PROCEEDINGS, 50th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 10-12, 2025
SGP-TR-229

# Advance in Radiogenic Hot Dry Rock, SE-China

Sun Zhanxue, Wang Andong, Chen Gongxin, Liu Tangwei, Shi Xinghua, He Ting

East China University of Technology, Nanchang, Jiangxi, 330013，China

E-mail address: zhxsun@ecut.edu.cn

**Keywords:** radiogenic heat production, geothermal resources, hot dry rock, SE-China

## ABSTRACT

The southeastern region of China is abundant in granite of various ages and types, as well as geothermal resources. The relationship between granite bodies and geothermal resources, especially the connection between granite's radiogenic heat production rate and the genesis of geothermal energy, represents a significant scientific issue. Over the past nearly fifteen years, we have conducted field geological surveys, rock density determinations, and radiogenic heat-producing element content measurements in the Nanling area of inland southeastern China and the Zhangzhou area along the southeast coast. Our data reveal significant differences between the two regions in terms of rock type, genesis, and radiogenic heat-producing element content. Granites in the Nanling area exhibit high radiogenic heat production rates, characteristics of high heat-producing granites. In contrast, granites in the southeast coastal areas have relatively lower heat production rates, slightly above the global average for granites. Although the heat source conditions are available for the both regions possessing high background heat flow values, it is essential to carry out in-depth research on whether there are matching conditions between high-thermogenic hidden granite and its overlying low-thermal conductivity sedimentary caprock, thus forming radiogenic hot dry rocks.

## 1. INTRODUCTION

The interior of the Earth containing vast amounts of heat is a huge thermal reservoir (Jaupart et al.,2016). This heat is transmitted from the Earth's interior to the surface through conduction, convection, radiation, and other mechanisms, giving rise to volcanic eruptions, hot springs, magmatic activities, seismic activities, and tectonic movements(Clauser and Huenges.,1995; Jaupart et al.,1998;McLaren et al.,2003; Mareschal et al.,2004; Smithson and Decker,1974). Radiogenic heat production (RHP) is the major source of the Earth's internal heat, of which between 50% and 80% originates from the decay of radioactive elements (Morgan,1984; McLennan and Taylor,1996;Pollack and Chapman ,1977). The RHP of three radioactive elements, uranium (U), thorium (Th), and potassium (K), which have long half-lives, high abundances, and generate significant amounts of heat, serves as the primary source of the Earth's internal heat(Arevalo et al.,2009; Hasterok and Chapman.,2011; Joshua et al.,2008; Rybach,1988). Radiogenic geothermal resource is an important part of geothermal resources, and previous studies have shown that high-, medium-, and low-temperature geothermal systems can all be formed from higher-than-normal levels of heat generated by radioisotope decay (Hasterok et al.,2019; Hasterok and Webb.,2017). The granite in southeast China is widely distributed, with unique basin-ridge tectonic characteristics, showing a relatively high heat flow background, dense hot springs, and good geothermal resource potential. In recent years, we have carried out field geological surveys of granite in the Zhangzhou Basin, Southeast coast region, and the northern part of Guangdong Province in Nanling inland region, Southeast China. These new data, together with other geological, geothermal, geochemical, geophysical evidences, provide new insights into the RHP features and lithospheric thermal regime.

## 2. GEOLOGICAL SETTING AND ANALYTICAL METHODS

### 2.1 Geological setting

The Nanling Mountains are located in the south-central part of South China, spanning across Hunan, Guangxi, Guangdong, Jiangxi, Fujian, and other provinces. They are roughly oriented in an E-W direction within the latitude range of N23°20′ to 26°40′ and the longitude range of E111° to 117°. In terms of tectonics, the eastern part belongs to the Circum-Western Pacific tectonic domain, while the western part extends into the Circum-Tethys-Himalayan tectonic domain. The distribution of rock masses and basins is primarily in the EW direction, controlled by five fault zones: the Pingxiang-Guilin Fault Zone, the Longyan-Dabu-Haifeng Fault Zone, the Ganjiang Fault Zone, the Sihui-Wuchuan Fault Zone, the Chaling-Guangchang buried fault, and the Wuzhou-Sihui buried fault. The granite belts within the region are mainly parallel and extend in the EW direction, consisting of the Qitianling-Jiufengshan granite belt (northern belt), Dadongshan-Guidong granite belt (middle belt), and Fogang-Xinfengjiang granite belt (southern belt) from north to south (Shu Liangshu et al., 2006; Zhou Xinmin, 2007). Since the Indosinian collision of landmasses on the north and southwest sides, the region has undergone multiple tectonic-magmatic-sedimentary events, resulting in the development of the largest scale of Early Mesozoic granite and rift basins in South China (Bao Zhiwei et al., 2003; Liu Changshi et al., 2003; Shu Liangshu et al., 2006; Zhou Xinmin, 2007).

