Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Radiogenic Heat Production and analysis in Jiangmen region, South China Block

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Keywords: heat production, heat producing elements, granites, South China Block

ABSTRACT

Natural beta decay of radioactive elements in Earth releases heat that boosted the evolution of the Earth and affected the geothermal structure of the lithosphere. Distribution and total amount of radioactive elements in the Earth is a key scientific question in Earth science. In general, radioactive elements are more concentrated in near surface crust. South China Block (SCB) is an extensional region and the lithosphere of SCB has been thinned since Mesozoic time. It's a major geothermal zone in China. Natural geothermal springs locate along faults and at the edge of rift basins. We collected 253 rock samples in the study area, which cover the typical geological units. The abundance of U, Th, K and the density are tested to calculate the heat production. The distribution of abundances and heat production were analysed and compared with previous work. This work contributes to global heat production database and study of local geological processes.

1. INTRODUCTION

The distribution of internal energy in the Earth is closely related with the formation and revolution of the Earth and has been a key question in Earth Science. The total heat loss of the Earth is about 47±2 TW (Davies and Davies, 2010). The major heat source is secular cooling and natural radioactive decay of heat producing elements (mainly ^{238}U, ^{232}Th, ^{40}K). But the distribution heat producing element and total radiogenic heat production is not clear. Radiogenic heat production from different Earth model are significantly different (Šrámek et al., 2016). Heat producing elements are more concentrated near surface. The heat contribution of felsic upper crust to surface heat flow through radioactive decay is significant, makes up to 50% of typical surface heat flow in stable continents. Artemieva et al. (2017) complied a global database GRANITE2017 on the abundances of heat producing elements and density.

Our study area is Jiangmen area, Guangdong Province in South China. It locates in South China Block, along the coastline. No heat flow data in study area (Hu et al., 2001), but quite some natural springs. The natural thermal springs in South China span an unusually large area and it's one of the major geothermal zones in China. The natural springs are closely associated with faulting and the Jurassic and Cretaceous granites of the region which covers about one third of South China. South China Block has attracted expensive attention to the Mesozoic tectono-thermal event which is mainly represented by the huge intrusive-volcanic magmatic belt with a width of ~1300 km (Li and Li, 2007; Zhou et al., 2006). Abundances of heat producing elements of granitic bodies in South China are extremely high (Sun et al., 2015; Zhao et al., 1995). More research is about the heat production of granitic bodies. To have a systematic study of the distribution of heat producing elements of this area, radiogenic heat production of the strata and granites are systematically studied in this paper.

2. GEOLOGICAL SETTING OF STUDY AREA

Study area geologically belong to South China Block, is located on the continental margin of the western Pacific Plate. The present South China tectonic framework is controlled by complex interactions between the Eurasian plate, paleo-Pacific Ocean plate, the Philippine Sea plate and Indian plate. This region has experienced multiple tectonic events since the Paleozoic (Wang et al., 2013), such as the Indosinian (late Permian to middle Triassic) orogeny and the Yanshanian (Jurassic-Cretaceous) tectono-magmatic events. The Yanshanian movement, a counterclockwise rotation of the Chinese continent with western subduction and compression of the Okhotsk and Izanagi plate, 205-135 Ma (Mesozoic time) (Wan, 2012), was the peak period of the tectonic and resulted in thinned lithosphere and extensive Mesozoic granites widely distributed.

Intrusive rocks in the study area are widely distributed, including in the lower Cretaceous monzonitic granites, lower Jurassic monzonitic granites, and Silurian granodiorite. Cretaceous monzonitic granites intruded into the previous intrusive Jurassic monzonitic granites, and Silurian granodiorites intruded into Cambrian strata. In addition to the above-mentioned intrusive rocks, there are different stages of rocks, from Cambrian strata to Quaternary strata. Faults are well developed with northeasterly major directions. Enping-Xinfeng fault, an important NE-direction fault in Guangdong province, was split into 2 faults in study area. The distribution of natural hot springs is dominated by the faults and Yanshanian magmatic intrusions. These deep faults and intrusions play an important role in the geothermal activity.

