Granitoids of the Osnitsky complex of Ukrainian Shield and the Brno Massif of Moravia: Comparison of structural-geological, petrophysical and petrogeochemical features of origin and petrological significance

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Received: 07.04.2010

Abstract

In this work we summarise basic results of our studies for the areas of tectonomagmatic activities in Moravia and at the western slope of Ukrainian Shield. The processes occurred there have resulted in development of volcuno-plutonic belts related to different blocks of the Earth's crust. There is a likeness in the origin and characteristics of granitoids in different areas of tectonomagmatic activity of the Earth's crust. This often forms a very close set of their composition and structural features reflecting the regularities of their origin. In spite of evident difference in the geological and structural positions of those granitoids, similarities and approaching trends in the changes of their structural, petrochemical and petrophysical characteristics should be marked. These characteristics can be taken as indicators of magmatism and mineralisations and can also serve as important distinguishing features of the ore-monitoring structures.

Keywords: Brno Massif, Ukrainian Shield, origin of granitoids, petrophysics, tectomagnetic activities, granitoid massifs

UDC: 550.4.552.1:53

1. Introduction

The problem of determination of granitoids' petrogenesis is interlinked with the studies of their paragenetic associations, and composition and physical characteristics. This problem may be solved in the most efficient way while studying the rocks in the regions of tectono-magmatic activities like at the territories joining to the Czech megablock (CMB) or the north-western margins of the Ukrainian Shield (US) located within the limits of the Volyn Fold Belt, including the Osnitsky block. Both of these blocks occupy the outlying positions of large ledges of ancient basements (the US and the CMB) on the territories of the Middle-European and Russian platforms. Their main feature is a complicated structure caused with later imposed disjunctive faults in the north-western or/and sublatitudinal directions, which are adjusted to a general layout of deeply seated faults. There also exists a sublatitudinal system of long-living breaking faults which causes the appearance of up-lifted belt ranging from the CMB to the Volyn area of the US. This up-lifted belt has been expressly found in the Palaeozoic, Mesozoic, and even Cainozoic Ages [1].

It is obvious that a comparison of composition-structural features of the rocks differing by their ages, regions and types of tectonomagmatic activity may provide useful information concerning similarities in the conditions of origin of granitoids of the Brno Massif and the Osnitsky complex in the north-western district of the US, as well as general regularities of their endogenous mineralisation and some other important points.

2. Results and discussion

2.1. Geological tectonic position

The CMB has been consolidated as a result of Variscian tectonogenesis and, immediately after that, it has parted into a row of structural floors, in accordance with sequential phases of development of the platform. As a whole, structural plan of the CMB has been formed on the basis of Assintian tectonic style. Therefore it is also possible to select the two structural-formation areas within the limits of the CMB: (1) the Czech and Moravian stable blocks, and (2) the area of intense Variscian tectonogenesis.

A tendency to differentiation is characteristic of all the granitoid intrusives of the CMB, which have traced from the Middle-Czech plutons through shallow massifs, dikes and, finally, to peripheral massifs. Formation of the granitoids is presented, as a rule, by a series of differentiations from diorites, quartz diorites and granodiorites to granites.

The Brno Massif is located inside the area of intense tectonic activity of the Alpine-Carpathian orogen [2, 3], and submerged in the platformic region. Moreover, the Moravian block is a peripheral, rigid and consolidating element of the CMB, belonging to the Epivariscian Middle-European platform. The Brno Massif is located on the east margin of the CMB and occupies the area of over 600 km^2.

The Brno Massif forms the most raised part of Brunia, where Brunia represents a large consolidated area of the Earth’s crust within the limits of Moravian block (including a row of smaller granitoid bodies). The structural-tectonic plan of Brunia includes both submeridional and south-eastern structural directions, which are the most typical. Besides, the south-eastern structural directions are the most ancient, being presumably linked with formation of the CMB itself. The submeridional system of faults is younger than the south-eastern one because of repeated tectonic alterations of the Brno Massif. Northern, eastern and southern contacts of the Brno Massif with the Palaeozoic deposits of Middle Moravia and piedmont foredeeps of Carpathians reveal transgressive or tectonic characters.

