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THE CORRELATION BETWEEN RADIOACTIVITY AND MINERAL ASSEMBLAGES: AN EXAMPLE FROM ALKALI FELDSPAR SYENITES; GFÖHL UNIT, MOLDANUBIAN ZONE

VZTAH RADIOAKTIVITY A MINERÁLNÍHO SLOŽENÍ HORNINY NA PŘÍKLADU ALKALICKO ŽIVCOVÉHO SYENITU OD NALOUČAN Z GFÖHLSKÉ JEDNOTKY MOLDANUBIKA

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Abstract

The Correlation Between Radioactivity and Mineral Composition: an Example from Alkali Feldspar Syenites; Gföhl Unit, Moldanubian Zone. *Acta Mus. Moraviae, Sci. geol.*, 83:73–84.

The leucocratic facies of the amphibol-bearing alkali feldspar syenites from Naloučany displays an extraordinary high content of radioactive elements – Th (up to 960 ppm) and U (up to 370 ppm). The elevated concentrations of Th (44–98 ppm) and U (10–40 ppm) are a typical feature of the whole body of alkali feldspar syenites. The Th and U concentrations display a direct dependence on the zircon content, and inherent source of radioactivity, inclusions of uranothorite. The unusual mineralogy and possible relations of the alkali feldspar syenites to the ultrapotassic, mafic magmas (HOLUB 1997) are the additional objects of this study.

Key words: Alkali feldspar syenite, petrology, radioactivity, zircon, uranothorite, genetic relations.

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Introduction

Two small – up to 100 m long – bodies of alkali feldspar syenites (AFS) crop out in the Oslava Valley near Naloučany, Northwest of the city Náměšť nad Oslavou (western Moravia). The syenite intrudes into biotite-bearing migmatites and gneisses of the Gföhl unit. Both bodies are separated from the next proximate bigger magmatic body, which is represented by durbachites of the Třebíč pluton (HOLUB 1997), by a several-hundred-meter-thick zone with amphibole-biotite-bearing gneisses and biotite-bearing migmatites.

High radioactivity of the alkali feldspar syenites was at the first time mentioned by WEISS (1974). He reported values between 37 and 55 of Q ppm U ekv and considered zircon and titanite to be the most important radioactive minerals. He drew the attention to the fact that the radioactivity of the Naloučany body is very close to the data obtained on the durbachites from the Třebíč pluton.

Similar high radioactivity of the alkali feldspar syenite (AFS) from Naloučany and Třebíč massifs, close spatial relationship of both bodies and leucocratic character of the Naloučany body support, according to WEISS (1974) and HÁJEK & LUNA (1972), the interpretation of the Naloučany body as being highly differentiated parts of the granitoid rocks of the Třebíč pluton.

HÁJEK & LUNA (1972) described as well a contact between the AFS and surrounding gneisses which was discovered in a test trench. The contact is sometimes narrow, sharp, discordant; sometimes diffuse, followed by apophysis of AFS. Migmatites may occasionally appear on the contact, and the authors interpreted the contact as an intrusion one. Our observation in a partly backfilled trench hit well with their observations and conclusions.

On the other hand, more recently, IVANOV (1984) and CHMELAŘ & CHMELAŘ (1992) described the replacement of plagioclase, quartz, amphibole and biotite by K-feldspar. They suggested the origin of the alkali feldspar syenite by high temperature K-metasomatism. The possible source rock of the alkali feldspar syenite was amphibolite or amphibole-biotite bearing-gneiss (CHMELAŘ & CHMELAŘ 1992).

Petrography of the alkali feldspar syenite

The alkali feldspar syenite is an orange-coloured, medium-grained rock. The mineral composition of the rock (Tab. 1) is (in vol. %) K-feldspar (77–92), amphibole (2–17), quartz (0.1–5), plagioclase (0.1–2.8), chloritised biotite and chlorite (0.1–1.1), zircon (0.3–5), ilmenite (0–1.6), titanite (bellow 0.5) and rare apatite.

Due to high K-feldspar and low quartz and plagioclase contents the rock plots in the APQ classification diagram (LE MAITRE 1989) in the field of alkali feldspar syenite or quartz alkali feldspar syenite (Fig. 1).

Tab. 1. Mineral composition of the alkali feldspar syenite from Naloučany
Minerální složení alkalicko živcových syenitů od Naloučan

Probe Nr.	1	2	3	4	5
Quartz	3.7	1.6	1.5	0.1	5.1
plagioclase	2.8	2.4	2.7	0.1	0.5
K-feldspar	81	92	77	88	86
biotite	0.2	0.5	0.3	0.2	–
amphibole	9.9	2	17	5.7	4.4
chlorite	–	0.6	0.6	–	0.1
zircon	0.4	0.5	0.5	4.9	3
opaque	1.6	0.1	0.1	–	0.1
rest	0.2	0.4	0.4	0.6	0.5
A	93	96	95	100	94
P	3	2.5	3	–	0.5
Q	4	1.5	2	–	5.5

