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Petrology and geochemistry of plutonic rocks from the Polička and Zábřeh crystalline units (NE Bohemian Massif)

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A b s t r a c t. Polička and Zábřeh Crystalline Complexes are units situated in the NE part of the Bohemian Massif. They are composed of similar metamorphosed volcanosedimentary sequences intruded by numerous plutonic bodies of Variscan age. The mafic, tonalite and granite plutonic suites were distinguished here based on petrology and geochemistry. Rocks of the mafic suite show a primitive chemical composition and were metamorphosed under conditions of lower amphibolite facies. Rocks of the tonalite suite are metaluminous and their chemical composition in the two units is almost the same, but these rocks differ in the fO_2 values. Contamination of magma by crustal rocks was confirmed by the data obtained from mineral chemistry. Submagmatic to solid-state deformation fabric in tonalites is concordant with the adjacent country rocks and points to syn-tectonic or early post-tectonic character of emplacement. Rocks of the tonalite suite were emplaced at different crustal levels in the Polička Crystalline Complex. In the southern part of the unit, crystallization of quartz gabbros occurred at pressures of 6 to 8 kbar, with temperature ranging within 659–785 °C. Conditions of 559–750 °C and 3–6 kbar dominated in other rock types of the tonalite suite. The PT conditions of tonalite intrusion in the Zábřeh Crystalline Complex are estimated at 706–795 °C and 3–4 kbar. These values correspond with those obtained from the adjacent metapelites. Granite suite is rather weakly represented, granites evolved from a mature source. A different magmatic pulse is the easiest way to explain quite different trends in variation diagrams compared to the spatially- and age-related tonalite suite.

K e y w o r d s : Polička Crystalline Complex, Zábřeh Crystalline Complex, plutonic rocks, tonalite, whole-rock geochemistry, geobarometry, geothermometry

Introduction

The Polička and Zábřeh crystalline complexes are two parts of a single geological unit (Fig. 1) situated in the NE part of the Bohemian Massif (e.g., Kodym and Svoboda, 1950). These crystalline complexes are exposed in opposite limbs of a large synclinal structure of Cretaceous sediments and are closely related to the adjacent anticlines (Svratka Anticline and Orlica-Snieźnik Dome). On the other hand, in the classical concept of Mísař et al. (1983), the Polička Crystalline Complex (PCC) is a unit related to the Bohemicum, and the Zábřeh Crystalline Complex (ZCC) is a unit related to the Lugicum.

Magmatic rocks of tonalite composition represent characteristic members of both complexes and can be used for correlation between them. The study of rocks was based on methods of petrography and whole-rock geochemistry complemented by petrological studies of selected samples (Tab. 1). Sets of geochemical samples (Tab. 2) from PCC and ZCC were supplemented by two samples from the Staré Město Belt (SMB). Major element data of Vávra (2002), Soldán (1972), Dovolil (1959) and Fiala (1929) were also used in the Harker's diagrams.

Samples of up to five kilograms in weight were processed in the laboratories of the Czech Geological Survey. Major element contents were determined using wet methods, trace element contents were determined using XRF (Sn, Zr), AAS (Co, Cr, Cs, Cu, Mo, Ni, Pb, Rb, V, Zn) methods, Y and REE contents were determined using ICP method. A list of samples is summarized in Table 1. Results of the analyses are shown in Table 2.

Table 1. A list of used samples.

	No.	locality	rocks
Polička unit	Pol3	Polička	Amf-Bt tonalite
	Pol4	Polička	Grt-Bt granite
	Pol5	Skalky	Amf-Bt granodiorite
	Pol6	Skalky	Bt granite
	Pol9	Jedlová	Cpx-Amf-Bt tonalite
	Pol317	Budislav	Bt granite
	Pol1011	Jedlová	Amf-Bt tonalite
	Pol130	Jedlová	Grt-Amf-Bt quartzgabbro
	Pol312	Budislav	Amf-Bt tonalite
	Pol25	Borová	Grt-Bt granodiorite
	Pol88	Korouhev	Amf gabbro
	Pol86	Korouhev	metaperidotite
	Pol50	Sádek	Bt-Amf diorite
	Pol10	Borová	Bt granite
	Pol1	Polička	Amf gabbro
	Pol2	Polička	Amf gabbro
	Pol8	Kamenec u Poličky	Amf-Bt tonalite
	Pol264	Polička	Bt granodiorite
	Pol95	Korouhev	Amf-Bt gabbro
Zábřeh unit	Zk20	Crhov	Amf-Bt granodiorite
	Zk37	Crhov	Amf-Bt granodiorite
	Zk38	Krchleby	serpentinite
	Zk40b	Krchleby	metagabbro
	SH 87	Rovensko	peridotite
	Mo342	Zátiší	Amf-Bt tonalite
	Mo341	Crhov	Amf-Bt granodiorite
	SH145	Václavov	Amf-Bt granodiorite
	SH159	Zborov	Bt granite
	SH204	Bušín	Amf-Bt tonalite
	ZK55	Crhov	Amf diorite

Table 2. Chemical composition of plutonic rocks from the PCC, ZCC and Staré Město Belt.

	Polička unit							Zábřeh unit						Staré Město Belt	
sample	Pol4	Pol6	Pol3	Pol5	Pol9	Pol1	Pol2	SH203	Mo341	Mo342	Mo324	SH145	SH204	SP6	SP18
suite	granite	granite	tonalite	tonalite	tonalite	mafic	mafic	granite	tonalite	tonalite	tonalite	tonalite	tonalite	tonalite	tonalite
SiO_2	73.02	72.80	61.38	62.16	61.97	48.46	48.42	73.25	53.91	60.62	56.53	61.52	62.93	58.71	58.58
TiO_2	0.20	0.17	0.69	0.63	0.71	0.79	0.87	0.11	1.04	0.74	0.87	0.67	0.62	0.83	0.83
Al_2O_3	13.80	14.88	16.45	16.64	16.05	17.95	16.82	14.59	17.24	15.18	16.52	15.62	15.23	16.88	16.23
Fe_2O_3	0.68	0.33	0.81	0.88	0.71	0.57	1.45	0.40	1.63	0.78	1.79	1.67	1.02	0.71	1.17
FeO	1.16	0.81	4.90	5.08	4.92	7.62	7.18	0.56	6.29	4.80	4.52	3.83	3.63	5.46	5.18
MnO	0.04	0.03	0.12	0.12	0.12	0.17	0.17	0.05	0.15	0.11	0.12	0.11	0.09	0.12	0.13
MgO	0.37	0.26	2.93	2.35	2.85	7.50	7.66	0.33	4.00	3.34	5.44	3.27	3.14	3.44	3.49
CaO	1.47	0.93	5.54	4.79	5.57	11.57	11.30	1.15	6.81	4.83	5.17	4.95	4.00	5.91	5.42
BaO	0.082	0.040	0.051	0.059	0.048	0.015	0.032	0.144	0.165	0.125	0.104	0.119	0.096	0.145	0.152
Li_2O	0.005	0.006	0.008	0.013	0.008	0.008	0.005	<0.005	0.006	0.005	0.009	0.005	0.005	<0.005	<0.005
Na_2O	2.54	4.30	2.71	2.92	2.87	2.07	2.22	4.91	3.14	2.87	3.80	3.04	2.96	3.25	2.90
K_2O	5.55	5.21	2.18	2.42	2.13	0.54	0.88	3.60	2.94	3.55	2.16	3.66	4.05	2.83	3.53
P_2O_5	0.12	0.12	0.13	0.15	0.11	0.08	0.15	0.09	0.40	0.27	0.31	0.26	0.26	0.29	0.31
CO_2	0.01	0.01	0.01	0.04	0.01	0.09	0.02	0.04	0.01	0.52	0.09	0.04	0.03	0.09	0.09
C	0.02	0.01	0.03	0.02	0.02	0.13	0.02	<0.005	0.04	0.02	0.02	<0.005	0.01	0.01	0.02
H_2O^+	0.54	0.20	1.04	1.23	0.98	1.60	2.02	0.50	1.48	1.40	1.88	1.38	1.27	1.40	2.08
F	0.06	0.07	0.10	0.09	0.07	0.09	0.09	0.05	0.12	0.11	0.13	0.09	0.08	0.09	0.10
S	0.01	0.01	0.02	0.03	0.03	0.12	0.07	0.03	0.02	0.04	0.06	<0.005	<0.005	0.04	0.03
H_2O^-	0.14	0.05	0.12	0.12	0.12	0.09	0.11	0.10	0.13	0.10	0.09	0.17	0.17	0.17	0.18
total	99.80	100.21	99.19	99.71	99.29	99.42	99.48	99.90	99.53	99.41	99.64	100.42	99.60	100.37	100.42
Co	11	<5	25	18	23	44	40	5	26	29	32	22	19	22	22
Cr	23	40	95	65	70	167	91	21	88	103	217	85	124	82	90
Cu	6	4	18	16	12	26	23	14	24	21	16	24	15	19	21
Ni	5	15	17	7	6	14	38	8	14	20	60	21	31	17	21
Rb	113	237	80	94	71	15	20	62	93	126	62	119	163	90	113
Sr	144	85	186	178	279	254	347	237	575	406	837	397	321	423	431
V	19	<15	101	63	85	234	224	<15	178	130	132	130	115	145	148
Sn	<7	<7	<7	<7	<7	<7	<7	<7	<7	<7	<7	<7	<7	<7	<7
Zn	33	33	84	89	77	83	74	34	112	80	97	91	85	113	106
Nb	<7	<7	<7	<7	<7	<7	<7	8	8	9	<7	13	16	13	8
Mo	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Zr	125	98	124	174	127	45	75	39	200	132	278	130	143	161	176
Pb	67	76	36	47	49	27	58	36	29	43	40	29	28	12	19
Cd	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8
Cs	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	12	11	<10	<10
Y	11.5	13.1	20.5	29.3	19.9	17.3	19.8	14.4	25.2	21.8	18.0	27.2	25.6	27.2	28.7
La	25.47	21.08	22.17	25.70	19.60	8.49	11.25	11.63	34.52	32.38	36.29	34.02	38.99	50.96	56.47
Ce	48.33	42.93	52.28	54.89	43.55	20.37	26.52	22.13	76.11	66.02	74.34	70.20	80.09	93.39	104.67
Pr	<5.00	<5.00	<5.00	5.37	<5.00	<5.00	<5.00	<5.00	8.07	7.26	7.87	8.72	9.28	10.99	12.85
Nd	21.76	18.65	20.70	26.38	20.26	12.87	16.50	9.60	38.12	30.37	35.33	35.26	33.84	41.41	47.69
Sm	4.07	3.89	4.54	5.50	5.31	2.69	3.96	2.07	7.07	5.83	6.36	7.17	7.04	7.56	8.56
Eu	0.89	0.39	1.14	1.18	1.01	1.00	1.24	0.48	1.77	1.23	1.88	1.50	1.29	1.64	1.67
Gd	3.02	3.32	4.35	5.85	3.98	3.32	4.39	2.14	7.47	6.03	5.44	6.18	5.69	6.69	7.02
Tb	<0.90	<0.90	<0.90	<0.90	<0.90	<0.90	<0.90	<0.90	<0.90	<0.90	<0.90	<0.90	<0.90	1.05	<0.90
Dy	2.08	2.64	3.82	5.40	3.75	3.16	3.86	2.33	4.82	4.10	3.58	5.18	4.69	5.38	5.44
Ho	<0.60	<0.60	0.72	1.03	0.69	0.66	0.72	<0.60	0.92	0.74	0.65	0.90	0.86	0.91	0.91
Er	<1.00	<1.00	1.93	2.86	1.98	1.81	2.08	1.37	2.56	2.65	1.66	2.85	2.51	2.52	2.99
Tm	<0.40	<0.40	<0.40	0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40
Yb	1.49	1.08	2.24	3.19	2.17	2.09	2.11	1.33	2.56	2.22	1.81	2.64	2.57	2.34	2.79
Lu	0.24	<0.16	0.33	0.47	0.28	0.29	0.30	0.18	0.35	0.32	0.26	0.38	0.37	0.30	0.38

