In situ measurements of natural radioactivity in selected igneous rocks of the Opava Mountain region

Agnieszka Dżaluk[1]
Dariusz Malczewski[1]
Jerzy Żaba[2]
Maria Dziurowicz[1]

[1]*Department of Applied Geology, Faculty of Earth Sciences, University of Silesia, Będzińska 60, 41-200 Sosnowiec: agnieszka.dzaluk@gmail.com; dariusz.malczewski@us.edu.pl; maria.dziurowicz@us.edu.pl;*
[2]*Department of Fundamental Geology, Faculty of Earth Sciences, University of Silesia, Będzińska 60, 41-200 Sosnowiec: jerzy.zaba@us.edu.pl*

Abstract
In situ gamma-ray measurements of four igneous rocks were taken in the Opava Mountains (Eastern Sudetes, Poland). The activity of naturally occurring radionuclides was measured using a portable GX3020 gamma-ray spectrometry workstation. The activity concentrations of ^{40}K varied from 914 ± 17 Bqkg^{-1} (gneiss, Kamienna Góra) to 2019 ± 37 Bqkg^{-1} (weathered granite, Sławniowice), while those of ^{232}Th from 7.5 ± 0.6 Bqkg^{-1} (weathered granite, Sławniowice) to 68 ± 0.9 Bqkg^{-1} (migmatitic gneiss, Nadziejów). The activities associated with ^{238}U decay series ranged from 10 ± 0.4 Bqkg^{-1} (weathered granite, Sławniowice) to 62 ± 1.6 Bqkg^{-1} (gneiss, Kamienna Góra). The results will be used in compiling Radiological Atlas of the Sudetes.

Key words: Natural radioactivity, ^{40}K, ^{232}Th, ^{238}U, the Opava Mountains

DOI: *10.2478/ctg-2014-0017*
Received: *30th June, 2014*
Accepted: *4th September, 2014*

1. Introduction

The region of the Opava Mountains is well known for its richness in rocks and minerals. They are difficult to access and far from the main tourist trails in the Sudetes. However, this region ensures numerous valuable and attractive geological and mining-heritage sites connected with gold exploitation. There are also several operating and abandoned quarries of the famous Sławniowice marbles that have been used for more than 600 years in German and Polish architecture (Słomka et al. 2009). The wide variety of rocks in the Opava Mountains and their geological conditions like strength and durability have allowed them to be used in the building industries and as decorative elements for houses, public buildings or gardens.

In this paper, the results of natural radioactivity measurements using an in situ gamma-ray portable spectrometry workstation, are presented for four igneous rocks from this region. The purpose of the measurements was to compare the results with the average activity concentrations of ^{40}K, ^{232}Th and ^{238}U (^{226}Ra) for similar types of rocks.

Although similar studies have already been conducted over a large area of the Sudeten Mountains, this is the first time such research has been carried out on the igneous rocks in the Opava Mountains.

2. Geological setting and measurement locations

The Opava Mountains are located in the Eastern Sudetes and represent their furthest eastern mountain range. They run almost latitudinally along the Polish border with the Czech Republic. The Opava Mountains are situated mostly in the Czech Republic. Only a

DE GRUYTER
OPEN

small fragment between Głuchołazy in west and Prudnik in east is situated in Poland. In the north the Opava Mountains are adjacent to the Głubczyce Plateau and in the north-west they border on the Paczkowskie Foothills. The highest peaks are the Příčný vrch (975 m a.s.l.) located on the Czech side and the Biskupia Kopa (890 m a.s.l.) in Poland.