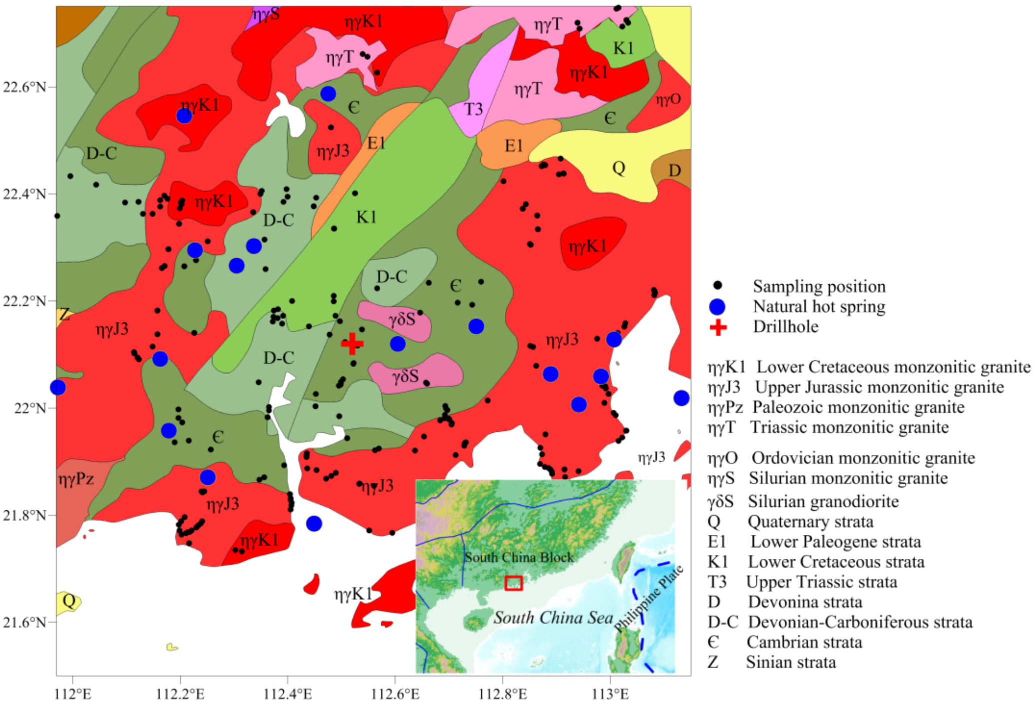

Figure 1: Geological map and location of samples in study area

3. ABUDNACES OF HEAT PRODUCING ELEMENTS AND ANALYSIS

253 samples were collected from the study area. Most major geological unites were covered, except Paleozoic monzonitic granite, Quaternary strata and Tertiary strata. No fresh samples of these geological unites were found in field trip.

The radiogenic heat production (A) of rocks is calculated with the following equation (Rybach, 1988)

$$A(\mu W/m^3) = 10^{-2} \times \rho(g/cm^3) \times (9.52 \times C_U(ppm) + 2.56 \times C_{Th}(ppm) + 3.48 \times C_K(\%)) \quad (1)$$

C_u, C_{Th} and C_k are the abundances of Uranium, Thorium and Potassium, respectively. ρ is density. All the rocks samples from study area are carried out for U, Th, and K content determination, in Beijing research Institute of Uranium geology. Part of the samples were measured for density in Institute of Geology and Geophysics, China Academy of Sciences. Less heat production data is got than abundant data. In order to have a better understanding of the abundances of heat producing elements, the distribution of U, Th, K were modelled. The distribution of HPE abundances span a huge range and strongly positively skewed (Fig 2). Rather than normal distribution, they generally fit a log-normal distribution (Ahrens, 1954; Huang et al., 2013). The other advantage of log-normal distribution is, the abundances are all positive. Both the normal distribution and log-normal distribution are used in order to compare with previous work.