1 – alkali feldspar syenite
2 – alkali feldspar syenite with a layered fabric, K-feldspar matrix
3 – alkali feldspar syenite with amphibole nodules
4, 5 – alkali feldspar syenite, fine grained leucocratic facies
1 – alkalicko živcový syenit
2 – alkalicko živcový syenit s páskovanou texturou, K-živcová matrix
3 – alkalicko živcový syenit s peckami amfibolu
4, 5 – alkalicko živcový syenit, leukokrátní facie

Several textural forms were observed within the body. They are characterised by concentration and distribution of the amphibole crystals. Amphibole is usually regularly dispersed in the rock. Its concentration fluctuates around 10 % (analyses Nr. 1 in Tab. 1). Occasionally amphibole forms small – up to 5 cm in diameter – nodules. The amphibole concentration increases in the nodules up to 17 % (Tab. 1 analysis 3). It forms as well up to one centimetre thick layers, which are followed by several centimetres thick layers of K-feldspar (analysis Nr. 2, Tab. 1). A multiple repeating of these layers forms a layered structure. The alkali feldspar syenite grades into a fine grained and leucocratic facies in the centre of the body. The amphibole concentration decreases in this fine-grained facies to 4.4–5.7 % and K-feldspar concentration increases up to 88 % (Tab. 1, analyses 4, 5). High concentration of zircon – up to 5 % is typical, on the other hand, ilmenite is completely absent in this facies.

All varieties of rock are penetrated by up to 10 cm thick quartz veins. The orientation of the veins is 112/70. Similar values were measured prior by Hájek & Luna (1972). This direction is parallel with an important local tectonic line – Bíteš fault, which runs approximately 150 m W from the syenite body (Weiss 1974). The quartz veins are rapidly tailing out, but they can continue as only a few millimetres thick layers for several meters. In the thin-section, very thin quartz veins grade into quartz-chlorite and chlorite veins. An important amount of quartz (Tab. 1, modal analyses), is caused by these very thin quartz veins. The elevated quartz content in some samples is therefore rather a secondary feature.

Radioactivity of the rocks

The concentrations of U and Th were measured using a portable gamaspectrometer GS – 256 produced by Geofyzika Brno by a method described by Breiter & Gnojek (1996).

The results are summarised, together with measurements of the magnetic susceptibility, in Tab. 2. The most wide-spread variety of the alkali feldspar syenite with regularly dispersed amphibole shows a large scale variation in the uranium concentration – between 10 and 40 ppm, the thorium variation is moderate (44–98 ppm). The variation of uranium concentration controls (1.9–5.2) the variation of the Th/U ratio. Similar values occur in the syenite with the amphibol nodules (8 ppm U, 52 ppm Th; Th/U – 6.4). The lower concentrations of uranium and simultaneously elevated Th/U ratio were in samples with a relatively higher magnetic susceptibility (Tab. 2).

Tab. 2. Th and U concentrations (in ppm) in the alkali feldspar syenites (measured using gammaspectrometer GS – 256) and magnetic suscebtibility (in 10–3 Si)
Koncentrace Th a U (ppm) v alkalicko živcových syenitech (měřeno gammaspektrometrem GS – 256) a magnetická susceptibilita (10 –3 Si)

Probe Nr.	1	2	3	4	5	6	7	8	10
Th	93	62.8	43.7	97.8	52.3	352.2	961.4	328	922
U	40.5	32.9	9.8	18.8	8.1	140.7	369.5	148.5	321
Th/U	2.3	1.9	4.5	5.2	6.5	2.5	2.6	2.2	2.82
k	0.18	0.1	0.20	0.31	0.28	0.07	0.11	0.09	0.17

1–4 – alkali feldspar syenites
5 – alkali feldspar syenite with amphibole nodules
6–10 – alkali feldspar syenite, fine grained leucocratic facies
1–4 – alkalicko živcový syenit
5 – alkalicko živcový syenit s peckami amfibolu
6–10 – alkalicko živcový syenit, leukokrátní facie

The leucocratic facies of the alkali feldspar syenite exhibits a very high concentration of both elements. The U reaches 140–370 ppm, Th 322–961 ppm respectively. The Th/U ratio shows only slight variation (2.2–2.8).

Rock forming minerals

K-feldspar

K-feldspar is a dominant mineral (Fig. 1, Tab. 1). It forms subhedral, up to 1.5 cm large, grains. Very fine inclusions of iron oxide are very likely responsible for its orange colour. The grains are homogeneous, if observed in the transmitted light. The observation using cathodoluminiscence equipment shows a zoned fabric with a bright blue core and rim and dark blue zone in between. Finally we are also able to distinguish a younger generation of K-feldspar which grows over as a very thin, dark blue coloured zone over the older K-feldspar grains. The blue CL in feldspar is related to the content of activators – Ti, Ga or defects – in the crystal structure (MARSCHALL 1988, FINCH & KLEIN 1996). However, we did not find any differences in the major elements between the individual zones and generations using microprobe technique. Distinct differences in the major element content were distinguished between K-feldspars from the syenites with regularly dispersed amphibole and K-feldspars from the leucocratic fine-grade facies. The K-feldspars from the leucocratic facies are enriched with K_2O (14.9–15.1 % vs. 13.7–14.8 %) and depleted of Na_2O (1.1 % vs. 1.3–2.5 %) and BaO (0.45–0.5 % vs. 0.6–0.8 %, Tab. 3).