Mineral phases were determined at the Department of Geochemistry of the Czech Geological Survey, Prague, using a Camscan-Link-ISIS electron microprobe with operating conditions 15 kV, 2.5 nA and 40 s. The mineral abbreviations used follow Kretz (1983).

Geological setting

Lithotectonic sequences of both geological units are very similar. The PCC is composed of medium-grained biotite and two-mica gneisses with bodies of amphibolites, marbles and calc-silicate rocks. The boundary with the Svratka Crystalline Complex in the SW is transitional, reworked by a younger N-S-oriented fault zone. The PCC is covered by Cretaceous sediments in the N and W. The metamorphic complex contains small bodies of basic and ultrabasic rocks. They were metamorphosed under the amphibolite-facies conditions with metamorphic degree increasing from NW to SE. They are intruded by the magmatic suite of tonalite-granodiorite-granite composition. Intrusions forming small tongue-like bodies (the Budislav Massif in the N and the Jedlová Massif in the SE) are concordant with the NNW-SSE-oriented structural trend in the PCC. An independent plutonic body (Miřetín intrusion) is situated along borders of the PCC with the Hlinsko Unit (Fig. 1).

The ZCC is a metamorphosed volcanosedimentary sequence with close affinities to the Nové Město phyllites and Staré Město Belt in the Lugicum (Svoboda et al. 1964). The principal lithological and tectonic structures in the ZCC are oriented E-W. The complex is composed of

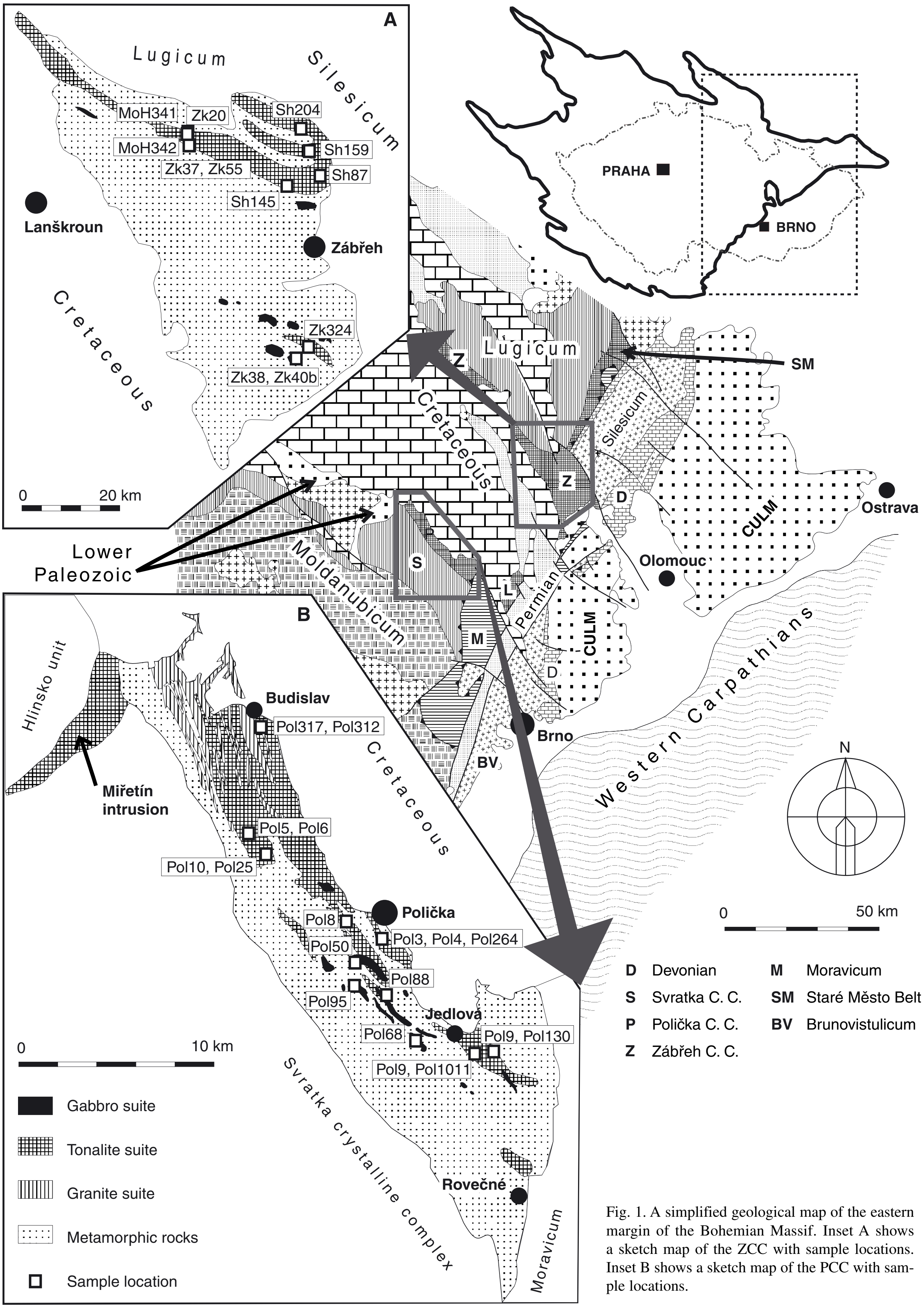

Fig. 1. A simplified geological map of the eastern margin of the Bohemian Massif. Inset A shows a sketch map of the ZCC with sample locations. Inset B shows a sketch map of the PCC with sample locations.

Table 3. Major rock types of the tonalite suite.

Rocks	Minerals	Geol. units	Plagioclase An (%)	Biotite Mg/(Mg+Fe)	Al^{IV} (apfu)	Ti (apfu)	Amphibole Mg/(Mg+Fe)	Si (apfu)
Garnet-bearing amphibole-biotite quartz gabbros	Pl+Qtz+Amp+Bt+Grt+Ilm±Czo	PCC	60–67	0.40–0.36	2.71–2.49	0.43–0.30	0.41–0.36	6.00–6.27
		ZCC	–	–	–	–	–	–
Amphibole-biotite granodiorites	Pl+Qtz+Amp+Bt±Ilm±Ttn±Kfs	PCC	35–53	0.49–0.42	2.71–2.36	0.39–0.29	0.93–0.54	6.46–7.48
		ZCC	44–39	0.46–0.42	2.54–2.42	0.33–0.43	0.56–0.54	6.75–6.92
Pyroxene-bearing amphibole-biotite tonalites	Pl+Qtz+Amp+Bt+Cpx±Ilm±Kfs	PCC	40–49	0.46–0.44	0.51–0.46	0.44–0.36	0.53–0.49	6.47–6.87
		ZCC	21–44	0.49–0.47	2.41–2.37	0.42–0.35	0.60–0.58	6.75–7.33
Biotite granodiorites, locally garnet-bearing	Kfs+Pl+Qtz+Bt+Ilm±Grt	PCC	39–42	0.29–0.28	2.60–2.59	0.34–0.31	–	–
		ZCC	–	–	–	–	–	–

two parts separated by a horizon of staurolite-bearing rocks following the valley of the Moravská Sázava River (Urban 1948, Zapletal 1934). The southern part is formed by a slightly matamorphosed monotonous flysch-like complex with prevailing metagreywackes. Large bodies of fine-grained amphibolites accompanied by rare lenses of marbles, serpentinites, garnet-bearing amphibolites and gabbros are common in the southern part of the unit. The northern part is composed of metamorphosed volcanosedimentary complex with rapidly increasing metamorphic degree up to the amphibolite facies towards the north. Fine-grained biotite (± muscovite) paragneisses and sillimanite-bearing gneisses to migmatites are typical rocks of the N part of the ZCC. Amphibolites, ultramafic rocks, metarhyolites and calc-silicate rocks are less frequent. Amphibolites from two parts of the ZCC differ in their geochemistry and correspond to the lower (MORB character) and upper (WPB character) amphibolite belts distinguished here by Melichar and Hanžl (1997). Concordant, E-W-elongated magmatic bodies of tonalite-granodiorite composition are exposed mostly in the northernmost (upper amphibolite) part of the unit. Only a small apophysis of tonalite is exposed in the S part of the ZCC near Bušínov.

