ABHANDLUNGEN DER GEOLOGISCHEN BUNDESANSTALT
Abh. Geol. B.-A. | ISSN 0378-0864 | ISBN 3-85316-004-2 | Band **56/1** | S. 201–212 | Wien, August 1999
Geologie ohne Grenzen
Festschrift 150 Jahre Geologische Bundesanstalt
Redaktion:
Harald Lobitzer & Pavol Grecula

Two-mica granites in the central part of the South Bohemian Pluton

Karel Breiter[1] and Friedrich Koller[2]

7 Text-Figures, 1 Table, 1 Plate

Österreichische Karte 1:50.000
Blätter 1, 5, 6

Bohemian Massif
South Bohemian Pluton
Moldanubicum
Granites
Geochemistry
Petrology

Zwei-Glimmergranite im zentralen Teil des Südböhmischen Plutons

Zusammenfassung

Innerhalb des zentralen Teils des Südböhmischen Plutons konnte drei unterschiedliche, stark peralumische Granite nachgewiesen werden. Alle drei Intrusionsereignisse können mit ihrer regionalen Verbreitung sowie an Hand ihrer unterschiedlichen mineralogischen und geochemischen Charakteristik definiert werden. Der älteste ist der Lásenice Granit, der vermutlich durch Aufschmelzung von Metasedimenten in einem "minimum melt"-System während des thermischen Höhepunktes der variszischen Metamorphose gebildet wurde. Das Hauptstadium der Intrusions wird von einer Abfolge von Čímeř Granit, Eisgarner Granit und von diversen Muskovitgraniten gebildet. Dieses war primär eine K-reiche, peralumische Schmelze, die relativ reich an Zr, Th und REE war und die mittels Fraktionierungprozessen eine Anreicherung an Na, P, F, Li, Rb, Sn, Nb, U und Ta erfahren hat. Das letzte Intrusionereignis fördert den tiefer sitzenden Zvůle Granitstock. Diese Schmelze kann man bezüglich ihrer Hauptelemente als fraktioniert ansehen, sie war aber im Gegensatz zu der vorhergehenden nicht in der Lage eine Anreicherung von Sn, Nb, U und Ta sowie der LIL-Elemente zu produzieren.

Abstract

Within the central part of the South Bohemian Pluton three strongly peraluminous granite intrusion events were recognised. All three events were defined in their surface extension and can be distinguished by their individual mineralogical and geochemical features.

The oldest one, the Lásenice granite, was produced by minimum melting of metasedimentary material during the thermal peak of the Variscan metamorphism. The main stage of intrusion history is represented by the suite of the Čímeř, Eisgarn, and muscovite granites. The original high-K peraluminous melt, which was rich in Zr, Th and REE, underwent an intensive fractionation process towards the enrichment in Na, P, F, Li, Rb, Sn, Nb, U and Ta. The last melting episode produced deep seated stocks of Zvůle type. This melt was evolved in case of major elements, but, in contrast to previous melt, not able to produce LILE and Sn, Nb, U, Ta-enrichment.

1. Introduction

More than 90% of the exposed surface of the South Bohemian Pluton (SBP) consists of several types of two-mica granites, which differ from each other only in granularity, eventually in presence of Kfs phenocrysts and biotite/muscovite ratio. The actually used Czech classification of the SBP-granites is based on the results of Koutek (1925) and Zoubek (1949). Based on macroscopic field observation in traditional quarry-areas they define the so called "granite types" – Mrákotín, Čímeř and Landštejn. These three granite types, mineralogically very similar, but texturally – at least on typical localities – well distinguishable, have been considered as three evolutionary phases – intrusions – of the pluton. In Austria, the medium- and coarse-grained varieties of two-mica granites in the surroundings of Litschau, Gmünd and Weitra are termed Eisgarn granite and subordinate bodies of the fine-grained varieties as Mauthausen granite (Waldmann, 1950).

Autor's addresses: [1]Czech Geological Survey, Geologická 6, CZ-152 00 Praha 5. [2]Universität Wien, Institut für Petrologie, Geozentrum, Althanstrasse 14 , A-1090 Wien.

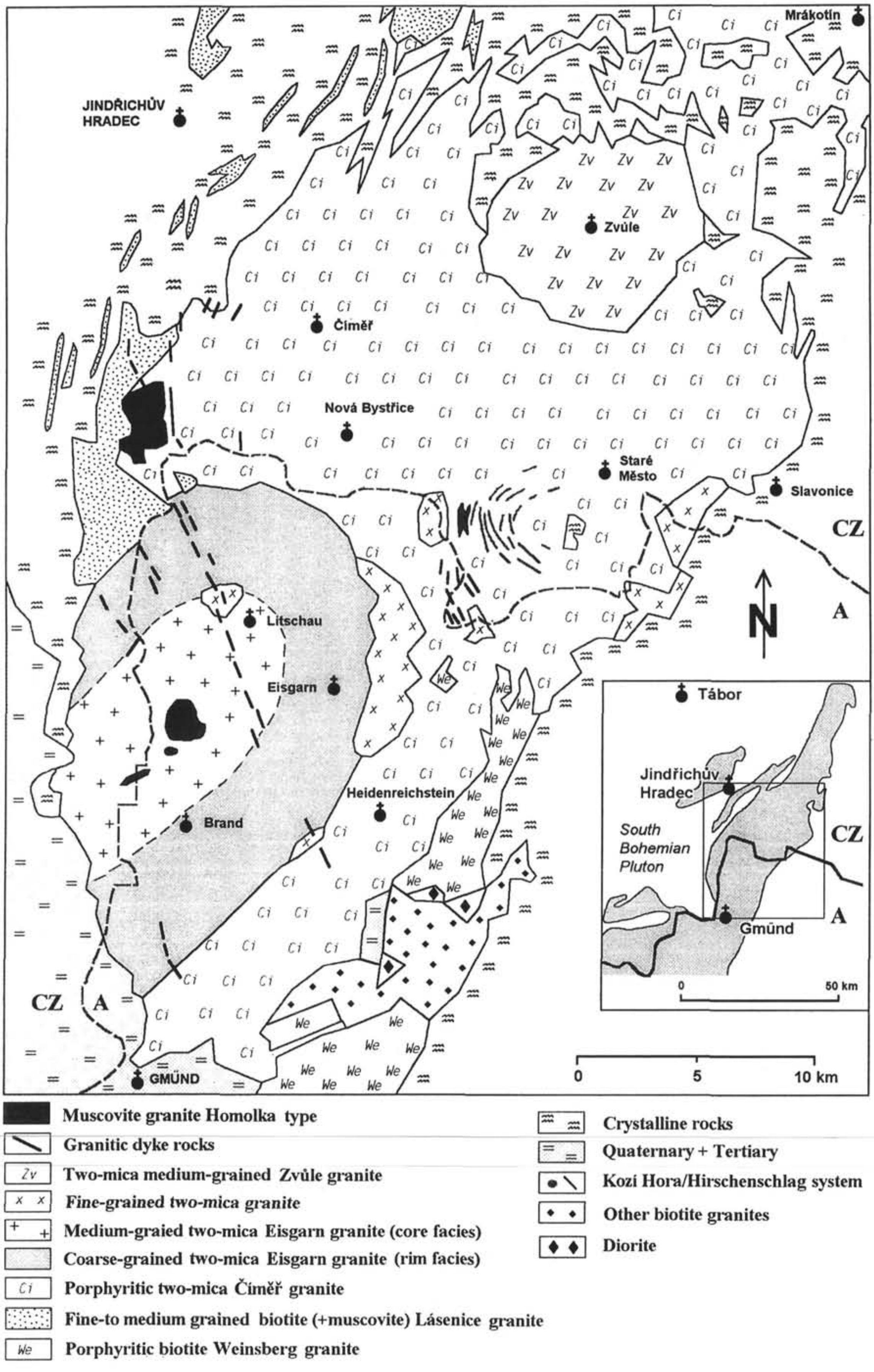


Fig. 1.
Simplified geological map of studied area.

Previous attempts to distinguish individual two-mica granite intrusions and to define their succession based on field relations (Czech maps 1:200 000 (DUDEK et al., 1963), and 1:50 000 (HRON, 1990, 1991), Austrian map 1:75 000 (WALDMANN, 1950)) have failed, caused by the fact that the area is insufficiently exposed and no contact between the intrusion types are exposed. Moreover, the individual granite types show large internal inhomogenities. Also the newest geochemical interpretations of Austrian two-mica granites (VELMER and WEDEPOHL, 1994; GERDES, 1997) oversimplified the situation taking all two-mica granites together into only one "Eisgarn group".

