many large bodies in orogenic belts and yet more inconsistent with experimental melting conditions in the crust: only wet crust can melt but only dry magma can move upwards (Pitcher, 1979; Cann, 1970). A number of other features, especially in geochemistry and crystallization of granitoids remains controversial; two stage crystallization of the main minerals of tonalites with anorthitic cores in plagioclases and relics of pyroxene in hornblendes is a good example. In all three hypotheses, this crystallization is used as evidence of the respective model: Whalen (1985) for fractional crystallization, Chappell et al. (1987) for restite model, Eberz — Nicholls et al. (1988) for magma mixing. Contrasting magmatic as well as metamorphic features (late magmatic, metasomatic — e.g. Zharikov — Gavrikova, 1987; Key, 1987 for some recent examples) cannot be denied in granitoid complexes and rocks (see also Palivcová et al., 1989). Special unusual ways — often inconsistent with geological observation as pointed out by Pitcher (1979) — had to be searched to bring the crustal magma through the crust into the present level: balooning, montgolfiers, diapirs. Cauldron emplacement i. e. violent and rapid magma rise is reasonably assumed as a dominant event in Andean batholiths, however alternating of compression and extension regimes in orogenic belts had to be assumed (Pitcher, 1979).

The CBP yields an extraordinary occasion to study Variscan multiple pluton composed of entirely different petrographic series in a distinct suitable tectonic position, on the boundary between oceanic and continental blocks (plates) of Bohemicum and Moldanubicum respectively. As mentioned above the granitoids originated in a relatively restricted time span of Variscan orogeny.

A simple method of macrochemistry evaluation combined with trace elements and REE distribution patterns together with a good knowledge of geological and structural features of CBP and adjacent area allowed to estimate the precursors lithology of granitoids. The evolution history and the recent geochemistry of geochemically different granitoids in four zones are well explicable as inherited features if volcanosedimentary and volcanic precursors are accepted as source rocks of the granitoids. These precursors may be compared in CBP in some cases with remnants of original unaltered rocks. In situ origin of granitoids is an inevitable conclusion.

It is clear that none of the accepted magmatic models which require depth origin of granitoid magma is consistent with the geochemical as well as geotectonic data. However, our conception discussed in the previous paper 1989, i.e. granitization to initial anatexis in situ can explain nearly all essential contrasting features of the CBP body. Some indications for granitization in situ were already previously formulated for some parts of the CBP as referred above.

The in situ granitization process leading to initial anatexis has following advantages:

a) It is able to remove the problem of magma segregation for large granitoid bodies, which is a severe constraint of magmatic anatectic model (Wickham, 1987; Pitcher, 1979).

b) It removes the difficulties of emplacement, the poorly understandable ways of the magma rise through the crust such as buoyancy, ballooning, montgolfiers and also diapirs with opposite dipping (Pitcher, 1979) as well as discrepancies between violent and non-violent features of granitoid intrusions

(Mehnert, 1987; Palivcová et al., 1989). Violent features may be interpreted as inherited features of magmatic, i.e. volcanic-subvolcanic stage of development; passive emplacement originated during granitization.

c) It removes the space problem of large granitoid masses which no magmatic conception may avoid.

d) It removes the necessary alternating of the conditions of extensions regime — needed to magma ascent (we concur with Castro, 1987 that the magma moves upwards predominantly in open ways), and of compression regime needed for granite formation in orogenic belts. However, this classic view was newly called in doubts by the new research of Wickham — Oxbourgh (1987) in Pyreneean orogenic belt. Anatectic and metamorphic conditions leading to granite formation originate there in extensional rifting regime without any crustal collision according to the authors. The problem requires special attention in CBP by our structural geologists as the petrogenetic conditions of some granitoids formation seem to be very similar in both regions (Palivcová et al., 1989). The severe question arises: Are the phenomena of extensional rifting conditions a typical feature of orogenic granite formation or could they be inherited petrified features of precursory origin preserved from the previous stage before orogeny?

e) It may explain almost the whole set of the other contrasting phenomena incentively summarized by Pitcher (1977, 1978) and in the CBP indicated by the present authors (1989).

The magmatic features of plutonic complexes inclusive hybridization, contamination, cumulation and also some shapes of bodies are explicable as inherited from the volcanic stage of the precursors. Mixed crustal/mantle geochemistry can be accounted rather to the mixing of volcanoclastic, pyroclastic and sedimentary material from various sources in to the sedimentary (accretion J. W.) pile before granitization; metamorphic features of crystallization are due to "effects" of granitization. The homogeneity, often coarse grained character of immense and thick volcanic deposits (especially lithocrystalloclastic deposits) are underestimated in the considerations about granitoid genesis up to now in our view.