No relevant radiometric ages have been published for the PCC except for the K-Ar data of Šmejkal (1960) who dated deformed granodiorites near Česká Rybná at 351 Ma. Amphibolites from the N part of the ZCC were dated at 336 ± 3.2 Ma using the Ar-Ar method by Maluski et al. (1995). Chemical U-Th-total Pb monazite age of 330 ± 21 Ma was established for the gneiss from the NE part of the ZCC by F. Finger (Hanžl et al. 2000). Tonalites from the Staré Město Belt, which can be well correlated with the Zábřeh ones, were dated by Parry et al. (1997) at 339 ± 7 Ma using zircon evaporization technique.

Petrography of plutonic rocks

Classification of plutonic rocks based on modal composition plotted into the QAP classification diagram is shown in Figure 2. Field and microscopic descriptions of plutonic rocks demonstrate a similar character of plutonic rocks in the two studied crystalline complexes, which can be subdivided into three suites:

I. Mafic suite formed by diorites, gabbros and ultramafic rocks.
II. Tonalite suite formed by granodiorites and tonalites.
III. Granite suite formed by granites to granodiorites.

I. Mafic suite

Polička Crystalline Complex

Rocks of the mafic suite form oval bodies several tens of metres to several kilometres in size, which occur within bodies of the tonalite suite or in their proximity. The bodies are located mainly in the central and southern part of the PCC in the area between villages Kamenec u Poličky and Jedlová. Basic and ultrabasic rocks were generally subjected only to nonpenetrative deformation with relations to the adjacent rocks. Contacts with rocks of the tonalite suite are sharp, and rocks of the mafic suite form xenoliths in the rocks of the tonalite suite, indicating that rocks of the mafic suite are the oldest plutonic rocks in the PCC.

Ultramafic rocks in the PCC (Korouhev) are dark green, composed of olivine (74–73.5% forsterite, 26% fayalite and 0–0.5% tefroite components), minerals of serpentine group, actinolite and chlorite. Ilmenite (84–85% ilmenite – $FeTiO_3$, 12% geikielite – $MgTiO_3$, 3–4% hematite – Fe_2TiO_3 and 2% pyrophanite – $MnTiO_3$ components) and Ni and Co sulphides are present as accessories.

Gabbros and diorites are coarse- to medium-grained rocks, often forming bodies with ultramafic rocks. They are usually represented by amphibole gabbro, locally with pyroxene, and by amphibole-biotite gabbro.

Amphibole gabbros consist mainly of amphibole and plagioclase. Amphibole

Table 4. Representative plagioclase analyses from rocks of the mafic and tonalite suites.

	Sample No.	Pol312	Pol1011	Pol9a	Pol9b	Pol5	Mo341	Zk55	Pol130	Pol130b	Pol95	Pol88
Composition in wt %	SiO_2	58.61	56.23	55.51	57.38	58.56	59.21	58.32	61.95	51.57	47.22	45.08
	Al_2O_3	26.38	27.30	27.89	26.56	25.45	26.03	25.43	25.07	30.81	33.61	34.05
	CaO	7.92	10.15	10.42	8.86	7.46	7.83	7.64	5.16	13.41	17.32	17.76
	Na_2O	6.58	5.70	5.91	6.98	7.46	6.91	6.59	7.99	4.06	1.71	1.13
	K_2O	–	–	–	–	0.58	–	0.31	0.30	–	–	–
	Total	99.49	99.38	99.73	99.78	99.51	99.98	98.29	100.47	99.85	99.86	98.02
Cations per 8 oxygens	Si	2.62	2.54	2.51	2.58	2.64	2.64	2.65	2.73	2.35	2.17	2.12
	Al	1.39	1.45	1.48	1.41	1.35	1.37	1.36	1.30	1.65	1.82	1.88
	Ca	0.38	0.49	0.50	0.43	0.36	0.37	0.37	0.24	0.65	0.85	0.89
	Na	0.57	0.50	0.52	0.61	0.65	0.60	0.58	0.68	0.36	0.15	0.10
	K	–	–	–	–	0.03	–	0.02	0.02	–	–	–
	SCat	4.97	4.98	5.01	5.02	5.03	4.98	4.97	4.97	5.01	5.00	4.99
	Mol %											
	An	40	50	49	41	35	39	38	26	65	85	90
	Ab	60	50	51	59	62	61	60	72	35	15	10
	Or	–	–	–	–	3	–	2	2	–	–	–

forms hypautomorphic to automorphic grains, while the areas among them are filled with oscillatory-zoned plagioclase of $An_{83–90}$. This plagioclase is locally replaced by a younger plagioclase of $An_{37–38}$. The replacement led to the development of veinlets of younger plagioclase along grain boundaries and within individual plagioclase crystals. Orthopyroxene is preserved in relics enclosed in amphibole. These correspond to enstatite ($En_{65–66}$, Fs_{31-32}, $Wo_{2–3}$). Phlogopite with Mg/(Mg+Fe) 0.75–0.74, Al^{IV} 2.57–2.73 and Ti contents of around 0.04 apfu is rare. The herein used classification of amphiboles follows Leake et al. (1997). Mineral formulae calculations are based on 23 oxygens and standardized for 13 cations (without Ca, Na and K). All the studied amphiboles plot in the field of calcic amphiboles. Gabbro contains mainly magnesiohornblendes and tschermakites, with some actinolite in grain cores. Si contents are highly variable (6.19–7.48 apfu) and Mg/(Mg+Fe) ratios lie in the range of 0.62–0.91.

Besides separate bodies, gabbros and ultrabasic rocks also form enclaves enclosed in rocks of the tonalite suite. Enclaves of ultrabasic rocks have mineral assemblage Ath + Tr + Tlc. The xenoliths of gabbro are composed of amphibole (magnesiohornblende and actinolite), plagioclase ($An_{80–85}$) and clinopyroxene, which is rimmed by amphibole aggregates. Mineral assemblages of the xenoliths are affected by contact metamorphism (Buriánek 2001).

Amphibole-biotite gabbros are less common, usually medium-grained and locally porphyritic. Phenocrysts are represented by phlogopite and amphibole. Plagioclase is generally oscillatory-zoned with $An_{55–53}$ (Tab. 4) and locally replaced by younger andesine with An_{42} along grain boundaries. Dark mica in amphibole-biotite gabbros corresponds to phlogopite with Mg/(Mg+Fe) 0.57–0.56 and Al^{IV} 2.43–2.47 apfu, Ti contents of 0.44–0.39 apfu.

Zábřeh Crystalline Complex

Bodies of totally serpentinized ultramafic rocks accompanied by (meta)gabbros are distributed as small lenses in a narrow belt with no relation to the tonalite in the S part of the ZCC. Small and very rare bodies of rocks with preserved peridotite textures are exposed in its northern part. These peridotites are composed of orthopyroxene, phlogopite and olivine. Pyroxene forms poikiloblasts enclosing xenomorphic olivine. Ultrabasic rocks are associated with amphibole gabbros and diorites and are usually related to the amphibolite belts. The original magmatic textures are overprinted by frequently observed metamorphic recrystallization. Chemical composition of minerals was studied on a single sample of diorite from the Zborov village (northern part of the ZCC). This diorite forms an enclave in rocks of the tonalite suite. It is composed of hypautomorphic amphibole and zoned plagioclase of An_{38-48}. Amphiboles have the composition of magnesiohornblendes to ferrotschermakites, Si contents are 6.45–6.78 apfu and Mg/(Mg+Fe) ratio 0.46–0.56. No relations between rocks of mafic suite and the tonalite one can be observed in the area. Intrusion of tonalite into gabbro-like rocks can be assumed from free small blocks in the field only.

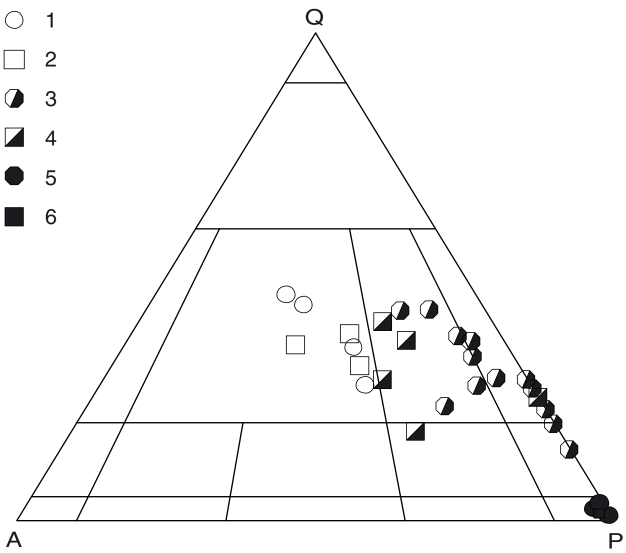

Fig. 2. Modal composition of plutonic rock in the QAP diagram. IUGS classification (Streckeisen 1976). Granite suite: 1 – PCC, 2 – ZCC; tonalite suite: 3 – PCC, 4 – ZCC; mafic suite: 5 – PCC, 6 – ZCC.