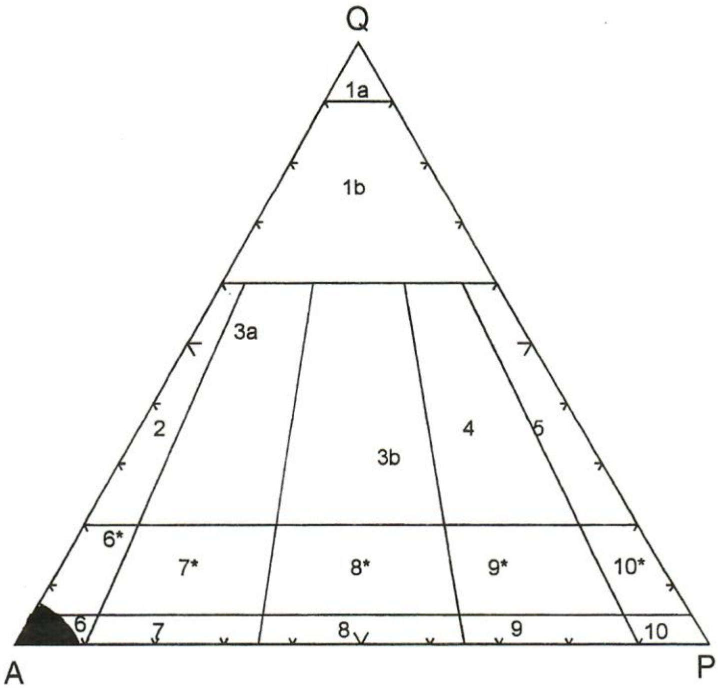

Fig. 1. APQ Diagram, alkali feldspar syenite.
6 – alkali feldspar syenite, 6* – alkali feldspar quartz syenite, 7* – quartz syenite, 3a – monzogranite, 8* – quartz monzonite

Tab. 3. Electron microprobe analyses of K-feldspar (1–4, formula calculated on 8 O) and scapolite
Mikrosondové analýzy draselného živce (1–4) a scapolitu

Probe Nr.	1	2	3	4	5
SiO_2	64.4	64.6	64	65	61.5
Al_2O_3	18.1	18.1	18	18	19.3
FeO	–	–	–	–	0.2
CaO	–	–	–	–	1.1
BaO	0.8	0.6	0.5	0.4	–
Na_2O	2.5	1.3	1.1	1.1	9.1
K_2O	13.7	14.8	14.9	15.1	0.7
Cl	–	–	–	–	0.8
Total	99.5	99.4	98.5	99.6	92.7
Si	2.99	3	3	3.01	–
Al	0.99	0.99	1	0.98	–
Na	0.23	0.12	0.1	0.1	–
K	0.81	0.88	0.89	0.89	–

1–4 – K-feldspar
1, 2 – alkali feldspar syenites; 3, 4 – leucocratic facies
5 – scapolite, alkali-feldspar syenite with amphibol nodules
1–4 draselný živec
1, 2 – alkalicko živcový syenit, 3, 4 – alkalicko živcový syenit, leukokratní facie
5 – skapolit, alkalicko živcový syenit s peckami amfibolu

Amphibole

The green, pleochroic, sub- to euhedral amphibole grains are the most wide-spread minor mineral. The grain size is similar to that of the K-feldspar – up to 1.5 cm. Amphibole is locally replaced along cleavage plains by chlorite. Results of two microprobe analyses are listed in Tab. 4. Calcic amphibole (CaO 11.3 %) rich in iron (FeO tot. 27 %) were found in the core. It is extraordinary rich in Cl (up to 4.3 %). It can be classified as chloro ferro-edenite (LEAKE et al. 1997). Calcic amphibole (CaO 11.1 %) which is depleted of SiO_2 (38.3 %) and enriched with Al_2O_3 (10.3 %), TiO_2 (2.3 %) and K_2O (1.8 %) forms the rim (Tab. 4). The chlorine content is slightly lower (2.5 %) but still extremely high (ZHU et al. 1994). The rim zone could be classified as chlorino-potassio hastingsite (LEAKE et al. 1997).

Plagioclase

Plagioclase was found in the rock only as strongly altered relics. Such relics appear in two different forms. The first one is represented by very small (up to 0.3 mm), elongated inclusions in K-feldspar. The up to 5 mm long, irregular aggregates which occur on the rim of K-feldspar grains represent the second form. Both forms of plagioclase are mostly completely replaced by a mixture of very fine-grained minerals. White mica and albite could be identified optically. A microprobe analysis (Tab. 3) indicates the presence of some other phase; the presence of chlorine, predominance of natrium over calcium and low total indicate scapolite-marialite.