KLEČKA and RAJLICH (1984) based on structural relations, showed, that the central part of the SBP is much more complicated and the exposed two-mica granites belong to several independent magmatic events. An important attempt to recognise the pluton structure was made by GNOJEK and PŘICHYSTAL (1997) giving first comparison of the Czech and Austrian sides of the pluton, based on geophysical, mainly gamma-ray measurements. BREITER et al. (1998) compiled all existing gamma-spectrometric data defining areal extent of individual granite intrusions.

The available isotopic age data of the two-mica granites by Rb/Sr- and Ar/Ar-methods reviewed by SCHARBERT (1998) do not allow to distinguish between individual intrusions. This is caused by the relative small variance of Rb/Sr ratio within each intrusion. The Ar/Ar age data resemble more likely the regional cooling during uplift than ages of crystallisation (SCHARBERT et al., 1997).

The aim of our study, supported by Czech-Austrian agency AKTION, was to characterise by geochemical, petrological, and mineralogical methods the individual types of two-mica granites of the SBP and to constrain a more realistic evolutionary model. Our work is concentrated to the central part of the SBP on both sides of Czech-Austrian border between the towns of Jindřichův Hradec, Gmünd, Slavonice and Mrákotín (Fig.1).

2. Geological Setting

The Variscan South Bohemian Pluton (SBP) is the largest granitoid complex (6000 km^2) within the Bohemian Massif. It intruded Moldanubian high-grade metamorphic rocks (mainly cordierite-biotite paragneisses) and crops out in the area between Jihlava (Bohemia) in the north and Donau river (Austria) in the south. The western part of the SBP is partly covered by Tertiary and Quaternary sediments.

The SBP is a complex batholith built up by several intrusions of different granite types. The succession of these individual granite types has been recently interpreted by FINGER and HÖCK (1986), SCHARBERT (1987), LIEW et al. (1989), KOLLER (1994, 1996), and VELLMER and WEDEPOHL (1994).

The studied area lies in the NE part of the SBP, in the so called "Central Moldanubian Pluton" (CMP), the largest individual (but not homogeneous) body of the SBP.

Based on gamma-ray spectrometry (GNOJEK and PŘICHYSTAL, 1997; BREITER et al., 1998) and all accessible structural and chemical data (KLEČKA and RAJLICH, 1984; KLEČKA and MATĚJKA, 1995; BREITER and SCHARBERT, 1995, 1998), a new typology of two-mica granites has been developed. The most substantial differences between older printed geological maps (WALDMANN, 1950, Czech edition 1:50 000) and our interpretation are in definition of the coarse-grained granites, formerly termed as Landštejn and Eisgarn, and in classification of the fine-grained granites N of Gmünd.

Following types of two-mica granites can be distinguished and their areal extent can be defined:

- The fine- to medium-grained two-mica to biotite **Lásenice granite** forms the Klenov body NW of the town Jindřichův Hradec and the area near the NW margin of the CMP (SW and NE of the town of Jindřichův Hradec (KLEČKA and RAJLICH, 1984).
- The medium- to coarse-grained porphyritic **Číměř granite** is characterised by the large amounts of tabular Kfs crystals, often showing fluidal orientation. Our data confirm that the areal extent of the Číměř granite is nearly identical with that shown in the 1:50 000 maps edited by the Czech Geological Survey (HRON, 1990, 1991). Within the Austrian part of CMP, the eastern peri-contact stripe between the towns of Slavonice and of Gmünd belongs to this type (as mentioned already by PŘICHYSTAL, 1992).The quarrying district around the villages of Mrákotín is built up by fine- (to medium-) grained granite named by KOUTEK (1925) the Mrákotín granite. In spite of its textural differences from the Číměř type proper, it is – from the chemical point of view – nearly identical and we interpret it as only local facies of the Číměř granite.
- The **Eisgarn granite** s.s. (according to WALDMANN, 1950) forms the central part of the CMP between the towns of Nová Bystřice and Gmünd. The SW part of this "central body" is buried below the Cretaceous and Tertiary sediments of the SE part of the Třeboň basin. It is texturally variable. The coarse-grained locally porphyritic granites prevail in the marginal part of the body while mostly medium-grained non-porphyritic granites are developed in its centre. The outer contact of Eisgarn granite towards the enveloping Číměř granite can be mapped only with difficulties because of its elluvial cover. In this case the gamma-ray spectrometric patterns resemble quite well the shape of the intrusion (compare PŘICHYSTAL, 1992; GNOJEK and PŘICHYSTAL, 1997). The boundary between the outer porphyritic and inner mostly medium-grained facies (Fig. 1) can be drawn only approximately, while both facies show transitions into each other.
- Several small bodies of a **fine-grained two-mica granite** are situated either within or along the margins of the Eisgarn granite. According to their geological position they should be younger that the Eisgarn s.s. granite and are not eqiuvalents of the Mauthausen granite as mentioned by WALDMANN (1950). They are certainly members of the Eisgarn suite.
- The medium- to coarse-grained, predominantly non-porphyritic **Zvůle granite** forms a ring-shaped body intruding the Číměř granite. This body was earlier named "Landštejn granite" (ZOUBEK, 1949). But Zoubek's type locality, the Landštejn castle, is situated outside this body, and the outcrops below the Landštejn castle are built up by a coarse porphyritic variety of the Číměř granite. Therefore we omit the name Landštejn and prefer the name "Zvůle" according to a small village in the centre of this body.

Both bodies of the coarse-grained granites (Eisgarn and Zvůle types) coincide in their distribution quite well with the gravity minima (MEURERS, 1992; GNOJEK in BREITER et al., 1998). This is explained by the presumed deepest roots of the pluton in these stock-shaped structures.

Two-mica granites of the CMP are intruded by three types of younger granites:

- A swarm of more than 30 dykes of granite porphyries and dyke rhyolites forms a 30 km long NNW–SSE trending zone between Lásenice in the north and Schrems in the south (KLEČKA, 1984; BREITER and SCHARBERT, 1995),
- Muscovite granites form several stocks and irregular bodies in the axial part of the pluton (e.g. Galthof and Pyhrabruck granites), or on the pluton periphery (e.g. Homolka and Šejby) (BREITER and SCHARBERT, 1995, 1998),
- Ring-shaped system of small stock and dykes of biotite granite and zones of metasomatism at KozíHora/Hirschen-