II. Tonalite suite

Granodiorites and tonalites are the most widely distributed group of plutonic rocks in the PCC and ZCC. Elongated bodies of tonalites in both crystalline complexes are aligned parallel to the dominant strike of foliation in the country rocks, i.e. E-W in the ZCC and NW-SE in the PCC. These are medium-grained rocks with hypautomorphic textures. Tonalites commonly pass into granodiorites and in some cases also into quartz diorites. Among rocks of the tonalite suite, tonalites predominate in the PCC while granodiorites dominate in the ZCC (Fig. 2). Rocks of the tonalite suite are composed of quartz, plagioclase, ± K-feldspar, biotite, amphibole, pyroxene, garnet and minerals of epidote group (Tab. 3). The accessories include apatite, zircon, sphene and ilmenite.

Rocks of the tonalite suite are mineralogically variable and can be subdivided into four groups: amphibole-biotite granodiorites to tonalites; pyroxene-bearing amphibole-biotite tonalites; garnet-bearing amphibole-biotite quartz gabbros and biotite granodiorites, locally garnet-bearing. All the groups can be found in the PCC and two of them (amphibole-biotite tonalites to granodiorites and pyroxene-bearing amphibole-biotite tonalites) in the ZCC.

Tonalites are usually deformed and feature a whole succession of deformations ranging from magmatic/submagmatic fabric to solid-state deformation described by Parry et al. (1997) from tonalites of the Staré Město Belt.

Polička Crystalline Complex

Granodiorites to tonalites concentrate in the Budislav massif situated in the northern part of the PCC. The massif is composed of amphibole-biotite tonalites and granodiorites, less commonly by biotite tonalites and granodiorites. To the SE, the abundance of granitoids in the PCC decreases, and the proportion of gabbros and ultrabasic rocks increases (see Fig. 1). The only significant body of tonalites in the SE part of the PCC is the body near Jedlová, formed by amphibole-biotite tonalites locally containing pyroxene and garnet, which may pass into quartz gabbros. Ilmenite is a very common accessory while sphene is rare.

Rocks of the tonalite suite locally host xenoliths of the country rocks. These xenoliths are most frequent in the northern part of the PCC. Here, they are arranged into zones several km long and up to tens of metres wide. They are mostly formed by calc-silicate rocks, marbles, skarns, biotite gneisses, two-mica gneisses with sillimanite, and basic rocks.

Rocks of the tonalite suite in the PCC show wider mineralogical variability compared to those in the ZCC, and can be subdivided into four groups: garnet-bearing amphibole-biotite quartz gabbros; amphibole-biotite tonalites to granodiorites; pyroxene-bearing amphibole-biotite tonalites; and biotite granodiorites, locally garnet-bearing.

Garnet-bearing amphibole-biotite quartz gabbros form the marginal part of the Jedlová massif. Hypautomorphic plagioclase grains show no zoning under the CL microscope and relatively homogeneous chemical composition (An_{60-67}). Replacement of the original plagioclase by a younger acid plagioclase (An_{26}) is sometimes observed. Quartz grains are anhedral. Grains of minerals of zoisite-epidote group with Ps_{14} ($Ps = Fe^{3+}/(Fe^{3+}+Al)$) are locally present. Garnet forms up to 4 mm large grains, often enclosing plagioclase, biotite and quartz inclusions. Garnet is partly replaced by biotite. Garnets in rocks of the tonalite suite are almandine ($Alm_{58–61}$) but show high contents of grossular component (Tab. 5). While almandine from metapelites from the vicinity of granitic rocks contains $Grs_{1–7}$, the content of Grs component in garnets from amphibole-biotite quartz gabbros lies within the range of 23–22 (Fig. 3). Pyrope and spessartine contents are low (Sps_{9-12}, $Pyr_{8–7}$). Biotite is homogeneously distributed throughout the rocks. The common accessory mineral in amphibole-biotite quartz gabbros is ilmenite (Tab. 5) with composition: 87–96% ilmenite, 3–12% pyrophanite and 0–10% hematite. Amphiboles from rocks of the tonalite suite have similar chemical compositions in both complexes (Fig. 4). An increase in Si content can be observed with increasing Mg/(Mg+Fe) ratio in amphiboles of different rock types. These values are the lowest in the case of quartz gabbro (ferrotschermakite to ferropargasite). Mineral chemistry (X_{Mg}

Table 5. Representative garnet and ilmenite analyses from rocks of the tonalite suite.

	Garnet					Ilmenite	
	Sample No.	Pol130	Pol25a	Pol25b		Pol31	Pol130
Composition in wt%	SiO_2	36.69	36.99	36.37		0.27	-
	TiO_2	–	–	–		51.00	61.40
	Al_2O_3	20.56	20.79	20.40		–	–
	FeO	27.20	29.03	30.72		42.39	37.25
	MgO	1.99	1.34	1.70		–	–
	MnO	5.33	6.33	6.17		5.61	1.72
	CaO	8.20	6.15	4.65		–	–
	Total	99.97	100.63	100.01		99.45	100.37
Cations per 24 oxygens	Si	5.92	5.96	5.92	Cations per 3 oxygens	0.01	–
	Al^{IV}	0.08	0.04	0.07		–	–
	Al^{VI}	3.83	3.91	3.85		–	–
	$Fe^{(2+)}$	3.67	3.91	4.20		0.99	0.75
	$Fe^{(3+)}$	–	–	–		0.04	–
	Ti	–	–	–		0.97	1.11
	Mg	0.48	0.32	0.41		–	–
	Mn	0.73	0.86	0.85		0.12	0.04
	Ca	1.42	1.06	0.81		–	–
	SCat	16.13	16.06	16.11		2.13	1.89
	Alm	58	64	67	Ilm	86	96
	Sps	12	14	14	Pyr	11	4
	Prp	8	5	7	Hem	3	–
	Grs	22	17	12			

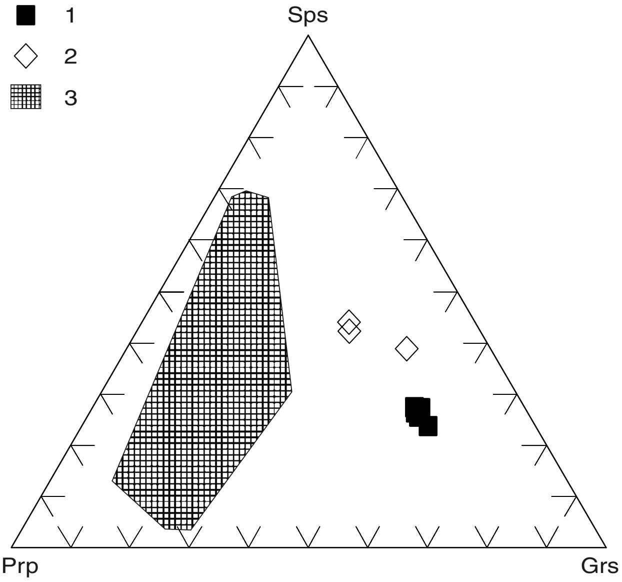

Fig. 3. A diagram showing chemical composition of garnets (Grs-Sps-Prp) from rocks of the PCC: 1 – amphibole-biotite quartz gabbros, 2 – biotite granodiorites, 3 – field of metapelites.

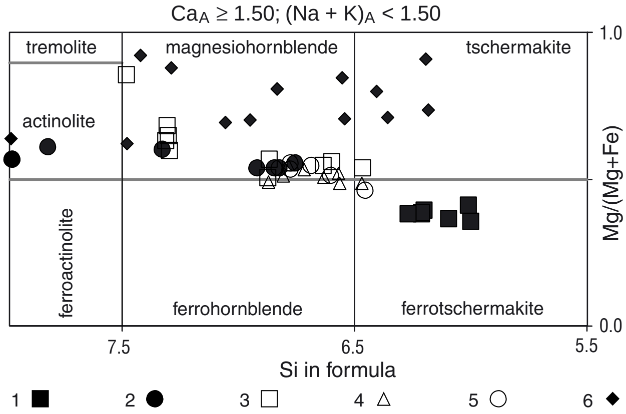

Fig. 4. Classification of amphiboles according to the nomenclature of Leake et al. (1997): 1 – amphibole-biotite quartz gabbro, PCC, 2 – amphibole-biotite tonalite, ZCC, 3 – amphibole-biotite tonalite, PCC, 4 – pyroxene-bearing amphibole-biotite tonalite, PCC, 5 – amphibole diorite, ZCC, 6 – amphibole and amphibole-biotite gabbro, PCC.

amphiboles and biotites are lower than X_{Mg} amphiboles and biotites in tonalite and granodiorite) indicates that amphibole-biotite quartz gabbros represent an untypical member of the tonalite suite (Tab. 3).

