Acta Mineralogica-Petrographica, Szeged, XL, 139–156, 1999

NATURAL RADIOACTIVE ELEMENT CONTENT OF OLD GRANITOID ROCKS IN THE GREAT HUNGARIAN PLAIN

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ABSTRACT

Mean concentrations of radioactive elements of granitoid areas were determined for lithostratic and geodynamic units on the basis of analyses of natural radioactive element content of borehole samples from old granitoid rocks of crystalline basement of the Great Hungarian Plain.

Granitoids of the basement of the Great Hungarian Plain can be characterised by high U and Th content. Uranium content exceeds mean value for granites in the Earth for almost every granitoid formation of the Great Hungarian Plain; in some places it is three times higher.

Radiological conditions of the given area comparing with that of Hungary as well as local features, accumulations, and leaching are discussed in summaries found at the end of subdivisions.

Accumulation factor for radioactive elements of Codru Terrain is given for units (complex by complex), while that of Kunság Terrain has been determined for subunits, too.

INTRODUCTION

Radiometric analysis of more than 150 granitoid rock samples from the crystalline basement of the Great Hungarian Plain was performed in the Department of Mineralogy, Geochemistry and Petrology, Attila József University, Szeged.

NP-424 P four-channel amplitude analyzer, ND-424 L detector, 7S117068 scintillator, NZ-490 lead castle and NY-424 Marinelli vessels were used for radiological analysis of the samples. The following data were detected by radioactive isotopic measurements:

- energy resolution by NaJ (Tl) scintillator referring to Cs137 661 keV gamma line: 8,4 %,
- base line scale energy linearity in the energy range of 0,02-1,5 MeV: 1,5 %,
- error at 2,7 MeV: 5 %,
- stability: a. peak position change referring to Cs137661 keV gamma line: ± 5 keV;
  b. impulse number change in peak position: according to statistics.

This laboratory apparatus provides simultaneous determination of four radiological parameters: specific activity, Th, U (Ra) (accepting an equilibrium for these two elements is practically correct, and deviation should be studied by more sensitive and reliable methods) and K concentrations.

Sample vessel filled by inert material (quartz sand) was used for determination of background values.

Detailed description of laboratory methods can be found in a text-book by SZEDERKÉNYI, PÁL MOLNÁR and VADOS (1994).

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Control measurements were performed in the Radiometric Laboratory of Mecsekérc Környezetvédelmi Rt. (Mecsek Ore Environmental Protection Company) (table 1). A multichannel spectrometric system (PCA - 3 Oxford analyzer and GR 2519 CANBERA Hp Ge detector) was used for rock-sample analysis. The obtained spectra were qualitatively and quantitatively evaluated by Gamma Trac Oxford Program.

Effective screening and relative high efficiency (25 %) of the measuring gauge as well as the long measuring time (20-25 thousands sec.) made reliable determination of the low radioactive element content possible, too. The gamma-spectrometry system was calibrated by international standards.

The difference between control samples and our measures was less than 10 % in every case.

Geographic position and petrographic characterisation of the units are also given, though, study on much more sample would need to prove a relationship between petrographic and radiological features.

RADIOLOGICAL CONDITIONS OF GRANITOID FORMATIONS IN CODRU TERRAIN (S-HUNGARIAN NAPPE BELT)

According to the widely accepted theory, continuation of Codru nappe system of the Romanian Apuseni Mountains can be found in the area of the Codru Terrain in the basement of Southern Great Hungarian Plain; regarding the Mesozoic formations, it corresponds to the Békés Zone.

It is supposed that it was formed before the Upper Cretaceous, during the Austrian-Pre Gosau Orogenic Phase. Bigger part of its area is in Vajdaság (Voivodina, Serbia) and in the northern part of Bánát. It is bordered by the Maros Ophiolite Zone in the south, and a half circle major tectonic line extending through Kelebia, Nagyszénás and Sarkadkeresztur villages in the north. On the basis of geodynamical studies and Pre Alpinic formations, further units (sub-terrains?) can be divided (SZEDERKÉNYI, 1998): Kelebia Complex (Unit), Tisza Complex (Unit), Battonya Complex (Unit), Sarkadkeresztúr Complex (Unit).

The eroded crystalline mass of Codru Terrain is characterised by three granitoid ranges divided by young tectonic movements, and by limbs of meso- and katametamorphic rocks joining with granitoid ranges:

1. The Mezőhegyes-Battonya range has a well-developed granite core; its northern limb is formed by crystalline schists of the Pusztaföldvár area, the southern one is in Romania.
2. Only the northern limb of the granitoid range having an axis zone of Deszk-Ferencszállás-Makó is in Hungary (Madaras-Kelebia-Ásotthalom-Üllés-Algyő area). Some narrow epimetamorphic zones of ENE-WSW strike with wide friction breccia belts are wedged into it at Algyő.
3. The Sarkadkeresztúr migmatite range can be found only in a length of 25 km in Hungary, its other part joints with the Codru Mountains in the east.

Battonya Complex (Battonya Unit)

Granite occurs in 48-50 % in drilling cores of metamorphic rocks from the Battonya Unit. This granite is dominantly light red, sometime grey, and porphyroblastic. Migmatite of the marginal zone represents further 15-20 %. In addition, this marginal zone is formed by kata- and mesometamorphic gneiss and mica-schist alternating each other, aplite and pegmatite veins, and some amphibolite intercalation in some places. This complex is broken through by Lower Permian rhyolite conduits.

