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Geological Formation Mechanism and Thermal Resources Assessment of Geothermal Spring in Lushan County, China

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Abstract: Geothermal resource is green and clean energy, and geothermal field is widely distributed in the world. Its development and utilization has little harm to the environment, can change the current situation of energy consumption mainly based on fossil energy, reduce carbon emissions, and promote the development of techniques for sustainable processing of natural resources. However, each geothermal field has its own characteristic structure, origin, and storage, so it is necessary to carry out targeted research. In this paper, the geothermal characteristics and geological characteristics of the geothermal belt in Lushan County, China are analyzed by means of remote sensing interpretation, field investigation and observation, geophysical exploration, long-term observation, pumping test, and hydrochemical analysis. Result of this study shows that the geothermal belt of Lushan geothermal fields is as a result of primary thermal control and heat conduction structures of the near east-west Checun-Xiatang deep fault as well as secondary thermal control and heat conduction structures of near north-east and north-west secondary faults; and annual recoverable geothermal energy of whole geothermal field is 4.41×10^{11} MJ. The research results will be beneficial for the development and utilization of Lushan hot springs. At the same time, it also provides reference for more geothermal research.

Keywords: geothermal spring; geological structure; geophysics; heat source; heat transfer mechanism

1. Introduction

Energy is the material basis for the existence and development of human society. Nowadays the energy problem has gradually become an important factor restricting the global economic and social development, especially the large-scale utilization of fossil fuels, which brings more and more serious environmental pollution problems. The fundamental way out of energy production and consumption revolution lies in renewable and clean energy. Compared with traditional fossil energy (coal, oil, natural gas) and nuclear energy, geothermal energy is an inexhaustible renewable clean energy. And compared with solar energy, wind energy, water energy, and other renewable energies, geothermal energy has the advantages of stability, high utilization rate, safety, low operation cost, comprehensive utilization: stable output without diurnal or dry season change; geothermal power generation can be used as both basic load and peak load regulation load; the average utilization efficiency of geothermal power generation is 73%, which is 5.2 times of the solar photovoltaic power generation, 3.5 times of

wind power generation; no explosion, dam break risk and low pollution; low initial investment and long-term income; from high temperature to low temperature, it can be used for power generation, heating, bathing and breeding. It is an ideal and alternative energy.

At present, geothermal research is very extensive. There were traditional methods for geothermal research and geothermal potential assessment, such as geological analysis [1–3], geological drilling [4,5], geophysics [1,6], geochemistry [1–3,5,7–16], gravity study [1,6,17], and other work methods. Some researches focused on geothermal development and application [18–22], and many employed new technologies, methods, and perspectives, including numerical simulation [23–25], remote sensing monitoring [26], isotopic geology [8,10,12,27–32], biological methods [33], ultra-high temperature geothermal research [34], geothermal database [35], and environmental protection and sustainable development [8,12].

Lots of above research results show that geothermal genesis is complex, and there is no universal theory suitable for all geothermal fields [36]. Therefore, in the geothermal exploration, the cause of formation should be determined accurately, which can reduce the uncertainty of technology and geology, reduce the investment risk of geothermal exploration and development, and the uncertainty of geothermal development policy, and create a bright future for geothermal utilization [37–39].

Lushan County, China is abundant in geothermal resources. There are five geothermal fields: Shangtang, Zhongtang, Xiatang, Wentang, and Shentang hot spring areas (“tang,” the suffix of five place names, means “hot water” in ancient Chinese), forming a 50-km geothermal and hotspring belt. Through the means of remote sensing geological interpretation, field geological survey, geophysical exploration, long-term observation, geological drilling, pumping test, and water chemistry test, this study aims to (1) investigate the formation mechanism and control structure of Lushan geothermal springs; (2) find out the distribution range and water sources, water circulation, heat sources, flows of geothermal springs; and (3) assess the amount of geothermal energy.

2. Materials and Methods

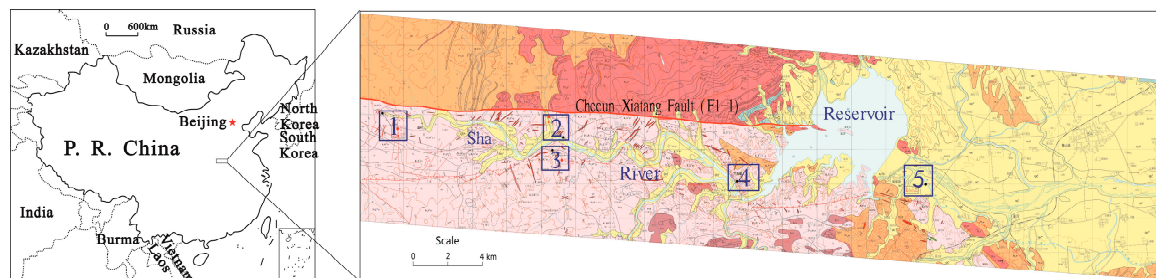
2.1. Geological Background of Research Area

Lushan County is located in the south margin of North China platform, adjacent to the Qinling Mountains fold system. It belongs to the second-order structural unit of Xiong’er mountain uplift in the south margin of North China platform, and the third-order structural unit Xiong’er mountain fault uplift. The crust has an obvious dual structure of platform type basement and cover. The regional strata belong to Mianchi-Queshan tertiary district, southeast of west-Henan sub district, North China district.

The research area is located at the joint of the Sino-Korean quasi platform and the Qinling fold system, that is, between the North-China plate and the Yangtze plate. As the Yangtze plate subducted and collided with the North China plate, the Qinling mountains became a famous intercontinental orogenic belt. Luanchuan-Queshan-Gushi deep fault in the southern margin of North-China plate is the northern boundary of the orogenic belt, and Xiangfan-Guangji deep fault in the northern margin of Yangtze plate is its southern boundary. Checun-Xiatang fault is a part of Luanchuan-Queshan-Gushi deep fault. The Lushan geothermal belt which has five hot springs is located in the south of the east section of Checun-Xiatang deep fault, 820–3000 m away from Checun-Xiatang fault. The five hot spring areas, Shangtang, Zhongtang, Wentang, Xiatang, and Shentang, are exposed from west to east at an equal distance of 10.5–10.8 km. And then to the east downstream there is the Matang geothermal field, a geothermal prospect investigation area. Figure 1 shows the geothermal fields, the big fault F1-1, the river, and the reservoir.

The magmatic activity in the area was strong, mainly distributed in the south of the Checun-Xiatang fault, and a few in the north of the fault. The fault structure was very developed, and the main structural line orientation is north-west-west direction near east-west trending. According to the distribution direction, the fault structures can be divided into three groups: near east-west, north-west, and north-east direction. The near east-west fault structure, with large scale and deep cutting, is the

main fault structure in the area. The northwest and northeast fault structures are small in scale but dense. Among the exposed rocks, granite is dominant, while the intermediate and basic rocks are only sporadically exposed, and the quaternary system is not very developed. Groundwater is mainly stored and transported in the structure fissures and weathering fractures of various rocks in the pre Cenozoic, belonging to structure fissure water or weathering fracture water. The groundwater of surface rivers and tributaries mainly occurs in the sand gravel of valley plain, which is the pore water of loose rock.



The geothermal fields: 1. Shangtang; 2. Zhongtang; 3. Wentang; 4. Xiatang; 5. Shentang

Figure 1. The relative position of the five geothermal fields and Checun-Xiatang fault in China.

2.2. Methods

This study employed remote sensing geological interpretation, field geological survey, geophysical exploration, geological drilling, long-term observation, pumping test, and hydrochemistry test and other technical means and working methods.

2.2.1. Geological Interpretation of Remote Sensing

ETM (enhanced thematic mapper) was used to explain and interpret the geomorphic types, micro geomorphic forms, ground lithology, fault structures, etc. (Figure 2).

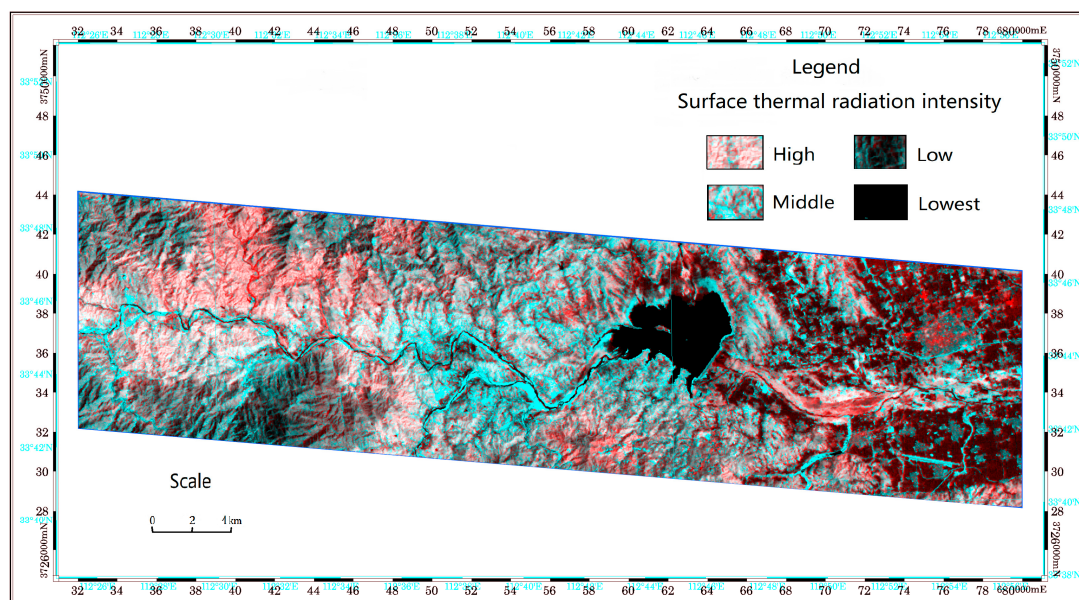


Figure 2. Enhanced thematic mapper (ETM) remote sensing surface thermal radiation map of Lushan geothermal belt.