In accordance with Stelcl and Weiss [4], formation of plutonic body of the Brno Massif has taken place in the Precambrian times in the area of activation and primary tectonic depression that have separated the CMB from the Western Carpathians. Therefore the Brno Massif is a core part of a composite anticline.

The two areas, western and eastern ones, are included in the Brno Massif and divided by a metabasite zone subsiding in the submeridional direction. The south-eastern and sublatitudinal directions break the massif into the three blocks (Northern, Central and

Southern) that differ by the level of erosion cutting. Structural analysis and petrological data testify a presence of about three structural floors in the Brno Massif [4].

The Osnitsky complex is located in the north-west of the US within the limits of Volyn Fold Belt which is separated from the adjoining protoplatform by the Sushchany-Perga Fault. It unites spatially and genetically linked rocks, from gabbro to leucocratic granites. The granitoid massifs reveal not too clear zonality. Their contours are fuzzy and xenoliths of the bearing strata occur in the peripheral parts [1]. The granites usually have sublatitudinal eastern to north-eastern extending.

The Osnitsky complex consists of (1) ultrametamorphic rocks (products of transformation of the rocks of Klesiv series) and (2) magmatic rocks. The intrusive rocks have been formed in the four successive phases: (a) gabbros, (b) diorites and quartz diorites, (c) grandiosities and granites, and (d) vein leucocratic granites [5]. Bodies of the granites have intruded there on a final phase of intrusion of the Osnitsky complex.

The final members of crystallisation of the Osnitsky complex have probably appeared from the melt arisen in the local areas of stratified plicate layers of metavulcanites, which have acquired capacities for moving under proper tectonic conditions [6]. The intrusive formations of the Osnitsky complex are linked with the areas of tectonic faults of submeridional or, in a less measure, sublatitudinal extending, as well as with the knots crossing these areas.

The structural positions of the Brno Massif and the Osnitsky complex reflect various and multifold influences distinguished in their structure, composition, degree of metamorphism, character of dislocation, tectonic plan, etc. Among these features we should mark at least those which are proper for tectonic-magmatic activations:

(1) The Brno Massif is formed as a result of successive phases of introduction of magma from a single differentiated source. Abyssal bodies prevail among the intrusive granitoids of the CMB, though the later stages of the intrusion have also had mesoabbysal depths and vein dike-like hypoabbysal bodies. Such formations may be referred to typically intrusive ones, though sometimes they could appear because of granitisation. Similar situation is observed for the origin of the Osnitsky complex, where both ultrametamorphic and magmatic formations are present.

(2) The intrusive bodies of the Brno Massif are related to the tectonic faults inherited from the CMB. There are typically close spatial and genetic interrelations of the granitoids with the areas of metabasites.

(3) Formation of the CMB has begun with the Variscian tectonogenesis and consisted in successive change of magmatic associations with different compositions. We also mark a compound poly-fascial structure of the massif and an obvious link with the Western Carpathians.

(4) The origin of the Osnitsky vulcanic-plutonic association in the north-western area of the US is associated with a tectonic-magmatic stage of activity in the region, which has been lasting approximately for 30 mln and has been completed by forming of the Osnitsky granitoides complex (1990 mln) [7].

2.2. Comparative description of composition and physical properties of granitoids of the Brno Massif and the Osnitsky complex

The Brno Massif and the Osnitsky complex are composed of various magmatic rocks, ranging from ultrabasites to granodiorites, plagiogranites, and normal and leucocratic granites (see Table 1).

