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Influence of granite distribution on formation and enrichment of deep geothermal resources in Fujian, Guangdong and Hainan Provinces

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ABSTRACT

A large number of granitoids are developed in Fujian, Guangdong and Hainan Provinces. Influenced by regional geology and tectonics, the formation process and geodynamic background are complex and diverse. Granite belongs to the middle and deep intrusive rocks, itself contains more radioactive thermal minerals, compact and hard, has good thermal conductivity, is a good heat conductor and heat storage body. Therefore, if the fractures in the granite body are developed and the cap layer is suitable, the deep medium-high temperature geothermal system can be formed. How to identify high quality granite fissure type heat reservoir becomes the key to search for deep geothermal resources. In order to find out the controlling effect of granite distribution and tectonic action on the formation and enrichment of deep geothermal resources in the area, the spatial distribution and intrusion time span of granite in the Fujian, Guangdong and Hainan Provinces, combined with the regional geothermal display, tectonic development and cap layer, The spatial distribution of high quality granite heat reservoir and its controlling effect on the formation and enrichment of deep geothermal resources in the area are defined, and the future exploration direction and breakthrough fields of deep geothermal favorable areas are pointed out.

1.INTRODUCTION

large number of granitoids are developed in the Fujian, Guangdong and Hainan Provinces, which are influenced by regional geology and tectonics, and their formation processes and geodynamic backgrounds are complex and diverse (Shu, et al., 2020;Zhang, et al., 2020;Wang, et al., 2021; Zhang, et al., 2021; Chen, et al., 2022; Luo, et al., 2022; Yan, et al., 2022a, 2022b).Granite belongs to the middle and deep intrusive rocks, itself contains more radioactive thermal minerals, compact and hard, has good thermal conductivity, is a good heat conductor and heat storage body. Therefore, if the fractures in the granite body are developed and the cap layer is suitable, deep medium-high temperature geothermal system can be formed (Wollenberg, et al., 1987;Qiu, et al., 2015; Zhou, 2015; Artemieva, et al., 2017; Zhou, et al., 2020; Ma, et al., 2021). The economy of Fujian, Guangdong and Hainan Provinces is developed, the population is large, and the demand for energy is relatively strong. As a green, low-carbon and large-scale geothermal energy, it has become one of the most ideal alternative energy sources in the region. Therefore, if the fractures in the granite body are developed and the cap layer is suitable, the deep medium-high temperature geothermal system can be formed. How to identify high quality granite fissure heat reservoir becomes the key to search for deep geothermal resources (He, et al., 2017, 2020;Zhang, et al., 2017, 2020; Zhang, et al., 2022).In order to find out the influence of granite distribution and tectonic action on the formation and enrichment of deep geothermal resources in the area, the spatial distribution and intrusion time span of granite in the Fujian, Guangdong and Hainan Provinces combined with the regional geothermal display, tectonic development and caprock, the spatial distribution of high quality granite heat reservoir and its influence on the formation and enrichment of deep geothermal resources in the area are defined, and the future exploration direction and breakthrough fields of deep geothermal favorable areas are pointed out.

2.GEOTHERMAL AND GEOLOGICAL BACKGROUND

The South China Plate is adjacent to the north, southwest and southeast of the North China Plate, the India Plate and the Philippines Plate respectively. The Jiangshan-Shaoxing and Pingxiang-Yushan faults are the internal boundaries of the South China Plate, which are divided into the Yangtze Craton and the Cathaysia block. It is generally believed that the two blocks were independent blocks before the Neoproterozoic era, and the collision occurred during the Neoproterozoic era. Finally, unified South China continent was formed (Deng, et al.,1996;Ren, 1999; Wang, et al., 2000; Wang, et al., 2003; Yu, et al., 2006; Xu, et al., 2007; Shu, 2012; Li, et al., 2013; Zhang, et al., 2013; Chen et al., 2022; Yan, et al., 2022a, 2022b). Since the Archean, the South China Plate has undergone the intense transformation of the Caledonian, Mesozoic Indosinian orogeny and Yanshanian extensional cleavage. It is distinguished from other parts of the world by multi-cycle tectonic evolution, diagenesis, mineralization and sedimentation (li, et al., 2007;Liu, et al., 2013; Zhang, et al., 2013; Zhou, 2015; Wang, 2017).Among them, the most remarkable granitic magmatism is widely developed at different periods, including Lvliang (1900Ma±), Jinning (1000-800 Ma), Caledonian (540-360Ma), Hercynian-Indosinian (360-195Ma) and Yanshanian (195-65 Ma).Among them, Yanshanian magmatic activity was the strongest, followed by Hercynian-Indosinian (Figure 1).Since the Proterozoic eon, with the general southeastward (oceanic) migration of tectonic zones, the age of granite formation tends to be younger, and the distribution of some granites may be reversed (inland) beyond that of tectonic zones migration. As a result, multi-stage and multi-stage compound granites are widely found in South China (Wang, et al., 2003).Due to its special tectonic location, Hainan Island has been affected by the expansion of the South China Sea since Cenozoic era, separated from the mainland by the Qiongzhou Strait, and its tectonic evolution is relatively independent. Its granites are widely distributed and developed from the Mesoproterozoic to the Late Cretaceous, but are mainly in the Hercynian to Indo-Chinese period (Figure 2).