2.2.2. Field Geological Survey

In the field survey, 1:25,000 topographic map was used as the base map, and portable GPS receiver (plain accuracy 1–3 m, forest or valley accuracy 5–10 m) and topographic features were used to determine the location. The observation points were mainly arranged at the geological and geomorphological change positions and hot spring exposed positions. The focuses of field survey were the ground lithology, fault structure, and geothermal display characteristics of Lushan geothermal springs and their periphery.

2.2.3. Geophysical Exploration

(a) IP Sounding (Induced Polarization Sounding Method)

A quadrupole sounding and a polarizability test profiles were arranged in Shentang geothermal field, and the design value of sounding point distance $AB/2$ was 1000 m.

(b) EH-4 Magnetotelluric Sounding

Three magnetotelluric sounding (EH-4) lines were arranged to identify the geothermal fields: one in the middle of Zhongtang and Wentang geothermal fields (Jc3), two in Shentang geothermal field (Jc1 and Jc2).

(c) Multi-Electrode Resistivity Method

Three multi-electrode resistivity lines were set up in Shentang geothermal field (W5, W6, and W7; Figure 3).

2.2.4. Geological Drilling

An exploration holes were completed in Shentang geothermal field and the depth is 300 m.

2.2.5. Pumping Test

The pumping tests of three existing geothermal wells in Shangtang geothermal field and one exploration holes in Shentang geothermal field were carried out to observe the water level, water volume, water temperature. The air temperature was measured at the same time.

2.2.6. Long-Term Observation

A long-term observation of geothermal springs (including two civil wells) had been carried out for one year, and the observation items include water level, water quantity, water temperature, and air temperature.

2.2.7. Hydrochemistry Test of Water

Water samples were collected, and the complete water quality analysis and brief analysis of water quality were carried out. The purpose of water quality test and analysis is to find the connection between the water from different places.

3. Results and Analysis

3.1. Geothermal Characteristics of Lushan Geothermal Springs

3.1.1. Geothermal Type and Geothermal Reservoir Structure

All the five hot springs have convective geothermal characteristics. The water temperature of Shangtang, Zhongtang, and Xiatang geothermal fields is more than 60 °C and less than 90 °C, which belongs to hot water in low-temperature geothermal resources. The water temperature of Wentang and Shentang geothermal fields is less than 60 °C and more than 40 °C, which belongs to the category of warm water in low-temperature geothermal resources.

All the hot springs are all controlled by fault structure, which belong to the fracture vein heat reservoir. The hot reservoir of Shangtang and Wentang consists of gneissic granite intruded by the Middle Proterozoic, the hot reservoir of Zhongtang and Xiatang consists of granite intruded by the early Cretaceous of the Mesozoic, the hot reservoir of Shentang consists of andesitic porphyrite of Xionger group of the Middle Proterozoic, and the underground geothermal water belongs to the fracture vein artesian water.

The thickness of the overburden in Shangtang, Zhongtang, Wentang, and Xiatang is about 1–4 m, and that in Shentang hot springs is 13.6–17 m. Therefore, all the hot reservoirs layer in Lushan are not well insulated and heat protected. Because of the lack of overburden, geothermal water migrates from the depth to the surface along the fracture channel, directly exposing the surface to form hot springs or forming geothermal anomalies only covered by thin layers above.

3.1.2. Chemical Characteristics of Geothermal Water

In Table 1, the analysis results of water quality are presented. As illustrated in the table, pH value of hot spring water is 7.36–9.08, and the mineralization degree is 0.355–0.705 g/L. It belongs to weak alkaline low mineralized $\text{HCO}_3\text{-Na}$ or $\text{HCO}_3\text{-SO}_4\text{-Na}$ type water. The content of Cl^- , SO_4^{2-} , K^+ , Na^+ , Ca^{2+} , Mg^{2+} in Shentang is significantly higher than that in other springs, and has a trend of gradually increasing from west to east. The content of Cl^- in Xiatang and Shentang is significantly higher than that in other springs. The content of SO_4^{2-} in Shentang is significantly higher than that in other springs, followed by Shangtang. Geothermal water contains copper, zinc, arsenic, and other trace elements, including radioactive elements radium and uranium. The content of other microelements is low. From Shangtang-Xiatang-Shentang, the mineralization degree, total hardness, and various ion contents gradually increased from west to east.

Compared with the chemical composition of nearby river water and shallow groundwater, the content of Ca^{2+} and Mg^{2+} in hot springs is generally lower than that of river water and regional shallow groundwater, while the content of HCO_3^- , SO_4^{2-} , Cl^- , K^+ , Na^+ , F^- is generally higher than that of river water and regional shallow groundwater. The average content of Na^+ is 11.3 times higher than that of river and regional shallow groundwater, while the content of Mg^{2+} is small or not. It can be seen from the hydrochemical characteristics that the geothermal water in Lushan hot springs belongs to uplift fracture type geothermal water, which is recharged by atmospheric precipitation.

Table 1. Analysis results of geothermal water quality in Lushan geothermal belt.

Test Items	Shangtang Hotspring	Shangtang River Water	Zhongtang Hotspring	Wentang Hotspring	Xiatang Hotspring	Xiatang River Water	Shentang Geothermal Well
pH value	8.48	7.41	8.7	8.62	7.42	7.04	7.91
Mineralization degree (g/L)	0.641	0.173	0.498	0.599	0.598	0.225	0.649
Cl ⁻ (mg/L)	22.41	5.02	22.68	21.36	33.02	6.62	33.8
SO ₄ ²⁻ (mg/L)	111.9	31.11	92.11	89.65	106.1	43.96	157.5
HCO ₃ ⁻ (mg/L)	229.9	61.76	140.7	200.7	251.0	110.9	171.5
CO ₃ ²⁻ (mg/L)	10.12	-	13.5	13.5	0	-	0
F ⁻ (mg/L)	15.91	0.76	16.78	16.23	17.3	-	13.54
Na ⁺ (mg/L)	120.0	11.8	126.0	148.0	180.0	12.80	160.0
K ⁺ (mg/L)	3.75	1.99	4.71	4.23	7.5	2.66	6.7
Ca ²⁺ (mg/L)	4.89	20.4	5.25	3.8	8.34	35.4	7.5
Mg ²⁺ (mg/L)	0.9	3.37	0.26	0.044	0.42	7.27	0.22
As ⁻ (mg/L)	0.029	-	0.024	0.024	0.0011	-	0.0026
Cu	<0.05	-	<0.05	<0.05	<0.05	-	<0.05
Zn	<0.05	-	<0.05	<0.05	<0.05	-	<0.05
Fe	<0.05	-	<0.05	<0.05	<0.05	-	<0.05
Mn	<0.05	-	<0.05	<0.05	<0.05	-	<0.05
U (g/L)	<2.0 × 10 ⁻⁷	-	1.40 × 10 ⁻⁷	-	-	-	-
Ra (g/L)	1.99 × 10 ⁻¹²	-	8.20 × 10 ⁻¹²	-	-	-	-
Hydrochemical type *	A-HCO ₃ -Na	A-HCO ₃ -Ca-Na	A-HCO ₃ -Na	-	A-HCO ₃ -Na	A-HCO ₃ -Ca	-

"-" means that the item was not tested; * The water hydrochemical types are classified by Shoka Lev Method.

3.1.3. Geothermal Water Temperature

According to the water quality test data of Shangtang geothermal well, the heat storage temperature calculated by K-Na temperature scale is 149.34 °C, and the temperature calculated by graphic method is 157.0 °C. The actual measured temperature in Shentang is 48 °C, which is lower than the above ones. It is inferred that the reason is the mixing of the upper shallow groundwater and the underground hot water [40].

3.1.4. Recharge, Runoff, and Discharge of Geothermal Water

According to the study of hydrogen and oxygen isotopes of geothermal water, most geothermal water is recharged by local precipitation. The water quality analysis data of hot spring also shows that it is mainly recharged by atmospheric precipitation. The atmospheric precipitation infiltrates along the structural fracture or fracture zone, passes through deep circulation heating, and then rises along the fracture channel, forming local geothermal anomaly or overflowing the surface to form hot spring. Its recharge, runoff, storage, and discharge conditions are strictly controlled by the fault structure. The five hot springs have sufficient supply sources, good heat storage permeability and strong runoff, for example, the self-flow of the boreholes in Shangtang is up to 137.29 m³/h, and the maximum water head is 15.58 m higher than the ground. All hot springs contain the same ions, and the content of each ion is relatively close, indicating that they have similar recharge sources, runoff and discharge channels, and have certain hydraulic connection [41].

3.2. Geological Characteristics of Lushan Geothermal Springs

3.2.1. Geological Characteristics of Shangtang Geothermal Field

(a) General Situation of Shangtang Hotspring

Shangtang hot spring outcrops on the first terrace on the south bank of Sha River, 8–18 m higher than the river, with an altitude of 270–280 m. The hot spring has a large thermal anomaly range, with a length of 640 m from north to south and a width of 250 m from east to west. It outcrops in the form of spring group, with many spring holes. The measured temperature of No.1 geothermal well (under exploitation) was 61 °C, and the flow was 100 m³/h; the measured temperature of No. 2 geothermal well was 61 °C, and the artesian flow was 46.5 m³/h; the measured temperature of No. 3

geothermal well was 61 °C, and the artesian flow is less than 1.0 m³/h. There were many spring spots around the main spring group.

(b) Combined Pumping Test

No. 1 and No. 3 wells combined pumping test. No. 1 $Q = 100 \text{ m}^3/\text{h}$. No. 2 well artesian flowed. The dynamic water level of No. 3 was 2.58 m, $Q = 100 \text{ m}^3/\text{h}$, and $q = 12.4 \text{ m}^3/\text{h}\cdot\text{m}$. The total water output was 132 m³/h, and the daily water output was 3168 m³/d.

No. 1 and No. 2 wells combined pumping test. No. 1 $Q = 100 \text{ m}^3/\text{h}$. The dynamic water level No. 3 was 3.1 m. The dynamic water level No. 2 well was 4.85 m. $Q = 70 \text{ m}^3/\text{h}$, and $q = 4.4 \text{ m}^3/\text{h}\cdot\text{m}$. The total water output is 170 m³/h, and the daily water output is 4080 m³/d.