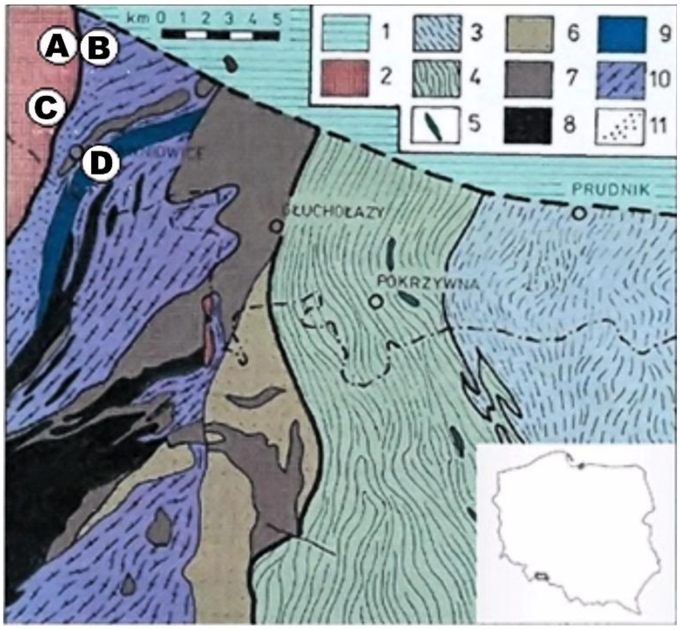
The Opava Mountains are built of rocks of different ages and lithologies. They belong to the western part of the Upper Silesia Block, which together with the Brno Block creates a structure that is called the Brunovistulicum. The mountains consist of five structural stages: the Žulova Massif, the Desna Series, the Vbrna Series, the Andělská-Hora Formation and the Horn-Benešov Formation, which run longitudinally (Janeczek et al. 1991; Żaba et al. 2005).

A geological sketch of the Opava Mountains and the location of in situ measurements are presented in Fig. 1.The first in situ location was in the Kamienna Góra quarry, where the fine- and medium-grained granite is exploited (Fig. 1, point A). This granite belongs to the Žulova Massif and occurs within the apophysis at a thickness of approximately 200 m and indicates the existence of acidic volcanism in this region.

The second location was also located in the Kamienna Góra quarry and the measurement was done close to the Proterozoic Desna Series gneiss (Fig. 1, point B), which covers the Žulova Massif.

The third measurement location was located in a closed, flooded migmatitic gneiss quarry in Nadziejów (Fig. 1, point C).

The fourth measuring point (Fig. 1, point D) was located in Sławniowice in strongly weathered granite which is characterized by a very high content of potassium feldspar.



1-sandstone and marble (Upper Cretaceous)
Žulova Massif
2-granitoid and associated contact phenomena (Upper Carboniferous)
Horn-Benešov Formation
3-sandstone, mudshale and conglomerate (Tournasian-Visean)
Andělská-Hora Formation
4-phyllite, metasandstone, crystalline limestone (Upper Fransian-Middle Visean)
5-greenstone (Upper Devonian-Lower Carboniferous)
Vbrna Series
6-phyllite, graphitic shale, crystalline limestone and metabasite (Middle Devonian)
7-quartzite, quartzitic shale and mica schist (Lower Devonian)
Jesenik Massif
8-amphibolite (Lower and Middle Devonian)
Desna Series
9-marble (Proterozoic?)
10-gneiss and biotite schist (Proterozoic)
11-contact zone of the Žulova granitoid intrusion

Fig.1. The geological sketch of the Opava Mountains (After: Żaba et al., 2005) with locations of the in situ measurements: A-granite, the Kamienna Góra quarry, B-gneiss, the Kamienna Góra quarry, C-migmatitic gneiss, Nadziejów, D-weathered granite, the Sławniowice quarry.

3. Materials and methods

The activities of naturally occurring radionuclides were measured in situ using a portable GX3020 gamma-ray workstation (Fig. 2). The system is based on a high-purity germanium (HPGe) detector with 32% relative efficiency and energy resolutions of 0.8 keV at

122 keV and 1.7 keV at 1330 keV. The ISOCS (In Situ Object Counting Software) and GENIE 2000 v.3 software were used for the efficiency calibration and the determination of radionuclides and their activities. For the determination of radionuclides and calculations of their activities concentrations the following gamma-ray transitions (in keV) were chosen: ^{214}Pb (241.98, 295.21 and 351.92), ^{214}Bi (609.31, 768.36, 1120.29 and 1764.49) of the ^{238}U series, ^{228}Ac (338.32, 911.60, 964.60 and 969.11) of the ^{232}Th and ^{40}K (1460.81) (non series).