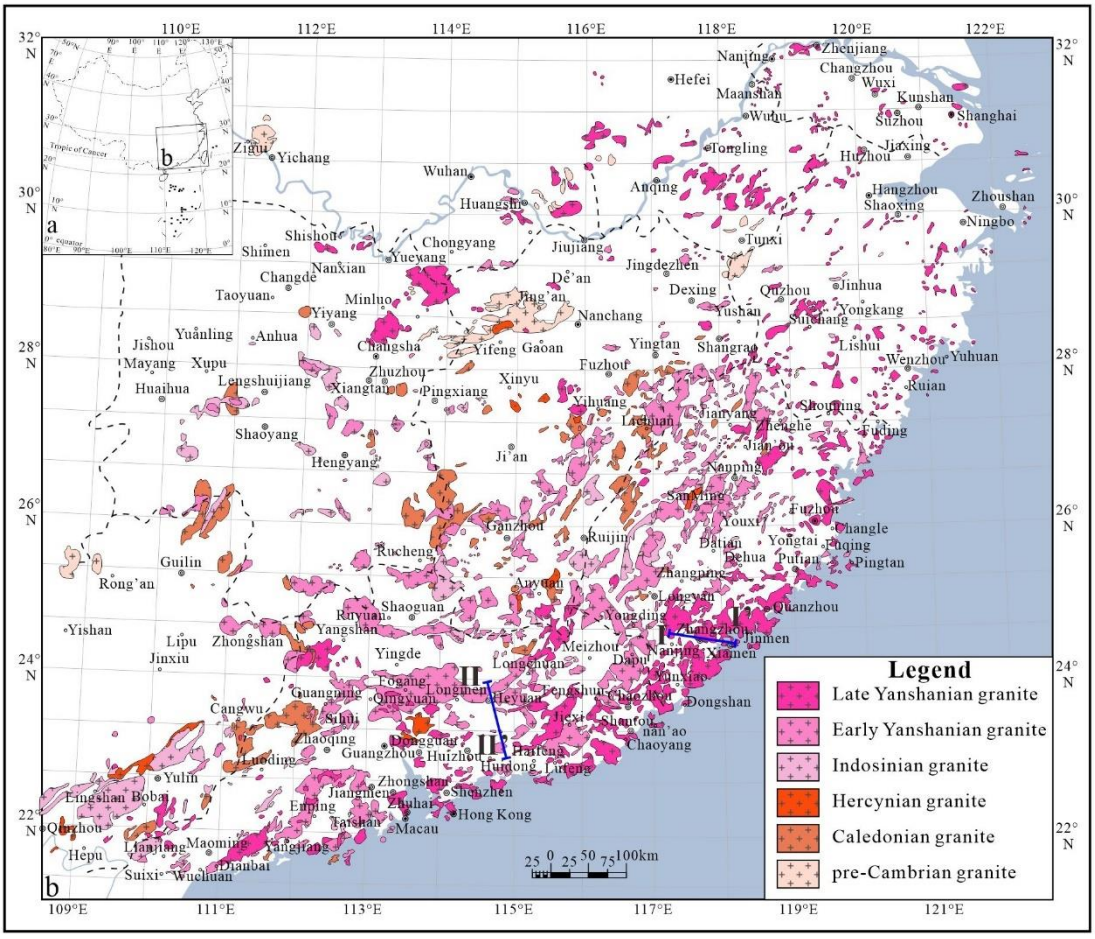

Figure 1: Granite distribution map of Cathaysia block(modified after Sun, 2006)