No. 2 and No. 3 wells combined pumping test. No. 1 well artesian flowed. The dynamic water level of No.2 was 0.85 m, $Q = 24 \text{ m}^3/\text{h}$, and $q = 28.2 \text{ m}^3/\text{h}\cdot\text{m}$. The dynamic water level of No. 3 was 2.50 m, $Q = 79 \text{ m}^3/\text{h}$, and $q = 31.6 \text{ m}^3/\text{h}\cdot\text{m}$. The total water output was 103 m³/h, and the daily water output was 2472 m³/d.

According to the pumping test results presented in Table 2, three wells were regarded as one well for analysis. The rock between 21.0–67.4 m was broken and fracture was developed. It was the main aquifer with a thickness of 46.4 m. The total pumping time was 96 h, the water temperature was 61 °C, the total water inflow was 6731 m³/d, the maximum drawdown was 15 m, the water flow per unit width was 18.7 m³/h·m, the hydraulic conductivity was 7.38 m/h, and the coefficient of transmissivity was 14.28 m²/h. After stopping pumping, it returned to artesian state in 34 min. It showed that in the fault fracture zone, the rock was broken, the fracture was developed, and the water permeability and water yield were very strong.

Table 2. Data of combined pumping tests of Shangtang geothermal field.

Serial No. of Well	Water Level (m)	Q (m ³ /h)	q (m ³ /h·m)	t (°C)	Daily Water Output (m ³ /d)
1	15.0	184.3	12.2	61.0	
2	14.0	73.1	5.22	61.0	
3	11.2	23.0	2.05	61.0	
Total water output		280.4			6731.0

(c) Geological Structure Characteristics

As shown in Figure 4, the main lithology of around Shangtang hot spring outcropping site was gneissic medium grain biotite potash feldspar granite unit (Pt₂H¹ξ), with an area of about 10 km². The intrusions all extended along the direction of regional structural line in a very irregular long belt, and the internal contact of the sequence was not clear. The intrusions appeared intrusion relationship with around Taihua Group, early Proterozoic shibanhe gneiss, and Mesoproterozoic penggou unit. There were strong contact metamorphism around the rock mass, mainly tremolite, chloritization, and epidotization. The second unit also had epidotization and chloritization internal alteration. The ground surface of hot spring outcropped was covered by quaternary silty clay and sand gravel layer, and the thickness of quaternary exposed by drilling was 4.2 m.

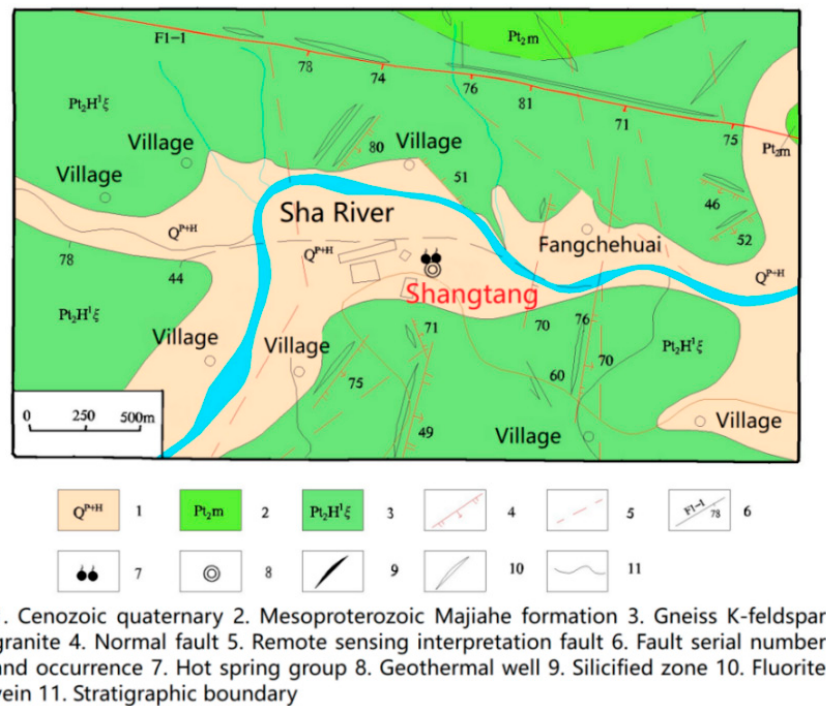


Figure 4. Geological structure of Shangtang geothermal field.

Shangtang hot spring is 820 m away from Checun-Xiatang fault (F1-1) in the north and 3100 m away from Erlangmiao-Wentang fault in the south. A slightly larger Fangchehuai fault (F3-1) is 500 m to the east of the hot spring, and a north-east fault dense belt is 500 m to the northwest. Sha River develops along the fault dense belt in this area, and the belt appears a Northeast-Southwest direction.

As shown in Figure 5, there are 5 NE and 3 NW faults in the geothermal area, with a NE fault distance of 30–60 m and a NW fault distant 60–130 m. Shangtang geothermal field is distributed at the intersection of NE fault F3 and NW fault F7 and F8. In the south of Shangtang, fluorite vein filled along the fault can be seen in the south of the mountain. These faults cut the rocks in Shangtang area into rhombus or wedge-shaped blocks. Five NE faults form broom structure, converging in NE direction and spreading in SW direction. In the south-west end of fault F3, the fault inclines to the southeast with an angle of about 70°. The fractures near the hanging wall develop parallel to the fault plane, and the footwall is broom-style fractures. The fractures converge at the fault plane and spread out away from the fault plane. No. 3 hot spring overflows right from the broom-style fracture. Shangtang hot spring is mainly outcropped between fault F1–F5, which shows that Shangtang hot spring is mainly controlled by the north-east broom-style fracture structure, and the north-west fracture plays the role of connecting the north-east fracture and enriching the underground hot water.

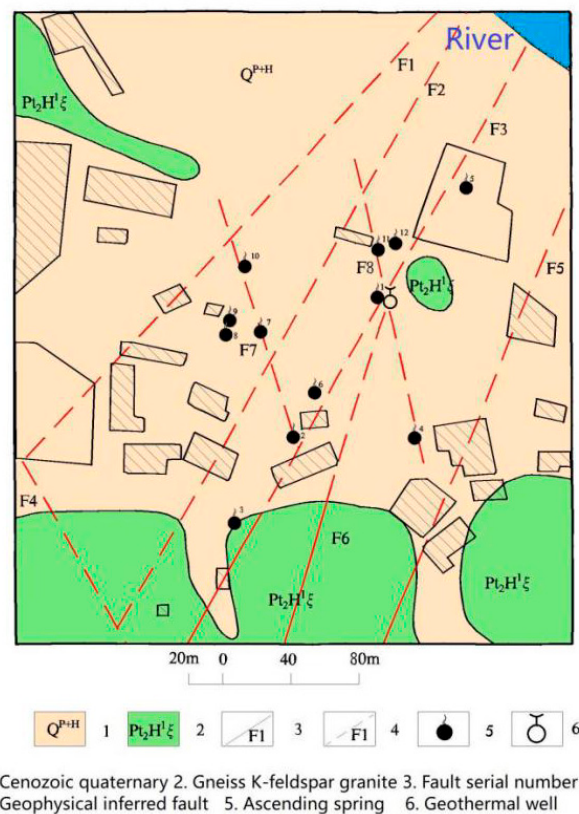


Figure 5. Location of hot spring and geothermal well in Shangtang.

The collected drilling data (Table 3) shows the strata: 21–23.0 m is fault breccia; 23–55.0 m is fault zone, rock is broken and fracture is developed; 57.7–61.9 m is rock fracture zone and fracture is developed; 65.4–67.4 m is fault breccia and fracture development. The rock cores of other strata are relatively complete, and the fractures are not very developed. In the 23–50 m layer, the artesian flow increases rapidly, which indicates that the rock in this layer has strong water permeability and water storage, and the water conductivity coefficient is 342.7 m²/d. This layer is the main geothermal water aquifer in Shangtang geothermal area. The temperature curve shows that the temperature is relatively low because of the large amount of shallow cold water mixed in above 4.2 m; after the quaternary system is exposed, the temperature increases rapidly, reaching the position of strong permeable aquifer, with the water temperature reaching 61 °C; until the end depth of the hole, it has been kept at 61 °C.

Table 3. Observation record on flow and temperature of Shangtang geothermal water.

Depth of Drilling Hole (m)	Temperature (°C)	Artesian Flow (m ³ /h)	Depth of Drilling Hole (m)	Temperature (°C)	Artesian Flow (m ³ /h)
1.6	31	0	29.05	61	78.00
3.0	37	0	31.0	61	104.00
6.91	43	0	41.0	61	126.00
8.0	55	1.00	50.0	61	133.00
10.57	57	1.00	60.0	61	133.00
14.0	58	6.00	61.9	61	140.19
16.94	60	18.01	67.4	61	133.00
23.0	60	18.01	81.18	61	137.29

(d) Geophysical Characteristics of Shangtang Filed

The collected geophysical exploration results show that the apparent resistivity ρ_s changes between 100–250 $\Omega\cdot\text{m}$ according to the $AB/2 = 40$ mps isoline graph and $AB/2 = 65$ mps isoline graph. In hot spring outcropping area it is generally low, less than 200 $\Omega\cdot\text{m}$, forming a low resistivity zone spreading to the west, northwest while converging to the southeast. The low resistance zone reflects the fracture zone with hot water. The apparent resistivity in the east is generally higher, more than 200 $\Omega\cdot\text{m}$, indicating that the rock in this area is relatively complete.

3.2.2. Geological Characteristics of Zhongtang and Wentang Geothermal Field

(a) General Situation of Zhongtang and Wentang Hotsprings

Zhongtang hot spring is located 10.5 km east of Shangtang geothermal field, with an altitude of 221 m, 8.3 m higher than Sha River. Zhongtang hot spring appears in the form of spring group, and the spring water is led into the pool for utilization. The long-term observation data (continuous observation for one year, observation interval ten days, measured by thermistor thermometer) showed that the water temperature was 61–63 °C and the average flow was 10.0 m³/h. The long-term observation data (same measuring method as above) of the geothermal well at about 20 m south of the hot spring were 63 °C and 3.94 m³/h.

