Geothermal geological characteristics and exploitation potential in Nanyang Basin

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Abstract: Based on the geothermal geological conditions and the geothermal resources development and utilization data of Nanyang Basin for many years, the geothermal fields in the basin are divided according to the study of fault structures. According to the pumping test data of geothermal wells, the permeability coefficients of the thermal storage aquifers of the geothermal wells were calculated using the steady-flow Dupuit formula and Kusakin's empirical formula. In this paper, the water conductivity of thermal reservoir is calculated by using the method of line diagram and recovery water level, and the characteristics of thermal reservoir aquifer group, geothermal fluid flow field, and hydrochemistry are described systematically. Based on the analysis method of groundwater exploitation potential index, the development and utilization potential of geothermal resources is studied, which has certain reference significance for the development and utilization of geothermal resources of sedimentary basins.

Key words: Nanyang Basin; aquifer; geothermal fluid; flow field; hydrochemistry

1. Introduction

According to the characteristics of geology, hydrology and energy transfer, the geothermal system is a system in which the dispersed heat energy is gathered and transported by some working fluid (water, steam) and constitutes energy resource in suitable environment [1]. Geothermal energy is a kind of cheap alternative energy and clean energy [2], which can provide heat energy, health care, planting, breeding, power generation and drying, etc. China is rich in geothermal resources, and geothermal energy development and utilization potential is huge. Nanyang Basin, located in the southeast of Henan province, is an area rich in geothermal resources in China and has good development prospects. Rybach and Muffler divide geothermal systems into convective and conductive types according to geological conditions and heat transfer patterns[3]. Chen Moxiang, Wang Jiyang, and Deng Xiao[4] based on the study of hydrothermal geothermal systems in China by Huang Shangyao, the hydrothermal geothermal systems in China are further divided into 2 types (thermal convection type in tectonic uplift and thermal conduction type in tectonic subsidence) and 5 types (volcanic, non-volcanic, deep circulation, faulted basin and depression basin), the geological structure and thermal background, structure and scale, heat source and water source, mineralization degree of hot water, utilization direction of geothermal energy, and representative areas and geothermal fields of each type of geothermal system are summarized and analyzed. The geothermal resources of Nanyang Basin belong to the hydrothermal (conductive) geothermal energy of sedimentary basin, and it has an ideal environment for storing and forming hot water [5]. The Mesozoic-cenozoic faulted basin geothermal system was formed by structural depression, and the formation mechanism of geothermal water can be summarized by the model of “Layer-controlled heat storage-lateral runoff recharge-geothermal flow heating”. According to this model, the favorable conditions for the formation and accumulation of hot water in the basin can be summed up into three interrelated points: (1) the development of large-scale and huge-thick reservoirs in the basin, (2) the suitable hydrodynamic environment, (3) good heating and heat preservation conditions [6]. According to the tectonic zoning based on statistical results of geothermal flow in Chinese mainland regions, the Nanyang Basin is located in the north China-northeast tectonic Chinese mainland with an average heat flow of 59-63 mw/m2[7], and it is mainly used in traditional industries such as hotel spa, greenhouse vegetable planting and so on. The study on the division of geothermal field, the characteristics of thermal reservoir aquifer group and the chemical characteristics of the geothermal fluid in Nanyang Basin is relatively low, it can provide a reliable basis for the development and utilization of geothermal resources in Nanyang Basin.

2. Regional geological characteristics of Nanyang Basin

Nanyang Basin is located in the Qin Mountains latitudinal structural belt and the Cathaysian type of structure reversed complex location, surrounded by mountains on three sides, southern opening, is formed in the late Yan Mountains tectonic movement in the Mesozoic and Cenozoic continental rift basin dominated by the Paleogene, the area is about 1.7×104km2[8]. The basement rocks of Nanyang Basin are Archean taihua complex, and the main sedimentary covers are middle-late Proterozoic Guandaokou Group, Luanchuan County Group, Ruyang Group and Luoyu Group. The sedimentary layers in the basin are thicker in the middle, the thickest being more than 6000m, and gradually thinning towards the edge of the basin, in the basin, there is a basic tectonic framework of two ridges (Shigang—Xinye Uplift, Tanghe Low Uplift) and three Sags (Nanyang Sag, Biyang Sag, Zaoyang-Xiangfan Sag [9].

3. Division of geothermal field in Nanyang Basin

In the Mesozoic and Cenozoic sedimentary basins widely developed in China, the basement of the faulted basin is developed in a local tectonic fissure system, and the deep circulating groundwater is welled up along the fissure channel and enriched on the top of the bedrock after heating, a concealed source of discharge or reservoir of hot water. In a depressed basin with relatively stable crustal activity and no major structural damage, groundwater heated under normal geothermal gradients moves up in permeable rock formations, the formation of large-area geothermal aquifers with regional significance at different depths [10]. Zhang Fuyou has studied the relationship between fault structure, shallow reservoir temperature and geothermal anomaly in Nanyang Basin. The more developed basement fault structure is, the higher shallow reservoir temperature is, the more obvious geothermal anomaly is, near Dengzhou, for example [11]. The series of faults developed in Henan province, such as Neixiang-Tongbai Fault (F1), Xinye Fault (F2) and Zaoyang-Xiangfan Fault Sag, are the important marks of the geothermal field division in Nanyang Basin. Due to the development and uneven subsidence of fault structures, sub-level uplift and Sag were formed in the basin, which cut the geothermal field into many small pieces. According to the geological structure and geothermal field zoning sketch map of Nanyang Basin(Fig.1), the geothermal field in Nanyang Basin is divided into three types: the geothermal field in Dengzhou-Shayan-Zhangdian Sag, the geothermal field in Xindianpu-Hanlongtan Sag and the geothermal field in Tanghe-Anpeng Sag, the geothermal field area of Dengzhou-Shayan-Zhangdian Sag is 3475.3 km2, that of Xindianpu-Hanlongtan Sag is 1845.2 km2, and that of Tanghe-Anpeng

Sag is 2148.8 km2. The main elements in the geothermal system include heat source, channel, water source and reservoir-cap rock[12]. These elements form the core of the geothermal field and are the material basis of the formation of the geothermal field.