Amphibole-biotite tonalites to granodiorites are the most widespread plutonic rocks in both complexes. They are usually represented by medium-grained rocks, locally strongly deformed. Plagioclase grains are hypautomorphic and show oscillatory zoning in CL, with cores having higher basicity than the rims. Zoning becomes indistinct in the proximity of xenoliths. Amphibole forms hypautomorphic to xenomorphic grains, sometimes overgrown by biotite. Amphiboles correspond to magnesiohornblende and passes to ferrotschermakite and ferrohornblende. Replacement of these amphiboles by younger actinolite locally occurs on rims. K-feldspar and quartz are xenomorphic and their content in the individual samples is variable. The rocks show generally weak preferred orientation, with very frequent relicts of submagmatic alignment. Biotite chemically corresponding to annite (Fig. 5) is a primary phase in all rocks of the tonalite suite of the PCC and ZCC. Amphibole-biotite tonalites contain ilmenites with composition (85–92% ilmenite, 7–11% pyrophanite, 2–4% hematite).

Pyroxene-bearing amphibole-biotite tonalites in the

Table 6. Representative amphibole and pyroxene analyses from rocks of the mafic and tonalite suites.

		Opx	Cpx				Amphibole					
	Sample No.	Pol88	Pol31	Pol9	Mo342		Pol130	Pol1011	Pol9	Pol88	Mo341	Mo342
Composition in wt %	SiO_2	52.12	52.81	51.68	52.07		40.69	44.78	45.11	47.86	45.49	52.8
	Al_2O_3	3.56	0.43	0.59	1.05		13.42	10.99	9.46	9.94	8.27	2.74
	TiO_2	–	–	–	–		1.46	1.20	0.96	–	0.96	–
	FeO	19.04	11.71	13.05	11.74		21.80	19.29	18.50	12.05	18.41	16.40
	MgO	23.61	10.77	10.60	11.47		6.32	9.05	9.65	14.34	9.96	12.96
	MnO	0.54	0.49	0.72	0.66		–	–	0.53	–	0.53	0.47
	CaO	1.27	24.21	23.25	22.54		11.58	10.76	11.99	11.52	11.95	12.56
	Na_2O	–	–	–	–		1.33	1.09	0.81	1.18	0.89	–
	K_2O	–	–	–	–		1.32	0.61	1.07	0.50	0.85	–
	Total	100.14	100.42	99.89	99.53		97.92	97.77	98.08	97.39	97.32	97.93
Cations per 6 oxygens	Si	1.91	2.00	1.98	1.99	Cations per 23 oxygens	6.20	6.60	6.72	6.84	6.82	7.67
	Al^{IV}	0.09	–	0.02	0.02		1.80	1.41	1.28	1.17	1.18	0.33
	Al^{VI}	0.06	0.02	–	0.03		0.62	0.51	0.38	0.51	0.29	0.14
	$Fe^{(2+)}$	0.55	0.37	0.40	0.37		2.37	1.56	1.88	0.73	1.90	1.72
	$Fe^{(3+)}$	0.03	–	0.02	–		0.41	0.81	0.42	0.71	0.41	0.27
	Ti	–	–	–	–		1.44	1.99	2.14	3.05	2.23	2.81
	Mg	1.29	0.61	0.60	0.65		0.17	0.13	0.11	–	0.11	–
	Mn	0.02	0.02	0.02	0.02		–	–	0.07	–	0.07	0.06
	Ca	0.05	0.98	0.95	0.92		1.89	1.70	1.91	1.76	1.92	1.96
	Na	–	–	–	–		0.39	0.31	0.23	0.33	0.26	–
	K	–	–	–	–		0.26	0.12	0.20	0.09	0.17	–
	SCat	4.00	4.00	4.00	4.00		15.54	15.12	15.35	15.18	15.34	14.96

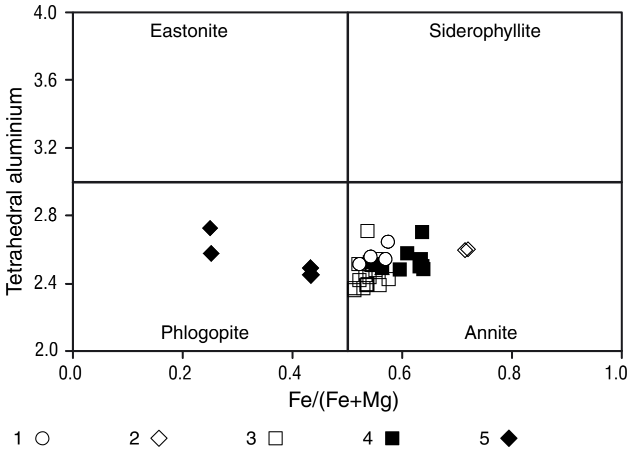

Fig. 5. Fe/(Fe+Mg) – tetrahedal Al diagram for biotite: 1 – biotite granite (granite suite PCC), 2 – biotite granodiorite (tonalite suite PCC), 3 – amphibole-biotite and pyroxene-bearing amphibole-biotite tonalite, PCC and ZCC, 4 – amphibole-biotite quartz gabbro, PCC, 5 – amphibole and amphibole-biotite gabbro, PCC.

PCC are negligible. They have been detected in a small massif near Jedlová. These rocks are medium- to fine-grained and differ from the above mentioned group only in the presence of clinopyroxene, which forms xenomorphic grains often overgrown by amphibole. Clinopyroxene corresponds to diopside (Tab. 6) with Mg/(Mg+Fe) 0.59–0.62. Pyroxenes formed by the reaction of tonalite magma with marbles have the Mg/(Mg+Fe) ratio of 0.62–0.90. Plagioclases show oscillatory zoning. K-feldspars are rare or absent. Amphibole corresponds to magnesiohornblende and passes to ferrotschermakite and ferrohornblende. Replacement of these amphiboles by younger actinolite locally occurs on rims.

Biotite granodiorites, locally garnet-bearing, are medium-grained rocks common in the central part of the Budislav Massif. The rocks generally show hypautomorphic texture but varieties with granophyric texture are also present. Plagioclase grains are mostly oscillatory-zoned. Xenomorphic garnet grains are max. 5 mm in size and enclose biotite and quartz inclusions. Xenomorphic grains of K-feldspar and quartz are always present. All biotites from amphibole-rich rocks (Tab. 7) of the tonalite suite fall in the range of calc-alkaline rocks recognized by Abdel-Rahman (1994). Amphibole-free rocks fall in the Abdel-Rahman's field for peraluminous rocks. Garnet is almandine with composition $Alm_{64–70}$ $Sps_{13–14}$ $Pyr_{5–7}$ $Grs_{11–17}$. Garnets from granitic rocks lack distinct zoning: e.g., garnet from biotite granodiorite has the composition of Alm_{64} Grs_{17} Pyr_5 Sps_{14} on rims, Alm_{69} Grs_{11} Pyr_7 Sps_{13} in the core.

Zábřeh Crystalline Complex

Tonalites in the ZCC are arranged into parallel, sill-like intrusions concentrated in the northern part of the complex. A negligible body of tonalite is exposed in the S part of the unit. Plutonic rocks are represented by amphibole-biotite tonalites to granodiorites, locally containing pyroxene. Ilmenite is rare while sphene is a common accessory in these rocks. Rocks of the tonalite suite in the ZCC were subdivided into two groups.

Amphibole-biotite granodiorites are medium-grained rocks, locally with small phenocrysts. Plagioclase grains are automorphic to hypautomorphic, oscillatory-zoned, and sometimes containing corroded cores. Plagioclase phenocrysts enclose biotite and sphene. Perthitic K-feldspar grains are hypautomorphic to xenomorphic. They sometimes have the form of phenocrysts, locally enclosing automorphic plagioclase grains. Amphibole is represented by aggregates of fine grains, locally intergrown by xenomorphic quartz. Amphibole aggregates are often overgrown by biotite. Amphibole corresponds to magnesiohornblende and tschermakite. Replacement of these amphiboles by younger actinolite locally occurs on rims.

Pyroxene-bearing amphibole-biotite tonalites to granodiorites are medium-grained rocks. Less deformed rock samples retained their magmatic fabric and locally resemble cumulate textures. Plagioclase grains are hypautomorphic, only locally showing a distinct oscillatory zoning. K-feldspar and quartz are xenomorphic. Clinopyroxene is diopside [Mg/(Mg+Fe) 0.63–0.65] and forms relicts enclosed in amphibole. Amphibole grains are often poikilitic (enclosing xenomorphic quartz) and their aggregates are sometimes overgrown by biotite. Amphibole corresponds to magnesiohornblende. Replacement of these amphiboles by younger actinolite locally occurs on rims.

Table 7. Representative biotite analyses from rocks of the mafic and tonalite suites.