Wentang hot spring is located at the back edge of the first terrace on the south bank of Sha River, with an altitude of 220 m, 820 m away from Zhongtang hot spring, and the two springs are facing each other across the river. The long-term observation data (same measuring method as above) showed that the flow was 2.2 m³/h and the water temperature was 49 °C. After the spring water was also led into the pool for utilization, the measured temperature reduced to 39–40 °C.

(b) Geological Structure Characteristics of Zhongtang and Wentang Hotsprings

Zhongtang hot spring outcrops in the middle porphyry medium grain biotite monzogranite intruded by Mesozoic, and the ground surface is covered by thin-layer deluvial deposit. It is 1420 m away from Checun-Xiatang fault (F1-1) in the north. Wentang hot spring outcrops in the gneissic mafic potash feldspar granite of Mesoproterozoic, and it is 2240 m away from the Checun-Xiatang fault in the north (Figure 6).

F3-2 fault passes through 750 m east of Zhongtang and 250 m east of Wentang, with a strike of 45° and an inclination of 65°. Fluorite vein, calcite vein, and quartz vein are filled along the fault. F3-3 fault passes through Zhongtang village, with a strike of 60°, and inclines to northwest, with an inclination of 53°. F3-4 fault passes through the south side of Zhongtang hot spring, with a strike of 45° and a kaolin alteration zone about 20 m wide along the fault zone. The F3-4 fault intersects F3-3 fault at Zhongtang village. There is F1-2 fault in the south of Wentang village. And some other faults or secondary faults are distributed in the area. For example, it is clear in satellite remote sensing images that there is a NW trending fault near Wentang hot spring. The strike of the fault is 355°, the dip angle is 77°, and the fracture width is 6.6 m. There are fault friction mirror surface, fault gouge, fault breccia, and silicified rock.

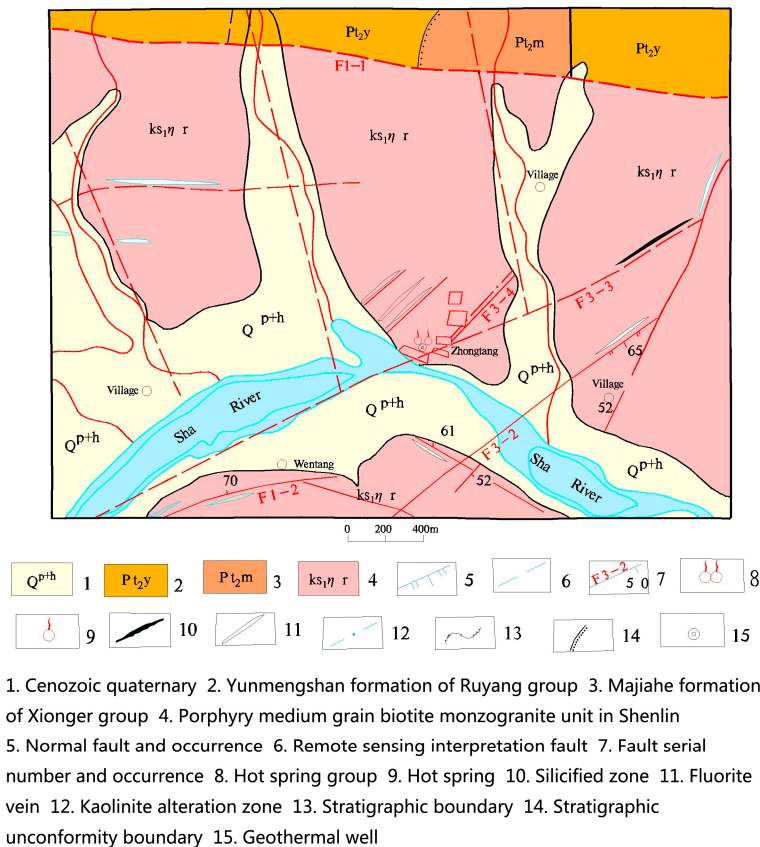


Figure 6. Geological structure of Zhongtang and Wentang geothermal field.

According to the above geological situation, the fault structure of Zhongtang and Wentang field is extremely developed, with obvious hydrothermal activity. Zhongtang hot spring is obviously controlled by fault F3-4, and Wentang hot spring is obviously controlled by fault F1-2. The intersections of fault F3-3 and F3-4, fault F1-2 and other faults provides favorable structural conditions for the outcropping of Zhongtang and Wentang hot springs.

(c) Geophysical Characteristics of Zhongtang and Wentang Filed

In the south bank of Sha River, a magnetotelluric sounding (EH-4) line with a length of 1000 m and a point distance of 50–100 m was arranged, and a total of 16 points were measured. The measured profile is shown in Figure 7. There is a depression with a depth of about 500 m from the starting point of the profile to 700 m, and there is a belt with a low resistivity at a depth of about 800 m. The Cagniard resistivity is 350 $\Omega \cdot m$. It is speculated that it is a water-bearing structural fracture zone, or the contact zone between the Mesoproterozoic intrusive rock and the metamorphic rock of Taihua Group. Because of the development of the original fracture and the influence of the later faults, the rock fracture contains hot water.

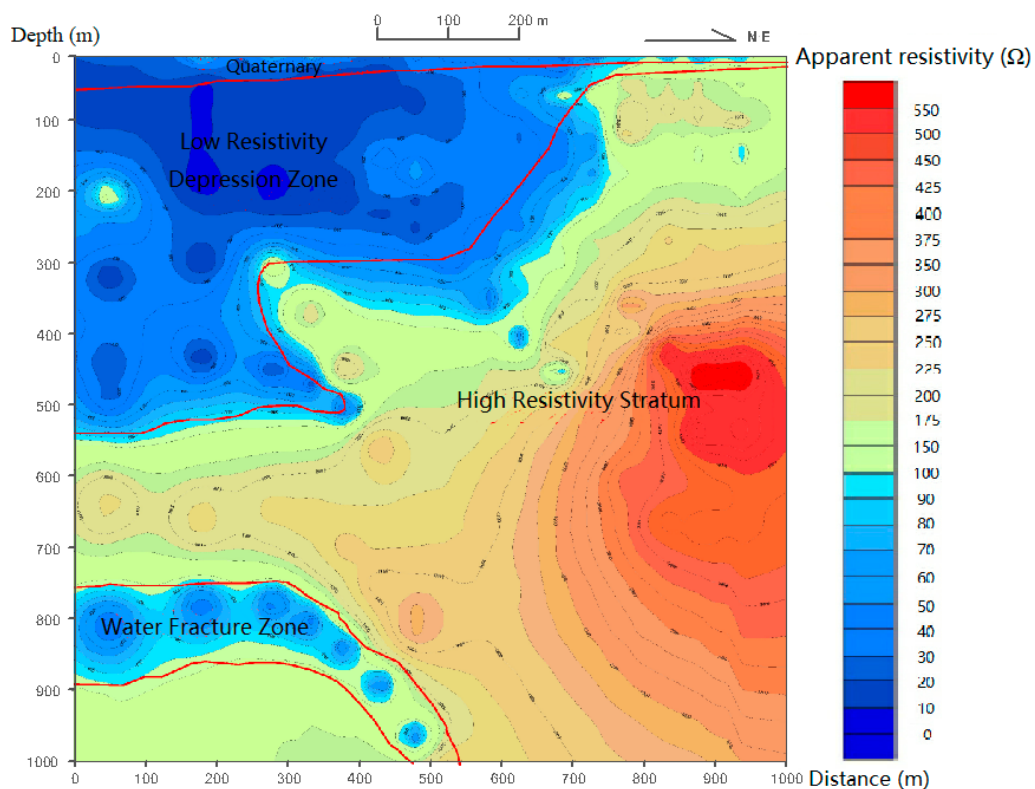


Figure 7. Resistivity profile of Zhongtang and Wentang geothermal fields.

3.2.3. Geological Characteristics of Xiatang Geothermal Field

(a) General Situation of Xiatang Hotspring

Xiatang hotspring is located 10.5 km to the east of Zhongtang hotspring, exposed at the northwest corner of Xiatang Street on the North Bank of Sha River, 150 m from the Bank of Sha River. The altitude is 179 m, about 4 m higher than Shahe. Xiatang hotspring outcrops in the form of spring group. According to the collected data, there were seven spring holes distributed in a nearly east-west linear direction, with a total flow of 30.71 m³/h and a water temperature of 64 °C. In this survey, the measured water temperature was 61–63 °C, there were 13 geothermal wells and 3–4 wells were in normal use. According to the investigation and statistics of the utilization of local water intake structures, the water flow was 200–350 m³/h, the average value was about 250 m³/h, and the daily water consumption was 5000 m³/d; the water level drawdown was about 29 m, and the maximum value was 38.2 m. The hotspring group was distributed in the range of 40 m from east to west and about 10 m from south to north. According to the previous drilling data, only cold water (mainly groundwater in the upper Quaternary loose layer) or no groundwater was found in the strata out of this range.

(b) Geological Structure Characteristics of Xiatang Hotspring

Xiatang hotspring outcrops in the middle porphyry biotite monzogranite of Yanshan period. Except that the area of Lianhua and Laozhaung villages in the north is the andesite porphyrite of Xionger group, which is distributed in the north-west direction, the rest surrounding area of the hot spring is all Yanshanian granite. Xiatang hotspring is 3100 m away from Checun-Xiatang fault (F1-1) in the north, 500 m away from Shuimozhuang-Lichun fault (F1-3) in the south, and the north-west direction Yangzhuang fault (F2-2) passes through the west of the spring. About 500 m east of the hot spring, it is a joint intensive belt with a width of 1 m, strike of 70°, incline to southeast, dip angle of 83°. Five to ten meters to the north of the belt is an east-west compressed foliation belt, with a dip angle of 80–84°. According to this, it can be inferred that the joint intensive belt and the compressed foliation

belt are a near east-west fault zone, but the exposure conditions are not good, and the fault plane is not clear. Xiatang hot springs mainly outcrop along the fault zone, and this fault and Yangzhuang fault (F2-2) should be the main control structures of Xiatang geothermal field (Figure 8).