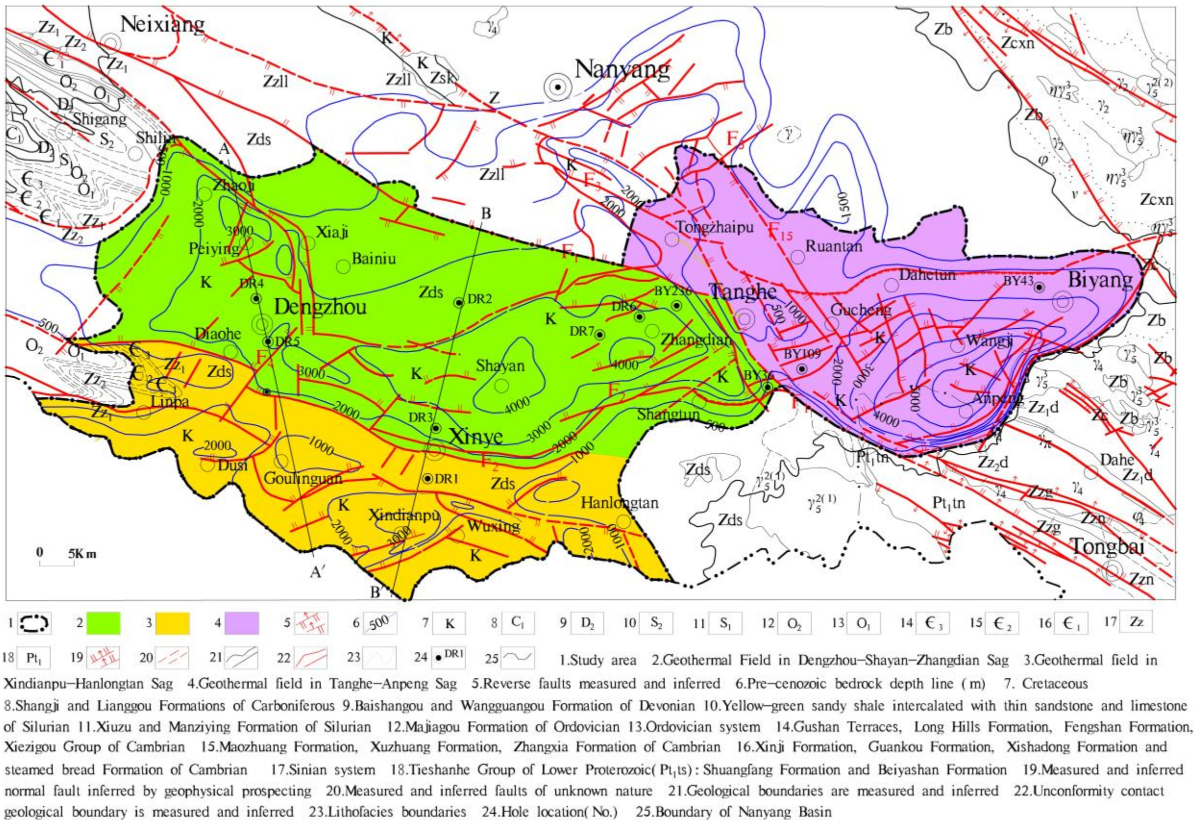

Fig.1 Geological Structure and Geothermal Field Zoning Sketch Map of Nanyang Basin

3.1 Geothermal Field in Dengzhou-Shayan-Zhangdian Sag

The geothermal field in Dengzhou-Shayan-Zhangdian Sag is bounded to the north and east by the Neixiang-Tongbai Fault (F1) and to the south by Xinye Fault (F2) in the Mujiaya-Neixiang-Tongbai-Shangcheng deep fault zone, the western boundary of the basin is the boundary of the basalt contour line of the Cenozoic era 500m ago, with an area of 3475.3 km2. It mainly consists of three sedimentary basins with the Dengzhou Basin, Shayan town of Xinye County and Zhangdian town of Tanghe County as the subsidence centers, the town of Shayan in Xinye County is one of the subsidence centers of the Nanyang Rift. It is divided into the south steep slope belt, the central depression belt, the North Gentle Slope Belt and a series of secondary depressions arranged in the east-west direction [13]. According to the borehole data, the Quaternary sedimentary thickness of the geothermal field is about 100m, and the lower part is Neogene (N) and Paleogene (E) fine sandstone, sandstone, glutenite and clay rock. In Neogene (N) and Paleogene (E), coarse sand, loose fine sandstone, sandstone and glutenite are the main thermal reservoirs. The Cenozoic sedimentary thickness of the geothermal field is generally 2,000-4,000 m. the Cenozoic sedimentary thickness of the Shayan area in Xinye County and the Zhangdian area in Tanghe County exceeds 4,000 m, and the thickest Paleogene strata in the depression is 4800 m [14]. In the west, the Cenozoic sedimentary basin centered on the Dengzhou basin was more than 3,000 m thick. Geothermal resources are mainly buried in Neogene Shangsi Formation, Paleogene Liaozhuang Formation and Hetaoyuan Formation. Six geothermal wells have been constructed in the geothermal field, and the Neogene Shangsi Formation, Paleogene Liaozhuang Formation and Hetaoyuan Formation with thermal reservoir have been revealed (Table 1), which shows that geothermal resources are widely distributed in the geothermal field.

The geothermal field in the Dengzhou-Shayan-Zhangdian Sag is located in the central Sag and the southern steep slope zone of the Nanyang Fault Sag. The thickness of the central sag is large, and the thickness of the southern steep slope varies greatly. The natural thermal reservoir water flows from the periphery to the middle, and the thermal control layer of the geothermal field has good continuity. The geothermal field in the Dengzhou-Shayan-Zhangdian Sag is located in the area where geothermal resources are widely distributed and geothermal fluid runoff occurs. According to the natural movement of geothermal fluid, the boundary of the geothermal field around Dengzhou-Shayan-Zhangdian belongs to the geothermal fluid recharge boundary, has no discharge boundary and belongs to the stagnant runoff zone. According to the analysis of future mining state, the boundary of geothermal field in Dengzhou-Shayan-Zhangdian Sag is geothermal fluid recharge boundary. According to the analysis of hydrogeological boundary conditions, the geothermal field is a confined thermal reservoir with no overflow recharge and infinite horizontal distribution.

Table.1 Summary of borehole heat-controlled formation thickness in geothermal field

Geothermal field	Well number	Well Deep (m)	Neogene Shangsi Formation		Paleogene Liaozhuang Formation		Paleogene Hetaoyuan Formation	
			Depth of the floor (m)	Thickness (m)	Depth of the floor (m)	Thickness (m)	Depth of the floor (m)	Thickness (m)
Geothermal Field in Dengzhou-Shayan-Zhangdian Sag	DR1	1500	779.45	49.45	1330.1	550.64	1500	169.9
	DR2	1390	858	358	1193.1	335.1	1390	196.9
	DR4	980.6	638.8	138.8	957.8	319	980.6	22.8
	DR5	1213	633.6	128.2	976.7	343.1	1213	236.3
	DR6	1886					1886	197
	DR7	580	580	80				
Geothermal field in Xindianpu-Hanlongtan Sag	DR3	1211.9	765.5	265.5	1210	465.4		
Geothermal field in Tanghe-Anpeng Sag	BY26	2337					303	158
	BY43	1726					147	135
	BY109	913					268	161
	BY236	2825					450	350