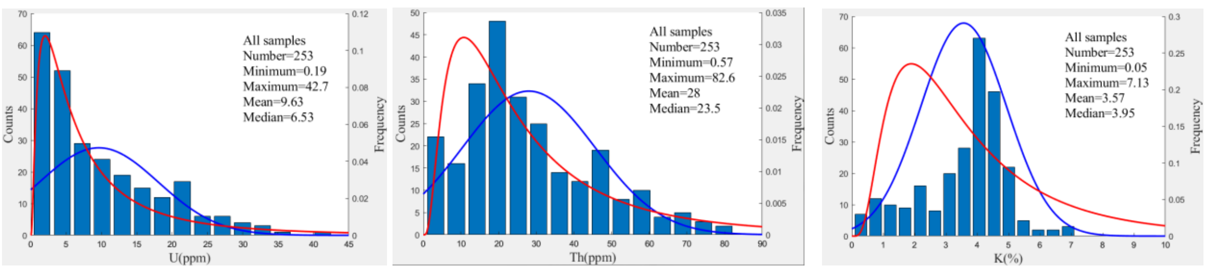

Figure 2: Comparation of normal distribution (blue line) and log-normal distributtion (red line) of heat producing elements-U(ppm), Th(ppm) and K(%).

The median heat production for different category is as: Early Yanshanian Granite (5.05 $\mu W/m^3$) >Late Yanshanian granite (3.78 $\mu W/m^3$)>Indosinian Granite (3.56 $\mu W/m^3$) >Paleozoic granite (2.23 $\mu W/m^3$) >Protozoic strata (1.9 $\mu W/m^3$) >Paleozoic strata(1.45 $\mu W/m^3$) >Mesozoic strata (1.42 $\mu W/m^3$). And the median heat production for 174 samples is 3.03 $\mu W/m^3$.

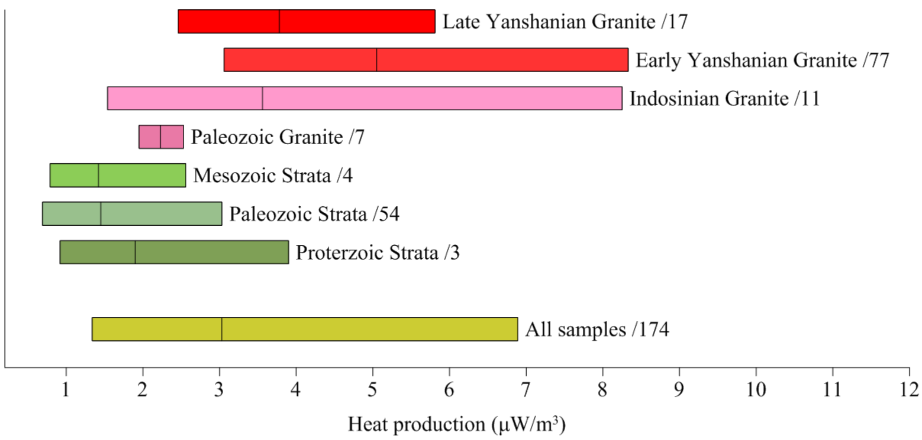

Figure 3: Summary of heat production of each category from log-normal distribution. The range in colours is 1 sigma, and the vertical line inside of the range is median value. The number behind the description is the number of samples.

This region has experienced multiple tectonic events since the Paleozoic, include the Indosinian (late Permian to middle Triassic) orogeny and the Yanshanian (Jurassic-Cretaceous) tectono-magmatic events. Granitic rocks are the most common magmatic products in collisional orogens. The heat production of granites is higher than strata. Of which Yanshanian granites are the most radiogenic. The heat production of Paleozoic granite is relatively concentrate.