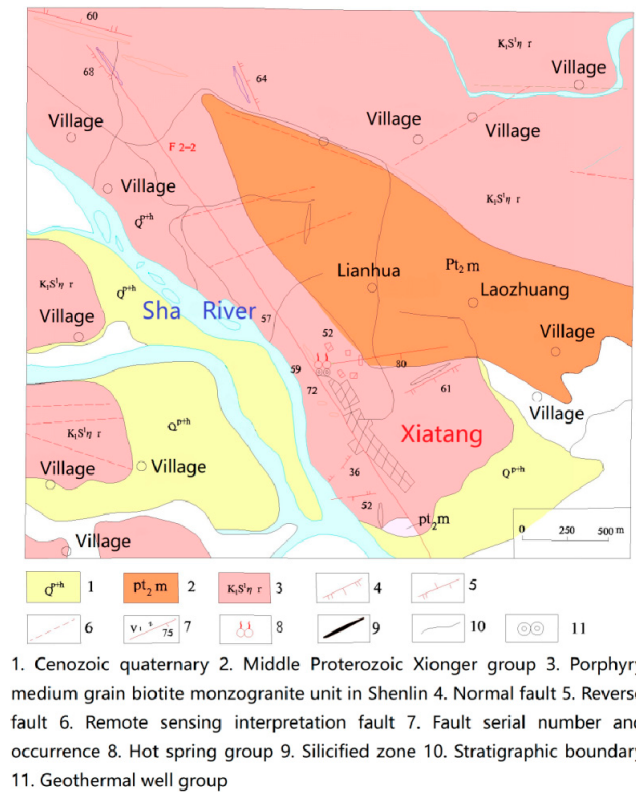
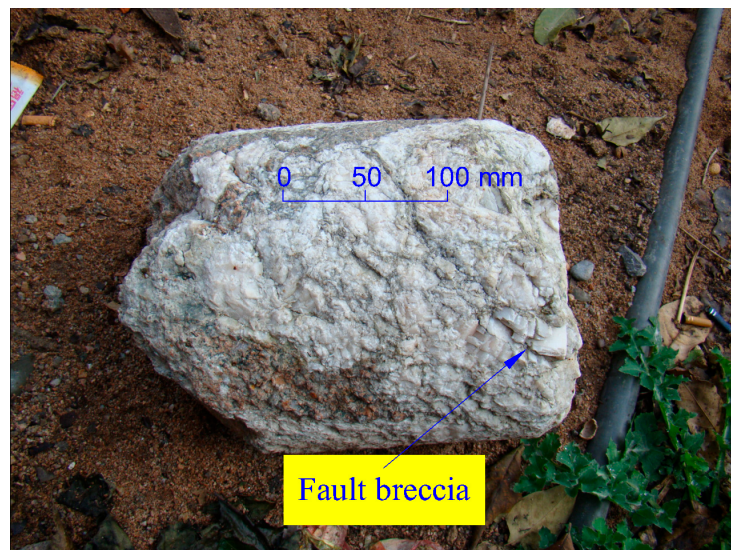
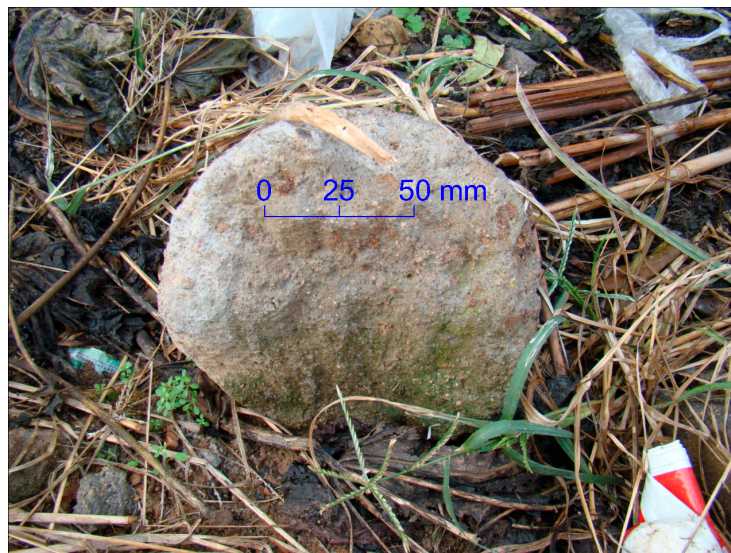


Figure 8. Geological structure of Xiatang geothermal field.

The drilling data collected revealed the strata of Xiatang field. 0–4.0 m, the rock core was loose and composed of deluvial silty clay mixed with gravel and gravel; the main component pebble was granite with a diameter of 2–15 mm. 4.0–150.0 m, the rock core was grayish brown and variegated granite, and it was columnar and massive; the main mineral composition was quartz, feldspar, pyroxene, hornblende, and mica. Among them, the core below 80 m was broken, fault fracture zone was visible, fracture was developed, and calcite vein distribution was visible. Geothermal water gushed out below this depth. A large number of pyrite was distributed on fracture surface, pore was developed, and fault breccia could be clearly seen (Figure 9).



(a)



(b)

Figure 9. Rock core of Xiatang geothermal drilling well: (a) Granite, pore developed, fault breccia; (b) granite, broken rock core.

3.2.4. Geological Characteristics of Shentang Geothermal Field

(a) General Situation of Shentang Hotspring

Shentang hotspring is 10.8 km away from Xiatang hot spring in the west, outcrops on a terrace on the south bank of Sha river, with an elevation of 150 m. The collected data showed that Shentang hotspring outcropped in the form of spring group, with three hotsprings in total, which were generally distributed in the north-east direction (20°). In this field survey of the study, all hotsprings did not show artesian flow. At present, two geothermal wells were working, from which the No. 2 well was 86 m deep, which was mainly used for bathing and breeding tropical fish, basically long-term working condition. Main parameters: water temperature 53°C ; water flow $45\text{ m}^3/\text{h}$; daily flow about $900\text{ m}^3/\text{d}$; water level 7.30 m; dynamic water level 12.50–13.70 m; water level drawdown about 5.20–6.40 m. The daily production of another well was about $900\text{ m}^3/\text{d}$, which was mainly used for bathing.

(b) Geological Structure Characteristics of Shentang Hotspring

Shentang hotspring is about 1400 m away from Checun-Xiatang fault in the north and 750 m away from Shuimozhuang-Licun fault in the south. Shentang geothermal field covers a large area of the quaternary system. According to the drilling data, the thickness of the quaternary system is 13.6–17.0 m, and the underlying bedrock is the andesite porphyrite of Xionger group. 700 m south of Shentang village is Yanshanian granite, in which two NE trending faults F2 are developed, extending to Shentang hotspring. In the southwest of this area, there is an andesite porphyrite of Xionger group, in which the near east-west silicified rock belt is relatively developed. According to the collected geological data, 9 NW and near EW faults were developed along the 2160 m distance of the dam axis of the nearby reservoir, among which the No.9 fault in the south of the dam had the largest scale with a fracture belt width of 200 m, which should be the Checun-Xiatang fault, indicating that the secondary faults of the parallel Checun-Xiatang fault were very developed. It can be inferred that the secondary faults parallel to the Checun-Xiatang fault and faults F1 and F2 are the main thermal control structures of Shentang geothermal field (Figure 10).

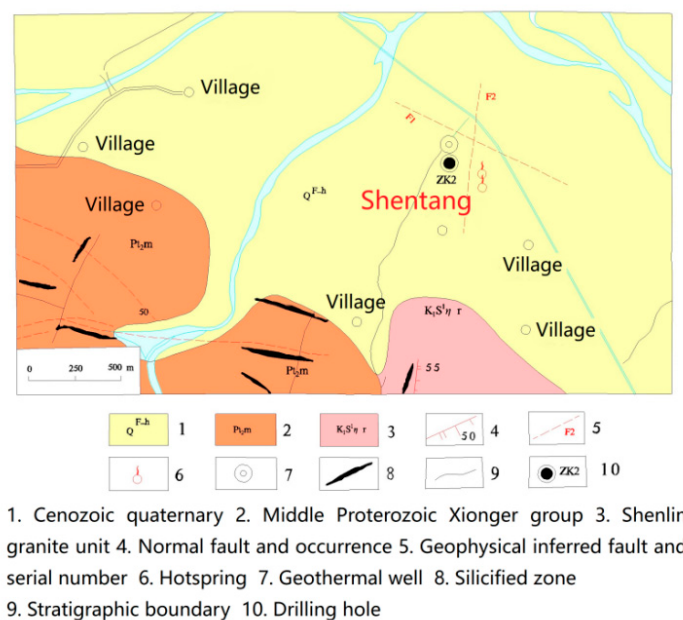


Figure 10. Geological structure of Shentang geothermal field.

(c) Geophysical Characteristics of Shentang Hotspring

(i) Magnetotelluric Sounding (EH-4) Characteristics

Two magnetotelluric sounding (EH-4) profiles were arranged on the east and west sides of Shentang hotspring, with an azimuth angle of about 30° (Figure 3). Jc1 profile was 500 m long, with a point distance of 50–100 m, and a total of 9 points were measured. Figure 11 shows that from the beginning of the profile to 350 m, it is a high resistivity geological body. From 350 to 600 m there is a relatively low resistivity depression, which is speculated to be a hot water bearing zone. The zone should be located in the contact zone between the volcanic rocks of the Middle Proterozoic Xionger group and the Yanshanian granite. The primary fracture was developed, and later it was affected by many fault activities. Then the rock among the zone was broken, rich in hot water, and became a deep thermal reservoir.