Since the nomenclature of metamorphic rocks of the units is quite varied depending on the authors, our classification is based on our own macro- and microscopic observations.

Radiometric analyses of fresh granitoid samples from boreholes in the Battonya Unit are listed in tables 2 and 3.

The following conclusions can be drawn from U, Th, K analyses of granitoid samples from the Mezőhegyes-Battonya granite range of Codru Terrain:

a. Mean U-Th-K content of granitoids of the Battonya Unit in the cases of fresh and weathered rocks:

Rock	Specific activity (Bq/kg)	U (ppm)	Ra (ppm)	Th (ppm)	K (%)
Fresh rock	192	8.8	8.1	13.3	2.7
Weathered rock	159	5.5	4.7	11	2.8

b. Ratio of U and Th content of fresh and weathered granitoids is 8,8:5,5 (1,6) and 13,3:11 (~1,2), respectively.

In the cases of drill cores, considerable conclusions concerning leaching can not be drawn. Metasomatised or hidrothermally altered samples that possibly did not come from surficial weathering crust of the granite bodies were also regarded as weathered rock-type. It is quite frequent that U-Th concentration exceeds values characteristic for the given area. Moreover, local accumulations may occur both in fresh and weathered sections even within one drilling.

c. Comparing the Battonya granitoid samples with the well-known and radiometrically thoroughly analysed granitoids of Southern Transdanubia, it can be stated that

- Mean U content of the granitoid of the Battonya Unit is approximately similar to that of surficial granitoid of Southern Transdanubia, however, the latter has 2,5-3 times higher Th content.

d. Uranium content of granitoids of the Battonya granite area is about twice higher than the world average U content of granites. However, their Th concentration is lower than the world average.

e. Pegmatoid samples from this area are characterised by higher U content than the mean value for the area. This was the only case where provable relation could be found between the radiometric features and the petrographic characters (texture, grain-size, mylonitization, etc.) of the samples.

f. Mean U and Th concentrations of the samples from the western (Mezőhegyes) part of the Battonya granite range are 15 and 20,7 g/t, respectively.

Mean U and Th content of the samples coming from the Battonya-Dombegyháza area decreases (U: 9 g/t; Th: 14,5 g/t). Uranium content ratio of granitoid samples from the western and the eastern part of the Battonya Unit is ~1,6 for the western part; in the cases of Th contents, this ratio is ~1,42 for the western part.

TABLE 1

*Analytical data of the control samples**

Samples	Specific activity Bq/kg	U (g/t)	Ra (U_{equ})	Th (g/t)	K (%)
ÁGK 1663	260 ± 3,5%	14 ± 5%	14 ± 3%	6 ± 5%	4,6 ± 5%
ÁGK 1315	150 ± 4,5%	8 ± 4%	7 ± 1,5%	12 ± 2%	2,3 ± 3%
ÁGK 1447	100 ± 5,0%	6 ± 4%	5 ± 2%	6 ± 2%	0,8 ± 4%
ÁGK 1609	330 ± 2,0%	17 ± 2%	15 ± 1,1%	23 ± 2%	3,1 ± 2,5%
ÁGK 2134	105 ± 6,0%	3 ± 6%	3 ± 3%	10 ± 2%	2,2 ± 3%
ÁGK 1461	450 ± 2%	28 ± 3%	27 ± 1,2%	14 ± 3%	3,4 ± 4%
ÁGK 1657	195 ± 3%	7 ± 4%	6 ± 2%	9 ± 2%	4,1 ± 3%
ÁGK 1508	520 ± 2,5%	29 ± 3%	28 ± 1,2%	25 ± 2%	3,9 ± 4%
ÁGK 1659	1490 ± 2%	120 ± 2%	115 ± 2%	5 ± 15%	3,4 ± 5%
ÁGK 965	240 ± 3%	12 ± 3%	12 ± 1,3%	13 ± 2%	4,3 ± 3%

**Notes* - *specific activity in Ra-226 equivalent*
- *the relative calculating statistical error given in % means a reliability level of 95 %.*

TABLE 2

Radiometric analyses of fresh granitoid samples from the boreholes in the Battonya Unit

Borehole	Rock type	Depth (m)	Specific activity (Bq/kg)	U (g/t)	Ra (U_{equi})	Th (g/t)	K (%)
Mezőhegyes-1	microcline granite	1148-1150m	305	16	15	20	3.2
Mezőhegyes-1	"	1167-1168m	280	13	13	21	3.0
Mezőhegyes-2	"	1187-1188m	360	18	17	26	2.9
Mezőhegyes-3	"	1163-1166m	385	21	19	28	3.4
Mezőhegyes-5	granodiorite	1203-1204,3m	410	24	23	31	2.9
Mezőhegyes-6	microcline granite	1214-1216m	250	11	11	16	3.1
Mezőhegyes-12	"	1194,5-1195,5m	390	22	21	28	3.7
Mezőhegyes-16	microgranite	1183m	195	8	7	10	3.8
Mezőhegyes-16	"	1193-1195m	170	7	6	15	3.1
Mezőhegyes-17	"	1214-1217m	365	20	19	30	2.7
Mezőhegyes-18	"	1220-1220.8m	330	17	15	23	3.1
Mezőhegyes-19	granite	1200-1201m	185	8	6	10	4.1
Mezőhegyes-20	"	1184-1186m	210	10	10	12	3.6
Dombegyháza-	microcline granite	1436-1440m	140	8	7	11	2.4