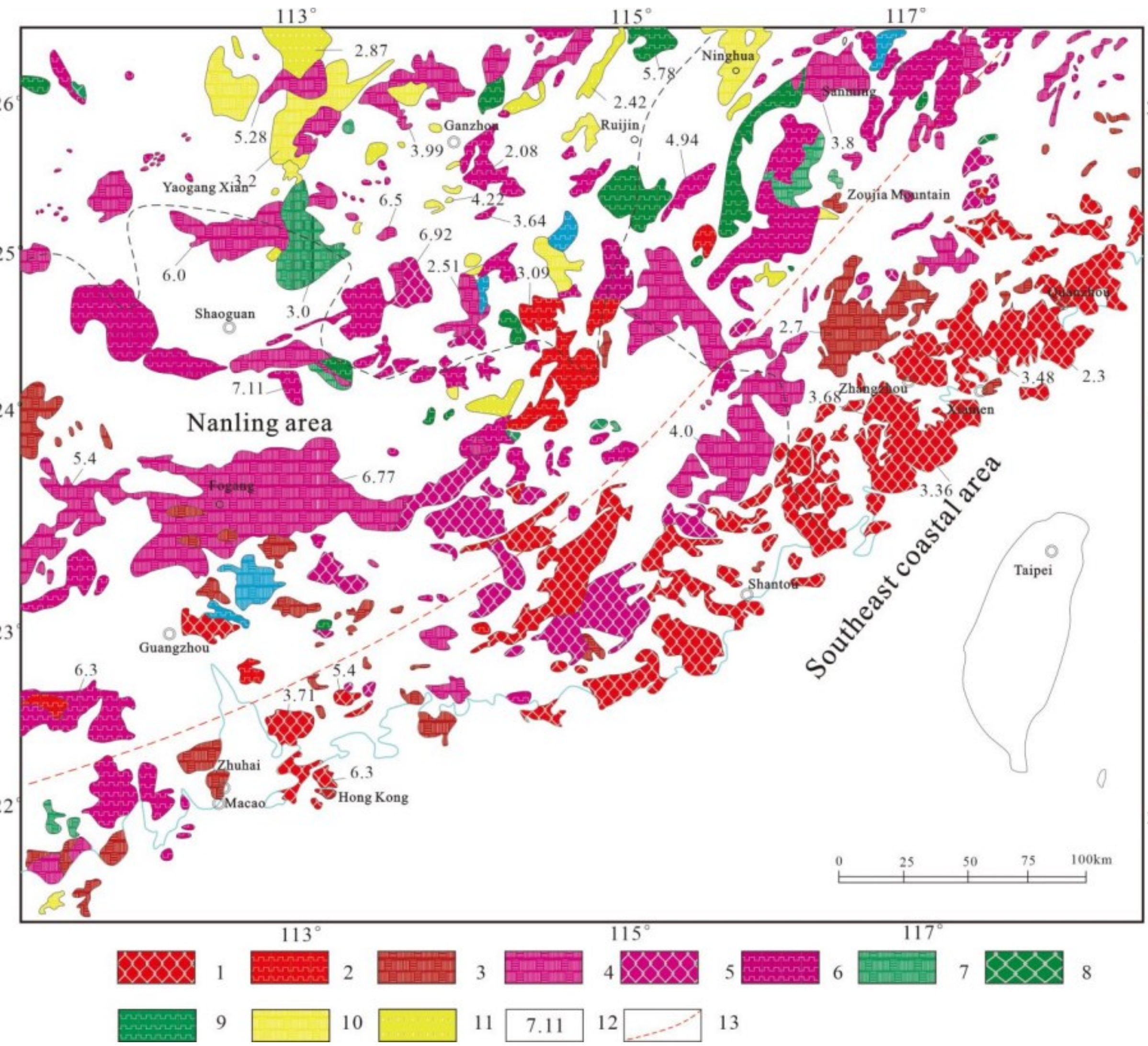


**Fig.1 The granite distribution map of the Nanling area and Southeast coast area （after Sun Tao, 2006）1—late Yanshanian quasi-aluminous granite ; 2—late Yanshanian strongly peraluminous granite ; 3—late Yanshanian weakly peraluminous granite ; 4—early Yanshanian weakly peraluminous granite ; 5—early Yanshanian quasi-aluminous granite ; 6—early Yans- hanian strongly peraluminous granite ; 7—Indo-chinese epoch weakly peraluminous granite ; 8—Indo-chinese epoch quasi-aluminous granite ; 9—Indo-chinese epoch strongly peraluminous granite ; 10—Caledonian weakly peraluminous granite ; 11—Caledonian strongly peraluminous granite ; 12—heat generation ; 13—boundary**