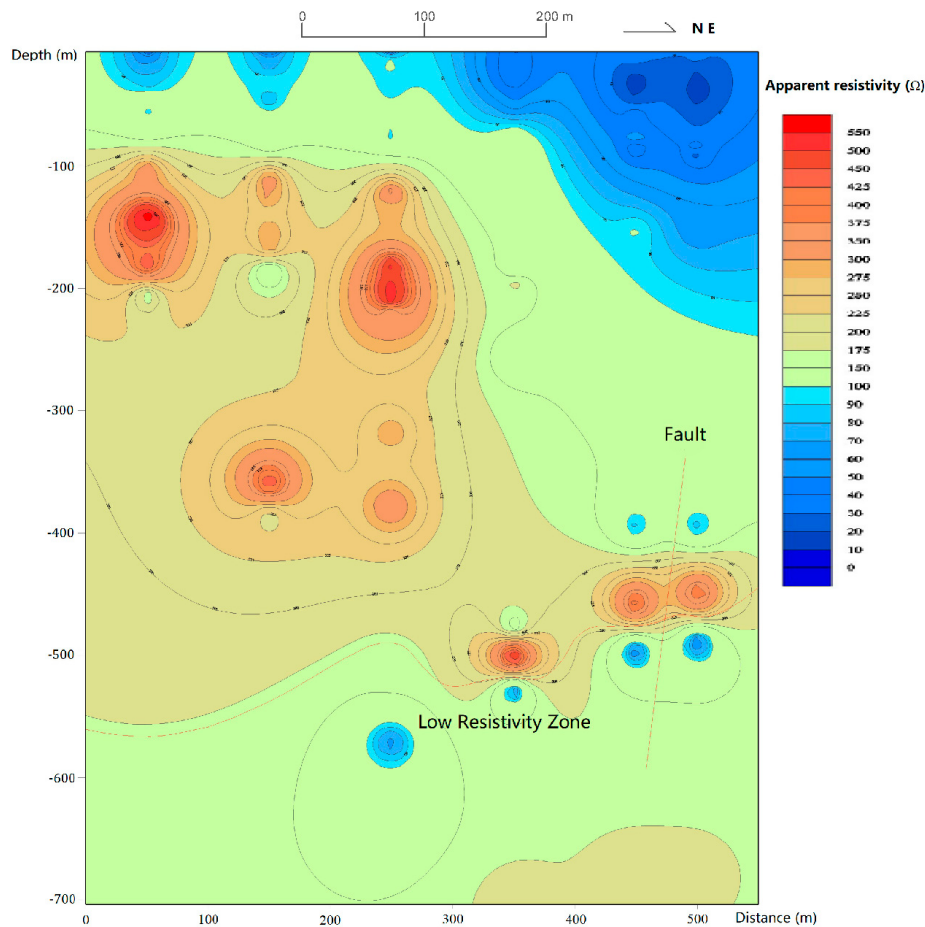


Figure 11. Jc1 apparent resistivity profile of Shentang geothermal field.

The JC2 profile is 600 m long, with a point distance 100 m, and a total of 6 points were measured. As shown in Figure 12, there is a 400 m depression of low resistivity from the starting point of the profile. The resistivity increases gradually from the surface to the deep underground, indicating that the upper stratum is relatively broken. There is a structural fracture zone inclined northward along the profile at the depth of 420 m. The Cagniard resistivity is $400 \Omega \cdot m$. The zone is supposed to be a structural fracture zone, but the resistivity is high, and the water content is small.

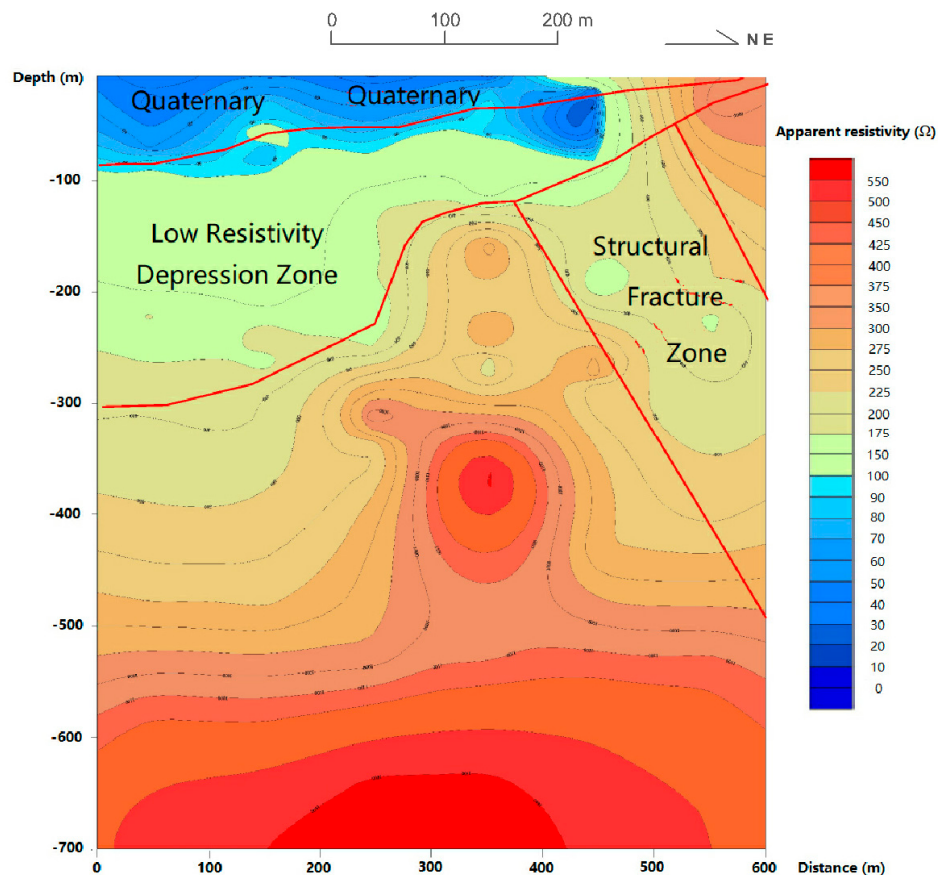


Figure 12. Jc2 apparent resistivity profile of Shentang geothermal field.

(ii) Resistivity Characteristics

There were three multi-electrode resistivity lines in Shentang field (W5, W6, W7; Figure 3).

The profiles with anomalies in W5 line mainly included Profile 3 (P3) and Profile 4 (P4). P3 was 300 m long, with a point distance 2.5 m. There were 120 measuring points in total. As shown in Figure 13, there is a steep low resistivity layer with resistivity less than 52.9 $\Omega\cdot\text{m}$ below the depth of 50 m in the 120–160 m interval on the right side of W5. The low resistivity layer is inferred to be a water-bearing fracture zone. In the 200–300 m interval below the depth of about 30 m there is another low resistivity layer which is inferred to be shale.

The parameters of P4 such as the length, the point distance, and the total measured points were same with P3. As shown in Figure 14, P4 coincides with some areas of P3, which proves that there is indeed a structural fracture zone on the right side of P4. The strata structure of P4 correspond to that of P3; both of them are sandy pebbles with high resistivity in the upper stratum, there are rock stratum with low resistivity in the middle part and completed stratum with high resistivity in the lower part. The two profiles P3 and P4 can verify each other.

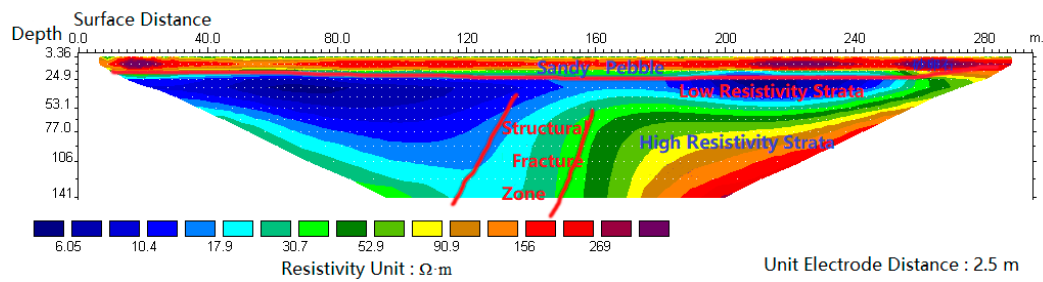


Figure 13. Profile 3 of W5 line in Shentang geothermal field.

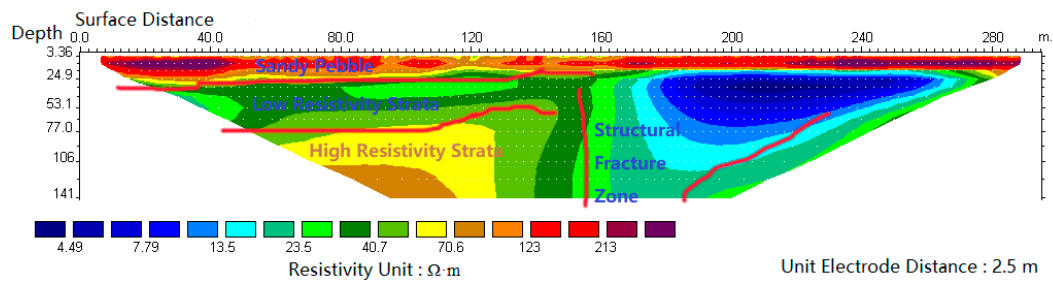


Figure 14. Profile 4 of W5 line in Shentang geothermal field.

The profile with anomalies in W6 line was Profile 1 (P1). P1 was 300 m long, with a point distance 2.5 m. There were 120 measuring points in total. Figure 15 shows the same strata of W6 line as those of W5 line, the structural fracture zone is obvious, and the stratum is the steepest in the 160 m area of the line. Comparing the analysis of W5 and W6 lines with geological map, it could be inferred that F1 fault fracture zone is located right in the steep area of structural fracture zone in P3 and P4 of W5 line and the structural fracture zone in P1 in the 160 m area of W6 line.

The profiles with anomalies in W7 line was Profile 2 (P2). P2 was 300 m long, with a point distance 2.5 m. There were 120 measuring points in total. As shown in Figure 16, P2 shows the same strata as W5 and W6, and the structural fracture zone is obvious. In the 80–150 m interval of W7, the structure is developed, and generally the resistivity is less than 53.4 $\Omega\cdot\text{m}$. Combined with the geological map, it is inferred that the structure may be the east extension of the Checun-Xiatang fault.