Borehole	Rock type	Depth (m)	Specific activity (Bq/kg)	U (g/t)	Ra ($U_{equi.}$)	Th (g/t)	K (%)
DNy-1 Dombegyháza-	migmatite	1465-1469m	190	9	8	13	3.4
DNy-1 Dombegyháza-	microcline granite	1313-1315m	120	4	3	11	2.4
D-1 Dombegyháza-	biotitic migmatite	1350-1352m	150	8	7	12	2.3
DNy-2 Battonya-1	microcline granite	1051-1055m	285	12	12	16	4.1
Battonya-1	"	1067-1067,5m	210	12	11	19	4.0
Battonya-3	granodiorite	1087m	260	10	10	23	3.3
Battonya-5	microcline granite	1033-1036m	225	11	10	14	4.2
Battonya-5	"	1050-1050,5m	170	8	7	13	2.2
Battonya-6	granite	1043m	230	7	6	18	4.6
Battonya-10	granite	1072-1073m	130	7	7	13	2.3
Battonya-13	microcline granite	1042-1047m	185	8	7	15	3.8
Battonya-13	"	1047-1052m	155	6	6	14	3,6
Battonya-14	"	1044-1045,5m	205	9	8	14	4,2
Battonya-15	"	1075-1077m	170	8	8	13	4.0
Battonya-17	"	1031-1036m	155	4	4	15	3.9
Battonya-28	"	1077-1078m	295	12	11	16	4.2
Battonya-36	granodiorite	1024-1026m	240	9	8	19	3.4
Battonya-36	"	1032-1033m	215	8	7	20	3.2
Battonya-37	pegmatitic granite	1043-1045m	445	22	21	23	3.1
Battonya-37	migmatite	1056-1058m	280	13	12	13	4.1
Battonya-41	microcline granite	1073-1075m	190	7	7	9	3,7
Battonya-45	migmatite	1081-1084m	305	14	13	19	3.5
Battonya-47	microcline granite	1108-1109m	205	9	8	8	3.7
Battonya-48	microcline-porphyroblastic granite	1174-1176m	170	7	7	11	2.8
Battonya-64	microcline granite	1024-1025,5m	215	10	8	11	3.6

Borehole	Rock type	Depth (m)	Specific activity (Bq/kg)	U (g/t)	Ra ($U_{equi.}$)	Th (g/t)	K (%)
Battonya-64	microcline granite	1031-1032,5m	245	8	7	14	3.3
Battonya-K-14	biotite granite	1075-1077m	180	7	6	13	2.6
Battonya-K-15	"	1080-1083m-	215	9	8	14	3.1
Battonya-K-16	"	1072-1077m	170	6	6	12	2.6

TABLE 3

Radiometric analyses of weathered granitoid samples from the boreholes in the Battonya Unit

Borehole	Rock type	Depth	Specific activity (Bq/kg)	U (g/t)	Ra (U_{equi})	Th (g/t)	K (%)
Mezőhegyes-7	microcline gran. (weathered)	1198-1199.5m	135	4	3	8	1.5
Mezőhegyes-9	granodiorite (weathered)	1187-1188m	165	7	6	11	2.6
Mezőhegyes-11	pegmatitic microcline gran. (weathered)	1262-1265m	195	7	7	16	2.3
Mezőhegyes-13	microcline gran. (weathered)	1184-1190m	120	4	3	11	2.4
Mezőhegyes-14	muscovite gran. (berezitic)	1191-1195m	145	5	4	10	3.0
Mezőhegyes-14	„	1205-1207m	180	6	5	13	3.3
Mezőhegyes-15	„	1194-1198m	105	3	3	10	2.3
Kunágota-1	biotite granite (kaolinic)	1797-1804m	195	7	6	10	4.2
Kunágota-2	granite (weathered)	1908-1911m	145	5	4	11	3.8
Battonya-49	microcline gran. (weathered)	1046-1049m	120	3	3	8	2.9
Battonya-63	muscovite gran. (berezitic)	1029-1034m	210	6	5	14	4.1
Battonya-75	microcline gran. (weathered)	1065-1071m	110	3	2	6	2.4
Battonya-K-6	microcline gran. (weathered)	1019-1020m	205	7	6	16	3.6
Battonya-K-9	microcline gran. (weathered)	1058-1060m	100	3	2	6	2.1
Battonya-K-13	granite	1069-1071m	190	8	8	13	4.0
Battonya-K-17	muscovite granite	1059-1061m	215	10	9	8	3.4
Battonya-K-18	" (weathered)	1079-1082m	115	4	3	7	3.2

Borehole	Rock type	Depth	Specific activity (Bq/kg)	U (g/t)	Ra (U_{equ})	Th (g/t)	K (%)
Battonya-K-19	granite (kaolinic)	1052-1054m	165	7	7	12	3.0
Végegyháza-K-1	granite (kaolinic)	1287-1290m	215	6	5	19	2.7

Tisza Complex (Tisza Unit)

The Tisza Unit is a rock mass of epi-, meso- and katametamorphic rocks, mainly alternating gneiss–mica-schists with intercalations of some amphibolite and leptinolite (mesometamorphic acidic tuff), marble and dolomitic marble of greater quantity as well as frequent Upper Cretaceous banatite intrusions (Ferencszállás Formation). Migmatite zones and smaller granitic bodies (4x1 km) are known in the Deszk-Ferencszállás-Makó axis zone of the complex. They are formed by pink or light grey porphyroblastic granite (GYALOG, 1996).