	Sample No.	Pol25	Pol1011	Pol130	Pol312	Pol9	Mo341a	Mo341a	Pol88
Composition in wt%	SiO_2	34.65	35.84	34.68	36.11	35.35	36.49	34.97	35.41
	TiO_2	2.85	3.12	2.61	3.36	3.33	3.62	3.34	0.38
	Al_2O_3	16.82	15.90	15.89	15.77	15.14	14.80	14.73	19.59
	FeO	26.51	21.16	24.29	19.45	21.37	20.73	22.32	11.01
	MgO	6.04	9.59	7.83	9.97	10.01	10.14	10.05	18.29
	K_2O	10.07	9.66	9.83	9.48	10.07	10.09	9.83	8.19
	Total	96.94	95.27	95.13	94.14	95.27	95.87	95.24	92.87
Cations per 22 oxygens	Si	5.41	5.53	5.46	5.58	5.49	5.60	5.46	5.27
	Ti	0.34	0.36	0.31	0.39	0.39	0.42	0.39	0.04
	Al^{IV}	2.59	2.47	2.54	2.42	2.51	2.41	2.54	2.73
	Al^{VI}	0.51	0.42	0.42	0.46	0.26	0.27	0.17	0.71
	Fe^{2+}	3.46	2.73	3.20	2.51	2.78	2.66	2.91	1.37
	Mg	1.41	2.21	1.84	2.30	2.32	2.32	2.34	4.06
	K	2.01	1.90	1.98	1.87	2.00	1.97	1.96	1.56
	SCat	15.71	15.62	15.74	15.53	15.73	15.64	15.77	15.74
	mg	28.88	44.69	36.49	47.74	45.50	46.58	44.52	74.75

III. Granite suite

Granites form dykes and tiny bodies throughout the PCC while a larger body is exposed

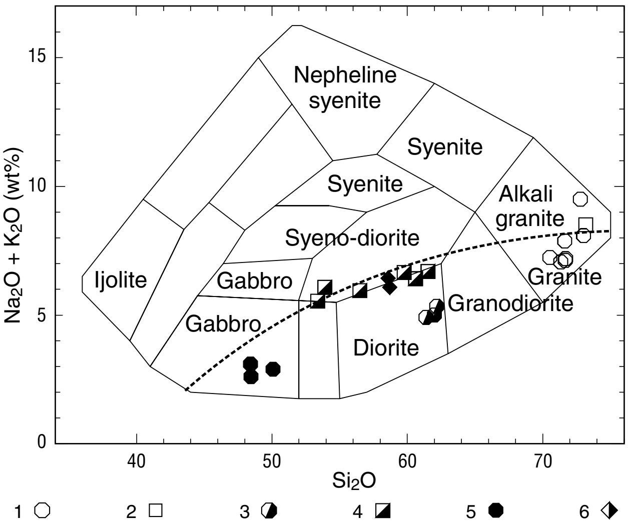

Fig. 6. Chemical classification of plutonic rocks using total alkali versus silica (TAS) diagram of Cox et al. (1989) adapted by Wilson (1989) for plutonic rocks. The curved dashed line subdivides the alkalic from sub-alkalic rocks – granite suite: 1 – PCC, 2 – ZCC; tonalite suite: 3 – PCC, 4 – ZCC; mafic suite: 5 – PCC; 6 – Staré Město tonalites.

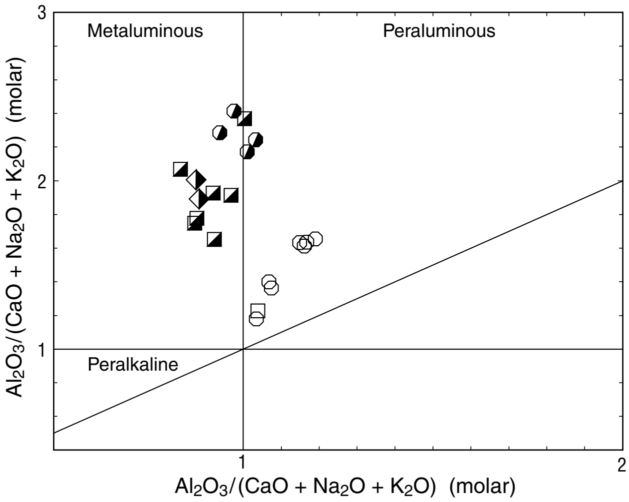

Fig. 7. A/NK – A/CNK diagram (Maniar and Piccoli 1989). Symbols as in Fig. 6.

only in the north, in the area of Proseč and Zderaz. These medium- to fine-grained muscovite-biotite to biotite granites to granodiorites are denoted as the Zderaz granite in the PCC. Their contacts with the ambient rocks are sharp. Xenoliths of the wall rocks are rare. No contact aureole was observed in the host metapelites. Although the granites penetrate rocks of the tonalite suite, a majority of the samples display signs of deformation of different intensity, ranging from undulatory extinction in quartz to dynamic recrystallization of feldspars.

In the ZCC, these rocks are less common and their contacts with tonalites were not found in the field. The dykes are deformed together with the host metamorphic rocks. Deformations in microscopic scale are often manifested by the formation of discrete foliation planes and by recrystallization of quartz and feldspar.

Granites show hypautomorphic, locally even panxenomorphic textures. They are generally fine-grained and contain xenomorphic K-feldspar and quartz. Plagioclase grains are usually hypautomorphic and correspond to oligoclase ($An_{16–22}$). Micas (biotite and muscovite) form up to 12 mod.% of the rock. Biotites in granites (granite suite) have the composition of annite: Mg/(Mg+Fe) 0.48–0.43 and Al^{IV} 2.47–2.65 apfu and Ti contents in the range of 0.36–0.41 apfu. In the classification of Abdel-Rahman (1994), these biotites lie along the line separating calc-alkaline rocks and peraluminous rocks. Garnet, sphene, apatite and zircon are present in accessory amounts.

Dyke rocks

Pegmatites and aplites are commonly present in the PCC, forming dykes several centimetres to several metres thick. Generally, pegmatites are not strongly differentiated. Granitic zone predominates, blocky or graphic zones are represented to a lesser degree. The pegmatites show a relatively simple mineral composition, being composed of K-feldspar, acid plagioclase and quartz. They also contain biotite, locally abundant muscovite, schorl and less frequent spessartine (Fiala 1929). Contacts with the country rocks are sharp. Other dyke rocks are rare. Dykes of minette were described by Fajst et al. (1962) from the area of the Bystré village. Only dykes of simple aplites and pegmatites have been found in the ZCC.

Whole-rock geochemistry

SiO_2 content in plutonic rocks efficiently separates petrographical suites: it is below 50 wt% in the mafic suite, between 54 and 68% in the tonalite suite (with higher variability in the ZCC) and approximately 72% in the granite suite (Tab. 2). Chemical classification of rocks in the SiO_2 vs. total alkali diagram (Cox et al. 1979) is shown in Figure 6. Plutonic rocks are calc-alkaline, with potassium abundance related to the high-K series. The A/CNK ratios range between 1 and 1.15 for the granitic suite and lie below 1 in rocks of the tonalite suite (Fig. 7).

Even though the diagrams of Harker (Fig. 8) show a scattered distribution of major and trace elements when plotted against SiO_2 contents, some linear trends can be traced. Different linear trends distinctly separate rocks of the granitic suite from those of the tonalite one (including two samples of tonalites from the Staré Město Belt) especially in the SiO_2 vs. P_2O_5, Rb, Sr or Ba diagrams. K/Rb ratios fit a narrow range between 200 and 300 in the tonalite suite and between 200 and 500 in the granite suite. These values correspond well with the values for mature continental crust (Taylor and McLennan 1985). Very low Rb/Sr ratio in the basic suite (0.06) documents primitive source of rocks. Rb/Sr ratios are more variable in the

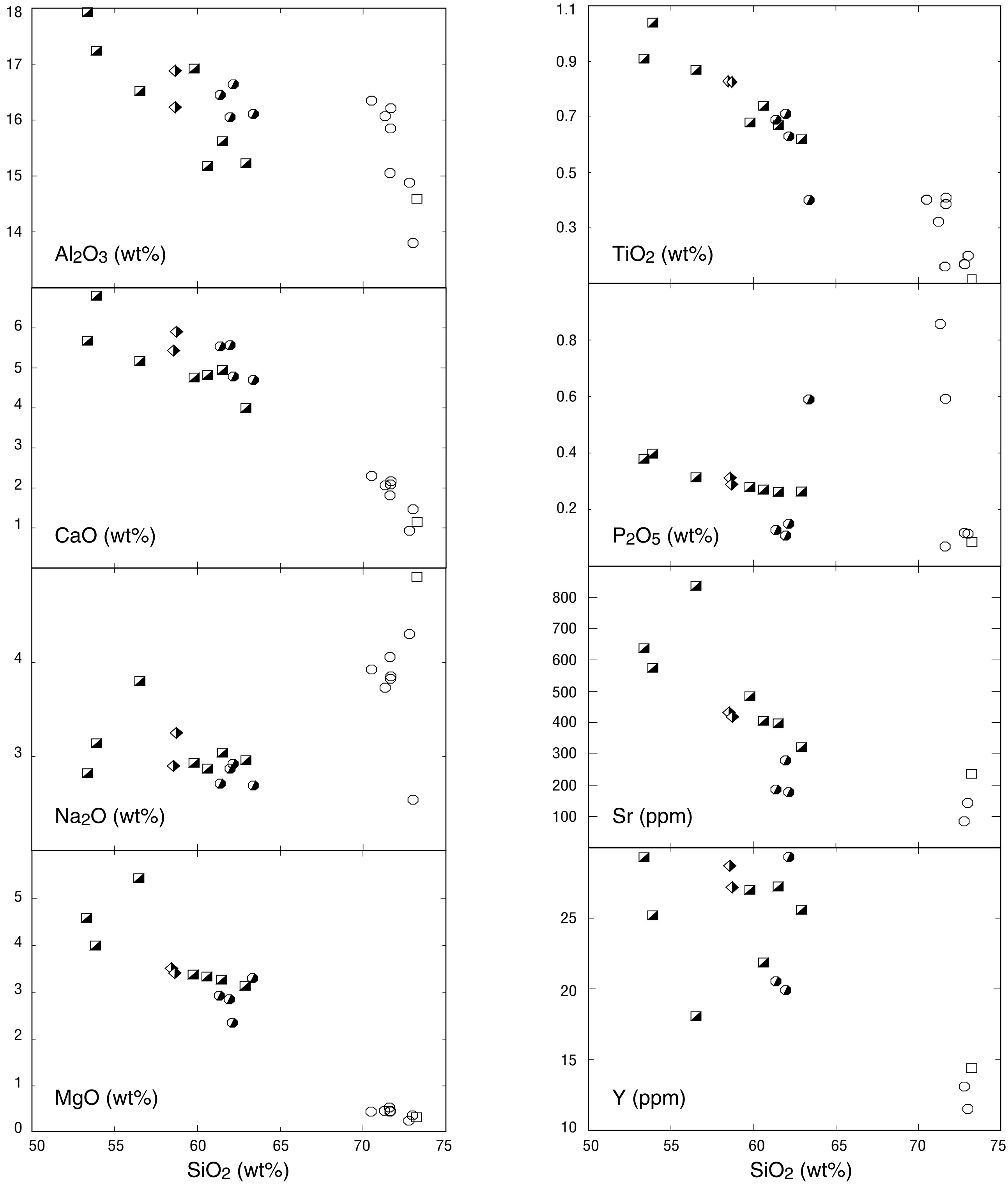

Fig. 8. Variation diagrams of selected major, minor and trace elements for rocks of the tonalite and granite suites; PCC, ZCC and Staré Město tonalites. Symbols as in Fig. 6.

tonalite and granite suites and values higher than 0.1 correspond to a more matured source of rocks.