Table 1

No.	2713	2868	3009	2721	2950	2963	3024	2720	2949	2954	2957
Granite type	Lásenice		Číměř						Eisgarn		
SiO_2	73,8	72,6	73,2	73,8	71,3	72,0	73,4	73,5	71,3	73,6	73,5
TiO_2	0,10	0,18	0,22	0,20	0,37	0,32	0,24	0,19	0,16	0,16	0,20
Al_2O_3	14,1	14,8	14,3	14,2	14,8	14,8	14,1	14,2	15,0	14,1	14,3
Fe_2O_3	0,26	0,33	0,15	0,25	0,87	0,44	0,12	0,19	0,52	0,78	0,70
FeO	0,68	0,79	1,23	1,06	1,04	1,30	1,20	0,99	0,85	0,70	0,72
MnO	0,03	0,03	0,03	0,02	0,03	0,03	0,03	0,02	0,30	0,39	0,03
MgO	0,20	0,24	0,47	0,32	0,56	0,62	0,41	0,28	0,29	0,22	0,27
CaO	0,69	0,66	0,76	0,83	0,90	0,92	0,92	0,77	0,69	0,62	0,74
BaO	0,02	0,02	0,02	0,03	0,03	0,04	n.a.	0,03	0,03	0,01	0,05
Li_2O	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,03	0,02
Na_2O	3,16	3,28	3,12	2,89	2,91	2,83	2,99	2,98	3,25	3,32	3,18
K_2O	5,15	4,91	5,19	5,65	5,35	5,45	5,39	5,48	5,91	4,60	5,32
P_2O_5	0,24	0,28	0,25	0,24	0,25	0,23	0,26	0,25	0,25	0,28	0,22
F	0,04	0,06	0,09	0,13	0,19	0,15	0,13	0,09	0,11	0,18	0,09
L.O.I.	0,73	0,81	0,91	0,71	1,2	0,96	0,84	0,64	0,97	1,02	0,87
H_2O^-	0,25	0,16	0,07	0,21	0,23	0,17	0,16	0,2	0,15	0,2	0,14
Total	99,4	99,2	100	100	99,9	100	100	99,8	99,5	99,8	100
Rb	246	268	297	288	332	308	268	293	371	390	338
Sr	55	59	67	66	71	82	69	65	54	27	38
Zr	43	57	88	117	148	122	93	85	62	49	80
Sn	<7	<7	10	<7	<7	<7	<7	<7	<7	18	<7
Zn	42	51	67	64	101	82	76	66	61	67	73
Nb	9	14	17	17	12	11	10	11	17	17	18
Pb	33	28	24	30	19	20	19	25	32	12	23
Ga	20	17	n.a.	28	27	23	n.a.	28	28	28	23
V	2	3	n.a.	4	14	18	n.a.	3	4	2	4
Th	5,1	5,6	17	23,5	34,7	37,2	14,7	15,9	17	14	18,5
U	6,8	6,4	11,7	8	6,5	9,9	4,6	10,1	8,4	7,1	10,4
La	10,6	n.a.	28,6	36	47,8	42,2	n.a.	26,1	21,1	14,8	24,7
Ce	22,3	n.a.	59,6	77,3	112	95,1	n.a.	56,5	49,2	35,5	57,7
Pr	<5	n.a.	8,25	10	12,6	13,4	n.a.	6,81	5,36	n.a.	6,78
Nd	9,63	n.a.	27,9	34,1	53,7	46,7	n.a.	25,6	23,1	17	27,5
Sm	2,97	n.a.	6,21	7,84	9,56	8,93	n.a.	5,68	5,32	4,06	6,06
Eu	0,25	n.a.	0,48	0,4	0,52	0,62	n.a.	0,4	0,37	n.a.	0,32
Gd	2,35	n.a.	4,34	5,3	5,15	4,8	n.a.	4,09	2,88	2,52	4,09
Dy	2,13	n.a.	2,24	2,59	2,06	2,44	n.a.	2,3	1,69	2,02	2,4
Y	9,74	n.a.	9,36	9,78	9,36	9,57	n.a.	9,84	7,31	10,6	12,3
No.	2964	2969	2978	2987	2965	2985	2776	2935	2937	2940	2941
Granite type	Eisgarn				fine-gr.Eisgarn			Zvůle			
SiO_2	75,0	72,5	73,8	74,0	70,7	72,8	74,3	71,5	71,1	72,4	71,8
TiO_2	0,07	0,24	0,19	0,10	0,22	0,17	0,11	0,18	0,17	0,21	0,17
Al_2O_3	14,2	14,5	14,0	14,6	14,7	14,6	14,4	15,9	15,3	14,3	14,9
Fe_2O_3	0,22	0,59	0,48	0,29	1,58	1,32	0,69	0,68	0,69	0,69	0,70
FeO	0,40	0,95	0,66	0,62	n.a.	n.a.	0,26	0,66	0,70	0,77	0,55
MnO	0,02	0,03	0,02	0,02	0,03	0,03	0,02	0,03	0,03	0,03	0,02
MgO	0,1	0,35	0,27	0,12	0,37	0,29	0,13	0,28	0,32	0,33	0,25
CaO	0,44	0,7	0,61	0,49	0,66	0,58	0,47	0,82	0,73	0,88	0,58
BaO	0	0,02	0,02	0,01	n.a.	n.a.	n.a.	0,02	0,03	0,02	0,06
Li_2O	0,04	0,03	0,02	0,04	n.a.	n.a.	0,01	0,04	0,03	0,03	0,03
Na_2O	3,59	3,08	2,96	3,54	3,18	3,13	3,42	3,84	3,33	3,38	3,32
K_2O	4,47	5,17	5,37	4,41	4,86	5,05	4,55	4,58	5,52	4,79	4,92
P_2O_5	0,31	0,26	0,22	0,32	0,29	0,29	0,25	0,32	0,27	0,29	0,29
F	0,21	0,22	0,16	0,22	n.a.	n.a.	0,08	0,09	0,09	0,07	0,08
L.O.I.	1,02	1,10	0,89	1,03	1,25	1,18	0,86	1,20	1,00	0,98	1,28
H_2O^-	0,2	0,21	0,17	0,11	n.a.	n.a.	0,18	0,3	0,19	0,23	0,27
Total	100	99,8	99,8	99,8	97,8	99,4	99,7	100	99,5	99,4	99,3
Rb	475	362	319	495	361	309	361	367	338	279	360
Sr	10	39	55	57	55	52	14	52	64	67	43
Zr	9	89	71	29	89	63	31	55	55	70	47
Sn	16	<7	12	18	n.a.	n.a.	<7	18	14	10	20
Zn	56	113	62	88	68	57	104	89	78	72	68
Nb	23	16	13	27	12	10	13	0,19	12	14	14
Pb	8	8	28	<7	28	29	13	21	23	24	21
Ga	33	19	20	26	19	18	18	33	32	29	26
V	<2	9	4	2	11	8	<2	5	5	6	7
Th	3,7	25,4	23,1	5,5	13,6	10	7,1	7,6	9,9	10	8,4
U	6,6	13,1	12,5	15,5	5,1	5	8,3	7,4	4,3	5,2	6,7
La	4,28	28,2	23,7	6,91	23,6	20,1	9,29	16,9	17,3	20,5	15,9
Ce	9,81	65,5	54,5	16,7	49,3	41,3	20,8	36,9	37,5	44,5	34,9
Pr	n.a.	9,01	7,59	n.a.	6,03	6,44	n.a.	<5	<5	5,07	n.a.
Nd	5,17	30,7	25,9	8,38	22,8	19,1	9,68	16,5	17,5	20,6	16,3
Sm	1,24	6,16	4,93	1,89	4,82	4,55	2,55	4,11	4,15	4,79	3,9
Eu	n.a.	0,31	0,34	n.a.	0,38	0,4	n.a.	0,3	0,37	0,44	0,34
Gd	n.a.	4,09	3,59	2,07	3,63	3,58	2,19	2,71	2,65	3,37	2,58
Dy	1,45	2,61	2,12	1,96	2,6	2,3	1,62	1,93	1,49	1,89	1,5
Y	7,91	10,1	8,78	11,4	12,4	10,3	7,44	8,59	6,82	8,48	6,79

Table 1

Chemical composition of typical samples of two-mica granites. Major elements in wt.%, trace elements in ppm.

Major and trace elements of samples Nos. 2965 and 2985 were analysed by XRF in the Geozentrum, University Wien. All other samples were analysed in laboratory of Czech Geological Survey, Praha: major elements by standard methods of wet chemistry, Rb, Sr, Zr, Sn, Nb, and Pb by XRF (detection limit 7 ppm), Ga and V by OES (detection limit 2 ppm), and REE by ICP-AAS. The contents of Tb, Ho, Er, Tm, Yb, and Lu are in all samples under detection limit (1 ppm for Er and Yb, 0.9 ppm for Tb, 0.6 ppm for Ho, 0.4 ppm for Tm, and 0.16 ppm for Lu). Th and U were analysed by gamma-ray spectrometry in ENVI-2000, Brno, detection limit lower than 1 ppm.

2713 – fine-grained biotite (+muscovite) granite of Lásenice type, abandoned quarry 2 km NNW of Horní Pěna.
2868 – fine-grained biotite (+muscovite) granite of Lásenice type with biotite nests up to 0,5 cm, blocks in forest, 1 km NE of Hutě near Příbraz.
3009 – medium grained porphyritic biotite (+muscovite) granite Čímĕř type, quarry, 1 km E of Čímĕř.
2721 – medium grained porphyritic biotite (+muscovite and andalusite) granite Čímĕř type, quarry Kavex, 1.5 km SW of Řásná.
2950 – medium grained biotite (+muscovite) granite of Čímĕř type, blocks in forest, 1 km SW of Rottal.
2963 – medium grained coarse porphyritic biotite (+muscovite) granite, quarry Fripess, Aalfang.
3024 – medium grained biotite (+muscovite) granite with scarce phenocrysts of Kfs of Čímĕř type, quarry Kavex, 0.5 km W of Mrákotín.
2720 – fine- to medium grained biotite (+muscovite, andalusite) granite of Čímĕř type, quarry Kavex, 1 km N of Sumrakov.
2949 – coarse grained porphyritic two-mica granite, rim facies of the Eisgarn granite, excavation for family house, Griesbach.
2954 – *medium- to coarse grained two-mica granite of the Eisgarn type with scarce phenocrysts of Kfs, outcrop Grasselstein, 2 km NW of* Litschau.
2957 – medium- to coarse grained two-mica granite with Kfs phenocrysts up to 4x2.5x0.5 cm of Eisgarn type, blocks, 0.5 km E of Langauhäuser, 3 km SW of Litschau.
2964 – medium grained muscovite (+biotite) granite, core facies of the Eisgarn granite, outcrop in Dreichsbachtal, 2 km W of Goprechts.
2969 – medium grained porphyritic two-mica granite, rim facies of the Eisgarn granite, outcrop near the road, 1 km NW of Altmans.
2978 – coarse grained porphyritic two-mica Eisgarn granite, crushed big blocks in forest, 2 km NE of Brand.
2987 – medium grained muscovite (+chloritised biotite) granite, core facies of the Eisgarn granite, blocks in forest, 2 km NW of Brand.
2965 – fine grained two-mica granite of Eisgarn type, small abandoned quarry in forest, 2 km NW of Aalfang.
2985 – fine grained two-mica granite of Eisgarn type with nests of biotite up to 1 cm, blocks in forest 1.3 km SE of Gross Radischen.
2776 – medium to coarse grained two-mica granite of Zvůle type, biotite is chloritised, small blocks in forest 1 km ENE of Rožnov, southern rim of the Zvůle body.
2935 – coarse grained porphyritic two-mica granite of Zvůle type, blocks in forest on top of small hill, 0.5 km S of Olšany, northern rim of the Zvůle body.
2937 – coarse grained porphyritic two-mica granite of Zvůle type, blocky outcrop 2 km N of Valtínov, northern part of the Zvůle body.
2940 – coarse grained two-mica granite with scarce Kfs phenocrysts, outcrop in forest 1.5 km S of Valtínov, central part of the Zvůle body.
2941 – medium- to coarse grained two-mica granite with scarce Kfs phenocrysts, outcrop in forest 0.8 k S of Terezín.

schlag with occurrence of molybdenite-magnetite greisens (Göd, 1989; Breiter et al., 1994).