The detector was mounted about 1 m above the surface and 0.5 m from the rock. The total duration of a single measurement was 2 h.

Fig.2. A portable gamma-ray spectrometry workstation GX3020 at location 1 (Kamienna Góra).

4. Results and discussion

The results of the gamma-ray activity concentrations of ^{40}K, ^{232}Th and ^{238}U are presented in Table 1. The gamma-ray spectra from the four rocks studied are shown in Fig.3.

Tab.1. ^{40}K, ^{232}Th and ^{238}U activity concentrations in studied rocks. Uncertainties are quoted as one standard deviation calculated by GENIE 2000 v. 3 software.

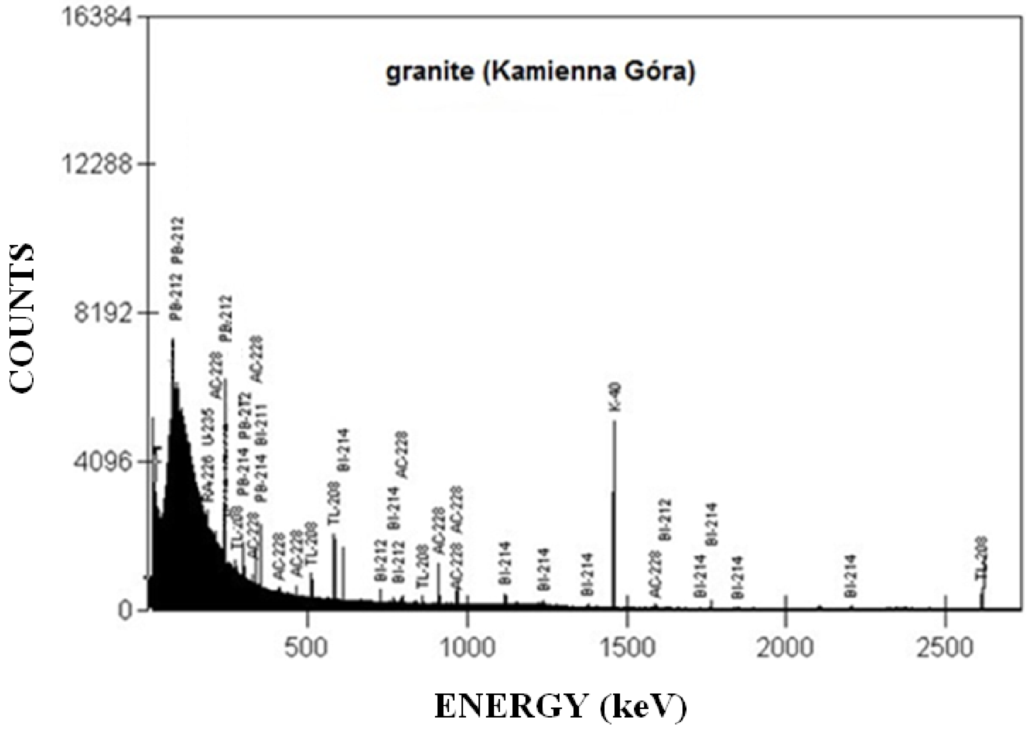
Nuclide	Activity (Bqkg^{-1})			
	Granite (Kamienna Góra)	Gneiss (Kamienna Góra)	Migmatitic gneiss (Nadziejów)	Weathered granite (Sławniowice)
^{40}K	1097 ± 21	914 ± 17	918 ± 17	2019 ± 37
^{232}Th	65.8 ± 0.9	59.5 ± 0.9	67.9 ± 0.9	7.5 ± 0.6
^{238}U	35.6 ± 1.7	61.7 ± 1.6	50.2 ± 1.6	10.4 ± 0.4