The exposed magmatic rocks in this area are mainly large granite batholiths, such as the Dadongshan-Guidong composite batholith, the Fogang composite batholith, and the Jiufeng-Zhuguangshan composite batholith, dating from the Caledonian to the late Yanshanian, with the early Yanshanian granite being the most widely distributed (Shen Weizhou et al., 1999; Sun Tao, 2006; Zhou Xinmin, 2007; Sun et al., 2015). Notably, late Yanshanian granitoids are not abundant in the Nanling region (Zhou and Li, 2000; Li et al., 2014), while the southeast coastal areas are mainly composed of late Yanshanian granites (Figure 1). There are three types of basins in the region: foreland-like basins, rift basins, and fault basins. Among them, fault basins are the most extensive, mainly distributed along the Ganjiang Fault Zone and the eastern part of the Sihui-Wuchuan Fault Zone (Shu Liangshu et al., 2004; Zhou Xinmin, 2007). Influenced by rock masses and faults, numerous hot springs are exposed in the Nanling region. In particular, 36 hot springs have been discovered in northern Guangdong, with 32 located within granite masses (Yao Jin et al., 2011), indicating abundant geothermal water resources in the region, closely associated with granite.

The southeast coastal region, located in the southeastern part of China, is characterized by an extensive distribution of Late Mesozoic volcanic-intrusive complexes. It constitutes a significant component of the circum-Pacific magmatic rock belt (Wang Dezi et al., 1999; Zhou and Li, 2000) (Figure 1). In terms of tectonic settings, this region lies within the interaction zone between the Eurasian Plate and the Pacific Plate (Wang Peizong et al., 1993). Since the Late Jurassic, apart from localized EW-trending structures in South China, most structures are oriented NE and NNE, indicating a major change in tectonic patterns related to the intense subduction of the ancient Pacific Plate towards the continent and subsequent extension-thinning processes (Wang Dezi and Zhou Xinmin, 2002; Shu Liangshu et al., 2002). The distribution of rock bodies and basins in the southeast coastal region is also predominantly NE and NNE. This study focuses on the Zhangzhou area in Fujian Province, situated between E117°–118° and N23.8°–25°, with a land area stretching 187 km north-south and 127 km east-west, covering approximately 13,000 km². The Zhangzhou rock body is the primary subject of this study, with an exposed area of about 900 km², sandwiched between the Changle-Nan'ao fault zone and the Zhenghe-Dapu fault zone (Li et al., 2014; Wang Andong et al., 2015). The exposed rocks are predominantly late Yanshanian granites. The region features pronounced basin development, with basin elevations primarily controlled by acidic to intermediate-acidic volcanic rocks and hypersuperficial acidic rock bodies (Ma Xingyuan et al., 1983; Li Guohua et al., 2008). Zhangzhou is located in an area of active plate movement with a relatively thin crust. The southeast coastal geothermal belt, where Zhangzhou is situated, is one of China's four major geothermal belts, abundant in geothermal resources and characterized by intense hydrothermal activities. It is the most densely populated region for low-to-medium temperature hot springs in China (Pang Zhonghe et al., 1987; Wang Jiyang, 1996; Wang Guiling et al., 2000).

### 2.2 Petrological features

The Nanling region is extensively exposed to granite, primarily of the S-type, which has a close relationship with rare metal mineralization and serves as the cradle for granite and mineralization studies in China (Zhou and Li, 2000, 2006; Li Xianhua et al., 2007; Huang et al., 2015). This area is dominated by multi-stage composite rock bodies, such as the Zhuguang, Guidong, Fogang, Xiazhuang, and Qitianling rock bodies. According to research statistics by Li Xianhua et al. (2007) and Chen Peirong et al. (2002), most of these are Early Yanshanian granites (165~160 Ma) with varying exposed areas. For instance, the Fogang rock body, with an exposed area exceeding 6000 km2, is the largest and most representative granite body in the Nanling region. The Early Yanshanian granites in the Nanling region are dominated by grayish-white biotite monzogranite and flesh-red biotite syenogranite, with some granodiorite as well (Figure 2A, B). They exhibit holocrystalline medium- to coarse-grained to inequigranular textures, porphyritic structures, and massive constructions. The primary constituent minerals include quartz, plagioclase, and orthoclase, with secondary minerals such as biotite, muscovite, and chlorite, and occasionally amphibole. The accessory minerals are primarily epidote and magnetite.

The granite types in the southeast coastal region are mainly of the I-A type, with large-scale exposure of Late Yanshanian granites (Wang Dezi and Zhou Xinmin, 2002; Li et al., 2014), further indicating that the rock bodies in the southeast coastal region and the Nanling region formed under different tectonic settings. The granite types in the southeast coastal region, represented by the Zhangzhou rock body, are complex and diverse, mainly including granodiorite, medium-grained granite, porphyritic granite, and biotite granite (Figure 2C, D). They exhibit porphyritic structures and massive constructions, with primary minerals such as quartz, amphibole, and predominantly potassium feldspar. The granite bodies in the southeast coastal region contain numerous micro-mafic enclaves (MMEs) and show mafic dike intrusions (Figure 2D), which are the most prominent field features of this region and distinctly different from the Nanling region. These features indicate intense crust-mantle mixing in this region, with mantle-derived heat making a significant contribution to the surface heat flow (Wang Dezi and Zhou Xinmin, 2002; Wang et al., 2016).