3.2 Geothermal field in Xindianpu-Hanlongtan Sag

The geothermal field in Xindianpu-Hanlongtan Sag is bounded by the Xinye Fault (F2) in the north and the Zaoyang-Xiangfan Fault Sag in the south, the boundary between the east and the west is the boundary of the pre-cenozoic bedrock isoline with an area of about 1845.2 km2. It is mainly a sedimentary basin with Xindianpu, Xinye County as the subsidence center. According to the borehole data, the Quaternary sedimentary thickness of the geothermal field is about 100m, and the lower part is Neogene (N) and Paleogene (e) fine sandstone, sandstone, glutenite and clay rock (mainly mudstone) . Neogene (N) and Paleogene (e) loose fine sandstone, sandstone and glutenite are the main thermal reservoirs. The depositional thickness of this geothermal field is generally 1000-3000 m, and that of Cenozoic in Xindianpu area is over 3000 m. The geothermal resources are mainly buried in the Neogene Shangsi Formation and Paleogene Liaozhuang Formation. A geothermal recovery well was constructed in the geothermal field, and the Neogene Shangsi Formation and Paleogene Liaozhuang Formation with thermal reservoir were revealed.

3.3 Geothermal field in Tanghe-Anpeng Sag

The geothermal field in the Tanghe-Anpeng Sag is bounded by the Nanyang-Tongbai Fault (F1) as the western boundary, and by a series of NW and NE trending faults developed in the Tanghe County and Tongbai County of the Nanyang Fault Sag as the thermal control tectonic boundary, with an area of about 2,148.8 km2, the subsidence center is located at Anpeng of Tongbai County. The quaternary sedimentary thickness of the geothermal field in the Tanghe-Anpeng Sag exceeds 100 m, and the loose fine sandstone, sandstone and glutenite of the Neogene (N) and Paleogene (E) are the main thermal reservoirs, the Cenozoic depositional thickness of the geothermal field is generally 1000-5000m, and that of Anpeng is more than 5000m. According to the data of 4 oil exploration holes, the geothermal resources are mainly buried in the Paleogene Hetaoyuan Formation. The structural, sedimentary and hydrodynamic conditions of petroliferous basins, which are formed by their unique formation and evolution process, make them have a good foundation to form large and medium-sized geothermal fields [15].

4. Characteristics of thermal reservoir aquifers

4.1 Characteristics of thermal reservoir aquifers in key research areas of Dengzhou

According to the A-A' hydrogeological profile (Fig.2), the Neogene Shangsi Formation (N2s) in the key research area of Dengzhou province is composed of thick fluvial facies and interbedded sand-clay deposits with a maximum sedimentary thickness of 100-250m, it is mainly composed of coarse sand, fine sand and siltstone, as well as glutenite and siltstone. The thickness of single sand layer is from several meters to tens of meters, and the cumulative thickness is mostly 50-200 meters. The thickness of sandstone is 40-50% of the total thickness of this formation. The stratiform thermal reservoir of Paleogene is composed of interbedded sandstone and mudstone with thick fluvial facies, the maximum thickness of which is 1000-3000m. The upper part of Paleogene is Liaozhuang Formation (E3l), and the lower part is Hetaoyuan Formation (E2h). Liaozhuang Formation (E3l)) is 300-350m thick, and the coarse clastic rocks are mainly coarse sandstone and medium sandstone, as well as glutenite, glutenite-bearing sandstone and fine sandstone. The thickness of sandstone is from several meters to tens of meters, and the cumulative thickness is mostly 110-180 meters. The thickness of sandstone accounts for 30-50% of the total thickness of this formation. The first member of Hetaoyuan Formation (E2h1) is 200-240m thick, and the coarse clastic rocks are mainly fine sandstone and siltstone. The thickness of sandstone is from several meters to more than ten meters, and the cumulative thickness is mostly 80-100 meters. The thickness of sandstone is 30-40% of the total thickness of this formation. The Shangsi Formation is a water-rich member of Neogene Thermal Reservoir. The water quality is mostly fresh water, the salinity is less than 1 g/L, and the hydrochemical type is HCO3-Na type. The first member of Liaozhuang Formation and Hetaoyuan Formation is the water-rich member of Paleogene Thermal Reservoir. The water quality is mostly fresh water, the salinity is more than 1.0 g/L, and the hydrochemical type is SO4·HCO3-Na type.