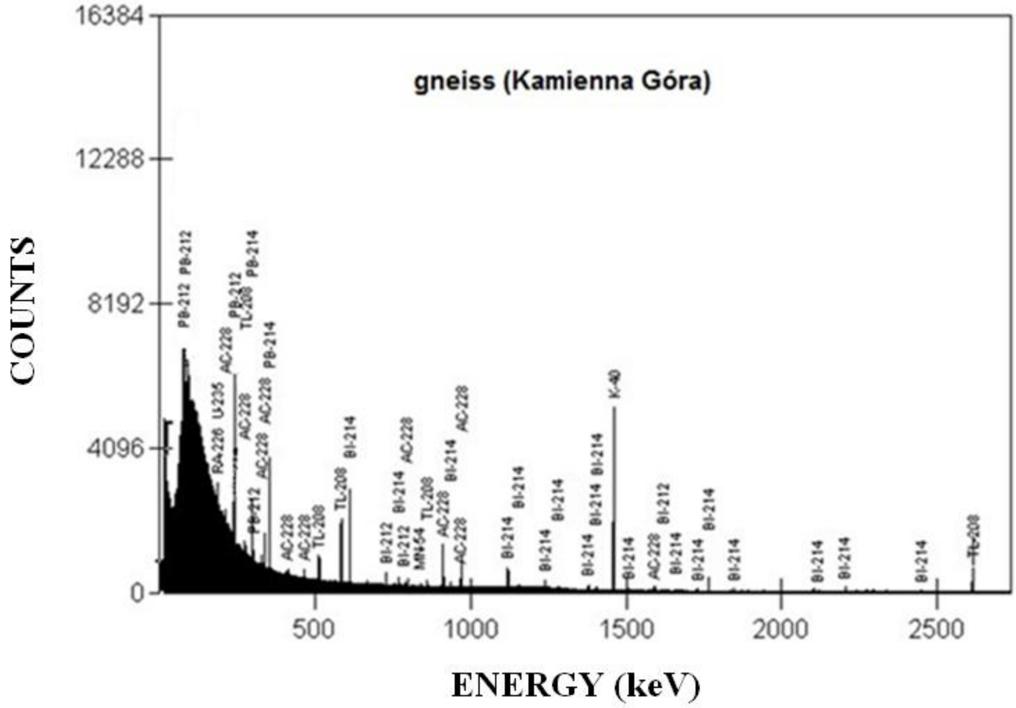
4.1. ^{40}K

The activity concentrations of ^{40}K ranged from 914 Bqkg^{-1} (gneiss, Kamienna Góra) to 2019 Bqkg^{-1} (weathered granite, Sławniowice). Intermediate values were measured in granite located in the Kamienna Góra quarry (1097 Bqkg^{-1}) and in migmatitic gneiss from Nadziejów (918 Bqkg^{-1}) (Fig. 4).

The average value of the activity concentration of ^{40}K for typical granite equals 1000 Bqkg^{-1} (Eisenbud & Gesell, 1997; Van

Schmus, 1995), which means that the measured values of granite and gneiss from the Kamienna Góra quarry and from Nadziejów are close to the typical one. The measured value of granite in the Sławniowice quarry is more than twice as high as the average, which is caused by a large amount of potassium feldspar (Dziedzicowa et al. 1981).