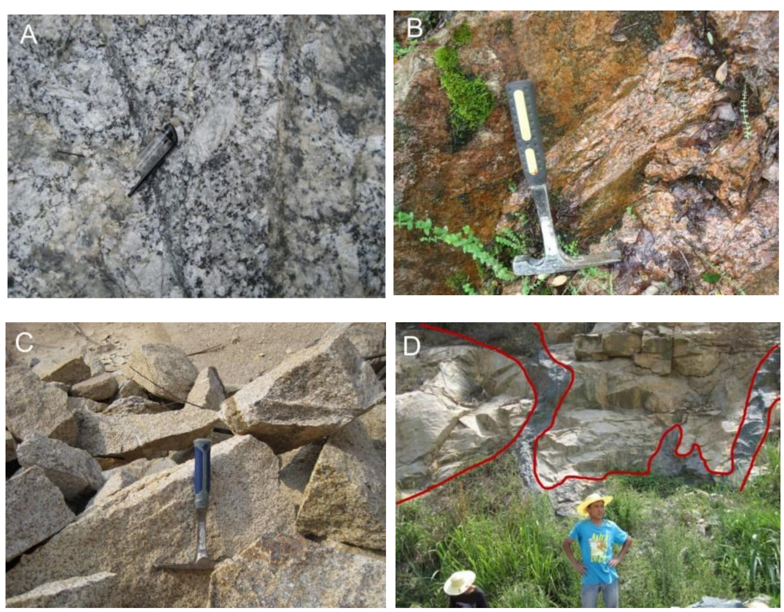


**Fig.2 The field photographs showing plutons from of Nanling area (A、B) and Zhangzhou area (C、D)**

### 2.3 Analytical methods

Radioactive elements exist in natural rocks, and radioactive decay heat is one of the primary sources of heat within the lithosphere. Among the numerous types of radioactive elements, only those with significant abundance, high heat production, and long half-lives are of geothermal research significance. U, Th, and $^{40}K$ possess these characteristics (Rybach et al., 1978; Zhao et al., 1995; Wang et al., 2015). In this study, measurements of radioactive heat-producing elements were conducted on 512 collected fresh rock samples, including 177 from the Nanling region and 335 from the Zhangzhou region. After indoor processing of the fresh rock samples, the measurements of U, Th, and K contents were completed by Guangzhou ALS Analytical and Testing Center. The ICP-MS solution method was used to determine the U and Th contents, with data accuracy within ±10%. The X-ray fluorescence spectrometry (XRF) method was employed to measure the K2O content, with an analytical accuracy within ±2%.

## 3. RESULTS AND DISCUSSIONS

### 3.1 Characteristics of radioactive heat-producing element content in rocks

The field gamma value is a crucial indicator of radioactive intensity, indirectly reflecting the abundance of radioactive heat-producing elements within the measured area. Field studies have revealed that the field gamma values of the Zhangzhou rock mass in the southeastern coast are relatively low, generally ranging between 20-50 γ. In contrast, the gamma values of granite bodies in the north of Guangdong and south of Jiangxi in southeastern China are generally higher, with a broader range of 40-180 γ, primarily falling between 60-110 γ (Figure 4). Although field gamma values represent qualitative to semi-quantitative analytical results, they align well with field geological characteristics. The granite in the Nanling Mountains, specifically in the north of Guangdong and south of Jiangxi, is predominantly S-type, rich in radioactive heat-producing elements such as uranium (U), thorium (Th), and potassium (K). Many granite bodies are uranium-ore-bearing granites. By contrast, the granite in the Zhangzhou area is mainly I-A composite granite, with a relatively significant contribution from mantle-derived materials. The relatively low content of incompatible radioactive heat-producing elements U, Th, and K results in naturally lower field gamma values.

Based on the newly measured data from the southeastern coastal regions presented in this paper (Table 1), combined with the findings of Sun et al. (2015), Wang Andong et al. (2015), and Yang Lizhong (2016) from our research group, the results show that the thorium (Th) content in granite from the Nanling region and the southeastern coastal regions ranges between 40-51 ppm and 14.58-25.3 ppm, respectively, with average values of 41.8 ppm and 23.67 ppm. The uranium (U) content is 9-18 ppm and 4.05-9.1 ppm, averaging at 12.6 ppm and 6.25 ppm, respectively. The potassium (K) content varies between 4.02-5.43% and 1.70-5.25%, with average values of 4.97% and 4.24%, respectively. The Th and U contents in the Nanling region are significantly higher than those in the southeastern coastal regions. Notably, the Fugang rock mass exhibits the highest Th content of 51 ppm within the region, and the Xiazhuang rock mass has the highest U content of 18 ppm. Except for the Liren School core, the K content of both rock masses is nearly identical.