The Indosinian orogeny experienced multiple subduction-collisional events in South China Block in response to closure of the Paleo Tethyan Ocean/back-arc basin. Most researchers consider that the Indosinian granites were originated from crustal basements with insignificant addition of the juvenile mantle derived magma (Deng et al., 2004; Ge, 2003; Wang et al., 2007). Study area was under regional compression at the earlier Indosinian stage, and a local extensional setting at the later stage. The distribution of 1 sigma heat production range of Indosinian Granite is from 1.54 μW/m^3 to 8.25 μW/m^3 despite the small number of samples.

The Yanshanian movement was the peak period of the tectonic and resulted in thinned lithosphere and extensive Yanshanian granites widely distributed. Yanshanian period was divided into the Early Yanshanian (180-142 Ma) and the late (142-67 Ma) sub-period. The magmatic belt of Yanshanian movement exceeds 1300 km from coastline in the Southeast to mainland in the Northwest. The Yanshanian granites mostly appear as massive structures (Fig.4) and were associated extensive intracontinental orogen. The Early Yanshanian granitoids (mainly upper Jurassic monzonitic granites in study area) mainly formed during a short time interval between 165 and 155 Ma and distributed preferentially along the NE- and EW- trending directions. Granites in Early Yanshanian movement have the highest heat production, 1 sigma range is 3.06-8.33 μW/m^3 with 5.05 μW/m^3 as median. The deep crustal melting, triggered by lithospheric extension and associated underplating of basaltic magmas, led to the intrusion of intraplate granites and rift-related magmatic during the Late Yanshanian movement (Xi et al., 2018). Median heat production from Late Yanshanian time is 7.61 μW/m^3.

Figure 4: The massive intrusion of Lower Cretaceous granite

In order to compare with previous study, Gaussian distribution is used in Table 1. The abundance of U of total 253 samples ranges from 0.19 ppm to 42.7 ppm, with a mean value 9.63 ppm, which is 3.57 times of the global average upper continental crust. The abundance of Th ranges from 0.57 ppm to 82.6 ppm, with a mean value 28 ppm, which is 2.67 times of the global average upper continental crust. And K ranges from 0.05% to 7.13 % with a mean value 3.57%, which is 1.55 times of the global average upper continental crust.

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Abundances of Granites in Guangdong The average abundances of U, Th, K from granitic rocks are 3.64, 2.77, 1.58 times of global granitic rocks (Artemieva et al., 2017), respectively. Province is much higher than global average. 5 granitic bodies from different region of Guangdong province is studied by (Sun et al., 2015), and the average heat production of them is about 2.33 times of global granitic rocks. Heat production of granitic rocks of study area are 1.87 times of global average granitic rocks. The granitic rock of Nanling inland region is higher than study area on coastline. This work confirmed the abundant heat producing elements and high heat production from Mesozoic time in Guangdong province.

Table 1: Comparison with previous study

Element	U (ppm)	Th (ppm)	K (%)	A (μW/m^3)	Data Source
Global Granitic rocks	3.93±3.27	14.8±13.2	2.79±1.44	2.7±1.87	Granite 2017, (Artemieva et al., 2017)
Continental Upper Crust	2.7±0.6	10.5±1.0	2.3±0.19	---	(Rudnick and Gao, 2003)
5 Granite bodies in Guangdong Province	12	41	4.41	6.29	(Sun et al., 2015)
Granitic rocks of study area	12.89±8.42	33.68±17.69	3.99±0.91	5.05±2.48	This study
All samples of study area	9.63±8.43	28±17.64	3.57±1.37	3.94±2.57	This study

4. CONCLUSION

Abundances of heat producing elements and heat production of samples in Jiangmen region, South China are systematically studied and analyzed. Early Yanshanian granites are most productive of all ages. Heat production of granitic rocks of study area are 1.87 times of global average granitic rocks. Abundances of heat producing elements of all samples from study area are 1.55-3.57 times of global continental upper crust. This work contributes to local study and global heat production and abundance of heat producing elements.