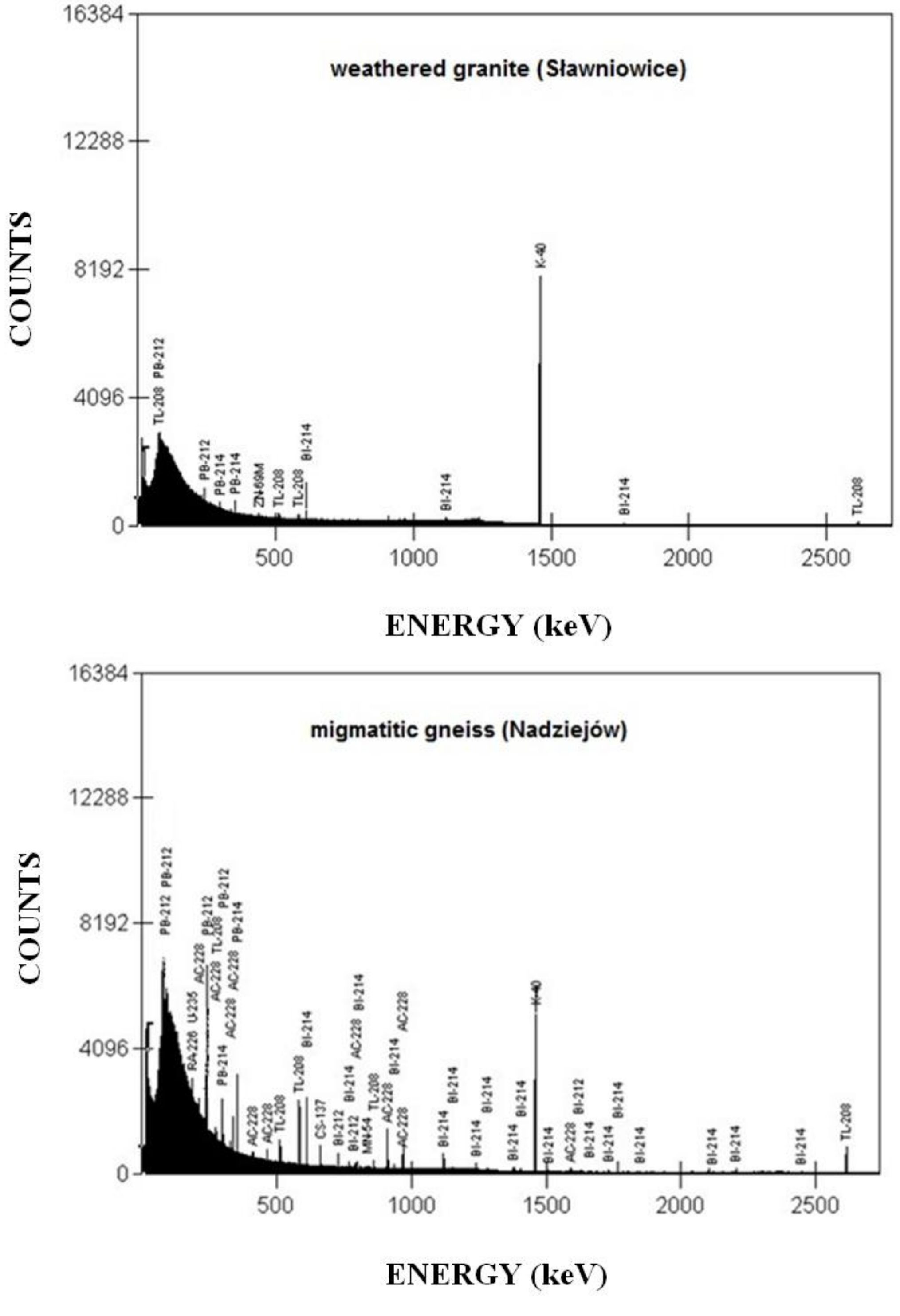


Fig.3. In situ gamma-ray spectra. The characteristic gamma-ray emitters are marked above the corresponding peaks.

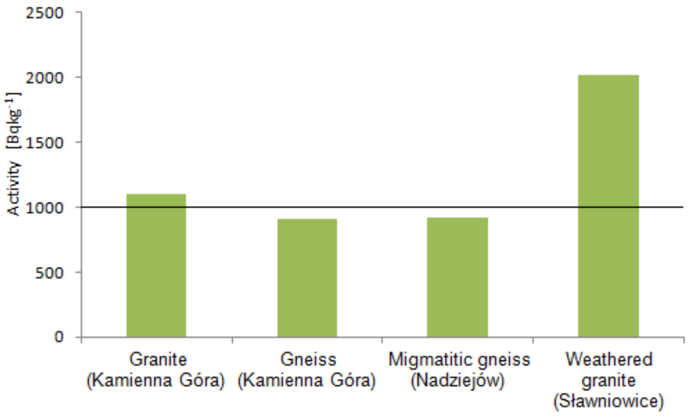


Fig.4. Activity concentrations of ^{40}K. *Black line* – average ^{40}K activity concentration in typical granites.

4.2. ^{232}Th

The highest activity concentrations of ^{232}Th were measured in migmatitic gneiss from Nadziejów (67.9 Bqkg^{-1}) and in granite from the Kamienna Góra quarry (65.8 Bqkg^{-1}), whereas the lowest activity concentration was noted in weathered granite in the Sławniowice quarry (7.5 Bqkg^{-1}). The value of the activity concentration of gneiss in the Kamienna Góra quarry amounted to 59.5 Bqkg^{-1} (Fig. 5).