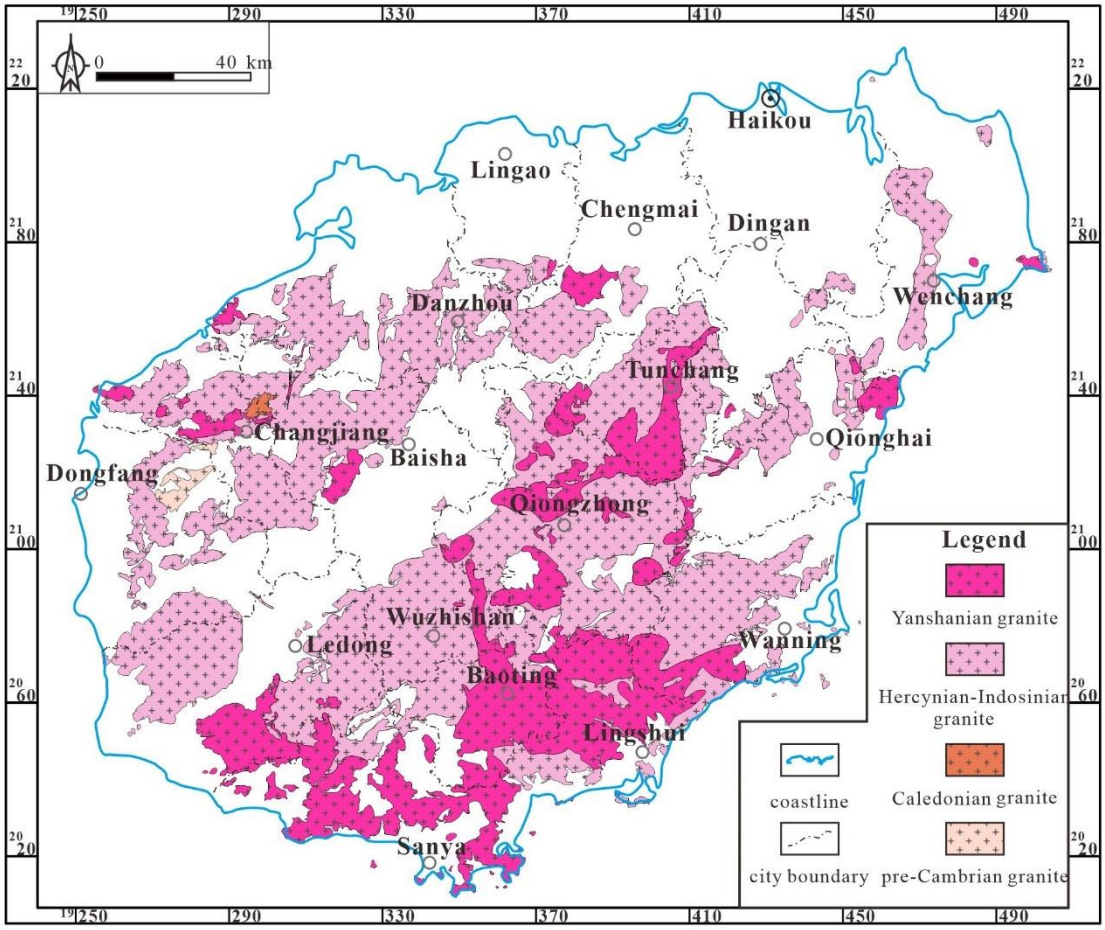

Figure 2: Granite distribution map of Hainan island

2.1 Terrestrial heat flow characteristics

The igneous rocks in South China are tectonically complex, and the land heat flow in South China is distributed in distinct zones, which is high in the east and southwest and low in the middle. The regional average earth heat flow value is 64.2 mW/m^2, slightly higher than the average earth heat flow in mainland China (61mW/m^2), and very close to the global average earth heat flow in continental areas (65 mW/m^2).The abnormal high value points are mainly distributed along the suture zone of plate boundary and the active zone of deep fault (Chapmen, et al., 1975;Wang, et al., 1988; Pollack, et al., 1993; Chen et al., 1996; He, et al., 2001; Jiang, et al., 2016, 2019).There are two northeast-trending high value anomaly zones in the eastern part of South China. One is the southeast coastal high heat flow anomaly zone represented by Fuzhou-Meizhou, and the other is the Northeast-trending high heat flow anomaly zone distributed in the Wuchuan-Sihui fault zone with beaded distribution of Maoming, Leizhou Peninsula and Qiongbei. These two anomaly zones are characterized by heat flow values greater than 80 mW/m^2.The low heat flow in the central region is distributed from south to north, and the wide and gentle low heat flow distribution area runs north-south from Baise to the southern foot of Dabie Mountains, while the high heat flow distribution area in the western region is only concentrated in southwest Yunnan (Yuan, et al., 2006;Qiu, et al., 2007; Zhang, et al., 2018; Zhao, et al., 2021).The high heat flow anomaly zone in the east is closely related to the formation and distribution of deep geothermal resources in this area.