These granite bodies are associated with aplite and pegmatite veins. Only the NW limb of the granitoid range can be found in Hungary (Madaras-Kelebia-Ásotthalom-Üllés-Algyő), its southern limb is in Yugoslavia (HAAS, 1996). In the Algyő area belonging to the northern limb some epimetamorphic bands of NE-WSW strike together with wide friction breccia zones are intercalated (Haas, 1996).

Granitoids are subordinated in the Algyő area, they occur in gneiss as 5-30 cm wide veins of aplite and microgranite (SZEDERKÉNYI, 1991).

Granite (dominantly light grey or pink porphyroblastic granite, subordinately micro- and medium-grained granite), occurs only in about 10-12 % of the cores from the Tisza Complex (Unit). Migmatite, aplite and pegmatite veins represent further 5-6 % (BALÁZS et al., 1984).

Radiometric analyses of granitoid samples from boreholes in the Tisza Unit are listed in table 4.

The following conclusions can be drawn from U-Th-K analyses of granitoid samples from Tisza Unit of the Southern Hungarian nappe zone (Codru Terrain):

a. Mean U-Th-K contents of granitoids of the Tisza Unit are 13,8 g/t, 10,9 g/t and 3,95 %, respectively.

b. The tectonically "tortured" cataclastic granite coming from the borehole Ferencszállás-8 has eye-strikingly high specific activity (1490 Bq/kg) resulted by the extreme high U content (120 g/t) of the sample. In all likelihood, it is a local maximum that could be resulted by local accumulation formed by solutions that contain leached uranium in a great quantity, and move in the fracture and collimation systems. Moreover, several km wide contact pneumatolytic and hydrothermal zone of "banatite" is characteristic for the Ferencszállás area.

This was the reason why the U concentration of the above mentioned sample was not taken into consideration in calculation of mean U content of granitoid formations of the Tisza Unit. This sample had increased the mean value for the area as high as 20,5 g/t because of the small number of samples. Otherwise, Th and K concentrations correspond to (or lower than) the mean value for the area (Th: 5 g/t; K: 3,4 %).

c. Mean U and Th contents of the granite of the Deszk-Ferencszállás-Makó axis zone are 12,6 and 10,6 g/t, respectively. There is a higher mean U concentration (15,2 g/t) in the Algyő area which is supposed to be the northern limb of the above mentioned axis zone. The relatively high U concentration can be explained by the fact that the granitoid samples of this area are often coming from pegmatites or aplite veins, and they were frequently influenced by metasomatic impacts.

There is no relevant difference in the mean Th content (at Algyő: 11,2 g/t; Deszk-Ferencszállás-Makó: 10,6 g/t).

d. Area of granitoids of the Tisza Unit is not lithostratigraphically uniform since products and influences of young magmatism can be found there (SZEDERKÉNYI, 1991). We do not have enough samples to detect these differences. It can be stated, however, that the mean U content of the analysed granites is 3-4 times higher than the world average for granites, while their Th content is about 40-50 % lower than world average.

Sarkadkeresztúr Complex (Sarkadkeresztúr Unit)

Position of the Sarkadkeresztur Major Tectonic Unit has been discussed for a long time. According to the present statement of the Hungarian Stratigraphic Committee, it is a part of the Southern Hungarian Nappe Zone.

The buried basement range was exposed by gravitational measures as early as 1934-35. It begins at Sarkadkeresztúr as a comb of E-W strike, and ends in Romania 18-20 km east of this village.

It is composed of light grey diatexite and some porphyroblastic granite. Its NNW and SSE part join with a katametamorhic gneiss-mica-schist margin intercalated amphibolite (GYALOG, 1996). Tectonically intercalated mesometamorphic rocks also occur in subordinated amount (SZEDERKÉNYI, 1991).

Migmatite coming from two-mica schists and gneiss is the most frequent formation of the area. Most of the samples underwent metasomatism and/or sericitization, chloritization, albitization (BALÁZS et al., 1984), however, geological conditions of this process have been discussed.

Mean U-Th-K contents of granitoid samples from the Sarkadkeresztur Unit are listed in table 5.

The following conclusions can be drawn from U, Th and K analyses of granitoid samples from the range of granitic axis zone of the Sarkadkeresztúr Unit:

a. Mean U-Th-K contents of granitoid from the Sarkadkeresztúr Unit:

U: 9,1 g/t; Th: 13,3 g/t; K: 4-45 %.

b. Mean U-Th-K content of the unambiguously granite samples are:

U: 7,6 g/t; Th: 13,6 g/t; K: 4,36 %.

There is no difference between Th and K contents of migmatite and granite in the studied area, however, mean U content of the migmatite (9,8 g/t) is much higher than that of granite.

c. Conclusions concerning geographical distribution of the analysed elements and leaching differences between fresh and weathered samples cannot be drawn because of small number of samples. In general, it can be stated that the mean U concentration of granitoids of the area is twice higher and the Th content is 40-45 % lower than the world average for granite.

