Radionuclide Data for Geothermal Prospection – A Contribution to the Geothermal Resources Map of Saxony

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Abstract. Geothermal energy is one of the long term perspectives in the field of renewable energy. A research and development project was started to evaluate the deep geothermal potential in Saxony, East Germany. The investigation is a contribution to the geothermal resources map of Saxony. The geological setting of Saxony is characterised by a variety of solid rocks. A lot of them are containing remarkable radionuclide concentrations, so they are source of radioactive heat generation due to radioactive decay. This source was investigated quantitativly.

Introduction

Geothermal energy comes in two forms: One form is the thermochemical energy (heat released from chemical reactions), the other the radiogenic energy (produced by radioactive decay). The source of the geothermal gradients is coming from conductive heat flow from the deep crust and mantle and from radioactive decay of uranium, thorium, and potassium isotopes on the other side. Some granitic rocks in the upper crust contain abnormally high concentrations of radioactive elements causing an enhanced heat flow towards the earth's surface.

Different authors (e.g. Paschen et al 2003) come to the conclusion that only 5% of available geothermal resources in Germany are stored in form of thermal water resources in heated aquifers. On the other hand 95% of the geothermal resources in Germany are stored in form of "dry heat" in crystalline rocks. Under this conditions Saxonia with a large portion of crystalline rocks offers good conditions for the use of geothermal energy.

The use of geothermal resources has an interesting potential considering the important part of surface-near solid rock units in Saxony. Due to the intensive exploration and mining activities in the region a remarkable number of information is known about the temperature distribution in the underground. Especially the variscic granites of the Ore Mountains are characterised by increased heat flow values, while in other regions only small heat flow rates are found. Within the well investigated Ore Mountains can be assumed, that a majority of the heat flow in this area is of radiogenic origin.

Geophysical techniques have a variety of applications to environmental problems. So geophysical techniques, especially radiometrics, can be an important tool in the field of geothermal exploration. Radiometrics, commonly referred to as gamma ray spectrometry, is prepared from airborne platforms, hand held instruments, or downhole logging to measure the radioactivity of the ground. Airborne surveys have been used to estimate abundances of potassium, thorium, and uranium for a variety of activities including regional lithologic discrimination, mineral exploration, and environmental background studies (Nielsen and others, 1990; Darnley and Ford,1989). Maps of terrestrial gamma radiation aided the geothermal mapping in this project. Data of gamma spectroscopy, which were collected on gamma spectroscopy flights by airplane, were be used for the spacial assessment of the radioactive heat generation potential in Saxony.

Investigations on Radioactive Heat Production

Fundamentals in Radioactive Heat Production

Radioactive Heat Generation RHG means the heat which is set free due to radioactive decay of natural radionuclides in the earth's crust and absorbed in the rock. The potential of RHG is depending on the concentration C of these nuclides in the rocks. Usually only the concentration of the most important and most frequent radionuclides are considered because in case of radioactive equilibrium the importance of short-lived isotopes arising within the radionuclide decay chains isn’t remarkable. The concentration of the decay products depends on the concentration of the natural mother nuclide and the decay rate of the daughter nuclide. Isotopes with short half-live times cause usually no substantial enrichment of heat within the rock. Therefore radioactive heat generation data in the literature are documented on the basis of the concentrations of the isotopes K-40, Th-232 and U-238. Generally the relation of the radioactive heat generation is indicated in the form:

$$RHG = A_1 \cdot d \cdot (A_2 \cdot c_U + A_3 \cdot c_{Th} + A_4 \cdot c_K)$$

with d... density and ci... concentrations of the radionuclides. On the basis of the priority of the rock density the amount of absorption of the gamma and/or particle radiation is expressed. The emitted radiation is absorbed the faster, the more largely the density is. Following values for the coefficients Ki are indicated in SCHÖN (1996):

$$RHG = 10^{-5} \cdot d \cdot (95.200 \cdot c_U + 25.600 \cdot c_{Th} + 3,48 \cdot c_K)$$

On the basis of the absorption potential is shown that the main part of the energy develops from the decay of the elements thorium and uranium. Potassium supplies on the average over all rocks an additional contribution of approximately 15 % of the total energy quantity. Depending on the kind and composition of the rock this portion can vary within larger ranges (see Table 1).

Table 1. Radiogenic heat production of rocks (after literature data).