**Table 1 Granite radioactive geochemical characteristics of Nanling area and Zhangzhou area**

| Location (Number of samples) | | Th/ppm | U/ppm | $K_2O$/% | References |
|---|---|---|---|---|---|
| Nanling Region | Zhuguang（128） | 40 | 11 | 5.43 | Sun et al.（2015） |
| | Guidong（4） | 41 | 9 | 4.02 | |
| | Xiazhuang（26） | 31 | 18 | 5.34 | |
| | Reshui（12） | 46 | 14 | 4.95 | |
| | Fogang（37） | 51 | 11 | 5.12 | |
| SE-China Coastal Region | Zhangzhou（219） | 25.3 | 6.45 | 4.62 | Wang et al.（2016） |
| | Liren School（11） | 24.7 | 9.1 | 1.70 | |
| | Zhishan Park（27） | 35.2 | 6.8 | 5.25 | |
| | Longjiao core sample（58） | 14.58 | 4.84 | 4.44 | authors |
| | Dongsi core sample（20） | 18.58 | 4.05 | 5.22 | authors |

### 3.2 Characteristics of radioactive heat production rate in rocks

Using the calculation method recommended by Rybach, it was found that both the Nanling region and the southeastern coastal region have relatively high average heat production rates per unit volume (Table 2). The range of radioactive heat production rates in the Nanling region is 2.45 to 7.11 $\mu W/m^3$. In the southeastern coastal region, the heat production rates for fresh outcrops range from 1.25 to 6.38 $\mu W/m^3$, and for drill hole samples, the range is 1.35 to 5.4 $\mu W/m^3$. The average radioactive heat production rates of granite in the Nanling region and the southeastern coastal region are 5.51 $\mu W/m^3$ and 3.52 $\mu W/m^3$, respectively, both exceeding the worldwide average heat production rate of granite at 2.5 $\mu W/m^3$ (McLaren et al., 2003). Overall, the heat production rates of rock masses in the Nanling region are significantly higher than those in the southeastern coastal region, with the highest radioactive heat production rate observed in the Reshui rock mass at 7.11 $\mu W/m^3$. The abundance of heat-producing elements in rocks from these two regions differs significantly, which corresponds to the field test results showing higher field gamma values in the Nanling region compared to the southeastern coastal region. The field gamma values and the heat production from radioactive element decay indicate that the content of radioactive elements and heat production rates in the Zhangzhou area of the southeastern coast are lower than those in the southern

Jiangxi-northern Guangdong region of the Nanling area, suggesting that the crustal heat contribution to surface heat flow in the southeastern coastal region is lower than that in the Nanling region, with mantle heat contribution playing a more significant role.

By synthesizing previous data on major and trace elements in granite bodies within the region (Department of Geology, Nanjing University, 1981; Hao Yi, 2010; Bai Daoyuan et al., 2007; Xu Yan et al., 2013; Wang Lili, 2015), and through corresponding calculations, the heat production rates of granite from different periods have been reflected. Influenced by magmatic activities of different periods, rocks from the Caledonian period exhibit the lowest heat production rates, while those from the Yanshanian period show higher rates (Figure 5). The dominant rocks in the Nanling region and the southeastern coastal region were formed during the early and late Yanshanian periods, respectively, with the former having higher heat production rates than the latter. There may be two reasons for this phenomenon: Firstly, remelted granite has a higher heat production rate, followed by syntectonic granite, and mantle-derived granite has the lowest rate (Zhao Ping, 1995; Wang Dezhi and Zhou Xinmin, 2002; Li Xianhua et al., 2007). The early Yanshanian period was the main stage of granite formation in the Nanling region, characterized by large-scale, multi-phase remelted composite rock bodies. Magmatic activities over multiple stages facilitated the migration of heat-producing elements to the shallow crust, while granite in the southeastern coastal region is mainly mantle-derived and syntectonic. Secondly, collision events and post-collision crustal extension during the Late Mesozoic period formed large-scale fault basins and fault structures in South China, providing favorable conditions for the migration of heat sources in both the Nanling and southeastern coastal regions. This period was also crucial for large-scale uranium mineralization in the Nanling region and for rock formation in the southeastern coastal region (Li Xianhua et al., 1997; Wang Dezhi and Zhou Xinmin, 2002; Deng Ping et al., 2003). Therefore, compared to the southeastern coastal region, the Nanling region has better enrichment conditions for radioactive heat-producing elements. Considering the relatively high radioactive heat production rate values in the Nanling region, it can be termed high heat-producing granite (HHPG) (Chopra and Wyborn, 2003).