Table 1. Composition of granitoids of the Brno Massif and the Osnitsky complex

N	Object	Petrotype	Main Zavaritsky petrochemical coefficients						Petrochemical classification
			s	*a*	*b*	*c*	*Q*	*a/s*	
1	Brno Massif	Plagiogranite Dubravice	84.4	16	–2.20	1.83	35	8.72	Supersaturated Al_2O_3
2		Plagiogranite Blansko	76.6	13.2	7.18	2.98	23.8	4.43	Normal row
3		Plagiogranite Kralove Pole	76	15.4	6.49	2.15	19	7.16	Normal row
4		Adamelit Veverska Bitishka	79.4	15.5	3.79	1.25	26.5	12.5	Normal row
5		Granite Kounice	83.4	13.5	–0.21	3.25	36.5	4.16	Supersaturated Al_2O_3
6		Granite Tetchice	86.5	13.3	–2.85	3.04	43.5	4.37	Supersaturated Al_2O_3
7		Granite Gliny	86	14.5	–2.12	1.61	41.4	9	Supersaturated Al_2O_3
8		Granodiorite Reni	86.4	14.2	–1.08	0.44	44.1	31.9	Supersaturated Al_2O_3
9		Granodiorite Krumlovsky Forest	86.4	14	–1.68	1.32	43.5	10.6	Supersaturated Al_2O_3
10		Granodiorite Vedrovice	85.1	13.3	–1.85	3.41	40.2	3.9	Supersaturated Al_2O_3
11		Granodiorite Olbramovice	83.3	11.8	2.65	2.3	40.7	5.12	Normal row
12	Osnitsky complex	Granite Osnitsky	87.3	14.8	–3.64	1.51	43.5	9.82	Supersaturated Al_2O_3
13		Granodiorite Osnitsky	83.2	15.6	–1.58	2.81	32.5	5.53	Supersaturated Al_2O_3
14		Granodiorite Yasnogorskiy	79.2	12.7	3.09	4.98	27.9	2.56	Supersaturated Al_2O_3
15		Quartz-monzodiorite Virovskiy	70.9	14.6	9.15	5.35	7.08	2.74	Normal row
16		Diorite Rokitnyanskiy	65.9	10.4	18.07	5.58	5.47	1.87	Normal row
17		Diorite Virovskiy	65.2	10.5	19.93	4.39	5.02	2.39	Normal row

Depending on the features of their composition, the rocks of the Brno Massif are divided into three groups [8]. *The first group* (the field of plagiogranites) includes granitoides of Doubravice, Blansko, Kralove Pole and granodiorite Osnitsky. They have fine, middle-grain and hypidiomorphic structures and a massive texture. The mineral composition is described by a low content of potassium feldspar, with prevailing zone-structure plagioclase and black-coloured minerals (amphibole and apatite-zircon associations).

The second group (placed between the fields of adamelites and granodiorites) includes granitoids of Veverska Bitishka, Krumlevsky Forest, Vedrovice, Reni and Olbramovice. In this group of rocks one observes hetero-grained porphyry structures, massive textures, mirmekites, etc. Amphibole and a lot of the altered minerals are rare. Notice that the first type of the Osnitsky granite has middle-grain, large-grain and porphyry structures, and includes a zonal plagioclase.

Finally, *the third group* includes granitoids of Kounice, Tetchice and Gliny. These rocks belong to normal lime-alkaline granites with hetero-grained and rarely porphyry structures, and a massive texture. A zonality of feldspars and different mutual reactionary relations are characteristic features of these rocks [4]. It is worthwhile that the second type of the Osnytsky granites reveals fine-grained and middle-grained structures, zonality of plagioclase, and a presence of several generations of potassium feldspars and quartz (see Fig.1).

A presence of molybdenum mineralisation represents distinguishing feature of the Brunia granitoids. Moreover, sometimes they can have an accompanying Cu-Fe mineralisation and scattered-compound mineralisation: aggregates of molybdenite in quartz veins, as well as mineralisation in cracks and loosen areas. The mineralisation of granitoides of the Osnitsky complex is of a mixed zircon-apatite-titanite-magnetitic character [9].

A majority of the granitoids under study belong to the class of supersaturated SiO_2 rocks ($45 < Q < 15$), except for the quartz monzodiorite Virovskiy, diorite Rokitnyanskiy and diorite Virovskiy (see rows 15–17 in Table 1). According to the values of alkalinity, the objects in the rows 1, 4, 7–9, 12 of Table 1 comprise a group of oversaturated alkalis of rocks ($a/s < 8$), while all the other granitoids (except for those presented in the rows 14 and 15) compose a group moderately rich of alkalis ($a/s < 3$). One should mention a characteristic presence in the Osnitsky complex' composition of unsaturated SiO_2 rocks, with relatively low alkalinity, being a reflection of composition evolution on the early phases of intrusion.