2.2 Characteristics of geothermal reservoir

In the igneous rock area of South China, granite and fissure heat reservoirs with similar compositions are the most developed, which can not only be used as heat source to generate radioactive heat, but also can be used as heat reservoir to store geothermal resources under certain conditions.

The volcanic rocks in Fujian Province consist of Proterozoic Eon, Carboniferous, Mesozoic and Neogene, which constitute four major cycles of volcanic activity. Proterozoic volcanic rocks are distributed in northwest Fujian and western Fujian, and most of them are produced in the form of volcanic interlayers. The protolith is intermediate acid pyroclastic rock, rhyolite, basalt-andesite, and so on. Carboniferous volcanic rocks are interbedded with basalt and acid volcanic rocks in southwest Fujian and central Fujian. The Mesozoic volcanic rocks are most developed in the east, all of which are continental eruptions. The ages are concentrated in the Late Jurassic to Early Cretaceous, and the Late Triassic to Early Jurassic is dominated by Andesitic and basaltic andesitic volcanic rocks with a small amount of acid pyroclastic rocks. In the late Jurassic, dacite-rhyolite volcanic rocks were dominant, with a small amount of basalt-Andesitic volcanic rocks. The early Cretaceous is dominated by dactylitic volcanic rocks. Neogene volcanic rocks can only be found in southeastern coastal areas and local areas of western Fujian. They are ultrabasic and basic volcanic rocks. The intrusive rocks in the province have a wide range of distribution and a large span of time. The Caledonian, Hercynian, Indosinian, Yanshan and Himalayan were developed, especially the Yanshan intrusive rocks have the largest scale, and most of the rocks are granite (more than 95% of the total volume of intrusive rocks).In terms of spatial distribution, Caledonian intrusive rocks are distributed in western Fujian, Hercynian and Indosinian intrusive rocks are mainly developed in central Fujian and southwest Fujian, middle Yanshanian (Late Jurassic) intrusive rocks are widely developed in the whole province, and late Yanshanian (Early Cretaceous) intrusive rocks are mostly exposed in eastern Fujian. The Himalayan intrusive rocks are mainly gabbro and diabase dikes scattered in central and southern Fujian (Liu, 1992).

In Guangdong Province, magma activity is frequent and intense, and its distribution area accounts for 40% of the land area. The intrusive rocks are mainly granitic, with a small amount of mafic, ultramafic and alkaline rocks. The volcanic rocks are mainly continental andesite-dacite-fluolite, followed by basalt and a small amount of trachet. According to the age of magmatic activity, it can be divided into the following periods: (1) Late Proterozoic period: Early Sinian Period, the eruption of Marine microbiceratite, basalt, andesite and rhyolite was observed in northwest, west and northeast Guangdong. (2) Early Paleozoic: At the end of the Silurian, the magmatic activity was relatively strong. S-type granites, I-type granites and ultramafic rocks developed in western, central and northeastern Guangdong, and the latter was accompanied by the eruption of andesite-Dacite-rhyolite. (3) Late Paleozoic - Early Mesozoic: the volcanic activity was weak, andesite-Dacite - rhyolite; in Late Paleozoic - Early Mesozoic, the autochthonous mixed rocks developed in Caledonian occurred local melting, forming the quasi - autochthonous mixed granite with slight gneiss structure, such as Guangning and Yunluogang. (4) Subduction zon-type magmatism in the Early Jurassic: Due to the subduction of the Pacific plate to Eurasia, magmatic eruptions and intrusions developed frequently from the Late Triassic and reached a peak in the Late Jurassic. Volcanism was a Marine eruption in Late Triassic to Early Jurassic. Alkaline basalt, andesite and rhyolite are found in northeast Guangdong. The Middle Jurassic is mainly composed of continental pyroclastic rocks intermingled with andesite and rhyolite in eastern and central Guangdong. Volcanic activity was most intense in the Late Jurassic, and it was a continuous potassic calc-alkaline series of continental andesite-dacite and rhyolite, dominated by rhyolite. From the east coast of Guangdong to the inland, the intensity of volcanic eruption weakened. In the Cretaceous, there were still two types of granite emplacement, type S and type I, but the activity intensity was obviously weakened. (5) Late Yanshanian - Himalayan rift magmatic activity: Since the Cretaceous, A series of intracontinental rifts have developed, such as Guancaohu, Beiling and other places, with bipeak volcanic rocks and A-type granite embeds

after volcanic eruptions. In Palaeocene introntinental rifts, such as the Sanshui Basin in central Guangdong, bipeak volcanic rocks are developed. Each eruption cycle starts with basalt and ends with rhyolite or trachyte. In the Leiqiong intercontinental rift between Neogene and Quaternary, the Neogene Marine basalts were formed in the Marine clastic rocks with multilayer interlayers. Quaternary is a continental environment, the continental overflow olivine tholeiitic basalt formed an area of thousands of square kilometers of quilt. In addition, small mafic intrusions and olivine basalt tubes of the Himalayan age are found in eastern Guangdong.