Titanite

Titanite occurs in two forms. It rarely grows over ilmenite grains, or forms independent, commonly idiomorphic grains. Titanite is, similarly to amphibole altered along the cleavage plains by chlorite or the chlorite overgrows titanite grains (Photo 1). Some EMP analyses are listed in Tab. 5. Titanite is homogeneous, the differences in the chemical composition between individual rock types are not significant (Tab. 5). Some titanite grains are in the centre or mostly completely altered (metamictised) (RIBBE 1982). The

Tab. 4. Electron microprobe analyses of amphibole (formula calculated on 23 O), chloritised biotite and chlorite (formula calculated on 11 O)
Mikrosondové analýzy amfibolu, chloritizovanáho biotitu a chloritu

Probe Nr.	1	2	3	4	5	6	7
SiO_2	38.3	41.7	38.4	39.6	35.3	27.1	28.4
TiO_2	2.3	0.65	0.4	–	–	0.2	1.7
Al_2O_3	10	7.33	15.2	14.8	15.6	17.5	17.1
FeO	25.4	27	24.5	23.7	27.3	39.5	36.9
MnO	0.5	0.6	0.2	–	0.2	0.3	0.5
MgO	4	4.5	5	7	7.3	6.9	7.2
CaO	11.1	11.3	0.3	0.7	1	0.1	1.5
Na_2O	1.8	1.6	–	–	–	–	–
K_2O	1.8	0.8	5.1	2	0.8	0.2	0.3
Cl	2.5	4.3	–	–	–	–	–
Total	97.7	99.7	89.1	87.8	87.5	91.8	93.6
Si	6.29	6.8	3.1	3.16	2.9	2.29	2.35
Al^{IV}	1.72	1.2	0.9	0.84	1.1	1.71	1.65
Al^{VI}	0.22	0.2	0.55	0.52	0.4	0.05	0.02
Ti	0.29	0.07	0.02	–	–	0.01	0.1
Mn	0.07	0.08	0.01	–	0.01	0.02	0.04
Mg	0.98	1.1	0.6	0.84	0.89	0.96	0.89
Fe	3.44	3.55	1.66	1.58	1.88	2.83	2.56
Fe	0.05	0.12	–	–	–	–	–
Ca	1.95	1.97	0.03	0.06	0.09	0.02	0.15
Na	0.03	–	–	–	–	–	–
Na	0.56	0.5	–	–	–	–	–
K	0.37	0.17	0.53	0.2	0.08	0.02	0.03
Xmg	0.22	0.23	0.27	0.35	0.32	0.25	0.26

1, 2 – amphibole, 1 – rim, 2 – core, alkali-feldspar syenite with amphibole nodules
3–5 chloritised biotite – alteration product of amphibol, 3 – alkali-feldspar syenite with amphibole nodules
4, 5 – alkali feldspar syenite – leucocratic facies
6, 7 – chlorite from titanite overgrowth, alkali-feldspar syenite with amphibole nodules
1, 2 – amfibol, 1 – okraj, 2 – střed, alkalicko živcový syenit s peckami amfibolu
3–5 chloritizovaný biotit zatlačující amfibol, 3 – alkalicko živcový syenit s peckami amfibolu, 4, 5 – alkalicko živcový syenit, jemnozrnná leukokrátní facie
6, 7 – chlorit obrůstajíci titanit, alkalicko živcový syenit s peckami amfibolu

metamict titanite is depleted of SiO_2 (3 %) and CaO (up to 0.8 %) and strongly enriched with TiO_2 (74–76 %). The phosphor (0.5–0.8 % P_2O_5) and niobium (up to 0.7 Nb_2O_5) were identified in the metamict grains too.

Biotite

Biotite is rare. It forms small, only 1 mm long tabular crystals, or overgrows the amphiboles. Nearly all biotite grains are chloritised.

Chlorite

Three main types of chlorite were found in the syenites.

Chlorite of the first type overgrows the amphibole grains or penetrates them along the cleavage plains. The Fe/Mg ratio is high, similar to amphibole (Tab. 4).

The second type of chlorite overgrows the titanite grains. It is, compared with the previous one, depleted of SiO_2 (27–28 vs. 35–40 %) and enriched with FeO tot. (37–40 vs. 24–27 %).

Tab. 5. Electron microprobe analyses of titanite (formula calculated on 5 O) and metamictised titanite
Mikrosondové analýzy titanitu a metamiktizovaného titanitu

Probe Nr.	1	2	3	4	5	6	7
SiO_2	31.1	30	31.5	30.8	31.1	3	3.3
P_2O_5	–	–	–	–	–	0.5	0.8
Nb_2O_5	–	–	–	–	–	–	0.7
TiO_2	37.7	36.4	37.3	38.4	37.1	75.9	73.9
Al_2O_3	1.7	2	1.9	1.3	2	3.4	4.6
V_2O_3	–	–	–	–	0.4	–	–
CaO	28.8	28.2	28.9	28.7	28.4	0.8	0.7
FeO	0.9	1.3	0.6	0.5	0.9	3.2	1.8
Total	100.2	97.9	100.2	99.7	99.9	86.8	85.8
Si	1.01	1	1.02	1	1.01	–	–
Ti	0.92	0.92	0.91	0.95	0.91	–	–
Al	0.07	0.08	0.07	0.05	0.08	–	–
Ca	1.04	1.01	1	1.01	0.99	–	–
Fe	0.03	0.04	0.02	0.01	0.3	–	–