One can note a tendency to decreasing coefficient of titaniferousness and increasing value of K_2O/Na_2O ratio when passing from the mafic rocks to acid ones [7]. Most of the amount of granitoids for the Brno Massif is near to the Osnitsky granodiorite and only the Vedrovice granodiorite, the Kounice granite and the Reni granodiorites are comparable with the Osnitsky granite.

Similar compositions of the Brno and Osnitsky granitoids are clearly reflected in their *petrophysical parameters*. Here highly dense granitoids of the northern block of the Brno Massif can be compared with the granodiorites Osnitsky and less dense varieties of rocks from the southern and central blocks with the hetero-grained Osnitsky granites. The leading factor of difference of the density property, the bulk density σ_0, varies depending on the mineral and chemical compositions.

The heat conductivity λ for the granitoids of the Brno Massif increases in southward direction and reaches its maximal values for the granodiorites Reni and Krumlovsky Forest, Olbramovice. It has the same characteristics as those of the Osnitsky complex' granitoids. One can see a significant dependence of the heat conductivity on the depth fascia, which also governs capacity properties of the rocks.

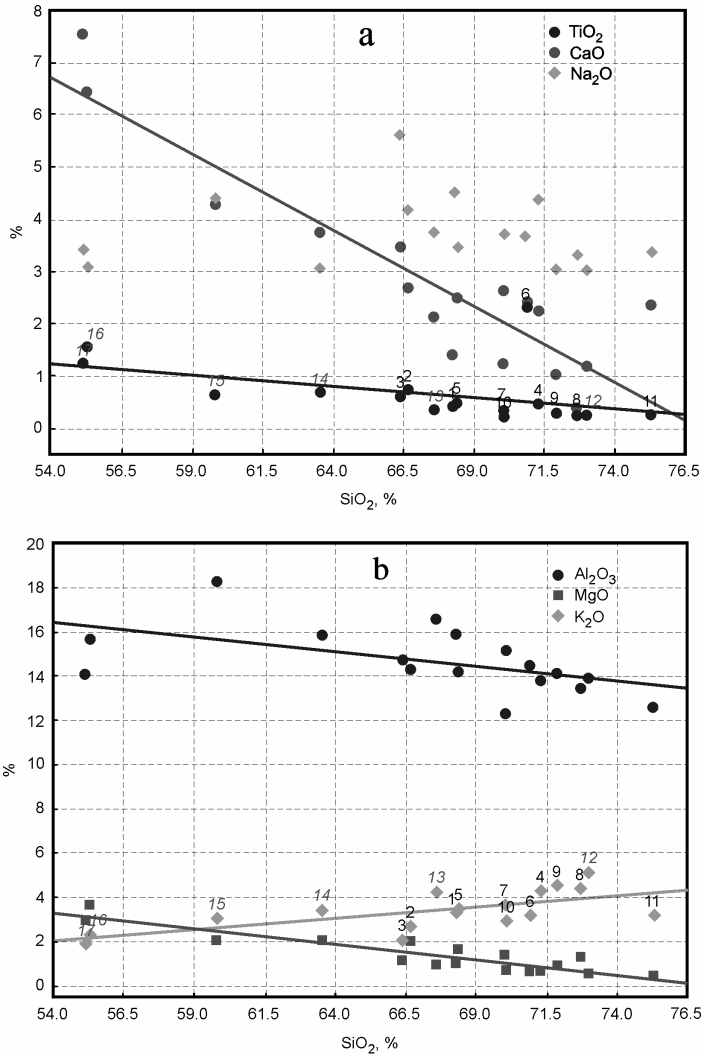


Fig. 1. Petrochemical variograms for granitoids of the Brno Massif and the Osnitsky complex. Numbers near the data points correspond to the petrotype numbers given in Table 1.

Except for anomalously radioactive granodiorites Gliny and Reny, all the other petrographic species of the Brno Massif are closely linked with the Osnitsky granodiorites.