The REE contents are 75–120 ppm in the PCC granitic rocks and about 200 ppm in the ZCC granitic rocks. There is no Eu anomaly in the rocks of the basic suite. Slight or negligible negative Eu anomaly is characteristic for the rock of the tonalite suite. Only one sample of granite from PCC shows a clear negative Eu anomaly with Eu/Eu* = 0.32. The rocks are only slightly enriched in LREE, and REE patterns are relatively flat (Fig. 9).

Tonalites of the Staré Město Belt correlate very well with the ZCC ones.

Trace element signatures according to Pearce et al. (1984) indicate volcanic-arc character of the tonalite suite, while the granite suite tends towards syn-collisional granites. The tonalite and granite suites are well separated in the R1-R2 diagram (Fig. 10) of Batchelor and Bowden (1985), where tonalites correspond to pre-plate collisional rocks and granites to syn-collisional ones.

Geothermometry and geobarometry

Solidus temperature in rocks of the tonalite and mafic suites was computed by amphibole-plagioclase thermometers (Holland and Blundy 1994), using amphibole and plagioclase rim compositions. Pressure in the tonalite suite was estimated by hornblende barometer (Anderson and Smith 1995). In rocks of the tonalite and granite suites, zircon saturation temperature was used as a thermometer (Watson and Harrison 1983). See the Appendix for used equations.

Polička Crystalline Complex

Basic and ultrabasic rocks of the mafic suite show signs of metamorphic alteration. Based on the mineral association (Atg + Tr + Chl + Ol), the temperature of metamorphism of the PCC ultrabasic rocks was estimated at 535 to 565 °C and pressure at 5 kbar (Buriánek 2001). The temperature obtained from the amphibole-plagioclase thermometer (Holland and Blundy 1994) for amphibole and amphibole-biotite gabbros ranges between 603 and 685 °C.

Amphibole-plagioclase thermometer (Holland and Blundy 1994) and amphibole barometer (Anderson and Smith 1995) were used for the individual rock groups of the tonalite suite (Fig. 11). The obtained data should indicate solidus temperatures of the studied rocks. The values for amphibole-biotite tonalites to granodiorites in the PCC are 659–751 °C and 2.5–6.3 kbar. Pyroxene-bearing amphibole-biotite tonalites indicate values of 655–712 °C and 4.4–5.4 kbar, and garnet-bearing amphibole-biotite quartz gabbros 659–785 °C and 6.1–8.8 kbar (Fig. 11). Different PT conditions can be observed between tonalites in the southern and in the northern part of the crystalline complex. Rocks from the Budislav Massif indicate values of 559–750 °C and 5.2–2.5 kbar, rocks from the small massif near Jedlová 656–785 °C and 6.3–4.4 kbar. The relatively wide ranges of the calculated pressures can probably be explained by the inhomogeneous composition of amphiboles. Frequent subsolidus temperatures obtained using the amphibole–plagioclase thermometer mainly in tonalites from the PCC (Fig. 11) and the occurrence of younger actinolite at the amphibole grain boundaries indicate low-grade metamorphic event after tonalite emplacement in the PCC. Zircon saturation temperatures of 730–766 °C were estimated for rocks of the tonalite suite and 741–765 °C for those of the granite one.

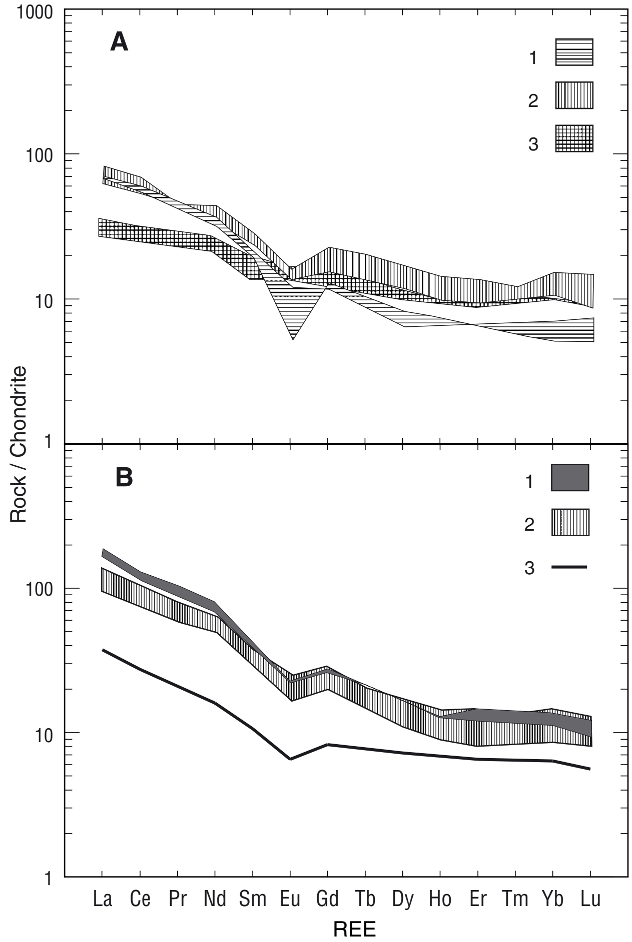

Fig. 9. Chondrite-normalized REE diagram of plutonic rock: A – plutonic rocks of the PCC: 1 – granite suite, 2 – tonalite suite, 3 – mafic suite; B – plutonic rocks in the ZCC and Staré Město Belt: 1 – Staré Město tonalites, 2 – tonalite suite, 3 – granite suite. Normalizing values from Boynton (1984).

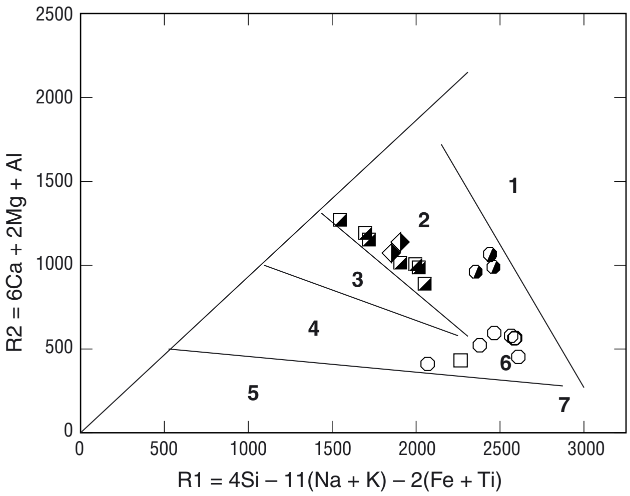

Fig. 10. R1-R2 diagram Batchelor and Bowden, 1985 for discriminating the tectonic setting of granites.
1 – Mantle Fractionates; 2 – Pre-plate Collision; 3 – Post-collision Uplift; 4 – Late-orogenic; 5 – Anorogenic; 6 – Syn-collision; 7 – Post-orogenic; other symbols as in Fig. 6.

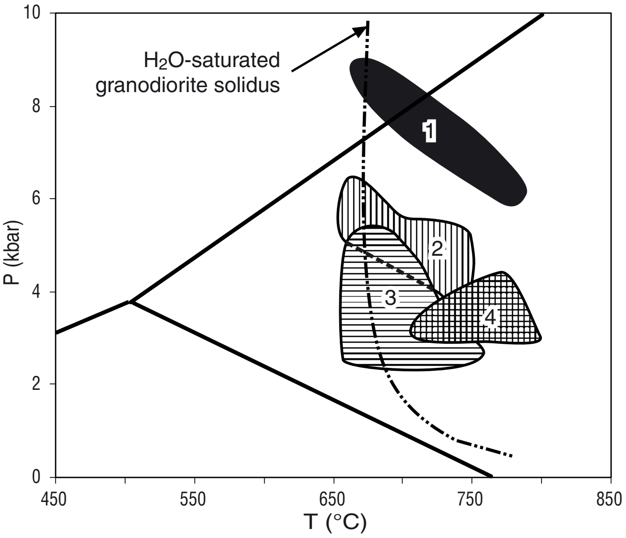

Fig. 11. P-T plot for rocks of the tonalite suite: 1 – amphibole-biotite quartz gabbro, PCC; 2 – tonalites in the southern and central part of the PCC; 3 – tonalites in the northern part of the PCC; 4 – amphibole-biotite tonalites, ZCC. Pressures were estimated using the hornblende barometer (Anderson and Smith, 1995) and temperatures using the plagioclase-hornblende thermometer (Holland and Blundy 1994). The Al_2SiO_5 triple point is from Holdaway and Mukhopadhyay (1993) and melting curve for granodiorite from Piwinskii and Wyllie (1968).