Igneous rocks are widely distributed in Hainan Province, with an outcropping area of 18037 km2, accounting for 53% of the whole island. Among them, the intrusive rocks are 13,550 km2, accounting for 75% of the igneous rock area, and the intrusive rocks account for 99% of the granite. According to the formation age, the granite can be divided into the Hercynian-Indosinian and Yanshanian stages. The Hercynian and Indosinian granite is not easy to be separated, which is the product of the evolution process of intra-continental rifting trough cracking, subsidence and sealing. The geochemical composition of the granite is Al poor, Ca rich, Fe. The volcanic rocks in Hainan Island are well developed and distributed from Proterozoic eon to Quaternary. Pre-permian volcanic rocks distributed sporadically in the Wuzhishan stratigraphic zone, belonging to Marine eruption. The rocks include ultramafic rocks, mafic rocks and acid volcanic rocks, all of which are embedded in the strata. Among them, the late Proterozoic volcanic rocks have high iron content, which provides iron source for the formation of Shilu type rich iron ore. The Yanshanian and Himalayan volcanic rocks were not only interlocked in strata, but also formed volcanic quilt. The Tertiary was an underwater eruption, and the Quaternary was an overland eruption.

2.3 Geothermal display and distribution characteristics

In the igneous rock area of South China, the surface hot spring is the main thermal manifestation. Hot springs are formed by underground thermal fluids flowing up to shallow or exposed to the surface at appropriate structural locations (mostly the junction of two groups of faults) and suitable geomorphic conditions (piedmont plain or intermountain basin and river valley), which belong to low temperature (<150°C) hydrothermal systems with deep circulation and convection in the plate, and most of them are low temperature (<90°C) hydrothermal systems. In southeast coastal areas, especially in Fujian, Guangdong and Hainan provinces, many hot springs are exposed in granite rock mass or in the fracture between granite rock mass and surrounding rock mass. In terms of geothermal field structure, most of them lack the thermal insulation cover composed of impervious and semi-pervious rock formations directly covering granite heat reservoir. There is little difference between the maximum temperature of natural outcrop hot water and the water temperature of drilling wellhead. Generally within 5°C.The water temperature of the well head is slightly higher than that of the spring water, mainly because the heat loss in the well during the upwelling process is less than that in the fracture channel. For example, in a well with a depth of 806m in Dengwu geothermal field in Fengshun, Guangdong Province, the highest temperature in the well is 94°C, the wellhead water temperature is 92°C, and the spring water temperature is 87°C. The temperature difference between water is only 5°C. In Guangdong Fengliang geothermal field of Fengshun County and Xinzhou geothermal field of Yangjiang City, Wells drilled at 620m depth and 309m depth were only 1.5°C and 5°C higher than spring water temperature respectively. In a geothermal field with a quaternary cap (even if the cap is only 10 to tens of meters thick), it is a different situation. The clay layer in the Quaternary system forms the insulation layer, and the sand and gravel layer form the shallow hot water reservoir, which is cooled mainly by the mixing of hot water with the shallow low temperature groundwater during the upwelling process. The wellhead water temperature is significantly higher than the spring point temperature. For example, in the Fuzhou and Zhangzhou geothermal fields in Fujian province and Dongshanhu geothermal field of Chao'an County in Guangdong province, the wellhead water temperature is 20-40°C higher than the deep spring point temperature.