A wide range of changes in the magnetic characteristics of the rocks is conditioned by chemism of both magma and substrata, as well as forms of isolation of ore minerals and history of their transformation. Successive formation of the intrusive phases has taken place at higher and higher depth levels, with a preserved level of oxygen potential and a gradual reduction of total iron content (see Fig. 2 and Fig.3). The magnetic susceptibility

χ has an evident trend to decrease for the middle-grained and coarse-grained granites and strong oxidisation of the ore minerals. These minerals show a secondary non-magnetisation and maximal values of the Kenigsberger's factor [8].

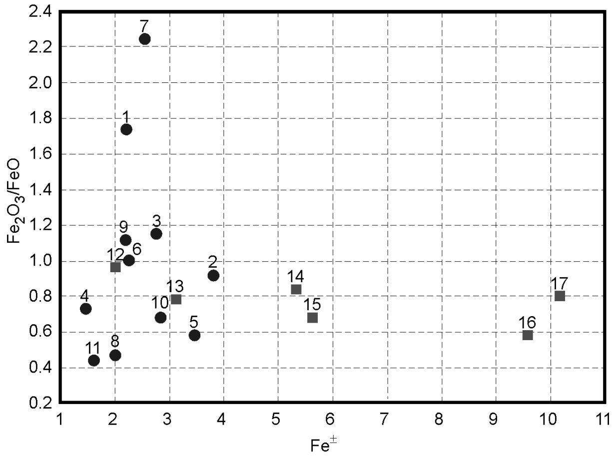


Fig. 2. Correlation of total iron composition Fe* and oxidisation degree of iron.

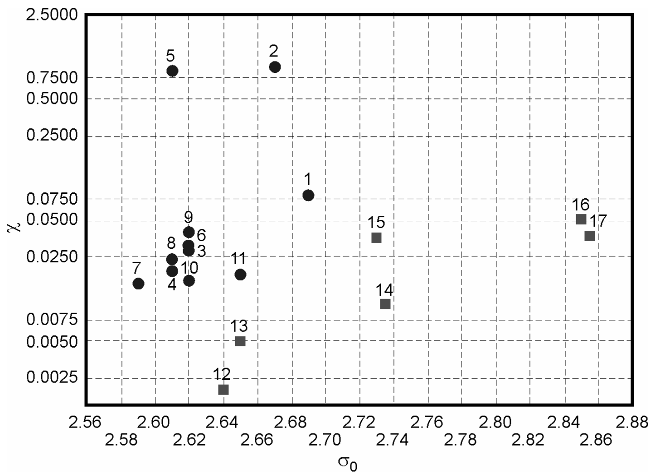


Fig. 3 Petrophysical classes displayed in the coordinates 'magnetic susceptibility χ' versus 'bulk density σ_0'.

2.3. Geodynamical conditions of origin of the granitoids

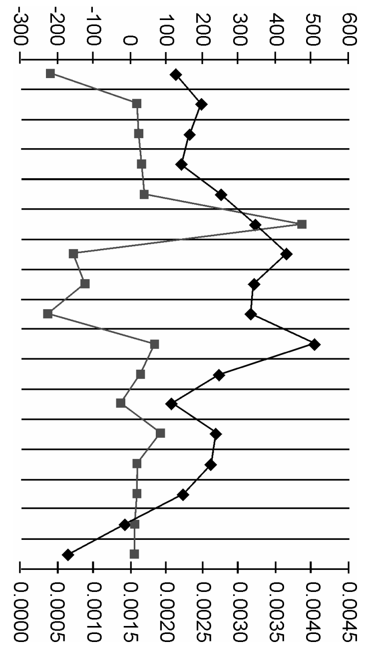
Depths of granitoid complexes have been estimated following from the geological-structural characteristics [6, 10, 11] and petrogeochemical indices. In particular, the petrochemical polarity coefficient (p. p. c.) reflects correlations of elements with various behaviours in the process of differentiation of rocks, thus allowing one to obtain quantitative relations describing a level of depth and that of the erosion cutting. In particular, increasing p. p. c. value would correspond to the erosion cutting depths [12].