1–5 – titanite
1 – leucocratic facies, 2–5 alkali-feldspar syenite with amphibole nodules, 2, 3 – rim, 4, 5 – core
6, 7 – metamictised titanite; alkali-feldspar syenite with amphibole nodules
1–5 titanit
1 – alkalicko živcový syenit, leukokratni facie, 2–5 alkalicko živcový syenit s peckami amfibolu, 2, 3 – kraj, 4, 5 – střed
6, 7 metamiktizovaný titanit, alkalicko živcový syenit s peckami amfibolu

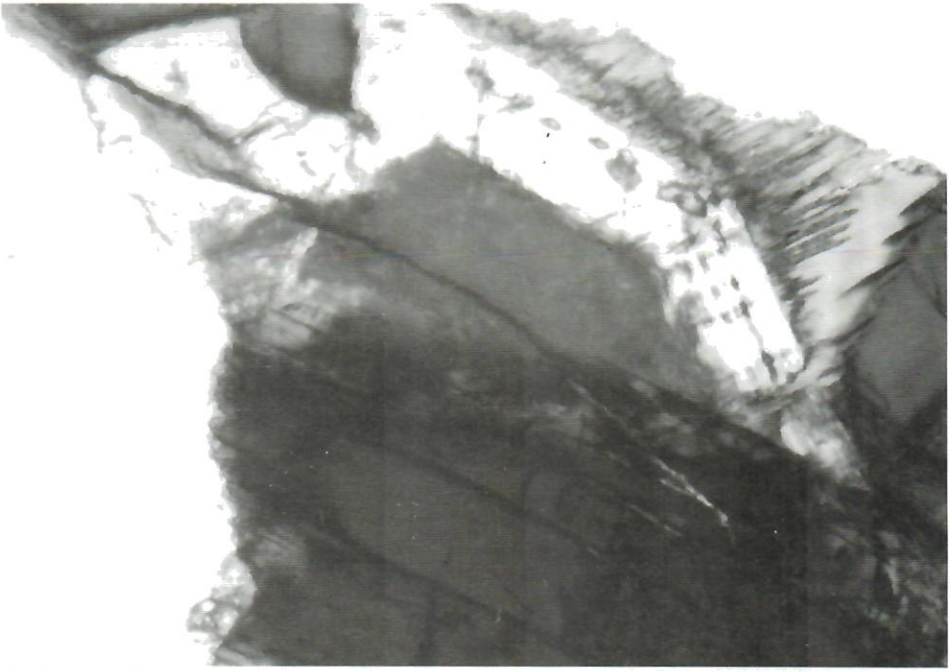

Photo 1. Titanite with a chlorite overgrowth. The dark zone in the center of the crystal is a product of the metamictisation. The black grain right down is an originally dark green amphibole. The length of the photograph is 1.2 cm. Without analyzer.

Foto 1. V centru metamiktizovaný titanit obrůstaný chloritem. V pravém dolním rohu se nachází zelený amfibol. Délka fotografie je 1,2 cm. Bez analyzátoru.

The third type of chlorite forms chlorite veins cutting the rock.

Radioactive minerals

The spectrum of radioactive minerals is, comparing with U – Th mineralisation in durbachites of Třebíč pluton near Tasov (SULOVSKÝ 1995, GOLIÁŠ 1995), relatively modest. Zircon with U and Th contents and uranothorite inclusion in zircon were identified.

Zircon

Distribution of zircon within the individual rock types is considerably unhomogeneous. The most common rock type – syenite with a regularly dispersed amphibole – displays the lowest concentration of zircon – about 0.5 %. The syenite with amphibole nodules contains up to 0.8 %, whereas the central leucocratic facies comprises up to 5 % of zircon. Zircon occurs as inclusions in K-feldspar, amphibole and titanite.

Significant differences were observed in the degree of alteration of zircon from the individual rock types. Zircons from the common syenites are relatively fresh, transparent, the metamictised areas appear only in the core of the crystals (Tab. 6 analyses Nr. 1, 2). Typical zircon contains approximately 1 % of HfO_2. Core is enriched with uranium (up to 0.6 % of UO_2) and submicroscopic inclusions of uranothorite were rarely found in the central zones of the zircon crystal using EMP. They, together with elevated uranium in zircon, are likely responsible for the metamictisation in the core.