From the perspective of geothermal resource types, the middle and low temperature hot water resources in the southeast coastal areas can be divided into two categories: one is the deep circulation convection type. The temperature of hot water mainly depends on the circulation depth of groundwater and the conditions such as flow and discharge. The occurrence and distribution of hot water are strictly controlled by active faults, and the vast majority of geothermal fields belong to this type. In this type of geothermal resources, karst subtypes can be divided. Hot water occurs in basins composed of carbonate strata of the Upper Paleozoic. Carbonate rocks are thick and widely distributed, and karst fractures are developed. The other type is conduction type, that is, under the mechanism of earth heat flow, geothermal resources exist in the sandstone layers of the middle and small sized, meso-Cenozoic sedimentary basins, including the Leiqiong Basin across the Qiongzhou Strait, Maoming, Sanshui Basin and Shiba Basin in Guangdong Province. The thermal reservoir in the basin is stratified sedimentary rock thermal reservoir, so it is widely distributed. The geothermal gradient of Cenozoic cover is generally about 3.5°C /100m.In some fault basins, such as the bedrock uplift area of Leiqiong Basin, the amplitude of the bedrock uplift and the thickness of the cover layer are properly configured, and the geothermal gradient of the cover layer above the uplift area is relatively high, generally up to 4-5°C /100m, forming local thermal anomalies. When the fault controlling the boundary of the uplift area has hot water upwelling, which becomes an additional heat source, the geothermal gradient can be as high as 5-8°C /100m, and the geothermal anomaly is more significant. This is the most favorable area for the development and utilization of geothermal in this area. The geothermal condition of Maoming Basin is quite special. Because the mudstone with a total thickness of 400m and low permeability with high thermal resistance is widely spread, it forms the cover layer of the underlying sandstone thermal reservoir. At a depth of 1000m, the average geothermal gradient can reach 4.0-4.5°C /100m, making it a low-temperature hot water basin.

3. SCREENING OF DEEP GEOTHERMAL FAVORABLE BELT IN FUJIAN , GUANGDONG AND HAINAN PROVINCES

The weathering crust and lithologic contact surface of granite in Fujian, Guangdong and Hainan Provinces are favorable areas for the development of heat storage. Under the influence of weathering leaching and tectonic denudation, fissure type and weathering crust type heat reservoir can be formed at the intrusive interface of rock mass and strata and weathered crust on the top surface of granite. The igneous rocks in South China experienced Caledonian, Hercynian, Indosinian, Yanshan and Himalayan tectono-thermal events, which provided objective conditions for the formation of heat reservoirs. The Paleogene, Neogene and quaternary of Cenozoic are mainly sandstone, conglomerate and alluvial deposits, which can be a set of good reservoir cap combination. These reservoir-cap assemblages exist in isolation or overlap to form various types of geothermal systems. For the deep layer, there are both hydrothermal geothermal systems and dry-hot rock geothermal systems.

Combined with the previous exploration and development of geothermal resources and the drilling of deep geothermal resources, the deep geothermal resources with large-scale development potential in the igneous rocks of South China are mainly distributed in the meso-Cenozoic basins and the surrounding areas, among which the Northern Gulf Basin, the Yuezhong Depression of Guangdong Greater Bay Area and the igneous rocks belt of southeast Fujian coast are the most advantageous resources.

3.1 Fujian area

In Fujian Province, where there is no modern magmatic heat source, the heat in the deep crust migrates upward by conduction, and mixes with the heat generated by the disintegration of radioactive elements in the granite in the shallower part, forming a relatively stable temperature field. Due to the intense compression of the Philippine plate from the southeast since the Neogene, the relatively brittle and consolidated continental crust in Fujian and Taiwan has produced a shovel-shaped fault system, and the fault grid has developed, forming the main water channel in this

area. Due to the difference of water head pressure and density, the abundant atmospheric precipitation seeps into the deep underground from the surrounding areas of the basin along the channel, absorbing the heat in the rocks, gradually changing from cold water to hot water. The deeper the fracture channel is buried, the higher the temperature of hot water formed. The underground hot water continues to move along the fault zone, and some of it is discharged from the surface or stored near the surface in suitable areas. This heated water, together with surrounding rock and overlying cap, constitutes a hydrothermal geothermal system. As the depth of geothermal water circulation is not deep (3 ~ 5km), a medium-low warm water thermal system is mainly formed. According to the drilling temperature of Zhangzhou Dry Heat 1 well, the temperature at 4000m depth is 109°C, which belongs to the medium-temperature geothermal system. Because the overall geothermal temperature in this area is not high, the lack of effective caprock, the temperature around the hydrothermal system is low, and the hot dry rock geothermal system cannot form high temperature, so the dry hot rock geothermal system is mainly distributed in the deep part of the hydrothermal system. In the depth where the temperature reaches 150°C but the fault is not developed, or the fault is developed but the water supply is insufficient, the dry hot rock type geothermal system can be formed.