The average value of ^{232}Th activity concentration for typical granite equals 70 Bqkg^{-1} (Eisenbud & Gesell, 1997; Van Schmus, 1995). None of the measured activities exceeded this value, although it is close to those that were noted in migmatitic gneiss from Nadziejów and in granite and gneiss from the Kamienna Góra quarry. However, the measured value for granite in the Sławniowice quarry is significantly lower than the average because it is strongly weathered.

4.3. ^{238}U (^{226}Ra)

Activity concentrations of ^{238}U were estimated assuming radioactive equilibrium in the ^{238}U-^{226}Ra-^{222}Rn-^{214}Pb-^{214}Bi decay chain. The assumption is fulfilled in the vast majority of minerals and rocks (Eisenbud & Gesell, 1997; Van Schmus, 1995). The highest activity concentration of the ^{238}U was noted in gneiss in the Kamienna Góra quarry (61.7 Bqkg^{-1}), whereas the lower activity occurred in weathered granite from the Sławniowice quarry (10.4 Bqkg^{-1}). Intermediate values were measured in granite located in the Kamienna Góra quarry (35.6 Bqkg^{-1}) and in migmatitic gneiss from Nadziejów (50.2 Bqkg^{-1}) (Fig.6).

The average value of the ^{238}U activity concentration for typical granite and gneiss amounted to 40 Bqkg^{-1} (Eisenbud & Gesell, 1997; Van Schmus, 1995), which means that this value was exceeded in two of the measured rocks: in gneiss from the Kamienna Góra quarry and in migmatitic gneiss from Nadziejów. The activity concentration of granite from the Kamienna Góra quarry was slightly lower than for the typical ones. The measured value of activity concentration for granite in the Sławniowice quarry was considerably lower than the average value of ^{238}U for typical granite and gneiss.

The values of the activity concentrations of ^{40}K, ^{232}Th and ^{238}U for granite and gneiss (excluding weathered granite from the Sławniowice quarry) are comparable to those from Świeradów Zdrój (Malczewski et al. 2004). A significantly higher value of the activity concentration of ^{232}Th for granite than this presented in the paper was measured in contact zone of the Karkonosze Massif, which is probably connected with the thermal metamorphism and metasomatic processes in the Karkonosze region (Bieda & Lizurek, 2008).

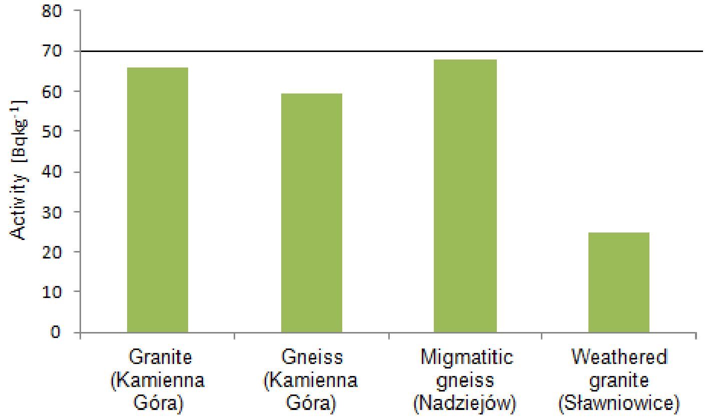


Fig.5. Activity concentrations of ^{232}Th. *Black line* – average ^{232}Th activity concentration in typical granites.

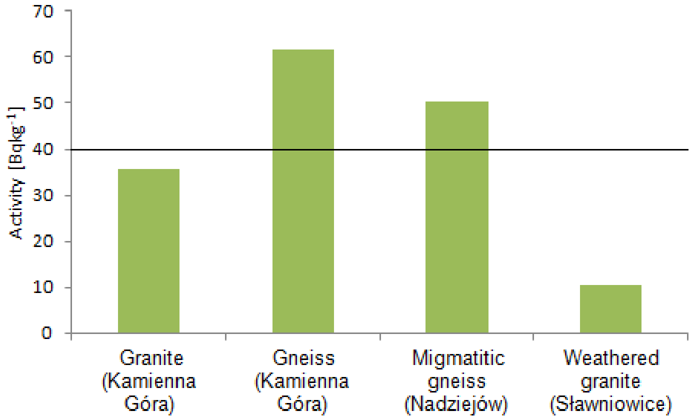


Fig.6. Activity concentrations of ^{238}U. *Black line* – average ^{238}U activity concentration in typical granites.