Tab. 6. Electron microprobe analyses of zircon (1–8, formula calculated on 4 O) and metamictised zircon (9–12)
Mikrosondové analýzy zirkonu (1–8) a metamiktizovaného zirkonu (9–12)

Probe Nr.	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	33.4	33.7	34.3	33.2	34	33.9	33.1	33.8	20.9	19.2	23.8	25.7
ZrO_2	65.9	66	67.3	65.3	65.4	67.2	65.7	64.9	40	30.5	48.4	57
HfO_2	1	1.2	1.7	1.4	1.4	0.9	1.4	1.3	–	–	–	1.1
UO_2	0.6	–	–	–	0.9	–	–	0.6	2.1	3	0.8	–
ThO_2	–	–	–	–	0.8	–	–	–	16.5	34.6	4.5	0.4
TiO_2	–	–	–	–	–	–	–	–	0.5	0.5	0.2	0.4
Al_2O_3	–	–	–	–	–	–	–	–	1.6	1.8	0.7	1.4
Ce_2O_3	–	–	–	–	–	–	–	–	–	0.8	–	–
FeO	–	–	–	–	–	–	–	–	4	1.7	6	1.7
CaO	–	–	0.2	–	–	–	–	–	1.8	1.6	1.5	2.1
MgO	–	–	–	–	–	–	–	–	–	0.4	–	–
Total	100.9	100.9	103.3	99.9	102.5	102	100.2	100.6	87.4	94.1	85.9	89.8
Si	1.01	1.02	1.01	1.02	1.02	1.01	1.01	1.03	–	–	–	–
Zr	0.98	0.97	0.97	0.97	0.96	0.98	0.98	0.96	–	–	–	–
Hf	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.11	–	–	–	–

Zircon
1, 2 – alkali feldspar syenite; 1 core, 2 – rim,
3 – alkali feldspar syenite with amphibole nodules
4–8 – leucocratic facies; 4, 5 – unalterated rim
Metamictised zircon
9–11 – leucocratic facies, 12 – alkali-feldspar syenite with amphibole nodules
zirkon
1, 2 – alkalicko živcový syenit, 1 – střed, 2 – okraj
3 – alkalicko živcový syenit s peckami amfibolu
4–8 – alkalicko živcový syenit, leukokratni facie, 4, 5 – nealterovaný okraj
metamiktizovaný zirkon
9–11 – leukokratni facie, 12 – alkalicko živcový syenit s peckami amfibolu

Zircon from leucocratic facies has different characteristics. They are, with the exception of the thin zone on its rim, dim and metamictised. Only some small unaltered areas of fresh zircon appear within these dim masses. Zircons from the leucocratic facies do not differ chemically from zircons of the common alkali feldspar syenite. Only rims are locally enriched with Th. (Tab. 6, analyses 5, 6). This type of zircon comprises a high amount of uranothorite inclusion (see next chapter).

Analyses of metamictised zircons are summarised in Tab. 6 (analyses Nr. 9–12). The major differences to compare with fresh zircons are low total (86–96 %), SiO_2 (19–26 %) and ZrO_2 (31–57 %). UO_2 (up to 3 %) and ThO (0.4–35 %) contents are, on the other hand, significantly increased as well as FeO (1.7–6 %), CaO (1.5–2.1 %), Al_2O_3 (0.7–1.8 %) and TiO_2 (0.2–0.5 %). Mg and Ce were found only in the metamictised material. The change of volume during the metamictisation (SPEER 1982a) is the origin of cracks in zircon itself and in the surrounding rock (Photo 2). The cracks are filled by iron oxide and hydroxide. Some "haloes" were observed along such cracks in the K-feldspar if the samples were observed using CL equipment. These "haloes" = very thin violet zones parallel to the crack in the blue K-feldspar, indicate possible circulation of radioactive fluids in the cracks.

Uranothorite

Uranothorite was found as inclusions in zircon particularly in the leucocratic facies. As a consequence of strong metamictisation of the host zircon, the uranothorite inclusion could be mostly identified only using microprobe. The intergrowth with zircon was observed only exceptionally.

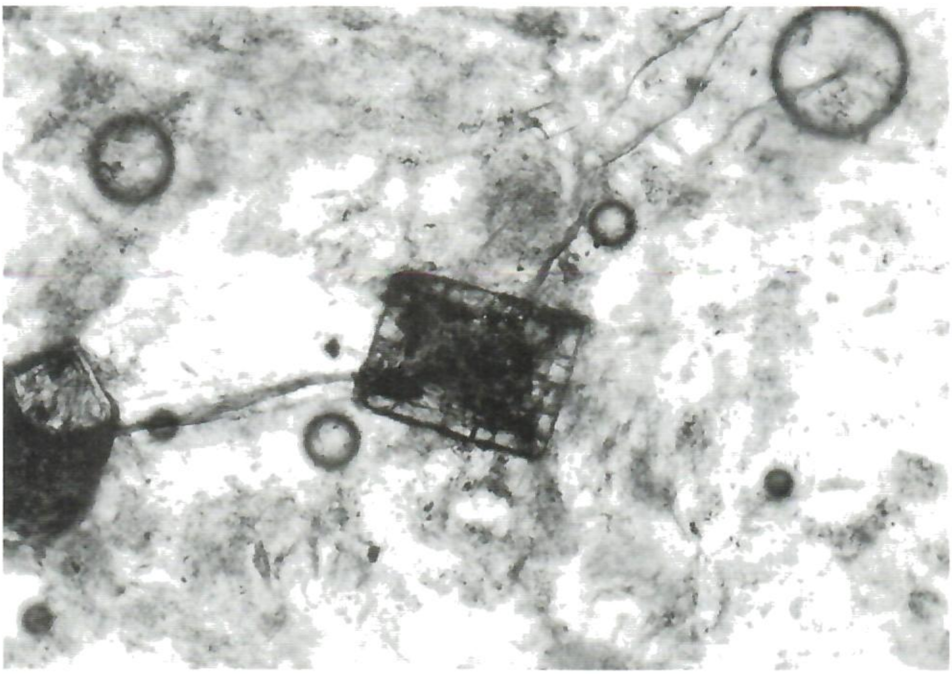

Photo 2. Strongly metamictised zircon with an unaltered rim. The cracks around the crystal, in the host K-feldspar, originated as a consequence of the change of volume during metamictisation. The length of the photograph is 1.2 cm. Without analyzer.