TABLE 4

Radiometric analyses of granitoid samples from the boreholes in the Tisza Unit

Borehole	Rock type	Depth	Specific activity (Bq/kg)	U (g/t)	Ra (U_{equ})	Th (g/t)	K (%)
Algyő-30	microgranite (hydrothermal weathered)	2723-2725m	240	12	11	11	5.1
Algyő-56	medium-grained microcline granite	2519-2521m	195	8	7	6	4.2
Algyő-57	granite	2660-2663m	275	14	13	6	4.4
Algyő-68	microgranite	2662-2665m	310	21	20	13	4.1
Algyő-82	"	2697-2698,5m	220	12	11	15	3.8
Algyő-94	"	2605-2606m	410	26	26	16	3.2
Algyő-442	granite	2505-2507m	265	14	14	12	4.1
Deszk-1	granite	2580-2582m	190	8	8	9	3.5
Deszk-1/A	microgranite	2382-2385m	270	15	14	18	2.7
Ferencszállás-3	microgranite	2382-2385m	180	7	6	10	3.9
Ferencszállás-3	biotite granite	2390-2393m	235	7	7	12	4.2
Ferencszállás-4	granite	2321-2324m	260	12	11	15	3.8
Ferencszállás-5	migmatite	2422-2423m	195	7	6	9	4.1
Ferencszállás-8	cataclastic granite	2535-2538m	1490	120	115	5	3.4
Ferencszállás-12	granite	2365-2371,5m	260	14	14	6	4.6
Ferencszállás-35	granite	2324,6-2327,7m	470	31	29	12	4.1

TABLE 5

Mean U-Th-K contents of granitoid samples of the Sarkadkeresztur Unit

Borehole	Rock type	Depth (m)	Specific activity (Bq/kg)	U (g/t)	Ra (U_{equ})	Th (g/t)	K (%)
Sarkadkeresztúr-6	microgranite (chloritic)	2860-2863m	240	12	12	13	4.3
Sarkadkeresztúr-9	porphyroblastic migmatite	2700-2703m	205	8	7	10	4.9
Sarkadkeresztúr-19	cataclastic granite	2814-2832m	310	14	14	17	4.8
Sarkadkeresztúr-19	migmatite	2805-2814m	210	8	8	15	4.0
Sarkadkeresztúr-18	microcl.-bearing migmatite	2900-2901m	245	11	10	14	5.1
Sarkadkeresztúr-22	porphyroblastic granite	2762-2770m	190	7	6	11	4.2
Sarkadkeresztúr-22	porphyroblastic granite	2850-2856m	280	9	8	17	4.5
Sarkadkeresztúr-34	porphyroblastic granite	2714-2722m	230	7	7	13	4.4
Sarkadkeresztúr-33	granitoid (chloritic)	2942-2945m	185	6	5	10	3.9

RADIOLOGICAL CONDITIONS OF THE MIDDLE HUNGARIAN "PARAAUTOCHTHON" (KUNSÁG TERRAIN) IN THE BASEMENT OF THE GREAT HUNGARIAN PLAIN

The Middle Hungarian "autochthon" (actually "paraautochthon"), which is recently called as Kunság Terrain on the basis of geodynamical considerations (Szederkényi, 1998), extends from the Middle Hungarian Lineament to the Southern Hungarian Nappe Zone (Codru Terrain). According to our present knowledge, it stretches to Transylvania in the East where it forms the so-called Bihar "autochthonous" part of the Apuseni Mountains and surficial crystalline mass of the area north of these mountains (SZEPESHÁZY, 1978; DIMITRESCU, 1981; SZEDERKÉNYI, 1984, 1991, 1998; BALÁZS et al., 1986).

According to the widely accepted concept, there are two parallel major crystalline schist anticline systems of ENE-WSW strike (which becomes to be E-W at the state-boundary) with granitoid axis zone. In fact, it is a symmetrical rock-complex in which migmatite, kata- and mesometamorphic amphibolite-facies zones (sometime lower metamorphic gneiss and mica-schists belts) occur at both sides of an anatectic granitoid zone. Therefore, this terrain is divided into two geodinamic and lithostratigraphic units (sub-terrains): Mórágy Complex (Unit) and Körös Complex (Unit) (HAAS, 1996).

1. Mórágy Complex is a granite range extending from Szigetvár and can be traced along the line of Western Mecsek - Mórágy Mountain - Soltvadkert - Kecskemét - Cegléd. It is associated by metamorphic limbs affected by younger faults at their sides. There is an intercalation of lower metamorphic range of schists of Ófalu and metasandstones of Nagykőrös at the axis zone (HAAS, 1996).

2. Anticline of granitoid axis zone of the Körös Complex is not a continuous mass; it is formed by three granitoid bodies of 30-70 km length and 15-30 km width connected by a migmatite zone: Baja-Jánoshalma, Jászszentlászló-Pálmonostora and Endrőd ranges.

Granite is the dominant rock of this ranges. Similarly to Ófalu schists of the Mórágy Complex, there is intercalation of Upper Cretaceous metasandstones and carbonate phyllites at the axis zone (HAAS, 1996). Considering the area accumulation factor, mean values of units can be calculated rather than those of formation unless belonging of the part-areas to one formation is beyond debate. The studied areas are divided according to the classification recommended by the Hungarian Stratigraphic Committee in this paper. (Of course, this concerns Codru Terrain, too.)

Mórágy Complex (Mórágy Unit)

This range is of light red, orthoclase- and microcline-rich (and containing many plagioclase crystals in some places), porphyroblastic granodiorite (subordinately granite) with dark grey, biotite- and amphibole-rich xenoliths and a network of aplite and pegmatite veins. Feldspar porphyroblasts of the granite is often oriented (lineated). Size of xenoliths coming from the former basic rocks may reach some meters.