Day	A in [µW/m³] after Buntebrath (1980)	A in [µW/m³] after Oelsner (1982)	A in [µW/m³] after Schön (1983)
granite	3.000	5.500	5.280
schiefer	-	2.100	1.550
diorite	1.100		1.300
ultrabasite	-	0,010	0,013
peridodite	0,010	-	0,010
gneiss	2.400	4.200	

Correlations between Gamma Radiation and RHG

After Bücker and Rybach (1996) correlations between the gamma radiation and the radioactive heat generation exist in the following way (where GR is gamma ray and API the investigation standard coming from petrol industries):

$$RHG\ [\mu W/m^3] = 0.0158\ (GR\ [API] - 0.8)$$

Ranges of radioactive heat generation of the most important rock classes are documented in the literature. Detailed geological and gammaspectrometric investigations of different magmatites were made in the 1970th by the former SDAG Wismut. In Fig. 1 is shown a comparison of the ranges of radioactive heat generation of the most important rock classes in Saxony. Considering the radiogenic energy it can be concluded that special attention has to be dedicated to sour intrusive rocks in the geothermal basis model. Sour intrusive rocks are especially granites and granitoide rocks. Due to their elevated radionuclide contents this rocks can be dedicated by airborne gamma ray spectrometry.

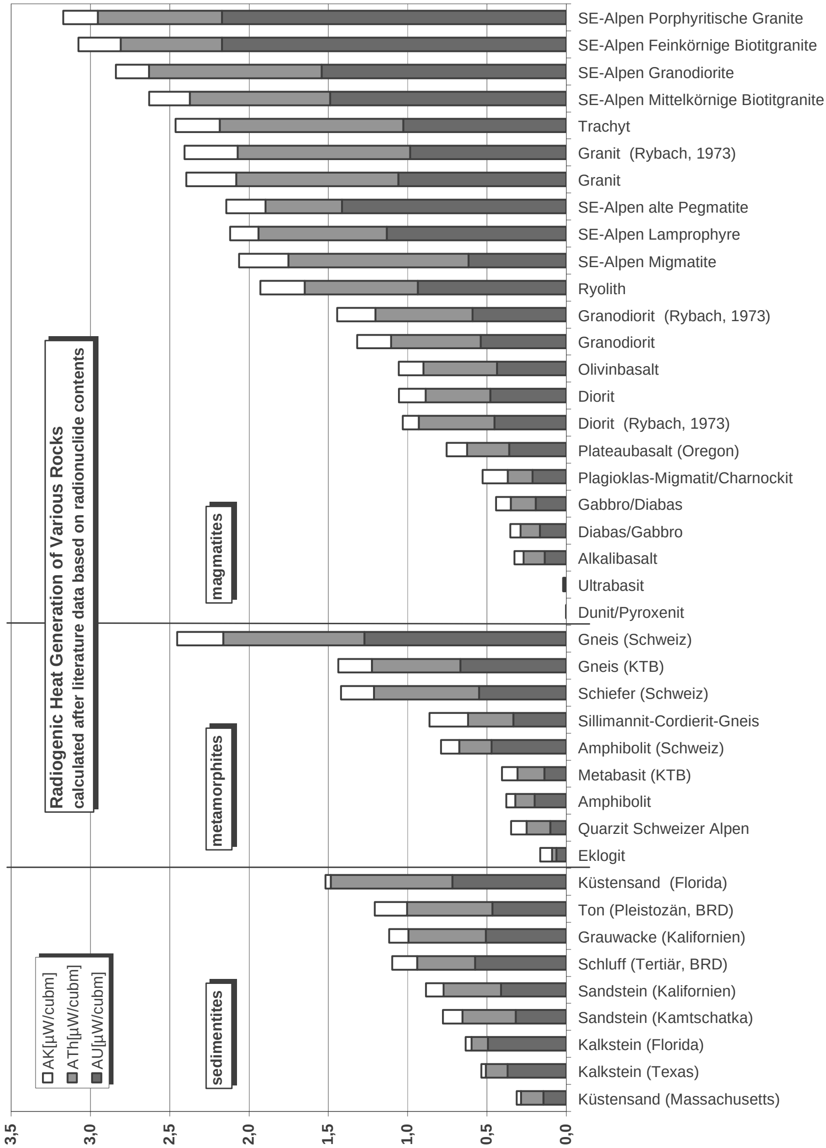

Fig. 1. Comparison of the ranges of radioactive heat generation of the most important rock classes (after Schön 1996, Just 1977, and Wismut, 1972).

Investigation Concept

The investigation concept is shown in Fig. 2. Using the airborne gamma ray spectrometry data which represent the spacial radionuclide contents the calculation of the radioactive heat generation was prepared for Saxony. The airborne gamma ray spectrometry data were of two sources: data of the EU project AREA and data of the Environmental authorities. The airborne measurements were calibrated using a combination of in situ and soil/rock sample data. The surficial radioactive heat generation data allow also a geothermal modeling into the deep geological layers.