The fasciae of depths have been calculated using the relations of multiplicative geochemical coefficients: R/(F+T), where R denotes the average weighted content of a given group of rare earth elements, and F and T those of the transition and rare-earth elements, respectively. The increase in the R/(F+T) index should be inversely proportional to increasing depth [13].

The oxygen fugacity has been estimated when calculating the iron oxidation coefficient $C_{Fe_2O_3}/C_{FeO}$ that reflects a partial pressure of O_2 in magma during crystallisation of Fe-containing minerals. The levels of oxygen fugacity have been referred to the "high" and "low" classes, issuing from the bimodal distribution of the iron oxidation coefficient values in the rocks under test and involving the additional petromagnetic data.

In order to reconstruct geodynamically the origin conditions of the granitoids, we have applied several classifications and a complete analysis of the petrophysical data. The results of a so-called S-I-A-M classification of granitoids [14] have confirmed that the formations of the Brno Massif's granitoids and the Osnitsky complex' granites are close enough, being referred to the groups I, S and, partly, to the group M. This suggests a mainly core origin of these objects (see Table 2).

Table 2. Origin conditions for granitoids of the Brno Massif and the Osnitsky complex



No	Oxygen-fugacity fO_2	Structural stage [4, 3]	Geodynamical classification [14]					
			Chuppel-White			Tauson		
			M	S	I	A	III	IV
1	high	II	51	51	56	422	23.9	44.3
2	low	II	54	58	65	424	17.1	35.2
3	high	II_1	77	54	50	394	17.9	39.4
4	low	II_1	113	76	66	359	8.8	28.2
5	low	I_0	76	69	74	426	8.8	25.0
6	high	I_1	72	59	62	412	16.0	28.3
7	high	II	79	66	70	423	12.4	30.2
8	low	III_2	75	87	91	450	31.5	55.1
9	high	III_1	85	101	108	466	27.0	49.7
10	low	III_0	73	77	86	445	13.2	23.5
11	low	III_0	95	71	64	388	25.5	47.4
12	low	III_0	157	105	97	320	32.2	8.5
13	low	III_0	273	224	210	200	6.3	18.3
14	low	III_0	401	355	341	123	21.1	45.1
15	low	III_0	563	518	504	185	28.5	52.0
16	low	III_0	230	195	181	272	60.5	84.1
17	low	III_0	272	281	284	518	41.2	64.2

* Upper scale and square data points correspond to the petrochemical parameter p. p. c., lower scale and rhombic data points to the chemical parameter R/(F+T), whereas the columns of geodynamical classification include the values of Euclidean distance.

Numerous features of secondary softening have been observed for the Brno Massif because of fragile deformations occurred at its flanks [8]. These deformations manifest themselves in a high degree of fracturing, wavy fading of quartz grains (e.g., for the plagiogranite Doubravice), a cataclastic structure (plagiogranite Blansko), flexure of scales of mica and amphibole, and numerous tracks of crushing (e.g., for the granite Kounice).

There is a paleotectonic condition imposing final differentiation of the Osnitsky complex, which is related to the granite Osnitsky and the granodioritt Yasnogorskiy, with predominating stress-induced extension [8].

Table 3. Reconstruction of paleogeodynamical conditions of the origin of granitoids for the Brno Massif and the Osnitsky complex

№	Petrotype	Tectonic regime	Tension-deformation conditions			Imposed tectonic regime [1]
			Type	Intensity	Tectonic regime	
1	Plagiogranite Dubravice	compression	uniform pressure	middle	fragile [1]	secondary extension
2	Plagiogranite Blansko	extension	uniform pressure	middle	fragile [1]	
3	Plagiogranite Kralove Pole	extension	uniaxial pressure	high	plastic	
4	Adamelit Veverska Bitishka	extension	uniform pressure	low	plastic	
5	Granite Kounice	extension	uniform pressure	low	fragile [1]	extension
6	Granite Tetchice	extension	uniform pressure	middle	fragile	
7	Granite Gliny	extension	–	–	–	
8	Granodiorite Reni	extension	uniaxial pressure	low	fragile	
9	Granodiorite Krumlovsky Forest	extension	uniform pressure	middle	plastic	
10	Granodiorite Vedrovice	extension	–	–	–	
11	Granodiorite Olbramovice	extension	–	–	–	secondary extension
12	Granite Osnitsky	compression	uniaxial pressure	high	fragile	
13	Granodiorite Osnitsky	compression	uniaxial pressure	high	fragile	
14	Granodiorite Yasnogorskiy	compression	uniform pressure	high	fragile	
15	Quartz-monzodiorite Virovskiy	compression	uniaxial pressure	high	plastic	
16	Diorite Rokitnyanskiy	compression	uniaxial pressure	high	plastic	
17	Diorite Virovskiy	compression	uniaxial pressure	middle	plastic	