Characteristic rocks of the Mórágy Unit are Mórágy-type granodiorite (from Szigetvár to Miske) and granite (it is a muscovite granite without lineation in Cegléd region) (HAAS, 1996).

The granitoid axis zone is bordered by a zone containing migmatite and alternating low- and high metamorphic rocks (gneiss - amphibolite - mica-schist) from the north-west and the south-east (GYALOG, 1996).

The petrographically varied granite represents 60-65 % of the cores of metamorphic rocks coming from this unit of the basement of the Great Hungarian Plain, and further 15-18 % of the cores is granitoid migmatite coming from mainly the marginal zone.

Radioactive element content of granitoid samples of Mórágy Complex found in boreholes of basement of the Great Hungarian Plain is shown by table 6.

The following conclusions can be drawn from radiological analysis of granitoid cores of the Mórágy Unit coming from the basement of the Great Hungarian Plain:

a. Mean U-Th-K content of the studied samples coming from the unit (sub-terrain):

U: 13,54 g/t Th: 17,9 g/t; K: 3,58 %.

b. Mean U-Th-K content of samples that were unambiguously qualified as granite:

U: 13,3 g/t; Th: 17,8 g/t; K: 3,4 %.

Therefore, there is not any significant difference between radioactive element content of granite and that of migmatite (probably it comes from mainly the marginal zone) of the anticline.

c. Regarding the weathered samples, group of the leached samples from weathering crust (U: 6 g/t; Th: 17 g/t) definitely separates from that of muscovite and sericite containing samples affected by hydrothermal metasomatism, which have a U content not less than the mean value for the area (calculating for the whole unit).

d. Three areas having characteristic radioactive element content can be separated by radiological analysis of granitoids of the region. Rocks of these areas also differ from each other in their petrographical features. Because of these differences, which were also mentioned in the summarised petrological characterisation of the unit, this kind of examination of the samples is reliable:

Samples from the Kecel-Soltvadkert region have higher Th content (20 g/t) than the mean value for the area; their U and K content corresponds to the average of the formation (U: 12,9 g/t; K: 3,5 g/t).

Uranium concentration in the Kecskemét region is higher than that of samples from the other part-areas (17,2 g/t), while Th content (17,6 g/t) corresponds to the mean Th content of the Mórágy Unit.

Concentrations of muscovite granite of the Cegléd region are lower than mean values of the unit (U: 10,2 g/t; Th: 16,3 g/t); the low U content is particularly eye-striking.

Unfortunately, connection between radiological features and petrographical characters can not be proved, however, the authors emphasized importance of further studies.

Körös Complex (Körös Unit)

The Körös Complex shows a petrographical variety: it is formed by alternating meso- and katametamorphic gneiss and mica-schist with some intercalation of leptinolite (mesometamorphic tuff) and amphibolite of considerable quantity in the eastern part of Transtibiscia. In the axis zone of the unit granite bodies wedged by migmatite of great quantity are known (GYALOG, 1996).

The granites are dominantly pink, porphyroblastic, and generally not-oriented, however, differences corresponding to the part-areas can also be found here. Granitoids of the complex underwent strong tectonic movements, and suffered mylonitization, diaphtoresis and cataclasis (e.g., Kömpöc, Kiskunhalas, Jánoshalma).

Granitic bodies do not represent a continuous range within this unit but form three granitic areas of 15-30 x 30-70 km connected by migmatite. These areas are situated in the regions of Baja-Jánoshalma, Jászszentlászló-Pálmonostora and Endrőd. Granitoids or granites *sensu stricto* were also found in boreholes which are relative far from the axis zones characterized by the above mentioned villages; therefore it is discussed whether these granitoid part-units are real ranges or only granitoid areas.

Radiometric analyses of granitoid samples from boreholes of the Körös Unit are listed in table 7.

The following conclusions can be drawn from radiological analyses of granitoid samples from the Körös Complex (Körös Unit):

a. Mean U-Th-K contents of granitoids of the Körös Unit are:

U: 10,56 g/t Th: 17,4 g/t K: 3,2 %.

b. Two groups of weathered granitoid samples are sharply separated on the basis of their radioactive element concentration. Samples from weathering zone of the granite ranges (which come from some meters below reaching the crystalline basement, or suffered strong tectonic, cataclastic effect) are leached comparing them with the average of the area (U: 7 g/t; Th: 12 g/t). In general, the other group is also affected by tectonic movements (mylonitization, diaphthoresis), but was influenced by hydrothermal-metasomatic effects; radioactive elements of samples from this group are not leached, in fact, their radioactive element concentration often exceeds the average of the area. Distribution of these samples does not seem to show geographic pattern, but it would be proved by petrological analysis of more samples.

c. Uranium content of granitoid samples from the Jánoshalma-Kiskunhalas region, which are generally tectonically "tortured", is the lowest one of the whole unit (U: 7,2 g/t); similarly, Th content of the region (Th: 14,2 g/t) is also lower than the average of the area.

TABLE 6

Radioactive element contents of granitoid samples from the boreholes of the Mórágy Complex in the basement of the Great Hungarian Plain.