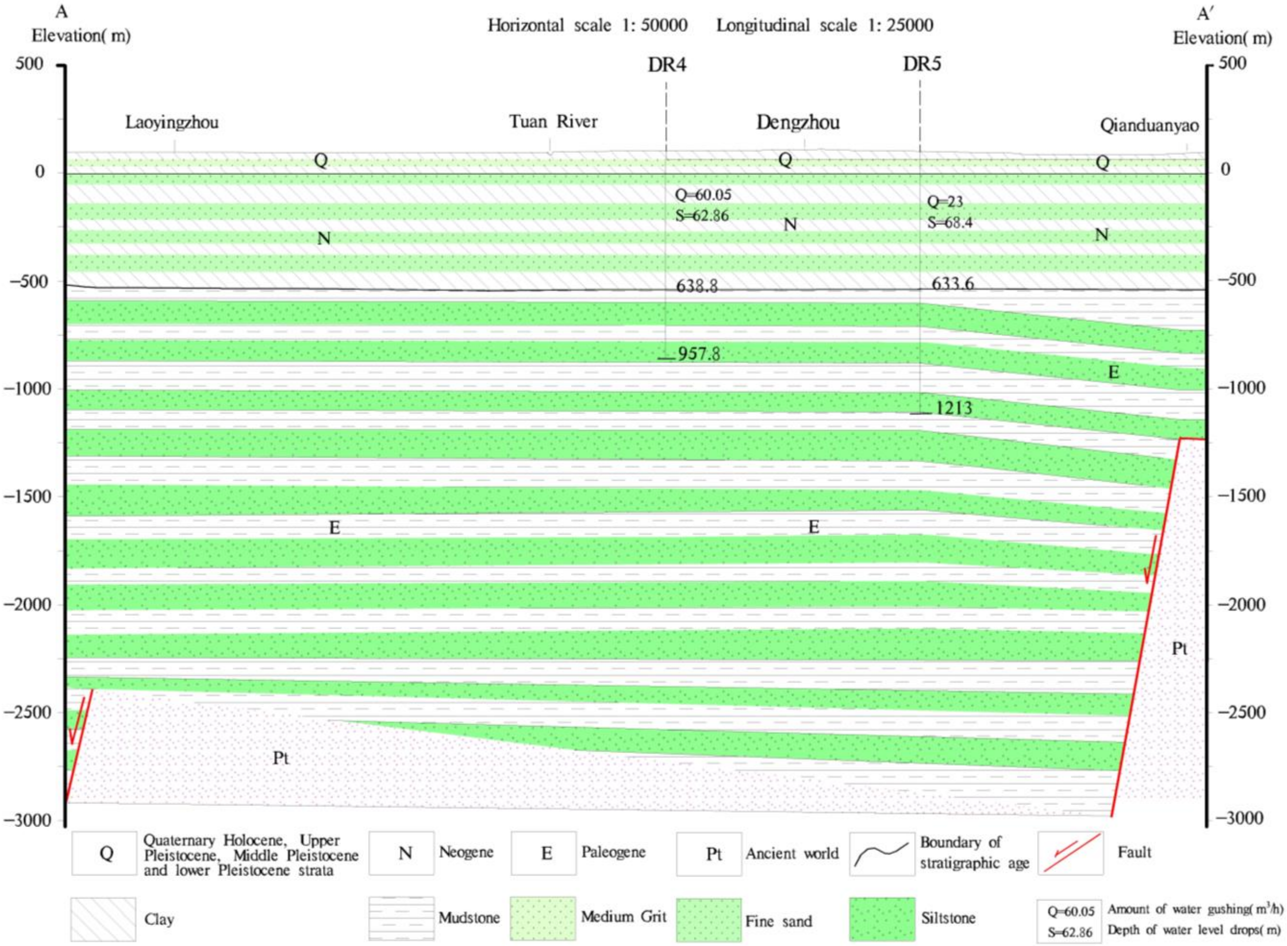

Fig.2 Hydrogeological section(A-A′)

According to the characteristics of A-A′ hydrogeological section and geophysical section in the study area, the depth of bedrock surface gradually increases from north to south and from west to east, moreover, the thermal reservoirs in this area have good water-bearing sand and sand-gravel layers with good water-bearing properties. Combined with geothermal well investigation data, the productivity of single well in the study area is 23-60 m3/h, with an average of 41.5 m3/h. The northwest of the study area in Dengzhou is classified as a water-rich area (over 40 m3/h) , the southeast part is divided into the middle rich water area (more than 20 m3/h) . The water inflow per unit is small, generally 0.33-0.96 m3/m·h, the minimum depth is 62 m, the maximum depth is 68 m.

Based on the statistical data of actual pumping tests of geothermal wells in the study area, the permeability coefficients of the aquifers in each well were calculated by using the steady flowing Kuibuyi formula and Kusakin's empirical formula. Using the pumping test data of the Dengzhou water supply works and the Dengzhou East supply wells, the permeability coefficient of the thermal reservoir in the northwest and southeast of the area is 0.50 m/d and 0.42 m/d, respectively, and the hydraulic conductivity is 39.10 and 56.83 m2/d, respectively. The water temperature at the wellhead is 40-44 °C. Based on the comprehensive analysis of the geothermal water quality data, the hydrochemical type is SO4·HCO3-Na type, the salinity is 1235-1363 mg/L, the pH is 7.46-7.96, the content of H2SiO3 is 24-29mg/L, the content of SR is 2.88-3.58 mg/L. The geothermal water temperature in the study area is 40-44 °C. it belongs to warm geothermal water and is the main geothermal mining layer in Dengzhou.

4.2 Characteristics of thermal reservoir aquifers in key research areas of Xinye County

According to the B-B′ hydrogeological section (Fig.3), the Neogene Shangsi Formation (N2s) bedded heat reservoir in the south of Xinye Fault (F2) is composed of sand and clay interbedded deposits with thick fluvial facies, the maximum sediment thickness is 270m, mainly fine sand and silty sand with coarse sand at the bottom. The thickness of single sand layer is from several meters to tens of meters, and the cumulative thickness is 180-200 meters. The thickness of sandstone is 50-70% of the total thickness of this formation. The stratiform reservoir of Paleogene is composed of interbedded sandstone and mudstone with thick fluvial-lacustrine facies, and the upper part is E3l (undiscovered). Liaozhuang Formation (E3l) is 300-500m thick, and the coarse clastic rocks are mainly fine sandstone and siltstone. The thickness of sandstone is from several meters to more than ten meters, and the cumulative thickness is 160-190 meters. The thickness of sandstone is 40-55% of the total thickness of this formation. The Neogene Shangsi Formation (N2s) in the north of Xinye Fault (F2) is a stratified heat reservoir composed mainly of sand and clay interbedded in thick fluvial facies with a maximum sedimentary thickness of 360 m, mainly of fine sand, silty fine sand and medium fine sand, at the bottom there is a single layer of coarse sand from a few meters to tens of meters thick, cumulative thickness of 150-170 m, sandstone thickness of the total thickness of 47-52% of the formation. The stratiform reservoir of Paleogene is composed of interbedded sandstone and mudstone with thick fluvial-lacustrine facies, the upper part of which is Liaozhuang Formation (E3l), the lower part of which is Hetaoyuan Formation (E2h) . The Liaozhuang Formation (E3l) is 330-400m thick, and the coarse-clastic rocks are mainly medium-grained sandstone, fine-grained sandstone and siltstone. The thickness of sandstone is from several meters to more than ten meters, and the cumulative thickness is 90-120 meters. The thickness of sandstone is 30-40% of the total thickness of this formation. The first member of Hetaoyuan Formation (E2h1) is 200-220m thick, and the coarse clastic rocks are mainly fine sandstone and siltstone. The thickness of sandstone is from several meters to more than ten meters, and the cumulative thickness is 40-80 meters. The thickness of sandstone is 20-30% of the total thickness of this formation. The Shangsi Formation is a water-rich member of Neogene Thermal Reservoir. The water quality is mostly fresh water, the salinity is less than 1.0 g/L, and the hydrochemical type is HCO3-Na type. The first member of the Liaozhuang Formation and the Hetaoyuan Formation is the water-rich member of the Paleogene Thermal Reservoir. The water quality is mostly fresh water, and the salinity is more than 1.0 g/L. the geochemical type of geothermal water to the north of the Xinye Fault (F2) is Cl·HCO3-Na type, the geochemical type of geothermal water in the south of Xinye Fault (F2) is SO4-Na type.

According to the characteristics of B-B′ hydrogeological section and geophysical prospecting section in the study area, the buried depth of bedrock surface increases gradually from south to north, and the thermal reservoir in the area has good water-bearing sand bed and water-bearing property. Combined with the investigation data of geothermal wells, the production capacity of single well in this study area is 33-51 m3/h, with an average of 41.8 m3/h, and the water-rich area is good. The north of Xinye Fault (F2) is divided into the water-rich area (> 40m3/h) , the south of Xinye Fault (F2) is divided into middle water-rich area (> 20m3/h) . The water inflow per unit is small, generally 0.35-1.10 m3/m·h, the minimum depth is 46 m, the maximum depth is 95 m.