3.2 Yuezhong area

The heat reservoir in central Guangdong is mainly characterized by water storage in structural fracture zone, which is obviously controlled by fault structure and influenced by lithology. The Lower Ordovician (O1) strata (sandstone, siltstone and shale) in the geothermal field, under the action of multiple intrusion and tectonic stress of magmatic rocks, produce hydrothermal metamorphism and dynamic metamorphism, forming metamorphic rocks mainly composed of metamorphic sandstone, biotite hornstone and metamorphic feldspar hornstone, followed by the hidden fine-grained porphyritic biotite granodiorite in the Kongshanbao-area of ZK3-CK26.Under the action of Tonghu Great Fault, rock fractures developed, especially tensile fractures in the contact zone between Ordovician rock and granodiorite rock strain (ZK3 hot well), forming a tectonic fracture zone dominated by contact zone between Ordovician rock and granodiorite. The thermal dissolution phenomenon (ZK2, ZK3, Guan 2 hole) can be seen on the local fracture surface. Meanwhile, the natural hot spring outcrops are scattered along the edge of the granodiorite (ZK3-CK26 hole mountain dome) in the shape of circular star spots. The thermal anomalies measured by the temperature borehole are also distributed along the edge of the mountain dome. The contact limit of Yanshanian granite intrusion into strata is developed in outcrops.

The hydrothermal geothermal system is mainly distributed in the contact zone between magmatic rock mass and surrounding rock, which is obviously controlled by faults, and is also controlled by late and recent volcanic mechanism and magmatic activity, that is, the geothermal system is comprehensively controlled by structure and magma. The late and recent tension-torsional fracture zone is a heat-conducting water structure, which controls the shallow discharge of hot water. It has the characteristics of heat-controlling compressional tectonic zone and volcanic mechanism, and heat-conducting water in tension-torsional fracture zone. Its hydrothermal origin mechanism: atmospheric precipitation, surface water or normal temperature groundwater infiltration through fracture structure and weathered fissure, in the deep circulation process of fracture fracture zone, absorb the heat of rocks heated by deep heat flow under normal or high geothermal background, rise out in appropriate positions (such as in the fault fissure through the surface and deep) or exposed by human engineering.

3.3 Beibuwan Basin

According to the development characteristics of regional rock strata and drilling results, the main deep geothermal reservoirs include granite fractured reservoirs of Hercynian and Yanshanian epoch. The pre-Mesozoic basement is Pre-Sinian, Lower Paleozoic, Upper Paleozoic and granite basement respectively.

The 2378-2380m core of Well Wushi 1 in the area is identified as altered granite at the end of Late Permian (254Ma), belonging to the late Hercynian magmatic activity, with strong surface weathering. Microfractures are distributed roughly parallel, and calcite veins are found inside. The alteration zone is about 200m thick and may be a favorable reservoir. The rock composition is mainly quartz, potassium feldspar, plagioclase, with metamorphic semi-eukaryotic granular structure, massive structure. Mainly composed of biotite, potassium feldspar, quartz, plagioclase, followed by a small amount of opaque metal minerals. The particle size of the mineral is relatively large, and slight brittle deformation occurs. Dynamic recrystallization of quartz can be seen locally. The whole rock has obvious secondary changes, mainly clayification and sericitization (Figure 3a). The rock is characterized by plagioclase with large particle size, high content and obvious alteration. Irregular micro-fissures and metamorphic deformation of quartz are common, and obvious clayification and sericitization of feldspar occur (Figure 3b). Irregular small amounts of veinaceous carbonate minerals, stellate, clumpy and irregular opaque metallic minerals are seen (Figure 3c).Some residual strain phenomena such as intrachrystalline crack, sub-granulation and dynamic recrystallization can be observed. The rock as a whole is relatively fresh and only slightly clayified (Figure 3d).