Results

Spacious Calculation of the Radioactive Heat Generation of Saxony

In Fig. 3. are shown the results of the spacious calculation of the radioactive heat generation. Due to the geological structure of Saxony the areas relevant for radioactive heat generation are in the western and middle part of Saxony. The geological structure indicates granites and gneisses in these parts of Saxony. The values of radioactive heat generation in these areas cover 2 to 10 µW/m³. The eastern part is covered by sedimentary rocks. The radioactive heat generation in these areas is

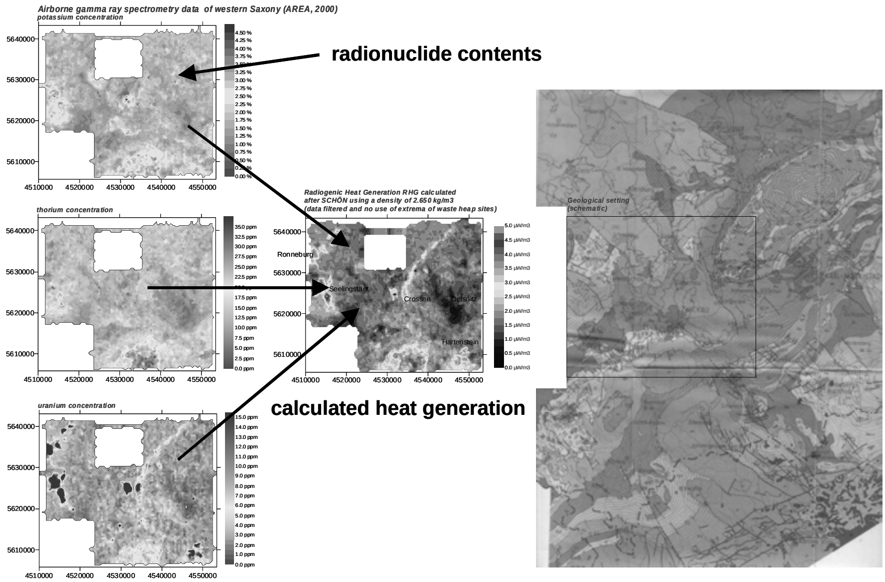

Fig.2. Method of the calculation of the radioactive heat generation due to radioactive decay based on spacial gamma spectroscopy data.

very low due to values between 0 to 2 µW/m³.

Values up to 15 µW/m³ are calculated in parts of the areas of former uranium mining in Saxony. These sites will be mitigated in the next few years.

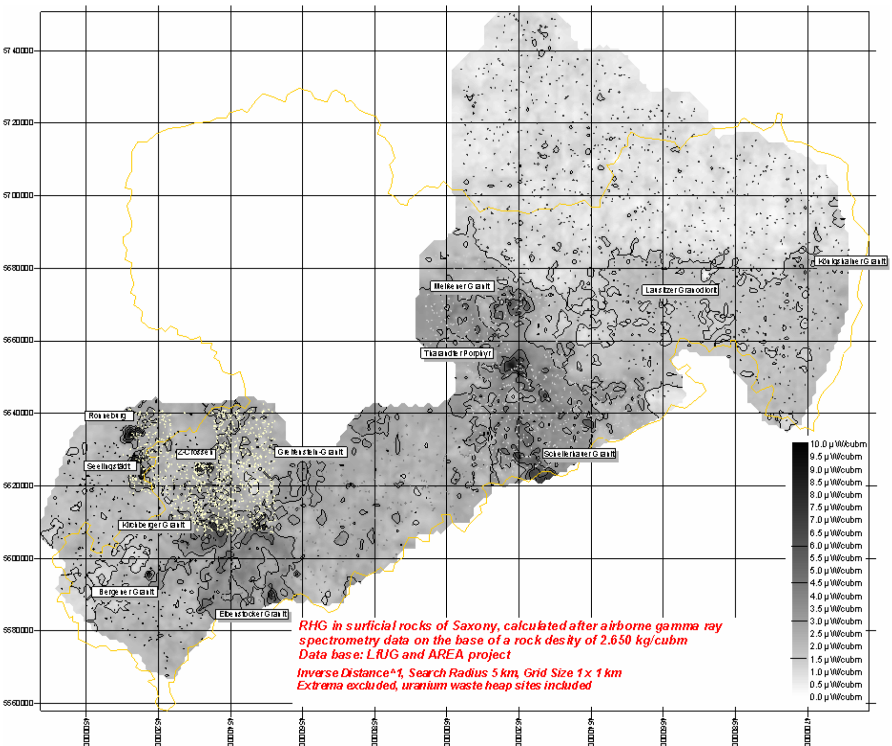

Fig. 3. Results of the spacial calculation of the RHG for Saxony.

Conclusions

The geological setting of Saxony is characterised by a variety of solid rocks. Some of them are containing remarkable radionuclide concentrations, so they are source of radioactive heat generation due to radioactive decay. The spacious calculation of the radioactive heat generation based on airborne gamma ray spectrometry data is a suitable tool for the investigation of the radioactive heat generation. But one has to consider that this geothermal source is small in comparision to thermo-chemical energy.

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