**Table 2 Granite radioactive heat generation of Nanling area and Southeast coastal area**

| Location | | A/μW/m³ | Reference |
|---|---|---|---|
| Nanling Region | Zhuguang（128） | 5.51 | Sun et al.（2015） |
| | | 6.89 | |
| | | 6.34 | |
| | | 5.78 | |
| | Guidong（4） | 7.44 | |
| | Xiazhuang（26） | 6.98 | |
| | | 7.03 | |
| | Reshui（12） | 7.11 | |
| | Fogang（37） | 7.56 | |
| | | 6.34 | |
| SE-China Coastal Region | Zhangzhou（219） | 3.68 | Wang et al.（2016） |
| | Liren School（11） | 4.05 | |
| | Zhishan Park（27） | 4.39 | |
| | Longjiao core sample（58） | 2.52 | authors |
| | Dongsi core sample（20） | 2.97 | authors |

**3.3 Deep temperature modeling**

Assuming a surface heat flow of 90 mW/m² (Table 3) and 80 mW/m² (Table 4) with a heat conductivity of the cover ranging from 1 to 3 W/mK, and a cover thickness (d) varying from 1 to 4 km in Nanling region, the following simulation results are presented for the base temperature (in Celsius) , under the conditions of Qm = 25 mW/m², granite thermal conductivity of 1.8 W/m•K, and a radioactive heat production rate of A = 6 μW/m³ . The surface temperature is set at 25° C.

Assuming a surface heat flow of 70 mW/m² (Table 5) and 60 mW/m² (Table 6) with a heat conductivity of the cover ranging from 1 to 3 W/mK, and a cover thickness (d) varying from 1 to 4 km in Zhangzhou region, the following simulation results are presented for the base temperature (in Celsius) , under the conditions of Qm = 50 mW/m², granite thermal conductivity of 1.8 W/m•K, and a radioactive heat production rate of A = 3.5 μW/m³ . The surface temperature is set at 25° C.

**Table 3 The basal temperatures with different thicknesses and thermal conductivities of cover assuming a surface heat flow of 90 mW/m² in Nanling region**

| Thickness of cover（Km） | k=1 W/m•K | k=2 W/m•K | k=3 W/m•K |
|---|---|---|---|
| d=1 | 115.8 | 70.47 | 55.36 |

| | | | |
|---|---|---|---|
| d=2 | 206.5 | 115.8 | 85.6 |
| d=3 | 297.5 | 161.3 | 115.9 |
| d=4 | 388.6 | 206.9 | 146.3 |

**Table 4 The basal temperatures with different thicknesses and thermal conductivities of cover assuming a surface heat flow of 80 mW/m² in Nanling region**

| Thickness of cover（Km） | k=1 W/m•K | k=2 W/m•K | k=3 W/m•K |
|---|---|---|---|
| d=1 | 105.4 | 65.44 | 52.05 |
| d=2 | 186 | 105.8 | 78.93 |
| d=3 | 267 | 146.2 | 105.9 |
| d=4 | 371 | 186.8 | 132.9 |

**Table 5 The basal temperatures with different thicknesses and thermal conductivities of cover assuming a surface heat flow of 70 mW/m² in Zhangzhou region**

| Thickness of cover（Km） | k=1 W/m•K | k=2 W/m•K | k=3 W/m•K |
|---|---|---|---|
| d=1 | 95.67 | 60.41 | 48.66 |
| d=2 | 166.3 | 95.72 | 72.19 |
| d=3 | 237.1 | 131 | 95.8 |
| d=4 | 308.2 | 166.7 | 119.5 |

**Table 6 The basal temperatures with different thicknesses and thermal conductivities of cover assuming a surface heat flow of 60 mW/m² in Zhangzhou region**

| Thickness of cover（Km） | k=1 W/m•K | k=2 W/m•K | k=3 W/m•K |
|---|---|---|---|
| d=1 | 85.61 | 55.38 | 45.3 |
| d=2 | 146.2 | 85.67 | 65.49 |
| d=3 | 207 | 116.1 | 85.75 |
| d=4 | 268 | 146.6 | 106.1 |

## 4. CONCLUSIONS

Based on a comprehensive comparison of geology, geophysics, radioactive geochemistry, and geothermics between the Nanling region and the southeastern coastal region, the following conclusions are drawn:

(1) The distribution of rock bodies and basins in the Nanling region is primarily in an east-west orientation, while in the southeastern coastal region, it is mainly in a north-northeast orientation. The former is controlled by the Tethyan tectonic domain, while the latter is controlled by the paleo-Pacific tectonic domain.

(2) There are significant differences in geophysical characteristics such as gravity, electromagnetism, seismicity, and radioactivity between the Nanling region and the southeastern coastal region. Overall, from the inland to the coastal areas, the depth of the Moho surface decreases, the deep temperature gradually rises, and the burial depth of the top of the asthenosphere gradually shallows.

(3) Through radioactive geochemical studies of numerous surface and core samples, it has been determined that the average radioactive heat production of granite in the Nanling region is 6.41 μW/m³, classifying it as high heat-producing granite (HHPG). In contrast, the average heat production rate of granite in the Zhangzhou region is 3.52 μW/m³. Both values are higher than the world average for granite, which is 2.50 μW/m³.