3. Chemical characteristics

In the period 1997–1998 we analysed by geochemical methods about 60 new samples from the study area. Together with c. 60 older samples analysed during the last 5 years by the CGS and GBA, we have sufficient data to characterise the chemical composition of all the defined granite types, their internal inhomogeneities and mutual genetic interrelations.

3.1. Main geochemical features

Major element geochemistry of all two-mica granites is rather uniform. Characteristic contents are (compare Fig. 3 and Tab. 1): SiO_2 71–75%, Al_2O_3 14–15.5%, CaO 0.5–1%, Fe_2O_3tot 1.2–1.5%, K_2O 4–6%, Na_2O 2.5–4%, P_2O_5 0.15–0.35%, F lower than 0.2%. All granites are peraluminous with ASI betwen 1.15 and 1.30. The major difference among defined granite types can be seen in Na/K-ratio: the relative most Na-enriched is the Lásenice granite, the most K-enriched (generally more than 5% K_2O) is the Čímĕř granite.

The contents of trace elements are much more variable. The difference between individual granite types can be better expressed on various plots (Fig. 4). Generally the following features can be defined:

- The Lásenice granite is poor in all trace elements (namely LILE and HFSE)
- The Čímĕř granite and the rim-facies of the Eisgarn granites are relatively rich in potassium and compatible trace elements such as Zr, Th and REE and can be classified as high-K peraluminous rocks.
- The Čímĕř granite is chemically not homogeneous as regarded from compatible trace elements, namely Zr ad Th (compare distribution of Th in Fig. 2).
- The Rb/Sr- and Rb/Zr-plots seem to support the idea that the Eisgarn granite was produced by further fractionation of the Čímĕř granite melt. The rubidium was during this fractionation enriched from ca 200 ppm to about 500 ppm, Sr depleted from c. 150 to c. 5 ppm and Zr depleted from about 180 ppm to 5 ppm.
- The Eisgarn granite is enriched in Si and Na, and more depleted in Ti, Fe, Mg, Ca, Ba, and K than the Čímĕř granite, but there is a distinct overlap of both granites (Fig. 3).
- The Eisgarn melt was able to fractionate effectively towards the center of the body producing small amounts of more evolved "muscovite granite" melt enriched in P, Na, Rb, U, Sn, Nb, and Ta.
- The Zvůle granite represents a relatively evolved melt with lower contents of compatible elements, but, in contradiction to the Eisgarn granite, without any enrichment in LILE and U.
- All rock types can be well defined by U- and Th values which allow to use gamma-ray meassurement as an effective tool for field mapping.
- The most effective diagram for distinguishing of all types of two-mica granites is the Rb vs. Th plot (Fig. 4d).

3.2. Internal structures of individual intrusions

The sampling density of the Eisgarn and Zvůle granites allow to construct simple mathematical models of the inner structure of both bodies in respect to their geochemical variation.

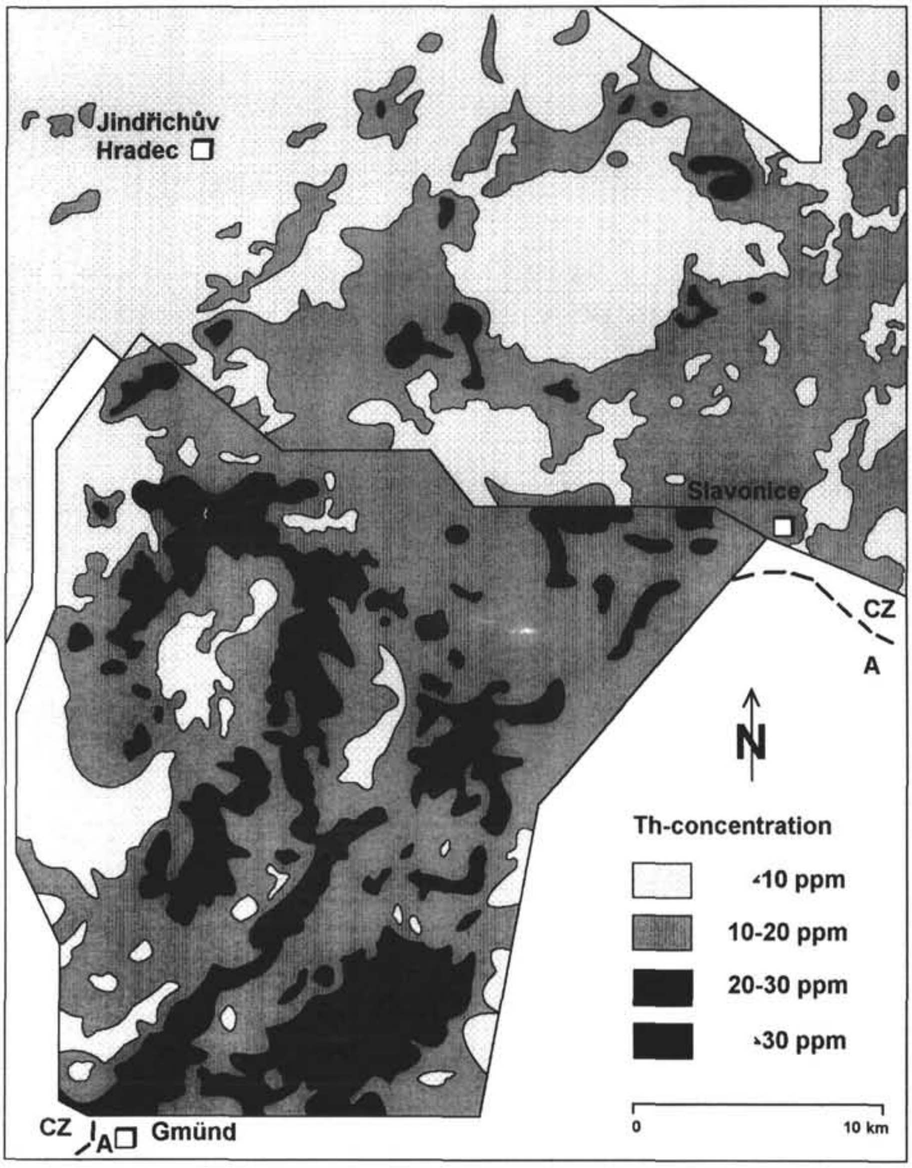


Fig. 2.
Simplified map of Th-distribution in studied area. The Austrian and frontier parts were measured by ground gamma-ray spectrometry (Gnojek and Přichystal, 1997), the Czech inland was measured by airborne gamma-ray spectrometry (Dědáček et al., 1990, 1991). For further details see Breiter et al. (1998). The area of this map is the same as the area of geological map on fig.1.

The Eisgarn body (Fig. 5) shows distinct zonation patterns of nearly all analysed elements: an increase of elements such as Rb, Na, P, and F and a decrease of K, Ca, Fe, Mg, Th, Zr, Sr etc. from the contact to the centre. The isolines conform with the contacts of the older granites and crystalline rocks on the NW, N, E, and SE margins. On the SW, the continuation of the intrusion is covered by Tertiary and Quaternary sediments of Třeboň basin. This zonation can be explained as a product of intensive inward oriented fractional crystallization after the intrusion. The earlier portion of the melt crystallizing along contacts zones was enriched by P-poor Kfs phenocrysts, relative Ca-rich P-poor plagioclase, relative Mg-rich biotite and accessories. On the opposite, the late melt in the centre of the intrusion produced Na, P-rich plagioclase, Al, Fe-rich biotite, P-enriched Kfs and only small amount of accessories. This model is in good agreement with the position of small bodies of P, F, Na, Rb, Sn, Nb-rich muscovite granites in the intrusion centre.

The Zvůle body is nearly homogeneous as regards major elements concentrations, but we found distinct ring-shaped zonality of Rb and Sr (Fig. 6). The relatively scarce type of "reversed" zonality is expressed here by increase of Rb and decrease of Sr from the centre towards to the rims. The most fractionated part of this body is situated along its southern contact.