Based on the statistical data of actual pumping tests of geothermal wells in the study area, the permeability coefficients of the aquifers of each well were calculated by using the steady flow Kuibuyi formula and Kusakin's empirical formula. Drawing on the pumping test data of the wells in Xinye County City North Park and Xinye County elderly retirement home, the permeability coefficients of the thermal reservoirs in the north and south of the fault are 0.41 m/d and 0.43 m/d, respectively, and the hydraulic conductivity is 44.57 m/d and 51.30 m/d, respectively. The water temperature at the wellhead is 49.5-51 °C. According to the data of geothermal water quality, the salinity is 1115-4354 mg/L, the pH is 7.92-8.20, the content of H2SIO3 is 18.8-20.4 mg/L, the content of Sr is 1.22-6.53 mg/L. The geothermal water temperature in this area is 49.5-51.0 °C. it belongs to warm geothermal water and is the main geothermal mining layer in Xinye county seat.

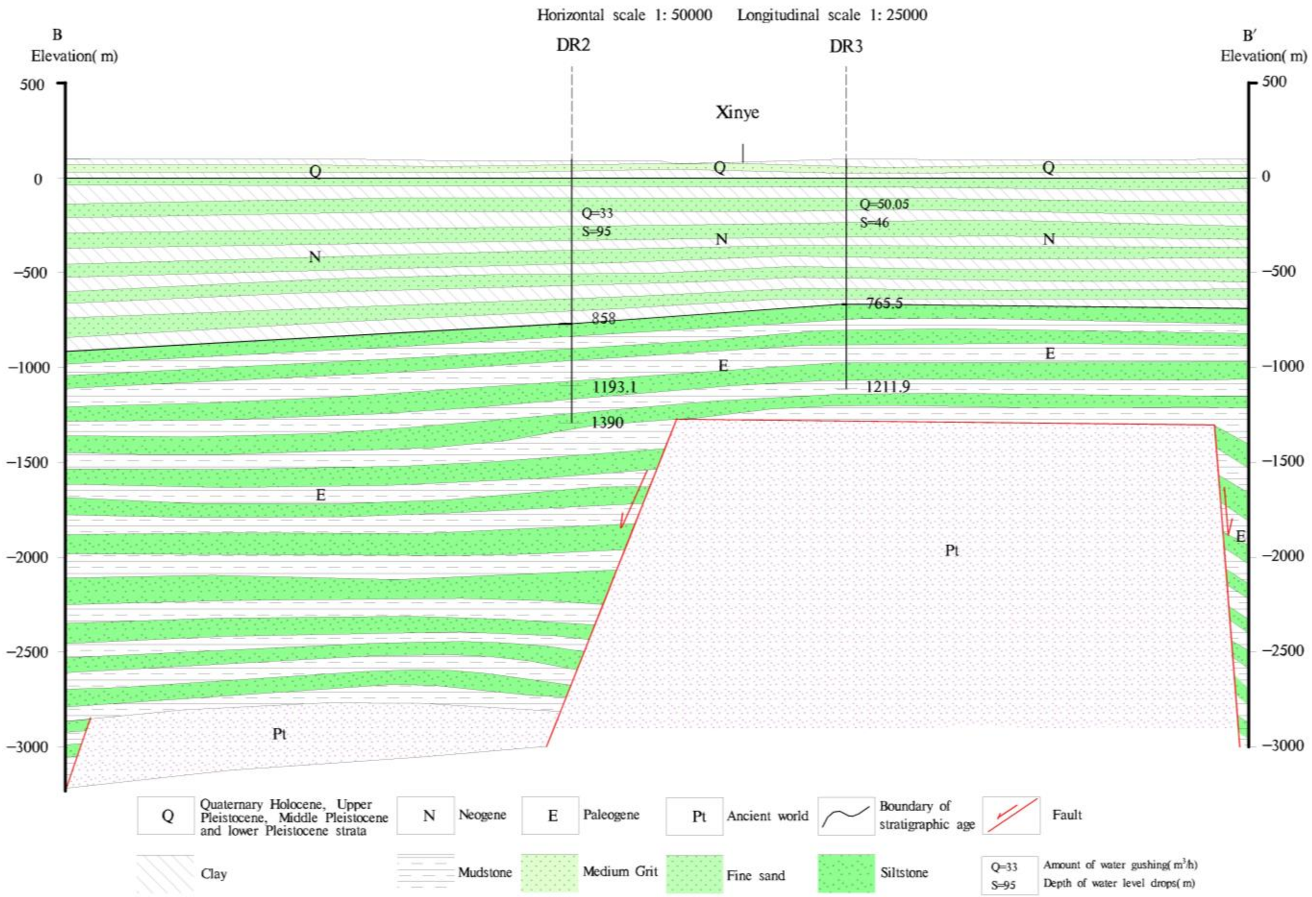

Fig.3 Hydrogeological section(B-B′)

4.3 Characteristics of thermal reservoir aquifers in the key research area of Nanyang Oilfield

Based on geothermal and petroleum drilling data from the Nanyang Oilfield, the Neogene Shangsi Formation (N2s) in the key research area of the Nanyang Oilfield is composed of thick fluvial facies-dominated conglomerate, sandstone and mudstone interbedded deposits, the maximum sedimentary thickness is 50-300m, mainly fine sandstone and siltstone, and there is bottom conglomerate at the bottom. The thickness of single sand layer is from several meters to more than ten meters, and the cumulative thickness is mostly 30-120 meters. The thickness of sandstone is 40-60% of the total thickness of this formation. The stratiform thermal reservoir of Paleogene is composed of interbedded sandstone and mudstone with thick fluvial facies, the maximum thickness of which is 1000-4800 meters. The upper part of Paleogene is the Walnut

Orchard Formation (E2h). The first member of Hetaoyuan Formation (E2h1) is 200-300m thick, and the coarse clastic rocks are mainly fine sandstone, medium sandstone and siltstone. The thickness of sandstone is from several meters to more than ten meters, and the cumulative thickness is mostly 25-180 meters. The thickness of sandstone is 20-40% of the total thickness of this formation. The Shangsi Formation is a water-rich member of the Neogene Thermal Reservoir. The water quality is mostly fresh water, the salinity is less than 1.0 g/L, and the hydrochemical type is HCO3-Na type. The first member of Hetaoyuan Formation is a water-rich member of Paleogene Thermal Reservoir. The water quality is mostly fresh water, the salinity is more than 1.0 g/L, and the hydrochemical type is Cl·HCO3-Na type. Geothermal field is closely related to hydrocarbon accumulation. The abnormal high temperature in the distribution area of oil and gas fields is a local anomaly, which is caused by hydrocarbon exothermic heat, trap heat accumulation and abnormal high pressure in oil and gas reservoirs, the best caprock for oil and gas is the abnormally high pressure formed in undercompacted mudstone, which is lithologic seal and pressure seal, and has much lower thermal conductivity than sandstone[16], thus, the heat from the bottom of the formation and the heat from the lateral movement of groundwater are concentrated. The volume of a trap can be considered a constant over a period of geological time, as shown by the thermodynamic ideal gas law that the higher the pressure, the higher the temperature in a constant volume state [17] , therefore, the formation of geothermal anomaly.