Following criticism and constraints may be opposed to the granitization model of the CBP:

a) the problem of the source of energy for "in situ" reworking; however, according to Barker (1983), "raising temperature may be produced in following ways: by introduction of the magma below, or by friction and shear, or by subduction transport onto higher temperature regions". We assume that shearing heat according to Nicolas et al. (1977) may be the most plausible explanation. The objections of e.g. Pinet (1987) may be removed if the transpression i.e. combination of simple shear and pure shear during orogeny is assumed as prerequisite of the heat generation. Thus the granitoids need not accompany every thrust line but only those in the transpressive regime, as is the case of the CBP according Rajlich et al. (1988). Deep magma chambers on tectonomagmatic lines may be additional supplier of the heat (M. P.);

b) the intrusion capability: we do not deny it at all if initial stages of anatexis were attained — however, only intrusions on small distances occur according to our view, observable directly at the contact of plutonic bodies. Dykes and sills yield a clear evidence that anatectic magma has capability to move on large distance only if open ways (faults etc.) are at disposal;

c) thermal contacts around granitoid bodies and the unchanged series (only contact metamorphosed "roof pendants"), preserved directly in the centre of the granitoid complex: this is certainly the crucial constraint of the granitization model. However, the effect of shear heating in a restricted area is not an unsuperable presumption according to our view. The problem concerning rheology and thermal effects of shearing should be studied with more attention in the future. The contact aureoles may be of two origin: inherited contacts of volcanic-subvolcanic precursors, e.g. necks, or contacts produced by the shear heating itself which may last after granitization; if the shear or friction heating is sufficient to melt the rocks up to vesiculation (J a u p a r t — P r o v o s t, 1985) it probably may cause the thermal contact effects, too. Maybe the contact metamorphism is a result of long lasted heating without required pressure at the end of granitization process.

Summarizing we believe that the advantages highly prevail the disadvantages of the in situ granitization (to initial anatexis) model, applied in this paper.

Conclusions

The CBP originated during Variscan orogeny in the area of the s.c. Central Bohemian lineament at the geophysically documented boundary zone between two units of Central Bohemia, Bohemicum and Moldanubicum (C h a l o u p s k ý, 1989). At the boundary of these two plates (according to J. W., V. L.) or blocks (M. P.), thermal and pressure conditions reaching up to amphibolite facies developed due to the movements in the shear zone during the tectonic regime (collision according to J. W.) in the Variscan orogeny. These conditions evoked wide-spreated — but localized to certain zones — processes of extensive situ migmatization and granitization.

Four main groups of granitoids of CBP were distinguished according to the precursors lithology based on the geochemistry of granitoids. The major chemistry as well as trace element geochemistry (especially REE) of these groups were evaluated in context to the position on the boundary zone between two entirely different plates (blocks) of the crust of the Bohemian Massif: Bohemicum with Proterozoic oceanic crust and Moldanubicum — mature continental crust. The individualized belts of the analogous precursors lithology are graphically presented on Fig. 2 and tabellary in Tab. 1. The zones were deduced from the geochemistry of a number of samples of individual intrusions of the CBP, plotted in TAS diagram of volcanic rocks. Collective TAS diagrams for the four groups are in Figs. 3—6.

The four groups of granitoids are the following:

1) *granitoids whose precursors were slightly alkaline volcanics typical for continental rifts* (on Moldanubian plate or block) — now durbachitic rocks — Fig. 3a, b;

2) *granitoids whose precursors were tholeiitic, calc-alkaline, and partly slightly alkaline* volcanics and their products (inclusive subvolcanic members) at the

margin of the Bohemicum, i.e. Jílové volcanic zone (representing island arc volcanics in the plate tectonic scheme according to J. W.) — tonalites of Sázava type, Něčín and Libčice granodiorites — Fig. 5a, b;

3) *granitoids whose precursors were mixed rocks in various proportions from the Jílové zone and Moldanubian region* — Blatná granodiorite, Červená granodiorite, Těchnice granodiorite, Kozárovice granodiorite, Sedlec granodiorite, part of Benešov granodiorite — Fig. 4a, b;

4) *granitoids whose precursors were mixed rocks of the Barrandian and Moldanubian source region* — marginal type, Nýrsko type, Kozlovice type, Klatovy type, Požáry type — Fig. 6a, b;

Basic rock were preliminary divided into groups one adjoining Moldanubicum and the second main group adjoining Bohemicum.

In situ granitization leading to initial anatexis is considered to be the most plausible explanation of the origin of granitoids in respect of their precursors geochemistry inherited from the source rocks. The advantages and disadvantges of the in situ granitization model are briefly discussed.
cussed.

This paper is a short summary of the detailed study of individual intrusions of the pluton.

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