(4) The deep temperature modeling data suggest that both Nanling region and Southeastern coastal region have good heat source conditions. However, the potential for hot dry rock resources hinges on whether high-thermogenic concealed granites and their overlying low-thermal conductivity sedimentary caprocks can be effectively marched-.

**REFERENCES**

Arevalo, R., McDonough W.F., Luong, M.: The K/U ratio of the silicate Earth: Insights into mantle composition, structure and thermal evolution. Earth and Planetary Science Letters 278(3), (2009), 361-369. doi:10.1016/j.epsl.2008.12.023

Clauser, C., and Huenges, E.: Thermal conductivity of rocks and minerals. In Ahrens TJ (Ed.) Rock physics & phase relations: A handbook of physical constants, Washington DC, AGU Publisher, 3, (1995), 105-126. doi: 10.1029/RF003p0105

Goes, S., Hasterok, D., Schutt, D.L., et al.: Continental lithospheric temperatures: A review, Physics of the Earth and Planetary Interiors, https://doi.org/10.1016/j.pepi.2020.106509.

Hasterok, D., Webb, J.: On the radiogenic heat production of igneous rocks. Geoscience Frontiers, 8(5), (2017), 919-940.

Hasterok, D., Chapman, D.S.: Heat production and geotherms for the continental lithosphere. Earth Planet Science Letters, 307, (2011), 59-70.

Hasterok, D., Gard, M., Cox, G., et al.: A 4 Ga record of granitic heat production: implications for geodynamic evolution and crustal composition of the early earth. Precambrian Research, 331, (2019), 105375.

He, L.J.: Thermal regime of the North China Craton: implications for carton destruction. Earth-Science Reviews 140, (2015), 14-26. doi: 10.1016/j.earscirev.2014. 10.011

Hu, S.B., He, L.J., Wang, J.Y.: Heat flow in the continental area of China: a new data set. Earth and Planetary Science Letters 179(2), (2000), 407-419. doi:10.1016/S0012- 821X(00)00126-6

Hu, S.B., He, L.J., Wang, J.Y.: Compilation of heat flow data in the China continental area (3rd edition). Chinese Journal of Geophysics 44(5), (2001) , 611-626 (in Chinese with English abstract).

Jaupart, C., Mareschal, J.C., Guillou-Frottier, L., Davaille, A.: Heat flow and thickness of the lithosphere in the Canadian Shield. Journal of Geophysical Research: Solid Earth 103(B7), (1998) , 15269-15286. doi: 10.1029/98JB01395

Jaupart, C., Mareschal, J.C., Larotsky, L.: Radiogenic heat production in the continental crust. Lithos, 262, (2016), 398-427.

Joshua, E., Ehinola, O., Akpanowo, M., Oyebanjo, O.: Radiogenic heat production in crustal rock samples of Southeastern Nigeria. European Journal of Scientific Research 23(2), (2008) , 305-316.

Li, Z, Qiu, J.S., Yang, X.: A review of the geochronology and geochemistry of Late Yanshanian (Cretaceous) plutons along the Fujian costal area of southeastern China: implications for magma evolution related to slab break-off and rollback in the Cretaceous. Earth-Science Reviews 128, (2014) , 232-248. doi:10.1016/j.earscirev.2013. 09.007

Li, Y., Luo, J., Tian, J., et al.: Formation of the hydrothermal system from granite reservoir for power generation in igneous rock areas of South China. Geothermics, 110(102673), (2023), 1-15.

Liu, X., Jahn, B. M., Zhao, Y., et al.: Late Pan-African granitoids from the Grove Mountains, East Antarctica: age, origin and tectonic implications. Precambrian Research, 145(1), (2006), 131-154.

Liu, X., Zhang, D., Yang, J., Xiao, C., et al.: High heat producing granites and prolonged extraction of tungsten and tin from melts. Geochimica et Cosmochimica Acta, 348, (2023), 340-354.

Li, Y., Luo, J., Tian, J., et al.: Formation of the hydrothermal system from granite reservoir for power generation in igneous rock areas of South China. Geothermics, 110(102673), (2023), 1-15.

Ma, F., Sun, H.L., Lin, W.J., Gan, H.N., Wang, G.L.: Target site selection and indexes matrix evaluation of EGS demonstration in China. Science and Technology Review 33(8), (2015) , 41-47. doi: 10.3981/j.issn.1000-7857.2015.08.006

Mareschal, J.C., Nyblade, A., Perry, H.K.C., Jaupart, C., Bienfait, G.: Heat flow and deep lithospheric thermal structure at Lac de Gras, Slave Province, Canada. Geophysical Research Letters, 31(12), (2004), doi: 10.1029/2004GL020133

McLaren, S., Sandiford, M., Hand, M., Neumann, N., Wyborn, L., Bastrakova, I.: The hot southern continent: heat flow and heat production in Australian Proterozoic terranes. Geological Society of America Special Papers 372,(2003), 157-167. doi: 10.1130/0-8137-2372-8.157

McLennan, S., Taylor, S.: Heat flow and the chemical composition of continental crust. The Journal of Geology 104(4), (1996), 369-377. doi: 10.1086/629834

Morgan, P.: The thermal structure and thermal evolution of the continental lithosphere. Physics and Chemistry of the Earth 15, (1984), 107-193. doi:10.1016/0079- 1946(84)90006-5

Pang, Z.H.: Zhangzhou basin geothermal system. Dissertation. Institute of Geology, Academia Sinica (in Chinese with English abstract) (1987).