▶

Fig. 4.
Trace element distribution in two-mica granites: a, Rb/Sr, b, Rb/Zr, c, U/Th, d, Rb/Th. Symbols see Fig. 3.

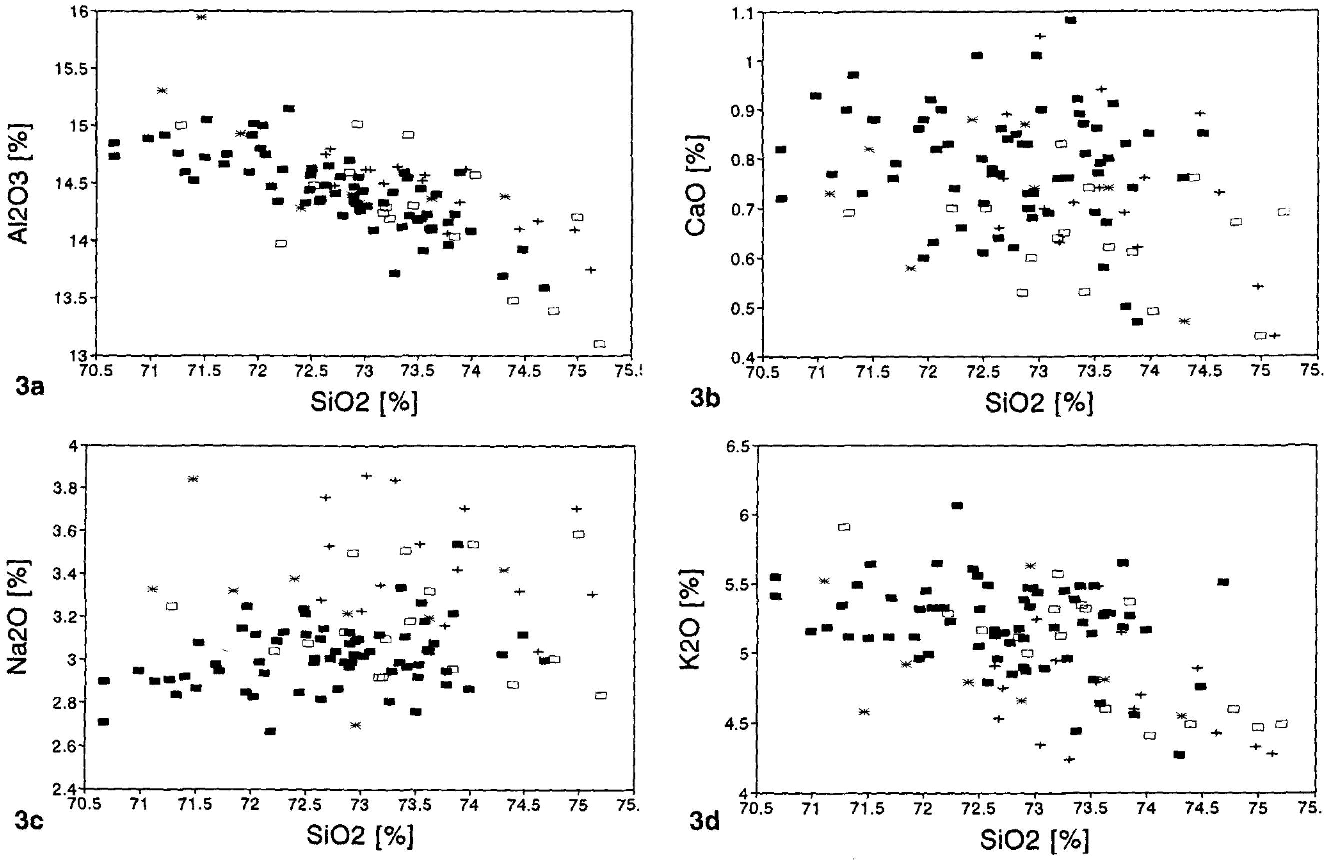
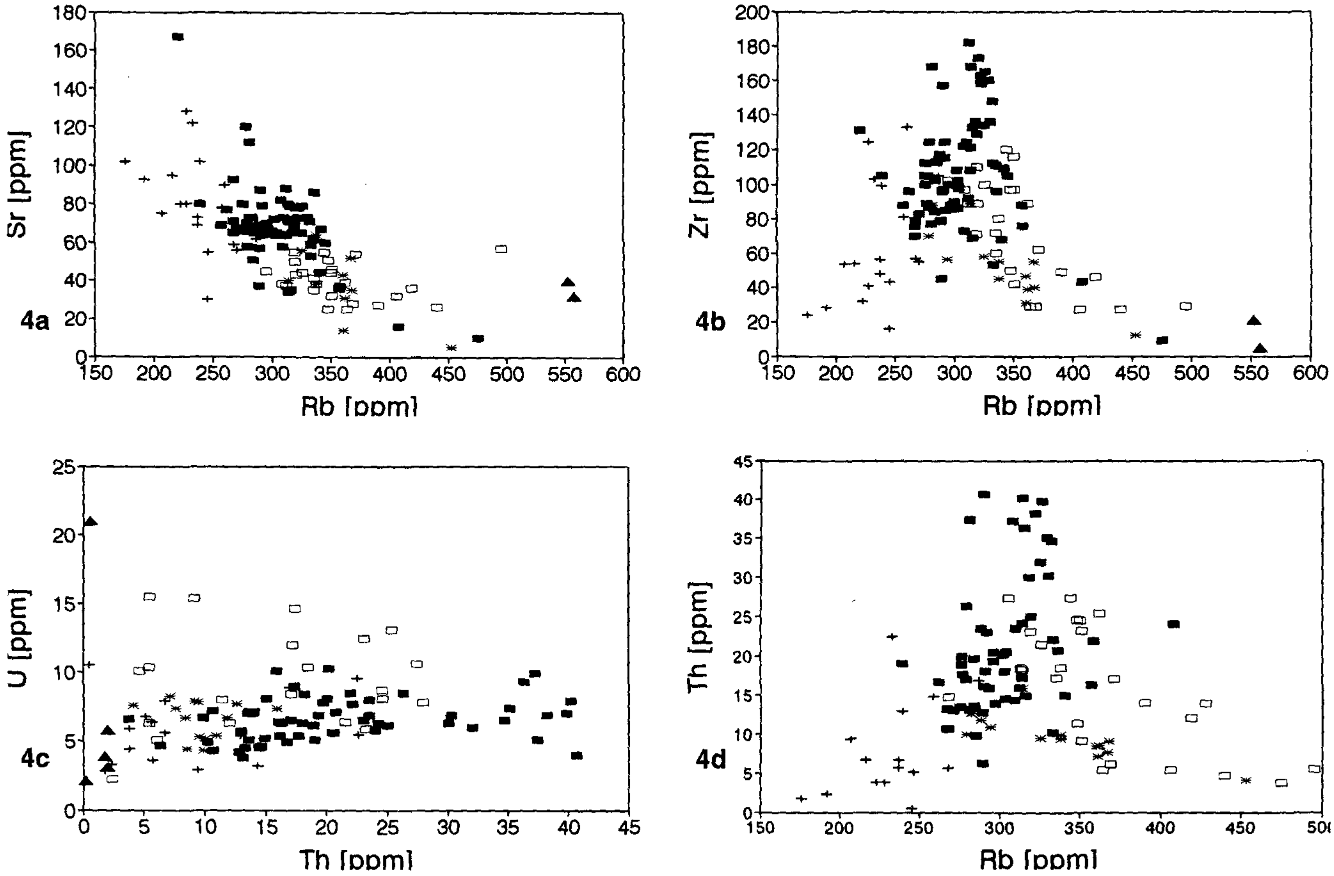


Fig. 3.
Harkers diagrams of two-mica granites of the CMP: a, SiO_2 vers. Al_2O_3, b, SiO_2 vers. CaO, c, SiO_2 vers. Na_2O, d, SiO_2 vers. K_2O.
■ Číměř, □ Eisgarn, ▲ Muscovite granites, + Lásenice, ✲ Zvůle