Borehole	Rock type	Depth (m)	Specific activity (Bq/kg)	U (g/t)	Ra (U_{equ})	Th (g/t)	K (%)
Soltvadkert-1	granite (weathered)	1148-1150m	195	5	4	16	3.8
Soltvadkert-1	"	1230-1239m	280	11	10	21	3.5
Soltvadkert-3	"	1500-1504m	330	14	13	24	3.4
Soltvadkert-3	"	1508-1513m	290	12	11	22	3.2
Soltvadkert-9	" (weathered)	1225-1231m	220	6	5	16	3.7
Soltvadkert-É-4	"	1138-1140m	450	17	15	29	3.3
Soltvadkert-K-1	"	1300-1305m	390	14	13	26	3.5
Soltvadkert-K-2	"	1345-1350m	365	12	11	22	3.6
Solti-3	"	1175-1179m	240	12	12	15	4.0
Kecel-K-2	"	2450-2451m	410	21	20	16	3.4
Kecel-K-1	mylonityc gran.	1995-2000m	285	18	18	13	3.1
Kecskemét-1	migmatite	1137-1140m	440	23	22	18	3.6
Kecskemét-2	microgranite	1081-1091m	460	19	17	21	4.0
Kecskemét-2	"	1152-1154m	390	21	20	16	3.7
Kecskemét-3	"	1092-1105m	320	17	15	19	3.4
Kecskemét-3	"	1145-1150m	290	14	14	15	4.1
Kecskemét-4	" (cataclastic)	1130-1134m	210	7	6	15	3.3
Kecskemét-Ny-2	migmatite	1156-1160m	395	11	10	21	3.8
Kecskemét-Ny-2	"	1180-1183m	325	14	13	17	3.4
Kecskemét-D-4	porphyroblastic migmatite	1614-1616m	450	28	27	14	3.4
Kecskemét-D-6	microgranite	1289-1298m	335	18	17	20	3.3
Nagykőrös-6	microgranite	1272-1273m	220	10	10	12	3.6

Borehole	Rock type	Depth (m)	Specific activity (Bq/kg)	U (g/t)	Ra (U_{equ})	Th (g/t)	K (%)
Nagykőrös-6	"	1294-1299m	265	12	11	16	3.4
Nagykőrös-D-1	"	1102-1104m	205	7	6	16	3.8
Nagykőrös-D-1	"	1125-1127m	280	6	5	19	4.3
Cegléd-1	muscovite gran.	1450-1475m	260	9	8	20	4.0
Cegléd-1	"	1478-1506m	275	16	15	16	3.6
Cegléd-1	"	1506-1509m	230	14	14	13	3.5
Cegléd-3	"	1624-1629m	195	7	6	14	3.5
Cegléd-3	"	1745-1748m	210	10	9	11	3.8
Cegléd-4	"	1811-1815m	280	15	14	17	3.5
Cegléd-5	migmatite	1599-1603m	255	9	8	23	3.6
Újszilvás-3	microgranite	2018-2021m	310	18	17	19	3.3

TABLE 7

Radiometric analyses of granitoid samples from the boreholes in the Körös Unit

Borehole	Rock type	Depth	Specific activity (Bq/kg)	U (g/t)	Ra (U_{equ})	Th (g/t)	K (%)
Jánoshalma-1	granite (migmatitic)	613-614m	145	7	6	11	2.5
Jánoshalma-5	"	678-682m	190	6	5	14	3.7
Jánoshalma-6	"	694-695m	210	6	5	16	3.6
Jánoshalma-6	"	712-714m	200	8	8	13	3.3
Jánoshalma-Új-1	"	556-558m	270	9	8	20	3.5
Kiskunhalas-Ny -5	"	1057-1070m	110	3	2	9	1.9
•Kiskunhalas-Ny-6	"	763-765m	140	6	4	14	2.1
Kiskunhalas-DNy-1	migmatite	950-951m	220	11	10	16	3.8
Kiskunhalas-DNy-1	migmatite	1050-1051m	185	9	8	15	3.0
Jászszentlászló-1	granite (migmatitic)	2083-2084m	310	15	14	24	3.3

Borehole	Rock type	Depth	Specific activity (Bq/kg)	U (g/t)	Ra (U_{equ})	Th (g/t)	K (%)
Jászszentlászló-1	"	2110-2111m	270	13	12	23	3.1
Jászszentlászló-2	"	2003-2004m	225	12	11	19	3.6
Jászszentlászló-2	"	2004-2007m	205	11	11	17	3.4
Jászszentlászló-4	"	2041-2053m	185	9	8	15	3.6
Jászszentlászló-4	"	2053-2062m	200	11	10	16	3.4
Kömpöc-1	"	3314-3317m	135	7	6	13	2.3
Kömpöc-3	mylonitic gran. (weathered)	2692-2695m	230	9	8	13	3.4
Szank-5	migmatitic gran.	2031-2032m	520	29	28	25	3.9
Szank-15	"	2229-2241m	315	17	16	23	3.2
Szank-31	"	2185-2187m	225	11	10	17	3.9
Szank-33	"	1949-1950m	290	12	12	20	3.6
Szank-50	"	1894-1896m	350	20	18	24	3.1
Szank-51	"	2054-2055m	385	22	21	26	3.4
Szank-63	"	2081-2084m	285	12	12	18	3.7
Szank-63	"	2123-2124m	340	13	12	19	3.9
Szank-79	"	1926-1927m	215	12	11	12	3.6
Szank-88	"	1869-1876m	265	10	10	21	3.4
Szank-103	"	1884-1886m	320	15	14	22	3.3
Szank-124	"	1950-1953m	410	23	22	22	3.3
Biharkeresztes-12	granite	1430-1436m	210	12	11	11	3.4
Dévaványa-2	migmatite	2780-2781m	105	3	3	10	2.2
Dévaványa-8	granite	2432-2438m	190	7	6	13	3.8
Füzesgyarmat-6	granite	2076-2077m	160	8	7	14	3.1
Füzesgyarmat-12	migmatite	2094-2103m	100	6	5	6	0.8
Endrőd-2	migmatite	2380-2394m	190	7	6	19	2.0