Foto 2. Silně metamiktizovaný zircon s nealterovaným okrajem. Trhliny vznikají v důsledku objemových změn v průběhu metamiktizace. Délka fotografie je 1,2 cm. Bez analyzátoru.

Fresh uranothorite is rare. Two analyses of unaltered uranothorite are given in the Tab. 7 (analyses Nr. 1, 2). Th (45–46 % ThO) prevails over U (33–34 % UO_2). Significant amounts of Pb (PbO 2 %) and Zr (ZrO_2 1 %) were detected.

The metamictised uranothorite displays a broad variation in ThO (38–63 %) and SiO_2 (13–19 %, Tab 7, analyses Nr. 3–7). The elevated concentration of Fe (up to 8.7 % FeO) and H_2O (6–20 %) are typical for metamictised uranothorites (SPEER 1982b). The different concentrations of UO_2 allow to distinguish two different types. The first one displays a relatively high, but still lower when compared with fresh samples, concentration of U (19–26 % UO_2) and simultaneously lower concentration of Zr (5–6 % ZrO_2). The second type does not contain U, but the Zr concentration is higher (13–18 % ZrO_2).

Discussion and conclusions

The Th concentration reaches 44–98 ppm in the coarse-grained syenite, the uranium concentration is even lower (10–40 ppm). The Th and U concentrations increase in the leucocratic, fine-grained syenite up to 961 ppm Th and 370 ppm U. U and Th are bind predominantly in zircon as inclusions of uranothorite and its metamictised products. The zircon concentration increases up to 10 times; from 0.5 % in the common, coarse-grained syenite to 5 % in the leucocratic syenite. The Th concentration increases in the same scale (from 44–98 to 322–961 ppm). The uranium copies more or less this dependence (10–40 – common syenite vs. 140–370 ppm – leucocratic syenite). The radioactivity displays a direct dependence on the concentration of zircon.

Tab. 7. Electron microprobe analyses of uranothorite (1, 2, formula calculated on 4 O) and metamictised uranothorite (3–7)
Mikrosondové analýzy uranothoritu (1, 2) a metamiktizovaného uranothoritu (3–7)

Probe Nr.	1	2	3	4	5	6	7
SiO_2	18.6	18.6	13.2	19	18.7	13.8	14.7
ThO_2	45.7	44.6	47	37.6	40.6	63.6	38.2
UO_2	32.9	34.1	–	19.4	25.6	–	–
ZrO_2	1	1	17.5	4.7	5.9	12.7	13.9
TiO_2	–	–	–	–	–	0.5	0.3
Al_2O_3	–	–	0.7	0.6	–	0.7	1.7
PbO	2	1.8	–	–	1.8	–	–
CaO	–	–	2	2.3	–	1.5	1.2
FeO	–	0.3	0.9	–	–	1.3	8.7
Na_2O	–	–	–	–	1.3	–	–
Total	100.2	100.4	81.3	83.6	93.9	94.1	78.7
Si	1	1	–	–	–	–	–
Th	0.56	0.55	–	–	–	–	–
U	0.4	0.41	–	–	–	–	–
Zr	0.03	0.03	–	–	–	–	–
Pb	0.03	0.03	–	–	–	–	–

1, 2 – uranothorite, leucocratic facies
3–7 – metamictised uranothorite
3 – alkali-feldspar syenite with amphibol nodules
4–7 – leucocratic facies
1, 2 – uranothorit, leukokratni facie
3–7 – metamiktizovaný uranothorit
3 – alkalicko živcový syenit s peckami amfibolu
4–7 – alkalicko živcový syenit, leukokratni facie

The Th/U ratio in the rock shows a large scale variation between 1.9–6.4. This variation is caused mostly by a fluctuation in U concentration. The U concentration in uranothorite (33–34 % UO_2 fresh – 19–26 % UO_2 metam.), as well as the Th/U ratio (1.3–1.4 to 1.6–1.9) decrease slightly during the metamictisation, indicating some U migration. Some metamictised uranothorite grains are even free of uranium. The cracks in the zircon crystals facilitate such migration. The observed haloes in K-feldspars possibly mark the migrations ways. The migration of uranium could explain the variation in U concentration estimated by gammaspectrometic measurements as well.