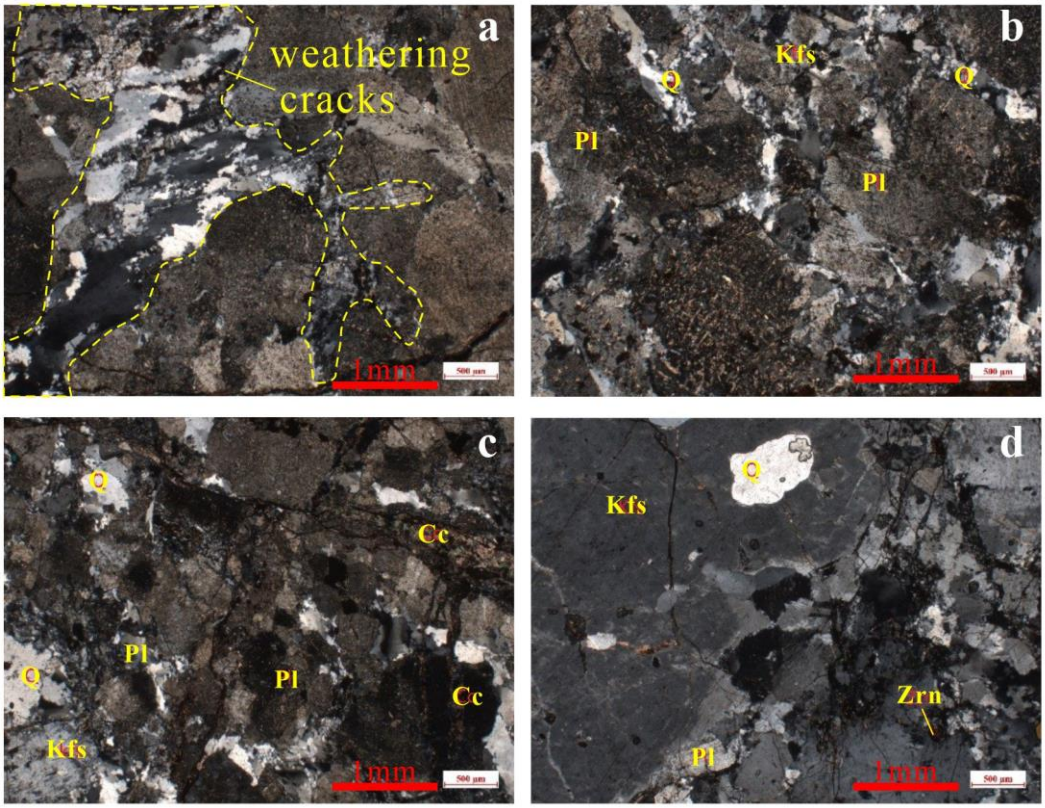

Figure 3: Images of WS-1 drill core under the microscope

a. cataclastic and altered granite(+); b. altered monzogranite(+);

c. altered granite filled with calcite vein(+); d. altered granite(+)

Cc: Calcite; Kfs: Potassium feldspar; Pl: Plagioclase; Q: Quartz; Zrn: Zircon

The deep geothermal system in the Beibuwan Basin can be called the control reservoir formation of high quality reservoir with suitable burial depth under high heat flow condition. Under the combined action of mantle plume, radioactive heat generation and inner crust melt, heat accumulation effect of Cenozoic and Cretaceous cover layer more than 3000m thick, with long flow fault as the center, geothermal resource enrichment area of high temperature

bedrock fissure is formed in the top weathering crust of Hercynian and Indosinian granite on the east and west sides. According to temperature calculation, it is expected to reach the level of hot and dry rock resources at around 5000m.

4. CONCLUSIONS

(1) Granitic magmatism occurred extensively in the South China Plate at different times, including the Lvliang (1900Ma±), Jinning (1000-800 Ma), Caledonian (540-360Ma), Hercynian-Indosinian (360-195Ma) and Yanshan (195-65 Ma). Among them, Yanshanian magmatic activity is the most intense, followed by Hercynian - Indosinian. Since the Proterozoic eon, with the overall southeast migration (that is, oceanic) of the tectonic belt, the age of granite formation tends to be younger, and the distribution of some granites may be reversed (inland) beyond that of the tectonic belt migration, resulting in the widespread occurrence of multi-stage and multi-stage compound granites in South China. These granites with good thermal conductivity and heat storage are excellent heat storage.

(2) The surface distribution of the igneous rock in South China is obviously divided into regions, with the overall characteristics of high in the east and southwest and low in the middle. There are two northest-trending high value anomaly zones in the east, one of which is the high heat flow anomaly zone along the southeast coast represented by Fuzhou-Meizhou. The other is the high heat flow anomaly zone in the northeast direction of Maoming, Leizhou Peninsula and north Hainan area, which is distributed in the Wuchuan-Sihui fault zone with beaded distribution. These two anomaly zones are characterized by heat flow values greater than 80 mW/m2.The low heat flow in the central region is distributed from south to north, and the wide and gentle low heat flow is distributed from Baise to the southern foot of Dabie Mountains, while the high heat flow in the western region is only concentrated in southwest Yunnan. The high heat flow anomaly zone in the east is closely related to the formation and distribution of deep geothermal resources in this area.

(3) Combined with the previous exploration and development of geothermal resources and the drilling of deep geothermal resources, the deep geothermal resources with large-scale development potential in the igneous rocks of South China are mainly distributed in the meso-Cenozoic basins and the surrounding areas, among which the Northern Gulf Basin, the Yuezhong Depression of Guangdong Greater Bay Area and the igneous rocks belt of southeast Fujian coast are the most advantageous resources.

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