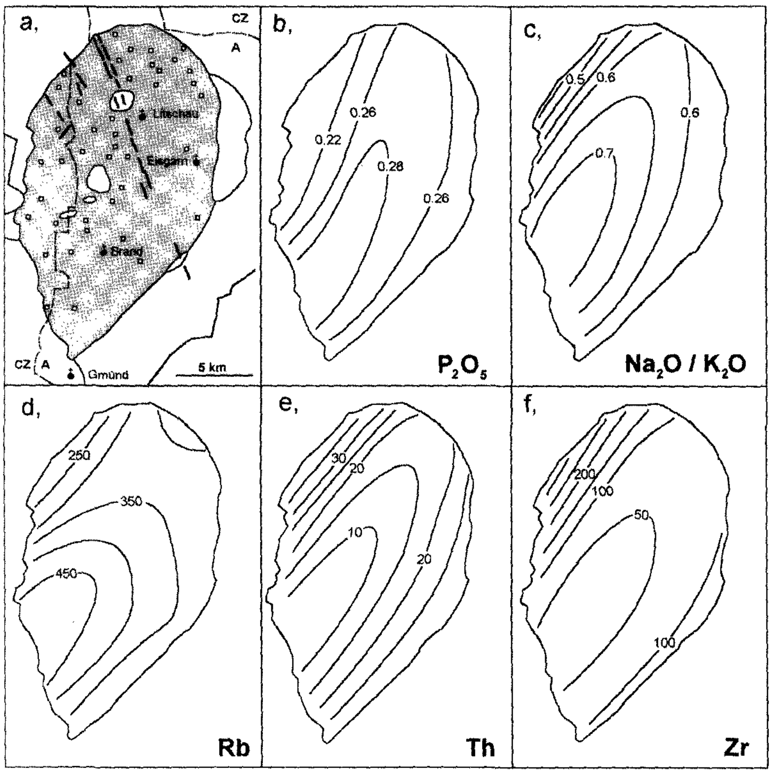


Fig. 5.
Idealised areal distribution of selected elements within the Eisgarn body. The isolines of element contents or ratios were constructed by methods of data interpolation by polynomial regression of third order.
a, Simplified geological sketch of the interpreted body. The interpreted area is dotted, localisation of used samples is expressed by small squares. b, Idealised distribution of P_2O_5 in wt.%, c, Idealised distribution of Na_2O/K_2O-ratio in wt.%, d, Idealised distribution Rb in ppm, e, Idealised distribution of Th in ppm, f, Idealised distribution of Zr in ppm.

4. Mineralogical remarks

4.1. Micas

The Fe/Mg-ratio in both micas, biotite and muscovite, is a sensitive indicator of the degree of granite fractionation. Systematically this ratio increases from the Číměř granite through the rim-facies of the Eisgarn granite to the core-facies of the Eisgarn granite and to the Zvůle granite.

The Al /Si-ratio in biotite increases in the same evolutionary line, which is in good agreement with the increasing peraluminous character of the granites (Fig. 7).

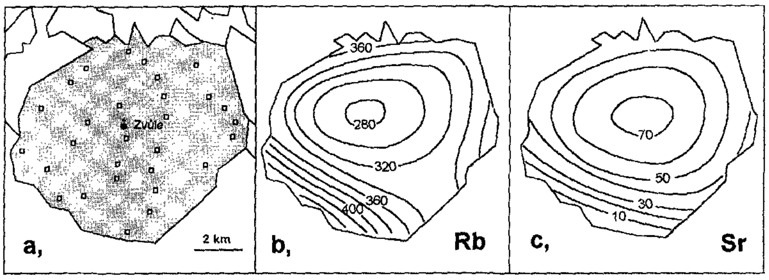


Fig. 6.
Idealised areal distribution of selected elements within the Zvůle body:
a, Simplified geological sketch of the interpreted area. The interpreted area is dotted, localisation of used samples is expressed by small squares. b, Idealised distribution of Rb in ppm, c, Idealised distribution of Sr in ppm.

Muscovite occurs in all investigated two-mica granites in the form of relative large flakes, often inter-growing with biotite and seems to be of primary magmatic origin. The Fe/Mg-ratio in the muscovite is in all cases distinctly higher than in the coexisting biotite.

4.2. Alkali feldspars and plagioclase

In the Číměř granite, plagioclase is mostly represented by oligoclase, in all other granites with oligoclase to albite. Associated muscovite granites contain only pure albite. The core of the plagioclase is in all investigated granite samples frequently strongly sericitised.

Potassium feldspar has been distinguished in two forms: the phenocrysts in Číměř granite and the rim-facies of the Eisgarn garnite are perthitised and contain many small inclusions of non-perthitised Kfs and albite. Relative smaller columns of Kfs in all granites are twinned, but only slightly perthitised.

Chemically, the Kfs from the Číměř granite are very poor in phosphorus (mostly below the detection limit), Kfs from the Eisgarn granite have low to moderate content of P, Kfs from associated muscovite granites are rich in phosphorus (ca 0.5% P_2O_5).

4.3. Alumosilicates

Andalusite occur either in the form of spindle-shaped crystals or in isometric relicts incorporated in large muscovite flakes. Andalusite is a rather common accessory mineral in all granite types, the samples from the surroundings of Mrákotín with contain up to 0.5 vol.%. In the vicinity of Mrákotín there are granite domains which are poor in muscovite with the mineral assemblage quartz+Kfs+oligoclase+biotite +andalusite. Generally, the assemblage biotite+muscovite+relicts of andalusite is rather common.

Fibrous aggregates of sillimanite have been found as alteration product of andalusite.

4.4. Accessory minerals

Apatite is the most abundant accessory phase. The early Mn-poor euhedral apatite (0.5–1% MnO) is common in all rock types, the late Mn-rich interstitial apatite (up to 3.5% of MnO) was found only in the core-facies of the Eisgarn granite. Monazite is much less abundant than apatite. Zircon is ubiquitous in small amounts. Anatase (secondary ?) was found in the most muscovite-rich facies of the Číměř and Eisgarn granites.

The very good correlation between Th and Ce (Breiter et al., 1998) in whole rock analyses suggests that the major host of Th is monazite in all granite types. This was confirmed also by the EMP analyses. The good correlation of Th and Zr can be explained by similar behaviour of these elements during the evolu-

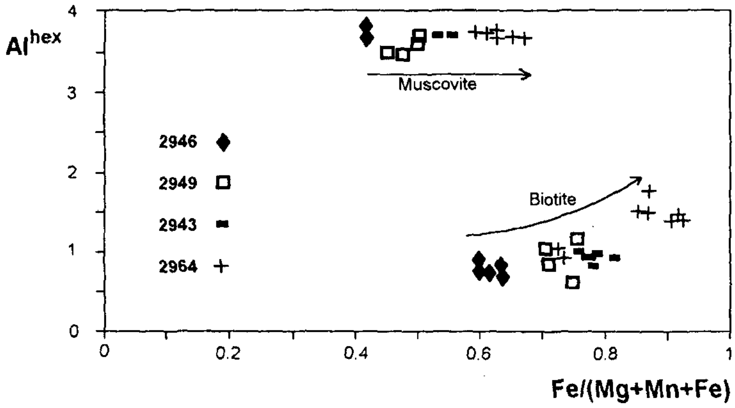


Fig. 7.
Evolution of biotite and muscovite chemistry during fractionation of the Číměř and Eisgarn granites (EMPA). 2946- Číměř granite, Kaproun, 2949- rim facies of the Eisgarn granite, Griesbach, 2943- Zvůle type granite, Javoří Vrch hill, 2964- core facies of the Eisgarn granite, Dreisbachthal.

tion of the melt, Th and Ce incorporated in the monazite, Zr in the zircon, respectively. Both monazite and zircon are common inclusions in biotite.

5. Granite typology and discussion

5.1. Lásenice granite

The Lásenice granite is composed by quartz, orthoclase, albite-oligoclase, mostly fresh biotite and subordinate muscovite. Sillimanite and sericitised andalusite are common. The granite was affected by shearing – secondary quartz and cracks filled by sericite are ubiquitous. Chemically, the Lásenice granite is characterised by very low contents of all compatible elements – Th , Zr, REE etc. and also U. The major element composition of this granite is near the "granite minimum melt" composition demonstrating an origin derived from crustal melting possibly during the thermal peak of the regional metamorphism in the sense of a typical S-type granite. This granite differs significantly from all the other granites in Bohemian part of the CMP, being comparable to the Altenberg granite in Austria (Finger et al., 1994).

5.2. Číměř granite

The medium- to coarse-grained porphyritic Číměř granite contains plenty of perthitised orthoclase phenocrysts hosting many small isometric nearly automorph grains of albite and not perthitised Kfs. Plagioclases (oligoclases) are smaller, sub-automorph, with strongly sericitised cores. Fresh biotite clearly predominates over fresh magmatic muscovite. Andalusite is common as relicts hosted in large mica flakes. Apatite and zircon are the most common accessory minerals, monazite is rare. All these accessory minerals occur mainly as inclusions in biotite, commonly surrounded by a pleochroitic halo.

The medium- to fine-grained granite from quarrying district around the village of Mrákotín was named by Koutek (1925) the Mrákotín granite. In spite of its textural differences from the Číměř type proper, it is – from the chemical point of view – nearly identical and we supposed that the Mrákotín granite is only a local facies of the Číměř intrusion.