According to the geophysical data collected in the study area, the buried depth of bedrock from north to south gradually increases, and the thermal reservoir in the area has good water-bearing sand and bottom conglomerate, and water-bearing performance is good. Combined with the investigation data of geothermal wells, the production capacity of single well in this study area is 21-60 m3/h, the average is 40.5 m3/h, the water-rich property is good, the unit water inflow is small, the average is 0.08-3.27 m3/m·h, the minimum depth is 18m, the maximum depth is 235m.

Based on the statistical data of actual pumping tests of geothermal wells in the study area, the permeability coefficients of the aquifers in each well were calculated by using the steady flowing Kuibuyi formula and Kusakin's empirical formula. The water conductivity of the thermal reservoir is 2.93 m2/d and 47.07 m2/d, respectively, calculated by the method of linear diagram and the method of recovering water level. The water temperature at the wellhead is 36-74°C. According to the data of geothermal water quality, the salinity is 460-9240mg/L, pH is 7.40-8.20, the content of H2SiO3 is 19-25mg/L, the content of Sr is 1.22-4.30 mg/L. According to the logging data of oil field, the well temperature of 2000 m depth can reach 68-96 °C, and the average temperature is 80°C. The geothermal water temperature in this area is 46-96°C, which belongs to warm water geothermal and hot water geothermal. The Neogene Shangsi Formation and the first member of Paleogene Hetaoyuan Formation are the main geothermal mining strata. In the oil-gas field distribution area of this area, the ground temperature is continuously abnormal and the ground temperature gradient is high, which is mainly because the formation temperature and the oil-gas generation complement each other and affect each other [18]. The high value area of the ground temperature gradient is also the distribution area of the oil field in the sag, the geothermal gradient is 4.1-5.2 °C/100m. In general, the trend of the geothermal field in the sag is that the geothermal gradient is high in the northwest slope, low in the southeast deep sag, and low in the center of the sag [19].

5. Chemical characteristics of geothermal fluids

5.1 Chemical composition characteristics of geothermal fluids

The geothermal resources in China can be divided into three basic types: volcanic magma type, uplift fault type and sedimentary basin type [20]. According to three basic types, it can be divided into three corresponding types of underground hot water [21]. Underground hot water is rich in chemical element, and the chemical element in groundwater is divided into constant, trace and ultra-trace components according to their contents [22]. The major components include K+, Na+, Ca2+, Mg2+, HCO3-, SO42-, Cl-, the minor components include Br, Sr, B, F, Li, As, and the ultra-minor components include Cu, Cd, Se, etc.. The main anions of geothermal water in the exploration area are HCO3-, SO42-, Cl-, CO32-, NO3-, and the main cations are K+, Na+, Ca2+, Mg2+, other ions include Fe, Mn, Cu, Zn, F-, CN-, As, Se, Hg, Cr6+, Pb, Cd, Li, Sr, Br-, I-, SiO2, Al and so on.

Table 2. Summary of main analysis items

Analyze the project		Dengzhou-Shayan-Zhangdian Sag				Xindianpu-Hanlongtan Sag
		800-1500(m)			1500-3000(m)	800-1500(m)
		Minimum(mg/L)	Maximum (mg/L)	Average (mg/L)	Average (mg/L)	Average (mg/L)
Cation	K＋	2.36	11.80	6.40	2.36	6.79
	Na＋	266	380	329.5	335	1545
	Ca2＋	21	94.2	50.63	21.2	114
	Mg2＋	5.24	31.1	16.01	5.25	28.3
Anions	HCO3-	249.80	356.9	292.2	249.8	208.2
	SO42-	119.6	717.4	382.88	120.6	2404
	Cl-	23.54	362.6	177.59	364.7	422.3
	NO3-	0.16	0.66	0.31	0.23	0.16
	F-	0.3	0.75	0.63	0.74	1.16
H2SiO3		18.8	29.0	23.13	19.1	20.4
Sr		1.22	3.58	2.23	1.22	6.53
Li		＜0.05	0.18	0.09	＜0.05	0.54
As		0.0001	0.016	0.006	0.0007	0.021
Hg		0.00001	0.00001	0.00001	0.00001	0.00001
Total soluble solids		982	1221	1072.25	990	4250
Total hardness		74.60	369.2	193.79	76.48	393.8
pH		7.46	8.48	8.03	8.20	7.92

It can be seen from table 2 that sodium ion content is the highest in the geothermal field of Dengzhou-Shayan-Zhangdian Sag, followed by calcium ion content. The content of sulfate is the highest in deep wells (800-1500m) , then bicarbonate and chloride are the highest, the content of chloride is the highest in ultra-deep Wells (1500-3000m) , then bicarbonate and sulfate are the highest. In the geothermal field of Xindianpu-Hanlongtan Sag, sodium ion content is the highest, followed by calcium ion content is the highest. The content of sulfate is the highest in the middle-deep wells (800-1500m) , followed by chloride and bicarbonate. No ultra-deep Wells (1500-3000m) are found in the geothermal field of Xindianpu-Hanlongtan Sag. Compared with other geothermal wells, the variation range of each ion is lahrger. Other ions, such as Cu, Zn, CN-, Se, Hg, Cr6+, Pb, Cd, I-, Boric acid, Al, etc, are all lower in content.