* I, II and III denote abyssal, mesoabyssal and hypoabyssal levels of depths, respectively, and 0, 1 and 2 lower, middle and upper subfasciae of the levels of depths, respectively.

The geodynamical peculiarities of the rocks may be confirmed coming from the corresponding geochemical features (see the results by Tauson [14]):

(1) All the granitoids of the Brno Massif, including the granodiorite Yasnogorskiy

and the quartz monzodiorite Virovskiy, are close to the granites of latite series from the viewpoint of their geodynamical conditions. According to [14], they belong to the fourth group, “rear parts of margins of the Nevadian type or the intercontinental zone” (see Table 2).

(2) The Osnitsky granites represent an ultimate factor while differentiating the Osnitsky complex. They are close to the granites of lime-alkaline series, being formed in “geodynamical condition of active continental margins (Nevadian type) and in central parts of structural-magmatic zonality of Californian type with affinity to central parts of massifs” [14]. That formation has large sizes (batholiths or belts) and is shaped in the folding regions. It has to belong to the third group (see Table 2).

Finally some paleogeodynamical conditions related to the origin of granitoids for the Brno Massif and the Osnitsky complex are explained in Table 3.

3. Conclusions

All the data available in the literature about the forms and the correlations of rocks [1, 8, 11], along with the geophysical simulation results [15, 3] for the Earth’s crust structures of the western slope of the US and the consolidated core part of the CMB, allow us to suggest similar tectonic conditions of formation of the latter objects. In particular, the structures of the upper part of core profile are built from the rocks of amphibolite fascia of metamorphism, where significant differentiation of the rocks is observed. In spite of different types of the initial composition of these regions, similarity of their geological development has resulted in the petrographic, petrogeochemical and petrophysical types of rocks, with a definite geochemical and metallogenic mineralisation. From this point of view, our comparative analysis of various characteristics of the Brno Massif’ and Osnitsky complex’ granitoids has enabled distinguishing a lot of their similarities:

(1) A successive intrusion is always present, with decline of depths of the magmatic sources.

(2) Some spatial dependence of formation of the petrographic granitoid types on the structural position of crystallised magma in the massifs.

(3) The general features of the both regions may also be determined with the deep seismic sounding results [15, 3]. In particular, the upper position of granitisation front is governed by the structures referred to the rocks of amphibolite fascia of metamorphism, thus corresponding to identical thermobaric conditions.

(4) In view of elaborating a new branch of the applied petrophysics and geophysics [16] and a technique for reconstructing paleogeodynamical conditions of granitoid origin on the basis of petrophysical information [10], we have also investigated a row of their paleogeodynamical features (see Table 3).

(5) Similar features of the deep structures of Earth’s crust and the conditions of its origin in the limits of western slope of the US and the Moravian block allow one to suppose a definite likeness in their composition and physical characteristics, as well as in their formation of similar minerals.

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Анотація. *У роботі узагальнено основні результати досліджень зон тектономагматичних активізацій Моравії і західного схилу Українського щита. Ці процеси привели до розвитку вулкано-плутонічних поясів, пов'язаних з різними блоками земної кори, для яких зазначено подібність цілої низки речовинно-структурних рис гранітоїдів. Незважаючи на очевидну відмінність геолого-структурної позиції даних гранітоїдів, помітні схожі і зближені тренди структурних, петрохімічних і петрофізичних характеристик. Ці характеристики можуть слугувати індикаторами магматизму, оруденіння і важливими маркерами рудоконтролюючих структур.*