Pang, Z.H.: Origin of sulphur compounds and application of isotope geothermometry in selected geothermal systems of China. In: IAEA [Ed.] Use of isotopes to trace the origin of acidic fluid in geothermal systems (2005).

Pollack. H., Chapman, D.: On the regional variation of heat flow, geotherms, and lithospheric thickness. Tectonophysics 38(3), (1977), 279-296. doi:10.1016/0040-1951(77) 90215-3

Rybach, L.: Determination of heat production rate. In: Hänel et al. [Ed.] Handbook of Terrestrial Heat Flow Density Determination, (1988), 125-142, Kluwer, Dordrecht.

Smithson, S., Decker, E.: A continental crustal model and its geothermal implications. Earth and Planetary Science Letters 22(3) , (1974) 215-225. doi:10.1016/ 0012-821X(74)90084-3

Sun, Z.X., Wang, A.D., Liu, J.H., Hu, B.Q., Chen, G.X.: Radiogenic Heat Production of Granites and Potential for Hot Dry Rock Geothermal Resource in Guangdong Province, Southern China. Proceedings World Geothermal Congress 2015, Melbourne, Australia, (2015) , 19-25.

Wang JY, Huang SP (1988) Compilation of heat flow data in the China continental area. Scientia Geologica Sinica 2: 196-204 (in Chinese with English abstract).

Wang JY, Huang SP (1990) Compilation of heat flow data in the China continental area (2nd edition). Seismology and Geology 12(4): 351-366 (in Chinese with English abstract).

Wang, J.Y.: Low-medium temperature geothermal system of convective type. Science press, Beijing (in Chinese with English abstract) (1993).

Wang, D.Z., Zhou, X.M.: The genesis of Late Mesozoic granitic volcanic-intrusive complex from SE China and its crustal evolution. Science Press, Beijing (in Chinese) (2002).

Wang, A.D., Sun, Z.X., Hu, B.Q., Liu, J.H., Liu, C.D.: Guangdong, a potential province for developing Hot Dry Rock geothermal resource. Applied Mechanics and Materials 492, (2014) , 583-585. doi: 10.4028/www.scientific.net/AMM.492.583

Xiao, Z., Wang, S., Qi, S., et al.: Petrogenesis, tectonic evolution and geothermal implications of Mesozoic granites in the Huangshadong geothermal field, South China. Journal of Earth Science, 31(1), (2020), 141-158.

Xiong, S.B., Jin, D.M., Sun, K.Q., Zou, Y.S., Fan, X.B., Du, X.G.: Some characteristics of deep structure of the Zhangzhou geothermal field and it's neighbourhood in the Fujian province. Acta Geophysica Sinica 34(1), (1991), 55-63 (in Chinese with English abstract).

Zhao, P., Wang, J.Y., Wang, J.A., Luo, D.G.: Characteristics of heat production distribution in SE China. Acta Petrologica Sinica 11(3), (1995), 292-305 (in Chinese with English abstract).

Zhao, P., He, L.J., Liu, S.W., Sun, Z.X.: Thermal structure of the Lithosphere. In Wang et al. [Ed.] Geothemics and Its Applications, Science Press (in Chinese with English abstract) (2015).

Zhou, X.R., Chen, A.G., Song, X.H., Wu, K.L., Yan, B.Q., Wu, Z.T.: Rb-Sr isotope ages and prelimary studies of genesis on Zhangzhou granitoid intrusive body, Fujian Province. Bulletin of Nanjing Institute of Geological Mineral and Resources 9(2), (1988), 55-67 (in Chinese with English abstract).

Zhou, X.M., Li, W.X.: Origin of Late Mesozoic igneous rocks in Southeastern China: implications for lithosphere subduction and underplating of mafic magmas. Tectonophysics, 326(3), (2000) , 269-287.

Zhou, Z.M., Ma, C.Q., Qi, S.H., et al.: Late Mesozoic high-heat-producing (HHP) and high-temperature geothermal reservoir granitoids: the most significant geothermal mechanism in South China. Lithos, (2020), 366-367, 105568.

Zhu, C.Q., Xu, M., Qiu, N.S., et al.: Comparison of γ-ray spectrometry and ICP-MS methods for measuring radioactiveheat-producing elements of rocks: a case study on borehole samples from the Sichuan Basin, China. Journal of Radioanalytical & Nuclear Chemistry, 314(3), (2017), 1527-1537.