According to W5, W6, and W7 analysis, the structural fracture zone in W5 and W6 is the NW F1 fault. In P2 of W7, the inferred fault is Checun-Xiatang fault.

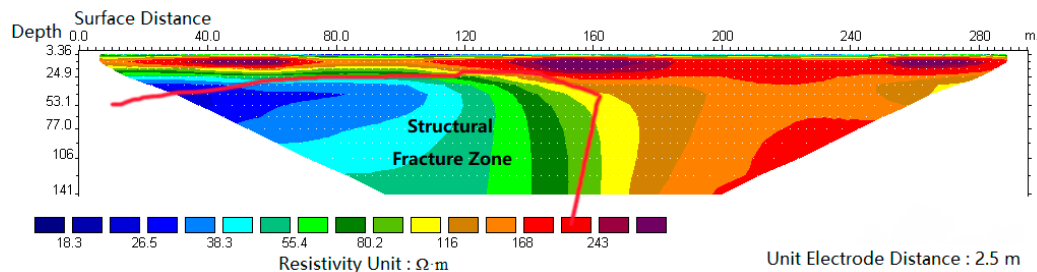


Figure 15. Profile 1 of W6 line in Shentang geothermal field.

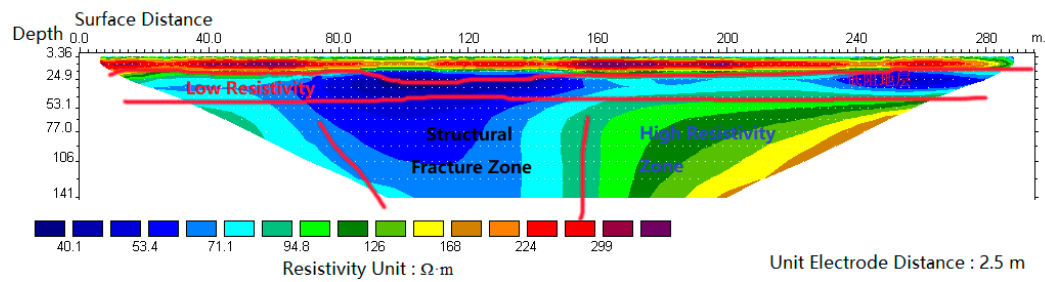


Figure 16. Profile 2 of W7 line in Shentang geothermal field.

(iii) Polarizability Characteristics

A polarizability profile was completed in Shentang geothermal field. As shown in Figure 17, there is a polarizability anomaly at a depth of about 350 m in Shentang geothermal field, indicating that the geological body at this depth has a large polarizability and may be a better water storage stratum. When the line drops below the depth of 500 m, the polarization curve becomes relatively scattered, and it is not obvious of the polarization in deep strata. Therefore, the polarizability cannot accurately measure the geoelectric anomaly, so it is not recommended as the judgment standard.

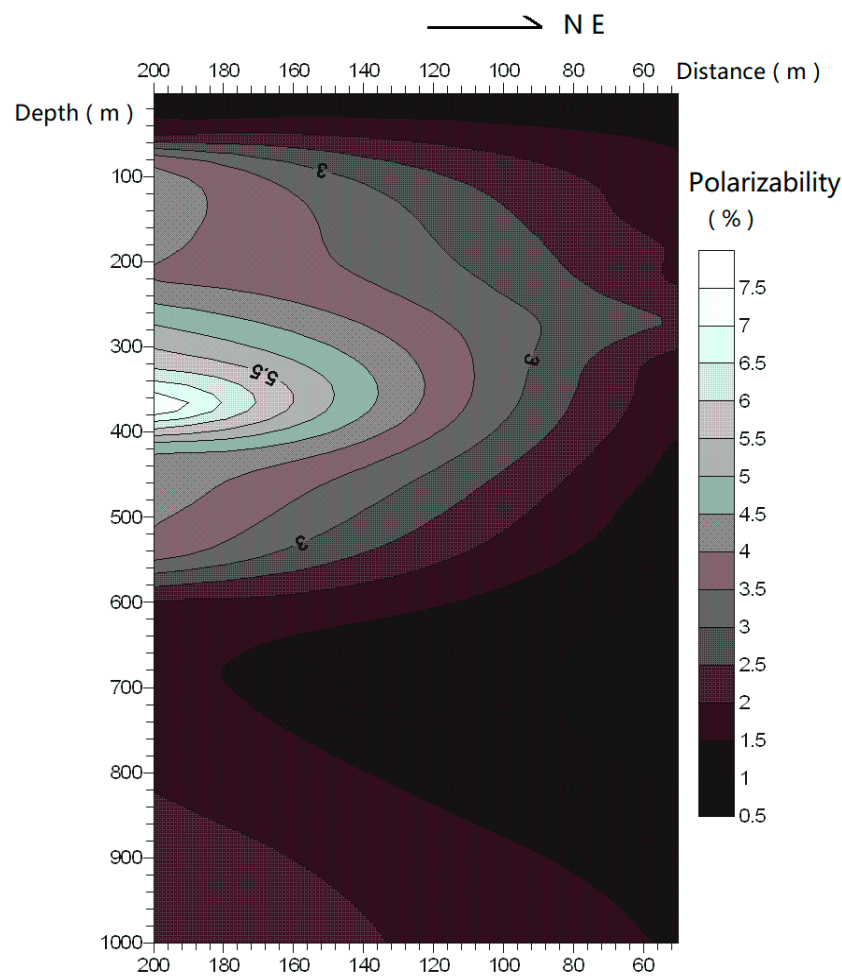


Figure 17. Polarization profile in Shentang field.

(d) Geological Drilling and Pumping Test

According to the above geophysical results, a hole with a depth of 300 m was located and drilled in the south of Shentang hot spring. Except the upper strata was quaternary system (about 13.6 m thick), the lower part was all andesite of Majiahe formation of Xionger group (Figure 18). Pumping test results: the maximum water temperature was 50 °C; the static water level was 18.00 m; the dynamic water level was 20.80 m; the depth of drawdown was 2.8 m; the water flow Q was 35.0 m³/h; the water flow per unit width was 12.5 m³/h·m.

Drilling results showed that there were fracture zones in the underground 50–80 m. Between the depth of 25.1–26.75 m, 30.95–32.65 m, 83.85–87.65 m, 105.9–107.3 m, 111.6–114.2 m, 121.2–123.1 m, 135.1–138.2 m, 174.5–182.0 m, 256–270 m, and 275–282 m, the rocks were broken and the apparent resistivities were low, so they should be water-bearing fracture zones. According to the electric logging curve, the well temperature reached a high value about 40 °C at about 80 m, and then it began to decline. The lowest value was about 30 °C between 120–180 m, so it was considered that there was cold water mixed in this section. The temperature started to rise again after 180 m, and it rose to about 40 °C at 300 m, indicating that the water temperature had a rising trend after the depth of 180 m.



Figure 18. Rock core of Shentang geothermal well, andesite of Majiahe formation in Xionger group. (a) Full view photo of rock core. (b,c) Close shot photos of broken rock core.

4. Discussion

4.1. Formation Mechanism of Lushan Geothermal Belt

The five hot springs are formed in the same condition of geological structure, so their hydrothermal activities and hydrochemical properties are similar. The northern boundary of geothermal belt is Checun-Xiatang fault, and the southern one is Erlangmiao-Wentang fault and Shuimozhuang-Lichun fault. The two boundaries are similar water and heat boundaries, and it is an independent hydrogeological unit between the two faults. In this unit, there is a complete process of water recharge-storage-heating-gushing.

4.1.1. Geothermal Water Recharge

The groundwater recharge of Lushan geothermal field mainly comes from surface water and groundwater. Among them, surface water recharge is the main, and groundwater recharge is the second.

(a) Surface Water

The surface river, Sha River, flows from west to east on the south side of the Checun-Xiatang fault, which is nearly parallel to Xiatang fault and 500–4000 m away from Xiatang fault. The river water is easy to infiltrate along the fault. In the west of Zhongtang geothermal field, there are mainly volcanic rocks, among which there are sandstone intercalations. The surface precipitation is easy to flow to Xiatang fault, and it infiltrates or flows into the underground storage space along the fracture zone and the south inclined main fault surface. In the north side of Zhongtang-Xiatang fault it is mainly composed of clastic rocks and locally carbonate rocks. The rock stratum tends to southeast. The surface precipitation can be stored along the rock layer to the main fault surface, or infiltrating along the main fault surface and both sides of the fracture zones to the water storage space. The atmospheric precipitation in the south side of Sha River flows into the river along the terrain, and infiltrate into the underground water storage space through Erlangmiao-Wentang fault and Shuimozhuang-Lishu fault along the fracture and secondary fault of granite.

Besides the above atmospheric precipitation supply, the atmospheric precipitation on both sides of Xiatang fault flows eastward into Sha River, infiltrates and recharges groundwater through the boundary fault of geothermal field.

(b) Groundwater

On the north side of Xiatang fault, there are different thickness carbonate rocks. Dolomite with thickness of 100–150 m and limestone with thickness of 200–250 m were also found in the research area. 2–3 km to the south of the geothermal field, the marble of Archaeozoic was remained in the granite, distributed in patches, covering an area of 4–6 km². All of these may store karst groundwater and transport it to geothermal field through some channel.

4.1.2. Water Storage Space

The water storage space of Lushan geothermal belt is mainly Checun-Xiatang fault. The fault had three stages of geological activities. In the early stage, it was formed at Yanshanian. The hanging wall dominated by granite on the south side thrusts against the footwall with huge nappe stress, forming a huge thick fracture zone of granite with a width of 500–1000 m. During this period, because of the compression fracture, there were few pores in the fracture zone, and the breccias of the fault breccia were relatively close with poor water capacity. The middle stage of the fault was at Cenozoic Era, and the main activity was tension activity. After the relaxation of thrust stress, the tension activity made the south plate of the fault fall, and the pores appeared in the fault zone. The late stage of the fault was at quaternary, the two plates of the fault made a left-lateral displacement, which was a torsional activity. Among the above three stages of activities, the space formed in the middle stage by the tensional activity was nearly 50 km long and 4000 m wide, which became the main water storage space of geothermal field.