Chemically, the Číměř granite represents a high-K peraluminous melt with high contents of compatible elements, which implies melting conditions well above the "granite minimum melt" system within the deeper (lower ?) parts of the continental crust. Inhomogenities within the intrusion, well indicated by field gammy-ray meassurement, imply insufficient homogenisation of the melt during intrusion. Areas indicated by Th-enrichment contain more early crystallised biotite-hosted apatite, monazite, and zircon. In areas with Th-depletion, the granite was affected by chloritization of biotite accompanied by destruction of accessory minerals.

5.3. Eisgarn granite

The rim facies of the Eisgarn granite s.s. resemble petrographically the Číměř granite containing large perthitised orthoclase phenocrysts, smaller sub-automorph sericitised oligoclaces, biotite rich in accessory apatite, zircon and monazite, and muscovite with relicts of andalusite. The core-facies contains, besides relatively scarce and often partly resorbed perthite phenocrysts, also small automorph columns of not-perthitised Kfs, and nearly automorph, only slightly perthitised albite. Muscovite prevails strongly chloritised accessory-poor biotite. Andalusite is rare or absent. Besides old isometric Mn-poor apatite, also young Mn-rich interstitial apatite is present.

The intrusive body is chemically well zoned. The degree of fractionation increases from the margin towards the centre; this is reflected for example by the increase in ratios of Rb/Sr from 7 to 40 and U/Th from 0.3 to 3 (compare also Fig. 5).

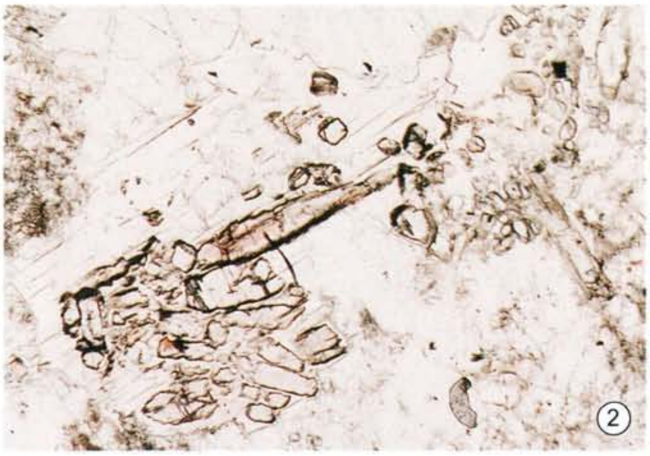
Several small bodies of fine-grained two-mica granites are located within or along the margins of the coarse-grained Eisgarn granite s.s. central body. This type of granite seems to be genetically related to the crystallisation of the Eisgarn granite melt, representing a late melt product.

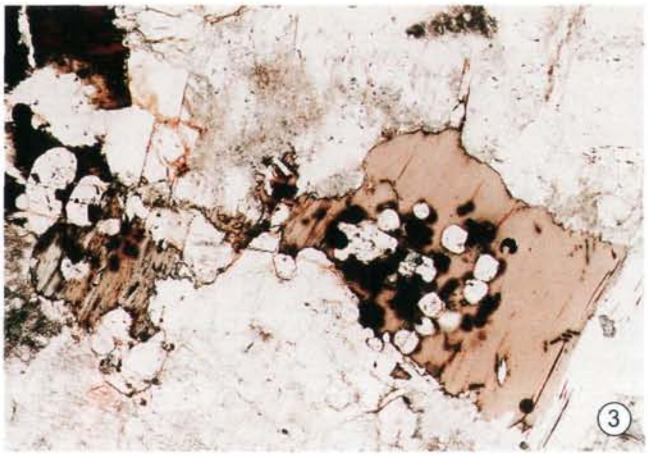
5.4. The Zvůle granite

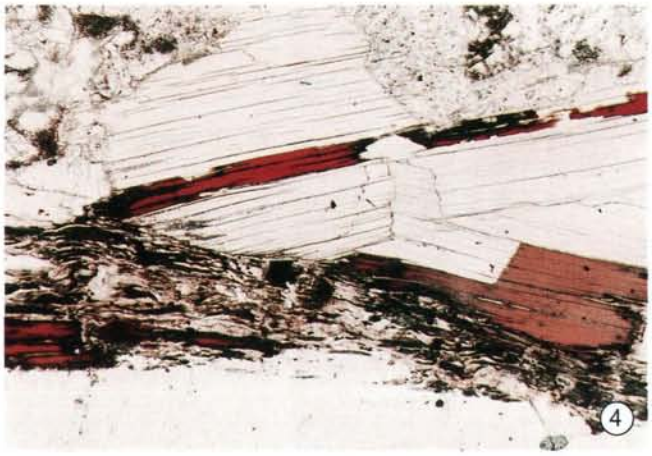
This body is clearly intrusive, younger than the enveloping granites and forms a deep-seated stock. The Zvůle granite is mineralogically characterised by the presence of sericitised perthitic orthoclase phenocrysts, nearly automorph albite with sericitised cores, and by muscovite predominating over biotite. Muscovite contains rather common relicts of andalusite. Biotite contains only scarce accessories and is, mainly in outer parts of the body, frequently chloritised. Apatite is the most abundant accessory phase.

Chemically, the granite is rich in Si, Al and Na and poor in Fe, Mg, Ca and compatible trace elements. In contrast to the Eisgarn granite, the Zvůle granite is not enriched in granitophile elements such as Li, Rb, Nb and Sn. The Zvůle melt was not able to produce extreme fractionated melts like the muscovite granites in case of fractionation of the Eisgarn melt.

The Zvůle granite body shows a rather weak reverse zoning expressed mainly by feldspar-hosted trace elements Rb and Sr. This can be explained by upwards fluid migration in magma reservoir producing Rb-enrichment in the uppermost part of the magma chamber. During following intrusion, the top portion of the crystal mush was emplaced along contact, while the lower, Sr-richer part of the magma, was emplaced







Photoplate

1. Čímeř granite, Aaffang, quarry Widy (sample No.2962). Relicts of andalusite in muscovite. Photo area 1.3x0.9 mm. Crossed nicols.
2. Eisgarn granite, rim facies, Griesbach (sample No.2949). Aggregate of andalusite crystals and relicts in muscovite. Proto area 3.6x2.3 mm. Crossed nicols.
3. Eisgarn granite, rim facies, Haugschlag (sample No.2974). Isometric apatite crystals within biotite flakes. Small monazite grains are surrounded by dark pleochroic halo. Photo area 3.6x2.3 mm. Parallel nicols.
4. Eisgarn granite, core facies, S of Galthof (sample No.2964). Primary coexisting biotite and muscovite. Biotite was later partly chloritised. Photo area 3.6x2.3 mm. Paralel nicols.
5. Čímeř granite, Kaproun (sample No.2946). Nearly automorph, zonally sericitised oligoclase crystal hosted in Kfs phenocryst. Photo area 3.6x2.3 mm. Crossed nicols.
6. Eisgarn granite, rim facies, Altmanns (sample No.2969). Small Kfs and albite crystals hosted in a large Kfs phenocryst. Photo area 3.6x2.3 mm. Crossed nicols.

later within the body centre. Similar typ of zonality was reported by JANOUŠEK et al. (1997) from the Říčany granite from the Central Bohemian Pluton.

5.5. Muscovite granites

The lowest thorium and highest uranium contents define well the group of muscovite granites (Fig. 4) which were not distinguished in the older printed maps. These granites are the products of expressive fractionation as they are rich in uranium, phosphorus and rare metals. The bodies of this granite have been recognised in the localities such as Homolka, Galthof and Nakolice-Pyhrabruck (as stocks) and Šejby (as dykes) and were described sufficiently (BREITER et al., 1994; BREITER and GNOJEK, 1996; BREITER and SCHARBERT, 1995, 1998).

6. Genetic interpretation

The compilation of geochemical and mineralogical data together with the results of gamma-ray spectrometry and within the framework of all important geological features among the different granite types (KLEČKA and RAJLICH, 1984; KLEČKA and MATĚJKA, 1995; BREITER and SCHARBERT, 1995) allow to present the following outlines of a genetic model for the CMP:

The Variscan peraluminous granites of the SBP were formed in the succession of the following three episodes by remelting of continental crust:

1. The evolution of the pluton started with the intrusion of the Lásenice granite. It is a peraluminous, typical S-type granite with low contents of all compatible elements, produced by remelting of metasedimentary material during the thermal peak of the Variscan metamorphism. The bodies of this granite were locally affected by flat shear zones (KLEČKA and RAJLICH, 1984).

2a. The second stage of the pluton history started by the intrusion of high-K peraluminous Th- and Zr-rich melt, which crystallised as medium- to coarse-grained porphyritic Číměř granite in the south, and fine- to medium-grained non-porphyritic Mrákotín granite in the north. This melt was considerably inhomogeneous as regards the content of Kfs phenocrysts and accessory minerals and, thus, the contents of the compatible elements such as Th, Zr and REE. Products of this intrusive phase built the largest part of the CMP.