The origin of the alkali feldspar syenites from Naloučany remains unclear. However some new observations might contribute to the discussion about its origin. The metasomatic origin (CHMELAŘ & CHMELAŘ 1992) of the rock seems to be improbable, because we verify intrusion contacts of AFS. On the other hand, some observed features like plagioclase and amphibole replacement, strong hematitisation of K-feldspars, chlorite veins etc. suggest that the mineral assemblages composition of the rock might be partly a product of late stage fluid alteration. The interpretation of the rock as a differentiation product of durbachites from Třebíč pluton (WEISS 1974) bring some difficulties as well. The acid members of the durbachite series – biotite bearing granites – differ significantly in their mineralogy and chemistry (cf. HOLUB 1997, WEISS 1974) from the alkali feldspar syenites. The biotite-bearing granites from the Třebíč pluton are in addition a product of magma mixing with an ultrapotassic mafic magma with a melt of leucogranitic composition, and not product of a magmatic differentiation (HOLUB 1997). The ultrapotassic and leucocratic character of the rock may suggest some relations of AFS to the ultrapotassic mafic magmas which play a major role in the origin of the durbachites series of the Třebíč pluton. The observed layered structure indicates a possible role of crystal cumulation in the processes which form the alkali feldspar syenites from Naloučany.

SOUHRN

Dvě drobná tělesa alkalicko živcových syenitů intrudující do biotitických rul a migmatitů vykazují vysokou koncentraci radioaktivních prvků – thoria (44–98 ppm) a uranu (10–40 ppm). V centrální, jemnozrnné a leukokrátní části tělesa byly gamaspektrometricky zjištěny až desetinásobné koncentrace Th – 960 ppm, a U – 370 ppm. Jediným zjištěným radioaktivním minerálem je zirkon obsahující četné uzavřeniny uranothoritu. Koncentrace zirkonu, která se v hornině pohybuje okolo 0,5 % vzrůstá v centrální leukokrátní části rovněž desetkrát – až na 5 %. Koncentrace Th a U v hornině je tedy prakticky přímo úměrná koncentraci zirkonu.

Podrobná charakteristika jednotlivých minerálů a stručná diskuse geneze horniny a jejího vztahu k třebíčskému masívu tvoří další součást článku.

REFERENCES

BREITER, K., GNOJEK, I., 1996: Radioactivity of the highly fractioned Homolka granite in the Moldanubian pluton, southern Bohemia. Věst. Ústř. úst. Geol. 71, 2, 173–176. Praha.

CHMELAŘ, J., CHMELAŘ, J., 1992: Závěrečná zpráva o ukončení vyhledávacího průzkumu úseku Naloučany, ložiska Jasenice. MS GEAM Dolní Rožínka.

FINCH, A., KLEIN, J., 1996: EPR and the cathodoluminiscence of alkali feldspars. International conference on cathodoluminiscence and related techniques in geosciences and geomaterials. 45–46. Nancy.

GOLIÁŠ, V., 1995: Radioaktivní akcesorické minerály třebíčského masívu. Bull. Min.-petr. Odd. NM. v Praze, 3, 1995, 56–61. Praha.

HÁJEK, J., LUNA, J., 1972: Alkalický syenit od Naloučan na Náměšťsku. Vlast. Sbor. Vysočiny. VII, 27–33. Jihlava.

HOLUB, F. V., 1997: Ultrapotassic plutonic rocks of the durbachite series in the Bohemian Massif: Petrology, geochemistry and petrogenetic interpretation. Sbor. geol. Věd. ř. ložisk. Geol. Mineral., 31, 5–26. Praha.

IVANOV, P. A., 1984: Otčot o proveděnych naučno-issledovatělskich rabotach za period s ijuna po sentjabr 1984. MS GEAM Dolní Rožínka.

LEAKE, E. B., 1997: Nomenclature of amphiboles. Report of the subcommittee on amphiboles of the International Mineralogical Association Commission on new minerals and mineral names. Eur. J. Mineral. 9, 623–651.

LE MAITRE, R. W. (ed.), 1989: A Classification of Igneous Rocks and Glossary of Terms. – Blackwell Scientific Publications. Oxford, London, Edinburgh, Boston, Melbourne.

MARSCHALL, D. J., 1988: Cathodoluminiscence of geological materials. Unwin Hyman Ltd. London. 146 p.

RIBBE, P. H., 1982: Titanite. In Ribbe eds. Orthosilicates. Reviews in Mineralogy 5. 137–150. Washington.

SPEER, J. A., 1982a: Zircon. In Ribbe eds. Orthosilicates. Reviews in Mineralogy 5. 67–112. Washington.

SPEER, J. A., 1982b: The actinide orthosilicates. In Ribbe eds. Orthosilicates. Reviews in Mineralogy 5. 113–133. Washington.

SULOVSKÝ, P., 1995: Charakteristika vzorků Budišov A a Budišov B. MS GEAM Dolní Rožínka.

WEISS, J., 1974: Amfibolické aplosyenity severně od Naloučan a jejich vztah k durbachitům třebíčského masívu. Věst. Ústř. Úst. Geol. 49, 227–230. Praha.

ZHU, C., XU, H., ILTON, E. S., VEBLEN, D. R., HENRY, D. J., TIVEY, M. K., THOMPSON, G., 1994: TEM – AEM observations of Cl-rich amphibole and biotite and possible petrologic implications. American Mineralogist. 79, 909–920.