5. Conclusions

The highest activity concentration of ^{40}K was measured in strongly weathered granite from the Sławniowice quarry, which is a result of a large content of potassium feldspar, whereas the lowest activity concentration was noted in gneiss in the Kamienna Góra quarry. The highest activity concentration associated with ^{232}Th was observed in migmatitic gneiss in Nadziejów. The lowest activity concentrations of ^{232}Th and ^{238}U were measured in granite from the Sławniowice quarry. Because it is strongly weathered it has a low content of dark minerals that contain thorium and uranium. The highest activity concentration of ^{238}U was measured in gneiss located in Kamienna Góra. The average activity concentration of ^{40}K in granite was exceeded in two rocks: in weathered granite from the Sławniowice quarry and in granite from the Kamienna Góra quarry. None of the values in the rocks that were measured exceeded the average value of the activity concentration associated with ^{232}Th. The average activity concentration of ^{238}U in granite was exceeded in gneiss in Kamienna Góra and in migmatitic gneiss in Nadziejów. Although in some measured rocks the activity concentrations of ^{40}K, ^{232}Th or ^{238}U are higher than the corresponding averages, the results of measurements in the Opava Mountains show no significant anomaly that could be dangerous for tourists or collectors of mineral.

References

Bieda A., Lizurek G. (2008) Natural radioactivity of rocks occurring in the contact zone of the Karkonosze Massif with the Szklarska Poręba schist belt. Acta Geodyn. Geomater. 150, 225-231.

Dziedzicowa H., Lorenc M., Wojnar B. (1981) Petrographic nomenclature of granitoids occurring in eastern part of the Sudetic Foreland according to the international classification of plutonic rocks (Nomenklatura petrograficzna granitoidów wschodniego Przedgórza Sudeckiego w międzynarodowej klasyfikacji skał plutonicznych). Prace Geologiczno-Mineralogiczne VIII. Acta Universitatis Wratislaviensis 521, 211-216 (in Polish).

Eisenbud M., Gesell T. (1997) Environmental radioactivity from natural, industrial and military sources. Academic Press, San Diego, CA, 134-200.

Janeczek J., Kozłowski K., Żaba J. (1991) Collecting minerals and rocks (Zbieramy minerały i skały). Wydawnictwo Geologiczne, Warszawa (in Polish).

Malczewski D., Teper L., Dorda J. (2004) Assessment of natural and anthropogenic radioactivity levels in rocks and soils in the environs of Świeradów Zdrój in Sudetes, Poland, by in situ gamma-ray spectrometry. Journal of Environmental Radioactivity 73, 233-245, DOI:10.1016/j.jenvrad.2003.08.010

Słomka T., Doktor M., Bartuś T., Mastej W., Łodziński M. (2009) Geoturist attraction of the Eastern Sudetic Geostrada. Geoturystyka 19, 61-72.

Van Schmus W. R. (1995) Natural radioactivity of the Crust and the Mantel. American Geophysical Union, 283-291, DOI: 10.1029/RF001p283

Żaba J., Ciesielczuk J., Malik K., Strzyżewska – Konieczna S. (2005) Structural and structural evolution of the Devonian and Carboniferous rocks in the Opava Mountains (Budowa i ewolucja strukturalna utworów dewońsko – karbońskich (strefa śląsko – morawska)). [In:] Geology and environmental protection of the Upper Silesia region (Geologia i zagadnienia ochrony środowiska w rejonie Górnośląskim) (ed. J. Jureczek, Z. Buła, J. Żaba). LXXVI Scientific Conference of Polish Geological Society. Państwowy Instytut Geologiczny, Polskie Towarzystwo Geologiczne, Warszawa, 116-127 (in Polis