2b. Further fractionation of the "Číměř melt" produced the Eisgarn s.s. granite in central part of the pluton between the towns of Nová Bystřice and of Gmünd. This melt was chemically more evolved and was able to undergo further intense fractionation. The expressive inward zoning of this body is well displayed in major and trace elements distribution patterns.

2c. Following intense fractionation of the "Eisgarn melt" finally produced small bodies of F, P, Rb, Li, U, Sn, Nb, Ta-rich muscovite granites.

3. New input of evolved Si-rich, but F, Rb, Li, U-poor melt produced deep-seated stocks of coarse-grained granites (the Zvůle stock in studied area, the Melechov and Čeřínek stock in the northern part of the SBP). The Zvůle stock displays a week reverse zonation.

The granitic dyke rocks are a products of the Číměř–Eisgarn melt evolution. They intruded between the phases 2b and 2c. Some of them could be younger than 2c. Generally, these N–S trending dykes indicated the beginning of the intense late-Variscan extension, which enabled the penetration of small portions of the residual melt into the uppermost parts of the CMP and to its gneiss mantle.

The only weakly peraluminous (ASI=1.07) intrusion of the Kozí Hora/Hirschenschlag granite-dyke system from another deep-seated source is considered to be the youngest one. This granite differs from other SBP granites by its lowest Sr_i (SCHARBERT, 1987).

Acknowledgements

This contribution represents an output of the project "Distribution of radioactive elements in the Eisgarn granite...", which was supported by the Czech-Austrian foundation AKTION (project 16p1) and by the KONTAKT–Program of Czech Ministry of Education (project ME-114).

The part of our work dealing with interpretation of airborne and ground gamma-ray spectrometry was kindly supported by Mrs. M. Chlupáčová from PETRAMAG Praha and Mr. I. Gnojek from Geofyzika Brno. Mr. T. Ntaflos (Wien) and Mr. I. Vavřín (Praha) are thanked for technical help with microprobe analyses. Mrs. S. Scharbert (Wien) is thanked for providing several samples for chemical analyses. Study of accessory minerals was performed by Mr. Z. Táborský from CGS Praha.

The mining companies Friepess and Poschacher (Austria) and KAVEX (Czech Republic) are thanked for permission to study granite outcrops in their quarries.The forest offices of Kinsky (Heidenreichstein), of Seilern-Aspang (Litschau) and of town Schrems are thanked for permission to perform field works in areas under their administration.

References

BREITER, K. & GNOJEK, I. (1996): Radioacivity of the highly fractionated Homolka granite in the Moldanubian pluton, southern Bohemia. Věstník Čes. geol. Úst., 71, 173–176. Praha.

BREITER, K., GNOJEK, I. & CHLUPÁČOVÁ, M. (1998): Radioactivity patterns - constraints for the magmatic evolution of the two-mica granites in the Central Moldanubian Pluton. Věst. Čes. geol. Úst. 73, 301–311.

BREITER, K., GÖD, R., KOLLER, F., SLAPANSKÝ, P. & KOPECKÝ, L.(1994): Excursion D: Mineralisierte Granite im Südböhmischen Pluton. Mitt. Österr. Miner. Ges. 139, 429–456.

BREITER, K. & SCHARBERT, S. (1995): The Homolka magmatic centre – an example of late-Variscan ore bearing magmatism in the South Bohemian batholith. (Southern Bohemia, Northern Austria). Jb. Geol. B.-A., 138, 9–25. Wien.

BREITER, K. & SCHARBERT, S. (1998): Latest intrusions of the Eisgarn Pluton (South Bohemia – Northern Waldviertel. Jb. Geol. B.-A. 141, 25–37. Wien.

DĚDÁČEK, K. et al. (1990): Letecký geofyzikální výzkum a geologická interpretace jz. Moravy I. MS, archiv ČGÚ Praha.

DĚDÁČEK, K. et al. (1991): Letecký geofyzikální výzkum a geologická interpretace jz. Moravy II. MS, archiv ČGÚ Praha.

DUDEK, A. et al. (1963): Geological map of Czechoslovak Republic 1:200 000, sheet Jindřichův Hradec. ÚÚG Praha.

FINGER, F., HAUNSCHMID, B. & SCHERMAIER, A. (1994): Excursion-guide to the Southern Bohemian Batholith 29.8.–31.8.1994. Salzburg.

FINGER, F. & HOCK, V. (1986): Zur magmatischen Entwicklung des Moldanubikums in Oberösterreich. Jahrb. Geol. B.-A. 129, 641–642.

GERDES, A. (1997): Geochemische und thermische Modelle zur Frage der spätorogenen Granitgesteine am Beispiel des Südböhmischen Batholiths: Basaltisches Underplating oder Krustenstapelung. PhD. Thesis, Göttingen, 113p.

GNOJEK, I. & PŘICHYSTAL, A. (1997): Ground geophysical and geological mapping in the central part of the Moldanubian Pluton. Jahrbuch Geol. B.-A. Wien., 140, 193–250.

GÖD, R. (1989):A contribution to the mineral potential of the southern Bohemian massif (Austria). Arch. f. Lagerst.forsch.Geol.B.-A., 11, 147–153.

HRON, J. (1990): Geological map of Czech Republic 1:50 000, sheet 33–12 Nová Bystřice. ČGÚ Praha.

HRON, J. (1991): Geological map of Czech Republic 1:50 000, sheet 23–34 Jindřichův Hradec. ČGÚ Praha.

Janoušek, V., Rogers, G., Bowes, D. R. & Vaňková, V. (1997): Cryptic trace-element variation as an indicator of reverse zoning in a granitic pluton: the Říčany granite, Czech Republic. Journal of Geol. Soc., 154, 807–815. London.

Klečka, M. (1984): Felzitické a sklovité žilné horniny z okolí Lásenice u Jindřichova Hradce. Čas. Mineral. Geol., 29, 293–298. Praha.

Klečka, M. & Matějka, D. (1995):Moldanubian batholith – an example of the evolution of the late Paleozoic granitoid magmatism in the Moldanubian zone, Bohemian massif (Central Europe). In: Srivastava, R. K. & Chandra, R. (Eds.): Magmatism in relation to diverse tectonic settings. 353–373. New Delhi.

Klečka, M. & Rajlich, P. (1984): Subhorizontal shear zones at the mantle and western periphery of the central massif of the Moldanubian pluton. Věst. Ústř. Úst. geol., 59, 275–282. Praha. (in Czech)

Koller, F., (1992): Die Granite im nördlichen Waldviertel – ein Statusbericht aus einem laufenden Forschungsprojekt. Mitt. Österr. Miner. Ges. 137, 322–324.

Koller, F., (1996): Plutonische Gesteine. In: Steininger, F. (Ed.): Erdgeschichte des Waldviertels. Das Waldviertel 45 (56), No.1/1996, 25–36. Horn.

Koutek, J. (1925): About granite from Mrákotín. Rozpr. Čes. akad. věd, II. tř., 34/18, 18p. Praha. (in Czech)

Liew, T. C., Finger, F. & Höck, V. (1989): The Moldanubian granitoid plutons of Austria: Chemical and isotopic studies bearing on their environmental setting. Chem. Geol., 78, 41–55.

Meurers, B. (1992): Korrigierte Bougueranomalie der Südlichen Böhmischen Masse (nach Subtraktion des Gravitationseffektes der Moho und der Molasse Sedimente). Schwerpunktprogramm S47GEO – Präalpidische Kruste in Österreich, Salzburg.

Přichystal, A. (1992): Final report on geological mapping in Kautzen-Reingers area (Niederösterreich). Manuscript, Geol. Survey of Austria, Vienna.

Scharbert, S. (1987): Rb-Sr Untersuchungen granitoider Gesteine des Moldanubikums in Österreich. Mitt. Österr. Miner. Ges. 132, 21–37. Wien.

Scharbert, S., Breiter, K. & Frank, (1997): The cooling history of the souhern Bohemian Massif. Jour. Czech. Geol. Soc. 42, p. 24. Praha.

Scharbert, S. (1998): Some geochronological data from the South Bohemian Pluton in Austria: a critical review. Acta Univ. Carol. Geol. 42, 114–118. Praha.

Velmer, C. & Wedepohl, K. H. (1994): Geochemical characterization and origin of granitoids from the South Bohemian Batholith in Lower Austria. Contrib. Mineral. Petrol. 118, 13–32.

Vrána, S. (1990): The Pelhřimov volcanotectonic circular structure. Věst. Ústř. Úst. geol., 65, 143–156.

Waldmann, L. (1950): Geologische Spezialkarte der Republik Österreich, 1:75 000, Blatt Litschau-Gmünd (4454). Geol.B.-A., Wien.

Zoubek, V. (1949): Zpráva o přehledném geologickém mapování na listu Jindř. Hradec (list spec. mapy 4354). Věst. Geol. Úst. ČSR, 24, 193–195. Praha.