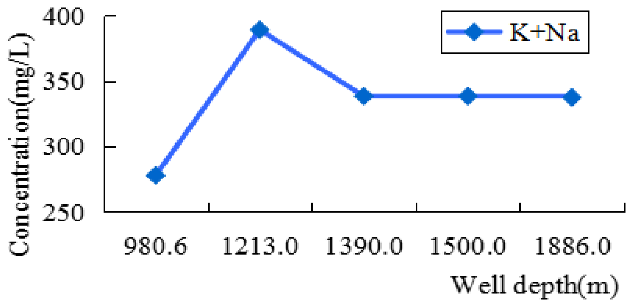

Fig.4 Variation curve of K,Na ion content with depth

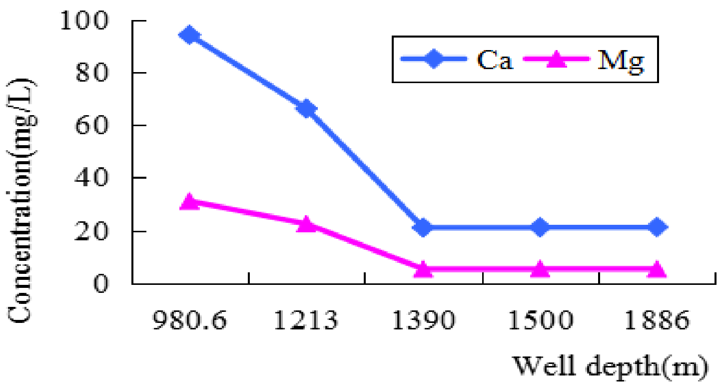

Fig.5 Variation curve of Ca, Mg ion content with depth

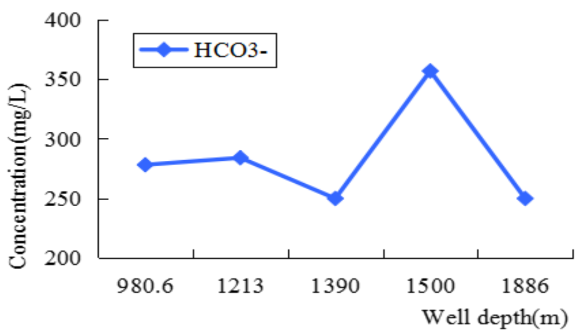

Fig.6 Variation curve of HCO3- content with depth

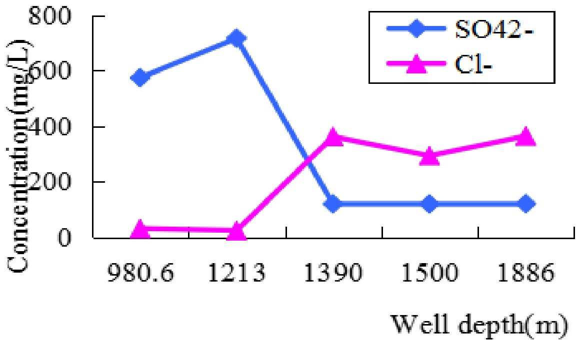

Fig.7 Variation curve of Cl-,SO42- content with depth

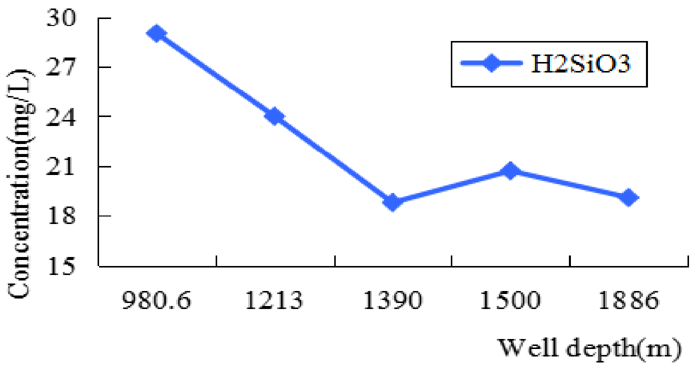

Fig.8 Variation curve of H2SiO3 content with depth

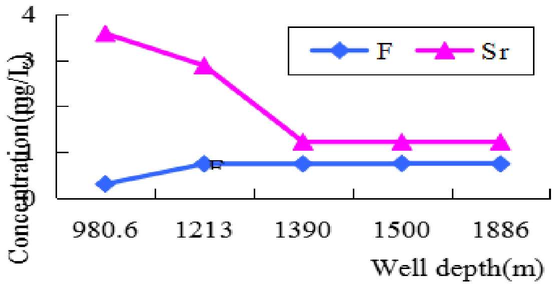

Fig.9 Variation curve of F, Sr content with depth

It can also be seen from the table that the hydrochemical characteristics of geothermal water in different depth sections of 800-1500m and 1500-3000m in the Dengzhou-Shayan-Zhangdian Sag have obvious changes. In cations, the content of sodium ion increases with the increase of depth, while the content of potassium, calcium and magnesium ion decreases with the increase of depth. In anions, the contents of sulfate, chloride, carbonate, nitrate and fluorine increased with the increase of depth, while the contents of bicarbonate decreased with the increase of depth. The contents of metasilicate, lithium, arsenic and total hardness decrease with increasing depth. The content of strontium increases with the depth. In 800-1500m geothermal water, 50.0% is alkaline water with pH > 8.0, and 50% is neutral water with pH 7.46-8.0. The average pH value is 8.03. The alkaline water with pH > 8.0 accounts for 100% of the geothermal water in the 1500-3000m section. The above analysis shows that the pH value also increases with the increase of depth. The average salinity of geothermal water in 800-1500m section is 1218 mg/L. The average salinity of 1500-3000m geothermal water is 9240 mg/L, which increases with the depth. The average content of anions and cations in geothermal water of 800-1500m section in Xindianpu-Hanlongtan Sag is higher than that of the same stratum in the geothermal field of Dengzhou-Shayan-Zhangdian Sag. Some components and their ratios in geothermal water can qualitatively indicate the temperature of geothermal fluid. D.E.White[23] concluded that the lower the Mg content and the ratio of Mg/Ca and Na/K, the higher the temperature in the reservoir. Similarly, high Na/Ca and Cl/HCO3 ratios and low Na/Li ratios mean high temperatures in the reservoir. The geothermal field in Xindianpu-Hanlongtan Sag has higher geothermal temperature than that in Dengzhou-Shayan-Zhangdian Sag. Above indicators confirm this conclusion and are in perfect agreement with D.E.White's research.

5.2 Hydrochemical types of geothermal fluids

In traditional hydrochemical classification, the limit value of hydrochemical classification is usually HCO3-, SO42-, Cl-, Na+, Ca2+, Mg2+(mg/l) >25%, that is, anions and cations (mg/L) > 25% of the water involved in the chemical type name [24].

The water quality analysis report of 5 geothermal wells in the geothermal field of Dengzhou-Shayan-Zhangdian Sag shows that there are 2 wells (DR4, DR5) of SO4·HCO3-Na type water, accounting for 40% , there are three wells (DR1, DR2, Dr6) of HCO3·Cl-Na and Cl·HCO3-Na types, accounting for 60% , and the only water quality analysis report of DR3 wells in the geothermal field of Xindianpu-Hanlongtan Sag shows that the hydrochemical type is SO4-Na type There is no geothermal well in the geothermal field of Tanghe -Anpeng Sag, so the hydrochemical type cannot be evaluated.

As can be seen from the above analysis, the main types of geothermal water chemistry in the Neogene and Paleogene of Dengzhou, Xinye County and Tanghe County are SO4·HCO3-Na type water, HCO3·Cl-Na type water, Cl·HCO3-Na type water and SO4-Na type water. The hydrochemical types in the Dengzhou Sag are SO4·HCO3-Na, and those in the Shayan-Zhangdian Sag are HCO3·Cl-Na and Cl·HCO3-Na, the hydrochemical type of geothermal field in Xindianpu-Hanlongtan Sag is SO4-Na type.