Borehole	Rock type	Depth	Specific activity (Bq/kg)	U (g/t)	Ra (U_{equ})	Th (g/t)	K (%)
Endrőd-2	"	2394-2425m	175	6	5	17	2.1
Kismarja-8	migmatitic gran.	925-928m	225	12	10	15	3.4
Kismarja-9	"	1169-1172m	270	11	10	17	3.2
Kismarja-31	"	1190-1191m	190	8	7	13	3.2
Mezősas-2	migmatite	2304-2308m	145	7	5	10	2.8
Mezősas-4	granite	2651-2656m	210	11	11	14	3.3
Mezősas-6	brecciated granite	2890-2891m	105	4	3	10	2.3
Szeghalom-9	granite	2203-2205m	230	12	10	15	3.1
Szeghalom-11	migmatite	2069-2070m	170	8	6	11	2.9
Szeghalom-39	granite	2070-2080m	260	10	10	19	3.6

Uranium concentration in the Jászszentlászló-Pálmonostora-Kömpöc-Szank granitoid region is extremely high: it is 40 % higher than mean value of the Körös Unit, and Th content is 50 % higher than mean value of the Unit (U: 14 g/t; Th: 22,1 g/t; K: 3,59 %).

Radioactive element content of the granitoid "range" near Endrőd is lower than mean concentrations of the Körös Unit (U: 8,25 g/t; Th: 13,38 g/t; K: 2,82 %).

d. On the basis of the radiological analyses of granitoid cores from the Körös Complex, it can be stated that U concentration of granitoids of this unit (in fact, 90 % of this granitoids is granite) is twice higher than the world average for granite. In this respect, these granitoids are similar to the granitoids of Mórágy Complex, which are on the surface in Southern Transdanubia. Their Th content, however, hardly exceeds mean concentration of Th for granitoids in the world.

Radioactive element content is highest in the middle part of the Körös Complex (Szank region), and mean concentrations of the three elements are decreasing both eastward and westward (U concentration is often reduced by half, and Th content is reduced by 40-50 %).

CONCLUSIONS

Mean radioactive element content of the granitoid rocks of the Codru Terrain (Southern Hungarian Nappe Zone) is the following: U: 10 g/t; Th: 8,42 g/t; K: 2,24 %.

Mean U, Th and K concentrations of the Kunság Terrain (Middle Hungarian "autochthon") are: U: 12,53 g/t; Th: 16,42 g/t; K: 3,44 %.

Within this terrain, the Mórágy Unit has higher (U: 13,54 g/t; Th: 17,9 g/t; K: 3,58 %), while the Körös Unit has lower (U: 10,6 g/t; Th: 17,4 g/t; K: 3,2 %) radioactive element contents.

Accumulation factor of radioactive elements of old granitoid rocks in the Great Hungarian Plain based on the analysed samples is listed in tables 8-11.

TABLE 8

U-Th-K accumulation factor of granitoid rocks from the Southern Hungarian Nappe Zone (Codru Terrain) for units (complexes)
(accumulation factor = mean value for unit/mean value for terrain)

	Battonya Unit	Tisza Unit	Sarkadkeresztúr Unit
U	0,88	1,38	0,9
Th	1,04	0,85	1,04
K	0,83	1,22	1,38

TABLE 9

U-Th-K accumulation factor of granitoid rocks from the Middle Hungarian "autochthon" (Kunság Terrain) for units (complexes)
(accumulation factor = mean value for unit/mean value for terrain)

	Mórágy Unit	Körös Unit
U	1,08	0,78
Th	1,09	0,72
K	1,04	0,88

TABLE 10

U-Th-K accumulation factor of granitoid rocks from the Mórágy Unit (Mórágy Complex) for part-areas
(accumulation factor = mean value for the studied part-area/mean value for unit)

	W-Mecsek part-area	Mórágy part-area	Kecel-Soltvadkert part-area	Kecskemét part-area	Cegléd area
U	1,56	0,47	0,87	1,17	0,69
Th	1	1,24	0,75	0,66	0,61
K	0,87	1,14	0,93	10,01	0,95

TABLE 11

U-Th-K accumulation factor of granitoid rocks from the Körös Unit (Körös Complex) for part-areas studied
(accumulation factor = mean value for the studied part-area/mean value for unit)

	Jánoshalma-Kiskunhalas part-area	Jászszentlászló-Pálmonostora-Kömpöc-Szank part-area	Endrőd part-area
U:	0,67	1,32	0,77
Th:	0,81	1,26	0,76
K:	0,95	1,12	0,88

ACKNOWLEDGEMENT

The authors thank István Vados for his help in the control measures. This work has been supported by the National Science Research Foundation (OTKA) No. F017369.

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Manuscript received 10. September 1999.