Zábřeh Crystalline Complex

In the ZCC, the examined sample of amphibole diorite forming an enclave in tonalites indicated temperatures of 750 to 790 °C using an amphibole-plagioclase thermometer.

Rocks of the tonalite suite yielded zircon saturation temperatures of 717–770 °C, and a sample from the granite suite yielded a temperature of 673 °C. In amphibole-biotite tonalites, temperatures of 706–795 °C were obtained using the amphibole–plagioclase thermometer, and the pressures obtained using the amphibole barometer are 2.9–4.3 kbar.

Metamorphic conditions of the contact aureole of plutonic rocks

THERMOCALC program (Powell and Holland 1988) was used for the calculation of PT conditions in the metapelites of both crystalline complexes. THERMOCALC program version 2.7 was run in average PT mode using the data set (8 December 1997) and activities from AX program (Holland and Powell 1998).

In the PCC, contact aureole in the proximity of intrusive bodies was only found in its northern part on the E margin of the Miřetín intrusion. Metapelites are exposed here with the following mineral association: Pl + Qtz + Bt + Crd + Grt ± And ± St. The PT conditions for the formation of this mineral association are 559 ± 65 °C and 2.6 ± 1.9 kbar. In the rest of the complex, rocks adjacent to plutonic bodies show the same mineral associations as the regional-metamorphosed gneisses, which indicate values of 566 to 675 °C and 5–7 kbar. Rocks indicating higher PT conditions of 687 ± 31 °C and 8.2 ± 1.4 kbar for the contact metamorphism occur only in the southern part of the crystalline complex, in the area of the small massif near Jedlová.

Plutonic rocks of the ZCC are usually accompanied by a contact aureole with mineral association Grt + Bt + Sil + Crd ± Ms ± Kfs, which indicates conditions of 707–777 °C and 4–6 kbar in gneisses. Regional-metamorphosed metapelites are characterized by mineral association Bt + Sil + Grt + Kfs. These rocks indicate temperatures of 681 ± 121 °C and pressure of 6.8 ± 2.1 kbar.

Conclusions

The Polička and Zábřeh crystalline complexes are units situated in the NE part of the Bohemian Massif, which are composed of a similar metamorphosed volcanosedimentary sequence. Elongated sill-like magmatic bodies of granodiorite-tonalite composition represent characteristic members of the units. They are assumed to be of Variscan age according to radiometric data by Parry et al. (1997) obtained from the same rocks of the Staré Město Belt. A good correlation was found between plutonic complexes of the Polička and Zábřeh crystalline complexes, so they can be interpreted as contrasting differentiated parts of a single magmatic belt. Petrological and geochemical data confirmed a striking similarity between tonalites of the Staré Město Belt and the ZCC. There is no doubt that these rocks evolved from the same magmatic source by similar or nearly the same magmatic processes.

The basic, tonalite and granite plutonic suites were distinguished here on the basis of petrology and geochemistry. The mafic suite is represented by gabbros, metagabbros and by rare, usually serpentinized peridotite bodies. The mafic suite is intruded by rocks of the tonalite and granite groups. Rocks of the mafic suite show a primitive chemical composition. They were subjected to metamorphism under conditions of lower amphibolite facies. These rocks are spatially related to the amphibolite bodies in both the crystalline complexes.

Prevailing tonalites represent the tonalite suite in the PCC while granodiorites prevail in the ZCC. However, rocks of the tonalite suite are metaluminous, mature crust is believed to be the major contaminant material according to trace elements signature. Contamination of the magma by crustal rocks was confirmed by the data obtained from mineral chemistry because pyroxenes correspond to clinopyroxenes produced by the reaction of the tonalite magma with Ca-rich rocks in the roof pendant.

Chemical composition of tonalites of the ZCC and SMB is nearly the same. Slightly different chemistry of the PCC tonalites points to a less evolved part of magmatic complex. Rocks of the tonalite suite in the two crystalline complexes, however, differ in the fO_2 values. The presence of ilmenite in the PCC indicates a higher oxygen fugacity. In contrast, the predominance of sphene in the ZCC indicates lower values of oxygen fugacity (Stein and Dietl 2001).

Submagmatic to solid-state deformation fabric in tonalites is concordant with the adjacent metamorphic country rocks and points to syntectonic or early post-tectonic character of the intrusion. Tonalites were subjected to only weak metamorphism, as indicated by the formation of younger actinolite, so they post-date regional metamorphic peak. Tonalite emplacement in the PCC was documented to have taken place at different depth levels. Amphibole-biotite and pyroxene-bearing amphibole-biotite tonalites indicate pressures of 6 to 3 kbar, with temperatures ranging within 559–785 °C. Values of 659–785 °C and 6.1–8.8 kbar assessed in garnet-bearing amphibole-biotite quartz gabbros correspond with those obtained from the adjacent metapelites. No distinct PT zoning was found in the tonalites of the ZCC. PT conditions during the emplacement of rocks of the tonalite suite were estimated at 706–795 °C and 3–4 kbar, similarly to metapelites in the contact aureole which gave PT conditions of 707–777 °C and 4–6 kbar.

Granite suite is rather weakly represented, granites evolved from a mature source. A different magmatic pulse is the easiest way to explain quite different trends in variation diagrams compared to the spatially related and age-related tonalite suite evolved in the accreted island-arc environment.

Petrological and geochemical data confirmed a similarity between plutonic complexes of the Polička and Zábřeh crystalline units.

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Appendix

The amphibole-plagioclase thermometers (Holland and Blundy 1994) are based on two independent reactions:

A. Edenite-tremolite (4 quartz + edenite = albite + tremolite). This reaction enables the application of thermometer A (Eq. 1) only to quartz-bearing igneous rocks:

$$T[\pm 313K] = \frac{-76.95 + 0.79P[kbar] + 39.4X_{Na}^{A} + 22.4X_{K}^{A} + (41.5 - 2.89P[kbar])X_{Al}^{M2}}{-0.0650 - 0.0083144\ln\left(\frac{27X_{vac}^{A}\ X_{Si}^{T}\ X_{Ab}^{Pl}}{256X_{Na}^{A}\ X_{Al}^{T}}\right)} \quad (1)$$

B. Edenite-richterite (edenite + albite = richterite + anorthite), The calibration thermometer B (Eq. 2) is based on this reaction and is applicable also to quartz-free igneous rocks:

$$T[\pm 313K] = \frac{81.44 - 33.6X_{Na}^{M4} - (66.88 - 2.92[kbar])X_{Al}^{M2} + 78.5X_{Al}^{T} + 9.4X_{Na}^{A}}{0.0721 - 0.0083144\ln\left(\frac{27X_{Na}^{M4}\ X_{Si}^{T}\ X_{An}^{Pl}}{64X_{Ca}^{M4}\ X_{Al}^{T}\ X_{Ab}^{Pl}}\right)} \quad (2)$$

where X is the molar fraction of species (plagioclase) or component (amphibole) in phase (albite and anorthite) or crystallographic site. The basic formula unit of amphibole is $A_{0\text{-}1}M4_2M13_3M2_2T_8O_{22}(OH)_2$. The site preferences are: tetrahedral sites T (Si, Al), M2 (Al, Cr, Fe^{3+}, Ti, Fe^{2+}, Mg), M13 (Fe^{2+}, Mg, Mn,), M4 (Ca, Na, Mn, Fe^{2+}, Mg), and A is the large vacant or partly-filled site (Na, K).

The mineral compositions are restricted to amphiboles which have $Na^{A} > 0.02$ apfu, $Al^{VI} > 1.8$ apfu, and Si in the range of 6.0–7.0 apfu and plagioclases with $X_{an} > 0.1$ and < 0.9. Thermometers are calibrated in the range of 400–1000 °C and 1–15 kbar.

The hornblende barometer of Anderson and Smith (1995) is based on the Al content in amphiboles (Eq. 3). Their application is restricted to amphiboles, which crystallized at high fO_2. The authors recommended to use only amphibole with a Fe/(Mg+Fe) ≤ 0.65. The formula of Anderson and Smith (1995) reads as follows:

$$T[\pm 313K] = \frac{81.44 - 33.6X_{Na}^{M4} - (66.88 - 2.92[kbar])X_{Al}^{M2} + 78.5X_{Al}^{T} + 9.4X_{Na}^{A}}{0.0721 - 0.0083144\ln\left(\frac{27X_{Na}^{M4}\ X_{Si}^{T}\ X_{An}^{Pl}}{64X_{Ca}^{M4}\ X_{Al}^{T}\ X_{Ab}^{Pl}}\right)} \quad (2)$$

Stein and Dietl (2001) concluded that amphibole theromobarometry gives better and more reliable results for amphiboles crystallizing under high fO_2 than those growing under low fO_2.

Zircon saturation temperature (Watson and Harrison 1983) marks the state when zircon started to crystallize from the melt (Eq. 4):

$$\mathrm{InD}_{Zr} = \ln - \left(\frac{\text{wt\% Zr in zircon}}{\text{Zr in the silicate liquid}}\right) = \{-3.8 - [0.85(M - 1)\} + \frac{1290}{T} \quad (4)$$

where T is temperature in Kelvin and M is defined as the cation fraction ratio M = (Na + K + 2Ca)/(Al * Si). This relationship appears to hold for the intervals of 750 to 1500 °C and 2–6 kbar. A basic assumption is that neither phase is cumulate, or restitic in origin.