4.1.3. Heat Source

The heat source of Lushan geothermal field mainly comes from the deep heat energy of the crust, and magma heat and shear heat also provide part of the heat source.

(a) Deep Heat Energy of Crust

The crust of Lushan area is more than 20 km thick. Checun-Xiatang deep fault and Liziyu-Banpoquan ductile shear zone are developed in and around the Lushan geothermal field.

Two structural zones provide channels for the deep heat energy to be transported upward. The Checun-Xiatang fault is a deep fault reaching the upper mantle, causing large-scale rock fault. The material heat energy in the melting state of the upper mantle is transmitted upward along the shear zone and fracture zone of the fault for a long and nonstop time. The deep heat energy can be transmitted to the surface and overflowed along the secondary faults (mainly NW and NE faults), forming a geothermal area with a width of several hundred meters and a length of tens of kilometers. Liziyu-Banpoquan ductile shear zone passes through the Proterozoic granite, which are granitic mylonites with a width of 100–1000 m, inclination 177–225°, and dip angle of 55–85°. This ductile shear zone is as deep as the upper mantle. The huge heat energy of the melting material in the upper mantle is transmitted upward along the shear zone, forming another deep heat transfer zone 2–3 km south of Xiatang fault. Lushan geothermal belt is right sandwiched between the two deep heat transfer zones.

(b) Magmatic Heat Sources

Granites developed in the Lushan geothermal field were formed in the Middle Proterozoic, Late Proterozoic, and Early Cretaceous. The Proterozoic granite is a ductile shear zone formed in deep environment, which contains a large amount of thermal energy. The early Cretaceous granite is the youngest intrusive rock in Lushan and its surrounding areas because of its relatively new age. It is possible that it is still in a melting state in the deep underground and has great thermal energy. The thermal energy preserved by the above two types of granites is transported upward along the North-South boundary faults of the geothermal field, which plays a certain role in the temperature rise of cold water in the geothermal field.

(c) Shear Structural Heat

The north and south boundaries faults of Lushan geothermal field all developed traces left by shear activities. In the late stage of Checun-Xiatang fault, the thermal energy generated by the shear activity was large enough to heat the recharge water in the geothermal field. In the southern boundary fault of geothermal field, the strike slip shear would make the minerals produce friction and generate heat energy, which would accumulate in the deep and transmit upward to form heat source.

4.1.4. Water Gushing Structure

The heat conduction structure of Lushan geothermal field is a complex fault system, which is composed of Checun-Xiatang fault in the north boundary, Erlangmiao-Wentang fault in the south boundary, and the NE and NW secondary faults oblique to the two main faults.

As mentioned before, the Checun-Xiatang fault experienced three stages of geological activities, in which the early compressive activities formed fracture zones, the middle tension activities formed water storage spaces, and the late torsional and left-lateral displacement activities were the activities of hot water being “squeezed out” and rising to the surface. The left-lateral displacement only distorted the strata on the north side of the fault, and the fault was not obvious. The granite on the south side of the fault was prone to fracture with other minerals because of the development of crystal-like phenocryst. Under the shear action, it was easy to form a NW trending fault, while the early NE thrust was easy to form NE fault. The joint of these two groups of faults was right the best channel for the rise of geothermal water. Because the Checun-Xiatang fault faces south with a dip angle of 75–85°, the location of hot spring artesian flow is to the south of the fault surface, which indicates that when the heated water stored in the fracture zone rises to the surface, it will overflow in the south of the fault.

In Shangtang field, broom structure was developed, that is, the NE fault converges to the NE and spreads to the SW. With the simultaneous action of the NW fault, geothermal water gushed out in a plane shape with an area of 4000 m², which was obviously caused by the faults. Zhongtang and Wentang field were not far away. The intersection of NE and NW faults made the geothermal water rise along the joint position of the two sets of faults to form hot springs, so the two gushing out points of Zhongtang and Wentang hot springs were actually one hot spring that was formed by a single

set of faults system. There was a large-scale northwest fault in Xiatang field, namely Yangzhuang fault, while the earlier NE fault was relatively small, the faults joint and interaction position was deep underground, therefore the geothermal water mainly rose along the northwest fault. There were two kinds of lithologies in the south of Shentang field, early Cretaceous granite and Majiahe formation andesite. The faults were mainly developed in granite. The granite area was not large, the water supply performance was not as good as the Shangtang, Zhongtang, and Xiatang, so the hot spring temperature is low. There was no granite outcropping in Matang geothermal prospect investigation area, the structure in the bedrock was not as developed as that in the granite, and the water storage property was more poor, so higher temperature water was not found in the area.

4.2. Assessment of Geothermal Resources

4.2.1. Natural Recharge of Geothermal Water

The south and north boundaries of Lushan geothermal belt are clear, they are similar water and heat boundaries, and it is an independent hydrogeological unit between the two faults. The total natural discharge and exploitation of the five geothermal fields is 397.94 m³/h, which can be regarded as the minimum natural recharge of Lushan geothermal field.

4.2.2. Exploitable Quantity of Geothermal Water

(a) Minimum Exploitable Quantity

The results of pumping and observation show that the minimum exploitable volumes of Shangtang, Zhongtang, Xiatang, Wentang, and Shentang under the condition of artesian flow are 132 m³/h, 13.94 m³/h, 200 m³/h, 2.0 m³/h, and 50 m³/h respectively. The total minimum exploitable quantity is 397.94 m³/h.

(b) Maximum Exploitable Quantity

The results of pumping test show that the maximum test water output of Shangtang geothermal field is 280.4 m³/h, and the data of Xiatang and Shentang are 250 m³/h and 125 m³/h respectively. The geothermal field data of Zhongtang and Wentang are lacked, and the exploitable quantities are estimated according to the natural flow, which are 13.94 m³/h and 2.0 m³/h respectively. The total quantity is 671.34 m³/h.

4.2.3. Assessment of Geothermal Energy

The geothermal capacity is calculated according to the maximum exploitable quantity, as shown in Table 4.

Calculation formula of exploitable quantity of geothermal fluid:

$$W_t = 4.1868Q(t - t_0) \quad (1)$$

where W_t is thermal power (kW); Q is recoverable amount of geothermal fluid (L/s); t is temperature of geothermal fluid (°C); t_0 is local annual average temperature (°C).

Estimation formula on accumulated heat energy of annual exploitation of geothermal fluid:

$$\sum W_t = 86.4DW_t/K \quad (2)$$

where $\sum W_t$ is exploitation of heat energy available for one year (MJ); D is annual number of exploitation days (total days converted by 24 h, d); W_t is value of thermal power (kW) calculated by Equation (1); K is the thermal efficiency ratio (the thermal efficiency of coal-fired boiler is calculated as 0.6); 86.4 is unit conversion factor.

The annual available heat energy of Lushan geothermal energy is 4.41×10^{11} MJ, which is equivalent to 15.05×10^6 tons of standard coal, i.e., 15 million tons of standard coal, or 10.53 million tons oil equivalent. The heat consumption in a heating season in North China is $0.2\text{--}0.3$ GJ/m². According to the heat consumption of 0.25 GJ/m², the five hot springs can provide 0.6 billion square meters of winter heating, which is equivalent to a megacity with a population of 10 million.

Table 4. Estimation of geothermal energy.

Geothermal Field	Shangtang	Zhongtang	Wentang	Xiatang	Shentang	Total
Recoverable Mount (m ³ /h)	280.4	13.94	2.0	250.0	125.0	671.34
Recoverable Heat (kW)	15,098.7	783.1	58.8	14,043.2	5131.7	35,115.5
Annual Recoverable Heat Energy (MJ)	1.89×10^{11}	9.83×10^9	7.39×10^8	1.76×10^{11}	6.44×10^{10}	4.41×10^{11}
Equivalent to Standard Coal (t/a)	6.45×10^6	0.34×10^6	0.025×10^6	6.01×10^6	2.20×10^6	15.05×10^6

5. Conclusions

Through remote sensing geological interpretation, field geological survey, geophysical exploration, geological drilling, long-term observation, pumping test, and hydrochemistry test and other technical means and working methods, this study analyzed the geothermal characteristics and geological characteristics of Lushan geothermal belt, basically found out the formation mechanism and thermal control structure of Lushan geothermal zone, and estimated the reserves of geothermal resources. The main conclusions are drawn as followings:

1. Lushan geothermal springs are exposed in the Checun-xiatang deep fault zone. The Checun-Xiatang deep fault zone is the northern boundary of Lushan geothermal belt, the Erlangmiao-Wentang fault zone and Shuimozhuang-Lichun fault zone are its southern boundary, and the Modaling-Huanghuai watershed is its western boundary. The Checun-Xiatang fault and its parallel secondary near East-West faults are the primary heat control and conduction structures, which are the main channels for upward convection of deep heat sources; the north-east faults are the secondary heat conduction and water conduction structures, which control the outcropping of five hot springs.
2. Lushan geothermal (hot spring) belongs to uplift fracture type, convection type, fracture vein type geothermal artesian water. It has no good heat insulation overburden, and is mainly recharged by atmospheric precipitation. Hydrochemical type of Shentang hot spring water belongs to HSiO₄-HCO₃-Na, and the others belong to HCO₃-SO₄-Na type. The temperature and quantity of all geothermal spring water are hardly affected by seasons. The results of geophysical exploration show that there is low resistivity layer in the 600–800 m underground, which is supposed to be the reservoir of geothermal water.
3. The water temperature of Shangtang, Zhongtang, and Xiatang hot springs is from 60 to 90 °C, which belongs to the hot water of low-temperature geothermal resources. The water temperature of Wentang and Shentang hot springs is from 40 to 60 °C, which belongs to the warm water of low-temperature geothermal resources. The minimum recoverable amount of Lushan geothermal field is 397.94 m³/h, and the maximum value is 671.4 m³/h. The annual recoverable heat energy is 4.41×10^{11} MJ.

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