5. ACKNOWLEGEDMENTS

This study was financially supported by grant of National Natural Science Foundation of China (No.41874100). The author also would like to thank Xiaocong Li, Jincheng He and Shuang Tan for the help in field work.

REFERENCES

Ahrens, L.H.: The lognormal distribution of the elements (a fundamental law of geochemistry and its subsidiary), *Geochimica et Cosmochimica acta*, **5**, 2, (1954), 49-73.

Artemieva, I.M., Thybo, H., Jakobsen, K. et al.: Heat production in granitic rocks: Global analysis based on a new data compilation GRANITE2017, *Earth-Science Reviews*, **172**, (2017), 1-26.

Davies, J.H., and Davies, D.R.: Earth's surface heat flux, *Solid Earth*, **1**, 1, (2010), 5-24.

Deng, X., Chen, Z., Li, X.e.a. et al.: SHRIMP U-Pb zircon dating of the Darongshan-Shiwandashan, *Geol Rev*, **50**, (2004), 426-432.

Ge, X.: Mesozoic magmatism in Hainan Island (SE China) and its tectonic significance: geochronology, geochemistry and Sr-Nd isotope evidences, *Doctor's Degree Dissertation, Institute of Geochemistry, Chinese Academy of Science, Guangzhou*, **29**, (2003).

Hu, S., He, L., and Wang, J.: Compilation of Heat Flow Data in the China Continental Area (3rd Edition), *Chinese Journal of Geophysics*, **44**, 5, (2001), 604-618.

Huang, Y., Chubakov, V., Mantovani, F. et al.: A reference Earth model for the heat‐producing elements and associated geoneutrino flux, *Geochemistry, Geophysics, Geosystems*, **14**, 6, (2013), 2003-2029.

Li, Z., and Li, X.: Formation of the 1300-km-wide intracontinental orogen and postorogenic magmatic province in Mesozoic South China: a flat-slab subduction model, *Geology*, **35**, 2, (2007), 179-182.

Rudnick, R., and Gao, S.: Composition of the continental crust, *Treatise on geochemistry*, **3**, (2003), 659.

Rybach, L.: Determination of heat production rate, *Handbook of Terrestrial Heat Flow Density Determination*(1988), 486.

Š rámek, O., Roskovec, B., Wipperfurth, S.A. et al.: Revealing the Earth's mantle from the tallest mountains using the Jinping Neutrino Experiment, *Scientific Reports*, **6**, (2016).

Sun, Z., Wang, A., Liu, J. et al.: Radiogenic heat production of granites and potential for hot dry rock geothermal resource in Guangdong Province, Southern China. *Proceedings world geothermal congress*.(2015).

Wan, T.: *The tectonics of China: data, maps and evolution*. Springer Science & Business Media,(2012).

Wang, Y., Fan, W., Sun, M. et al.: Geochronological, geochemical and geothermal constraints on petrogenesis of the Indosinian peraluminous granites in the South China Block: a case study in the Hunan Province, *Lithos*, **96**, 3-4, (2007), 475-502.

Wang, Y., Fan, W., Zhang, G. et al.: Phanerozoic tectonics of the South China Block: key observations and controversies, *Gondwana Research*, **23**, 4, (2013), 1273-1305.

Xi, Y., Wang, G., Liu, S. et al.: The formation of a geothermal anomaly and extensional structures in Guangdong, China: Evidence from gravity analyses, *Geothermics*, **72**, (2018), 225-231.

Zhao, P., Wang, J., Wang, J. et al.: Characteristics of heat production distribution in SE China, *Acta Petrologica Sinica*, **3**, (1995), 004.

Zhou, X., Sun, T., Shen, W. et al.: Petrogenesis of Mesozoic granitoids and volcanic rocks in South China: a response to tectonic evolution, *Episodes*, **29**, 1, (2006), 26.