6. Analysis of development and utilization potential

6.1 Analysis method

The annual recoverable hot water amount in the key study area of the geothermal field of

Dengzhou-Shayan-Zhangdian is 2.19×106m3/a, and the area of heat storage is 252.1 km2. The annual recoverable hot water amount in other study areas is 29.64×106 m3/a, and the area of heat storage is 3223.2 km2. The annual recoverable hot water and heat storage area in the key study area of Xindianpu-Hanlongtan geothermal field are 4.21×105 m3/a and 50.4 km2 respectively, while the annual recoverable hot water and heat storage area in other study areas are 4.87×106 m3/a and 1794.8 km2 respectively. In the study area of Tanghe-Anpeng geothermal field, the annual recoverable hot water is 2.42×106 m3/a, and the thermal storage area is 2148.8 km2. In the key study area of the geothermal field of Dengzhou-Shayan-Zhangdian, the annual actual recoverable hot water is 6.6×105 m3/a, and in the key study area of the Xindianpu-Hanlongtan geothermal field, the annual actual recoverable hot water is 1.32×105m3/a. The annual recoverable hot water quantity is the annual allowable recoverable hot water quantity. The exploitation potential of geothermal resources in the study area can be judged by groundwater exploitation potential index [25]. The formula is as follows:

P=Qallowable/Qactual

P—Groundwater exploitation potential index.

Qallowable——The allowable exploitation of hot water per year(m3/a).

Qactual——The actual exploitation of hot water per year(m3/a).

The discriminant indicators for the P value are as follows:

P >1.2, there is potential for exploitation, can expand the exploitation.

1.2 ≥ P ≥ 0.8, balance between mining and filling.

P < 0.8, lack of potential, has been overtapped.

Areas (layers) with mining potential can also be further divided according to the allowable amount of increased mining:

Areas with small mining potential,can increase the allowable amount of exploitation < 10×104 m3/km2.a.

Areas with larger mining potential,can increase the allowable amount of exploitation(10-20)×104 m3/km2.a.

Areas with large mining potential,can increase the allowable amount of exploitation >20×104 m3/km2.a.

The allowable amount of mining can be increased=Permissible mining per unit area－Actual mining volume per unit area.

6.2 Analysis of geothermal water resource exploitation potential

According to the calculation formula and principle above, the geothermal water exploitation potential index of the key research area of Dengzhou-Shayan-Zhangdian geothermal field P = 3.32>1.2 belongs to the mining potential area, which can be expanded to increase the allowable exploitation amount to 6.07×103 m^3/km^2.a< 10×104 m^3/km^2.a, which belongs to the area with small potential; there are no geothermal wells in the general research area of Dengzhou-Shayan-Zhangdian geothermal field, which belongs to the mining potential area, and the allowable mining amount can be increased to 9.20×103 m^3/km^2.a<10×104 m^3/km^2.a, belongs to the area with small potential. The geothermal water exploitation potential index of the key research area of Xindianpu-Hanlongtan geothermal field is P = 3.19 > 1.2, which belongs to the mining potential area and can be expanded to increase the allowable exploitation amount to 5.73×103 m^3/km^2.a<10×104 m^3/km^2.a, which belongs to the area with small potential. There are no geothermal wells in the Tanghe-Anpeng geothermal field research area, which belongs to the area with mining potential, and the allowable mining amount can be increased to 1.13×1103 m3/km2.a<10×104 m3/km2.a, which belongs to the area with small potential.

6.3 Identify key exploration and development areas

From the data analysis above, it can be seen that the actual annual amount of hot water extracted in the key research area of Nanyang Basin is small, which belongs to the area with mining potential, and can be appropriately expanded for exploitation, but the exploitation potential is small. Geothermal resources in other areas have not yet been exploited, and there is currently a lack of geothermal water mining well data and geothermal exploration well data, so it should be identified as a key exploration and development area. In addition, detailed geological and geothermal data and water quantity and quality data should be obtained by exploration, and scientific and reasonable development and utilization plans should be put forward before gradual and gradual development, and attention should be paid to the scientific and reasonable arrangement of well spacing. The above data analysis concluded that the allowable amount of geothermal field in the study area can be increased to less than 10×104 m3/km2.a, which belongs to the area with small potential, mainly due to the large buried depth of the thermal storage aquifer, atmospheric precipitation, surface water and other water sources cannot directly replenish the thermal storage aquifer, but mainly through slow lateral runoff recharge and upper middle and deep aquifer overflow replenishment to replenish water sources, that is, the recharge resources are limited, large-scale overexploitation is not possible, can only be used to meet the needs of medical treatment, bathing, greenhouse, A supplementary recoverable water resource required for special purposes such as aquaculture.

7. Conclusion

(1) The Nanyang Basin geothermal reservoir belongs to the sedimentary basin type (conductive type) geothermal system. According to the fault that controls the buried depth of the neogene floor, the Nanyang Basin is divided into Dengzhou-Shayan-Zhangdian Sag geothermal field, Xindianpu-Hanlongtan Sag geothermal field, and Tanghe-Anpeng Sag geothermal field. According to the thermal storage temperature and the depth of thermal reservoir burial, the Dengzhou-Shayan-Zhangdian Sag geothermal field is divided into warm water reservoir (hot reservoir buried depth 500-800m), warm hot water reservoir (hot reservoir buried depth 800-1500m), hot water reservoir (hot reservoir buried depth 1500-3000m), Xindianpu-Hanlongtan Sag geothermal field is divided into warm water reservoir (hot reservoir buried depth 500-800m), warm hot water reservoir (hot reservoir buried depth 800-1500m), Tanghe-Anpeng Sag geothermal field is divided into hot water reservoir (hot reservoir buried depth 500-3000m).

(2) The chemical type of geothermal water water in the sedimentary basin of Nanyang Basin is mainly SO4·HCO3-Na type water, HCO3·Cl-Na type water, Cl·HCO3-Na type water, SO4-Na type water. Among them, the water chemistry type of Dengzhou Sag area is SO4· HCO3-Na type, and the water chemistry type in Shayan-Zhangdian Sag area was HCO3·Cl-Na and Cl·HCO3-Na type, Xindianpu-Hanlongtan Sag geothermal field hydrochemical type is SO4-Na type.

(3) Dengzhou-Shayan-Zhangdian Sag geothermal field, Xindianpu-Hanlongtan Sag geothermal field, Tanghe-Anpeng Sag geothermal field have a small annual actual amount of hot water, which belongs to the potential area and can be expanded to exploit, and the allowable exploitation of the three geothermal fields can be increased is less than 10×104 m3/km2·a, which belongs to the area with small potential. The investigation area of Xinye County, the investigation area north of the Diao River and the south of Fugang in Dengzhou City, the research area north of

Mawan and the north of the Qingshui River south of Duanzhuang in Tanghe County have been identified as key exploration and development prospective areas, and further efforts should be intensified.

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